HVAC

EQUATIONS, DATA, AND RULES OF THUMB

THIRD EDITION

ARTHUR A. BELL, JR., P.E. • W. LARSEN ANGEL, P.E., LEED AP

Mc Graw Hill Education

About the Author

A. About the Author

Arthur A. Bell, Jr., PE, is a registered professional engineer and certified mechanical, plumbing, fire, and energy conservation code official in the Commonwealth of Pennsylvania with more than 31 years of experience in the design of HVAC systems. In addition, he has been involved in the design of plumbing systems, fire protection systems, and construction field engineering-mechanical systems. Mr. Bell is also the author of *HVAC Design Portfolio*, published by McGraw-Hill.

W. Larsen Angel, PE, is a registered professional engineer in the State of Maryland with more than 25 years of experience in the design of HVAC systems. In addition, he has been involved in the design of plumbing systems and electrical systems. Mr. Angel is also the author of *HVAC Design Sourcebook*, published by McGraw-Hill.

Citation

EXPORT

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. About the Author, Chapter (McGraw-Hill Professional, 2016), AccessEngineering

Dedication

B. Dedication

To Lisa, my lovely wife of twenty-five years, and to my two wonderful sons. *Soli Deo gloria*

Part 1: Introduction

1. Part 1: Introduction

1.01. Background

A. **The heating, ventilation, and air conditioning (HVAC) equations, data, rules of thumb, and other information contained within this reference manual were assembled to aid the beginning engineer and designer in the design of HVAC systems. In addition, the experienced engineer or designer may find this manual useful as a quick design reference guide, field manual, and teaching tool.**

B. **The following pages compile information from various reference sources listed in Part 53 of this manual, from college HVAC class notes, from continuing education design seminars and classes, from engineers, and from personal experience. This document was put together as an encyclopedic type reference in contract specification outline format where information could be looked up quickly, in lieu of searching through volumes of textbooks, reference books and manuals, periodicals, trade articles, and product catalogs.**

1.02. Rules of Thumb

A. **Rules of thumb listed herein should be used considering the following:**
   1. Building loads are based on building gross square footage.
   2. Building loads generally include ventilation and make-up air requirements.

3. These rules of thumb may be used to estimate system loads during the preliminary design stages of a project.

4. Building loads for construction documents should be calculated using the *ASHRAE Handbook of Fundamentals* or similar computational procedure in lieu of using these rules of thumb for final designs. When calculating heating and cooling loads, actual occupancy, lighting, and equipment information should be obtained from the owner, architect, electrical engineer, other design team members, or from technical publications such as ASHRAE.

B. **Many of the rules of thumb listed within this reference manual were developed many years ago. I have received many questions when conducting seminars regarding these rules of thumb. The most often asked question is "Are the cooling and heating load rules of thumb still accurate with the mandate of energy codes and tighter and improved building envelope construction?" The answer to this question is yes. The reason the cooling rules of thumb are still accurate is that the internal loads have increased substantially and cooling loads have switched from building-envelope-dependent, to lighting-dependent, and now to people-and-equipment-dependent (more people and equipment placed in the same area). The reason the heating load rules of thumb are still reasonably accurate is that the ventilation air (outdoor air load dictated by code) has increased.**

1.03. Codes and Standards

A. **Code items contained herein were included more for comparison purposes than for use during design. All code items (i.e., ICC, ASHRAE, NFPA) are subject to change, and federal, state, and local codes should be consulted for applicable regulations and requirements.**

B. **The following codes were used unless otherwise noted.**

1. 2015 International Code Council Series of Codes (ICC):
    a. 2015 International Building Code (herein referred to as 2015 IBC).

    b. 2015 International Mechanical Code (herein referred to as 2015 IMC).

    c. 2015 International Energy Conservation Code (herein referred to as 2015 IECC).

d. 2015 International Plumbing Code (herein referred to as 2015 IPC).

e. 2015 International Fire Code (herein referred to as 2015 IFC).

f. 2015 International Fuel Gas Code (herein referred to as 2015 IFGC).

g. 2015 International Residential Code (herein referred to as 2015 IRC).

h. 2015 International Existing Building Code.

i. 2015 International Performance Code for Buildings and Facilities.

j. 2015 International Private Sewage Disposal Code.

k. 2015 International Property Maintenance Code.

l. 2015 International Zoning Code.

m. 2015 International Wildland-Urban Interface Code.

2. American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE):
   a. ASHRAE Standard 15—2013 (herein referred to as ASHRAE 15-2013).

   b. ASHRAE Standard 55—2013 (herein referred to as ASHRAE 55-2013).

   c. ASHRAE Standard 62.1—2013 (herein referred to as ASHRAE 62.1-2013).

   d. ASHRAE Standard 62.2—2013 (herein referred to as ASHRAE 62.2-2013).

   e. ASHRAE Standard 90.1—2013 (herein referred to as ASHRAE 90.1-2013).

   f. ASHRAE Standard 90.2—2007 (herein referred to as ASHRAE 90.2-2007).

3. National Fire Protection Association Codes (NFPA):
   a. NFPA 90A—2015 Installation of Air-Conditioning and Ventilating Systems.

   b. NFPA 96—2014 Ventilation Control and Fire Protection of Commercial Cooking Operations.

Part 2: Definitions

2. Part 2: Definitions

2.01. General

A. *Furnish.* Except as otherwise defined in greater detail, the term *furnish* is used to mean "supply and deliver to the project site, ready for unloading, unpacking, assembly, installation, and similar operations" as applicable to each instance.

B. *Install.* Except as otherwise defined in greater detail, the term *install* is used to describe operations at the project site including actual "unloading, unpacking, assembly, erection, placing, anchoring, connecting, applying, working to dimension, finishing, curing, protecting, testing to demonstrate satisfactory operation, cleaning, and similar operations" as applicable in each instance.

C. *Provide.* Except as otherwise defined in greater detail, the term *provide* means to furnish and install, complete and ready for intended use and successfully tested to demonstrate satisfactory operation as applicable in each instance.

D. *Remove.* Except as otherwise defined in greater detail, the term *remove* means to disassemble, dismantle, and/or cut into pieces in order to remove the equipment from the site and to properly dispose of the removed equipment and pay for all associated costs incurred.

E. *Replace.* Except as otherwise defined in greater detail, the term *replace* means to remove the existing equipment and to provide new equipment of the same size, capacity, electrical characteristics,

function, etc., as the existing equipment.

F. *Relocate.* Except as otherwise defined in greater detail, the term *relocate* means to carefully remove without damaging item and to install where shown on the contract documents and/or as directed by the design professional and/or owner.

G. *Shall. Shall* indicates action that is mandatory on the part of the contractor.

H. *Will. Will* indicates action that is probable on the part of the contractor.

I. *Should. Should* indicates action that is probable on the part of the contractor.

J. *May. May* indicates action that is permissible on the part of the contractor.

K. *Indicated.* The term *indicated* is a cross-reference to graphic representations, details, notes, or schedules on the drawings; to other paragraphs or schedules in the specifications; and to similar means of recording requirements in the contract documents. Where terms such as *shown, noted, scheduled,* and *specified* are used in lieu of *indicated,* it is for the purpose of helping the reader locate the cross-reference, and no limitation is intended except as specifically noted.

L. *Shown.* The term *shown* is a cross-reference to graphic representations, details, notes, or schedules on the contract drawings and to similar means of recording requirements in the contract documents.

M. *Detailed.* The term *detailed* is a cross-reference to graphic representations, details, notes, or schedules on the contract drawings and to similar means of recording requirements in the contract documents.

N. *Specified.* The term *specified* is a cross-reference to paragraphs or schedules in the specifications and to similar means of recording requirements in the contract documents. The specifications include the general provisions, special provisions, and the technical specifications for the project.

O. *Including, Such as.* The terms *including* and *such as* shall always be taken in the most inclusive sense, namely "including, but not limited to" and "such as, but not limited to."

P. *Supply, Procurement.* The terms *supply* and *procurement* shall mean to purchase, procure, acquire, and deliver complete with related accessories.

Q. *At No Additional Cost.* The phrase "at no additional cost" shall mean at no additional cost to the owner and at no additional cost to the design professional or construction manager.

R. *Approved, Accepted.* Where used in conjunction with the design professional's response to submittals, requests, applications, inquiries, reports, and claims by the contractor, the meaning of the terms *approved* and *accepted* shall be held to the limitations of the design professional's responsibilities to fulfill requirements of the contract documents. The terms *approved* and *accepted* shall also mean to permit the use of material, equipment, or methods conditional upon compliance with the contract documents.

S. *Approved Equal, Approved Equivalent.* The terms *approved equal* and *approved equivalent* shall mean possessing the same performance qualities and characteristics and fulfilling the same utilitarian function and approved by the design professional.

T. *Directed, Requested, Required, etc.* Where not otherwise explained, terms such as *directed, requested, required, authorized, selected, approved, accepted, designated, prescribed, ordered,* and *permitted* mean "directed by the design professional," "requested by the design professional," "required by the design professional," and similar phrases. However, no such implied meaning will be interpreted to expand the design professional's responsibility into the contractor's area of construction supervision.

U. *Review.* The term *review* shall mean limited observation or checking to ascertain general conformance with the design concept of the work and with information given in the contract documents. Such action does not constitute a waiver or alteration of the contract document requirements.

V. *Suitable, Reasonable, Proper, Correct, and Necessary.* Such terms

shall mean as suitable, reasonable, proper, correct, or necessary for the purpose intended as required by the contract documents, subject to the judgment of the design professional or the construction manager.

W. *Option.* The term *option* shall mean a choice from the specified products, manufacturers, or procedures which shall be made by the contractor. The choice is not "whether" the work is to be performed, but "which" product, "which" manufacturer, or "which" procedure is to be used. The product or procedure chosen by the contractor shall be provided at no increase or additional cost to the owner, design professional, or construction manager, and with no lessening of the contractor's responsibility for its performance.

X. *Similar.* The term *similar* shall mean generally the same but not necessarily identical; details shall be worked out in relation to other parts of the work.

Y. *Submit.* The term *submit* shall mean, unless otherwise defined in greater detail, transmit to the design professional for approval, information, and record.

Z. *Project Site, Work Site.* The term *project site* shall be defined as the space available to the contractor for performance of the work, either exclusively or in conjunction with others performing other work as part of the project or another project. The extent of the project site is shown on the drawings or specified and may or may not be identical with the land upon which the project is to be built. The project site boundaries may include public streets, highways, roads, interstates, etc., public easements, and property under ownership of someone other than the client and are not available for performance of work.

AA. *Testing Laboratories.* The term *testing laboratories* shall be defined as an independent entity engaged to perform specific inspections or tests of the work, either at the project site or elsewhere, and to report and, if required, interpret the results of those inspections or tests.

BB. *Herein.* The term *herein* shall mean the contents of a particular section where this term appears.

CC. *Singular Number.* In all cases where a device or part of equipment

or system is herein referred to in the singular number (such as fan, pump, cooling system, heating system, etc.), it is intended that such reference shall apply to as many such items as are required by the contract documents and to complete the installation.

DD. *No Exception Taken.* The term *no exception taken* shall mean the same as *approved*.

EE. *Approved as Noted, Make Corrections Noted, or Revise—No Resubmittal Required.* The terms *approved as noted, make corrections noted,* and *revise—no resubmittal required* shall mean the submittal essentially complies with the contract documents except for a few minor discrepancies that have been annotated directly on the submittal that will have to be corrected on the submittal and the work correctly installed in the field by the contractor.

FF. *Revise and Resubmit.* The term *revise and resubmit* shall mean the contractor shall revise the submittal to conform with the contract documents by correcting moderate errors, omissions, and/or deviations from the contract documents and resubmit it for review prior to approval and before any material and/or equipment can be fabricated, purchased, or installed by the contractor.

GG. *Disapproved/Resubmit.* The term *disapproved/resubmit* shall mean the contractor shall revise the submittal to conform with the contract documents by correcting serious errors, omissions, and/or deviations from the contract documents and resubmit it for review prior to approval and before any material and/or equipment can be fabricated, purchased, or installed by the contractor.

HH. *Disapproved or Rejected.* The terms *disapproved* and *rejected* shall mean the contractor shall discard and replace the submittal because the submittal did not comply with the contract documents in a major way.

II. *Submit Specified Item.* The term *submit specified item* shall mean the contractor shall discard and replace the submittal with a submittal containing the specified items because the submittal contained improper manufacturer, model number, material, etc.

JJ. *Acceptance.* The formal acceptance by the owner or design professional of the work, as evidenced by the issuance of the

acceptance certificate.

KK. *Contract Item, Pay Item, Contract Fixed Price Item.* A specifically described item of work that is priced in the contract documents.

LL. *Contract Time, Time of Completion.* The number of calendar days (not working days) set forth in the contract documents for completion of the work.

MM. *Failure.* Any detected inability of material or equipment, or any portion thereof, to function or perform in accordance with the contract documents.

NN. *Substantial Completion. Substantial completion* shall be defined as the sufficient completion and accomplishment by the contractor of all work or designated portions thereof essential to fulfillment of the purpose of the contract, so the owner can occupy or utilize the work or designated portions thereof for the use for which it is intended.

OO. *Final Completion, Final Acceptance. Final completion* or *final acceptance* shall be defined as completion and accomplishment by the contractor of all work including contractual administrative demobilization work, all punch list items, and all other contract requirements essential to fulfillment of the purpose of the contract, so the owner can occupy or utilize the work for the use for which it is intended.

PP. *Pre-Final Inspection or Observation.* The term *pre-final inspection or observation* shall be held to the limitations of the design professional's responsibilities to fulfill the requirements of the contract documents and shall not relieve the contractor from contract obligations. The term *pre-final inspection* shall also mean all inspections conducted prior to the final inspection by the owner, the design professional, or both, verifying that all the work, with the exception of required contractual administrative demobilization work, inconsequential punch list items, and guarantees, has been satisfactorily completed in accordance with the contract documents.

QQ. *Final Inspection or Observation.* The term *final inspection or observation* shall be held to the limitations of the design professional's responsibilities to fulfill the requirements of the contract documents and shall not relieve the contractor from contract

obligations. The term *final inspection* shall also mean the inspection conducted by the owner, the design professional, or both, verifying that all the work, with the exception of required contractual administrative demobilization work, inconsequential punch list items, and guarantees, has been satisfactorily completed in accordance with the contract documents.

RR. *Reliability.* The probability that a system will perform its intended functions without failure and within design parameters under specified operating conditions for which it is designed and for a specified period of time.

SS. *Testing.* The term *testing* may be described as the inspection, investigation, analysis, and diagnosis of all systems and components to ensure that the systems are operable, meet the requirements of the contract documents, and are ready for operation. Included are such items as:

1. Verification that the system is filled with water and is not air bound.
2. Verification that expansion tanks of the proper size are connected at the correct locations and that they are not waterlogged.
3. Verification that all system components are in proper working order and properly installed. Check for proper flow directions.
4. Checking of all voltages for each motor in the system.
5. Checking that all motors rotate in the correct direction and at the correct speed.
6. Checking all motors for possible overload (excess amperage draw) on initial start-up.
7. Checking of each pump for proper alignment.
8. Checking all systems for leaks, etc.
9. Checking all systems and components to ensure they meet the contract document requirements as far as capacity, system operation, control function, and other items required by the contract documents.

TT. ***Adjusting.*** **The term** ***adjusting*** **may be described as the final setting of balancing devices such as dampers and valves, establishing and setting minimum variable frequency controller speed, in addition to automatic control devices, such as thermostats and pressure/temperature controllers to achieve maximum system performance and efficiency during normal operation. Adjusting also includes final adjustments for pumps by regulation of motor speed, partial close-down of pump discharge valve or impeller trim (preferred over the partial close-down of pump discharge valve).**

UU. ***Balancing.*** **The term** ***balancing*** **is the methodical regulation of system fluid flow-rates (air and water) through the use of workable and industry-accepted procedures as specified to achieve the desired or specified flow rates (CFM or GPM) in each segment (main, branch, or subcircuit) of the system.**

VV. ***Commissioning.*** **The term** ***commissioning*** **is the methodical procedures and methods for documenting and verifying the performance of the building envelope, HVAC, plumbing, fire protection, electrical, life safety, and telecom/data systems so that the systems operate in conformity with the design intent. Commissioning will include testing; adjusting; balancing; documentation of occupancy requirements and design assumptions; documentation of design intent for use by contractors, owners, and operators; functional performance testing and documentation necessary for evaluating all systems for acceptance; and adjusting the building systems to meet actual occupancy needs within the capability of the systems. The purpose of commissioning of building systems is to achieve the end result of a fully functional, fine-tuned, and operational building.**

WW. ***Functional Performance Testing.*** **The term** ***functional performance testing*** **shall mean the full range of checks and tests carried out to determine if all components, subsystems, systems, and interfaces between systems function in accordance with the contract documents. In this context,** ***function*** **includes all modes and sequences of control operation, all interlocks and conditional control responses, and all specified responses to abnormal emergency conditions.**

XX. ***Confined Spaces. Confined spaces*** **(according to OSHA**

regulations) are spaces which must have these three characteristics:

1. The space must be large enough and configured to permit personnel to enter and work.

2. The space is not designed for continuous human occupancy.

3. The space has limited or restricted means of entry and exit.

4. Two categories of confined spaces exist:
   a. *Non-Permit Required Confined Spaces (NRCS).* Spaces that contain no physical hazards that could cause death or serious physical harm, and cannot possibly contain any atmospheric hazards.

   b. *Permit Required Confined Spaces (PRCS).* Spaces that contain or may contain a hazardous atmosphere (atmospheric hazards—oxygen deficiency or enrichment 19.5 percent acceptable minimum and 23.5 percent acceptable maximum; flammable contaminants; and toxic contaminants—product, process, or reactivity); a liquid or finely divided solid material such as grain, pulverized coal, etc., that could surround or engulf a person; or some other recognized serious safety or health hazard such as temperature extremes or mechanical or electrical hazards (boilers, open transformers, tanks, vaults, sewers, manholes, pits, machinery enclosures, vats, silos, storage bins, rail tank cars, and process or reactor vessels).

YY. Hazardous Location Classifications

1. Hazardous locations are those areas where a potential for explosion and fire exist because of flammable gases, vapors, or dust in the atmosphere, or because of the presence of easily ignitable fibers or flyings in accordance with the National Electric Code (*NEC—NFPA 70*).

2. *Class I Locations.* Class I locations are those locations in which flammable gases or vapors are, or may be, present in the air in quantities sufficient to produce explosive or ignitable mixtures.
   a. *Class I, Division 1 Locations.* These are Class I locations where the hazardous atmosphere is expected to be present during normal operations. It may be present continuously, intermittently, periodically, or during normal repair or maintenance operations. Division 1 locations are also those locations where a breakdown in the operation of processing equipment results in the release of hazardous vapors while providing a source of ignition with the simultaneous failure of electrical equipment.

b. *Class I, Division 2 Locations.* These are Class I locations in which volatile flammable liquids or gases are handled, processed, or used, but in which they can escape only in the case of accidental rupture or breakdown of the containers or systems. The hazardous conditions will occur only under abnormal conditions.

3. *Class II Locations.* Class II locations are those locations that are hazardous because of the presence of combustible dust.
   a. *Class II, Division 1 Locations.* These are Class II locations where combustible dust may be in suspension in the air under normal conditions in sufficient quantities to produce explosive or ignitable mixtures. This may occur continuously, intermittently, or periodically. Division 1 locations also exist where failure or malfunction of machinery or equipment might cause a hazardous location to exist while providing a source of ignition with the simultaneous failure of electrical equipment. Included also are locations in which combustible dust of an electrically conductive nature may be present.

   b. *Class II, Division 2 Locations.* These are Class II locations in which combustible dust will not normally be in suspension in the air, and normal operations will not put the dust in suspension, but where accumulation of the dust may interfere with the safe dissipation of heat from electrical equipment or where accumulations near electrical equipment may be ignited by arcs, sparks, or burning material from the equipment.

4. *Class III Locations.* Class III locations are those locations that are hazardous because of the presence of easily ignitable fibers or flyings, but in which the fibers or flyings are not likely to be in suspension in the air in quantities sufficient to produce ignitable mixtures.
   a. *Class III, Division 1 Locations.* These are locations in which easily ignitable fibers or materials producing combustible flyings are handled, manufactured, or used.

   b. *Class III, Division 2 Locations.* These locations are where easily ignitable fibers are stored or handled.

2.02. Systems

A. *Mechanical Systems.* The term *mechanical systems* shall mean for the purposes of these contract documents all heating, ventilating, and air conditioning systems and all piping systems as specified and as shown on the mechanical drawings and all services and appurtenances incidental thereto.

B. *Plumbing Systems.* The term *plumbing systems* shall mean for the purposes of these contract documents all plumbing fixtures, plumbing systems, piping systems, medical vacuum, medical compressed air, medical gas, laboratory vacuum, laboratory compressed air, and all laboratory gas systems as specified and as shown on the plumbing drawings and all services and appurtenances incidental thereto.

C. *Fire Suppression Systems*. The term *fire suppression systems* shall mean for the purposes of these contract documents all fire protection piping systems, standpipe, wet-pipe, dry-pipe, preaction, foam suppression, and all fire protection systems as specified and as shown on the fire protection drawings and all services and appurtenances incidental thereto.

D. *Ductwork*. The term *ductwork* shall include ducts, fittings, flanges, dampers, insulation, hangers, supports, access doors, housings, and all other appurtenances comprising a complete and operable system.

1. *Supply Air Ductwork*. The term *supply air ductwork* shall mean for the purposes of these contract documents all ductwork carrying air from a fan or air handling unit to the room, space, or area to which it is introduced. The air may be conditioned or unconditioned. Supply air ductwork extends from the fan or air handling unit to all the diffusers, registers, and grilles.

2. *Return Air Ductwork*. The term *return air ductwork* shall mean for the purposes of these contract documents all ductwork carrying air from a room, space, or area to a fan or air handling unit. Return air ductwork extends from the registers, grilles, or other return openings to the return fan (if used) and the air handling unit.

3. *Exhaust Air Ductwork.* The term *exhaust air ductwork* shall mean for the purposes of these contract documents all ductwork carrying air from a room, space, area, or equipment to a fan and then discharged to the outdoors. Exhaust air ductwork extends from the registers, grilles, equipment, or other exhaust openings to the fan, and from the fan to the outdoor discharge point.

4. *Relief Air Ductwork*. The term *relief air ductwork* shall mean for the purposes of these contract documents all ductwork carrying air from a room, space, or area without the use of a fan or with the use of a return fan to be discharged to the outdoors. Relief air ductwork extends from the registers, grilles, or other relief openings to the outdoor discharge point, or from the return fan discharge to the outdoor discharge point.

5. *Outside Air Ductwork.* The term *outside air ductwork* shall mean for the purposes of these contract documents all ductwork carrying unconditioned air from the outside to a fan or air handling unit. Outdoor air ductwork extends from the intake point or louver to the fan, air handling unit, or connection to the return air ductwork.

6. *Mixed Air Ductwork.* The term *mixed air ductwork* shall mean for the purposes of these Contract Documents all ductwork carrying a mixture of return air and outdoor air. Mixed air ductwork extends from the point of connection of the return air and outdoor air ductwork to the fan or air handling unit.

7. *Supply Air Plenum.* The term *supply air plenum* shall mean for the purposes of these contract documents all ductwork in which the discharges of multiple fans or air handling units connect forming a common supply header, or all ductwork or ceiling construction forming a common supply box where supply air ductwork discharges into the box at limited locations for air distribution to supply diffusers which are directly connected to the plenum.

8. *Return Air Plenum.* The term *return air plenum* shall mean for the purposes of these contract documents all ductwork in which the suctions of multiple return fans or the discharges of multiple return fans connect forming a common suction or discharge return header or the space above the architectural ceiling and below the floor or roof structure used as return air ductwork.

9. *Exhaust Air Plenum.* The term *exhaust air plenum* shall mean for the purposes of these contract documents all ductwork in which the suctions of multiple exhaust fans or the discharges of multiple exhaust fans connect forming a common suction or discharge exhaust header or the ductwork formed around single or multiple exhaust air discharge openings or louvers to create a connection point for exhaust air ductwork.

10. *Relief Air Plenum.* The term *relief air plenum* shall mean for the purposes of these contract documents all ductwork in which multiple relief air ductwork connections are made forming a common relief air header.

11. *Outdoor Air Plenum.* The term *outdoor air plenum* shall mean for the purposes of these contract documents all ductwork in which the suctions of multiple fans or air handling units connect to form a common outside air header or the ductwork formed around single or multiple outside air openings or louvers to create a connection point for outside air ductwork.

12. *Mixed Air Plenum*. The term *mixed air plenum* shall mean for the purposes of these contract documents all ductwork in which multiple return air and multiple outdoor air ductwork connections are made forming a common mixed air header.

13. *Vents, Flues, Stacks, and Breeching*. The terms *vents, flues, stacks*, and *breeching* shall mean for the purposes of these contract documents ductwork conveying the products of combustion to atmosphere for safe discharge.

E. *Piping*. The term *piping* shall include pipe, fittings, valves, flanges, unions, traps, drains, strainers, insulation, hangers, supports, and all other appurtenances comprising a complete and operable system.

F. *Wiring.* The term *wiring* shall include wire, conduit, raceways, bus duct, fittings, junction and outlet boxes, switches, cutouts, receptacles, and all other appurtenances comprising a complete and operable system.

G. *Product.* The term *product* shall include materials, equipment, and systems for a complete and operable system.

H. *Motor Controllers.* The term *motor controllers* shall be manual or magnetic starters (with or without switches), variable frequency controllers, individual push buttons, or hand-off-automatic (HOA) switches controlling the operation of motors.

I. *Control Devices.* The term *control devices* shall be automatic sensing and switching devices such as thermostats, float, and electro-pneumatic switches controlling the operations of mechanical and electrical equipment.

J. *Work, Project.* The terms *work* and *project* shall mean labor, operations, materials, supervision, services, machinery, equipment, tools, supplies, and facilities to be performed or provided including work normally done at the location of the project to accomplish the requirements of the contract including all alterations, amendments, or extensions to the contract made by change order.

K. *Extra Work.* The term *extra work* shall be any item of work not provided for in the awarded contract as previously modified by change order (change bulletin) or supplemental agreement, but which is either requested by the owner or found by the design professional to be necessary to complete the work within the intended scope of the Contract as previously modified.

L. *Concealed.* The term *concealed* shall mean hidden from normal sight; includes work in crawl spaces, above ceilings, in walls, in chases, and in building shafts.

M. *Exposed.* The term *exposed* shall mean not concealed.

N. *Below Ground.* The term *below ground* shall mean installed underground, buried in the earth, or buried below the ground floor slab.

O. *Above Ground.* The term *above ground* shall mean not installed underground, not buried in the earth, and not buried below the ground floor slab.

P. *Conditioned.* The term *conditioned* shall mean for the purposes of these contract documents rooms, spaces, or areas that are provided with mechanical heating and cooling.

Q. *Unconditioned and Nonconditioned.* The terms *unconditioned* and *nonconditioned* shall mean for the purposes of these contract documents rooms, spaces, or areas that are not provided with mechanical heating or cooling.

R. *Heated.* The term *heated* shall mean for the purposes of these contract documents rooms, spaces, or areas that are provided with mechanical heating only.

S. *Air Conditioned.* The term *air conditioned* shall mean for the purposes of these contract documents rooms, spaces, or areas that are provided with mechanical cooling only.

T. *Unheated.* The term *unheated* shall mean for the purposes of these contract documents rooms, spaces, or areas that are not provided with mechanical heating.

U. *Ventilated Spaces.* The term *ventilated spaces* shall mean for the purposes of these contract documents rooms, spaces, or areas supplied with outdoor air on a continuous or intermittent basis. The outdoor air may be conditioned, heated, unconditioned, or unheated.

V. *Indoor.* The term *indoor* shall mean for the purposes of these contract documents items or devices contained within the confines of a building, structure, or facility and items or devices that are not exposed to weather. The term *indoor* shall generally reference ductwork, piping, or equipment location (indoor ductwork, indoor piping, indoor equipment).

W. *Outdoor.* The term *outdoor* shall mean for the purposes of these contract documents items or devices not contained within the confines of a building, structure, or facility and items or devices that are exposed to weather. The term *outdoor* shall generally reference ductwork, piping, or equipment (outdoor ductwork, outdoor piping, outdoor equipment).

X. *Hot.* The term *hot* shall mean for the purposes of these contract documents the temperature of conveyed solids, liquids, or gases that are above the surrounding ambient temperature or above 100°F (hot supply air ductwork, heating water piping).

Y. *Cold.* The term *cold* shall mean for the purposes of these contract documents the temperature of conveyed solids, liquids, or gases that are below the surrounding ambient temperature or below 60°F (cold supply air ductwork, chilled water piping).

Z. *Warm.* The term *warm* shall mean for the purposes of these contract documents the temperature of conveyed solids, liquids, or gases that are at the surrounding ambient temperature or between 60°F and 100°F (condenser water piping).

AA. ***Hot/Cold.*** **The term** ***hot/cold*** **shall mean for the purposes of these contract documents the temperature of conveyed solids, liquids, or gases that can be either hot or cold depending on the season of the year (heating and air conditioning supply air ductwork, dual temperature piping systems).**

BB. ***Removable.*** **The term** ***removable*** **shall mean detachable from the structure or system without physical alteration or disassembly of the materials or equipment or disturbance to other construction.**

CC. ***Temporary Work.*** **Work provided by the contractor for use during the performance of the work, but which is to be removed prior to final acceptance.**

DD. ***Normally Closed (NC).*** **The term** ***normally closed*** **shall mean the valve, damper, or other control device shall remain in, or go to, the closed position when the control air pressure, the control power, or the control signal is removed. The position the device will assume when the control signal is removed.**

EE. ***Normally Open (NO).*** **The term** ***normally open*** **shall mean that the valve, damper, or other control device shall remain in, or go to, the open position when the control air pressure, the control power, or the control signal is removed. The position the device will assume when the control signal is removed.**

FF. ***Traffic Level or Personnel Level.*** **The term** ***traffic level or personnel level*** **shall mean for the purposes of these contract documents all areas, including process areas, equipment rooms, boiler rooms, chiller rooms, fan rooms, air handling unit rooms, and other areas where insulation may be damaged by normal activity and local personnel traffic. The area extends vertically from the walking surface to 8'0" above walking surface and extends horizontally 5'0" beyond the edge of the walking surface. The walking surface shall include floors, walkways, platforms, catwalks, ladders, and stairs.**

2.03. Contract Documents

A. ***Contract Drawings.*** **The terms** ***contract drawings*** **and** ***drawings*** **shall mean all drawings or reproductions of drawings pertaining to the construction or plans, sections, elevations, profiles, and details of the work contemplated and its appurtenances.**

B. ***Contract Specifications.*** **The terms** ***contract specifications*** **and** ***specifications*** **shall mean the description, provisions, and other requirements pertaining to the method and manner of performing the work and to the quantities and qualities of materials to be furnished under the contract. The specifications shall include the general provisions, the special provisions, and the technical specifications.**

C. ***Contract Documents.*** **The term** ***contract documents*** **shall include contract drawings, contract specifications, addenda, amendments, shop drawings, coordination drawings, general provisions, special provisions, the executed agreement and other items required for, or pertaining to, the contract, including the executed contract.**

D. ***Addenda.*** **Addenda are issued as changes, amendments, or clarifications to the original or previously issued contract documents. Addenda are issued in written and/or drawing form prior to acceptance or signing of the construction contract.**

E. ***Amendments (Change Orders, Change Bulletins).*** **Amendments (change orders, change bulletins) are issued changes or amendments to the contract documents. Amendments are issued in written and/or drawing form after acceptance or signing of the contract.**

F. ***Submittals or Shop Drawings.*** **The term** ***submittals*** **or** ***shop drawings*** **shall include drawings, coordination drawings, diagrams, schedules, performance characteristics, charts, brochures, catalog cuts, calculations, certified drawings, and other materials prepared by the contractor, subcontractor, manufacturer, or distributor that illustrate some portion of the work in accordance with the requirements of the contract documents used by the contractor to order, fabricate, and install the general construction, mechanical, plumbing, fire protection, and electrical equipment and systems in a building.**

The corrections or comments annotated on a shop drawing during the design professional's review do not relieve the contractor from full compliance with the contract documents regarding the work. The

design professional's check is only a review of the shop drawing's general compliance with the information shown in the contract documents. The contractor remains responsible for continuing the correlation of all material and component quantities and dimensions, coordination of the contractor's work with that of other trades, selection of suitable fabrication and installation techniques, and performance of work in a safe and satisfactory manner.

G. *Product Data.* Illustrations, standard schedules, performance charts, instructions, brochures, diagrams, and other information furnished by the contractor to illustrate a material, product, or system for some portion of the work.

H. *Samples.* Physical examples that illustrate material, equipment, or workmanship and establish standards to which the work will be judged.

I. *Coordination Drawings.* The terms *coordination drawings* and *composite drawings* are drawings created by the respective contractors showing work of all contractors superimposed on the sepia or mylar of the basic shop drawing of one of the contractors to coordinate and verify that all work in a congested area will fit in an acceptable manner.

J. *Contract.* A set of documents issued by the owner for the work, which may include the contract documents, the advertisement, form of proposal, free competitive bidding affidavit, affidavit as to taxes, certification of bidder, buy America requirements, disadvantaged business enterprise forms, bid bond, agreement, waiver of right to file mechanics lien, performance bond, payment bond, maintenance bond(s), certification regarding lobbying, disclosure form to report lobbying, and other forms that form part of the contract as required by the owner and the contract documents.

K. *Payment Bond.* The approved form of security furnished by the contractor and its surety as a guarantee to pay promptly, or cause to be paid promptly, in full, such items as may be due for all material furnished, labor supplied or performed, rental of equipment used, and services rendered in connection with the work.

L. *Maintenance Bond.* The approved form of security furnished by the

contractor and its surety as a guarantee on the part of the contractor to remedy, without cost to the owner, any defects in the work that may develop during a period of twelve (12) months from the date of substantial completion.

M. ***Performance Bond.*** **The approved form of security furnished by the contractor and its surety as a guarantee on the part of the contractor to execute the work.**

N. ***Working Drawings.*** **Drawings and calculations prepared by the contractor, subcontractor, supplier, distributor, etc., that illustrate work required for the construction of, but which will not become an integral part of, the work. These shall include, but are not limited to, drawings showing contractor's plans for temporary work such as decking, temporary bulkheads, support of excavation, support of utilities, groundwater control systems, forming and false-work, erection plans, and underpinning.**

O. ***Construction Drawings or Coordination Drawings.*** **Detailed drawings prepared by the contractor, subcontractor, supplier, distributor, etc., that illustrate in exact and intricate detail, work required for the construction contract. These drawings often show hanger locations, vibration isolators, ductwork and pipe fittings, sections, dimensions of ducts and pipes, and other items required to construct the work.**

P. ***Project Record Documents.*** **A copy of all contract drawings, shop drawings, working drawings, addenda, change orders, contract documents, and other data maintained by the contractor during the work. The contractor's recording, on a set of prints, of accurate information and sketches regarding the exact detail and location of the work as actually installed, recording such information as the exact location of all underground utilities, contract changes, and contract deviations. The contractor's information is then transferred to the original contract documents by the design professional for the owner's permanent record unless otherwise directed or specified.**

Q. ***Proposal Guarantee.*** **Cashier's check, certified check, or bid bond accompanying the proposal submitted by the bidder as a guarantee that the bidder will enter into a contract with the owner for the**

performance of the work indicated and file acceptable bonds and insurance if the contract is awarded to it.

R. *Project Schedule.* The schedule for the work as prepared and maintained by the contractor in accordance with the contract documents.

S. *Certificate of Substantial Completion.* Certificate issued by the owner or design professional certifying that a substantial portion of the work has been completed in accordance with the contract documents with the exception of contractual administrative demobilization work, inconsequential punch list items, and guarantees. The certificate of substantial completion shall establish the date of substantial completion, shall state the responsibilities of the owner and the contractor for security, maintenance, heat, utilities, damage to the work, and insurance, and shall fix the time within which the contractor shall complete the items listed therein. Warranties required by the contract documents shall commence on the date of substantial completion of the work or a designated portion thereof unless otherwise provided in the certificate of substantial completion or the contract documents.

T. *Certificate of Final Completion (Final Acceptance).* Certificate issued by the owner or design professional certifying that all of the work has been completed in accordance with the contract documents to the best of the owner's or design professional's knowledge, information, and belief, and on the basis of that person's observations and inspections including contractual administrative demobilization work and all punch list items. The certificate of final completion shall establish the date of owner acceptance. Warranties required by the contract documents shall commence on the date of final completion of the work unless otherwise provided in the certificate of substantial completion or the contract documents.

U. *Acceptance Certificate.* Certificate to be issued by the owner or design professional certifying that all the work has been completed in accordance with the contract documents.

V. *Award.* The acceptance by the owner of the bid from the responsible bidder (sometimes the lowest responsible bidder) as evidenced by the written notice to award to the bidder tendering said

bid.

W. ***Bid (Proposal).*** **The proposal of the bidder for the work, submitted on the prescribed bid form, properly signed, dated, and guaranteed, including alternates, the unit price schedule, bonds, and other bidding requirements as applicable.**

X. ***Certificate of Compliance.*** **Certificate issued by the supplier certifying that the material or equipment furnished is in compliance with the contract documents.**

Y. ***Agreement.*** **The instrument executed by the owner and the contractor in conformance with the contract documents for the performance of the work.**

Z. ***Field Order.*** **A notice issued to the contractor by the design professional specifying an action required of the contractor.**

AA. ***Request for Information or Request for Interpretation (RFI).*** **A notice issued by the contractor to the design professional or owner requesting a clarification of the contract documents.**

BB. ***Notice to Proceed.*** **A written notice from the owner to the contractor or design professional directing the contractor or design professional to proceed with the work.**

CC. ***Advertisement, Invitation to Bid.*** **The public or private announcement, as required by law or the owner, inviting bids for the work to be performed, material to be furnished, or both.**

2.04. Contractors/Manufacturers/Authorities

A. ***Contractor.*** **The term** ***contractor*** **shall mean the individual, firm, partnership, corporation, joint venture, or any combination thereof or their duly authorized representatives who have executed a contract with the client for the proposed work.**

B. ***Subcontractor or Trade Contractor.*** **The terms** ***subcontractor*** **or** ***trade contractor*** **shall mean all the lower-tier contractors, material suppliers, and distributors that have executed a contract with the contractor for the proposed work.**

C. ***Furnisher or Supplier.*** **The terms** ***furnisher*** **or** ***supplier*** **shall be defined as the "entity" (individual, partnership, firm, corporation, joint venture, or any combination thereof) engaged by the contractor, its subcontractor, or sub-subcontractor, to furnish a particular unit of material or equipment to the project site. It shall be a requirement that the furnisher or supplier be experienced in the manufacture of the material or equipment they are to furnish.**

D. ***Installer.*** **The term** ***installer*** **shall be defined as the "entity" (individual, partnership, firm, corporation, joint venture, or any combination thereof) engaged by the contractor, its subcontractor, or sub-subcontractor to install a particular unit of work at the project site, including installation, erection, application, and similar required operations. It shall be a requirement that the installer be experienced in the operations they are engaged to perform.**

E. ***Provider.*** **The term** ***provider*** **shall be defined as the "entity" (individual, partnership, firm, corporation, joint venture, or any combination thereof) engaged by the contractor, its subcontractor, or sub-subcontractor to provide a particular unit of material or equipment at the project site. It shall be a requirement that the provider be experienced in the operations they are engaged to perform.**

F. ***Bidder.*** **An individual, firm, partnership, corporation, joint venture, or any combination thereof submitting a bid for the work as a single business entity and acting directly or through a duly authorized representative.**

G. ***Authority Having Jurisdiction.*** **The term** ***authority having jurisdiction*** **shall mean federal, state, and/or local authorities or agencies thereof having jurisdiction over work to which reference is made and authorities responsible for "approving" equipment, installation, and/or procedures.**

H. ***Surety.*** **The corporate body that is bound with, and for, the contractor for the satisfactory performance of the work by the contractor, and the prompt payment in full for materials, labor, equipment, rentals, and services, as provided in the bonds.**

I. *Acceptable Manufacturers.* The term *acceptable manufacturers* shall mean the specified list of manufacturers considered acceptable to bid the project for a specific piece of equipment. Only the equipment specified has been checked for spatial compatibility. If the contractor elects to use an optional manufacturer from the acceptable manufacturers list in the specifications, it shall be the contractor's responsibility to determine and ensure the spatial compatibility of the manufacturer's equipment selected.

Part 3: Equations

3. Part 3: Equations

3.01. Airside System Equations and Derivations

A. Equations

$$H_S = 1.08 \times CFM \times \Delta T$$

$$H_L = 0.68 \times CFM \times \Delta W_{GR.}$$

$$H_L = 4840 \times CFM \times \Delta W_{LB.}$$

$$H_T = 4.5 \times CFM \times \Delta h$$

$$H_T = H_S + H_L$$

$$SHR = \frac{H_S}{H_T} = \frac{H_S}{H_S + H_L}$$

H_S	= sensible heat (Btu/h)
H_L	= latent heat (Btu/h)
H_T	= total heat (Btu/h)
ΔT	= temperature difference (°F)
$\Delta W_{GR.}$	= humidity ratio difference (Gr.H_2O/lbs.DA)
$\Delta W_{LB.}$	= humidity ratio difference (lbs.H_2O/lbs.DA)
Δh	= enthalpy difference (Btu/lbs.DA)
CFM	= air flow rate (cubic feet per minute)
SHR	= sensible heat ratio
m	= mass flow (lbs.DA/h)
c_a	= specific heat of air (0.24 Btu/lbs.DA °F)
DA	= dry air

B. Derivations

1. Standard air conditions:
   a. Temperature: 60°F
   b. Pressure: 14.7 psia (sea level)
   c. Specific volume: 13.33 ft.^{3}/lbs.DA
   d. Density: 0.075 lbs./ft.^{3}
   e. L_V = Latent heat of water @60°F: 1060 Btu/lbs.
2. Sensible heat equation:

H_S	$= m \times c_a \times \Delta T$
c_P	= 0.24 (Btu/~~lbs.DA~~. · °F) × 0.075 ~~lbs.DA~~/ft.^{3} × 60 min./h
	= 1.08 Btu min./h ft.^{3} °F
H_S	= 1.08 (Btu min./h ft.^{3} °F) × CFM (ft.^{3}/min.) × ΔT (°F)
H_S	$= 1.08 \times CFM \times \Delta T$

3. Latent heat equation:

H_L	$= m \times L_V \times \Delta W_{GR}$
L_V	= 1060 Btu/~~lbs.H_2O~~ × 0.075 lbs.DA/ft.^{3} × 60 min./h × 1.0 ~~lbs.H_2O~~/7,000 Gr.H_2O
	= 0.68 Btu lbs.DA min./hft.^{3} Gr.H_2O
H_L	= 0.68 (Btu lbs.DA min./hft.^{3} Gr.H_2O) × CFM (ft.^{3}/min.) × ΔW_{GR} (Gr.H_2O/lbs.DA)
H_L	$= 0.68 \times CFM \times \Delta W_{GR}$

4. Total heat equation:

H_T	$= m \times \Delta h$
Factor	= 0.075 lbs.DA/ft.^{3} × 60 min./h = 4.5 lbs.DA min./hft.^{3}
H_T	= 4.5 (lbs.DA min./hft.^{3}) × CFM (ft.^{3}/min.) × Δh (Btu/lbs.DA)
H_T	$= 4.5 \times CFM \times \Delta h$

3.02. Waterside System Equations and Derivations

A. Equations

$$H = 500 \times GPM \times \Delta T$$

$$GPM_{EVAP.} = \frac{TONS \times 24}{\Delta T}$$

$$GPM_{COND.} = \frac{TONS \times 30}{\Delta T}$$

H	= total heat (Btu/h)
GPM	= water flow rate (gallons per minute)
ΔT	= temperature difference (°F)
TONS	= air conditioning load (tons)
$GPM_{EVAP.}$	= evaporator water flow rate (gallons per minute)
$GPM_{COND.}$	= condenser water flow rate (gallons per minute)
c_w	= specific heat of water (1.0 Btu/lbs.H_2O)

B. Derivations

1. Standard water conditions:
   a. Temperature: 60°F
   b. Pressure: 14.7 psia (sea level)
   c. Density: 62.4 lbs./$ft.^3$
2. Water equation

H	= m × c_w × ΔT
c_w	= 1.0 Btu/~~Lb H_2O~~ °F × 62.4 ~~lbs.H_2O/ft^3~~ × 1.0 ~~ft^3~~/7.48052 gal. × 60 min./h
	= 500 Btu min./h °F gal.
H	= 500 Btu min./h °F gal. × GPM (gal./min.) × ΔT (°F)
H	= 500 × GPM × ΔT

3. Evaporator equation:

GPM_{EVAP}	= H/(500 × ΔT)
Factor	= 12,000 ~~Btu/h~~/1.0 tons ÷ 500 ~~Btu~~ min./~~h~~ °F gal.
	= 24°F gal./tons min.
GPM_{EVAP}	= tons (tons) × 24 (°F gal./tons min.)/ΔT (°F)
GPM_{EVAP}	= tons × 24/ΔT

4. Condenser equation:

GPM_{COND}	= 1.25 × GPM_{EVAP} = 1.25 × tons × 24/ΔT
GPM_{COND}	= tons × 30/ΔT

3.03. Air Change Rate Equations

$$\frac{AC}{HR} = \frac{CFM \times 60}{VOLUME}$$

$$CFM = \frac{\frac{AC}{HR} \times VOLUME}{60}$$

AC/H	= air change rate per hour
CFM	= air flow rate (cubic feet per minute)
VOLUME	= space volume (cubic feet)

3.04. English/Metric Airside System Equations Comparison

A. Sensible Heat Equations

$$H_S = 1.08 \frac{Btu\ min.}{Hr\ ft^3\ {}^\circ F} \times CFM \times \Delta T$$

$$H_{SM} = 72.42 \frac{kJ\ min.}{hr.\ m^3\ {}^\circ C} \times CMM \times \Delta T_M$$

B. Latent Heat Equations

$$H_L = 0.68 \frac{Btu\ min.\ Lb\ DA}{hr.\ ft^3\ Gr\ H_2O} \times CFM \times \Delta W$$

$$H_{LM} = 177{,}734.8 \frac{kJ\ min.\ kg\ DA}{hr.\ m^3 kg\ H_2O} \times CMM \times \Delta W_M$$

C. Total Heat Equations

$$H_T = 4.5 \frac{lb\ min.}{hr.\ ft.^3} \times CFM \times \Delta h$$

$$H_{TM} = 72.09 \frac{kg\ min.}{hr.\ m^3} \times CMM \times \Delta h_M$$

$H_T = H_S + H_L$

$H_{TM} = H_{SM} + H_{LM}$

H_S	= sensible heat (Btu/h)
H_{SM}	= sensible heat (kJ/h)
H_L	= latent heat (Btu/h)
H_{LM}	= latent heat (kJ/h)
H_T	= total heat (Btu/h)
H_{TM}	= total heat (kJ/h)
ΔT	= temperature difference (°F)
ΔT_M	= temperature difference (°C)
ΔW	= humidity ratio difference (Gr.H_2O/lbs.DA)
ΔW_M	= humidity ratio difference (kg.H_2O/kg.DA)
Δh	= enthalpy difference (Btu/lbs.DA)
Δh_M	= enthalpy difference (kJ/lbs.DA)
CFM	= air flow rate (cubic feet per minute)
CMM	= air flow rate (cubic meters per minute)

3.05. English/Metric Waterside System Equation Comparison

$$H = 500\ \frac{Btu\ min.}{hr.\ gal.\ °F} \times GPM \times \Delta T$$

$$H_M = 250.8\ \frac{kJ\ min.}{hr.\ Liters\ °C} \times LPM \times \Delta T_M$$

H	= total heat (Btu/h)
H_M	= total heat (kJ/h)
ΔT	= temperature difference (°F)
ΔT_M	= temperature difference (°C)
GPM	= water flow rate (gallons per minute)
LPM	= water flow rate (liters per minute)

3.06. English/Metric Air Change Rate Equation Comparison

$$\frac{AC}{HR} = \frac{CFM \times 60\ \frac{min.}{h}}{VOLUME}$$

$$\frac{AC}{HR_M} = \frac{CMM \times 60\ \frac{min.}{h}}{VOLUME_M}$$

AC/H	= air change rate per hour – English
AC/H_M	= air change rate per hour – Metric
AC/H	= AC/H_M
VOLUME	= space volume (cubic feet)
$VOLUME_M$	= space volume (cubic meters)
CFM	= air flow rate (cubic feet per minute)
CMM	= air flow rate (cubic meters per minute)

3.07. English/Metric Temperature and Other Conversions

$$°F = 1.8°C + 32$$

$$°C = \frac{°F - 32}{1.8}$$

°F	= degrees Fahrenheit
°C	= degrees Celsius
kJ/h	= Btu/h × 1.055
CMM	= CFM × 0.02832
LPM	= GPM × 3.785
kJ/kg	= Btu/lbs. × 2.326
meters	= ft. × 0.3048
sq. meters	= sq. ft. × 0.0929
cu. meters	= cu. ft. × 0.02832
kg	= lbs. × 0.4536
1.0 GPM	= 500 lbs. steam/h
1.0 lbs. stm./h	= 0.002 GPM
1.0 lbs. H_2O/h	= 1.0 lbs. steam/h
kg/cu. meter	= lbs./cu. ft. × 16.017 (Density)
cu. meters/kg	= cu. ft./lbs. × 0.0624 (Specific Volume)
kg H_2O/kg DA	= Gr.H_2O/lbs.DA/7,000 = lbs.H_2O/lbs.DA

3.08. Steam and Condensate Equations

A. General

$$LBS.STM./HR = \frac{BTU/HR}{H_{FG}} = \frac{BTU/HR}{960}$$

$$LBS.STM.COND./HR = \frac{EDR}{4}$$

$$EDR = \frac{BTU/HR}{240}$$

$$LBS.STM.COND./HR = \frac{GPM \times 500 \times SP.GR. \times C_w \times \Delta T}{H_{FG}}$$

$$LBS.STM.COND./HR = \frac{CFM \times 60 \times D \times C_a \times \Delta T}{H_{FG}}$$

B. Approximating Condensate Loads

$$LBS.STM.COND./HR = \frac{GPM(WATER) \times \Delta T}{2}$$

$$LBS.STM.COND./HR = \frac{GPM(FUEL\ OIL) \times \Delta T}{4}$$

$$LBS.STM.COND./HR = \frac{CFM(AIR) \times \Delta T}{900}$$

stm.	= steam
GPM	= quantity of liquid (gallons per minute)
CFM	= quantity of gas or air (cubic feet per minute)
SP.GR.	= specific gravity
D	= density (lbs./cubic feet)
C_a	= specific heat of air (0.24 Btu/lbs.)
Cw	= specific heat of water (1.00 Btu/lbs.)
H_{FG}	= latent heat of steam (Btu/lbs.) at steam design pressure (ASHRAE Fundamentals)
ΔT	= final temperature minus initial temperature
EDR	= equivalent direct radiation

3.09. Building Envelope Heating Equation and R-Values/U-Values

$$H = U \times A \times \Delta T$$

$$R = \frac{1}{C} = \frac{1}{K} \times Thickness \ \text{(in.)}$$

$$R = \frac{1}{\Sigma R}$$

H	= heat flow (Btu/h)
ΔT	= temperature difference (°F)
A	= area (sq.ft.)
U	= U-Value (Btu./h sq.ft. °F): See Part 35 for definitions.
R	= R-Value (h sq.ft. °F/Btu.): See Part 35 for definitions.
C	= conductance (Btu./h sq.ft. °F): See Part 35 for definitions.
K	= conductivity (Btu. in./h sq.ft. °F): See Part 35 for definitions.
ΣR	= sum of the individual R-Values

3.10. Fan Laws

$$\frac{CFM_2}{CFM_1} = \frac{RPM_2}{RPM_1}$$

$$\frac{SP_2}{SP_1} = \left[\frac{CFM_2}{CFM_1}\right]^2 = \left[\frac{RPM_2}{RPM_1}\right]^2$$

$$\frac{BHP_2}{BHP_1} = \left[\frac{CFM_2}{CFM_1}\right]^3 = \left[\frac{RPM_2}{RPM_1}\right]^3 = \left[\frac{SP_2}{SP_1}\right]^{1.5}$$

$$BHP = \frac{CFM \times SP \times SP.GR.}{6356 \times FAN_{EFF.}}$$

$$MHP = \frac{BHP}{M / D_{EFF.}}$$

CFM	= cubic feet/minute
RPM	= revolutions/minute
SP	= static pressure, in. W.G.
BHP	= brake horsepower
Fan Size	= constant
Air Density	= constant
SP.GR.(Air)	= 1.0
FAN_{EFF}	= 65–85%
M/D_{EFF}	= 80–95%
M/D	= motor/drive

3.11. Pump Laws

$$\frac{GPM_2}{GPM_1} = \frac{RPM_2}{RPM_1}$$

$$\frac{HD_2}{HD_1} = \left[\frac{GPM_2}{GPM_1}\right]^2 = \left[\frac{RPM_2}{RPM_1}\right]^2$$

$$\frac{BHP_2}{BHP_1} = \left[\frac{GPM_2}{GPM_1}\right]^3 = \left[\frac{RPM_2}{RPM_1}\right]^3 = \left[\frac{HD_2}{HD_1}\right]^{1.5}$$

$$BHP = \frac{GPM \times HD \times SP.GR.}{3960 \times PUMP_{EFF.}}$$

$$MHP = \frac{BHP}{M/D_{EFF.}}$$

$$VH = \frac{V^2}{2g}$$

$$HD = \frac{P \times 2.31}{SP.GR.}$$

GPM	= gallons/minute
RPM	= revolutions/minute
HD	= head in ft. H_2O
BHP	= brake horsepower
Pump Size	= constant
Water Density	= constant
SP.GR.	= specific gravity of liquid with respect to water
SP.GR.(Water)	= 1.0
$PUMP_{EFF}$	= 60–80%
M/D_{EFF}	= 85–95%
M/D	= motor/drive
P	= pressure (psi)
VH	= velocity head in ft. H_2O
V	= velocity (ft./sec.)
g	= acceleration due to gravity (32.16 ft./sec.^{2})

3.12. Pump Net Positive Suction Head (NPSH) Calculations

$NPSH_{AVAIL} > NPSH_{REQ'D}$

$NPSH_{AVAIL}$	$= H_A \pm H_S - H_F - H_{VP}$
$NPSH_{AVAIL}$	= net positive suction available at pump (feet)
$NPSH_{REQ'D}$	= net positive suction required at pump (feet)
H_A	= pressure at liquid surface (feet – 34 feet for water at atmospheric pressure)
H_S	= height of liquid surface above (+) or below (–) pump (feet)
H_F	= friction loss between pump and source (feet)
H_{VP}	= absolute pressure of water vapor at liquid temperature (feet – ASHRAE Fundamentals)
Note: Calculations may also be performed in psig, provided that all values are in psig.	

3.13. Mixed Air Temperature

$$T_{MA} = \left(T_{ROOM} \times \frac{CFM_{RA}}{CFM_{SA}}\right) + \left(T_{OA} \times \frac{CFM_{OA}}{CFM_{SA}}\right)$$

$$T_{MA} = \left(T_{RA} \times \frac{CFM_{RA}}{CFM_{SA}}\right) + \left(T_{OA} \times \frac{CFM_{OA}}{CFM_{SA}}\right)$$

CFM_{SA}	= supply air CFM
CFM_{RA}	= return air CFM
CFM_{OA}	= outside air CFM
T_{MA}	= mixed air temperature (°F)
T_{ROOM}	= room design temperature (°F)
T_{RA}	= return air temperature (°F)
T_{OA}	= outside air temperature (°F)

3.14. Psychrometric Equations

$$W = 0.622 \times \frac{P_W}{P - P_W}$$

$$RH \cong \frac{W_{ACTUAL}}{W_{SAT}} \times 100\%$$

$$RH = \frac{P_W}{P_{SAT}} \times 100\%$$

$$H_S = m \times c_P \times \Delta T$$

$$H_L = L_v \times m \times \Delta W$$

$$H_T = m \times \Delta h$$

$$W = \frac{(2501 - 2.381\,T_{WB})(W_{SAT\ WB}) - (T_{DB} - T_{WB})}{(2501 + 1.805\,T_{DB} - 4.186\,T_{WB})}$$

$$W = \frac{(1093 - 0.556\,T_{WB})(W_{SAT\ WB}) - (0.240)(T_{DB} - T_{WB})}{(1093 + 0.444\,T_{DB} - T_{WB})}$$

W	= specific humidity, lbs.H_2O/lbs.DA or Gr.H_2O/lbs.DA
W_{ACTUAL}	= actual specific humidity, lbs.H_2O/lbs.DA or Gr.H_2O/lbs.DA
W_{SAT}	= saturation specific humidity at the dry bulb temperature
$W_{SAT\ WB}$	= saturation specific humidity at the wet bulb temperature

P_W	= partial pressure of water vapor, lbs./sq.ft.
P	= total absolute pressure of air/water vapor mixture, lbs./sq.ft.
P_{SAT}	= saturation partial pressure of water vapor at the dry bulb temperature, lbs./sq.ft.
RH	= relative humidity, %
H_S	= sensible heat, Btu/h
H_L	= latent heat, Btu/h
H_T	= total heat, Btu/h
m	= mass flow rate, lbs.DA/h or lbs.H_2O/h
c_P	= specific heat, Air—0.24 Btu/lbs.DA, Water—1.0 Btu/lbs.H_2O
T_{DB}	= dry bulb temperature, °F
T_{WB}	= wet bulb temperature, °F
ΔT	= temperature difference, °F
ΔW	= specific humidity difference, lbs.H_2O/lbs.DA or Gr.H_2O/lbs.DA
Δh	= enthalpy difference, Btu/lbs.DA
L_V	= latent heat of vaporization, Btu/lbs.H_2O

3.15. Ductwork Equations

$$TP = SP + VP$$

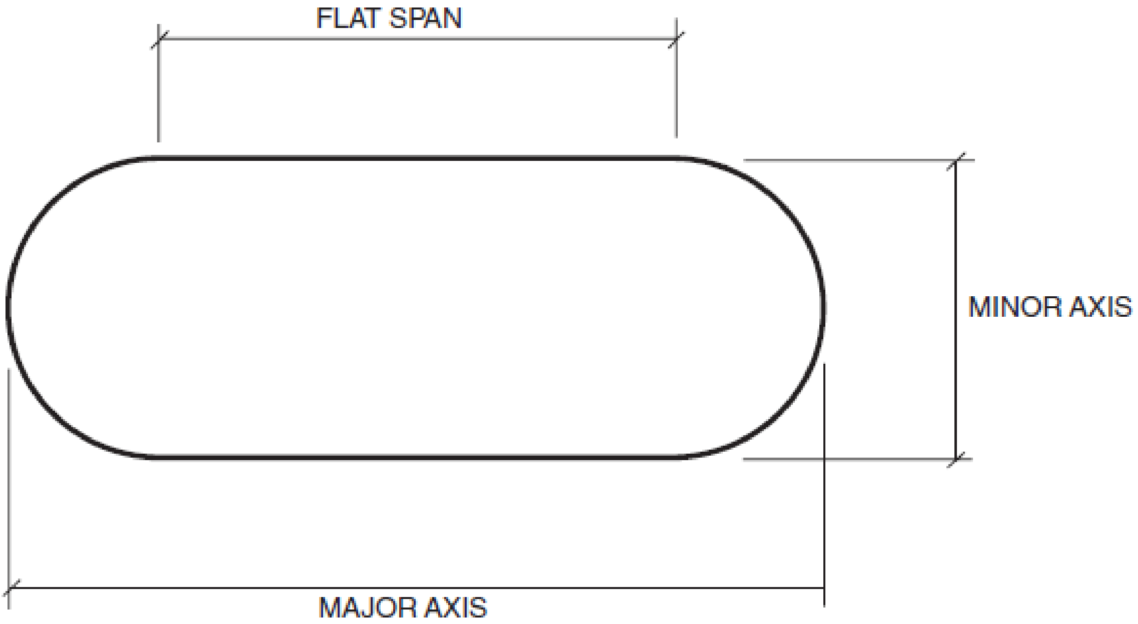
$$VP = \left[\frac{V}{4005}\right]^2 = \frac{(V)^2}{(4005)^2}$$

$$V = \frac{Q}{A} = \frac{Q \times 144}{W \times H}$$

$$D_{EQ} = \frac{1.3 \times (A \times B)^{0.625}}{(A + B)^{0.25}}$$

TP	= total pressure
SP	= static pressure, friction losses
VP	= velocity pressure, dynamic losses
V	= velocity, ft./min.
Q	= air flow rate through duct, CFM
A	= area of duct, sq.ft.
W	= width of duct, in.
H	= height of duct, in.
D_{EQ}	= equivalent round duct size for rectangular duct, in.
A	= one dimension of rectangular duct, in.
B	= adjacent side of rectangular duct, in.

3.16. Equations for Flat Oval Ductwork



$$FS = MAJOR - MINOR$$

$$A = \frac{(FS \times MINOR) + \frac{(\pi \times MINOR^2)}{4}}{144}$$

$$P = \frac{(\pi \times MINOR) + (2 \times FS)}{12}$$

$$D_{EQ} = \frac{1.55 \times (A)^{0.625}}{(P)^{0.25}}$$

FS	= flat span dimension in inches
MAJOR	= major axis dimension in inches (larger dimension)
MINOR	= minor axis dimension in inches (smaller dimension)
A	= cross-sectional area in square feet
P	= perimeter or surface area in square feet per lineal feet
D_{EQ}	= equivalent round duct diameter

3.17. Steel Pipe Equations

A	$= 0.785 \times ID^2$
W_P	$= 10.6802 \times T \times (OD - T)$
W_W	$= 0.3405 \times ID^2$
OSA	$= 0.2618 \times OD$
ISA	$= 0.2618 \times ID$
A_M	$= 0.785 \times (OD^2 - ID^2)$
A	= cross sectional area (sq.in.)
W_P	= weight of pipe per foot (lbs.)
W_W	= weight of water per foot (lbs.)
T	= pipe wall thickness (in.)
ID	= inside diameter (in.)
OD	= outside diameter (in.)
OSA	= outside surface area per foot (sq.ft.)
ISA	= inside surface area per foot (sq.ft.)
A_M	= area of the metal (sq.in.)

3.18. Steam and Steam Condensate Pipe Sizing Equations

A. Steam Pipe Sizing Equations

$$\Delta P = \frac{(0.01306) \times W^2 \times \left(1 + \frac{3.6}{ID}\right)}{3600 \times D \times ID^5}$$

$$W = 60 \times \sqrt{\frac{\Delta P \times D \times ID^5}{0.01306 \times \left(1 + \frac{3.6}{ID}\right)}}$$

$$W = 0.41667 \times V \times A_{INCHES} \times D = 60 \times V \times A_{FEET} \times D$$

$$V = \frac{2.4 \times W}{A_{INCHES} \times D} = \frac{W}{60 \times A_{FEET} \times D}$$

ΔP	= pressure drop per 100 ft. of pipe, psig/100 ft.
W	= steam flow rate, lbs./h
ID	= actual inside diameter of pipe, in.
D	= average density of steam at system pressure, lbs./cu.ft.
V	= velocity of steam in pipe, ft./min.
A_{INCHES}	= actual cross-sectional area of pipe, sq.in.
A_{FEET}	= actual cross-sectional area of pipe, sq.ft.

B. Steam Condensate Pipe Sizing Equations

$$FS = \frac{H_{S_{SS}} - H_{S_{CR}}}{H_{L_{CR}}} \times 100$$

$$W_{CR} = \frac{FS}{100} \times W$$

FS	= flash steam, percentage %
H_{SSS}	= sensible heat at steam supply pressure, Btu/lbs.
H_{SCR}	= sensible heat at condensate return pressure, Btu/lbs.
H_{LCR}	= latent heat at condensate return pressure, Btu/lbs.
W	= steam flow rate, lbs./h
W_{CR}	= condensate flow based on percentage of flash steam created during condensing process, lbs./h. Use this flow rate in the preceding steam equations to determine the condensate return pipe size.

3.19. Air Conditioning Condensate

$$GPM_{AC\ COND} = \frac{CFM \times \Delta W_{LB.}}{SpV \times 8.33}$$

$$GPM_{AC\ COND} = \frac{CFM \times \Delta W_{GR.}}{SpV \times 8.33 \times 7000}$$

$GPM_{AC\ COND}$	= air conditioning condensate flow (gal./min.)
CFM	= air flow rate (cu.ft./min.)
SpV	= specific volume of air (cu.ft./lbs.DA) = 13.33 ft^3/lbs. DA at 60°F
$\Delta W_{LB.}$	= specific humidity (lbs.H_2O/lbs.DA)
$\Delta W_{GR.}$	= specific humidity (Gr.H_2O/lbs.DA)

3.20. Humidification

$$GRAINS_{REQ'D} = \left(\frac{W_{GR.}}{SpV}\right)_{ROOM\ AIR} - \left(\frac{W_{GR.}}{SpV}\right)_{SUPPLY\ AIR}$$

$$POUNDS_{REQ'D} = \left(\frac{W_{LB.}}{SpV}\right)_{ROOM\ AIR} - \left(\frac{W_{LB.}}{SpV}\right)_{SUPPLY\ AIR}$$

$$LBS.STM./HR = \frac{CFM \times GRAINS_{REQ'D} \times 60}{7000} = CFM \times POUNDS_{REQ'D} \times 60$$

$GRAINS_{REQ'D}$	= grains of moisture required (Gr.H_2O/cu.ft.)
$POUNDS_{REQ'D}$	= pounds of moisture required (lbs.H_2O/cu.ft.)
CFM	= air flow rate (cu.ft./min.)
SpV	= specific volume of air (cu.ft./lbs.DA)
$W_{GR.}$	= specific humidity (Gr.H_2O/lbs.DA)
$W_{LB.}$	= specific humidity (lbs.H_2O/lbs.DA)

3.21. Humidifier Sensible Heat Gain

$$H_S = (0.244 \times Q \times \Delta T) + (L \times 380)$$

H_S	= sensible heat gain (Btu/h)
Q	= steam flow (lbs. steam/h)
ΔT	= steam temperature – supply air temperature (°F)
L	= length of humidifier manifold (ft.)

3.22. Expansion Tanks

$$CLOSED\ V_T = V_S \times \frac{\left[\left(\frac{v_2}{v_1}\right) - 1\right] - 3\alpha\Delta T}{\left[\frac{P_A}{P_1} - \frac{P_A}{P_2}\right]}$$

$$OPEN\ V_T = 2 \times \left\{\left(V_S \times \left[\left(\frac{v_2}{v_1}\right) - 1\right]\right) - 3\alpha\Delta T\right\}$$

$$DIAPHRAGM\ V_T = V_S \times \frac{\left[\left(\frac{v_2}{v_1}\right) - 1\right] - 3\alpha\Delta T}{1 - \left(\frac{P_1}{P_2}\right)}$$

V_T	= volume of expansion tank (gallons)	
V_S	= volume of water in piping system (gallons)	
ΔT	= T_2 – T_1 (°F)	
T_1	= lower system temperature (°F)	
	Heating Water	T_1 = 45–50°F temperature at fill condition
	Chilled Water	T_1 = supply water temperature
	Dual Temperature	T_1 = chilled water supply temperature

		supply temperature
T_2	= higher system temperature (°F)	
	Heating Water	T_2 = supply water temperature
	Chilled Water	T_2 = 95°F ambient temperature (design weather data)
	Dual Temperature	T_2 = heating water supply temperature
P_A	= atmospheric pressure (14.7 psia)	
P_1	= system fill pressure/minimum system pressure (psia)	
P_2	= system operating pressure/maximum operating pressure (psia)	
v_1	= SpV of H_2O at T_1 (cu.ft./lbs.H_2O) ASHRAE Fundamentals	
v_2	= SpV of H_2O at T_2 (cu.ft./lbs.H_2O) ASHRAE Fundamentals	
α	= linear coefficient of expansion	
	$\alpha_{STEE} = 6.5 \times 10^{-6}$	
	$\alpha_{COPPER} = 9.5 \times 10^{-6}$	
System Volume Estimate:		
	12 gal./ton	
	35 gal./BHP	
System Fill Pressure/Minimum System Pressure Estimate:		
	Height of System + 5 to 10 psi OR 5–10 psi, whichever is greater.	
System Operating Pressure/Maximum Operating Pressure Estimate:		
	150 lbs. Systems	45–125 psi
	250 lbs. Systems	125–225 psi

3.23. Air Balance Equations

SA	= Supply Air
RA	= Return Air
OA	= Outside Air
EA	= Exhaust Air
RFA	= Relief Air
SA	= RA + OA = RA + EA + RFA
If minimum OA (ventilation air) is greater than EA, then	
OA = EA + RFA	
If EA is greater than minimum OA (ventilation air), then	
OA = EA	RFA = 0
For Economizer Cycle:	
OA = SA = EA + RFA	RA = 0

3.24. Efficiencies

$$COP = \frac{BTU\ OUTPUT}{BTU\ INPUT} = \frac{EER}{3.413}$$

$$EER = \frac{BTU\ OUTPUT}{WATTS\ INPUT} = COP \times 3.413$$

$$KW/TON = \frac{12,000\ BTU/HR\ TON}{COP \times 3,517 BUT/HR\ KW}$$

Turndown Ratio = Maximum Firing Rate: Minimum Firing Rate (e.g., 5:1, 10:1, 25:1)

$$OVERALL\ THERMAL\ EFF. = \frac{GROSS\ BTU\ OUTPUT}{GROSS\ BTU\ INPUT} \times 100\%$$

$$COMBUSTION\ EFF. = \frac{BTU\ INPUT - BTU\ STACK\ LOSS}{BTU\ INPUT} \times 100\%$$

Overall Thermal Efficiency Range 75–90%

Combustion Efficiency Range 85–95%

3.25. Cooling Towers and Heat Exchangers

$APPROACH_{CT'S} = LWT - AWB$

$APPROACH_{HE'S} = EWT_{HS} - LWT_{CS}$

$RANGE = EWT - LWT$

EWT	= entering water temperature (°F)
LWT	= leaving water temperature (°F)
AWB	= ambient wet bulb temperature (Design WB – °F)
HS	= hot side
CS	= cold side

3.26. Cooling Tower/Evaporative Cooler Blowdown Equations

$$C = \frac{(E+D+B)}{(D+B)}$$

$$B = \frac{E-[(C-1)\times D]}{(C-1)}$$

E	= $GPM_{COND.} \times R \times 0.0008$
D	= $GPM_{COND.} \times 0.0002$
R	= $EWT - LWT$
B	= blowdown, GPM
C	= cycles of concentration
D	= drift, GPM
E	= evaporation, GPM
EWT	= entering water temperature, °F
LWT	= leaving water temperature, °F
R	= range, °F

3.27. Electricity

A. General

KVA	= *KW* + *KVAR*
PF	= *KW/KVA*

B. Single-Phase Power

$$KW_{1\phi} = \frac{V \times A \times PF}{1000}$$

$$KVA_{1\phi} = \frac{V \times A}{1000}$$

$$BHP_{1\phi} = \frac{V \times A \times PF \times DEVICE_{EFF.}}{746}$$

$$MHP_{1\phi} = \frac{BHP_{1\phi}}{M / D_{EFF.}}$$

C. Three-Phase Power

$$KW_{3\phi} = \frac{\sqrt{3} \times V \times A \times PF}{1000}$$

$$KVA_{3\phi} = \frac{\sqrt{3} \times V \times A}{1000}$$

$$BHP_{3\phi} = \frac{\sqrt{3} \times V \times A \times PF \times DEVICE_{EFF.}}{746}$$

$$MHP_{3\phi} = \frac{BHP_{3\phi}}{M / D_{EFF.}}$$

KVA	= total power (kilovolt amps)
KW	= real power, electrical energy (kilowatts)
KVAR	= reactive power or "imaginary" power (kilovolt amps reactive)
V	= voltage (volts)
A	= current (amps)
PF	= power factor (0.75–0.95)
BHP	= brake horsepower
MHP	= motor horsepower
EFF	= efficiency
M/D	= motor drive

3.28. Moisture Condensation on Glass

$$T_{GLASS} = T_{ROOM} - \left[\frac{R_{IA}}{R_{GLASS}} \times (T_{ROOM} - T_{OA}) \right]$$

$$T_{GLASS} = T_{ROOM} - \left[\frac{U_{GLASS}}{U_{IA}} \times (T_{ROOM} - T_{OA}) \right]$$

If $T_{GLASS} < DP_{ROOM}$ condensation occurs

T	= temperature (°F)
R	= R-Value (h sq.ft. °F/Btu)
U	= U-Value (Btu./h sq.ft. °F)
IA	= inside airfilm
	= design outside air temperature
DP	= dewpoint

3.29. Calculating Heating Loads for Loading Docks, Heavily Used Vestibules and Similar Spaces

A. **Find volume of space to be heated (cu.ft.).**

B. **Determine acceptable warm-up time for space (min.).**

C. **Divide volume by time (CFM).**

D. **Determine inside and outside design temperatures—assume inside space temperature has dropped to the outside design temperature because doors have been open for an extended period of time.**

E. **Use sensible heat equation to determine heating requirement using CFM and inside and outside design temperatures determined earlier in this Part.**

3.30. Ventilation of Mechanical Rooms with Refrigeration Equipment

A. **For a more detailed description of ventilation requirements for mechanical rooms with refrigeration equipment, see ASHRAE Standard 15 and Part 8.**

B. **Completely Enclosed Equipment Rooms**

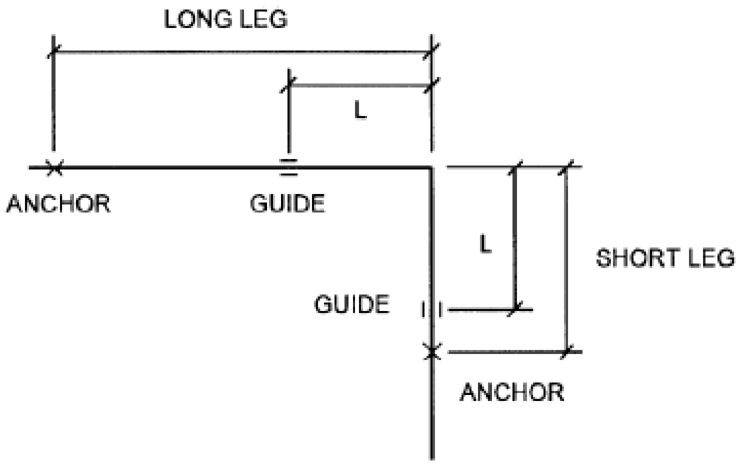
CFM	$= 100 \times G^{0.5}$
CFM	= exhaust air flow rate required (cu.ft./minute)
G	= mass of refrigerant of largest system (pounds)

C. **Partially Enclosed Equipment Rooms**

FA	$= G^{0.5}$
FA	= ventilation free opening Area (sq.ft.)
G	= mass of refrigerant of largest system (pounds)

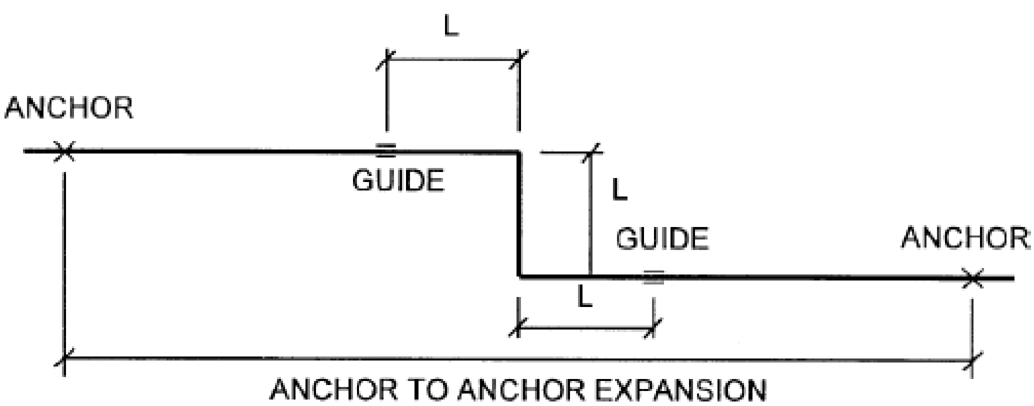
3.31. Pipe Expansion Equations

A. L-Bends



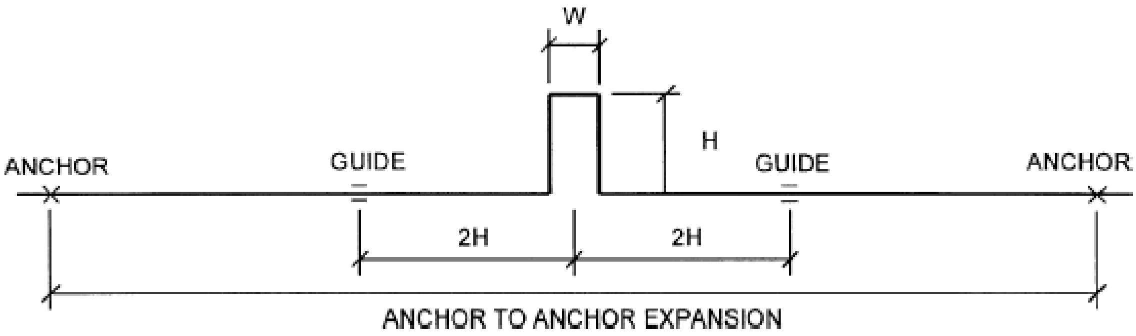
L	$= 6.225 \times \sqrt{\Delta D}$
F	= 500 LB./PIPE DIA. × PIPE DIA.
L	= length of leg required to accommodate thermal expansion or contraction, feet
Δ	= thermal expansion or contraction of long leg, inches
D	= pipe outside diameter, inches
F	= force exerted by pipe expansion or contraction on anchors and supports, lbs. See Tables in Part 18 for solved equations.

B. Z-Bends



L	$= 4 \times \sqrt{\Delta D}$
F	= 200 – 500 *LB.*/*PIPE DIA*. × *PIPE DIA*.
L	= length of offset leg required to accommodate thermal expansion or contraction, feet
Δ	= anchor to anchor expansion or contraction, inches
D	= pipe outside diameter, inches
F	= force exerted by pipe expansion or contraction on anchors and supports, lbs. See Tables in Part 18 for solved equations.

C. U-Bends or Expansion Loops



L	$= 6.225 \times \sqrt{\Delta D}$
F	= 200 LB./PIPE DIA. × PIPE DIA.
L	$= 2H + W$
H	$= 2W$
L	$= 5W$
L	= length of loop required to accommodate thermal expansion or contraction, ft.
D	= anchor to anchor expansion or contraction, in.
D	= pipe outside diameter, in.
F	= force exerted by pipe expansion or contraction on anchors and supports, lbs.

3.32. Relief Valve Vent Line Maximum Length

$$L = \frac{9 \times P_1^2 \times D^5}{C^2} = \frac{9 \times P_2^2 \times D^5}{16 \times C^2}$$

P_1	= 0.25×[(PRESSURE SETTING ×1.1)+14.7]
P_2	= [(PRESSURE SETTING ×1.1)+14.7]
L	= maximum length of relief vent line in feet
D	= inside diameter of pipe in inches
C	= minimum discharge of air in lbs./min.

3.33. Relief Valve Sizing

A. Liquid System Relief Valves—Spring-Style Relief Valves

$$A = \frac{GPM \times \sqrt{G}}{28.14 \times K_B \times K_V \times \sqrt{\Delta P}}$$

B. Liquid System Relief Valves—Pilot-Operated Relief Valves

$$A = \frac{GPM \times \sqrt{G}}{36.81 \times K_V \times \sqrt{\Delta P}}$$

C. Steam System Relief Valves

$$A = \frac{W}{51.5 \times K \times P \times K_{SH} \times K_N \times K_B}$$

D. Gas and Vapor System Relief Valves—lbs./h

$$A = \frac{W \times \sqrt{TZ}}{C \times K \times P \times K_B \times \sqrt{M}}$$

E. Gas and Vapor System Relief Valves—SCFM

$$A = \frac{SCFM \times \sqrt{TGZ}}{1.175 \times C \times K \times P \times K_B}$$

F. Relief Valve Equation Definitions

1. A	= Minimum required effective relief valve discharge area (sq.in.)
2. GPM	= Required relieving capacity at flow conditions (gal./min.)
3. W	= Required relieving capacity at flow conditions (lbs./h)
4. SCFM	= Required relieving capacity at flow conditions (standard cu.ft./min.)
5. G	= Specific gravity of liquid, gas, or vapor at flow conditions Water = 1.0 for most HVAC applications Air = 1.0
6. C	= Coefficient determined from expression of ratio of specific heats C = 315 if value is unknown
7. K	= Effective coefficient of discharge

7. K	= Effective coefficient of discharge K = 0.975
8. K_B	= Capacity correction factor due to back pressure K_B = 1.0 for atmospheric discharge systems
9. K_V	= Flow correction factor due to viscosity K_V = 0.9 to 1.0 for most HVAC applications with water
10. K_N	= Capacity correction factor for dry saturated steam at set pressures above 1500 psia and up to 3200 psia K_N = 1.0 for most HVAC applications
11. K_{SH}	= Capacity correction factor due to the degree of superheat K_{SH} = 1.0 for saturated steam
12. Z	= Compressibility factor Z = 1.0 if value is unknown
13. P	= Relieving pressure (psia) P = Set pressure (psig) + over pressure (10% psig) + atmospheric pressure (14.7 psia)
14. ΔP	= Differential pressure (psig) ΔP = Set pressure (psig) + over pressure (10% psig) – back pressure (psig)
15. T	= Absolute temperature (°R = °F + 460)
16. M	= Molecular weight of the gas or vapor

G. Relief Valve Sizing Notes

1. When multiple relief valves are used, one valve shall be set at or below the maximum allowable working pressure, and the remaining valves may be set up

to 5 percent over the maximum allowable working pressure.

2. When sizing multiple relief valves, the total area required is calculated on an over pressure of 16 percent or 4 psi, whichever is greater.

3. For superheated steam, the following correction factor values may be used:

a. Superheat up to 400°F:	0.97	(range 0.979–0.998)
b. Superheat up to 450°F:	0.95	(range 0.957–0.977)
c. Superheat up to 500°F:	0.93	(range 0.930–0.968)
d. Superheat up to 550°F:	0.90	(range 0.905–0.974)
e. Superheat up to 600°F:	0.88	(range 0.882–0.993)
f. Superheat up to 650°F:	0.86	(range 0.861–0.988)
g. Superheat up to 700°F:	0.84	(range 0.841–0.963)
h. Superheat up to 750°F:	0.82	(range 0.823–0.903)
i Superheat up to 800°F:	0.80	(range 0.805–0.863)
j. Superheat up to 850°F:	0.78	(range 0.786–0.836)
k. Superheat up to 900°F:	0.75	(range 0.753–0.813)
l. Superheat up to 950°F:	0.72	(range 0.726–0.792)
m. Superheat up to 1000°F:	0.70	(range 0.704–0.774)

4. Gas and vapor properties:

Gas and vapor properties

Gas or Vapor	Molecular Weight	Ratio of Specific Heats	Coefficient C	Specific Gravity
Acetylene	26.04	1.25	342	0.899
Air	28.97	1.40	356	1.000
Ammonia (R-717)	17.03	1.30	347	0.588
Argon	39.94	1.66	377	1.379
Benzene	78.11	1.12	329	2.696
N-Butane	58.12	1.18	335	2.006
Iso-Butane	58.12	1.19	336	2.006
Carbon Dioxide	44.01	1.29	346	1.519
Carbon Disulphide	76.13	1.21	338	2.628
Carbon Monoxide	28.01	1.40	356	0.967
Chlorine	70.90	1.35	352	2.447
Cyclohexane	84.16	1.08	325	2.905
Ethane	30.07	1.19	336	1.038
Ethyl Alcohol	46.07	1.13	330	1.590
Ethyl Chloride	64.52	1.19	336	2.227
Ethylene	28.03	1.24	341	0.968
Helium	4.02	1.66	377	0.139
N-Heptane	100.20	1.05	321	3.459
Hexane	86.17	1.06	322	2.974
Hydrochloric Acid	36.47	1.41	357	1.259

Gas or Vapor	Molecular Weight	Ratio of Specific Heats	Coefficient C	Specific Gravity
Hydrogen	2.02	1.41	357	0.070
Hydrogen Chloride	36.47	1.41	357	1.259
Hydrogen Sulphide	34.08	1.32	349	1.176
Methane	16.04	1.31	348	0.554
Methyl Alcohol	32.04	1.20	337	1.106
Methyl Butane	72.15	1.08	325	2.491
Methyl Chloride	50.49	1.20	337	1.743
Natural Gas	19.00	1.27	344	0.656
Nitric Oxide	30.00	1.40	356	1.036
Nitrogen	28.02	1.40	356	0.967
Nitrous Oxide	44.02	1.31	348	1.520
N-Octane	114.22	1.05	321	3.943
Oxygen	32.00	1.40	356	1.105
N-Pentane	72.15	1.08	325	2.491
Iso-Pentane	72.15	1.08	325	2.491
Propane	44.09	1.13	330	1.522
R-11	137.37	1.14	331	4.742
R-12	120.92	1.14	331	4.174
R-22	86.48	1.18	335	2.985
R-114	170.93	1.09	326	5.900
R-123	152.93	1.10	327	5.279
R-134a	102.03	1.20	337	3.522
Sulfur Dioxide	64.04	1.27	344	2.211

Toluene	92.13	1.09	326	3.180
Gas or	**Molecular**	**Ratio of**	**Coefficient**	**Specific**

3.34. Motor Drive Formulas

$$D_{FP} \times RPM_{FP} = D_{MP} \times RPM_{MP}$$

$$BL = [(D_{FP} + D_{MP}) \times 1.5708] + (2 \times L)$$

D_{FP}	= fan pulley diameter
D_{MP}	= motor pulley diameter
RPM_{FP}	= fan pulley RPM
RPM_{MP}	= motor pulley RPM
BL	= belt length
L	= center to center distance of fan and motor pulleys

3.35. Domestic Water Heater Sizing

$$H_{OUTPUT} = GPH \times 8.34\ LBS./GAL. \times \Delta T \times 1.0$$

$$H_{INPUT} = \frac{GPH \times 8.34\ LBS./GAL. \times \Delta T}{\%EFFICIENCY}$$

$$GPH = \frac{H_{INPUT} \times \%EFFICIENCY}{\Delta T \times 8.34\ LBS./GAL.} = \frac{KW \times 3413\ BTU/KW}{\Delta T \times 8.34\ LBS./GAL.}$$

$$\Delta T = \frac{H_{INPUT} \times \%EFFICIENCY}{GPH \times 8.34\ LBS./GAL.} = \frac{KW \times 3413\ BTU/KW}{GPH \times 8.34\ LBS./GAL.}$$

$$KW = \frac{GPH \times 8.34\ LBS./GAL. \times \Delta T \times 1.0}{3413\ BTU/KW}$$

$$\%COLD\ WATER = \frac{T_{HOT} - T_{MIX}}{T_{HOT} - T_{COLD}}$$

$$\%HOT\ WATER = \frac{T_{MIX} - T_{COLD}}{T_{HOT} - T_{COLD}}$$

H_{OUTPUT}	= heating capacity – output
H_{INPUT}	= heating capacity – input
GPH	= recovery rate – gallons per hour
ΔT	= temperature rise – °F
kW	= kilowatts
T_{COLD}	= temperature – cold water – °F
T_{HOT}	= temperature – hot water – °F
T_{MIX}	= temperature – mixed water – °F

3.36. Domestic Hot Water Recirculation Pump/Supply Sizing

A. **Determine the approximate total length of all hot water supply and return piping.**

B. **Multiply this total length by 30 Btu/ft. for insulated pipe and 60 Btu/ft. for uninsulated pipe to obtain the approximate heat loss.**

C. **Divide the total heat loss by 10,000 to obtain the total pump capacity in GPM.**

D. **Select a circulating pump to provide the total required GPM and obtain the head created at this flow.**

E. **Multiply the head by 100 and divide by the total length of the longest run of the hot water return piping to determine the allowable friction loss per 100 feet of pipe.**

F. **Determine the required GPM in each circulating loop and size the hot water return pipe based on this GPM and the allowable friction loss as determined earlier.**

3.37. Swimming Pools

A. Sizing Outdoor Pool Heater

1. Determine pool capacity in gallons – obtain from architect if available.

Length × Width × Depth × 7.5 gal./cu.ft. (If depth is not known, assume an average depth of 5.5 feet.)

2. Determine heat pick-up time in hours from owner.

3. Determine pool water temperature in °F from the owner. If owner does not specify temperature, assume 80°F.

4. Determine the average air temperature on the coldest month in which the pool will be used.

5. Determine the average wind velocity in miles per hour. For pools less than 900 square feet and where the pool is sheltered by nearby buildings, fences, shrubs, etc., from the prevailing wind, an average wind velocity of less than 3.5 mph may be assumed. The surface heat loss factor of 5.5 Btuh/sq.ft. °F in the following equation assumes a wind velocity of 3.5 mph. If a wind velocity of less than 3.5 mph is used, multiply the equation by 0.75; for 5.0 mph, multiply the equation by 1.25; and for 10 mph, multiply the equation by 2.0.

6. Pool heater equations:

$$H_{POOLHEATER} = H_{HEAT-UP} + H_{SURFACE\ LOSS}$$

$$H_{HEAT-UP} = \frac{GAL. \times 8.34\ LBS./GAL. \times \Delta T_{WATER} \times 1.0\ BTU/LBS.°F}{HEAT\ PICK\text{-}UP\ TIME}$$

$$H_{SURFACE\,LOSS} = 5.5\ BTU/HRSQ.\ FT.°F \times \Delta T_{WATER/ARI} \times POOL\,AREA$$

$$\Delta T_{WATER} = T_{FINAL} - T_{INITIAL}$$

$$T_{FINAL} = POOL\ WATER\ TEMPERATURE$$

$$T_{INITIAL} = 50°F$$

$$\Delta T_{WATER/AIR} = T_{FINAL} - T_{AVERAGE\,AIR}$$

H	= heating capacity (Btu/h)
ΔT	= temperature difference (°F)

Citation

EXPORT

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. Part 3: Equations, Chapter (McGraw-Hill Professional, 2016), AccessEngineering

Part 4: Conversion Factors

4. Part 4: Conversion Factors

4.01. Length

1 mile	= 1760 yds. = 5280 ft. = 63,360 in. = 1.609 km
1 ft.	= 0.3048 m = 30.48 cm = 304.8 mm
1 in.	= 2.54 cm = 25.4 mm
1 cm	= 0.3937 in.
1 m	= 39.37 in. = 3.2808 ft. = 1.094 yds.
1 km	= 3281 ft. = 0.6214 miles = 1094 yds.
1 fathom	= 6 feet = 1.828804 meters
1 furlong	= 660 feet

4.02. Weight

1 gal.H_2O	= 8.33 lbs.H_2O
1 lb.	= 16 oz. = 7000 grains = 0.4536 kg
1 ton	= 2000 lbs. = 907 kg
1 kg	= 2.205 lbs.
1 lb.steam	= 1 lb.H_2O

4.03. Area

1 sq.ft.	= 144 sq.in.
1 acre	= 43,560 sq.ft. = 4840 sq.yds. = 0.4047 hectares
1 sq.mile	= 640 acres
1 sq.yd.	= 9 sq.ft. = 1296 sq.in.
1 hectare	= 2.417 acres
1 sq.m	= 1,550 sq.in. = 10.7639 sq.ft. = 1.1968 sq.yds.

4.04. Volume

1 cu.yd.	= 27 cu.ft. = 46,656 cu.in. = 1616 pints = 807.9 quarts = 764.6 liters
1 cu.ft.	= 1,728 cu.in.
1 liter	= 0.2642 gallons = 1.057 quarts = 2.113 pints
1 gallon	= 4 quarts = 8 pints = 3.785 liters
1 cu.m	= 61,023 cu.in. = 35.3134 cu.ft. = 1.3093 cu.yds.
1 barrel oil	= 42 gallons oil
1 barrel beer	= 31.5 gallons beer
1 barrel wine	= 31.0 gallons wine
1 bushel	= 1.2445 cu.ft. = 32 quarts (dry) = 64 pints (dry) = 4 pecks
1 hogshead	= 63 gallons = 8.42184 cu.ft.

4.05. Velocity

1 mph	= 5280 ft./h = 88 ft./min. = 1.467 ft./sec. = 0.8684 knot
1 knot	= 1.1515 mph = 1.8532 km/hr. = 1.0 nautical mile/h
1 league	= 3.0 miles (approx.)

4.06. Speed of Sound in Air

1128.5 ft./sec.	= 769.4 mph

4.07. Pressure

14.7 psi	= 33.95 ft. H_2O = 29.92 in. Hg = 407.2 in. W.G. = 2116.8 lbs./sq.ft.
1 psi	= 2.307 ft. H_2O = 2.036 in. Hg = 16 oz = 27.7 in. WC
1 ft. H_2O	= 0.4335 psi = 62.43 lbs./sq.ft.
1 oz	= 1.73 in. WC

4.08. Density

A. Water

62.43 lbs./cu.ft.	= 8.33 lbs./gal. = 0.1337 cu.ft./gal.
1 cu.ft.	= 7.48052 gallons = 29.92 quarts = 62.43 lbs.H_2O

B. Standard Air @ 60°F, 14.7 psi

13.329 cu.ft./lbs.	= 0.0750 lbs./cu.ft.
1 lb./cu.ft.	= 177.72 cu.ft./lb.
1 cu.ft./lb.	= 0.00563 lbs./cu.ft.
1 kg/cu.m	= 16.017 lbs./cu.ft.
1 cu.m/kg	= 0.0624 cu.ft./lb

4.09. Energy

1 hp	= 0.746 kW = 746 watts = 2,545 Btuh. 1.0 kva
1 kW	= 1,000 watts = 3413 Btuh = 1.341 hp
1 watt	= 3.413 Btuh
1 ton AC	= 12,000 Btuh cooling = 15,000 Btuh heat rejection

1 Btuh	= 1 Btu/h
1 bhp	= 34,500 Btuh (33,472 Btuh) = 34.5 lbs.stm/h = 34.5 lbs.H_2O/h = 0.069 gpm = 4.14 gph = 140 edr (sq.ft. of equivalent direct radiation)
1 therm	= 100,000 Btuh
1 mbh	= 1,000 Btuh
1 lb.stm/h	= 0.002 gpm
1 gpm	= 500 lbs.stm./h
1 edr (equivalent direct radiation)	= 0.000496 gpm = 0.25 lbs.stm.cond./h
1,000 edr	= 0.496 gpm
1 edr hot water	= 150 Btu/h
1 edr steam	= 240 Btu/h
1 edr	= 240 Btu/h (up to 1,000 ft. above sea level)
1 edr	= 230 Btu/h (1,000 ft.–3,000 ft. above sea level)
1 edr	= 223 Btu/h (3,000 ft. –5,000 ft. above sea level)
1 edr	= 216 Btu/h (5,000 ft.–7,000 ft. above sea level)
1 edr	= 209 Btu/h (7,000 ft.–10,000 ft. above sea level)

4.10. Flow

1 mgd (million gal./day)	= 1.547 cu.ft./sec. = 694.4 gpm
1 cu.ft./min.	= 62.43 lbs.H_2O/min. = 448.8 gph

4.11. HVAC Metric Conversions

kJ/h	= Btu/h × 1.055
cmm	= cfm × 0.02832
lpm	= gpm × 3.785
kJ/kg	= Btu/lb. × 2.326
meters	= ft. × 0.3048
sq. meters	= sq. ft. × 0.0929
cu. meters	= cu. ft. × 0.02832
kg	= lbs. × 0.4536
1.0 gpm	= 500 lbs.steam/h
1.0 lb.stm./h	= 0.002 gpm
1.0 lb.H_2O/h	= 1.0 lb.steam/h
kg/cu.m	= lbs./cu.ft. × 16.017 (density)
cu.m/kg	= cu.ft./lb. × 0.0624 (specific volume)
kg H_2O/kg DA	= Gr H_2O/lb. DA/7000 = lb. H_2O/lb. DA

4.12. Fuel Conversion Factors

A. **Electric Baseboard to Hydronic Baseboard**
   1. KWH × 1.19 = KWH for electric boiler
   2. KWH × 0.033 = gal. for oil-fired boiler
   3. KWH × 0.046 = therms for gas-fired boiler

B. **Electric Furnace to Hydronic Baseboard**
   1. KWH × 1.0 = KWH for electric boiler
   2. KWH × 0.028 = gal. for oil-fired boiler
   3. KWH × 0.038 = therms for gas-fired boiler

C. **Ceiling Cable to Hydronic Baseboard**

1. KWH × 1.06 = KWH for electric boiler
2. KWH × 0.03 = gal. for oil-fired boiler
3. KWH × 0.041 = therms for gas-fired boiler

D. **Heat Pump to Hydronic Baseboard**

1. KWH × 1.88 = KWH for electric boiler
2. KWH × 0.052 = gal. for oil-fired boiler
3. KWH × 0.073 = therms for gas-fired boiler

E. **Electric Baseboard to Warm Air Furnace**

1. KWH × 1.19 = KWH for electric furnace
2. KWH × 0.039 = gal. for oil-fired furnace
3. KWH × 0.054 = therms for gas-fired furnace

F. **Electric Furnace to Fuel-Fired Furnace**

1. KWH × 0.032 = gal. for oil-fired furnace
2. KWH × 0.045 = therms for gas-fired furnace

G. **Ceiling Cable to Warm Air Furnace**

1. KWH × 1.06 = KWH for electric furnace
2. KWH × 0.034 = gal. for oil-fired furnace
3. KWH × 0.048 = therms for gas-fired furnace

H. **Heat Pump to Warm Air Furnace**

1. KWH × 1.88 = KWH for electric furnace
2. KWH × 0.061 = gal. for oil-fired furnace
3. KWH × 0.085 = therms for gas-fired furnace

I. **Warm Air Systems to Hydronic Baseboard System**

1. gal. oil for W.A. × 0.857 = gal. for hydronics
2. therms gas for W.A. × 0.857 = therms for hydronics
3. gal. oil for W.A. × 1.2 = therms for hydronics

4. therms gas for W.A. × 0.612 = gal. for hydronics

Citation

EXPORT

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. Part 4: Conversion Factors, Chapter (McGraw-Hill Professional, 2016), AccessEngineering

Part 5: Cooling Load Rules of Thumb

5. Part 5: Cooling Load Rules of Thumb

5.01. Offices, Commercial

A. General

1. Total Heat	300–400 sq.ft./ton	(Range 230–520)
2. Total Heat	30–40 Btuh/sq.ft.	(Range 23–52)
3. Room Sens. Heat	25–28 Btuh/sq.ft.	(Range 19–37)
4. SHR	0.75–0.93	
5. Perimeter Spaces	1.0–3.0 cfm/sq.ft.	
6. Interior Spaces	0.5–1.5 cfm/sq.ft.	
7. Building Block cfm	1.0–1.5 cfm/sq.ft.	
8. Air Change Rate	4–10 AC/h	

B. Large, Perimeter

1. Total Heat	225–275 sq.ft./ton
2. Total Heat	43–53 Btuh/sq.ft.

C. Large, Interior

1. Total Heat	300–350 sq.ft./ton
2. Total Heat	34–40 Btuh/sq.ft.

D. Small

1. Total Heat	325–375 sq.ft./ton
2. Total Heat	32–37 Btuh/sq.ft.

5.02. Banks, Court Houses, Municipal Buildings, Town Halls

A. Total Heat	**200–250 sq.ft./ton**	**(Range 160–340)**
B. Total Heat	**48–60 Btuh/sq.ft.**	**(Range 35–75)**
C. Room Sens. Heat	**28–38 Btuh/sq.ft.**	**(Range 21–48)**
D. SHR	**0.75–0.90**	
E. Air Change Rate	**4–10 AC/h**	

5.03. Police Stations, Fire Stations, Post Offices

A. Total Heat	**250–350 sq.ft./ton**	**(Range 200–400)**
B. Total Heat	**34–48 Btuh/sq.ft.**	**(Range 30–60)**
C. Room Sens. Heat	**25–35 Btuh/sq.ft.**	**(Range 20–40)**
D. SHR	**0.75–0.90**	
E. Air Change Rate	**4–10 AC/h**	

5.04. Precision Manufacturing

A. Total Heat	**50–300 sq.ft./ton**
B. Total Heat	**40–240 Btuh/sq.ft.**
C. Room Sens. Heat	**32–228 Btuh/sq.ft.**
D. SHR	**0.80–0.95**
E. Air Change Rate	**10–50 AC/h**

5.05. Computer Rooms

A. Total Heat	**50–150 sq.ft./ton**
B. Total Heat	**80–240 Btuh/sq.ft.**
C. Room Sens. Heat	**64–228 Btuh/sq.ft.**
D. SHR	**0.80–0.95**
E. Air Flow	**2.0–4.0 cfm/sq.ft.**
F. Air Change Rate	**15–20 AC/h**

5.06. Restaurants

A. Total Heat	**100–250 sq.ft./ton**	**(Range 75–300)**
B. Total Heat	**48–120 Btuh/sq.ft.**	**(Range 40–155)**
C. Room Sens. Heat	**21–62 Btuh/sq.ft.**	**(Range 20–80)**
D. SHR	**0.65–0.80**	
E. Air Flow	**1.5–4.0 cfm/sq.ft.**	
F. Air Change Rate	**8–12 AC/h**	

5.07. Kitchens (Depends Primarily on Kitchen Equipment)

A. Total Heat	**150–350 sq.ft./ton**	**(at 85°F space)**
B. Total Heat	**34–80 Btuh/sq.ft.**	**(at 85°F space)**
C. Room Sens. Heat	**20–56 Btuh/sq.ft.**	**(at 85°F space)**
D. SHR	**0.60–0.70**	
E. Air Flow	**1.5–2.5 cfm/sq.ft.**	
F. Air Change Rate	**12–15 AC/h**	

5.08. Cocktail Lounges, Bars, Taverns, Clubhouses, Nightclubs

A. Total Heat	**150–200 sq.ft./ton**	**(Range 75–300)**
B. Total Heat	**60–80 Btuh/sq.ft.**	**(Range 40–155)**
C. Room Sens. Heat	**27–40 Btuh/sq.ft.**	**(Range 20–80)**
D. SHR	**0.65–0.80**	
E. Spaces	**1.5–4.0 cfm/sq.ft.**	
F. Air Change Rate	**15–20 AC/h**	**Cocktail Lounges, Bars, Taverns, Clubhouses**
G. Air Change Rate	**20–30 AC/h**	**Night Clubs**

5.09. Hospital Patient Rooms, Nursing Home Patient Rooms

A. Total Heat	**250–300 sq.ft./ton**	**(Range 200–400)**
B. Total Heat	**40–48 Btuh/sq.ft.**	**(Range 30–60)**
C. Room Sens. Heat	**32–46 Btuh/sq.ft.**	**(Range 25–50)**
D. SHR	**0.75–0.85**	

5.10. Buildings w/100 percent OA Systems (e.g., Laboratories, Hospitals)

A. Total Heat	**100–300 sq.ft./ton**
B. Total Heat	**40–120 Btuh/sq.ft.**

5.11. Medical/Dental Centers, Clinics, and Offices

A. Total Heat	**250–300 sq.ft./ton**	**(Range 200–400)**
B. Total Heat	**40–48 Btuh/sq.ft.**	**(Range 30–60)**
C. Room Sens. Heat	**32–46 Btuh/sq.ft.**	**(Range 25–50)**
D. SHR	**0.75–0.85**	
E. Air Change Rate	**8–12 AC/h**	

5.12. Residential

A. Total Heat	**500–700 sq.ft./ton**
B. Total Heat	**17–24 Btuh/sq.ft.**
C. Room Sens. Heat	**12–20 Btuh/sq.ft.**
D. SHR	**0.80–0.95**

5.13. Apartments (Eff., One-Room, Two-Room)

A. Total Heat	**350–450 sq.ft./ton**	**(Range 300–500)**
B. Total Heat	**27–34 Btuh/sq.ft.**	**(Range 24–40)**
C. Room Sens. Heat	**22–30 Btuh/sq.ft.**	**(Range 20–35)**
D. SHR	**0.80–0.95**	

5.14. Motel and Hotel Public Spaces

A. Total Heat	**250–300 sq.ft./ton**	**(Range 160–375)**
B. Total Heat	**40–48 Btuh/sq.ft.**	**(Range 32–74)**
C. Room Sens. Heat	**32–46 Btuh/sq.ft.**	**(Range 25–60)**
D. SHR	**0.75–0.90**	

5.15. Motel and Hotel Guest Rooms, Dormitories

A. Total Heat	**400–500 sq.ft./ton**	**(Range 300–600)**
B. Total Heat	**24–30 Btuh/sq.ft.**	**(Range 20–40)**
C. Room Sens. Heat	**20–25 Btuh/sq.ft.**	**(Range 15–35)**
D. SHR	**0.80–0.95**	

5.16. School Classrooms

A. Total Heat	**225–275 sq.ft./ton**	**(Range 150–350)**
B. Total Heat	**43–53 Btuh/sq.ft.**	**(Range 35–80)**
C. Room Sens. Heat	**25–42 Btuh/sq.ft.**	**(Range 20–65)**
D. SHR	**0.65–0.80**	
E. Air Change Rate	**4–12 AC/h**	

5.17. Dining Halls, Lunch Rooms, Cafeterias, Luncheonettes

A. Total Heat	**100–250 sq.ft./ton**	**(Range 75–300)**
B. Total Heat	**48–120 Btuh/sq.ft.**	**(Range 40–155)**
C. Room Sens. Heat	**21–62 Btuh/sq.ft.**	**(Range 20–80)**
D. SHR	**0.65–0.80**	
E. Spaces	**1.5–4.0 cfm/sq.ft.**	
F. Air Change Rate	**12–15 AC/h**	

5.18. Libraries, Museums

A. Total Heat	**250–350 sq.ft./ton**	**(Range 160–400)**
B. Total Heat	**34–48 Btuh/sq.ft.**	**(Range 30–75)**
C. Room Sens. Heat	**22–32 Btuh/sq.ft.**	**(Range 20–50)**
D. SHR	**0.80–0.90**	
E. Air Change Rate	**8–12 AC/h**	

5.19. Retail, Department Stores

A. Total Heat	**200–300 sq.ft./ton**	**(Range 200–500)**
B. Total Heat	**40–60 Btuh/sq.ft.**	**(Range 24–60)**
C. Room Sens. Heat	**32–43 Btuh/sq.ft.**	**(Range 16–43)**
D. SHR	**0.65–0.90**	
E. Air Change Rate	**6–10 AC/h**	

5.20. Drug, Shoe, Dress, Jewelry, Beauty, Barber, and Other Shops

A. Total Heat	**175–225 sq.ft./ton**	**(Range 100–350)**
B. Total Heat	**53–69 Btuh/sq.ft.**	**(Range 35–115)**
C. Room Sens. Heat	**23–54 Btuh/sq.ft.**	**(Range 15–90)**
D. SHR	**0.65–0.90**	
E. Air Change Rate	**6–10 AC/h**	

5.21. Supermarkets

A. Total Heat	**250–350 sq.ft./ton**	**(Range 150–400)**
B. Total Heat	**34–48 Btuh/sq.ft.**	**(Range 30–80)**
C. Room Sens. Heat	**25–40 Btuh/sq.ft.**	**(Range 22–67)**
D. SHR	**0.65–0.85**	
E. Air Change Rate	**4–10 AC/h**	

5.22. Malls, Shopping Centers

A. Total Heat	**150–350 sq.ft./ton**	**(Range 150–400)**
B. Total Heat	**34–80 Btuh/sq.ft.**	**(Range 30–80)**
C. Room Sens. Heat	**25–67 Btuh/sq.ft.**	**(Range 22–67)**
D. SHR	**0.65–0.85**	
E. Air Change Rate	**6–10 AC/h**	

5.23. Jails

A. Total Heat	**350–450 sq.ft./ton**	**(Range 300–500)**
B. Total Heat	**27–34 Btuh/sq.ft.**	**(Range 24–40)**
C. Room Sens. Heat	**22–30 Btuh/sq.ft.**	**(Range 20–35)**
D. SHR	**0.80–0.95**	

5.24. Auditoriums, Theaters

A. Total Heat	**0.05–0.07 tons/seat**
B. Total Heat	**600–840 Btuh/seat**
C. Room Sens. Heat	**325–385 Btuh/seat**
D. SHR	**0.65–0.75**
E. Air Flow	**15–30 cfm/seat**
F. Air Change Rate	**8–15 AC/h**

5.25. Churches

A. Total Heat	**0.04–0.06 tons/seat**
B. Total Heat	**480–720 Btuh/seat**
C. Room Sens. Heat	**260–330 Btuh/seat**
D. SHR	**0.65–0.75**
E. Air Flow	**15–30 cfm/seat**
F. Air Change Rate	**8–15 AC/h**

5.26. Bowling Alleys

A. Total Heat	**1.5–2.5 tons/alley**
B. Total Heat	**18,000–30,000 Btuh/alley**
C. Air Change Rate	**10–15 AC/h**

5.27. All Spaces

A. Total Heat	**300–500 cfm/ton@20°F ΔT**
B. Total Heat	**400 cfm/ton ± 20%@20°F ΔT**
C. Perimeter Spaces	**1.0–3.0 cfm/sq.ft.**
D. Interior Spaces	**0.5–1.5 cfm/sq.ft.**
E. Building Block cfm	**1.0–1.5 cfm/sq.ft.**
F. Air Change Rate	**4 AC/h minimum**
G. Total heat includes ventilation. Room sensible heat does not include ventilation.	

5.28. Cooling Load Calculation Procedure

A. **Obtain Building Characteristics**

1. Construction materials.
2. Construction material properties: U-values, R-values, shading coefficients, solar heat gain coefficients.
3. Size.
4. Color.
5. Shape.
6. Location.
7. Orientation, N, S, E, W, NE, SE, SW, NW, etc.
8. External/internal shading.
9. Occupancy type and time of day.

B. **Select Outdoor Design Weather Conditions**

1. Temperature.

2. Wind direction and speed.

3. Conditions in selecting outdoor design weather conditions:

    a. Type of structure, heavy, medium, or light.

    b. Is structure insulated? If the structure is heated or cooled, the structure must be insulated by code.

    c. Is structure exposed to high winds?

    d. Infiltration or ventilation load.

    e. Amount of glass.

    f. Time of building occupancy.

    g. Type of building occupancy.

    h. Length of reduced indoor temperature.

    i. What is daily temperature range, minimum/maximum?

    j. Are there significant variations from ASHRAE weather data?

    k. What type of heating devices will be used?

    l. Expected cost of fuel.

4. See Part 15 for code restrictions on the selection of outdoor design conditions.

C. **Select the indoor design temperature to be maintained in each space. See Part 15 for code restrictions on the selection of indoor design conditions.**

D. **Estimate temperatures in unconditioned spaces.**

E. **Select and/or compute U-values for walls, roof, windows, doors, partitions, etc.**

F. **Determine the area of walls, windows, floors, doors, partitions, etc.**

G. **Compute the conduction heat gains for all walls, windows, floors, doors, partitions, skylights, etc.**

H. **Compute the solar heat gains for all walls, windows, floors, doors, partitions, skylights, etc.**

I. **Infiltration heat gains are generally ignored unless space temperature and humidity tolerance are critical.**

J. **Compute the ventilation heat gain required.**

K. **Compute the internal heat gains from lights, people, and equipment.**

L. **Compute the sum of all heat gains indicated in items G, H, I, J, and K earlier in this list.**

M. **Include morning cool-down for buildings with intermittent use and night setup. See Part 15 for code restrictions on the excess HVAC system capacity permitted for morning cool-down.**

N. **Consider equipment and materials that will be brought into the building above the inside design temperature.**

O. **Cooling load calculations should be conducted using industry-accepted methods to determine the actual cooling load requirements.**

P. **Cooling load calculations are often performed using computer simulation programs. These programs greatly simplify the calculation process; however, the basic procedures and input information required are the same.**

5.29. Cooling Load Peak Time Estimate (for Calculating Cooling Loads by Hand)

MONTH OF PEAK ROOM COOLING LOAD FOR VARIOUS EXPOSURES

Window Characteristics			Probable Month of Peak Room Cooling Loa						
% Glass	Shade Coef.	Overhang	N	S	E	W	NE	SE	SW
25	0.4	0	July	Sept.	July	July	July	Sept.	Sept.
25	0.4	1:2	July	Oct.	July	Aug.	July	Sept.	Sept.
25	0.4	1:1	July	Oct.	July	July	July	Sept.	Oct.
25	0.6	0	July	Sept.	July	July	July	Sept.	Sept.
25	0.6	1:2	July	Oct.	July	Aug.	July	Sept.	Sept.
25	0.6	1:1	July	Dec.	July	Sept.	July	Sept.	Oct.
50	0.4	0	July	Sept.	July	July	July	Sept.	Sept.
50	0.4	1:2	July	Oct.	July	Aug.	July	Sept.	Sept.
50	0.4	1:1	July	Dec.	July	Sept.	July	Sept.	Oct,
50	0.6	0	July	Oct.	July	July	July	Sept.	Sept.
50	0.6	1:2	July	Dec.	July	Aug.	July	Sept.	Oct.
50	0.6	1:1	July	Dec.	July	Sept.	July	Sept.	Dec.

Notes:

1. **Percent glass is the percent of gross wall area for the particular exposure.**
2. **The shading coefficient refers to the overall shading coefficient. A shading coefficient of 0.4 is approximately equal to double-pane glas with the heat-absorbing plate out and the regular plate in, combined with medium-color Venetian blinds.**
3. **Although the room peak for south, southeast, and southwest exposur is September or later, the system peak will likely be in July.**
4. **The value for the overhang is the ratio of the depth of the overhang t the height of the window with the overhang at the same elevation as top of the window.**
5. **The roof will peak in June or July.**

Part 6: Heating Load Rules of Thumb

6. Part 6: Heating Load Rules of Thumb

6.01. All Buildings and Spaces

A. **20–60 Btuh/sq.ft.**

B. **25–40 Btuh/sq.ft. Average**

6.02. Buildings w/100 Percent OA Systems (i.e., Laboratories, Hospitals)

A. **40–120 Btuh/sq.ft.**

6.03. Buildings w/Ample Insulation, Few Windows

A. **AC tons × 12,000 Btuh/ton × 1.2**

6.04. Buildings w/Limited Insulation, Many Windows

A. **AC tons × 12,000 Btuh/ton × 1.5**

6.05. Walls Below Grade (Heat Loss at Outside Air Design Condition)

A. **–30°F – 6.0 Btuh/sq.ft.**

B. **–25°F – 5.5 Btuh/sq.ft.**

C. **–20°F – 5.0 Btuh/sq.ft.**

D. **–15°F – 4.5 Btuh/sq.ft.**

E. **–10°F – 4.0 Btuh/sq.ft.**

F. **–5°F – 3.5 Btuh/sq.ft.**

G. **0°F – 3.0 Btuh/sq.ft.**

H. **5°F – 2.5 Btuh/sq.ft.**

I. **10°F – 2.0 Btuh/sq.ft.**

J. **15°F – 1.9 Btuh/sq.ft.**

K. **20°F – 1.8 Btuh/sq.ft.**

L. **25°F – 1.7 Btuh/sq.ft.**

M. **30°F – 1.5 Btuh/sq.ft.**

6.06. Floors Below Grade (Heat Loss at Outside Air Design Condition)

A. **–30°F – 3.0 Btuh/sq.ft.**

B. **–25°F – 2.8 Btuh/sq.ft.**

C. **–20°F – 2.5 Btuh/sq.ft.**

D. **–15°F – 2.3 Btuh/sq.ft.**

E. **–10°F – 2.0 Btuh/sq.ft.**

F. **–5°F – 1.8 Btuh/sq.ft.**

G. **0°F – 1.5 Btuh/sq.ft.**

H. **5°F – 1.3 Btuh/sq.ft.**

I. **10°F – 1.0 Btuh/sq.ft.**

J. **15°F – 0.9 Btuh/sq.ft.**

K. **20°F – 0.8 Btuh/sq.ft.**

L. **25°F – 1.7 Btuh/sq.ft.**

M. **30°F – 0.5 Btuh/sq.ft.**

6.07. Heating System Selection Guidelines

A. **If heat loss exceeds 450 Btu/h per lineal feet of wall, heat should be provided from under the window or from the base of the wall to prevent downdrafts.**

B. **If heat loss is between 250 and 450 Btu/h per lineal feet of wall, heat should be provided from under the window or from the base of the wall, or it may be provided from overhead diffusers, located adjacent to the perimeter wall, discharging air directly downward, blanketing the exposed wall and window areas.**

C. **If heat loss is less than 250 Btu/h per lineal feet of wall, heat should be provided from under the window or from the base of the wall, or it may be provided from overhead diffusers, located adjacent to or slightly away from the perimeter wall, discharging air directed at, or both directed at and directed away from, the exposed wall and window areas.**

6.08. Heating Load Calculation Procedure

A. **Obtain Building Characteristics**

1. Construction materials.

2. Construction material properties: U-values, R-values, shading coefficients, solar heat gain coefficients.

3. Size.

4. Color.

5. Shape.

6. Location.

7. Orientation, N, S, E, W, NE, SE, SW, NW, etc.

8. External/internal shading.

9. Occupancy type and time of day.

B. **Select Outdoor Design Weather Conditions**

1. Temperature.

2. Wind direction and speed.

3. Conditions in selecting outdoor design weather conditions:

   a. Type of structure: heavy, medium, or light.

   b. Is structure insulated? If the structure is heated or cooled, it must be insulated according to code.

   c. Is structure exposed to high wind?

   d. Infiltration or ventilation load.

   e. Amount of glass.

   f. Time of building occupancy.

   g. Type of building occupancy.

   h. Length of reduced indoor temperature.

   i. What is daily temperature range, minimum/maximum?

   j. Are there significant variations from ASHRAE weather data?

   k. What type of heating devices will be used?

   l. Expected cost of fuel.

4. See Part 15 for code restrictions on selection of outdoor design conditions.

C. **Select indoor design temperature to be maintained in each space. See Part 15 for code restrictions on selection of indoor design conditions.**

D. **Estimate temperatures in unheated spaces.**

E. **Select and/or compute U-values for walls, roof, windows, doors, partitions, etc.**

F. **Determine area of walls, windows, floors, doors, partitions, etc.**

G. **Compute heat transmission losses for all walls, windows, floors, doors, partitions, etc.**

H. **Compute heat losses from basement and/or grade level slab floors.**

I. **Compute infiltration heat losses.**

J. **Compute ventilation heat loss required.**

K. **Compute sum of all heat losses indicated in items G, H, I, and J shown earlier.**

L. **For a building with sizable and steady internal heat release, a credit may be taken, but only a portion of the total. Use extreme caution!!! For most buildings, credit for heat gain should not be taken.**

M. **Include morning warm-up for buildings with intermittent use and night set-back. See Part 15 for code restrictions on excess HVAC system capacity permitted for morning warm-up.**

N. **Consider equipment and materials that will be brought into the building below the inside design temperature.**

O. **Heating load calculations should be conducted using industry accepted methods to determine actual heating load requirements.**

P. **Heating load calculations are often performed using computer simulation programs. These programs greatly simplify the calculation process; however, the basic procedures and input information required are the same.**

Part 7: Infiltration Rules of Thumb

7. Part 7: Infiltration Rules of Thumb

7.01. General

A. **Below Grade or Interior Spaces—No infiltration losses or gains are taken for rooms located below grade or interior spaces.**

B. **Buildings that are not humidified have no latent infiltration heating load.**

C. **Winter sensible infiltration loads will generally be 1/2 to 3 times the conduction heat losses (average 1.0 to 2.0 times).**

7.02. Heating Infiltration (15-mph wind)

A. **Air Change Rate Method**
  1. Range 0 to 10 AC/h
  2. Commercial buildings:
     a. 1.0 AC/h one exterior wall
     b. 1.5 AC/h two exterior walls
     c. 2.0 AC/h three or four exterior walls
  3. Vestibules 3.0 AC/h

B. **CFM/sq.ft. of Wall Method**
  1. Range 0 to 1.0 CFM/sq.ft.

2. Tight buildings 0.1 CFM/sq.ft.

3. Average buildings 0.3 CFM/sq.ft.

4. Leaky buildings 0.6 CFM/sq.ft.

C. **Crack Method**

1. Range 0.12 to 2.8 CFM/ft. of crack

2. Average 1.0 CFM/ft. of crack

7.03. Cooling Infiltration (7.5-mph wind)

A. **Cooling load infiltration is generally ignored unless close tolerances in temperature and humidity control are required.**

B. **Cooling infiltration values are generally taken as 1/2 of the values listed earlier for heating infiltration.**

Citation

EXPORT

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. Part 7: Infiltration Rules of Thumb, Chapter (McGraw-Hill Professional, 2016), AccessEngineering

Part 8: Ventilation Rules of Thumb

8. Part 8: Ventilation Rules of Thumb

8.01. 2015 IMC and ASHRAE Standard 62.1-2013

MINIMUM VENTILATION RATES

Occupancy Classification	Occupant Density People/1,000 SF[a]	CFM per Person	CFM per SF[a]	Exhaust Airflow Rate CFM/SF[a]
Correctional Facilities				
Booking/waiting	50	7.5	0.06	–
Cell—with plumbing fixtures[b]	25	5	0.12	1.0
Cell—without plumbing fixtures	25	5	0.12	–
Day room	30	5	0.06	–
Dining halls (see food and beverage service)	–	–	–	–
Guard Stations	15	5	0.06	–
Dry Cleaners, Laundries				
Coin-operated dry cleaner[c]	20	15	–	–

Notes:

a. Based on *net occupiable floor area*

Occupancy Classification	Occupant Density People/1,000 SF	CFM per Person	CFM per SF	Exhaust Airflow Rate CFM/SF
Coin-operated laundries	20	7.5	0.06[d], 0.12[e]	2[illegible]
Commercial dry cleaner[c]	30	30	–	–
Commercial laundry[c]	10	25	–	–
Storage, pick-up[c]	30	7.5	0.12	–
Education				
Art classroom[b]	20	10	0.18	0.7
Auditoriums	150	5	0.06	–
Classrooms (ages 5 to 8)	25	10	0.12	–
Classrooms (ages 9 plus)	35	10	0.12	–
Computer lab	25	10	0.12	–
Corridors (see public spaces)	–	–	–	–
Daycare (through age 4)	25	10	0.18	–
Daycare sickroom[g]	25	10	0.18	–
Lecture classroom	65	7.5	0.06	–
Lecture hall (fixed seats)	150	7.5	0.06	–
Locker/dressing rooms[b]	–	–	–	0.25
Media center	25	10	0.12	–
Multiuse assembly	100	7.5	0.06	–
Music/theater/dance	35	10	0.06	–
Science laboratories[b]	25	10	0.18	1.0
Smoking lounges[c,f]	70	60	–	–

Occupancy Classification	Occupant Density People/1,000 SF	CFM per Person	CFM per SF	Exhaust Airflow Rate CFM/SF
Sports locker rooms[b]	–	–	–	0.5
University/college laboratories[g]	25	10	0.18	–
Wood/metal shops[b]	20	10	0.18	0.5
Food and Beverage Service				
Bars, cocktail lounges	100	7.5	0.18	–
Cafeteria, fast food	100	7.5	0.18	–
Dining rooms	70	7.5	0.18	–
Kitchens (cooking)[f]	20[g]	7.5[g]	0.12[g]	0.7[c]
Hospitals, Nursing and Convalescent Homes				
Autopsy rooms[f]	–	–	–	0.7
Medical procedure rooms	20	15	–	–
Operating rooms	20	30	–	–
Patient rooms	10	25	–	–
Physical therapy	20	15	–	–
Recovery and ICU	10	15	–	–
Hotel, Motels, Resorts, and Dormitories				
Barracks sleeping areas[g]	20	5	0.06	–
Bathrooms/toilet—private[b]	–	–	–	25/50[h]
Bedroom/living room	10[g]	5	0.06	–
Conference/meeting[c]	–	5	0.06	–
Dormitory sleeping areas[c]	–	5	0.06	–
Gambling casinos	–	7.5	0.18	–
Laundry rooms, central[g]	10	5	0.12	–

Notes:

a. Based on *net occupiable floor area*

Occupancy Classification	Occupant Density People/1,000 SF	CFM per Person	CFM per SF	Exhaust Airflow Rate CFM/SF
Laundry rooms, within dwelling units[g]	10	5	0.12	–
Lobbies/prefunction	30[g]	7.5	0.06	–
Multipurpose assembly	120[g]	5	0.06	–
Miscellaneous spaces[g]				
Banks or bank lobbies[g]	15	7.5	0.06	–
Freezer and refrigerated spaces (<50°F)[g]	–	10	–	–
General manufacturing (excludes heavy industrial and processes using chemicals)[g]	7	10	0.18	–
Janitor closets, trash rooms, recycling[g]	–	–	–	1.00
Kitchenettes[g]	–	–	–	0.30
Shipping/receiving[g]	2	10	0.12	–
Sorting, packing, light assembly[g]	7	7.5	0.12	–
Transportation waiting[g]	100	7.5	0.06	–
Offices				
Breakrooms[g]	50	5	0.12	–
Conference rooms	50	5	0.06	–
Main entry lobbies	10	5	0.06	–
Occupiable storage rooms for dry	2	5	0.06	–

Notes:

a. Based on *net occupiable floor area*.

Occupancy Classification	Occupant Density People/1,000 SF	CFM per Person	CFM per SF	Exhaust Airflow Rate CFM/SF
materials[g]				
Office spaces	5	5	0.06	–
Reception areas	30	5	0.06	–
Telephone/data entry	60	5	0.06	–
Private Dwellings, Single and Multiple				
Common corridors[g]	–	–	0.06	–
Garages, common for multiple units[c,f]	–	–	–	0.75
Garages, separate for each dwelling[f]	–	–	–	100 cfm per car
Kitchens[f]	–	–	–	25/100[h]
Living areas[c,i]	Based upon number of bedrooms. First bedroom, 2; each additional bedroom, 1	0.35 ACH but not less than 15 cfm/person[d], 5[e]	–[d], 0.06[e]	–
Toilet rooms and bathrooms[b,c]	–	–	–	20/50[h]
Public Spaces				
Breakrooms[g]	25	5	0.06	–
Corridors	–	–	0.06	–
Courtrooms	70	5	0.06	–
Elevator car[c]	–	–	–	1.0
Legislative chambers	50	5	0.06	–
Libraries	10	5	0.12	–
Lobbies[g]	150	5	0.06	–
Museums (children's)	40	7.5	0.12	–

Occupancy Classification	Occupant Density People/1,000 SF	CFM per Person	CFM per SF	Exhaust Airflow Rate CFM/SF
Museums/galleries	40	7.5	0.06	–
Occupiable storage rooms for liquids or gels[g]	2	5	0.12	–
Places of religious worship	120	5	0.06	–
Shower room (per shower head)[b,c]	–	–	–	50/20[h]
Smoking lounges[c,f]	70	60	–	–
Toilet rooms—public[b]	–	–	–	50/70[j]
Retail Stores, Sales Floors and Showroom Floors				
Dressing rooms	–	–	–	0.25
Mall common areas	40	7.5	0.06	–
Sales (except as below)	15	7.5	0.12	–
Shipping and receiving[c]	–	–	0.12	–
Smoking lounges[c,k]	70	60	–	–
Storage rooms[c]	–	–	0.12	–
Warehouses (see storage)	–	–	–	–
Specialty Shops				
Automotive motor-fuel dispensing stations[f]	–	–	–	1.5
Auto repair rooms[g]	–	–	–	1.50
Barber	25	7.5	0.06	0.5
Beauty salons[f]	25	20	0.12	0.6
Embalming rooms[c,f]	–	–	–	2.0
Nail salons[f,k]	25	20	0.12	0.6

Notes:

Occupancy Classification	Occupant Density People/1,000 SF	CFM per Person	CFM per SF	Exhaust Airflow Rate CFM/SF
Pet shops (animal areas)	10	7.5	0.18	0.9
Supermarkets	8	7.5	0.06	–
Sports and Amusement				
Bowling alleys (seating area)	40	10	0.12	–
Disco/dance floors	100	20	0.06	–
Game arcades	20	7.5	0.18	–
Gym, stadium (play area)	–[d], 7[e]	–[d], 20[e]	0.30[d], 0.18[e]	–
Health club/aerobics room	40	20	0.06	–
Health club/weight room	10	20	0.06	–
Ice arenas without combustion engines	–	–	0.30[c]	0.5
Spectator areas	150	7.5	0.06	–
Swimming pools (pool and deck area)	–	–	0.48	–
Storage				
Repair garages, enclosed parking garages[f,l]	–	–	–	0.75
Soiled laundry storage rooms[g]	–	–	–	1.00
Storage rooms, chemical[g]	–	–	–	1.50
Warehouses	–	10[g]	0.06	–
Theaters				
Auditoriums (see education)	–	–	–	–

Notes:

a. Based on *net occupiable floor area*.

Occupancy Classification	Occupant Density People/1,000 SF	CFM per Person	CFM per SF	Exhaust Airflow Rate CFM/SF
Lobbies[c]	150	5	0.06	–
Stages, studios	70	10	0.06	–
Ticket booths[c]	60	5	0.06	–
Transportation				
Platforms[c]	100	7.5	0.06	–
Transportation waiting[c]	100	7.5	0.06	–
Workrooms				
Bank vaults/safe deposit	5	5	0.06	–
Computer (without printing)	4	5	0.06	–
Copy, printing rooms	4[c]	5[c]	0.06[c]	0.5
Darkrooms	–	–	–	1.0
Meat processing[c,i]	10	15	–	–
Pharmacy (prep. area)	10	5	0.18	–
Photo studios	10	5	0.12	–

Notes:

a. **Based on *net occupiable floor area*.**

b. **Mechanical exhaust is required and recirculation from such spaces is prohibited except that recirculation shall be permitted where the resulting supply airstream consists of not more than 10 percent air recirculated from these spaces. Recirculation of air that is contained completely within such spaces shall not be prohibited (see 2015 IMC Section 403.2.1, Items 2 and 4).**

c. **2015 IMC only.**

d. **2015 IMC.**

e. **ASHRAE Standard 62.1-2013.**

f. **Mechanical exhaust required and the recirculation of air from such**

Occupancy Classification	Occupant Density People/1,000 SF	CFM per Person	CFM per SF	Exhaust Airflow Rate CFM/SF

f. Mechanical exhaust required and the recirculation of air from such spaces is prohibited. Recirculation of air that is contained completely within such spaces shall not be prohibited (see 2015 IMC Section 403.2.1, Item 3).

g. ASHRAE Standard 62.1-2013 only.

h. Rates are per room unless otherwise indicated. The higher rate shall be provided where the exhaust system is designed to operate intermittently. The lower rate shall be permitted only where the exhaust system is designed to operate continuously while occupied.

i. Spaces unheated or maintained below 50°F are not covered by these requirements unless the occupancy is continuous.

j. Rates are per water closet or urinal. The higher rate shall be provided where the exhaust system is designed to operate intermittently. The lower rate shall be permitted only where the exhaust system is designed to operate continuously while occupied.

k. For nail salons, each manicure and pedicure station shall be provided with a *source capture system* capable of exhausting not less than 50 cfm per station. Exhaust inlets shall be located in accordance with Section 502.20. Where one or more required source capture systems operate continuously during occupancy, the exhaust rate from such systems shall be permitted to be applied to the exhaust flow rate required by Table 403.3.1.1 for the nail salon.

l. Ventilation systems in enclosed parking garages shall comply with 2015 IMC Section 404.

A. **Breathing zone outdoor airflow volumes must be corrected as follows:**
$V_{BZ} = R_P P_Z + R_A A_Z$ Breathing zone outdoor airflow for each zone.
where:

A_Z = area of the zone.

P_Z = people per zone.

R_P = outdoor airflow rate for people.

R_A = outdoor airflow rate per area.

B. **Single Zone Systems:**

$V_{OT} = V_{OZ} = V_{BZ}/E_Z$ Outdoor air intake flow rate for single zone systems.

where:

V_{OT} = system outdoor air intake flow rate

V_{OZ} = zone outdoor airflow rate

E_Z = zone air distribution effectiveness factor from the table below.

C. **100-Percent Outdoor Air Systems:**

$V_{OT} = V_{OZ1} + V_{OZ2} + \ldots$ Outdoor air intake flow rate for100-percent outdoor air systems.

D. **Multiple Zone Recirculating Systems:**

$Z_p = V_{OZ}/V_{PZ}$ Primary outdoor air fraction for each zone—OA corrected for zone air distribution effectiveness divided by the primary airflow rate supplied to the zone (zone with highest primary outdoor air fraction shall be used in selection of E_V).

where:

V_{PZ} = primary airflow rate supplied to the zone. For variable volume supply, V_{PZ} shall be the lowest expected primary airflow rate to the zone when it is fully occupied.

E_V = system ventilation efficiency from table below.

E. **Uncorrected Outdoor Air Intake for Multiple Zone Recirculating Systems:**

$V_{OU} = D\ \Sigma_{\text{all zones}} R_P P_Z + \Sigma_{\text{all zones}} R_A A_Z$

where:

D = Occupant diversity: the ratio of the system population to the sum of the zone populations, determined in accordance with the following equation:

$D = P_S/\Sigma_{\text{all zones}} P_Z$

where:

P_S = System population: the total number of occupants in the area served by the system. For design purposes, P_S shall be the maximum number of occupants expected to be concurrently in all zones served by the system.

F. **Corrected Outdoor Air Intake for Multiple Zone Recirculating Systems:**

$V_{OT} = V_{OU}/E_V$ Outdoor air intake flow rate for multiple zone systems corrected for ventilation effectiveness.

Zone Air Distribution Effectiveness

Air Distribution Configuration	E_Z
Ceiling supply of cool air.	1.0
Ceiling supply of warm air and floor return.	1.0
Ceiling supply of warm air at least 15°F above space temperature and ceiling return.	0.8
Ceiling supply of warm air less than 15°F above space temperature and ceiling return provided that the 150 fpm supply air jet reaches to within 4.5 feet of the floor level.	1.0
Ceiling supply of warm air less than 15°F above space temperature and ceiling return provided that the supply air jet is less than 150 fpm.	0.8
Floor supply of cool air and ceiling return provided that the 150 fpm supply jet reaches at least 4.5 feet above the floor. *Note*: Most underfloor air distribution systems comply with this provision.	1.0
Floor supply of cool air and ceiling return, provided low velocity displacement ventilation achieves unidirectional flow and thermal stratification.	1.2
Floor supply of warm air and floor return.	1.0
Floor supply of warm air and ceiling return.	0.7
Makeup supply drawn in on the	0.8

Zone Air Distribution Effectiveness

Air Distribution Configuration	E
Makeup supply drawn in on the opposite side of the room from the exhaust and/or return	0.8
Makeup supply drawn in near to the exhaust and/or return location.	0.5

System Ventilation Efficiency Table

Max Z_p Zone with Max % OA	E_V
≤0.15	1
≤0.25	0.9
≤0.35	0.8
≤0.45	0.7
≤0.55	0.6
≤0.65	0.5
≤0.75	0.4
>0.75	0.3

8.02. *ASHRAE Standard 62.1-2013*: Return Air, Transfer Air, or Exhaust Air Classifications

A. **Class 1: Air with low contaminant concentration, low sensory-irritation intensity, and inoffensive odor. Class 1 air may be recirculated or transferred to any space. This includes:**

1. Offices.
2. Reception/waiting areas.
3. Telephone/data entry.
4. Lobbies.
5. Conference/meeting rooms.
6. Corridors.

7. Storage rooms.

8. Break rooms.

9. Coffee stations.

10. Equipment rooms.

11. Mechanical rooms.

12. Electrical/telephone closets.

13. Elevator machine rooms.

14. Laundry rooms within dwelling units.

15. Sports arena.

16. Correctional facility day room and guard station.

17. Educational facilities: classrooms, lecture classrooms, lecture halls, computer lab, media center, music/theater/dance studios, multiuse assembly.

18. Hotels, motels, resorts, dormitories: bedrooms, living rooms, barracks, sleeping quarters, lobbies, prefunction spaces, multipurpose assembly.

19. Computer rooms.

20. Photo studios.

21. Shipping/receiving rooms.

22. Transportation waiting rooms.

23. Public assembly spaces: auditorium seating area, places of religious worship, courtrooms, legislative chambers, libraries, lobbies, museums/galleries (all types).

24. Mall common areas.

25. Supermarkets.

26. Sports and entertainment: sports arena (play area), spectator areas, disco/dance floors, bowling alleys, gambling casinos, game arcades, stages, studios.

B. **Class 2: Air with moderate contaminant concentration, mild sensory-irritation intensity, or mildly offensive odors. Air that is not harmful or objectionable but is inappropriate for transfer or recirculation to spaces used for different purposes. Class 2 air may be recirculated within the space of origin but may not be recirculated or transferred to Class 1 spaces. Class 2 air may be recirculated or transferred to other Class 2 or Class 3 spaces with the same occupancy and use, or where contaminants are from similar sources and will not react to form more hazardous contaminants. Class 2 air may be recirculated or transferred to Class 4 spaces. This includes:**

1. Kitchens (commercial) and kitchenettes.
2. Toilet/bath rooms (public and private).
3. Locker rooms.
4. Locker/dressing rooms.
5. Central laundry rooms.
6. Science laboratories.
7. University and college laboratories.
8. Art classrooms.
9. Retail sales areas.
10. Barber shops.
11. Beauty and nail salons.
12. Prison cells with toilets.
13. Darkrooms.
14. Pet shops (animal areas).
15. Copy printing rooms.
16. Wood/metal shop classrooms.
17. Correctional facility booking/waiting areas.
18. Food and beverage services: restaurant dining rooms, cafeterias, fast food establishments, bars, cocktail lounges.

19. Bank vaults/safe deposit vaults.
20. Pharmacy preparation areas.
21. Warehouses.
22. Coin-operated laundries.
23. Gym/stadium (play areas).
24. Swimming pools and decks.
25. Health club/aerobics rooms.
26. Health club/weight rooms.
27. Hydraulic elevator machine rooms.

C. **Class 3: Air with significant contaminant concentration, significant sensory-irritation intensity, or offensive odor. Class 3 air may be recirculated within the space of origin only and cannot be recirculated to any other space. This includes:**
   1. Commercial kitchen hoods other than grease hoods.
   2. Residential kitchen vented hoods.
   3. Refrigeration machinery rooms.
   4. Boiler rooms.
   5. Soiled laundry storage areas.
   6. Janitor closets.
   7. Trash/recycle rooms.
   8. General chemical/biological laboratories.
   9. Daycare sick rooms.

D. **Class 4: Air with highly objectionable fumes or gases or with potentially dangerous particles, bio-aerosols, or gases, at such high concentrations as to pose a health hazard. Class 4 air shall not be recirculated or transferred to any space or recirculated within the space of origin. This includes:**

1. Commercial kitchen grease hoods.
2. Laboratory hoods.
3. Paint spray booths.
4. Diazo printing equipment discharges.
5. Chemical storage rooms.
6. Auto repair rooms.
7. Parking garages.

8.03. *ASHRAE Standard 62.2-2013*

A. **Outdoor air must be provided to each dwelling unit in accordance with the following table:**

Floor Area Square Feet	Number of Bedrooms				
	1	2	3	4	5
<500	30	38	45	53	60
501–1,000	45	53	60	68	75
1,001–1,500	60	68	75	83	90
1,501–2,000	75	83	90	98	105
2,001–2,500	90	98	105	113	120
2,501–3,000	105	113	120	128	135
3,001–3,500	120	128	135	143	150
3,501–4,000	135	143	150	158	165

Floor Area Square Feet	Number of Bedrooms 1	2	3	4	5
4,001–4,500	150	158	165	173	180
4,501–5,000	165	173	180	188	195

Notes:

1. **In lieu of the preceding table, the following equation may be used to determine the minimum outdoor air quantity.**

   $Q_{OA} = 0.03 \times A_{FLOOR} + 7.5 \times (N_{BR} + 1)$.

   Q_{OA} **= Quantity of Outdoor Air—CFM.**

   A_{FLOOR} **= Floor Area of Residence—Square Feet.**

   N_{BR} **= Number of Bedrooms—Minimum of 1.**

2. **Exhaust requirements:**
   - **a. Intermittent:**
     1. **Kitchen: 100 CFM.**
     2. **Bathroom: 50 CFM.**
   - **b. Continuous:**
     1. **Kitchen: 5.0 AC/h**
     2. **Bathroom: 20 CFM.**

8.04. ASHRAE Standard 170-2013 *Ventilation of Health Care Facilities* (incorporated as Part 4 of the 2014 Facility Guidelines Institute *Guidelines for Design and Construction of Hospitals and Outpatient Facilities*)

Area Designation	Pressure Relationship	Minimum OA AC/h	Minimum Total AC/h
Surgery and Critical Care			
Operating room (Classes B and C)	Pos	4	20

Area Designation	Pressure Relationship	Minimum OA AC/h	Minimum Total AC/h
Operating/surgical cystoscopic rooms	Pos	4	20
Delivery room (Caesarean)	Pos	4	20
Substerile service area	NR	2	6
Recovery room	NR	2	6
Critical and intensive care	NR	2	6
Intermediate care	NR	2	6
Wound intensive care (burn unit)	NR	2	6
Newborn intensive care	Pos	2	6
Treatment room	NR	2	6
Trauma room (crisis or shock)	Pos	3	15
Medical/anesthesia gas storage	Neg	NR	8
Laser eye room	Pos	3	15
ER waiting rooms	Neg	2	12
Triage	Neg	2	12
ER decontamination	Neg	2	12
Radiology waiting rooms	Neg	2	12
Procedure room (Class A surgery)	Pos	3	15
Emergency department exam/treatment room	NR	2	6
Inpatient Nursing			
Patient room	NR	2	4
Nourishment area or room	NR	NR	2
Toilet room	Neg	NR	10
Newborn nursery suite	NR	2	6
Protective environment room	Pos	2	12
Airborne Infectious Isolation (AII) room	Neg	2	12
Combination AII/Protective	Pos	2	12

Notes:

Area Designation	Pressure Relationship	Minimum OA AC/h	Minimum Total AC/h
Environment (PE) room			
AII anteroom	Neg	NR	10
PE anteroom	Neg	NR	10
Combination AII/PE anteroom	Neg	NR	10
Labor/delivery/recovery/postpartum (LDRP)	NR	2	6
Labor/delivery/recovery (LDR)	NR	2	6
Patient Corridor	NR	NR	2
Nursing Facility			
Resident room	NR	2	2
Resident gathering/activity/dining	NR	4	4
Resident unit corridor	NR	NR	4
Physical therapy	Neg	2	6
Occupational therapy	NR	2	6
Bathing room	Neg	NR	10
Radiology			
X-ray (diagnostic and treatment)	NR	2	6
X-ray (surgery/critical care and catheterization)	Pos	3	15
Darkroom	Neg	2	10
Diagnostic and Treatment			
Bronchoscopy, sputum collection, and pentamidine administration	Neg	2	12
Laboratory, general	Neg	2	6
Laboratory, bacteriology	Neg	2	6
Laboratory, biochemistry	Neg	2	6
Laboratory, cytology	Neg	2	6
Laboratory, glass washing	Neg	2	10
Laboratory, histology	Neg	2	6

Notes

Area Designation	Pressure Relationship	Minimum OA AC/h	Minimum Total AC/h
Laboratory, histology	Neg	2	6
Laboratory, microbiology	Neg	2	6
Laboratory, nuclear medicine	Neg	2	6
Laboratory, pathology	Neg	2	6
Laboratory, serology	Neg	2	6
Laboratory, sterilizing	Neg	2	10
Laboratory, media transfer	Pos	2	4
Nonrefrigerated body-holding room	Neg	NR	10
Autopsy room	Neg	2	12
Pharmacy	Pos	2	4
Examination room	NR	2	6
Medication room	NR	2	4
Gastrointestinal endoscopy procedure room	NR	2	6
Endoscope cleaning	Neg	2	10
Treatment room	NR	2	6
Hydrotherapy	Neg	2	6
Physical therapy	Neg	2	6
Dialysis treatment area	NR	2	6
Dialyzer reprocessing room	Neg	NR	10
Nuclear medicine hot lab	Neg	NR	6
Nuclear medicine treatment room	Neg	2	6
Sterilizing			
Sterilizer equipment room	Neg	NR	10
Central Medical and Surgical Supply			
Soiled or decontamination room	Neg	2	6
Clean workroom	Pos	2	4
Sterile storage	Pos	2	4

Area Designation	Pressure Relationship	Minimum OA AC/h	Minimum Total AC/h
Service			
Food preparation center	NR	2	10
Warewashing	Neg	NR	10
Dietary storage	NR	NR	2
Laundry, general	Neg	2	10
Soiled linen sorting and storage	Neg	NR	10
Clean linen storage	Pos	NR	2
Linen and trash chute room	Neg	NR	10
Bedpan room	Neg	NR	10
Bathroom	Neg	NR	10
Janitor's closet	Neg	NR	10
Support Space			
Soiled workroom or soiled holding	Neg	2	10
Clean workroom or clean holding	Pos	2	4
Hazardous material storage	Neg	2	10

Notes:

Pos = Positive Pressure Relationship

Neg = Negative Pressure Relationship

NR = No Requirement

8.05. Enclosed Parking Garages

A. **2015 IMC**

1. Ventilation rates:
   a. Minimum: 0.05 CFM/SF.

   b. Design: 0.75 CFM/SF.

c. Mechanical ventilation systems may reduce the 0.75 CFM/SF ventilation requirement when the system operates automatically by means of carbon monoxide detectors applied in conjunction with nitrogen dioxide detectors. Such detectors shall be installed in accordance with their manufacturers' recommendations.

B. **Enclosed Parking Garage Design Recommendations**

1. Exhaust 0.75 CFM/SF at one end of the garage on each floor using a masonry plenum or ductwork (a floor-to-floor exhaust plenum is normally easier because floor-to-floor heights are generally limited in a garage and ductwork does not fit). Exhaust 1/2 of the air high and 1/2 of the air low. This will remove contaminants that are heavier than air (flammable vapors) and contaminants that are lighter than air (carbon monoxide).

2. Supply approximately 0.75 CFM/SF at the other end of the garage on each floor using a masonry plenum or ductwork (a floor-to-floor supply plenum is normally easier because floor-to-floor heights are generally limited in a garage and ductwork does not fit). Supply 1/2 of the air high and 1/2 of the air low. This exhaust and supply design will provide a sweeping air motion through the garage. Depending on the location of the entrances and exits to the garage, the supply quantity may be reduced to allow air to enter through the entrances and exits provided that short circuiting of the supply air is prevented.

3. Utilize VFDs to control the speed and the airflow of the fan based on vehicle operation and the presence of occupants, or carbon monoxide detectors applied in conjunction with nitrogen dioxide detectors. Note that the minimum garage ventilation rate is only 8 percent of the design airflow (0.05 CFM/SF divided by 0.75 CFM/SF). A single fan operated by a VFD will only turn down to about 25 percent. Use at least two fans with VFDs; this will permit a turndown of 12.5 percent and will allow for partial capacity in the event of fan failure.

4. Garages should not be heated. The volume of air, even under code minimum airflow requirements, has a substantial impact and is a waste of energy.

8.06. Outside Air Intake and Exhaust Locations

A. **2015 IMC**

1. Intakes or exhausts—10 feet from lot lines, buildings on same lot or center line of street or public way.

2. Intakes—10 feet horizontally from any hazardous or noxious contaminant (plumbing vents, chimneys, vents, stacks, alleys, streets, parking lots, loading docks). When within 10 feet horizontally, intake must be a minimum of 3 feet below or 25 feet above any source of contaminant.

3. Exhausts—shall not create a public nuisance or be directed onto walkways. For environmental air exhaust systems, outlets shall be 3 feet from property lines, 3 feet from operable openings into buildings for all occupancies other than Group U, and 10 feet from mechanical air intakes.

4. Opening protection:
   a. Protect intake and exhaust openings with corrosion resistant screens, louvers, or grilles.

   b. Exhaust openings: between 1/4" and 1/2" opening screens.

   c. Intake openings—residential: between 1/4" and 1/2" opening screens.

   d. All other intake openings: between 1/4" and 1" opening screens.

B. **NFPA 90A-2015**

1. Outside air intakes shall be located to avoid drawing in combustible materials and toxic or hazardous vapors.

2. Outside air intakes shall be protected with corrosion resistant screens not larger than 1/2" mesh.

3. Outside air intakes shall be located to minimize the hazard from fires in other structures. Intakes shall be equipped with a fire damper when protection from fire hazards is required.

4. Outside air intake shall be located so as to minimize the introduction of smoke into the building. Intakes shall be equipped with a smoke damper when protection from smoke hazards is required.

C. **ASHRAE Standard 62.1-2013—Air Intake Minimum Separation Distances**

1. Significantly contaminated exhaust (high contaminant concentration, significant sensory-irritation intensity, offensive odor): 15 feet.

2. Noxious or dangerous exhaust air with highly objectionable fumes or gases

and or exhaust air with potentially dangerous contaminants (laboratory exhaust, fumes, gases, potentially dangerous particles, bio-aerosols, gases at high concentrations to be harmful): 30 feet.

3. Plumbing vents terminating less than 3 feet above the level of the outdoor air intake: 10 feet.
4. Plumbing vents terminating at least 3 feet above the level of the outdoor air intake: 3 feet.
5. Vents, chimneys, flues, and other combustion appliance discharge: 15 feet.
6. Garage entry, automobile loading area, drive-in queue: 15 feet.
7. Truck loading area or dock, bus parking/idling area: 25 feet.
8. Driveway, street, or parking area: 5 feet.
9. Street or thoroughfare with high traffic volume: 25 feet.
10. Roof, landscaped grade or other surface directly below intake: 1 foot (or expected average snow depth, whichever is greater).
11. Garbage storage/pickup area, dumpsters: 15 feet.
12. Cooling tower intake or basin: 15 feet.
13. Cooling tower exhaust: 25 feet.
14. Class 1 air: 10 feet (the author's interpretation of Class 1 air).
15. Class 2 air: 15 feet (the author's interpretation of Class 2 air).
16. Class 3 air: 15 feet (see item number 1 preceding the definition of Class 3 air).
17. Class 4 air: 30 feet (see item number 2 preceding the definition of Class 4 air).

D. **ASHRAE Standard 170-2013** *Ventilation of Health Care Facilities* **(incorporated as Part 4 of the 2014 Facility Guidelines Institute** *Guidelines for Design and Construction of Hospitals and Outpatient Facilities*

1. Outdoor air intakes shall be located at least 25 feet from cooling towers and all exhaust outlets of ventilating systems, combustion equipment stacks, medical-surgical vacuum systems, plumbing vents, or areas that may collect

vehicular exhaust or other noxious fumes. Prevailing winds and/or proximity to other structures may require greater clearances.

2. The bottom of outdoor air intakes serving central systems shall be as high as practical, but at least 6 feet above ground level, or if installed above the roof, 3 feet above roof level.

3. Relief air is exempt from the 25 foot separation requirement. Relief air is defined as air that otherwise could be returned to an air handling unit from the occupied space but is being discharged to the outdoors to maintain building pressure, such as during outside air economizer operation.

4. Exhaust outlets from areas that may be contaminated shall discharge in a vertical direction at least 10 feet above roof level and shall be located not less than 10 feet horizontally from air intakes, openable windows/doors, or areas that are normally accessible to the public or maintenance personnel and that are higher in elevation than the exhaust discharge.

5. Exhaust outlets from areas that may be contaminated shall be arranged to minimize recirculation of exhaust air into the building.

8.07. Indoor Air Quality (IAQ)

A. **Causes of Poor IAQ**

1. Inadequate ventilation—50 percent of all IAQ problems are due to lack of ventilation.

2. Poor intake/exhaust locations.

3. Inadequate filtration or dirty filters.

4. Intermittent airflow.

5. Poor air distribution.

6. Inadequate operation.

7. Inadequate maintenance.

B. **IAQ Control Methods**

1. Control temperature and humidity.

2. Ventilation—dilution.

3. Remove pollution source.

4. Filtration.

C. **IAQ Factors**

1. Thermal environment.

2. Smoke.

3. Odors.

4. Irritants—dust.

5. Stress problems (perceptible, nonperceptible).

6. Toxic gases—carbon monoxide, carbon dioxide.

7. Allergens—pollen.

8. Biological contaminants—bacteria, mold, pathogens, legionella, micro-organisms, fungi.

D. **CO_2 Levels and IAQ**

1. Outdoor background level:	500–700 PPM CO_2 avg.
2. *ASHRAE Standard 62.1* recommends:	1000–1200 PPM CO_2 max.
3. OSHA and U.S. Air Force standard:	650 PPM CO_2 max.
4. Human discomfort begins:	800–1000 PPM CO_2.
5. Long-term health effects:	>12,000 PPM CO_2.

8.08. Effects of Carbon Monoxide

A. **Effects of Various Concentrations of Carbon Monoxide with Respect to Time are shown in the following table.**

Hours of Exposure	Concentration of Carbon Monoxide in PPM ± Barely Perceptible	Sickness	Deadly
0.5	600	1000	2000
1.0	200	600	1600
2	100	300	1000
3	75	200	700
4	50	150	400
5	35	125	300
6	25	120	200
7	25	100	200
8	25	100	150

B. **Carbon Monoxide Concentration versus Time versus Symptoms are shown in the following table.**

Concentration of CO in the Air	Inhalation Time	Toxic Symptoms Developed
9 PPM	Short-term exposure	ASHRAE recommended maximum allowable concentration for short term exposure in living area.
35 PPM	8 hours	The maximum allowable concentration for a continuous exposure, in any 8-hour period, according to federal law.
200 PPM	2–3 hours	Slight headache, tiredness, dizziness, nausea; maximum CO concentration exposure at any time as

Concentration of CO in the Air	Inhalation Time	Toxic Symptoms Developed
		prescribed by OSHA
400 PPM	1–2 hours	Frontal headaches
	after 3 hours	Life threatening
	–	Maximum PPM in flue gas (on a free air basis) according to EPA and AGA
800 PPM	45 minutes	Dizziness, nausea, and convulsions
	2 hours	Unconscious
	2–3 hours	Death
1,600 PPM	20 minutes	Headache, dizziness, nausea
	1 hour	Death
3,200 PPM	5–10 minutes	Headache, dizziness, nausea
	30 minutes	Death
6,400 PPM	1–2 minutes	Headache, dizziness, nausea
	10–15 minutes	Death
12,800 PPM	1–3 minutes	Death

C. **Carbon monoxide is lighter than air (specific gravity is 0.968).**

8.09. Toilet Rooms

A. ***ASHRAE Standard 62.1-2013***

1. Private: 50 CFM/room for intermittent operation, 25 CFM/room for continuous operation. For toilet rooms intended to be occupied by one person at a time.

2. Public: 70 CFM/water closet and urinal where periods of heavy use are expected to occur, 50 CFM/water closet and urinal otherwise.

B. ***2015 IMC***

1. Private: 50 CFM/room for intermittent operation, 25 CFM/room for continuous operation. For toilet rooms intended to be occupied by one person at a time.

2. Public: 70 CFM/water closet and urinal for intermittent operation, 50 CFM/water closet and urinal for continuous operation.

C. **Recommended Design Requirements**

1. 2.0 CFM/sq.ft.

2. 10 AC/h

3. 100 CFM/water closet and urinal.

4. Toilet room ventilation:

    a. For toilet rooms with high fixture densities (stadiums, auditoriums), the 50 CFM/water closet and urinal dictates.

    b. For toilet rooms with ceiling heights over 12 feet, the 10 AC/h dictates.

    c. For toilet rooms with ceiling heights 12 feet and under, the 2.0 CFM/sq.ft. dictates.

    d. If toilet rooms are designed for a 100 CFM/water closet or urinal, you will always meet the 2.0 CFM/sq.ft. and the 10 AC/h recommended airflow requirements.

8.10. Electrical Rooms

A. **Recommended Minimum Ventilation Rate**

1. 2.0 CFM/sq.ft.

2. 10.0 AC/h

3. 5 CFM/KVA of transformer.

B. **Electrical Room Design Guidelines**

1. Determine heat gain from transformers, panelboards, and other electrical equipment contained in the electrical room. Then, determine required airflow for ventilation or tempering of space.

2. Generally, electrical equipment rooms only require ventilation to keep equipment from overheating. Most electrical rooms are designed for 95°F to 104°F; however, consult the electrical engineer for equipment temperature

tolerances. If space temperatures 90°F and below are required by equipment, air conditioning (tempering) of the space will be required.

3. If outside air is used to ventilate the electrical room, the electrical room design temperature will be 10°F to 15°F above outside summer design temperatures.

4. If conditioned air from an adjacent space is used to ventilate the electrical room, the electrical room temperature can be 10°F to 20°F above the adjacent spaces.

8.11. Mechanical Rooms

A. **Recommended Minimum Ventilation Rate**

1. 2.0 CFM/sq.ft.

2. 10.0 AC/h

B. **Mechanical Equipment Room Design Guidelines**

1. Determine heat gain from motors, pumps, fans, transformers, panelboards, and other mechanical and electrical equipment contained in the mechanical room. Then, determine the required airflow for the ventilation or tempering of space.

2. Generally, mechanical equipment rooms only require ventilation. Most mechanical rooms are designed for 95°F to 104°F; however, verify mechanical equipment temperature tolerances. If space temperatures below 90°F are required by mechanical equipment, air conditioning (tempering) of the space will be required.

3. A number of products (DDC control panels, variable frequency drives, other electronic components) will perform better if the mechanical room is tempered in lieu of just ventilating the room.

4. If outside air is used to ventilate the mechanical room, the mechanical room design temperature will be 10°F to 15°F above outside summer design temperatures.

5. If conditioned air from an adjacent space is used to ventilate the mechanical room, the mechanical room temperature can be 10°F to 20°F above the adjacent spaces.

C. **Boiler Rooms—Cleaver Brooks 10 CFM/BHP**

1. 8 CFM/BHP combustion air.
2. 2 CFM/BHP ventilation.
3. 1 BHP = 33,500 Btuh.

D. **Chiller Rooms—*ASHRAE Standard* 15-2013 and *ASHRAE Standard* 34-2013**

1. See *ASHRAE Standard 15-2013* and *ASHRAE Standard 34-2013* for complete refrigeration system requirements.
2. Scope:
   a. To establish safeguards for life, limb, health, and property.
   b. To define practices that are consistent with safety.
   c. To prescribe safety standards.
3. Application: The standard applies to all mechanical and absorption refrigerating systems and heat pumps used in institutional, public assembly, residential, commercial, large mercantile, industrial, and mixed-use occupancies; to parts and components added after adoption of this code; and to substitutions of refrigerant having a different designation.
4. Refrigerant classification is shown in the following table:

Safety Group

Higher Flammability	A3	B3
Lower Flammability	A2	B2 Ammonia
No Flame Propagation	A1 R-11, R-12, R-22, R-134a, R-410a	B1 R-123
	Lower toxicity	Higher toxicity

5. Requirements for refrigerant use:
   a. Requirements for refrigerant use are based on the probability that the refrigerant will enter an occupied space and on the type of occupancy (institutional, public assembly, residential, commercial, large mercantile, industrial, and mixed-use).

b. The total amount of refrigerant permitted to be installed in a system is determined by the type of occupancy, the refrigerant group, and the probability that refrigerant will enter the occupied space.

c. Refrigerant piping shall not be installed in an enclosed stairways, stair landings, or means of egress.

d. Refrigeration system components shall not interfere with free passage through public hallways, and limitations regarding size are based on refrigerant type.

6. Service provisions:
   a. All serviceable components of refrigerating systems shall be safely accessible.

   b. Properly located stop valves, liquid and vapor transfer valves, refrigerant storage tanks, and adequate venting are required when needed for safe servicing of equipment.

   c. Refrigerant systems with more than 6.6 lbs. of refrigerant require stop valves at:
      1. The suction inlet of each compressor, compressor unit, or condensing unit.

      2. The discharge outlet of each compressor, compressor unit, or condensing unit.

      3. The outlet of each liquid receiver.

   d. Refrigerant systems with more than 110 lbs. of refrigerant require stop valves at:
      1. The suction inlet of each compressor, compressor unit, or condensing unit.

      2. The discharge outlet of each compressor, compressor unit, or condensing unit.

      3. The inlet of each liquid receiver, except for self-contained systems or where the receiver is an integral part of the condenser or condensing unit.

      4. The outlet of each liquid receiver.

      5. The inlet and outlet of condensers when more than one condenser is

used in parallel.

e. Stop valves shall be suitably labeled.

7. Installation requirements:
   a. Air ducts passing through machinery rooms shall be of tight construction and shall have no openings in such rooms. Access doors and panels in ductwork and air handling units shall be gasketed and tight fitting.

   b. Refrigerant piping crossing an open space that affords passageway in any building shall not be less than 7'-3" above the floor.

   c. Passages shall not be obstructed by refrigerant piping.

   d. Refrigerant piping shall not be placed in, or pass through, any elevator, dumbwaiter, or other shaft containing moving objects or in any shaft that has openings to living quarters or main exits.

   e. Refrigerant piping shall not be installed vertically through floors from one story to another except as follows:
      1. Basement to first floor, top floor to mechanical equipment penthouse or roof.

      2. Adjacent floors served by the refrigerating system.

      3. Where the refrigerant concentration does not exceed that listed in Table 4-1 or Table 4-2 of ASHRAE Standard 34 for the smallest occupied space through which the refrigerant piping passes.

      4. For the purpose of interconnecting separate pieces of equipment in other than industrial occupancies and where the refrigerant concentration exceeds that listed in Table 4-1 or Table 4-2 of ASHRAE Standard 34 for the smallest occupied space. The piping may be carried in an approved, rigid and tight, continuous fire-resistive pipe, duct, or shaft having no openings into floors not served by the refrigerating system or carried exposed on the outer wall of the building. Or the piping may be located on the exterior wall of a building when vented to the outdoors or to the space served by the system and not used as an air shaft, closed court, or similar space.

8. Refrigeration equipment room requirements:
   a. Provide proper space for service, maintenance, and operation.

b. Minimum clear headroom shall be 7'-3".

c. Doors shall be outward opening, self-closing, fire-rated, tight fitting, and adequate in number to ensure freedom for persons to escape in an emergency. No other openings shall be permitted in equipment rooms that will permit passage of refrigerant to other parts of the building.

d. Refrigeration equipment rooms require a refrigerant detector located in the equipment room in an area where refrigerant from a leak will concentrate, set to alarm and start the ventilation system when the level reaches the refrigerant's toxicity level. The alarm shall annunciate visual and audible alarms inside the refrigerating machinery room and outside each entrance to the refrigerating machinery room. The alarm shall be of the manual reset type with the reset located inside the refrigeration equipment room.

e. Periodic test of alarm and sensors are required.

f. Mechanical rooms shall be vented to the outdoors.

g. Mechanical ventilation shall be capable of exhausting the air quantity determined by the formula in Section 8.11.5. The exhaust quantity depends on the amount of refrigerant contained in the system. To obtain a reduced airflow for normal ventilation, multiple fans, multispeed fans, or fans with variable frequency drives may be used. Provision shall be made for inlet air to replace that being exhausted. Openings for inlet air shall be positioned to avoid recirculation.

h. Minimum ventilation rate shall be 0.5 CFM per square foot of machine room area or 20 CFM per person.

i. No open flames that use combustion air from the machinery room shall be installed where any refrigerant other than carbon dioxide (R-744), water (R-718), or ammonia (R-717) is used. A sealed air duct may be used to supply combustion air to fuel-burning appliances in the machinery room, or a refrigerant detector may be used to automatically shut down the combustion process in the event of refrigerant leakage.

j. There shall be no flame-producing device or continuously operating hot surface over 800°F permanently installed in the room.

k. Walls, floors, and ceilings shall be tight and of non-combustible construction with a minimum 1-hour fire resistance rating.

l. The machinery room shall have a door that opens directly to the outside or through a vestibule equipped with self-closing, tight-fitting doors.

m. All machinery room wall, floor, and ceiling penetrations shall be sealed.

n. Where Groups A2, A3, B2, and B3 refrigerants are used, the machinery room shall conform to Class I, Division 2 of the National Electric Code. Groups A1 and B1 are exempt from this requirement.

o. Emergency shutdown of the refrigeration equipment shall be provided immediately outside the machinery room door.

p. Ventilation fans shall be on a separate electrical circuit and shall have a control switch located immediately outside the machinery room door so they can be activated in an emergency.

q. Refrigeration compressors, piping, equipment, valves, switches, ventilation equipment, and associated appurtenances shall be labeled in accordance with *ANSI/ASME A13.1.*

8.12. Combustion Air

A. **2015 IMC**

1. Oil-fired appliances shall be provided with combustion air in accordance with NFPA 31.

2. The requirements for combustion and dilution air for gas-fired appliances shall be in accordance with the *International Fuel Gas Code*.

B. **NFPA 54—2015 National Fuel Gas -Code**

1. Inside air:
   a. Minimum required space volume: 50 $ft.^3$ per 1,000 Btu/h of the combined fuel-burning appliance input capacity.

   b. Number of openings: Two openings are required—one within 1 foot of the ceiling of the room, and one within 1 foot of the floor.

c. Opening size on the same story: The net free area of each opening shall be equal to 1.0 square inch for each 1,000 Btu/h of the combined fuel-burning appliance input rating (the sum of all appliances within the room), 100 square inches minimum. The minimum dimension of air openings shall not be less than 3 inches.

d. Opening size on the different stories: The net free area of each opening shall be equal to 2.0 square inches for each 1,000 Btu/h of the combined fuel-burning appliance input rating (the sum of all appliances within the room).

2. Outdoor air:
   a. Two permanent opening methods:
      1. Number of openings: Two openings are required—one within 1 foot of the ceiling of the room and one within 1 foot of the floor.

      2. Direct opening size: The net free area of each opening shall be equal to 1.0 square inch for each 4,000 Btu/h of the combined fuel-burning appliance input rating (the sum of all appliances within the room).

      3. Horizontal duct opening size: The net free area of each opening shall be equal to 1.0 square inch for each 2,000 Btu/h of the combined fuel-burning appliance input rating (the sum of all appliances within the room).

      4. Vertical opening size: The net free area of each opening shall be equal to 1.0 square inch for each 4,000 Btu/h of the combined fuel-burning appliance input rating (the sum of all appliances within the room).

   b. One permanent opening method:
      1. Number of openings: One opening is required—one within 1 foot of the ceiling.

      2. The appliance will have at least 1 inch clearance on the sides and back of the appliance, and 6 inches in front of the appliance.

      3. The opening shall directly communicate with the outdoors or shall communicate through vertical or horizontal ducts to the outdoors.

      4. Opening size: The net free area of each opening shall be equal to 1.0 square inch for each 3,000 Btu/h of the combined fuel-burning appliance input rating (the sum of all appliances within the room). Not

less than the sum of the areas of all vent connectors in the space.

3. Combination indoor and outdoor combustion air:
    a. Indoor openings shall comply with the indoor air requirements listed above.

    b. Outdoor openings shall comply with the outdoor air requirements listed above.

    c. The outdoor opening shall be sized to compensate for the deficiency in available volume of all communicating interior spaces. The minimum size of outdoor opening(s) shall be the full size of the outdoor opening(s) calculated in accordance with the requirements listed above, multiplied by 1 minus the ratio of available interior volume divided by the required interior volume.

4. Forced combustion air supply:
    a. Where combustion air is provided by mechanical means, the system shall deliver a minimum of 0.35 CFM per 1,000 Btu/h of the combined fuel-burning appliance input rating (the sum of all appliances within the room).

    b. Appliances shall be interlocked with a makeup air unit to prevent operation if the makeup air unit is not operating.

5. Direct vent appliances:
    a. Appliances must be listed and labeled for a direct combustion air connection.

    b. Appliances must be installed in accordance with the manufacturers' installation instructions.

6. Combustion air ducts:
    a. Galvanized steel construction.

    b. Unobstructed termination.

    c. Same cross-sectional area as the free area of the openings.

    d. Serves a single appliance enclosure.

    e. Separate ducts must be provided for the upper and lower combustion air openings. The separation between these ducts shall be maintained from source to discharge.

f. Ducts that serve the upper combustion air opening cannot slope downward toward the source of the combustion air.

g. The bottom of the combustion air opening shall be a minimum of 12 inches above grade.

h. Ducts shall not be screened where terminating in an attic space.

i. The remaining space within a chimney surrounding a chimney liner, gas vent, special gas vent, or plastic piping shall not be used to supply combustion air.

7. Opening protection:
   a. Metal louver: Maximum 75 percent free area.

   b. Wood louvers: Maximum 25 percent free area.

   c. Dampers (fire, smoke, control): Dampers shall be interlocked to operate with the appliance. Manually operated dampers are not permitted.

8.13. Hazardous Locations

A. **Hazardous location requirements for electrical and electronic equipment are defined in the *2014 National Electrical Code* (*NEC NFPA 70*), Articles 500 through 510.**

B. **Hazardous Classifications**
   1. Class I: Class I locations are those spaces where flammable gases or vapors are, or where they may be present in the air in quantities sufficient to produce explosive or ignitable mixtures.
      a. Class I locations are subdivided into four groups based on the type of flammable gases or vapors:
         1. Group A: Acetylene.

         2. Group B: Flammable gas (hydrogen, ethylene oxide, propylene oxide); flammable liquid-produced vapor, or combustible liquid-produced vapor mixed with air that may burn or explode, having either a maximum experimental safe gap (MESG) value less than or equal to 0.45 mm or a minimum igniting current ratio (MIC ratio) less than or equal to 0.40.

3. Group C: Flammable gas (Ethyl Ether, Ethylene); flammable liquid-produced vapor, or combustible liquid-produced vapor mixed with air that may burn or explode, having either a maximum experimental safe gap (MESG) value greater than 0.45 mm and less than or equal to 0.75 mm, or a minimum igniting current ratio (MIC ratio) greater than 0.40 and less than or equal to 0.80.

4. Group D: Flammable gas (Acetone, Ammonia, Butane, Gasoline, Propane); flammable liquid-produced vapor, or combustible liquid-produced vapor mixed with air that may burn or explode, having either a maximum experimental safe gap (MESG) value greater than 0.75 mm or a minimum igniting current ratio (MIC ratio) greater than 0.80.

b. Class I locations are also subdivided into two divisions:
   1. Class I, Division 1:
      a. Locations where ignitable concentrations of flammable gases or vapors can exist under normal operating conditions; or

      b. Locations where ignitable concentrations of flammable gases or vapors may exist frequently because of repair or maintenance operations or because of leakage; or

      c. Locations where breakdown or faulty operation of equipment or processes might release ignitable concentrations of flammable gases or vapors, and might cause the simultaneous failure of electric equipment.

   2. Class I, Division 2:
      a. Locations where volatile flammable liquids or flammable gases are handled, processed, or used, but in which the liquids, vapors, or gases will normally be confined within closed containers or closed systems where they can escape only in case of an accidental rupture or breakdown of such containers or systems, or in the case of abnormal operation or equipment; or

      b. Locations where ignitable concentrations of gases or vapors are normally prevented by positive mechanical ventilation, and have the potential to become hazardous through failure or abnormal operation of the ventilating equipment; or

      c. Locations that are adjacent to Class I, Division 1 locations, and to which ignitable concentrations of gases or vapors might occasionally be communicated unless such communication is prevented by adequate positive pressure ventilation from a source of clean air, and effective safeguards against ventilation failure are provided.

2. Class II: Class II locations are spaces or areas that contain combustible dusts.
   a. Class II locations are subdivided into three groups based on the type of combustible dusts:
      1. Group E: Atmospheres containing combustible metal dusts, including aluminum, magnesium, and their commercial alloys, or other combustible dusts whose particle size, abrasiveness, and conductivity present similar hazards in the use of electrical equipment.

      2. Group F: Atmospheres containing combustible carbonaceous dusts that have more than 8 percent total entrapped volatiles or have been sensitized by other materials so that they present an explosion hazard (coal, carbon black, charcoal, and coke dust).

      3. Group G: Atmospheres containing combustible dusts not included in Group E or F, such as flour, grain, wood, plastic, and chemicals.

   b. Class II, Division 1:
      1. Locations in which combustible dust is in the air under normal operating conditions in quantities sufficient to produce explosive or ignitable mixtures; or

      2. Locations where mechanical failure or abnormal operation of machinery or equipment might cause such explosive or ignitable mixtures to be produced, and might also provide a source of ignition through the simultaneous failure of electrical equipment, through the operation of protection devices, or from other causes; or

      3. Locations in which Group E combustible dusts may be present in quantities sufficient to be hazardous.

   c. Class II, Division 2:
      1. Locations in which combustible dust due to abnormal operations may be present in the air in quantities sufficient to produce explosive or ignitable mixtures; or

      2. Locations where combustible dust accumulations are present but are normally insufficient to interfere with the normal operation of electrical equipment or other apparatus, but could as a result of infrequent

malfunctioning of handling or processing equipment become suspended in the air; or

3. Locations in which combustible dust accumulations on, in, or in the vicinity of the electrical equipment could be sufficient to interfere with the safe dissipation of heat from electrical equipment, or could be ignitable by abnormal operation or the failure of electrical equipment.

3. Class III: Class II locations are spaces or areas that contain easily ignitable fibers or flyings, but where such fibers or flyings are not likely to be in suspension in the air in quantities sufficient to produce ignitable mixtures.
   a. Class III, Division 1: Locations in which easily ignitable fibers or materials producing combustible flyings are handled, manufactured, or used.

   b. Class III, Division 2: Locations in which easily ignitable fibers are stored or handled other than in the process of manufacturing.

C. **Hazardous Location Protection Techniques**

1. Purged and pressurized systems: Spaces and equipment are pressurized at pressures above the external atmosphere with noncontaminated air or other nonflammable gas to prevent explosive gases or vapors from entering the enclosure.

2. Intrinsically safe systems: Electrical circuits are designed so that they do not release sufficient energy to ignite an explosive atmosphere.

3. Explosion-proof equipment: Explosion-proof equipment is designed and built to withstand an internal explosion without igniting the surrounding atmosphere.

4. Nonincendive circuits, components, and equipment: Circuits designed to prevent any arc or thermal effect produced, under intended operating conditions of the equipment or produced by opening, shorting, or grounding of the field wiring, is not capable, under specified test conditions, of igniting the flammable gas, vapor, or dust-air mixtures.

5. Oil immersed equipment: The arcing portions of the equipment are immersed in an oil at a depth that the arc will not set off any hazardous gases or vapors above the surface of the oil.

6. Hermetically sealed equipment: The equipment is sealed against the external atmosphere to prevent the entry of hazardous gases or vapors.

7. Dust-ignition-proof equipment: Dust-ignition-proof equipment is designed and built to exclude dusts and, where installed and protected, will not permit arcs, sparks, or heat generated or liberated inside the enclosure to cause ignition of the exterior accumulations or atmospheric suspensions of a specified dust on or in the enclosure.

8. Dust-tight equipment: Dust-tight equipment is designed to prevent the entrance of dust into equipment.

9. Combustible gas detection system: Gas detection equipment shall be listed for detection of the specific gas or vapor to be encountered.

10. Classification versus Protection Techniques is shown in the following table:

Protection Techniques	Class I		Class II		Class III	
	Div 1	**Div 2**	**Div 1**	**Div 2**	**Div 1**	**Div 2**
Purged and Pressurized	X	X	X	X	X	X
Intrinsically Safe Systems	X	X	X	X	X	X
Explosion-Proof Equipment	X	X	N/A	N/A	N/A	N/A
Nonincendive Circuits, Components, and Equipment	N/A	X	N/A	X	X	X
Hermetically Sealed Equipment	N/A	X	N/A	X	X	X
Oil Immersed Equipment	N/A	X	N/A	N/A	N/A	N/A
Dust-Ignitionproof Equipment	N/A	N/A	X	X	N/A	N/A
Dusttight Equipment	N/A	N/A	N/A	X	X	X
Combustible Gas Detection Systems	X	X	N/A	N/A	N/A	N/A

Notes:

X = Appropriate to the classification.

N/A = Not acceptable to the classification.

D. **Ventilation Requirements**

1. Ventilation, natural or mechanical, must be sufficient to limit the concentrations of flammable gases or vapors to a maximum level of 25 percent of their Lower Flammable Limit/Lower Explosive Limit (LFL/LEL).

2. Minimum ventilation required: 1.0 CFM/sq.ft. of floor area or 6.0 air changes per hour, whichever is greater. If a reduction in the classification is desired, the airflow must be four times the airflow just specified.

3. Recommendation: Ventilate all hazardous locations with 2.0 CFM/sq.ft. of floor area or 12 air changes per hour minimum with half the airflow supplied and exhausted high (within 6 inches of the ceiling or structure) and half the airflow supplied and exhausted low (within 6 inches of the floor).

4. A ventilation rate that is a minimum of four times the ventilation rate required to prevent the space from exceeding the maximum level of 25 percent LFL/LEL using fugitive emissions calculations.

5. Ventilate the space so accumulation pockets for lighter-than-air or heavier-than-air gases or vapors are eliminated.

6. Monitoring of the space is recommended to ensure that the 25 percent LFL/LEL is not exceeded.

E. **Hazardous Location Definitions**

1. *Boiling Point*. The temperature at which the vapor pressure of a liquid equals the atmospheric pressure of 14.7 pounds per square inch absolute.

2. *Combustible Liquids*. Liquids having flash points at or above 100°F. Combustible liquids shall be subdivided as Class II or Class III liquids as follows:
   a. Class II. Liquids having flash points at or above 100°F and below 140°F.

   b. Class IIIA. Liquids having flash points at or above 140°F and below 200°F.

   c. Class IIIB. Liquids having flash points at or above 200°F.

3. *Explosion*. An effect produced by the sudden violent expansion of gases, which can be accompanied by a shockwave or disruption, or both, of enclosing materials or structures. An explosion might result from chemical changes such as rapid oxidation, deflagration, or detonation; decomposition of molecules, and runaway polymerization; or physical changes such as pressure tank ruptures.

4. *Explosive*. Any chemical compound, mixture, or device, the primary or common purpose of which is to function by explosion.

5. *Flammable*. Any material capable of being ignited from common sources of heat or at a temperature of 600°F or less.

6. *Flammable Compressed Gas*. An air/gas mixture that is flammable when the gas is 13 percent or less by volume or when the flammable range of the gas is wider than 12 percent regardless of the lower limitation determined at atmospheric temperature and pressures.

7. *Flammable Liquids*. Liquids having flash points below 100°F and having vapor pressures not exceeding 40 pounds per square inch absolute at 100°F. Flammable liquids shall be subdivided as Classes IA, IB, and IC as follows:
   a. Class IA. Liquids having flash points below 73°F and having boiling points below 100°F.

   b. Class IB. Liquids having flash points below 73°F and having boiling points above 100°F.

   c. Class IC. Liquids having flash points at or above 73°F and below 100°F.

8. *Flammable Solids*. A solid, other than a blasting agent or explosive, that is capable of causing a fire through friction, absorption of moisture, spontaneous chemical change, or retaining heat from manufacturing or processing, or which has an ignition temperature below 212°F, or which burns so vigorously and persistently when ignited as to create a serious hazard.

9. *Flash Point*. The minimum temperature in °F at which a flammable liquid will give off sufficient vapors to form an ignitable mixture with air near the surface or in the container, but will not sustain combustion.

10. *Noncombustible*. A material that, in the form in which it is used and under the conditions anticipated, will not ignite, burn, support combustion, or release flammable vapors when subject to fire or heat.

11. *Pyrophoric*. A material that will spontaneously ignite in air at or below 130°F.

Thumb, Third Edition. Part 8: Ventilation Rules of Thumb, Chapter (McGraw-Hill Professional, 2016), AccessEngineering

Part 9: Humidification Rules of Thumb

9. Part 9: Humidification Rules of Thumb

9.01. Window Types and Space Humidity Values

A. Single Pane Windows	**±10 percent RH Maximum**
B. Double Pane Windows	**±30 percent RH Maximum**
C. Triple Pane Windows	**±40 percent RH Maximum**

D. The preceding numbers are based on the following:

1. 0°F, outside design temperature.
2. 72°F, inside design temperature.
3. $R_{\text{INSIDE AIR FILM}} = 0.680$ $U_{\text{INSIDE AIR FILM}} = 1.471$
4. $R_{\text{SINGLE GLASS}} = 0.909$ $U_{\text{SINGLE GLASS}} = 1.100$
5. $R_{\text{DOUBLE GLASS}} = 1.667$ $U_{\text{DOUBLE GLASS}} = 0.600$
6. $R_{\text{TRIPLE GLASS}} = 2.000$ $U_{\text{TRIPLE GLASS}} = 0.500$
7. Standard air at sea level.
8. The relative humidity numbers presented earlier in this list are rounded for ease of remembrance.
9. The glass R-values and U-values are for average glass construction. Modern glass construction can achieve higher R-values/lower U-values.

10. For additional information on moisture condensation on glass, see the tables at the end of this chapter.

9.02. Proper Vapor Barriers

A. **Proper vapor barriers and moisture control must be provided to prevent moisture condensation in walls and to prevent mold, fungi, bacteria, and other plant and micro-organism growth.**

9.03. Human Comfort

A. **30–60 percent RH**

9.04. Electrical Equipment, Computers

A. **35–55 percent RH**

9.05. Winter Design Relative Humidities

A. **Outdoor Air Below 32°F**
   1. 70–80 percent RH
   2. Design Wet Bulb Temperatures 2 to 4°F below Design Dry Bulb Temperatures

B. **Outdoor Air 32–60°F: 50 percent RH**

9.06. Optimum Relative Humidity Ranges for Health

Health Aspect	Optimum Relative Humidity Range for Controlling Health Aspect
Bacteria	20–70%
Viruses	40–78%
Fungi	0–70%
Mites	0–60%
Respiratory Infections (1)	40–50%
Allergic Rhinitis and Asthma	40–60%
Chemical Interactions	0–40%
Ozone Production	75–100%
Combined Health Aspects	40–60%

Note:

(1) Insufficient data above 50 percent RH.

9.07. Moisture Condensation on Glass

The subsequent moisture condensation tables are based on the following:

1. $R_{INSIDE\ AIR\ FILM}$ = 0.680	$U_{INSIDE\ AIR\ FILM}$ = 1.471
2. $R_{SINGLE\ GLASS}$ = 0.909	$U_{SINGLE\ GLASS}$ = 1.100
3. $R_{DOUBLE\ GLASS}$ = 1.818	$U_{DOUBLE\ GLASS}$ = 0.550
4. $R_{TRIPLE\ GLASS}$ = 2.500	$U_{TRIPLE\ GLASS}$ = 0.400
5. Standard air at sea level.	

The glass surface temperatures, which are also the space dewpoint temperatures, listed in the moisture condensation tables that follow, were developed using the equations in Part 3.

	Single Pane Glass	Double Pane Glass	Triple Pane Glass

Temp. Room °F	Temp. Outside °F	Single Pane Glass T_{GLASS} / $T_{DEWPOINT}$	Single Pane Glass % R.H.	Double Pane Glass T_{GLASS} / $T_{DEWPOINT}$	Double Pane Glass % R.H.	Triple Pane Glass T_{GLASS} / $T_{DEWPOINT}$	Triple Pane Glass % R.H.
65	–30	–6.1	4.5	29.5	25.9	39.2	38.5
	–25	–2.3	5.6	31.3	27.9	40.5	40.5
	–20	1.4	6.9	33.2	30.2	41.9	42.8
	–15	5.2	8.4	35.1	32.6	43.2	45.0
	–10	8.9	10.1	36.9	35.1	44.6	47.5
	–5	12.6	12.1	38.8	37.9	46.0	50.1
	0	16.4	14.5	40.7	40.8	47.3	52.7
	5	20.1	17.2	42.6	44.0	48.7	55.5
	10	23.9	20.3	44.4	47.1	50.0	58.3
	15	27.6	23.9	46.3	50.7	51.4	61.4
	20	31.3	27.9	48.2	54.5	52.8	64.7
	25	35.1	32.6	50.0	58.3	54.1	67.9
	30	38.8	37.9	51.9	62.6	55.5	71.4
	35	42.6	44.0	53.8	67.1	56.8	74.9
	40	46.3	50.7	55.6	71.7	58.2	78.3
66	–30	–5.8	4.4	30.1	25.6	39.9	38.2
	–25	–2.1	5.5	32.0	27.7	41.2	40.2
	–20	1.7	6.7	33.8	29.9	42.6	42.5
	–15	5.4	8.2	35.7	32.3	44.0	44.8
	–10	9.1	9.9	37.6	34.9	45.3	47.1
	–5	12.9	11.8	39.4	37.4	46.7	49.7
	0	16.6	14.1	41.3	40.4	48.0	52.2
	5	20.4	16.8	43.2	43.5	49.4	55.1
	10	24.1	19.8	45.1	46.8	50.8	58.0
	15	27.8	23.3	46.9	50.1	52.1	60.9
	20	31.6	27.3	48.8	53.8	53.5	64.1
	25	35.3	31.8	50.7	57.8	54.8	67.2
	30	39.1	37.0	52.5	61.8	56.2	70.8
	35	42.8	42.8	54.4	66.3	57.6	74.4
	40	46.6	49.5	56.3	71.0	58.9	78.0
67	–30	–5.6	4.3	30.7	25.4	40.6	37.9
	–25	–1.8	5.4	32.6	27.5	42.0	40.1
	–20	1.9	6.6	34.5	29.7	43.3	42.2

Temp. Room °F	Temp. Outside °F	Single Pane Glass T / T	% R.H.	Double Pane Glass T / T	% R.H.	Triple Pane Glass T / T	% R.H.
	–15	5.7	8.0	36.3	32.0	44.7	44.5
	–10	9.4	9.7	38.2	34.5	46.1	46.9
	–5	13.1	11.6	40.1	37.2	47.4	49.3
	0	16.9	13.8	41.9	39.9	48.8	52.0
	5	20.6	16.4	43.8	43.0	50.1	54.6
	10	24.4	19.4	45.7	46.2	51.5	57.5
	15	28.1	22.7	47.6	49.7	52.9	60.6
	20	31.8	26.6	49.4	53.2	54.2	63.5
	25	35.6	31.1	51.3	57.1	55.6	66.9
	30	39.3	36.0	53.2	61.3	56.9	70.1
	35	43.1	41.8	55.0	65.4	58.3	73.7
	40	46.8	48.2	56.9	70.1	59.7	77.5
68	–30	–5.3	4.3	31.3	25.1	41.3	37.7
	–25	–1.6	5.3	33.2	27.2	42.7	39.8
	–20	2.2	6.5	35.1	29.4	44.1	42.0
	–15	5.9	7.8	37.0	31.8	45.4	44.2
	–10	9.7	9.5	38.8	34.1	46.8	46.6
	–5	13.4	11.3	40.7	36.8	48.1	48.9
	0	17.1	13.5	42.6	39.6	49.5	51.6
	5	20.9	16.0	44.4	42.5	50.9	54.4
	10	24.6	18.9	46.3	45.7	52.2	57.0
	15	28.4	22.2	48.2	49.1	53.6	60.1
	20	32.1	26.0	50.0	52.6	54.9	63.0
	25	35.8	30.3	51.9	56.4	56.3	66.3
	30	39.6	35.2	53.8	60.5	57.7	69.7
	35	43.3	40.7	55.7	64.8	59.0	73.0
	40	47.1	47.1	57.5	69.2	60.4	76.7
69	–30	–5.1	4.2	32.0	25.0	42.1	37.6
	–25	–1.3	5.2	33.8	26.9	43.4	39.5
	–20	2.4	6.3	35.7	29.1	44.8	41.7
	–15	6.2	7.7	37.6	31.4	46.2	44.0
	–10	9.9	9.2	39.5	33.9	47.5	46.2
	–5	13.6	11.1	41.3	36.4	48.9	48.7
	0	17.4	13.2	43.2	39.2	50.2	51.2
	5	21.1	15.6	45.1	42.2	51.6	53.9
	10	24.9	18.5	46.9	45.2	53.0	56.8
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Temp. Room °F	Temp. Outside °F	Single Pane Glass		Double Pane Glass		Triple Pane Glass	
		T / T	% R.H.	T / T	% R.H.	T / T	% R.H.
	15	28.6	21.7	48.8	48.6	54.3	59.5
	20	32.3	25.3	50.7	52.1	55.7	62.7
	25	36.1	29.6	52.5	55.7	57.0	65.7
	30	39.8	34.3	54.4	59.8	58.4	69.1
	35	43.6	39.8	56.3	64.0	59.8	72.6
	40	47.3	45.9	58.2	68.6	61.1	76.0
70	–30	–4.8	4.1	32.6	24.8	42.8	37.3
	–25	–1.1	5.0	34.5	26.8	44.2	39.4
	–20	2.7	6.2	36.3	28.8	45.5	41.4
	–15	6.4	7.5	38.2	31.1	46.9	43.7
	–10	10.2	9.1	40.1	33.6	48.2	45.9
	–5	13.9	10.8	41.9	36.0	49.6	48.3
	0	17.6	12.9	43.8	38.8	51.0	51.0
	5	21.4	15.3	45.7	41.7	52.3	53.5
	10	25.1	18.0	47.6	44.8	53.7	56.3
	15	28.9	21.2	49.4	48.0	55.0	59.0
	20	32.6	24.8	51.3	51.5	56.4	62.1
	25	36.3	28.8	53.2	55.3	57.8	65.3
	30	40.1	33.6	55.0	59.0	59.1	68.4
	35	43.8	38.8	56.9	63.2	60.5	71.9
	40	47.6	44.8	58.8	67.7	61.8	75.3
71	–30	–4.6	4.0	33.2	23.6	43.5	37.0
	–25	–0.8	5.0	35.1	26.5	44.9	39.1
	–20	2.9	6.0	37.0	28.7	46.2	41.1
	–15	6.7	7.4	38.8	30.8	47.6	43.3
	–10	10.4	8.8	40.7	33.2	49.0	45.7
	–5	14.1	10.6	42.6	35.8	50.3	48.0
	0	17.9	12.6	44.4	38.4	51.7	50.5
	5	21.6	14.9	46.3	41.3	53.0	53.0
	10	25.4	17.6	48.2	44.3	54.4	55.8
	15	29.1	20.7	50.1	47.6	55.8	58.7
	20	32.8	24.1	51.9	50.9	57.1	61.6
	25	36.6	28.2	53.8	54.6	58.5	64.7
	30	40.3	32.7	55.7	58.5	59.8	67.8
	35	44.1	37.9	57.5	62.5	61.2	71.3
	40	47.8	43.7	59.4	66.9	62.6	74.9

Temp. Room °F	Temp. Outside °F	Single Pane Glass T / T	% R.H.	Double Pane Glass T / T	% R.H.	Triple Pane Glass T / T	% R.H.
72	–30	–4.3	4.0	33.8	24.3	44.3	36.9
	–25	–0.6	4.8	35.7	26.3	45.6	38.8
	–20	3.2	5.9	37.6	28.4	47.0	41.0
	–15	6.9	7.2	39.5	30.6	48.3	43.0
	–10	10.7	8.7	41.3	32.9	49.7	45.3
	–5	14.4	10.4	43.2	35.4	51.1	47.8
	0	18.1	12.3	45.1	38.1	52.4	50.1
	5	21.9	14.6	46.9	40.8	53.8	52.8
	10	25.6	17.2	48.8	43.8	55.1	55.3
	15	29.4	20.5	50.7	47.1	56.5	58.2
	20	33.1	23.6	52.6	50.5	57.9	61.2
	25	36.8	27.5	54.4	54.0	59.2	64.2
	30	40.6	32.0	56.3	57.8	60.6	67.4
	35	44.3	36.9	58.2	61.9	61.9	70.6
	40	48.1	42.7	60.0	66.0	63.3	74.2
73	–30	–4.1	3.8	34.5	24.2	45.0	36.7
	–25	–0.3	4.8	36.3	26.0	46.3	38.6
	–20	3.4	5.8	38.2	28.1	47.7	40.7
	–15	7.2	7.1	40.1	30.3	49.1	42.9
	–10	10.9	8.5	42.0	32.7	50.4	45.0
	–5	14.7	10.2	43.8	35.0	51.8	47.4
	0	18.4	12.1	45.7	37.7	53.1	49.7
	5	22.1	14.3	47.6	40.5	54.5	52.4
	10	25.9	16.9	49.4	43.3	55.9	55.1
	15	29.6	19.7	51.3	46.5	57.2	57.4
	20	33.4	23.1	53.2	49.9	58.6	60.7
	25	37.1	26.9	55.0	53.3	59.9	63.6
	30	40.8	31.2	56.9	57.1	61.3	66.8
	35	44.6	36.1	58.8	61.2	62.7	70.2
	40	48.3	41.6	60.7	65.4	64.0	73.5
74	–30	–3.8	3.8	35.1	24.0	45.7	36.4
	–25	–0.1	4.7	37.0	25.9	47.1	38.4
	–20	3.7	5.7	38.8	27.8	48.4	40.4
	–15	7.4	6.9	40.7	30.0	49.8	42.5
	–10	11.2	8.3	42.6	32.3	51.2	44.8
	–5	14.9	9.9	44.5	34.8	52.5	47.0
	0	18.6	11.8	46.3	37.3	53.9	49.5

Room Temp. °F	Outside Temp. °F	Single Pane Glass T / T	Single Pane Glass % R.H.	Double Pane Glass T / T	Double Pane Glass % R.H.	Triple Pane Glass T / T	Triple Pane Glass % R.H.
	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	5	22.4	14.0	48.2	40.1	55.2	51.9
	10	26.1	16.4	50.1	43.0	56.6	54.6
	15	29.9	19.3	51.9	46.0	58.0	57.5
	20	33.6	22.6	53.8	49.3	59.3	60.2
	25	37.3	26.2	55.7	52.9	60.7	63.3
	30	41.1	30.5	57.5	56.4	62.0	66.2
	35	44.8	35.2	59.4	60.4	63.4	69.6
	40	48.6	40.7	61.3	64.6	64.8	73.1
75	–30	–3.5	3.7	35.7	23.8	46.4	36.2
	–25	0.2	4.6	37.6	25.6	47.8	38.2
	–20	3.9	5.6	39.5	27.7	49.2	40.3
	–15	7.7	6.8	41.3	29.7	50.5	42.2
	–10	11.4	8.1	43.2	32.0	51.9	44.5
	–5	15.2	9.7	45.1	34.4	53.2	46.7
	0	18.9	11.6	46.9	36.9	54.6	49.1
	5	22.6	13.6	48.8	39.6	56.0	51.7
	10	26.4	16.1	50.7	42.6	57.3	54.2
	15	30.1	18.9	52.6	45.7	58.7	57.0
	20	33.9	22.1	54.4	48.8	60.0	59.7
	25	37.6	25.7	56.3	52.3	61.4	62.7
	30	41.3	29.7	58.2	56.0	62.8	65.9
	35	45.1	34.4	60.0	59.7	64.1	69.0
	40	48.8	39.6	61.9	63.8	65.5	72.4
76	–30	–3.3	3.6	36.4	23.6	47.2	36.1
	–25	0.4	4.5	38.2	25.4	48.5	37.9
	–20	4.2	5.5	40.1	27.4	49.9	39.9
	–15	7.9	6.6	42.0	29.5	51.2	41.9
	–10	11.7	8.0	43.8	31.7	52.6	44.2
	–5	15.4	9.5	45.7	34.1	54.0	46.5
	0	19.1	11.3	47.6	36.6	55.3	48.8
	5	22.9	13.4	49.4	39.2	56.7	51.3
	10	26.6	15.7	51.3	42.1	58.0	53.8
	15	30.4	18.5	53.2	45.1	59.4	56.5
	20	34.1	21.5	55.1	48.4	60.8	59.4
	25	37.8	25.0	56.9	51.7	62.1	62.2
	30	41.6	29.1	58.8	55.3	63.5	65.3

Temp. Room °F	Temp. Outside °F	Single Pane Glass T/T	Single Pane Glass % R.H.	Double Pane Glass T/T	Double Pane Glass % R.H.	Triple Pane Glass T/T	Triple Pane Glass % R.H.
	35	45.3	33.6	60.7	59.2	64.8	68.3
	40	49.1	38.8	62.5	63.1	66.2	71.7
77	–30	–3.0	3.6	37.0	24.4	47.9	35.8
	–25	0.7	4.4	38.8	25.2	49.3	37.8
	–20	4.4	5.3	40.7	27.2	50.6	39.7
	–15	8.2	6.5	42.6	29.3	52.0	41.8
	–10	11.9	7.8	44.5	31.5	53.3	43.8
	–5	15.7	9.3	46.3	33.7	54.7	46.1
	0	19.4	11.1	48.2	36.3	56.1	48.6
	5	23.1	13.0	50.1	38.9	57.4	50.9
	10	26.9	15.4	51.9	41.6	58.8	53.5
	15	30.6	18.0	53.8	44.6	60.1	56.0
	20	34.4	21.1	55.7	47.9	61.5	58.9
	25	38.1	24.5	57.6	51.3	62.9	61.9
	30	41.8	28.4	59.4	54.7	64.2	64.7
	35	45.6	32.8	61.3	58.5	65.6	68.0
	40	49.3	37.8	63.2	62.5	66.9	71.1
78	–30	–2.8	3.5	37.6	23.2	48.6	35.6
	–25	0.9	4.3	39.5	25.1	50.0	37.5
	–20	4.7	5.3	41.3	26.9	51.3	39.4
	–15	8.4	6.3	43.2	29.0	52.7	41.5
	–10	12.2	7.6	45.1	31.2	54.1	43.7
	–5	15.9	9.1	47.0	33.5	55.4	45.8
	0	19.7	10.8	48.8	35.9	56.8	48.2
	5	23.4	12.8	50.7	38.5	58.1	50.5
	10	27.1	15.0	52.6	41.3	59.5	53.1
	15	30.9	17.7	54.4	44.2	60.9	55.8
	20	34.6	20.6	56.3	47.3	62.2	58.4
	25	38.4	24.0	58.2	50.7	63.6	61.3
	30	42.1	27.8	60.0	54.0	64.9	64.2
	35	45.8	32.0	61.9	57.8	66.3	67.4
	40	49.6	37.0	63.8	61.8	67.7	70.7
79	–30	–2.5	3.5	38.2	23.0	49.4	35.5
	–25	1.2	4.2	40.1	24.8	50.7	37.3
	–20	4.9	5.1	42.0	26.8	52.1	39.3
	–15	8.7	6.2	43.8	28.7	53.4	41.2
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Temp. Room °F	Temp. Outside °F	Single Pane Glass T	/ % R.H.	Double Pane Glass T	/ % R.H.	Triple Pane Glass T	/ % R.H.
	–10	12.4	7.5	45.7	30.9	54.8	43.4
	–5	16.2	8.9	47.6	33.2	56.2	45.6
	0	19.9	10.6	49.5	35.6	57.5	47.8
	5	23.6	12.5	51.3	38.1	58.9	50.3
	10	27.4	14.7	53.2	40.9	60.2	52.7
	15	31.1	17.3	55.1	43.8	61.6	55.3
	20	34.9	20.2	56.9	46.8	63.0	58.1
	25	38.6	23.4	58.8	50.1	64.3	60.8
	30	42.3	27.1	60.7	53.6	65.7	63.9
	35	46.1	31.3	62.5	57.1	67.0	66.8
	40	49.8	36.0	64.4	61.0	68.4	70.1
80	–30	–2.3	3.4	38.9	22.9	50.1	35.3
	–25	1.5	4.2	40.7	24.6	51.4	37.0
	–20	5.2	5.0	42.6	26.5	52.8	39.0
	–15	8.9	6.1	44.5	28.5	54.2	41.0
	–10	12.7	7.3	46.3	30.6	55.5	43.0
	–5	16.4	8.7	48.2	32.8	56.9	45.3
	0	20.2	10.4	50.1	35.3	58.2	47.4
	5	23.9	12.2	51.9	37.7	59.6	49.9
	10	27.6	14.4	53.8	40.5	61.0	52.4
	15	31.4	16.9	55.7	43.4	62.3	54.9
	20	35.1	19.7	57.6	46.4	63.7	57.6
	25	38.9	22.9	59.4	49.5	65.0	60.3
	30	42.6	26.5	61.3	53.0	66.4	63.3
	35	46.3	30.6	63.2	56.6	67.8	66.4
	40	50.1	35.3	65.0	60.3	69.1	69.5

Part 10: People/Occupancy Rules of Thumb

10. Part 10: People/Occupancy Rules of Thumb

10.1. 2015 IMC and ASHRAE Standard 62.1-2013

OCCUPANCY SCHEDULE

Occupancy Classification	Max. Occupant Load	
	People per 1,000 SF	SF/Person
Correctional Facilities		
Booking/waiting	50	20
Cell—with plumbing fixtures	25	40
Cell—without plumbing fixtures	25	40
Day room	30	33
Dining halls (see food and beverage service)		
Guard stations	15	67
Dry Cleaners, Laundries		
Coin-operated dry cleaner	20	50
Coin-operated laundries	20	50

Occupancy Classification	Max. Occupant Load	
	People per 1,000 SF	SF/Person
Commercial dry cleaner	30	33
Commercial laundry	10	100
Storage, pick-up	30	33
Education		
Art classroom	20	50
Auditoriums	150	6
Classrooms (ages 5 to 8)	25	40
Classrooms (ages 9 plus)	35	28
Computer lab	25	40
Corridors (see public spaces)	–	–
Daycare (through age 4)	25	40
Daycare sickroom	25	40
Lecture classroom	65	15
Lecture hall (fixed seats)	150	6
Locker/dressing rooms	–	–
Media center	25	40
Multiuse assembly	100	10
Music/theater/dance	35	28
Science laboratories	25	40
Smoking lounges	70	14
Sports locker rooms	–	–
University/college laboratories	25	40
Wood/metal shops	20	50
Food and Beverage Service		
Bars, cocktail lounges	100	10

Occupancy Classification	Max. Occupant Load	
	People per 1,000 SF	SF/Person
Cafeteria, fast food	100	10
Dining rooms	70	14
Kitchens (cooking)	20	–
Hospitals, Nursing and Convalescent Homes		
Autopsy rooms	–	–
Medical procedure rooms	20	50
Operating rooms	20	50
Patient rooms	10	100
Physical therapy	20	50
Recovery and ICU	10	100
Hotels, Motels, Resorts, and Dormitories		
Barracks sleeping areas	20	50
Bathrooms/toilet—private	–	–
Bedroom/living room	10	100
Laundry rooms, central	10	100
Laundry rooms, within dwelling units	10	100
Conference/meeting	–	–
Dormitory sleeping areas	–	–
Gambling casinos	–	–
Lobbies/prefunction	30	33
Multipurpose assembly	120	8
Miscellaneous Spaces		
Banks or bank lobbies	15	67
Freezer and refrigerated spaces (<50°F)	–	–

Occupancy Classification	Max. Occupant Load	
	People per 1,000 SF	SF/Person
General manufacturing (excludes heavy industrial and processes using chemicals)	7	140
Janitor closets, trash rooms, recycling	–	–
Kitchenettes	–	–
Shipping/receiving	2	500
Sorting, packing, light assembly	7	140
Transportation waiting	100	10
Offices		
Conference rooms	50	20
Main entry lobbies	10	100
Occupiable storage rooms for dry materials	2	500
Office spaces	5	200
Reception areas	30	33
Telephone/data entry	60	16
Private Dwellings, Single and Multiple		
Common corridors	–	–
Garages, common for multiple units	–	–
Garages, separate for each dwelling	–	–
Kitchens	–	–
Living areas	Based upon number of bedrooms. First bedroom, 2; each additional bedroom, 1	–
Toilet rooms and	–	–

Occupancy Classification	Max. Occupant Load	
	People per 1,000 SF	SF/Person
bathrooms		
Public spaces		
Breakrooms	25	40
Corridors	–	–
Courtrooms	70	14
Elevator car	–	–
Legislative chambers	50	20
Libraries	10	100
Lobbies	150	6
Museums (children's)	40	25
Museums/galleries	40	25
Occupiable storage rooms for liquids or gels	2	500
Places of religious worship	120	8
Shower room (per shower head)	–	–
Smoking lounges	70	14
Toilet rooms—public	–	–
Retail Stores, Sales Floors, and Showroom Floors		
Dressing rooms	–	–
Mall common areas	40	25
Sales (except as below)	15	66
Shipping and receiving	–	–
Smoking lounges	70	14
Storage rooms	–	–
Warehouses (see storage)	–	–
Specialty Shops		

Occupancy Classification	Max. Occupant Load: People per 1,000 SF	Max. Occupant Load: SF/Person
Automotive motor-fuel dispensing stations	–	–
Barber	25	40
Beauty salons	25	40
Nail salons	25	40
Embalming rooms	–	–
Pet shops (animal areas)	10	100
Supermarkets	8	125
Sports and Amusement		
Bowling alleys (seating area)	40	25
Disco/dance floors	100	10
Game arcades	20	50
Gym, stadium (play area)	7	–
Health club/aerobics room	40	25
Health club/weight room	10	100
Ice arenas without combustion engines	–	–
Spectator areas	150	6
Swimming pools (pool and deck area)	–	–
Storage		
Repair garages, enclosed parking garages	–	–
Soiled laundry storage rooms	–	–
Storage rooms,	–	–

Occupancy Classification	Max. Occupant Load	
	People per 1,000 SF	SF/Person
Storage rooms, chemical		
Warehouses	–	–
Theaters		
Auditoriums (see education)	–	–
Lobbies	150	6
Stages, studios	70	14
Ticket booths	60	16
Transportation		
Platforms	100	10
Transportation waiting	100	10
Workrooms		
Bank vaults/safe deposit	5	200
Computer (without printing)	4	250
Copy, printing rooms	4	250
Darkrooms	–	–
Meat processing	10	100
Pharmacy (prep. area)	10	100
Photo studios	10	100

Part 11: Lighting Rules of Thumb

11. Part 11: Lighting Rules of Thumb

11.01. Code Lighting Power Level Requirements—Building Area Method

Building Area	Watts/Square Foot 2015 IECC and ASHRAE Std 90.1-2013
Auditorium	–
Automotive Facility	0.80
Bank/Financial Institution	–
Classroom/Lecture Hall	–
Convention Center	1.01
Corridor, Restroom, Support Area	–
Courthouse	1.01
Dining-Bar, Lounge Leisure	1.01
Dining-Cafeteria, Fast Food	0.90
Dining-Family	0.95
Dormitory	0.57
Exercise Center	0.84
Exhibition Hall	–

Building Area	Watts/Square Foot 2015 IECC and ASHRAE Std 90.1-2013
Grocery Store	–
Fire Station	0.67
Gymnasium	0.94
Healthcare Clinic	0.90
Hospital	1.05
Hotel/Motel	0.87
Industrial Work, <20' Ceiling Height	–
Industrial Work, ≥20' Ceiling Height	–
Kitchen	–
Library	1.19
Lobby–Hotel	–
Lobby–Other	–
Mall, Arcade, or Atrium	–
Multifamily	0.51
Manufacturing Facility	1.17
Museum	1.02
Office	0.82
Parking Garage	0.21
Penitentiary	0.81
Police Station	0.87
Post Office	0.87
Religious Building	1.00
Restaurant	–
Retail	1.26
School/University	0.87
Sports Arena	0.91
Storage, Industrial and Commercial	–
Theater-Motion Picture	0.76

Building Area	Watts/Square Foot 2015 IECC and ASHRAE Std 90.1-2013
Theater-Performance	1.39
Town Hall	0.89
Transportation	0.70
Warehouse	0.66
Workshop	1.19
Other	–

11.02. Code Lighting Power Level Requirements—Space-by-Space Method

Common Space Type		Watts/Square Foot 2015 IECC and ASHRAE Std 90.1-2013
Atrium		
	That is 40 feet or less in height	0.03/ft. total height
	That is greater than 40 feet in height	0.04 + 0.02/ft. total height
Audience Seating Area		
	In a Gymnasium	0.65
	In an Auditorium	0.63
	In a Convention Center	0.82
	In a Penitentiary	0.28
	In Religious Buildings	1.53
	In a Sports Arena	0.43
	In a Performing Arts Theater	2.43
	In a Motion Picture Theater	1.14
Notes:	All Other Audience Seating Areas	0.43

Common Space Type		Watts/Square Foot 2015 IECC and ASHRAE Std 90.1-2013
	Areas	
Automotive-Service Repair		0.67
Banking Activity Area		1.01
Classroom/Lecture/Training		
	In a Penitentiary	1.34
	All Other Classroom/Lecture/Training	1.24
Computer Rooms		1.71
Conference/Meeting/Multipurpose		1.23
Confinement Cells		-[a], 0.81[b]
Convention Center-Exhibit Space		1.45
Copy/Print Rooms		0.72
Corridor		
	In a Facility for the Visually Impaired	0.92
	In a Hospital	0.79[a], 0.99[b]
	In a Manufacturing Facility	0.41
	All Other Corridors	0.66
Courtroom		1.72
Dining Areas		
	In a Penitentiary	0.96
	In a Facility for the Visually Impaired	1.90[a], 2.65[b]
	In a Bar/Lounge/Leisure Dining	1.07
	In a Cafeteria or Fast Food Dining	0.65
	In Family Dining	0.89
	All Other Dining Areas	0.65
Dormitory-Living Quarters		0.38

Notes:

Common Space Type		Watts/Square Foot 2015 IECC and ASHRAE Std 90.1-2013
Dormitory-Living Quarters		0.38
Dressing Rooms for Performing Arts Theater		0.61
Electrical/Mechanical Rooms		0.95[a], 0.42[b]
Emergency Vehicle Garage		0.56
Facility for the Visually Impaired		
	In a Chapel	2.21
	In a Recreation Room/Common Living Room	2.41
Fire Station-Sleeping Quarters		0.22
Food Preparation		1.21
Guest Rooms		0.47[a], 0.91[b]
Gymnasium/Fitness Centers		
	In an Exercise Area	0.72
	In a Playing Area	1.20
Healthcare Facility		
	In an Exam/Treatment Room	1.66
	In an Imaging Room	1.51
	In a Medical Supply Room	0.74
	In a Nursery	0.88
	In a Nurse's Station	0.71
	In an Operating Room	2.48
	In a Patient Room	0.62
	In a Physical Therapy Room	0.91
	In a Recovery Room	1.15
Laboratory		
	In or as a classroom	1.43
	All Other Laboratories	1.81
Laundry/Washing Area		0.60

Common Space Type		Watts/Square Foot 2015 IECC and ASHRAE Std 90.1-2013
Library		
	In Reading Area	1.06
	In the Stacks	1.71
Loading Dock, Interior		0.47
Lobby		
	In a Facility for the Visually Impaired	1.80
	For an Elevator	0.64
	In a Hotel	1.06
	In a Motion Picture Theater	0.59
	In a Performing Arts Theater	2.00
	All Other Lobbies	0.90
Locker Room		0.75
Lounge/Breakroom		
	In a Healthcare Facility	0.92
	All Other Lounges/Breakrooms	0.73
Manufacturing Facility		
	In a Detailed Manufacturing Area	1.29
	In an Equipment Room	0.74
	In an Extra High Bay Area (>50 feet Floor-to-Ceiling Height)	1.05
	In a High Bay Area (25–50 feet Floor-to-Ceiling Height)	1.23
	In a Low Bay Area (<25 feet Floor-to-Ceiling Height)	1.19
Museum		
	In a General Exhibition Area	1.05
Notes:	In a Restoration Area	1.02

Common Space Type		Watts/Square Foot 2015 IECC and ASHRAE Std 90.1-2013
Office		
	Enclosed	1.11
	Open Plan	0.98
Parking Area, Interior		0.19
Pharmacy Area		1.68
Post Office-Sorting Area		0.94
Religious Buildings		
	In a Fellowship Hall	0.64
	In a Worship/Pulpit/Choir Area	1.53
	Fellowship Hall	0.9
Restrooms		
	In a Facility for the Visually Impaired	1.21
	All Other Restrooms	0.98
Retail Facilities		
	In a Sales Area	1.59[a], 1.44[b]
	In a Dressing/Fitting Room	0.71
	In a Mall Concourse	1.10
Seating Area, General		0.54
Sports Arena		
	For a Class I Facility	3.68
	For a Class II Facility	2.40
	For a Class III Facility	1.80
	For a Class IV Facility	1.20
Stairwell		0.69
Storage Room		0.63[a]
	< 50 ft^2	1.24[b]
Notes:	All Other Storage Rooms	0.63[b]

Common Space Type		Watts/Square Foot 2015 IECC and ASHRAE Std 90.1-2013
Transportation Facility		
	In a Baggage/Carousel Area	0.53
	In an Airport Concourse	0.36
	At a Terminal Ticket Counter	0.80
Warehouse		
	For Medium to Bulky, Palletized Items	0.58
	For Smaller, Hand-Carried Items	0.95
Workshop		1.59

Notes:

a. 2015 IECC.

b. ASHRAE Standard 90.1-2013.

Part 12: Appliance/Equipment Rules of Thumb

12. Part 12: Appliance/Equipment Rules of Thumb

12.01. Offices and Commercial Spaces

A. **Total Appliance/Equipment Heat Gain 0.5–8.0 watt/sq.ft.**

B. **Computer equipment loads for office spaces range between 0.5 watt/sq.ft. and 3.5 watts/sq.ft. (2.0 watts/sq.ft. is recommended). If actual computer equipment loads are available, they should be used in lieu of the values listed here.**

C. **Depending on the facility, the appliance/equipment diversity factors can range from 25 to 75 percent (recommend diversities of 50 percent are recommended).**

12.02. Computer Rooms, Data Centers, and Internet Host Sites

A. 2.0–500.0 watts/sq.ft. (Recommend 300 watts/sq.ft. Minimum)

12.03. Telecommunication Rooms

A. 50.0–120.0 watts/sq.ft.

12.04. Electrical Equipment Heat Gain

A. Transformers

1. 150 KVA and smaller	50 watts/KVA
2. 151–500 KVA	30 watts/KVA
3. 501–1000 KVA	25 watts/KVA
4. 1001–2500 KVA	20 watts/KVA
5. Larger than 2500 KVA	15 watts/KVA

B. Switchgear

1. Low voltage breaker 0–40 amps	10 watts
2. Low voltage breaker 50–100 amps	20 watts
3. Low voltage breaker 225 amps	60 watts
4. Low voltage breaker 400 amps	100 watts
5. Low voltage breaker 600 amps	130 watts
6. Low voltage breaker 800 amps	170 watts
7. Low voltage breaker 1,600 amps	460 watts
8. Low voltage breaker 2,000 amps	600 watts
9. Low voltage breaker 3,000 amps	1,100 watts
10. Low voltage breaker 4,000 amps	1,500 watts
11. Medium voltage breaker/switch 600 amps	1,000 watts
12. Medium voltage breaker/switch 1,200 amps	1,500 watts
13. Medium voltage breaker/switch 2,000 amps	2,000 watts
14. Medium voltage breaker/switch 3,000 amps	2,500 watts

C. Panelboards

1. 2 watts per circuit.

D. Motor Control Centers

1. 500 watts per section—each section is approximately 20" wide × 20" deep × 84" high

E. Starters

1. Low voltage starters size 00	50 watts
2. Low voltage starters size 0	50 watts
3. Low voltage starters size 1	50 watts
4. Low voltage starters size 2	100 watts
5. Low voltage starters size 3	130 watts
6. Low voltage starters size 4	200 watts
7. Low voltage starters size 5	300 watts
8. Low voltage starters size 6	650 watts
9. Medium voltage starters size 200 amps	400 watts
10. Medium voltage starters size 400 amps	1,300 watts
11. Medium voltage starters size 700 amps	1,700 watts

F. Variable Frequency Drives

1. 2–6% of the KVA rating: 3% is most common

G. Miscellaneous Equipment

1. Bus duct	0.015 watts/ft./amp
2. Capacitors	2 watts/KVAR

Notes:

1. Actual electrical equipment heat gain values will vary from one manufacturer to another—use actual values when available.

2. In the past, electrical equipment rooms only required ventilation to keep equipment from overheating. Most electrical rooms were designed for 95°F to 104°F, although electrical equipment used today may require a maximum design temperature of 90°F because of electronic components and controls. Consult your electrical engineer for equipment temperature tolerances. If space temperatures below 90°F are required by the equipment, the air conditioning (tempering) of space will be required.

3. If outside air is used to ventilate the electrical room, the electrical room design temperature will be 10°F to 15°F above outside summer design temperatures.

4. If conditioned air from an adjacent space is used to ventilate the electrical room, the electrical room temperature can be 10°F to 20°F above the adjacent spaces.

5. Elevator machine rooms require 90°F space temperature (maximum) due to electronic components of elevator equipment. Therefore, elevator machine rooms must be air conditioned (tempered).

12.05. Motor Heat Gain

A. Motors Only

1. Motors 0–2 hp	190 watts/hp
2. Motors 3–20 hp	110 watts/hp
3. Motors 25–200 hp	75 watts/hp
4. Motors 250 hp and Larger	60 watts/hp

Motors and driven equipment are shown in the following table:

Motor Horsepower	The Location of Motor and Driven Equipment with Respect to a Conditioned Space or Airstream		
	Motor In, Driven Equipment In Btu/h	Motor Out, Driven Equipment In Btu/h	Motor In, Driven Equipment Out Btu/h
1/20	360	130	240
1/12	580	200	380
1/8	900	320	590
1/6	1,160	400	760
1/4	1,180	640	540
1/3	1,500	840	660
1/2	2,120	1,270	850
3/4	2,650	1,900	740
1	3,390	2,550	850
1-½	4,960	3,820	1,140
2	6,440	5,090	1,350
3	9,430	7,640	1,790
5	15,500	12,700	2,790
7-½	22,700	19,100	3,640
10	29,900	24,500	4,490
15	44,400	38,200	6,210
20	58,500	50,900	7,610
25	72,300	63,600	8,680
30	85,700	76,300	9,440
40	114,000	102,000	12,600
50	143,000	127,000	15,700
60	172,000	153,000	18,900
75	212,000	191,000	21,200
100	283,000	255,000	28,300
125	353,000	318,000	35,300
150	420,000	382,000	37,800
200	569,000	509,000	50,300
250	699,000	636,000	62,900

12.06. Miscellaneous Guidelines

A. **Actual equipment layouts and information should be used for calculating equipment loads.**

B. **Movie projectors, slide projectors, overhead projectors, and similar types of equipment can generally be ignored because lights are off when being used and the lighting load will normally be larger than this equipment heat gain.**

C. **Items such as coffee pots, microwave ovens, refrigerators, food warmers, etc., should be considered when calculating equipment loads.**

D. **Kitchen, laboratory, hospital, computer room, and process equipment should be obtained from the owner, architect, engineer, or consultant due to the extreme variability of equipment loads.**

Part 13: Cooling Load Factors

13. Part 13: Cooling Load Factors

13.01. Diversity Factors

A. *Diversity factors* are an engineer's judgment applied to various people, lighting, equipment, and total loads to consider actual usage. Actual diversities may vary depending on building type and occupancy. Diversities listed here are for office buildings and similar facilities.

B. Room/Space Peak Loads

1. People	1.0 × Calculated Load.
2. Lights	1.0 × Calculated Load.
3. Equipment	1.0 × Calculated Load.[a]

[a]Calculated Load may have a diversity factor that has been calculated using individual pieces of equipment, equipment as a group, or incorporating no equipment at all.

C. Floor/Zone Block Loads

1. People	0.90 × Sum of Peak Room/Space People Loads.
2. Lights	0.95 × Sum of Peak Room/Space Lighting Loads.
3. Equipment	0.90 × Sum of Peak Room/Space Equipment Loads.
4. Floor/Zone Total Loads	0.90 × Sum of Peak Room/Space Total Loads.

D. Building Block Loads

1. People	0.75 × Sum of Peak Room/Space People Loads.
2. Lighting	0.95 × Sum of Peak Room/Space Lighting Loads.
3. Equipment	0.75 × Sum of Peak Room/Space Equipment Loads.
4. Building Total Load	0.85 × Sum of Peak Room/Space Total Loads.

13.02. Safety Factors

A. Room/Space Peak Loads	**1.1 × Calc. Load.**
B. Floor/Zone Loads (Sum of Peak)	**1.0 × Calc. Load.**
C. Floor/Zone Loads (Block)	**1.1 × Calc. Load.**
D. Building Loads (Sum of Peak)	**1.0 × Calc. Load.**
E. Building Loads (Block)	**1.1 × Calc. Load.**

13.03. Cooling Load Factors

A. Lighting Load Factors

1. Existing lighting fixtures

a. Fluorescent lights	1.25 × Bulb Watts.
b. Incandescent lights	1.00 × Bulb Watts.
c. HID lighting	1.25 × Bulb Watts.

2. New lighting fixtures

a. Fluorescent lights	0.85–1.15 × Bulb Watts.
b. Incandescent lights	1.00 × Bulb Watts.
c. HID lighting	0.85–1.15 × Bulb Watts.
d. Electronic ballasts have provided better energy performance. Electronic ballast factors are very dependent on the manufacturer, type of lighting fixture, and type of lamp. Consult electrical engineer for exact lighting watts required for fixtures.	

B. Return Air Plenum (RAP) Factors

1. Heat of lights to space with RAP	0.76 × Lighting Load.
2. Heat of lights to RAP	0.24 × Lighting Load.
3. Heat of roof to space with RAP	0.30 × Roof Load.
4. Heat of roof to RAP	0.70 × Roof Load.

D. Ducted Exhaust or Return Air (DERA) Factors

1. Heat of lights to space with DERA	1.00 × Lighting Load.
2. Heat of roof to space with DERA	1.00 × Roof Load.

C. Other Cooling Load Factors (CLFs) are in accordance with ASHRAE recommendations.

1. CLF × Other Loads.

Citation

EXPORT

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. Part 13: Cooling Load Factors, Chapter (McGraw-Hill Professional, 2016), AccessEngineering

Part 14: Heating Load Factors

14. Part 14: Heating Load Factors

14.01. Safety Factors

A. Room/Space Peak Loads	**1.1 × Calc. Load**
B. Floor/Zone Loads (Sum of Peak)	**1.0 × Calc. Load**
C. Floor/Zone Loads (Block)	**1.1 × Calc. Load**
D. Building Loads (Sum of Peak)	**1.0 × Calc. Load**
E. Building Loads (Block)	**1.1 × Calc. Load**
F. Generally: Sum of Peak Loads	**1.1 × Block Loads**

14.02. Heating Load Credits

A. **Solar. Credit for solar gains should not be taken unless the building is specifically designed for solar heating. Solar gain is not a factor at night when design temperatures generally reach their lowest point.**

B. **People. Credit for people should not be taken. People gain is not a factor at night when design temperatures generally reach their lowest point because buildings are generally unoccupied at night.**

C. **Lighting. Credit for lighting should not be taken. Lighting is an inefficient means to heat a building and lights are generally off at night when design temperatures generally reach their lowest point.**

D. **Equipment. Credit for equipment should not be taken unless a reliable source of heat is generated 24 hours a day (e.g., computer facility, industrial process). Only a portion of this load should be considered (50 percent) and the building heating system should be able to keep the building from freezing if these equipment loads are shut down for extended periods of time. Consider what would happen if the system or process shut down for extended periods of time.**

14.03. Heating System Selection Guidelines

A. **If heat loss exceeds 450 Btu/h per lineal feet of wall, heat should be provided from under the window or from the base of the wall to prevent downdrafts.**

B. **If heat loss is between 250 and 450 Btu/h per lineal feet of wall, heat should be provided from under the window or from the base of the wall, or it may be provided from overhead diffusers, located adjacent to the perimeter wall, discharging air directly downward, and blanketing the exposed wall and window areas.**

C. **If heat loss is less than 250 Btu/h per lineal feet of wall, heat should be provided from under the window or from the base of the wall, or it may be provided from overhead diffusers, located adjacent to or slightly away from the perimeter wall, discharging air directed at, or both directed at and directed away from, the exposed wall and window areas.**

Part 15: Design Conditions and Energy Conservation

15. Part 15: Design Conditions and Energy Conservation

15.01. Design Conditions

A. Outside Design Conditions

1. Outdoor design conditions should be taken from either the *ASHRAE Handbook of Fundamentals*, local weather data, or some other recognized source.

2. ASHRAE summer design conditions are based on the following:
   a. Total yearly hours: 8,760 hours.

   b. Annual extreme values represent maximum summer design conditions.

   c. 0.4 percent design values represent summer design conditions that, on average, are exceeded fewer than 35 hours annually above stated conditions.

   d. 1.0 percent design values represent summer design conditions that, on average, are exceeded fewer than 88 hours annually above stated conditions.

   e. 2.0 percent design values represent summer design conditions that, on average, are exceeded fewer than 175 hours annually above stated conditions.

   f. 5.0 percent design values represent summer design conditions that, on average, are exceeded fewer than 438 hours annually above stated conditions.

3. ASHRAE winter design conditions are based on the following:
   a. Total yearly hours: 8,760 hours.

   b. Annual extreme values represent maximum winter design conditions.

   c. 99.6 percent design values represent winter design conditions that, on average, are exceeded fewer than 35 hours annually below stated conditions.

   d. 99.0 percent design values represent winter design conditions that, on average, are exceeded fewer than 88 hours annually below stated conditions.

4. Outside design condition example: Ambient weather conditions are based on Pittsburgh (Allegheny County Airport), Pennsylvania weather data from the American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc. (ASHRAE) *Handbook of Fundamentals, 2005 Edition* (see Fig. 15.1).

Design conditions for PITTSBURGH, PA, USA

Station Information

Station name	WMO#	Lat	Long	Elev	StdP	Hours +/- UTC	Time zone code	Period
1a	*1b*	*1c*	*1d*	*1e*	*1f*	*1g*	*1h*	*1i*
PITTSBURGH	**725200**	**40.50N**	**80.22W**	**1224**	**14.058**	**-5.00**	**NAE**	**7201**

Annual Heating and Humidification Design Conditions

Coldest month	Heating DB		Humidification DP/MCDB and HR						Coldest month WS/MCDB				MCWS/PCWD to 99.6% DB	
			99.6%			99%			0.4%		1%			
	99.6%	99%	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS	MCDB	MCWS	PCWD
2	*3a*	*3b*	*4a*	*4b*	*4c*	*4d*	*4e*	*4f*	*5a*	*5b*	*5c*	*5d*	*6a*	*6b*
1	**1.8**	**7.5**	**-7.1**	**3.9**	**4.3**	**-2.3**	**5.1**	**9.7**	**28.5**	**25.6**	**25.9**	**24.6**	**9.6**	**260**

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

Hottest month	Hottest month DB range	Cooling DB/MCWB						Evaporation WB/MCDB						MCWS/PCWD to 0.4% DB	
		0.4%		1%		2%		0.4%		1%		2%			
		DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	WB	MCDB	MCWS	PCWD
7	*8*	*9a*	*9b*	*9c*	*9d*	*9e*	*9f*	*10a*	*10b*	*10c*	*10d*	*10e*	*10f*	*11a*	*11b*
7	**18.9**	**89.1**	**72.5**	**86.2**	**70.9**	**83.8**	**69.3**	**74.9**	**85.0**	**73.3**	**82.5**	**71.9**	**80.3**	**10.3**	**240**

Dehumidification DP/MCDB and HR									Enthalpy/MCDB					
0.4%			1%			2%			0.4%		1%		2%	
DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB
12a	*12b*	*12c*	*12d*	*12e*	*12f*	*12g*	*12h*	*12i*	*13a*	*13b*	*13c*	*13d*	*13e*	*13f*
71.8	**123.0**	**80.1**	**70.3**	**116.9**	**78.2**	**69.0**	**111.6**	**76.8**	**31.5**	**85.1**	**30.0**	**82.7**	**28.7**	**80.5**

Extreme Annual Design Conditions

Extreme Annual WS			Extreme Max WB	Extreme Annual DB				n-Year Return Period Values of Extreme DB							
				Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years	
1%	2.5%	5%		Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
14a	*14b*	*14c*	*15*	*16a*	*16b*	*16c*	*16d*	*17a*	*17b*	*17c*	*17d*	*17e*	*17f*	*17g*	*17h*
23.5	**19.8**	**17.9**	**81.3**	**92.6**	**-4.6**	**3.5**	**7.9**	**95.1**	**-10.3**	**97.2**	**-14.9**	**99.1**	**-19.3**	**101.7**	**-25.1**

Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures

%	Jan		Feb		Mar		Apr		May		Jun	
	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB
	18a	*18b*	*18c*	*18d*	*18e*	*18f*	*18g*	*18h*	*18i*	*18j*	*18k*	*18l*
0.4%	**61.9**	**55.8**	**64.5**	**53.3**	**76.4**	**58.8**	**82.1**	**61.8**	**85.9**	**68.3**	**90.5**	**72.2**
1%	**58.0**	**52.8**	**61.6**	**52.4**	**73.0**	**56.7**	**79.9**	**61.4**	**84.2**	**66.8**	**88.2**	**71.1**
2%	**55.1**	**50.4**	**58.1**	**49.1**	**70.0**	**55.6**	**77.1**	**60.3**	**82.4**	**65.6**	**86.4**	**70.4**

%	Jul		Aug		Sep		Oct		Nov		Dec	
	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB
	18m	*18n*	*18o*	*18p*	*18q*	*18r*	*18s*	*18t*	*18u*	*18v*	*18w*	*18x*
0.4%	**93.4**	**74.1**	**92.4**	**73.6**	**87.2**	**70.4**	**77.9**	**64.0**	**71.5**	**59.5**	**63.9**	**56.4**
1%	**91.4**	**73.5**	**90.2**	**73.4**	**85.1**	**70.1**	**76.1**	**62.8**	**69.1**	**58.2**	**61.2**	**54.5**
2%	**89.5**	**73.1**	**88.0**	**72.3**	**83.0**	**68.8**	**74.1**	**61.4**	**66.6**	**56.5**	**58.7**	**53.2**

Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures

%	Jan		Feb		Mar		Apr		May		Jun	
	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB
	19a	*19b*	*19c*	*19d*	*19e*	*19f*	*19g*	*19h*	*19i*	*19j*	*19k*	*19l*
0.4%	**56.4**	**60.8**	**56.0**	**62.5**	**61.2**	**72.0**	**65.2**	**76.3**	**71.9**	**81.5**	**75.3**	**86.1**
1%	**54.0**	**57.4**	**53.4**	**58.8**	**59.4**	**68.2**	**63.7**	**75.1**	**70.6**	**80.0**	**74.2**	**84.6**
2%	**50.9**	**55.1**	**51.1**	**55.9**	**57.3**	**66.3**	**62.2**	**73.5**	**68.9**	**78.4**	**73.2**	**83.1**

%	Jul		Aug		Sep		Oct		Nov		Dec	
	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB
	19m	*19n*	*19o*	*19p*	*19q*	*19r*	*19s*	*19t*	*19u*	*19v*	*19w*	*19x*
0.4%	**77.3**	**88.5**	**77.0**	**87.8**	**74.0**	**82.9**	**66.9**	**73.6**	**61.8**	**67.7**	**58.4**	**62.1**
1%	**76.2**	**86.9**	**75.6**	**85.9**	**72.9**	**81.0**	**65.4**	**72.2**	**60.3**	**66.1**	**56.7**	**60.3**
2%	**75.2**	**85.4**	**74.5**	**83.9**	**71.5**	**78.9**	**64.0**	**70.6**	**59.0**	**64.7**	**54.2**	**57.6**

Monthly Mean Daily Temperature Range

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
20a	*20b*	*20c*	*20d*	*20e*	*20f*	*20g*	*20h*	*20i*	*20j*	*20k*	*20l*
14.1	**15.6**	**18.2**	**20.3**	**20.3**	**19.9**	**18.9**	**18.7**	**19.0**	**18.8**	**15.4**	**13.5**

WMO#	World Meteorological Organization number	Lat	Latitude, °	Long	Longitude, °
Elev	Elevation, ft	StdP	Standard pressure at station elevation, psi		
DB	Dry bulb temperature, °F	DP	Dew point temperature, °F	WB	Wet bulb temperature, °F
WS	Wind speed, mph	Enth	Enthalpy, Btu/lb	HR	Humidity ratio, grains of moisture per lb of dry air
MCDB	Mean coincident dry bulb temperature, °F	MCDP	Mean coincident dew point temperature, °F	MCWB	Mean coincident wet bulb temperature, °F
MCWS	Mean coincident wind speed, mph	PCWD	Prevailing coincident wind direction, °, 0 = North, 90 = East		

Figure 15.1.

a. Abbreviations:

1. db = dry bulb temperature.
2. wb = wet bulb temperature.

3. dp = dewpoint temperature.

b. Pittsburgh, PA summer design conditions:
   1. Average annual extreme value: 92.6°F db/81.3°F wb.
   2. Annual extreme value (20 years): 99.1°F db/81.3°F wb.
   3. 0.4% values: 89.1°F db/74.9°F wb.
   4. 1.0% values: 86.2°F db/73.3°F wb.
   5. 2.0% values: 83.8°F db/71.9°F wb.

c. Pittsburgh, PA winter design conditions:
   1. Average annual extreme value: –4.6°F db.
   2. Annual extreme value (20 years): –19.3°F db.
   3. 99.6% values: 1.8°F db/–7.1°F dp.
   4. 99.0% values: 7.5°F db/–2.3°F dp.

5. Recommended outside design conditions values:
   a. General facilities and spaces—office buildings, schools, commercial and industrial facilities, other noncritical temperature and humidity control facilities:
      1. Summer: 1.0% values.
      2. Winter: 99.0% values.
   b. Semicritical facilities and spaces—hospitals, medical facilities, laboratories, other semicritical temperature and humidity control facilities:
      1. Summer: 0.4% values.
      2. Winter: 99.6% values.
   c. Critical facilities and spaces—laboratories, computer facilities, high-tech industrial, other critical temperature and humidity control facilities:
      1. Summer: 0.4% values.
      2. Winter: 99.6% values.
      3. Annual extreme values may even be appropriate here.
   d. Mechanical equipment rooms, electrical equipment rooms, and similar

spaces:

1. Summer: 2.0% values.
2. Winter: 99.0% values.

B. Indoor Design Conditions

INDOOR DESIGN CONDITIONS

Facility Type/Spaces (1)	Cooling		Hea
	Temperature °F Dry Bulb	Humidity %RH	Temperatu °F Dry Bul
Office Buildings, Commercial Facilities			
Offices	75	50	70
Conference Rooms, Meeting Rooms, Classrooms, Training Rooms	75	50	70
Reception Areas, Lobbies, Corridors	75	50	70
Network Computer Rooms	72 ± 2	–	72 ± 2
Telecommunication Areas/Data Entry	75	50	70
General Spaces			
Mechanical/Electrical/Equip. Rooms	85–90	–	60
Elevator Machine Rooms	85–90	–	65
Telecommunication Rooms	72 ± 2	–	72 ± 2
Toilet Rooms, Locker Rooms, Shower Rooms	78	50	70
Janitor Closets, Housekeeping	85	–	60
Lobbies, Corridors, Elevator Lobbies, Atriums	75	50	70
Vestibules, Entrances, Stairs	–	–	60
Stairs on Perimeter of Building or w/Glass	80	–	60
Storage	78	50	70

Notes:

Facility Type/Spaces (1)	Cooling		Hea
	Temperature °F Dry Bulb	Humidity %RH	Temperatu °F Dry Bul
Storage	75	50	70
Garages—Open	–	–	–
Garages—Enclosed	–	–	50 (9)
Educational Facilities			
Auditoriums, Gymnasiums, Multipurpose Rooms	75	50	70
Classrooms, Lecture Halls	75	50	70
Laboratories—High School (4)	75	50	70
Laboratories—College or University (4)	75 ± 2	45 ± 5	72 ± 2
Libraries	75	50	70
Music Rooms, Art Rooms	75	50	70
Training Shops	75	50	70
Food and Beverage Service			
Restaurants, Dining Rooms, Bars, Lounges, Cocktail Lounges	75	50	70
Cafeteria, Fast Food	75	50	70
Kitchens, Dishwashing	80	–	68
Hotels, Motels, Resorts, and Dormitories			
Conference Rooms, Meeting Rooms, Ballrooms	75	50	70
Bedrooms, Bathrooms	75	50	70
Dormitory Sleeping Areas	75	50	70
Living Rooms, Dining Rooms	75	50	70
Gambling Casinos, Gaming Rooms	75	50	70
Correctional Facilities			
Prison Cells	75	50	70
Dining Halls, Day Rooms	75	50	70
Guard Stations	75	50	70
Retail Stores and Specialty Shops			

Notes:

Facility Type/Spaces (1)	Cooling		Hea
	Temperature °F Dry Bulb	Humidity %RH	Temperatu °F Dry Bul
Retail Stores and Specialty Shops			
Malls and Arcades	75	50	70
Department Stores, Supermarkets, Showroom Floors, Clothiers, Furniture	75	50	70
Dressing Rooms	75	50	70
Shipping and Receiving	–	–	60
Storage Rooms	78	50	70
Warehouses (7)	78	50	70
Barber Shop, Beauty Shop, Nail Salons	75	50	70
Hardware, Drug Stores, Fabric Stores, Specialty Stores	75	50	70
Pet Stores	75	50	70
Automobile Showrooms	75	50	70
Theaters			
Auditoriums, Concert Halls, Performing Arts Centers—Seating Area (5)	75	50	70
Stages, Performing Arts Studios—Performance Areas (5)	72 ± 2	40 ± 5	72 ± 2
3D Theaters (6)	72	50	70
Lobbies, Ticket Booths, On-Call Windows	75	50	70
Sports and Entertainment			
Ballrooms, Disco, Dance Establishments	75	50	70
Bowling Alleys, Game Rooms, Arcades	75	50	70
Firing Ranges	75	50	70
Gymnasiums, Playing Floors	75	50	65

Notes:

Facility Type/Spaces (1)	Cooling Temperature °F Dry Bulb	Humidity %RH	He Temperatu °F Dry Bul
Swimming Pools, Natatoriums	75	50	70
Spectator Areas	75	50	70
Transportation			
Bus Stations, Airports	75	50	70
Waiting Areas	75	50	70
Storage Facilities			
Repair Garages (8)	–	–	65
Warehouses (7)	78	50	70
Workrooms			
Bank Vaults	75	50	70
Darkrooms	75	50	70
Duplicating, Printing	75	50	70
Pharmacy	75	50	70
Photo Studios	75	50	70
Private Dwelling—Single and Multiple			
Living Rooms, Dining Rooms, Bedrooms, Kitchens	75	50	70
Toilet Rooms, Bathrooms	78	50	70
Garages	–	–	50 (9)
Laboratories, Computer Facilities, High-Tech Industrial, Special Facilities (4)			
Laboratories—Research	72 ± 2	45 ± 5	72 ± 2
Computer Rooms, Data Centers, Internet Host Sites, Server Rooms, Demarc Rooms	70 ± 2	45 ± 5	70 ± 2
High Tech	68 ± 2	45 ± 5	68 ± 2
High Tech (low humidity)	68 ± 2	35 ± 5	68 ± 2
Animal Research Rooms	68–84 ± 2	40–70 ± 5	68–84 ± 2
Museums, Galleries, Rare Document Libraries, Archives	72 ± 2	40 ± 5	72 ± 2

Notes:

Facility Type/Spaces (1)	Cooling		Hea
	Temperature °F Dry Bulb	Humidity %RH	Temperatu °F Dry Bul
Surgical and Critical Care (2)			
Operating room (Class B and C)	75	max 60	68
Operating/surgical cystoscopic rooms	75	max 60	68
Delivery room (Caesarean)	75	max 60	68
Substerile service area	–	–	–
Recovery room	75	max 60	70
Critical and intensive care	75	max 60	70
Intermediate care	75	max 60	70
Wound intensive care (burn unit)	75	max 60	70
Newborn intensive care	78	max 60	72
Treatment room	75	max 60	70
Trauma room (crisis or shock)	75	max 60	70
Medical/anesthesia gas storage	–	–	–
Laser eye room	75	max 60	70
ER waiting rooms	75	max 65	70
Triage	75	max 60	70
ER decontamination	75	–	–
Radiology waiting rooms	75	max 60	70
Procedure room (Class A surgery)	75	max 60	70
Emergency department exam/treatment room	75	max 60	70
Inpatient Nursing			
Patient room	75	max 60	70
Nourishment area or room	–	–	–
Toilet room	–	–	–
Newborn nursery suite	78	max 60	72
Protective environment room	75	max 60	70

Facility Type/Spaces (1)	Cooling Temperature °F Dry Bulb	Humidity % RH	Hea Temperatu °F Dry Bul
Airborne Infectious Isolation (AII) room	75	max 60	70
Combination AII/Protective Environment (PE) room	75	max 60	70
AII anteroom	–	–	–
PE anteroom	–	–	–
Combination AII/PE anteroom	–	–	–
Labor/delivery/recovery/postpartum (LDRP)	75	max 60	70
Labor/delivery/recovery (LDR)	75	max 60	70
Patient Corridor	–	–	–
Nursing Facility			
Resident room	75	–	70
Resident gathering/activity/dining	75	–	70
Resident unit corridor	–	–	–
Physical therapy	75	–	70
Occupational therapy	75	–	70
Bathing room	75	–	70
Radiology			
X-ray (diagnostic and treatment)	78	max 60	72
X-ray (surgery/critical care and catheterization)	75	max 60	70
Darkroom	–	–	–
Diagnostic and Treatment			
Bronchoscopy, sputum collection, and pentamidine administration	73	–	68
Laboratory, general	75	–	70
Laboratory, bacteriology	75	–	70
Laboratory, biochemistry	75	–	70

Facility Type/Spaces (1)	Cooling		Hea
	Temperature °F Dry Bulb	Humidity %RH	Temperatu °F Dry Bul
Laboratory, cytology	75	–	70
Laboratory, glass washing	–	–	–
Laboratory, histology	75	–	70
Laboratory, microbiology	75	–	70
Laboratory, nuclear medicine	75	–	70
Laboratory, pathology	75	–	70
Laboratory, serology	75	–	70
Laboratory, sterilizing	75	–	70
Laboratory, media transfer	75	–	70
Nonrefrigerated body-holding room	75	–	70
Autopsy room	75	–	68
Pharmacy	–	–	–
Examination room	75	max 60	70
Medication room	75	max 60	70
Gastrointestinal endoscopy procedure room	73	max 60	68
Endoscope cleaning	–	–	–
Treatment room	75	max 60	70
Hydrotherapy	80	–	72
Physical therapy	80	max 65	72
Dialysis treatment area	78	–	72
Dialyzer reprocessing room	–	–	–
Nuclear medicine hot lab	75	–	70
Nuclear medicine treatment room	75	–	70
Sterilizing			
Sterilizer equipment room	–	–	–
Central Medical and Surgical Supply			
Soiled or decontamination room	78	–	72

Facility Type/Spaces (1)	Cooling Temperature °F Dry Bulb	Humidity %RH	Hea Temperatu °F Dry Bul
Clean workroom	78	max 60	72
Sterile storage	78	max 60	72
Service			
Food preparation center	78	–	72
Warewashing	–	–	–
Dietary storage	78	–	72
Laundry, general	–	–	–
Soiled linen sorting and storage	–	–	–
Clean linen storage	78	–	72
Linen and trash chute room	–	–	–
Bedpan room	–	–	–
Bathroom	78	–	72
Janitor's closet	–	–	–
Support Space			
Soiled workroom or soiled holding	–	–	–
Clean workroom or clean holding	–	–	–
Hazardous material storage	–	–	–

Notes:

1. **Indoor design conditions are recommendations that may be used whe the facility used have no specific criteria. When codes, processes, or require different design conditions than those listed here, they shoul design purposes.**

2. **ASHRAE Standard 170-2013 *Ventilation of Health Care Facilities* (inco Part 4 of the 2014 Facility Guidelines Institute *Guidelines for Design a Construction of Hospitals and Outpatient Facilities*) provides ranges f spaces. The systems shall be capable of maintaining the rooms withir temperature and relative humidity ranges listed in the table during n operation. Some specialty procedures may require special temperatu relative humidity levels. The hospital staff should be consulted to det special requirements.**

Facility Type/Spaces (1)	Cooling		Hea
	Temperature	Humidity	Temperatu
	°F Dry Bulb	%RH	°F Dry Bul

3. **Surgeons or procedures may require room temperatures and relative that exceed the minimum indicated ranges.**

4. **With laboratories, computer facilities, high-tech industrial, special fa museums, and other spaces requiring critical temperature and relativ control, the owners and their staff should be consulted to verify the s requirements. Requirements provided here are for general guidance o**

5. **Some performances will require strict temperature and relative humi during the performance. Careful consideration must be given to the ty performances and their requirements when designing these facilities.**

6. **3D type theaters (IMAX and OMNIMAX) should be maintained at temp or below 72°F because the incidents of motion sickness increase cons above these temperatures.**

7. **Warehouse temperature and relative humidity requirements can vary considerably depending on the materials being stored.**

8. **Repair garages are generally not air conditioned. If air conditioning is cooling design temperature recommendation would be 80 to 85°F.**

9. **Heating parking garages is not recommended because minimum-code ventilation rates require heating of the makeup air for the heating to effective.**

15.02. General Energy Conservation Requirements

A. **The major energy codes referenced by the 2015 International Building Code (2015 IBC) and the 2015 International Mechanical Code (2015 IMC) are:**

1. 2015 International Energy Conservation Code (2015 IECC is based on and references ASHRAE Standard 90.1-2013).

2. ASHRAE Standard 90.1-2013.

B. **ASHRAE Standard 90.1-2013 requires glazing systems to be certified in accordance with National Fenestration Rating Council (NFRC) Standards 100, 200, 300, and 400 and tested by a laboratory accredited by a nationally recognized accreditation organization for**

the following:

1. Air leakage.

2. U-values.

3. Emissivity coatings.

4. Solar Heat Gain Coefficients (SHGCs).

5. Shading Coefficients (SCs).

6. Visible Light Transmittance (VT).

7. Condensation Resistance Ratings (CRs).

C. **National Fenestration Rating Council Product Certification Program (NFRC 700-2015)**

1. Paragraph 4 reads " … products may be authorized for certification only if they have been rated in accordance with NFRC-approved procedures, computer programs, and test methods."

2. Paragraph 4.3.2 reads "Product Evaluation. A Licensee shall obtain from an NFRC-accredited laboratory NFRC required ratings for each product to be authorized for certification."

3. Paragraph 4.3.2.1 reads "Valid Computational Procedure."
   a. Paragraph 4.3.2.1.A reads "This procedure is used for obtaining U-factor ratings. The licensee shall obtain a simulation report from an NFRC-accredited simulation laboratory for each product line to be authorized for certification."

   b. Paragraph 4.3.2.1.B reads "The licensee shall then obtain a physical test report from an NFRC-accredited test laboratory. The test report shall contain the test results of the baseline product (the representative product of the product line) chosen by the licensee in order to validate the simulations conducted for the product line."

4. Paragraph 4.3.2.2 reads "Computational Procedure. This procedure is used for obtaining SHGC, VT, and Condensation Resistance ratings. Under this procedure, the licensee shall obtain a simulation report from an NFRC-accredited simulation laboratory for each product line to be authorized for certification. The Testing Alternative procedure for these ratings is to be used only if the product cannot be simulated."

D. **As can be seen in paragraphs 15.02.B and C, shown earlier, glazing systems must be certified and the certification must involve a physical product test. I include this information to emphasize this building envelope requirement, because many design professionals are unaware of the magnitude of these requirements and the potential construction cost impacts. Recommended specification text is indicated in the following.**

1. A representative sample of each glazing product to be installed on the project shall be tested in a certified, independent, testing laboratory in accordance with NFRC testing procedures.

2. Glazing products shall include, but are not limited to, curtain wall assemblies, field-assembled units, factory-assembled units, spandrel glazing units, operable units, fixed units, glazing with and without frit, clear units, tinted/colored units, low e-units, low iron units, metal-/aluminum-framed units, wood-framed units, sealed units, and all other glazing units.

3. U-values and solar heat gain coefficients (SHGCs) shall be determined by an NFRC test method at a certified, independent testing laboratory and shall be expressed as Btu/(h $ft.^2$ °F) for each glazing product. Test glazing products with a 15-mph wind (6.7 m/s), 0°F (–18°C) cold side temperature, and 70°F (21°C) warm side temperature. The NFRC testing procedure shall include both the thermal computer model and the physical product test.

4. Maximum U-values must be specified and include the effects of the framing system.
   a. For example: Maximum U-values including the frame shall be 0.46 Btu/(h $ft.^2$ °F).

   b. Include the maximum U-values obtained from ASHRAE Std 90.1 or the IECC, or values used in the COMcheck program or the Energy Model that shows compliance.

5. The maximum SHGC must be specified.
   a. For example: the maximum SHGC shall be 0.39.

   b. The maximum SHGC values obtained from ASHRAE Std 90.1 or the IECC, or values used in the COMcheck program or the Energy Model that shows compliance.

E. **Prescriptive Code Approach**

1. The prescriptive approach is an explicitly defined design approach based on

design, construction, and maintenance requirements for all building systems.

2. The prescriptive approach is less flexible.

3. The prescriptive approach requires less design effort.

4. The following is an illustration of the ASHRAE Standard 90.1 prescriptive approach.

THE ASHRAE STANDARD 90.1 PRESCRIPTIVE APPROACH

Architectural Building Envelope		**Mechanical HVAC**		**Plumbing Water Heating**	**Elect Light**
Mandatory Requirements		**Mandatory Requirements**		**Mandatory Requirements**	**Manda Require**
Prescriptive Method	Building Envelope Trade-off Method	Simple Method	Prescriptive Method	Prescriptive Method	Space-by-Space Method

F. **Performance Code Approach**

1. The performance approach is a design approach based on performance goals, objectives, and criteria.

2. The performance approach is more flexible.

3. The performance approach requires a much greater design effort.

4. The following is an illustration of ASHRAE Standard 90.1 performance approach.

ASHRAE STANDARD 90.1 PERFORMANCE APPROACH

Architectural Building Envelope	Mechanical HVAC	Plumbing Water Heating	Electrical Lighting	Ele Pow
Mandatory Requirements	Mandatory Requirements	Mandatory Requirements	Mandatory Requirements	Mar Requ
Energy Cost Budget Method "The Energy Model"				

G. **As can be seen in the previous illustrations, all disciplines (architectural, mechanical, plumbing, and electrical) must be actively involved in the energy conservation aspects of building design and construction. Even the contractors must be cognizant of how their construction activities and policies affect the end product with respect to energy conservation. This book will concentrate on the HVAC aspects of energy conservation. However, some of the lighting energy conservation requirements are contained in Part 11.**

H. **It's always surprising when a design colleague or someone else involved in the design process raises the question(s): "Who is going to enforce these energy conservation requirements (implying who understands these requirements well enough to enforce them)? or Who are the "Energy Police" who will enforce these requirements? The answer should roughly be: "It is the design professional's responsibility to enforce these requirements, especially if they have RA (registered architect) or PE (professional engineer) after their names." Your professional license as an architect or engineer requires you to uphold the laws and codes of the jurisdictions in which you are licensed, in addition to protecting the public health and safety. Therefore, it is ultimately the design professionals' responsibility.**

I. **Energy Performance Computer Programs are quite useful in determining compliance. The Department of Energy (DOE) has a free residential compliance program (REScheck) and a free commercial compliance program (COMcheck) that can be downloaded from their web site. It is easy to use, and many municipalities accept the output from these programs as certification of compliance. These programs also provide checklists that assist in the design of the building or**

structure. These programs utilize the prescriptive requirements to determine compliance and generally cannot be used to determine the compliance for the performance approach.

J. **Summaries of the energy codes outlining/highlighting the more frequently uses requirements are indicated in the following. For detailed design requirements, consult the official code text.**

15.03. 2015 IECC

A. **Scope and Intent**

1. Minimum prescriptive and performance requirements for building energy conservation.
2. Applicable buildings: residential and commercial.
3. Systems covered—provide effective use of energy in buildings:
    a. Architectural—Building envelope.
    b. Mechanical—HVAC and plumbing.
    c. Electrical—Power and lighting.
4. The code is not intended to limit flexibility or negate the safety, health, or environmental requirements of building design and construction.

B. **Design Conditions**

1. The United States is categorized into eight climate zones with Climate Zone 1 at the tip of Florida and Climate Zone 8 in Alaska.
2. Outdoor design conditions—2013 ASHRAE Handbook of Fundamentals.
3. Indoor design conditions.
    a. Heating: 72°F maximum.
    b. Cooling: 75°F minimum.

C. **Residential Energy Efficiency —Mandatory Requirements**

1. Duct insulation
    a. Supply and return ducts in attics 3 inches in diameter and greater: Insulation with R-value = 8.0.

b. Supply and return ducts in attics less than 3 inches in diameter: Insulation with R-value = 6.0.

c. Supply and return ducts in other portions of the building 3 inches in diameter and greater: Insulation with R-value = 6.0.

d. Supply and return ducts in other portions of the building less than 3 inches in diameter: Insulation with R-value = 4.2.

e. Exception: ducts completely inside the building envelope do not require insulation.

2. Pipe insulation

a. Pipe fluid above 105°F: Insulation with R-value = 3.0.

b. Pipe fluid below 55°F: Insulation with R-value = 3.0.

c. Domestic hot water: Insulation with R-value = 3.0.

D. **Commercial Energy Efficiency Requirements**

1. The 2015 IECC references ASHRAE Standard 90.1—Energy Standard for Buildings Except Low Rise Residential Buildings, but also provides its own prescriptive and performance requirements.

2. Mandatory requirements:

a. Heating and cooling load calculations shall be performed in accordance with *ASHRAE Standard 183* and equipment size based on these calculations.

b. Heating and cooling loads shall be adjusted to account for energy recovery systems.

c. Minimum HVAC equipment performance requirements are defined in the code. These requirements are not included here. Chiller performance requirements can be found in Part 28.

d. Thermostatic controls shall be provided for all HVAC systems. Humidity controls shall be provided for HVAC systems where humidification or dehumidification, or both are provided.

e. A 5°F deadband is required between heating and cooling setpoints.

f. Off-hour setback controls are required.

g. Damper controls: Outdoor air and exhaust air systems (gravity vents and louvers) shall be provided with motorized shutoff dampers when the system is not in use.
    1. Exception: Gravity dampers are permitted in buildings that are two stories and less in height.

    2. Exception: Gravity dampers are permitted in buildings of any height located in Climate Zones 1, 2, or 3.

    3. Exception: Gravity dampers are permitted in systems with airflows of 300 CFM and less.

h. Energy recovery systems shall be provided when the following conditions are met:
    1. HVAC systems where the supply airflow rate of a fan system exceeds the values listed in 2015 IECC, Tables C403.2.7(1) and C403.2.7(2) based on climate zone and percentage of outdoor airflow rate at design conditions.

    2. The energy recovery system shall recover at least 50 percent of the energy difference between the enthalpy difference of the outside air and the room air (50-percent minimum efficiency).
        a. Exceptions:
            1. Where energy recovery systems are prohibited by the *International Mechanical Code*.

            2. Laboratory fume hood systems that include at least one of the following:
                a. VAV exhaust hoods with supply air and exhaust airflow reduction to 50 percent or less of the system design airflow.

                b. Direct makeup air delivered to the laboratory fumes hoods equal to at least 75 percent of the exhaust flow rate, heated no warmer than 2°F below the room design temperature, cooled to no cooler than 3°F above the room design temperature, no humidification added, and no simultaneous heating and cooling used for dehumidification control.

            3. Heating only systems with design space temperatures less than 60°F.

4. Where 60 percent of the outdoor heating energy is provided by site recovered energy or site solar energy.

5. Heating energy recovery in Climate Zones 1 and 2.

6. Cooling energy recovery in Climate Zones 3C, 4C, 5B, 5C, 6B, 7, and 8.

7. Systems requiring dehumidification that employ energy recovery in series with the cooling coil.

8. Where the largest exhaust source is less than 75 percent of the design outdoor airflow.

9. Systems expected to operate less than 20 hours per week at the outdoor air percentage covered by Table C403.2.7(1).

10. Hazardous exhaust systems: See Part 17.

11. Commercial kitchen hoods.

3. Energy recovery control or bypass must be provided to permit the operation of airside economizers.

i. Ductwork:
1. Construction and materials: See Part 17.

2. Insulation: See Part 35.

j. Piping:
1. Construction and materials: See Part 18 through Part 22.

2. Insulation: See Part 35.

k. HVAC system balancing is required for both the air systems and the hydronic systems.

l. Operation and maintenance manuals are required to be turned over to the owner.

3. Economizers—prescriptive approach:
a. See 2015 IECC, Sec. C403.3 for detailed requirements.

b. Economizer systems shall be integrated with the mechanical cooling system and be capable of providing partial cooling even where additional mechanical cooling is required to provide the remainder of the cooling load.

c. HVAC system design and economizer controls shall be such that economizer operation does not increase building heating energy during normal operation.

d. Air economizers:
   1. Air economizer systems shall be capable of modulating outdoor air and return air dampers to provide up to 100 percent of the design supply air quantity as outdoor air for cooling.

   2. Economizer dampers shall be capable of being sequenced with the mechanical cooling equipment and shall not be controlled by only mixed-air temperature.

   3. Air economizers shall be capable of automatically reducing outdoor air intake to the design minimum outdoor air quantity when outdoor air intake will no longer reduce cooling energy usage.

   4. Systems shall be capable of relieving excess outdoor air during air economizer operation to prevent overpressurizing the building. The relief air outlet shall be located to avoid recirculation into the building.

e. Water-side economizers:
   1. Water-side economizers shall be capable of providing 100 percent of the cooling load at outside air temperatures of 50°F db/45°F wb and below.

4. Hydronic and multiple-zone HVAC systems controls and equipment—prescriptive approach:
   a. See 2015 IECC, Sec. C403.4 for detailed requirements.

   b. Fan control:
      1. Each cooling system shall be designed to vary the indoor fan airflow as a function of load.

      2. Static pressure sensors used to control VAV fans shall be located such that the controller setpoint is not greater than 1.2 inches w.c.

3. For systems with direct digital control of individual zones reporting to the central control panel, the static pressure setpoint shall be reset based on the zone requiring the most pressure. In such case, the setpoint is reset lower until one zone damper is nearly wide open.

c. Hydronic systems controls:

1. Three-pipe hydronic systems are prohibited.

2. Two-pipe changeover hydronic systems shall be provided with a deadband of at least 15°F, operation of one mode for at least four hours before changing to the other mode, and automatic controls that allow heating and cooling supply temperatures at the changeover point to be no more than 30°F apart.

3. Hydronic heat pump systems shall be designed with a 20°F deadband between the removal of heat and the addition of heat to the loop. A bypass around the closed circuit evaporative cooler or the cooling tower is required for climate zones 3 and 4 to prevent heat loss, except for minimum flow to prevent freezing. For climate zones 3 and 4 where a separate heat exchanger is used to isolate the cooling tower from the heat pump loop, heat loss shall be controlled by shutting down the circulation pump on the cooling tower loop. For climate zones 5 through 8, where a closed circuit evaporative cooler or cooling tower is used, a separate heat exchanger shall be used to isolate the cooling tower from the heat pump loop, and heat loss shall be controlled by shutting down the circulation pump on the cooling tower loop. All water-source heat pumps shall be provided with two-position control valves on all heat pump systems with total pump energy exceeding 10 horsepower to stop flow when the heat pump has cycled off (variable flow water distribution system).

4. Hydronic heating and cooling systems 500,000 Btu/h capacity or greater shall have automatic supply-water temperature reset controls using coil valve position, zone-return water temperature, building-return water temperature, or outside air temperature as an indicator of building heating or cooling demand. The temperature shall be capable of being reset by not less than 25 percent of the design supply-to-return water temperature difference.

5. Hydronic heating and cooling systems 500,000 Btu/h capacity or greater with a combined motor capacity of 10 horsepower or greater with three or more control valves shall reduce system pump flow by at least 50 percent of the design flow rate utilizing adjustable speed drives on pumps or multiple-staged pumps where at least 1/2 of the total pump horsepower can be turned off or where control valves are designed to modulate closed as a function of load. Pump flow shall be controlled to maintain one control valve nearly wide open or to satisfy the minimum differential pressure.

6. Boiler systems with a design input greater than 1,000,000 Btu/h and less than or equal to 5,000,000 Btu/h shall have a minimum turndown ratio of 3 to 1; greater than 5,000,000 Btu/h and less than or equal to 10,000,000 Btu/h shall have a minimum turndown ratio of 4 to 1; and greater than 10,000,000 Btu/h shall have a minimum turndown ratio of 5 to 1.

7. Chilled water and boiler plants having more than one chiller and/or boiler shall have the capability to reduce flow automatically through the chiller/boiler plant when a chiller/boiler is shut down.

d. Heat rejection equipment fans 7.5 horsepower and greater shall have automatic controls in order to reduce fan speed to 2/3 of full speed or less.

e. Complex mechanical systems serving multiple zones:

1. Supply air systems serving multiple zones shall be variable air volume systems that, during periods of occupancy, are designed and capable of being controlled to reduce primary air supply to each zone to 30 percent of maximum supply air, 300 CFM or less, minimum ventilation requirements, higher rate if approved by the code official, or the airflow rate required to maintain pressure relationships or minimum air change rates before reheating, recooling, or mixing takes place.

2. Fractional horsepower fan motors that are greater than or equal to 1/12 horsepower and less than 1 horsepower shall be electronically commutated motors or shall have a minimum motor efficiency of 70 percent.

3. Multiple-zone HVAC systems shall include controls that automatically reset the supply air temperature not less than 25 percent of the difference between the design supply air temperature and the design

room temperature in response to representative building loads or to outdoor air temperature.

4. Multiple-zone HVAC systems with direct digital control of individual zone boxes reporting to a central control panel shall have automatic controls configured to reduce outdoor air intake flow below design rates in response to changes in system ventilation efficiency as defined by the *International Mechanical Code*.

f. Condenser water heat recovery is required for the heating or reheating of service hot water, provided the facility operates 24 hours per day and the total water-cooled system exceeds 6,000,000 Btu/h capacity of heat rejection and the design service water heating load exceeds 1,000,000 Btu/h.

g. Cooling systems shall not use hot gas bypass or other evaporator pressure control systems unless the system is designed with multiple steps of unloading or continuous capacity modulation. The capacity of the hot gas bypass shall be limited to 50 percent of total capacity for systems with a rated capacity greater than or equal to 240,000 Btu/h, and 25 percent of total capacity for systems with a rated capacity less than 240,000 Btu/h.

E. **Performance Approach**

1. When using a performance-based energy compliance approach for either a residential or commercial facility, the energy model will have to be performed at least twice: once for the standard reference design using the standard energy performance values defined in the code and once using the proposed design performance values as defined on the construction documents.

2. Energy analysis shall be performed over a full calendar year (8,760 hours) using climatic data, energy rates, building envelope data, occupancy schedules, and simulated loads as applicable to the location.

3. The heating and cooling system zoning, orientation, and other building features for the standard building shall be the same as the proposed building except:

a. The window area of the standard design shall be the same as the proposed design, or 35 percent of the above-grade wall area, whichever is less.

b. The skylight area of the standard design shall be the same as the proposed design, or 3 percent of the gross roof area, whichever is less.

15.04. ASHRAE Standard 90.1-2013

A. **Purpose: To provide minimum requirements for the energy-efficient design of buildings except low-rise residential buildings.**

B. **Scope**
   1. Application:
      a. New buildings and their systems.
      b. New portions of buildings and their systems.
      c. New systems and equipment in existing buildings.
      d. New equipment or building systems specifically identified as part of industrial or manufacturing processes.
   2. Building elements and systems:
      a. Building envelope.
      b. HVAC systems.
      c. Service water heating systems.
      d. Electrical power distribution and metering systems.
      e. Electric motors, belts, and drives.
      f. Lighting.
   3. The code is not intended to limit flexibility or to negate safety, health, or environmental requirements of building design and construction.

C. **Mandatory Provisions**
   1. Mechanical equipment shall meet minimum equipment efficiencies. These requirements were not included here. Chiller performance requirements can be found in Part 28.
   2. Heating and cooling load calculations shall be performed in accordance with ASHRAE Standard 183-2007 (RA2014) and equipment size based on these calculations.

3. The supply of heating and cooling energy shall be individually controlled by a thermostat responding to temperatures within the zone.

4. A 5°F deadband is required between heating and cooling setpoints. Where heating and cooling systems serving a zone are controlled by separate thermostats, provisions in the control system shall prevent the simultaneous heating and cooling of the zone.

5. HVAC systems shall be provided with off-hour controls:
   a. Exceptions:
      1. HVAC systems intended to operate continuously.

      2. HVAC systems with design heating and cooling capacities less than 15,000 Btu/h and with accessible on/off controls.

   b. Automatic shutdown shall be equipped with at least one of the following:
      1. Time schedules for seven different day types:
         a. Capable of retaining control programs for a minimum of 10 hours during a power outage.

         b. Accessible manual override for system operation up to two hours.

      2. Occupant sensor.

      3. Manually operated timer with 2-hour operation limitation.

      4. Interlock with security system—security system activation shuts down the HVAC system.

   c. Setback controls:
      1. Heating systems: Provide controls with a setback temperature of at least 10°F lower than the occupied heating setpoint (or 4°F lower than the occupied heating setpoint for radiant heating systems).

      2. Cooling systems: Provide controls with a setup temperature of at least 5°F higher than the occupied cooling setpoint.

   d. Optimum start controls (system with setback controls and DDC).

   e. Zone isolation controls for HVAC systems serving zones that are intended to operate or be occupied nonsimultaneously.

6. Ventilation control:

a. Stair and elevator shaft vents shall be equipped with motorized dampers that are closed during normal building operation and are opened as required by fire and smoke detection systems.

b. Damper controls: Outdoor air and exhaust air systems (gravity vents and louvers) shall be provided with motorized shutoff dampers when the system is not in use or during preoccupancy building warm-up, cool-down, and setback.
   1. Exception: Gravity dampers are permitted for exhaust and relief in buildings three stories and less in height and in buildings of any height in Climate Zones 1, 2, and 3.

   2. Exception: Gravity dampers are permitted in systems with an airflow of 300 CFM or less.

   3. Exception: Ventilation systems serving unconditioned spaces.

c. Recommendation: Provide all dampers with a maximum damper leakage rate of 4.0 CFM per square foot of damper area at 1.0 inches water column differential.

d. Ventilation fan controls: Fans greater than 3/4 horsepower shall have automatic shutdown controls that shut off fans when not required.

e. Demand control ventilation is required for HVAC systems serving spaces larger than 500 square feet with an occupant density exceeding 25 people per 1,000 square feet (some exceptions apply; see ASHRAE Standard 90.1-2013, Sec. 6.4.3.8). The HVAC systems must also have one or more of the following:
   1. Air-side economizer.

   2. Automatic modulating control of the outdoor air damper.

   3. Design outdoor airflow greater than 3,000 CFM.

f. Ductwork:
   1. Construction and materials: See Part 17.

   2. Insulation: See Part 35.

g. Piping:
   1. Construction and materials: See Part 18 through Part 22.

   2. Insulation: See Part 35.

h. Construction requirements:
   1. Record drawings shall be required.
   2. Operation and maintenance manuals shall be required.
   3. Air distribution and hydronic systems shall be balanced.
   4. HVAC control systems shall be commissioned for projects larger than 50,000 square feet.

D. **Simplified Prescriptive Approach**

1. Building meeting the following:
   a. Two stories or less.
   b. 25,000 square feet or less.
2. HVAC system serves a single zone.
3. HVAC system varies indoor fan airflow.
4. HVAC provided by packaged or split system equipment.
5. Airside economizer shall be provided.
6. System changeover shall be by a manual changeover or by a dual setpoint thermostat.
7. The system does not permit simultaneous heating and cooling.

E. **Prescriptive Approach**

1. Economizers—either an airside or a waterside economizer is required as indicated in the following tables.

Climate Zones	**Comfort Cooling Capacity Requiring Economizer**
1A, 1B	No economizer required
2A, 2B, 3A, 4A, 5A, 6A, 3B, 3C, 4B, 4C, 5B, 5C, 6B, 7, 8	≥ 54,000 Btu/h

Climate Zones	Computer Room Cooling Capacity Requiring Economizer
1A, 1B, 2A, 3A, 4A	No economizer required
2A, 5A, 6A, 7, 8	≥ 135,000 Btu/h
3B, 3C, 4B, 4C, 5B, 5C, 6B	≥ 65,000 Btu/h

a. Exceptions:
    1. Systems smaller than those indicated in the tables under the design conditions listed.
    2. In hospitals and ambulatory surgery centers where 75 percent or more of the HVAC system serve spaces that require humidification levels above a 35°F dewpoint temperature.
    3. Where 25 percent or more of the HVAC system serves spaces that require humidification levels above a 35°F dewpoint temperature.
    4. Systems that utilize condenser heat recovery.
    5. Residential HVAC systems where the capacity is less than five times the requirements listed in the preceding table.
    6. Systems that serve spaces whose sensible cooling load at design conditions, excluding transmission and infiltration loads, is less than or equal to transmission and infiltration losses at an outdoor temperature of 60°F.
    7. Systems expected to operate less than 20 hours per week.
    8. Where the use of outdoor air for cooling will affect supermarket open refrigerated casework systems.
    9. Other exceptions apply; see ASHRAE Standard 90.1-2013, Sec. 6.5.1.

2. Airside economizers:
    a. Design capacity: 100 percent of the supply air quantity.
    b. Controls: Must be sequenced with mechanical cooling systems and shall not be controlled by only mixed air temperature.

c. Minimum position: System shall reduce outside airflow to the minimum position when the outside air will no longer reduce cooling energy usage.

d. Relief: HVAC systems must provide a means to relieve excess outside air.

e. Sensors must meet certain accuracies (see ASHRAE Standard 90.1-2013, Sec. 6.5.1.1.6).

3. Waterside economizers:
   a. Design capacity: 100 percent of the expected system cooling load at outside air temperatures of 50°F db/45°F wb and below.

   b. Maximum water pressure drop: 15 feet of water.

4. Economizer control:
   a. Economizers shall provide partial cooling even when additional mechanical cooling is required to meet the load.

   b. Economizers shall not increase the building heating energy use during normal operation.

   c. Economizer control methods.

Climate Zones	Allowed Control Types	Prohibited Control Types
1B, 2B, 3B, 3C, 4B, 4C, 5A, 5B, 5C, 6A, 6B, 7, 8	Fixed dry bulb Differential dry bulb Fixed enthalpy Differential enthalpy	
1A, 2A, 3A, 4A	Fixed dry bulb Fixed enthalpy Differential enthalpy	Differential dry bulb

5. Thermostatic zone controls shall reduce the following:
   a. Reheating.

   b. Recooling.

   c. Mixing.

   d. Simultaneous heating and cooling.

e. Exceptions: When the quantity of air to be reheated, recooled, or mixed is no greater than the following:
   1. The prescribed code ventilation requirements.
   2. Zones where special pressure relationships are required to prevent cross-contamination.
   3. Code required minimum air change rates—hospitals are an example.
   4. Where 75 percent or more of the energy required for reheating is provided by an energy recovery system.
   5. Laboratory exhaust systems.
   6. Other exceptions apply; see ASHRAE Standard 90.1-2013, Sec. 6.5.2.1.

6. Humidistatic zone controls shall reduce the following:
   a. Reheating.
   b. Recooling.
   c. Mixing.
   d. Simultaneous heating and cooling.
   e. Exceptions:
      1. Systems that reduce supply air quantities to 50 percent or lower.
      2. Individual cooling systems with capacity less than or equal to 80,000 Btu/h and reduces cooling capacity to 50 percent before reheating.
      3. Individual cooling systems with capacity of 40,000 Btu/h or less.
      4. HVAC systems serving process needs and requirements.
      5. Where 75 percent or more of the energy required for reheating is provided by an energy recovery system.

7. Hydronic systems controls
   a. Three-pipe hydronic systems are prohibited.
   b. Two-pipe changeover hydronic systems shall be provided with a deadband of at least 15°F, operation of one mode for at least four hours before changing to the other mode, and automatic control that allows

heating and cooling supply temperatures at the changeover point to be no more than 30°F apart.

c. Hydronic heat pump systems shall be design with a 20°F deadband between the removal of heat and the addition of heat to the loop. Bypass around the closed circuit evaporative cooler or the cooling tower is required for Climate Zones 3 through 8 with heating degree days in excess of 1800 to prevent heat loss, except for minimum flow to prevent freezing.

d. Hydronic systems having 10 horsepower or more of total pump system power:
   1. Provide control valves to modulate or step closed as a function of load to reduce water flow to 50 percent or less of the design flow rate.

   2. Chilled water pumps serving variable-flow systems having motors exceeding 5 horsepower shall have controls and/or devices (such as variable-speed control) that will result in pump motor demand of not more than 30 percent of their design wattage at 50 percent of the design water flow.
      a. Exception: Where minimum flow required is less than the minimum flow required by the equipment manufacturer for proper equipment operation and where the total pump system power is 75 horsepower or less.

      b. Exception: Systems with no more than three control valves.

e. Hydronic heating and cooling systems 300,000 Btu/h capacity or greater shall have automatic supply-water temperature reset controls using zone-return water temperature, building-return water temperature, or outside air temperature as an indicator of building heating or cooling demand.

f. Heat rejection equipment: Heat rejection equipment fans 7.5 horsepower and greater shall have automatic controls to be able to reduce fan speed to 2/3 of full speed or less and as a function of leaving water temperature or condensing temperature/pressure of the heat rejection device.

g. Condenser water heat recovery is required for heating or reheating of service hot water provided the facility operates 24 hours per day and the total water cooled system exceeds the 6,000,000 Btu/h capacity of heat rejection and the design service water heating load exceeds 1,000,000 Btu/h.

8. Fan system power and efficiency.
    a. See ASHRAE Standard 90.1-2013, Sec. 6.5.3.1.

9. Fan control.
    a. See ASHRAE Standard 90.1-2013, Sec. 6.5.3.2.

10. Multiple-zone VAV system ventilation optimization control.
    a. See ASHRAE Standard 90.1-2013, Sec. 6.5.3.3.

11. Supply air temperature reset controls.
    a. See ASHRAE Standard 90.1-2013, Sec. 6.5.3.4.

12. Fractional horsepower fan motors.
    a. See ASHRAE Standard 90.1-2013, Sec. 6.5.3.5.

13. Energy recovery systems are required for individual fan systems with a design supply fan capacity that exceeds the values listed in ASHRAE Standard 90.1-2013, Tables 6.5.6.1-1 and 6.5.6.1-2 based on climate zone and percentage of outdoor airflow rate at design conditions. The energy recovery system will have a minimum energy recovery effectiveness of 50 percent (50 percent of the difference between the outside air enthalpy and the return air enthalpy at design conditions).
    a. Exceptions:
        1. Laboratory exhaust systems as defined in the following.

        2. Commercial kitchen hoods.

        3. Hazardous exhaust systems: See Part 17.

        4. Heating only systems with design space temperatures less than 60°F.

        5. Where 60 percent of the outdoor heating energy is provided by site recovered energy or site solar energy.

        6. Heating energy recovery in Climate Zones 1 and 2.

        7. Cooling energy recovery in Climate Zones 3C, 4C, 5B, 5C, 6B, 7, and 8.

        8. Where the largest exhaust source is less than 75 percent of the design outdoor airflow.

        9. Systems requiring dehumidification that employ energy recovery in series with the cooling coil.

10. Systems expected to operate less than 20 hours per week at the outdoor air percentage covered by Table 6.5.6.1-1.

14. Commercial kitchen hood exhaust systems.
    a. See ASHRAE Standard 90.1-2013, Sec. 6.5.7.1.

15. Buildings with laboratory exhaust systems having a total exhaust airflow rate greater than 5,000 CFM shall have at least one of the following features:
    a. VAV laboratory exhaust and room supply system capable of reducing exhaust and makeup airflow rates and/or incorporate a heat recovery system to precondition makeup air from laboratory exhaust that shall meet the following:
       $A + B \times (E/M) \geq 50\%$
       where

       A = percentage that the exhaust and makeup airflow rates can be reduced from design conditions

       B = percentage sensible recovery effectiveness

       E = exhaust airflow rate through the heat recovery device at design conditions

       M = makeup airflow rate of the system at design conditions

    b. VAV exhaust hoods with supply air and exhaust airflow reduction to 50 percent or less of the system design airflow.

    c. Direct makeup air delivered to the laboratory fumes hoods equal to at least 75 percent of the exhaust flow rate, heated no warmer than 2°F below the room design temperature, cooled to no cooler than 3°F above the room design temperature, no humidification added, and no simultaneous heating and cooling used for dehumidification control.

    d. Heat recovery systems to precondition makeup air without using any exceptions.

16. Hot gas bypass:
    a. Hot gas bypass shall not be used unless the system has multiple steps of capacity control or continuous modulation capacity control.

    b. Hot gas bypass shall be limited as follows:
       1. System capacity ≤ 240,000 Btu/h: 15% of total system capacity.

2. System capacity > 240,000 Btu/h: 10% of total system capacity.

F. **Performance Approach—Energy Cost Budget Method (Compliance Only)**

1. Mandatory energy conservation requirements must still be met using the performance approach.

2. The energy cost budget for the proposed building must be less than or equal to the energy cost budget for the budget building design for compliance.

3. When using a performance-based energy compliance approach for a commercial facility, the energy model will have to be performed at least twice: once for the budget building design using the budget energy performance values defined in the code, and once using the proposed building design values as defined on the construction documents.

4. See ASHRAE Standard 90.1-2013, Sec. 11 for complete requirements of the energy cost budget method.

G. **Performance Rating Method—Normative Appendix G**

1. This performance rating method is intended for use in rating the energy efficiency of building designs that exceed the minimum requirements of this code.

2. Mandatory energy conservation requirements must still be met using the performance rating method.

3. The improved performance of the proposed building design is calculated in accordance with provisions of this appendix using the following formula: Percentage improvement = 100 × (Baseline building performance – Proposed building performance)/Baseline building performance

4. See ASHRAE Standard 90.1-2013, Normative Appendix G for complete requirements of the performance rating method.

15.05. ASHRAE Standard 90.2-2007

A. **Purpose: To provide minimum requirements for the energy-efficient design of residential buildings.**

B. **Duct Insulation**

1. All portions of the air distribution system used for heating or cooling shall be insulated with R-8 insulation.

2. Ducts are not required to be insulated:
   a. When supply and return ductwork are within the conditioned space.

   b. If it is exhaust ductwork.

C. **Pipe Insulation**

1. Piping shall be insulated as follows:

		Nominal Pipe or Tube Diameter				
Fluid Design Operating Temperature	**Conductivity Btu in./h ft.2 °F**	**<1"**	**1" to 1-1/4"**	**1-1/2" to 3-1/2"**	**4" to 6"**	**≥8"**
Heating Systems—Hot Water and Steam Condensate						
201–250°F	0.27–0.30	1.5	1.5	2.0	2.0	2.0
141–200°F	0.25–0.29	1.0	1.0	1.0	1.5	1.5
105–140°F	0.22–0.28	0.5	0.5	1.0	1.0	1.0
Heating Systems—Steam						
212–250°F 0–15 Psig	0.27–0.30	1.5	1.5	2.0	2.0	2.0
Cooling Systems—Chilled Water, Glycol, Brine, and Refrigerant						
40–55°F	0.22–0.28	0.5	0.5	1.0	1.0	1.0
< 40°F	0.22–0.28	0.5	1.0	1.0	1.0	1.5

D. **Ventilation: See Part 8 or ASHRAE Standard 62.2.**

Part 16: HVAC System Selection Criteria

16. Part 16: HVAC System Selection Criteria

16.01. HVAC System Selection Criteria

A. **Building Type**

1. Institutional: hospital, prisons, nursing homes, education.
2. Commercial: offices, stores.
3. Residential: hotel, motel, apartments.
4. Industrial: manufacturing.
5. Research and development: laboratories.

B. **Owner Type**

1. Government.
2. Developer.
3. Business.
4. Private.

C. **Performance Requirements**

1. Supporting a process: computer facility, telephone facility.
2. Promoting a germ-free environment.
3. Increasing sales and rental income.
4. System efficiency.

5. Increasing property salability.
6. Standby and reserve capacity.
7. Reliability, life expectancy: frequency of maintenance and failure.
8. How will equipment failures affect the building? Owner operations?

D. **Capacity Requirements**

1. Cooling loads: magnitude and characteristics.
2. Heating loads: magnitude and characteristics.
3. Ventilation.
4. Zoning requirements:
   a. Occupancy.
   b. Solar exposure.
   c. Special requirements.
   d. Space temperature and humidity tolerances.

E. **Spatial Requirements**

1. Architectural constraints:
   a. Aesthetics.
   b. Structural support.
   c. Architectural style and function.
2. Space available to house equipment and location.
3. Space available for distribution of ducts and pipes.
4. Acceptability of components obtruding into occupied space, physically and visually.
5. Furniture placement.
6. Flexibility.
7. Maintenance accessibility.
8. Roof.

9. Available space constraints.

10. Are mechanical rooms/shafts required?

F. **Comfort Considerations**

1. Control options.

2. Noise and vibration control.

3. Heating, ventilating, and air conditioning.

4. Filtration.

5. Air quality control.

G. **First Cost**

1. System cost. Return on investment.

2. Cost to add zones.

3. Ability to increase capacity.

4. Contribution to life safety needs.

5. Air quality control.

6. Future cost to replace and/or repair.

H. **Operating Costs**

1. Energy costs.

2. Energy type:

   a. Electricity. Voltage available, rate schedule.

   b. Gas.

   c. Oil.

   d. District steam.

   e. District chilled water.

   f. Other sources.

3. Energy types available at project site.

4. Equipment selection.

I. **Maintenance Cost**

1. Cost to repair.

2. Capabilities of owner's maintenance personnel.

3. Cost of system failure on productivity.

4. Economizer cycle:
   a. Airside economizer.

   b. Waterside economizer.

5. Heat recovery.

6. Future cost to replace.

7. Ease and quickness of servicing.

8. Ease and quickness of adding zones.

9. Extent and frequency of maintenance.

J. **Codes**

1. Codes govern HVAC and other building systems design.

2. Most building codes are adopted and enforced at the local level.

3. Most of the states have adopted the International Series of Codes.

4. Codes are not enforceable unless adopted by municipality, borough, county, state, etc.

5. Codes regulate:
   a. Design and construction.

   b. Allowable construction types.

   c. Building height.

   d. Egress requirements.

   e. Structural components.

   f. Light and ventilation requirements.

   g. Material specifications.

6. Code approaches:
   a. Prescriptive. Dictate specific materials and methods (ASTM A53, Steel Pipe, Welded).

   b. Performance. Dictate desired results (HVAC system to provide and maintain a design temperature of 70°F winter and 75°F/50 percent RH summer).

7. Codes developed because of:
   a. Loss of life.

   b. Loss of property.

   c. Pioneered by insurance industry.

8. 2015 International Code Council Series of Codes (ICC):
   a. 2015 International Building Code.

   b. 2015 International Mechanical Code.

   c. 2015 International Energy Conservation Code.

   d. 2015 International Plumbing Code.

   e. 2015 International Fire Code.

   f. 2015 International Fuel Gas Code.

   g. 2015 International Residential Code.

   h. 2015 International Existing Building Code.

   i. 2015 International Performance Code for Buildings and Facilities.

   j. 2015 International Private Sewage Disposal Code.

   k. 2015 International Property Maintenance Code.

   l. 2015 International Zoning Code.

   m. 2015 International Wildland-Urban Interface Code.

16.02. Heating System Selection Guidelines

A. **If heat loss exceeds 450 Btu/h per lineal feet of wall, heat should be provided from under the window or from the base of the wall to prevent downdrafts.**

B. **If heat loss is between 250 and 450 Btu/h per lineal feet of wall, heat should be provided from under the window or from the base of the wall, or it may be provided from overhead diffusers, located adjacent to the perimeter wall, discharging air directly downward, and blanketing the exposed wall and window areas.**

C. **If heat loss is less than 250 Btu/h per lineal feet of wall, heat should be provided from under the window or from the base of the wall, or it may be provided from overhead diffusers, located adjacent to or slightly away from the perimeter wall, discharging air directed at, or both directed at and directed away from, the exposed wall and window areas.**

Part 17: Air Distribution Systems

17. Part 17: Air Distribution Systems

17.01. Ductwork Systems

A. Ductwork Sizing Criteria Table

DUCTWORK SIZING CRITERIA

System Type	Maximum Friction Rate in. W.G./100 ft.	Minimum Velocity ft./min.	Maximum Velocity ft./min.	Comments/Reasons
General Air Handling Systems				
Low Pressure Ducts	0.10 (0.15)	–	1,500–1,800	When CFM > 6,000 velocity governs; when CFM < 6,000 friction rate governs; applicable for supply, return, exhaust, and outside air systems
Medium Pressure Ducts	0.20 (0.25)	–	2,000–2,500	When CFM > 6,000 velocity governs; when CFM < 6,000 friction rate governs; applicable for supply systems only

Notes:

1. **Friction rates in parenthesis should only be used when space constraints dictate.**
2. **Maximum aspect ratio 4:1; unless space constraints dictate greater aspect ratios.**

System Type	Maximum Friction Rate in. W.G./100 ft.	Minimum Velocity ft./min.	Maximum Velocity ft./min.	Comments/Reasons
High Pressure Ducts	0.40 (0.45)	–	2,500–3,500	When CFM > 5,000 velocity governs; when CFM < 5,000 friction rate governs; applicable for supply systems only
Transfer Air Ducts	0.03–0.05	–	1,000	When CFM > 3,200 velocity governs; when CFM < 3,200 friction rate governs
Outside Air Shafts	0.05–0.10	–	1,000	When CFM > 1,200 velocity governs; when CFM < 1,200 friction rate governs
Gravity Relief Air Shafts	0.03–0.05	–	1,000	When CFM > 3,200 velocity governs; when CFM < 3,200 friction rate governs
General Exhaust and Special Exhaust Systems				
General Exhaust Ducts	0.10 (0.15)	–	1,500–1,800	When CFM > 6,000 velocity governs; when CFM < 6,000 friction rate governs
Toilet Exhaust Ducts	0.10 (0.15)	–	1,500–1,800	When CFM > 6,000 velocity governs; when CFM < 6,000 friction rate governs
Kitchen Hood Exhaust Ducts	–	1,500	2,200	2015 IMC: 500 FPM min.; NFPA 96-2014: 500 FPM min.
Dishwasher Exhaust Ducts	0.10 (0.15)	1,500	2,200	
Acid,	0.50 (0.60)	1,000	3,000	Mains and risers

Notes:

System Type	Maximum Friction Rate in. W.G./100 ft.	Minimum Velocity ft./min.	Maximum Velocity ft./min.	Comments/Reasons
Ammonia, and Solvent Mains				1,500–3,000 FPM; Branches and lateral 1,000–2,000 FPM
Acid, Ammonia, and Solvent Stacks	–	3,000	4,000	
Silane Ducts	–	250	–	Velocity across the neck of the cylinder or cabinet window or access port
Louvers				
Intake	–	–	500	Maximum velocity through free area; assuming 50% free area—max. velocity 250 FPM through gross louver area
Exhaust or Relief	–	–	700	Maximum velocity through free area; assuming 50% free area—max. velocity 350 FPM through gross louver area

Notes:

1. **Friction rates in parenthesis should only be used when space constraints dictate.**
2. **Maximum aspect ratio 4:1; unless space constraints dictate greater aspect ratios.**
3. **When diffusers, registers, and grilles are mounted to supply, return, and exhaust ducts, duct velocities should not exceed 1,500 FPM or noise will result.**

B. Ductwork System Sizing

1. Low pressure: 0.10 (0.15) in. W.G./100 ft.; 1,500–1,800 FPM maximum.
2. Medium pressure: 0.20 (0.25) in. W.G./100 ft.; 2,000–2,500 FPM maximum.
3. High pressure: 0.40 (0.45) in. W.G./100 ft.; 2,500–3,500 FPM maximum.
4. Transfer ducts: 0.03–0.05 in. W.G./100 ft.; 1,000 FPM maximum.
5. Transfer grilles: 0.03–0.05 in. W.G. pressure drop.
6. Outside air shafts: 0.05–0.10 in. W.G./100 ft.; 1,000 FPM maximum.
7. Gravity relief air shafts: 0.03–0.05 in. W.G./100 ft.; 1,000 FPM Maximum.
8. Decrease or increase duct size whenever the duct changes by 4" or more in one or two dimensions. Do *NOT* use fractions of an inch for duct sizes.
9. Try to change only one duct dimension at a time because it is easier to fabricate fittings and therefore generally less expensive—that is, 36 × 12 to 30 × 12 in lieu of 36 × 12 to 32 × 10.
10. Duct taps should be 2" smaller than the main duct to properly construct and seal the duct. The duct size should be 2" wider than diffusers, registers, and grilles.
11. All 90-degree square elbows should be provided with double radius turning vanes. Elbows in dishwasher, kitchen, and laundry exhausts should be of unvaned smooth radius construction with a radius equal to 1-½ times the width of the duct.
12. Provide flexible connections at the point of connection to equipment in all ductwork systems (supply, return, and exhaust) connected to air handling units, fans, and other equipment.
13. Provide access doors to access all fire dampers, smoke dampers, smoke detectors, volume dampers, motor-operated dampers, humidifiers, coils (steam, hot water, chilled water, electric), and other items located in ductwork that requires service and/or inspection.
14. All rectangular duct taps should be made with shoe (45 degree) fittings. Do *NOT* use splitter dampers or extractors.
15. NFPA 90A-2015:

a. Service openings shall be located at approximately 20-foot intervals in horizontal ducts and at the base of each vertical riser to facilitate cleaning unless the ductwork can be accessed through removable diffusers, registers, and grilles.
   1. Exception: Service openings are not required where all of the following can be met:
      a. The occupancy has no process that produces combustible material such as dust, lint, or greasy vapors (banks, offices, churches, hotels, and health care facilities, except kitchens, laundries, and manufacturing portions of such facilities).

      b. The air inlets are at least 7 feet above the floor and are protected by metal screens (registers, grilles) that prevent paper, refuse, or other combustible solids from entering the system.

      c. The minimum return duct design velocity is 1,000 FPM.

b. Air outlets and inlets shall be located at least 3" above the floor unless provisions have been made to prevent dirt and dust from entering the system. Where outlets are located less than 7 feet above the floor, outlet openings shall be protected by a grille or screen with a maximum ½" opening size (register or grille).

16. Maximum ductwork hanger spacing:
    a. SMACNA minimum requirements:
       1. Horizontal: 8 to 10 feet maximum.

       2. Vertical: One- or two-story intervals—12 to 24 feet.

    b. Recommended:
       1. Horizontal ducts less than 4 square feet: 8 feet maximum.

       2. Horizontal ducts 4 to 10 square feet: 6 feet maximum.

       3. Horizontal ducts greater than 10 square feet: 4 feet maximum.

       4. Vertical round ducts: 12 feet maximum.

       5. Vertical rectangular ducts: 10 feet maximum.

DUCTWORK SUPPORT

Ductwork Type	Maximum Hanger Spacing Feet
Horizontal Ducts Less than 4 Square Feet	8
Horizontal Ducts 4 to 10 Square Feet	6
Horizontal Ducts Greater than 10 Square Feet	4
Vertical Round Ducts	12
Vertical Rectangular Ducts	10

C. Friction Loss Estimate

1. 1.5 × System Length (ft./100) × Friction Rate (in. W.G./100 ft.).

D. Ductwork Sizes

1. 4" × 4" smallest rectangular size.
2. 8" × 4" smallest recommended size.
3. Rectangular ducts: Use even duct sizes—that is, 24 × 12, 10 × 6, 72 × 36, 48 × 12.
4. 4:1 maximum recommended aspect ratio.
5. 3" smallest round size, odd and even sizes available.
6. Round ducts available in 0.5-inch increments for duct sizes through 5.5-inch diameter, 1-inch increments for duct sizes 6 inches through 20 inches, and 2-inch increments for duct sizes 22 inches and greater.

17.02. Duct Construction

A. **Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) Duct Construction Manuals:**
   1. *SMACNA—HVAC Duct Construction Standards—Metal and Flexible*, Third Edition, referred to herein as SMACNA-HVAC.
   2. *SMACNA—Fibrous Glass Duct Construction Standards*, Seventh Edition, referred to herein as SMACNA-FG.

3. *SMACNA—Rectangular Industrial Duct Construction Standard*, Second Edition, referred to herein as SMACNA-IDC.

4. *SMACNA—Round Industrial Duct Construction Standard*, Second Edition, referred to herein as SMACNA-RIDC.

5. *SMACNA—Thermoplastic Duct (PVC) Construction Manual*, Second Edition, referred to herein as SMACNA-PVC.

B. ***SMACNA-HVAC* Pressure Ratings**

1. ±½; ±1; ±2; ±3; ±4; ±6; ±10.

C. ***SMACNA-IDC* and *SMACNA-RIDC* Pressure Ratings**

1. +12" to + 100" by multiples of 2".

2. –4" to –100" by multiples of –2".

D. **SMACNA Ductwork Testing**

1. –4" W.G. and lower: 1.5 × Pressure Rating.

2. –3" to +3" W.G.: Generally not tested.

3. +4" W.G. and higher: 1.5 × Pressure Rating.

E. **ASHRAE Standard 90.1-2013: A minimum of 25 percent of duct systems designed to operate at static pressures exceeding 3" WC and all ductwork located outdoors shall be leak tested according to industry-accepted procedures.**

F. **Recommended Testing**

1. All supply duct systems operating at static pressures 3" and higher must be leak tested from air the handling unit to the vertical riser and from the vertical riser to 5 feet beyond shaft penetration on each and every floor (ductwork hidden in shaft construction).

2. All return duct systems operating at static pressures 3" and higher must be leak tested from the air handling unit to the vertical riser and from the vertical riser to 5 feet beyond shaft penetration on each and every floor (the ductwork is hidden in the shaft construction).

3. Leak test a representative sample of duct systems designed to operate at static pressures exceeding 3" WC on each floor to complete the minimum 25-percent leak testing required by ASHRAE Standard 90.1 and other energy conservation codes.

G. ***SMACNA-HVAC* Ductwork Seal Classes**

1. Seal Class A: 2–5 percent total system leakage (seal all transverse joints, longitudinal seams, and duct penetrations).

2. Seal Class B: 3–10 percent total system leakage (seal all transverse joints and longitudinal seams).

3. Seal Class C: 5–20 percent total system leakage (seal all transverse joints).

4. Unsealed: 10–40 percent total system leakage.

5. SMACNA recommended seal classes.

SMACNA DUCTWORK SEAL CLASSES

Seal Class	Applicable Static Pressure Construction Class
A	4" WC and higher
B	3" WC
C	2" WC
C	½" WC and higher for all ductwork upstream of VAV terminal units

H. **ASHRAE Standard 90.1-2013 Ductwork Seal Class**

1. ASHRAE Standard 90.1-2013 requires ductwork and all plenums with a pressure rating to be constructed to Seal Class A (seal all transverse joints, longitudinal seams, and duct penetrations).

I. **Recommended Ductwork Seal Classes**

1. Seal Class A: Seal all transverse joints, longitudinal seams, and duct penetrations.

2. Seal Class B: Seal all transverse joints and longitudinal seams.

3. Seal Class C: Seal all transverse joints.

RECOMMENDED DUCTWORK SEAL CLASSES

	SMACNA Pressure Class (in. WC)						
	±½	**±1**	**±2**	**±3**	**±4**	**±6**	**±10**
Supply Ductwork							
Outdoors	A	A	A	A	A	A	A
Unconditioned Space	B	B	B	A	A	A	A
Conditioned Space	B	B	B	A	A	A	A
Return Ductwork							
Outdoors	A	A	A	A	A	A	A
Unconditioned Space	B	B	B	B	A	A	A
Conditioned Space	B	B	B	B	A	A	A
	SMACNA Pressure Class (in. WC)						
	±½	±1	±2	±3	±4	±6	±10
Exhaust Ductwork							
Outdoors	B	B	B	B	A	A	A
Unconditioned Space	B	B	B	B	A	A	A
Conditioned Space	B	B	B	B	A	A	A

J. **Ductwork Materials**

1. Galvanized Steel: HVAC Applications; Most Common; Galvanized steel sheets meeting *ASTM A90, A525, and A527, Lock Forming Quality.*

ASTM Galvanized Coating Designations	Minimum Coating Weight oz./sq.ft. Triple Spot Test Average Total Both Sides	Single Spot Test One Side	Single Spot Test Total Both Sides
G210	2.10	0.72	1.80
G185	1.85	0.64	1.60
G165	1.65	0.56	1.40
G140	1.40	0.48	1.20
G115	1.15	0.40	1.00
G90	0.90	0.32	0.80
G60	0.60	0.20	0.50
G40	0.40	0.12	0.30
G30	0.30	0.10	0.25

2. Carbon steel: Breechings, flues, and stacks; carbon steel meeting *ASTM A569* for stacks and breechings 24" and larger; galvanized sheet steel meeting *ASTM A527* with *ANSI/ASTM A525 G90* zinc coating for stacks and breechings less than 24".

3. Aluminum: Moisture laden air streams; aluminum base alloy sheets meeting *ASTM B209*, Lock Forming Quality.

4. Stainless steel: Kitchen hood and fume hood exhaust; stacks and breechings (prefabricated); Type 304, 304L, 316, or 316L stainless steel sheets meeting *ASTM A167*:
    a. 304 and 316: Non-welded applications.
    b. 304L and 316L: Welded applications.
    c. Kitchen exhaust finish:
        1. Concealed: None.
        2. Exposed: No. 2B, No. 4, or match equipment (No. 4 preferred).

d. Lab fume exhaust finish:
   1. Concealed: No. 2B.
   2. Exposed: No. 2B.

5. Fiberglass: HVAC applications; 1"-thick glass duct board meeting U.L. 181.
6. Fiberglass reinforced: Chemical exhaust; plastic (FRP).
7. Polyvinyl chloride (PVC): Chemical exhaust, underground ducts; PVC conforming to *NFPA 91*, *ASTM D1784*, *D1785, D1927*, and *D2241*.
8. Concrete: Underground ducts, air shafts; reinforced concrete pipe meeting *ASTM C76, Class IV*.
9. Gypsum: Air shafts (generally provided by architects).
   a. 2015 IMC:
      1. Temperature shall not exceed 125°F.
      2. Gypsum board surface temperature must be maintained above the dewpoint.
      3. Gypsum board ducts shall not be used for supply air.
   b. NFPA 90A-2015: Gypsum board ducts shall be permitted to be used for negative pressure exhaust and return ducts where the temperature of the conveyed air does not exceed 125°F.
10. Copper: ornamental.
11. Polyvinyl Steel and Stainless Steel (PVS and PVSS): Chemical exhaust; common type: Halar-coated stainless steel, Teflon-coated stainless steel.
12. Sheet metal gauges (applies to preceding item numbers 1, 3, 4, and 10):
   a. 16, 18, 20, 22, 24, 26 SMACNA or welded construction.
   b. 10, 11, 12, 13, 14 welded construction only.

K. **Flexible Duct**

1. 5–8 ft. maximum recommended length.
2. Insulated, uninsulated.
3. NFPA 90A-2015: 14 feet maximum.

L. **Ductwork Sheet Metal Gauges and Weights**

SMACNA HVAC DUCTWORK SHEET METAL GAUGES

	SMACNA Pressure Class												
	±½		±1		±2		±3		±4		±6		±1
Maximum Duct Dimension	A	B	A	B	A	B	A	B	A	B	A	B	A
4"–8"	26	–	26	–	26	–	24	26	24	26	24	26	22
9"–10"	26	–	26	–	26	–	24	26	22	26	24	24	20
11"–12"	26	–	26	–	26	–	24	26	22	26	20	24	18
13"–14"	26	–	26	–	24	26	22	24	20	24	20	22	18
15"–16"	26	–	26	–	24	26	22	24	20	24	18	22	16
17"–18"	26	–	24	26	22	26	20	24	18	24	18	22	16
19"–20"	24	26	24	26	20	26	18	24	18	24	16	22	–
21"–22"	22	26	22	26	18	26	18	24	18	24	16	22	–
23"–24"	22	26	22	26	18	26	18	24	18	22	16	22	–
25"–26"	20	26	20	26	18	26	18	24	16	22	–	20	–
27"–28"	18	26	18	26	18	24	18	22	16	22	–	20	–
29"–30"	18	26	18	26	18	24	18	22	16	22	–	18	–
31"–36"	181	26	18	24	16	24	16	20	–	20	–	18	–
37"–42"	6	26	16	24	–	22	–	20	–	18	–	16	–
43"–48"	16	26	16	22	–	22	–	18	–	18	–	16	–
49"–54"	–	26	–	22	–	20	–	18	–	18	–	16	–
55"–60"	–	24	–	22	–	20	–	18	–	16	–	16	–
61"–72"	–	22	–	18	–	18	–	16	–	16	–	16	–
73"–84"	–	22	–	18	–	16	–	16	–	16	–	16	–
85"–96"	–	20	–	18	–	16	–	16	–	16	–	16	–
97"–108"	–	18	–	16	–	16	–	16	–	16	–	16	–
109"–120"	–	16	–	16	–	16	–	16	–	16	–	16	–

Notes:

1. **The table is based on the following:**
   a. **Column A: Duct gauge requirement with no reinforcement.**

   b. **Column B: Duct gauge with reinforcement as indicated below.**

c. ±½" Pressure Class: 5 feet reinforcing spacing for 19"–120".

d. ±1" Pressure Class: 5 feet reinforcing spacing for 17"–108", and 4 fe spacing for 109"–120".

e. ±2" Pressure Class: 5 feet reinforcing spacing for 13"–84", 4 feet spacing for 85"–108", and 3 feet spacing for 109"–120".

f. ±3" Pressure Class: 5 feet reinforcing spacing for 4"–84", 4 feet spacing for 85"–96", and 3 feet spacing for 97"–120".

g. ±4" Pressure Class: 5 feet reinforcing spacing for 4"–60", 4 feet spacing for 61"–72", and 3 feet spacing for 73"–120".

h. ±6" Pressure Class: 5 feet reinforcing spacing for 4"–48", 4 feet spacing for 49"–60", and 3 feet spacing for 61"–120".

i. ±10" Pressure Class: 5 feet reinforcing spacing for 4"–42", 4 feet spacing for 43"–54", 3 feet spacing for 55"–72", and 2 feet spacing f 73"–120".

2. Lighter sheet metal gauges may be used with additional reinforcing, and heavier gauges may be used with less reinforcing (see the SMAC manuals).

3. Commercial installations recommend a 24-gauge minimum.

	SMACNA Pressure Class												
Maximum	±½		±1		±2		±3		±4		±6		±1
Duct Dimension	A	B	A	B	A	B	A	B	A	B	A	B	A

SHEET METAL GAUGES AND WEIGHTS

	Material Weight lbs./sq.ft.		
Sheet Metal Gauge	Galvanized Steel	300 Series Stainless Steel	Aluminum
26	0.906	0.748	0.224
24	1.156	0.987	0.282
22	1.406	1.231	0.352
20	1.656	1.491	0.451
18	2.156	2.016	0.563
16	2.656	2.499	0.718
14	3.281	3.154	0.901
12	4.531	4.427	1.141
10	5.781	5.670	1.436

SHEET METAL GAUGES

Sheet Metal Gauge	Thickness Inches	Remarks	Sheet Metal Gauge	Thickness Inches	Remarks
0	0.3125	Welded Ductwork Only	19	0.0437	SMACNA Ductwork Construction
1	0.2810		20	0.0375	
2	0.2650		21	0.0343	
3	0.2500		22	0.0312	
4	0.2340		23	0.0280	
5	0.2187		24	0.0250	
6	0.2030		25	0.0218	
7	0.1875		26	0.0187	
8	0.1720		27	0.0170	Gauges Not Permitted for Ductwork Construction
9	0.1560		28	0.0156	
10	0.1400		29	0.0140	
11	0.1250		30	0.0125	
12	0.1090		31	0.0109	
13	0.0937		32	0.0100	
14	0.0780		33	0.0093	
15	0.0700		34	0.0085	
16	0.0625	SMACNA Ductwork Construction	35	0.0078	
17	0.0560		36	0.0070	
18	0.0500				

17.03. Kitchen Exhaust Ducts and Hoods

A. For examples of kitchen hood exhaust systems, see Figs. 17.1 through 17.3.

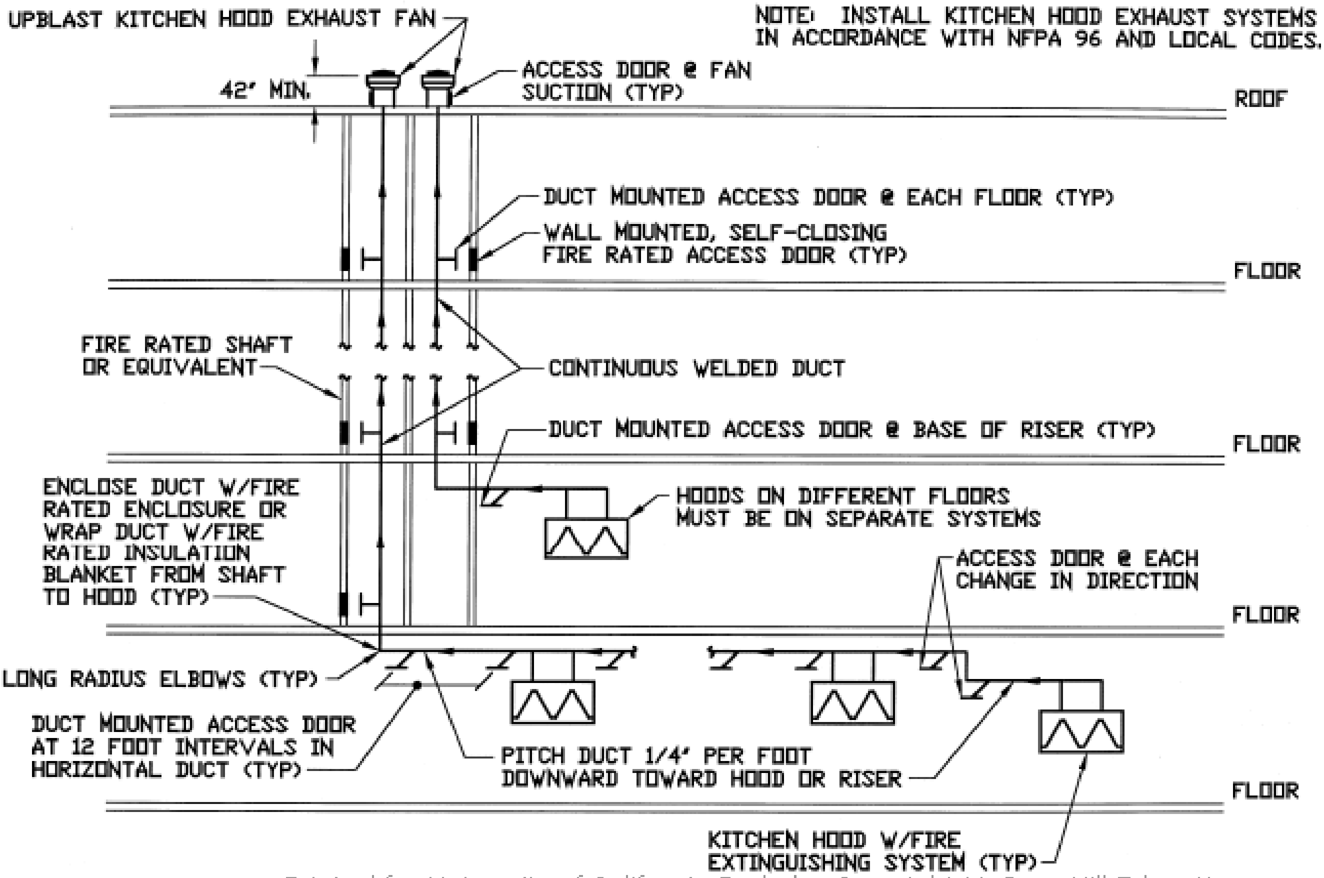


Figure 17.1. KITCHEN HOOD EXHAUST SYSTEM–UPBLAST FAN.

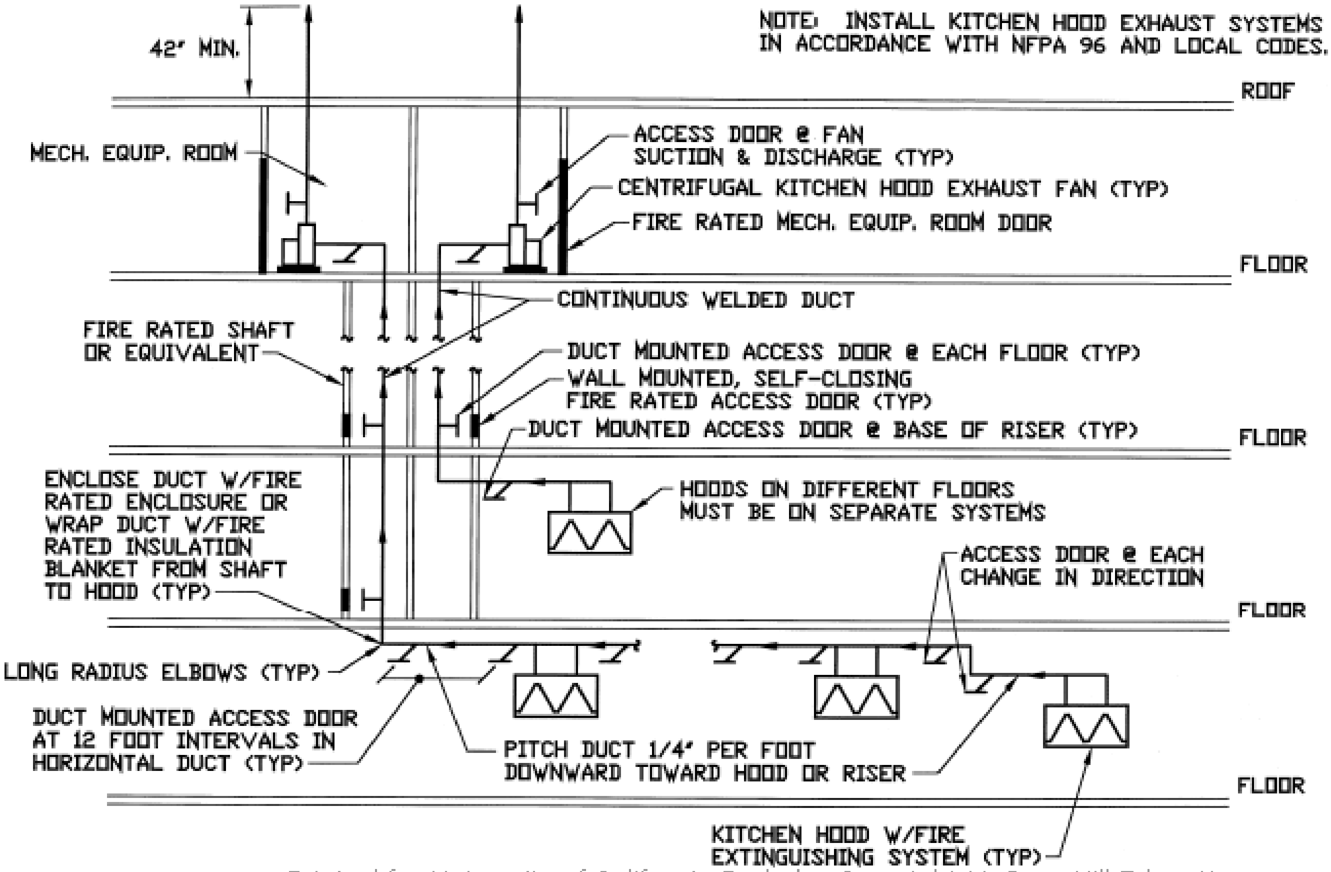


Figure 17.2. KITCHEN HOOD EXHAUST SYSTEM–UTILITY SET FAN.

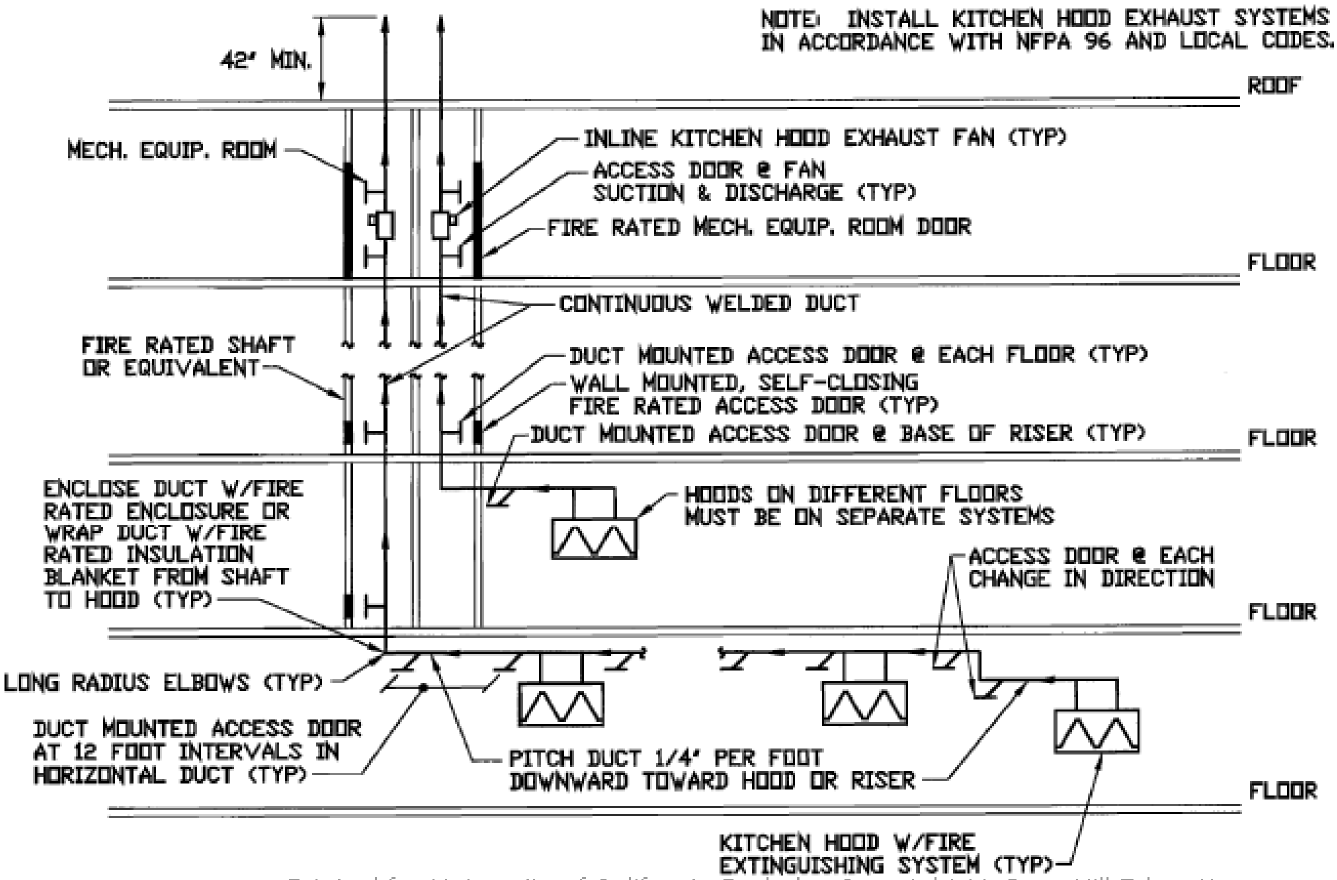


Figure 17.3. KITCHEN HOOD EXHAUST SYSTEM–INLINE FAN.

B. *2015 IMC*

1. Exhaust/makeup air:
   a. Exhaust systems: 500 ft./min. minimum duct velocity.

   b. Type I hood exhaust systems shall be independent of all other exhaust systems. Combining Type I systems permitted if all of the following are met:
      1. Hoods are located on the same floor.

      2. Hoods located in the same room or adjoining rooms.

      3. Interconnecting ducts do not penetrate fire rated assemblies.

      4. Solid fuel appliances must have separate exhaust system.

   c. Type II hood exhaust systems shall be independent of all other exhaust systems. Combining Type II hoods is permitted following the same rules as listed for Type I hoods.

   d. Hoods serving solid fuel cooking appliances must have separate exhaust systems from all the other hoods.

   e. Makeup air systems: ΔT shall not be greater than 10°F, unless it is part of the AC system or will not cause a decrease in comfort conditions.

   f. Supply air shall be approximately equal to the exhaust air.

   g. The exhaust shall terminate a minimum of 40" above the roof.

2. Duct sheet metal construction:
   a. 16 ga. steel.

   b. 18 ga. 304 stainless steel.

   c. Type I hood exhaust ducts shall be all welded or brazed construction.

   d. Type I hood horizontal duct slope:
      1. Horizontal ducts 75 feet or less in length: 1/4" per foot.

      2. Horizontal ducts greater than 75 feet in length: 1" per foot.

   e. Type I hood exhaust ducts shall be enclosed in a fire rated enclosure from the penetration of the ceiling, wall, or floor to the point of the outlet terminal. The rating of the enclosure shall not be less than that of the assembly penetrated and not less than 1 hour.
      1. Horizontal (in kitchen): Fire rated duct wrap recommended.

2. Horizontal (shaft offsets): Shaft enclosure recommended.

3. Vertical: Shaft enclosure recommended.

3. Cleanouts:
   a. Base of riser.

   b. Horizontal:
      1. Every 20 feet.

      2. Not more than 10 feet from changes in direction that are greater than 45 degrees.

4. Hoods:
   a. Type I hoods: Serve appliances that produce grease or smoke—such as griddles, fryers, broilers, ovens, ranges, and wok ranges.
      1. Type I hood exhaust system shall operate automatically through an interlock with the cooking appliances, by means of heat sensors, or by other approved methods.

   b. Type II hoods: Serve appliances that produce heat or steam but do not produce grease or smoke—such as steamers, kettles, pasta cookers, and dishwashers.

   c. Domestic appliances used for commercial purposes shall be provided with Type I or Type II hoods as applicable.

   d. Hood construction:
      1. Type I hoods:
         Steel: 18 gauge
         Stainless steel: 20 gauge

      2. Type II hoods:
         Steel 22 gauge
         Stainless steel: 24 gauge

   e. Hood exhaust:

	Minimum CFM per Lineal Foot of Hood			
	Type of Cooking Appliances			
Type of Hood	**Extra-Heavy Duty**	**Heavy Duty**	**Medium Duty**	**Light Duty**

Type of Hood	Minimum CFM per Lineal Foot of Hood Type of Cooking Appliances			
	Extra-Heavy Duty	Heavy Duty	Medium Duty	Light Duty
Wall-Mounted Canopy	550	400	300	200
Single Island Canopy	700	600	500	400
Double Island Canopy (per side)	550	400	300	250
Backshelf/Pass-Over	Not permitted	400	300	250
Eyebrow	Not permitted	Not permitted	250	250

Notes:

1. **Airflows indicated in the table are net quantity of exhaust air and shall be calculated by subtracting any airflow supplied directly to a hood cavity from the total exhaust flow rate of the hood.**

2. **Where more than one type of appliance is located under a single hood, the highest exhaust rate shall be used.**

3. **Extra-heavy duty cooking appliances: Cooking appliances using solid fuel as the primary source of heat for cooking, such as wood, charcoal, briquettes, and mesquite. Type I hoods serving barbeque pits, barbeque cooking appliances, solid fuel burning stoves and ovens, hickory grilles, charbroilers, and charcoal grilles. Hoods serving these systems must have separate exhaust systems from all the other hoods.**

4. **Heavy duty cooking appliances: Type I hoods serving electric under-fired broilers, electric chain (conveyor) broilers, gas open-burner ranges (with or without oven), electric and gas wok ranges, and electric and gas over-fired (upright) broilers and salamanders.**

5. **Medium duty cooking appliances: Type I hoods serving electric discrete element ranges (with or without oven), electric and gas hot-top ranges, electric and gas griddles, electric and gas double-sided griddles, electric and gas fryers (open deep fat fryers, donut fryers, kettle fryers, and pressure fryers), electric and gas pasta cookers, electric and gas conveyor pizza ovens, electric and gas**

tilting skillets (braising pans), and electric and gas rotisseries.

6. **Light duty cooking appliances: Type I hoods serving electric and gas ovens (standard, bake, roasting, revolving, retherm, convection, combination convection/steamer, conveyor, deck or deck style pizza, and pastry), electric and gas steam-jacketed kettles, electric and gas compartment steamers (both pressure and atmospheric), and electric and gas cheesemelters.**

	Minimum CFM per Lineal Foot of Hood			
	Type of Cooking Appliances			
Type of Hood	Extra-Heavy Duty	Heavy Duty	Medium Duty	Light Duty

C. NFPA 96-2014

1. Exhaust/makeup air:
   a. Exhaust systems: 500 ft./min. minimum duct velocity.

   b. Supply air shall be adequate to prevent negative pressures from exceeding 0.02" WC.

   c. Exhaust shall terminate a minimum of 40" above the roof.

   d. Exhaust ducts shall not pass through fire walls.

   e. All ducts shall lead directly to the exterior of the building to reduce the risk of fire hazard.

   f. Exhaust ducts shall be independent of all other exhaust systems.

   g. Hoods serving solid fuel cooking appliances must have separate exhaust systems from all the other hoods.

2. Duct sheet metal construction:
   a. Carbon steel: 16 gauge

   b. Stainless steel: 18 gauge

   c. Exhaust ducts shall be all welded construction.

   d. Horizontal duct slope:
      1. All ducts shall be installed without forming drips or traps that might collect residues.

      2. All duct runs up to 75 feet in length shall be installed with a minimum of 2 percent slope. Duct runs greater than 75 feet in length shall be installed with a minimum of 8 percent slope.

e. Exhaust ducts shall be enclosed in a fire rated enclosure from the penetration of the ceiling, wall, or floor to the point of the outlet terminal.
   1. Horizontal (in kitchen): Fire rated duct wrap recommended.
   2. Horizontal (shaft offsets): Shaft enclosure recommended.
   3. Vertical: Shaft enclosure recommended.
   4. 1 hour rating minimum for buildings less than four stories.
   5. 2 hour rating minimum for buildings four stories or more.

f. Exhaust duct enclosures shall be vented to the exterior of the building through weather-protected openings.

g. Each exhaust duct system shall constitute an individual system serving only exhaust hoods in one fire zone on one floor.

h. Common duct (manifold) systems: Master kitchen exhaust ducts that serve multiple tenants shall include provisions to bleed air from outdoors or from adjacent spaces into the master exhaust duct to maintain the necessary minimum air velocity in the master exhaust duct.
   1. The bleed air duct shall have a fire damper at least 12" from the master exhaust duct connection.
   2. The bleed air duct shall have a volume balancing damper upstream of the fire damper.
   3. The bleed air duct cannot be used for exhaust of grease-laden vapors and shall be labeled as such.
   4. The bleed air duct shall have the same construction requirements as the exhaust duct.

i. Dampers shall not be installed in exhaust ducts or exhaust duct systems.

3. Cleanouts:
   a. Horizontal: Every 12 feet.
   b. Vertical: Every floor.

4. Hoods:
   a. Steel: 18 gauge.
   b. Stainless steel: 20 gauge.

5. Hood exhaust: Exhaust air volumes for hoods shall be of sufficient level to provide for capture and removal of grease-laden cooking vapors.

6. Fire damper: A fire damper with a 286°F fusible link is required at each supply air connection to the hood.
   a. Exception: If the supply air connection discharges air out the face of the hood rather than the bottom or into the hood and is isolated from the exhaust hood by continuously welded construction, it does not require a fire damper.

D. ASHRAE Standard 154-2011

1. Exhaust/makeup air:
   a. Exhaust systems: 500 ft./min. minimum duct velocity.

   b. The commercial kitchen ventilation system shall provide pressure differentials to control odor migration and to control dust, dirt, and insects.
      1. Kitchen—negative (maximum 0.02 in. w.c.) with respect to dining and other adjacent areas.

      2. Negative with respect to outdoors when the food-service facility shares a wall with an adjacent non-food-service facility, such as a retail center.

   c. Exhaust discharge shall be designed to prevent re-entrainment into air intakes.

   d. The minimum horizontal distance between intakes and discharge shall be 10 feet.

2. Hoods:
   a. Type I hoods: A hood designed to capture heat, smoke and/or grease-laden vapor produced by a cooking process, incorporating listed grease-removal devices and fire suppression equipment. Equipment requiring Type I hoods—ranges, fryers, griddles, broilers, and ovens that produce smoke or grease-laden vapors.

   b. Type II hoods: A hood designed to capture heat, odors, products of combustion, and/or moisture where smoke or grease laden vapor is not present. A Type II hood may or may not have filters or baffles and does not have a fire-suppression system. Equipment requiring Type II hoods—

dishwashers, microwave ovens, toasters, steam tables, popcorn poppers, hot dog cookers, coffee makers, rice cookers, egg cookers, and holding/warming ovens.

c. Mounting heights and overhang requirements:

Type of Hood	Mounting Height	End Overhang	Front Overhang	Rear Overhang
Wall-Mounted Canopy	78"	6"	12"	N/A
Single Island Canopy	78"	12"	12"	12"
Double Island Canopy	78"	12"	12"	N/A
Eyebrow	78"	N/A	12"	N/A
Backshelf/Pass-over	24"	6"	10"	N/A

Note:

1. **Mounting heights are minimum dimensions and are listed with respect to the finished floor except the backshelf/pass-over hoods, which are the maximum dimensions above the cooking surface.**

d. Hood exhaust:

	Type II Minimum Net Exhaust Flow Rate CFM/Lineal Foot of Hood Length	
Type of Hood	**Light Duty**	**Medium Duty**
Wall-Mounted Canopy	200	300
Single Island Canopy	400	500
Double Island Canopy	250	250
Eyebrow	250	250
Backshelf/Pass-over	200	300

e. Appliance duty level:

1. Light duty: A cooking process requiring an exhaust airflow rate of less than 200 CMF/ft. for capture, containment, and removal of the cooking effluent and products of combustion. Gas and electric ovens (standard, bake, roasting, revolving, rethermalizer, convection, combination convection/steamer, conveyor, deck or deck style pizza and pastry ovens, electric and gas steam–jacketed kettles, electric and gas compartment steamers, electric and gas cheesemelters, and electric and gas rethermalizers).

2. Medium duty: A cooking process requiring an exhaust airflow rate of 200 to 300 CMF/ft. for capture, containment, and removal of the cooking effluent and products of combustion. Electric discrete element ranges, electric and gas hot-top ranges, electric and gas griddles, electric and gas double-sided griddles, electric and gas fryers (open deep fat fryers, donut fryers, kettle fryers, and pressure fryers), electric and gas pasta cookers, electric and gas conveyor (pizza) ovens, electric and gas tilting skillets/braising pans, and electric and gas rotisseries.

3. Heavy duty: A cooking process requiring an exhaust airflow rate of 300 to 400 CMF/ft. for capture, containment, and removal of the cooking effluent and products of combustion. Electric and gas underfired broilers, electric and gas chain (conveyor) broilers, gas open-burner ranges (with or without oven), electric and gas wok ranges, electric and gas overfired (upright) broilers, and salamanders.

4. Extra-heavy duty: A cooking process requiring an exhaust airflow rate of greater than 400 CMF/ft. for capture, containment, and removal of the cooking effluent and products of combustion. Appliances using solid fuel such as wood, charcoal, briquettes, and mesquite.

E. Figures 17.4 and 17.5 are photographs of an upblast kitchen hood exhaust fan and makeup air unit in their installed conditions.

Figure 17.4. PHOTOGRAPH OF AN UPBLAST KITCHEN HOOD EXHAUST FAN.

Figure 17.5. PHOTOGRAPH OF A KITCHEN HOOD MAKEUP AIR UNIT.

17.04. Louvers

A. **Louvers: Use stationary louvers only. Do not use operable louvers because they become rusty or become covered with snow and ice and may not operate:**
   1. Intake (outdoor air): 500 ft./min. maximum velocity through free area.
   2. Exhaust or relief: 700 ft./min. maximum velocity through free area.
   3. Free area range:
      a. Metal: 40–70 percent of gross area. Recommend using 50 percent free area.
      b. Wood: 20–25 percent of gross area.
   4. Pressure loss: 0.01–0.10" W.G.

17.05. Volume Dampers (Manual or Balancing Dampers)/ Motor Operated Dampers (Control Dampers)

A. Damper Characteristics

1. Opposed blade: Balancing, mixing, modulating, and 2-position control applications.

2. Parallel blade: Two-position applications (open/closed).

3. Pressure Loss: 0.15" W.G. @ 2000 FPM (full open)

4. Size dampers at a flow rate of approximately 1,200–1,500 CFM/sq.ft. (1,200–1,500 FPM) rather than on duct size.

5. Linkage type:
   a. Concealed—inside duct. When specifying concealed linkage, be careful of duct air temperatures and actuator ratings (e.g., generator radiator exhaust can reach temperatures in excess of some actuator ratings).

   b. Exposed—outside duct.

6. Dampers may be specified with integral insulation.

B. Damper Leakage Classes (AMCA Certified)

1. Class I dampers:
   4.0 CFM/sq.ft. @ 1" W.G. differential.
   8.0 CFM/sq.ft. @ 4" W.G. differential.
   11.0 CFM/sq.ft. @ 8" W.G. differential.
   14.0 CFM/sq.ft. @12" W.G. differential.

2. Class II dampers:
   10.0 CFM/sq.ft. @ 1" W.G. differential.
   20.0 CFM/sq.ft. @ 4" W.G. differential.
   28.0 CFM/sq.ft. @ 8" W.G. differential.
   35.0 CFM/sq.ft. @ 12" W.G. differential.

3. Class III dampers:
   40.0 CFM/sq.ft. @ 1" W.G. differential.
   80.0 CFM/sq.ft. @ 4" W.G. differential.
   112.0 CFM/sq.ft. @ 8" W.G. differential.
   140.0 CFM/sq.ft. @ 12" W.G. differential.

C. Damper Types

1. Standard V-groove blade—approximately 2,000 FPM maximum velocity.

2. Airfoil blade—approximately 4,000 FPM maximum velocity.

D. Recommended

1. Two-position ducted applications: AMCA certified Ultra-low Leakage Class with a maximum 8.0 CFM/sq.ft. leakage rate at a 4" WC pressure differential, airfoil-parallel blade, motor-operated damper.

2. All other ducted applications: AMCA certified Ultra-low Leakage Class with a maximum 8.0 CFM/sq.ft. leakage rate at 4" WC pressure differential, airfoil-opposed blade, motor operated damper.

3. Non-ducted applications: AMCA certified Ultra-low Leakage Class with a maximum 8.0 CFM/sq.ft. leakage rate at 4" WC pressure differential, insulated-airfoil-opposed blade, motor-operated damper.

17.06. Fire Dampers, Smoke Dampers, and Combination Fire/Smoke Dampers

A. Fire, Smoke, and Combination Damper Classifications

1. Damper type:
   a. Expanding curtain type (fire damper only):
      1. Type A: Frame and damper storage are located in the airstream.

      2. Type B: Damper storage is totally recessed out of the airstream.

      3. Type C: Frame and damper storage are totally recessed out of the airstream.

      4. Recommend using Type C in ducted and ducted transfer applications and Type A in transfer grille applications (to fit within the grille dimension, must oversize the grille to account for the frame and blades).

   b. Opposed blade type:
      1. V-groove blades: Maximum velocity of 2,000 FPM.

      2. Airfoil blades: Maximum velocity of 4,000 FPM.

      3. Blades and frame are located in the airstream. Must account for the pressure drop of the damper and frame in static pressure calculations.

      4. Leakage class:

a. Leakage Class I:
   4.0 CFM/sq.ft. @ 1" WC pressure differential.
   8.0 CFM/sq.ft. @ 4" WC pressure differential.
   11.0 CFM/sq.ft. @ 8" WC pressure differential.
   14.0 CFM/sq.ft. @ 12" WC pressure differential.

b. Leakage Class II:
   10.0 CFM/sq.ft. @ 1" WC pressure differential.
   20.0 CFM/sq.ft. @ 4" WC pressure differential.
   28.0 CFM/sq.ft. @ 8" WC pressure differential.
   35.0 CFM/sq.ft. @ 12" WC pressure differential.

c. Leakage Class III: (Not Permitted by IMC Code)
   40.0 CFM/sq.ft. @ 1" WC pressure differential.
   80.0 CFM/sq.ft. @ 4" WC pressure differential.
   112.0 CFM/sq.ft. @ 8" WC pressure differential.
   140.0 CFM/sq.ft. @ 12" WC pressure differential.

d. Leakage Class IV: (Not Permitted by IMC Code)
   60.0 CFM/sq.ft. @ 1" WC pressure differential.
   120.0 CFM/sq.ft. @ 4" WC pressure differential.
   168.0 CFM/sq.ft. @ 8" WC pressure differential.
   210.0 CFM/sq.ft. @ 12" WC pressure differential.

2. Fire rating:
   a. 1-½ hour.

   b. 3 hour.

3. Closure rating:
   a. *U.L. 555* and UL 555S require fire, smoke, and fire/smoke dampers to bear an affixed label stating whether the damper is static or dynamic rated.

   b. Dynamic Rating: Dynamic rated dampers must be U.L. tested and show airflow and maximum static pressure against which the damper will operate (fully close). Dampers are tested to 4" static pressure for "no duct" applications and 8" static pressure for "in duct" applications.

   c. Static Rating: Static rated dampers have not been U.L. tested against airflow and may not close under medium-to-high airflow conditions that may be encountered in HVAC systems that do not shut down in the event of fire.

    d. Recommend using dynamically rated fire/smoke dampers in all applications.

4. Temperature rating of fusible links:
    a. Standard: 165°F.
    b. Optional expanding curtain type (see code requirements): 212°F, 285°F.
    c. Optional blade type (see code requirements): 212°F, 250°F, 285°F, 350°F, 450°F.
    d. Smoke control requirements:
        1. Primary: 285°F (can be overridden by the fire department).
        2. Secondary: 350°F (cannot be overridden by fire department).

B. Fire/Smoke Damper Recommendations

1. Fire dampers (HVAC applications):
    a. Curtain type: Type C, 1-½ or 3 hours to match wall construction, Expanding Curtain Type Fire Damper with 165°F fusible link for all applications (including transfer duct applications) except transfer grille applications shall be Type A.
    b. Blade type: 3,000 FPM minimum velocity, Airfoil Blade, Leakage Class I at 4" WC pressure differential, 1-½ or 3 hours to match wall construction, Dynamic Fire Damper at 8" WC closure rating with 165°F fusible link.
2. Smoke Dampers and Combination Fire/Smoke Dampers (HVAC Applications):
    a. Blade type: 3,000 FPM minimum velocity, Airfoil Blade, Leakage Class I at 4" WC pressure differential, 1-½ or 3 hours to match wall construction, Dynamic Fire Damper at 8" WC closure rating with 250°F primary fusible link and 350°F secondary fusible link.
3. Fire dampers, smoke dampers, and combination fire/smoke dampers (smoke control applications):
    a. Blade type: 3,000 FPM minimum velocity, Airfoil Blade, Leakage Class I at 4" WC pressure differential, 1-½ or 3 hours to match wall construction, Dynamic Fire Damper at 8" WC closure rating with 285°F primary fusible link and 350°F secondary fusible link.
4. Fire dampers, smoke dampers, and fire/smoke dampers: Blowout panels should be considered for ductwork systems under the following circumstances:

a. Whenever, the potential exists for fire, smoke, and/or fire/smoke dampers to close suddenly and cause system pressures to exceed construction pressures of the ductwork especially in systems utilizing dynamic rated dampers.

b. Whenever human operation of fire, smoke, and/or fire/smoke dampers is required by code, by local authorities, or for smoke evacuation systems, in the event that the fire department personnel or owner's operating personnel inadvertently close all the dampers, and system pressures exceed construction pressures of the ductwork.

C. 2015 IMC

1. Installation shall comply with the IMC and manufacturer's installation instructions and listing.

2. Testing procedures:
   a. Fire dampers: UL 555.

   b. Smoke dampers: UL 555S.

   c. Combination fire/smoke dampers: UL 555 and UL 555S.

   d. Ceiling dampers: UL 555C.

   e. Actuators: UL 555 and UL 555S.

3. Fire protection rating:
   a. Less than 3-hour rated assemblies: 1-½ hours

   b. Three hours and above rated assemblies: 3 hours

4. Fire damper actuating devices:
   a. HVAC systems: 50°F above the normal operating temperature within the duct system, but not less than 160°F.

   b. Smoke control systems: 350°F maximum.

5. Smoke damper actuating devices:
   a. Elevated temperature rating: 250°F minimum, 350°F maximum.

   b. Duct mounted smoke damper: Provide duct mounted smoke detector located within 5 feet with no inlet/outlets between damper and detector.

   c. Unducted smoke damper: Provide space-mounted smoke detector located within 5 feet horizontally of wall opening with damper.

d. Smoke dampers may be controlled by the smoke detection system where a smoke detection system is installed in all areas served by the duct in which the damper will be located.

e. Smoke damper leakage rating shall be Class I or II.

6. Combination fire/smoke damper actuating devices:
   a. Smoke control system: 50°F above smoke control design temperature, but not less than 160°F or more than 350°F.

   b. Smoke detectors as indicated under smoke damper actuating devices.

7. Access: Fire, smoke, and fire/smoke dampers shall be provided with an approved means of access. Access doors shall be labeled with 0.5"-high letters minimum reading: "FIRE DAMPER," "SMOKE DAMPER," or "FIRE/SMOKE DAMPER," respectively.

8. Fire dampers are required at duct and transfer openings at the following locations:
   a. Fire walls.

   b. Fire barriers:
      1. Exception: Dampers are not required in penetrations of walls with a required 1-hour fire-resistance rating or less by a ducted HVAC system that is of sheet steel not less than 26 gauge and is continuous from the air-handling equipment to the air outlet or inlet terminals in areas of other than Use Group H where the building is equipped throughout with an automatic sprinkler system.

      2. Exception: Dampers are not required in ducts used as an approved smoke control system *where the damper would interfere with the operation of the smoke control system*.

   a. Fire partitions:
      1. Exception: Dampers are not required in penetrations of tenant separation and corridor walls in buildings of other than Use Group H where the building is equipped throughout with an automatic sprinkler system.

      2. Exception: Dampers are not required in duct systems constructed of code-approved materials that meet all of the following:
         a. Duct size 100 sq. in. or less.

b. Duct constructed of a minimum of 24 gauge steel.

c. Duct cannot have openings that communicate the corridor with adjoining rooms or spaces.

d. Duct is installed above a ceiling.

e. Duct shall not terminate at a fire rated wall with a register.

f. A minimum 12" long × 16 gauge sleeve shall be centered at each duct opening.

3. Exception: Dampers are not required in penetrations of walls with a required 1-hour fire-resistance rating or less by a ducted HVAC system that is of sheet steel not less than 26 gauge and is continuous from the air-handling equipment to the air outlet or inlet terminals in areas of other than Use Group H where the building is equipped throughout with an automatic sprinkler system.

9. Smoke dampers are required at duct and transfer openings at the following locations:
   a. Smoke barriers and corridors with smoke and draft controls.
      1. Exception: Dampers are not required at corridor penetrations where the building is equipped throughout with an approved smoke control system.

      2. Exception: Ducts penetrating smoke barriers where the duct serves a single smoke compartment and are constructed of steel.

      3. Exception: Dampers are not required in ducts that do not serve the corridor and are constructed of minimum 26 gauge steel.

10. Fire and smoke dampers or combination fire/smoke dampers are required at duct and transfer openings at the following locations:
    a. Shaft enclosures:
       1. Exception: Fire dampers are not required in exhaust systems equipped with steel exhaust air subducts extending at least 22" vertically in an exhaust shaft and where there is continuous airflow upward to the outside.

       2. Exception: Fire dampers are not required in penetrations tested in accordance with ASTM E 119 or UL 263 as part of the fire-resistance-rated assembly.

3. Exception: Smoke dampers are not required in bathroom, toilet, kitchen, and clothes dryer exhaust openings equipped with 26 gauge minimum steel exhaust air subducts extending at least 22" vertically in an exhaust shaft and where there is continuous airflow upward to the outside in Groups B and R occupancies equipped throughout with an automatic sprinkler system.

4. Exception: Fire dampers and smoke dampers are not required in ducts used as an approved smoke control system where the damper would interfere with the operation of the smoke control system.

5. Exception: Fire dampers and smoke dampers are not required in parking garage exhaust ducts that are separated from other building shafts by not less than 2-hour fire-resistance-rated assemblies.

6. Exception: Fire dampers and smoke dampers are not required in kitchen and clothes dryer exhaust systems.

b. Horizontal Assemblies (floor, floor/ceiling, roof ceiling): Horizontal assemblies shall be protected by shaft enclosures.
   1. Exception: Fire dampers may be permitted to be installed at each floor provided the duct does not connect more than two floors in occupancies other than I-2 (Hospital) Occupancies and I-3 (Prison) Occupancies.

c. Fire/smoke dampers may be an individual fire damper and smoke damper in series or a combination fire/smoke damper.

D. NFPA 90A-2015

1. Installation shall comply with the manufacturer's installation instructions and UL listing.

2. Testing procedures:
   a. Fire dampers: UL 555.

   b. Smoke dampers: UL 555S.

   c. Combination fire/smoke dampers: UL 555 and UL 555S.

   d. Ceiling dampers: UL 555C.

   e. Actuators: UL 555 and UL 555S.

3. Fire protection rating:

   a. Less than 3-hour-rated assemblies: 1-½ hours

   b. Three-hour and above rated assemblies: 3 hours

4. Fire damper actuating devices:
   a. HVAC systems: 50°F above ambient temperature, but not less than 160°F.

   b. Smoke control systems: 50°F above smoke control design temperature, but not more than 350°F.

5. Smoke damper actuating devices:
   a. Duct Mounted Smoke Damper: Provide duct mounted smoke detector located within 5 feet with no inlet/outlets between damper and detector.

   b. Unducted Smoke Damper: Provide space mounted smoke detector located within 5 feet of wall opening with damper.

   c. Smoke dampers may be controlled by area smoke detectors at smoke doors, corridors, or where total coverage smoke detection system is employed.

6. Combination fire/smoke damper actuating devices:
   a. Smoke Control System: 50°F above smoke control design temperature, but not more than 350°F.

   b. Smoke detectors as indicated under smoke damper actuating devices.

7. Access: A service opening shall be provided adjacent to each fire damper, smoke damper, fire/smoke damper, and smoke detector. Service openings shall be identified with letters 0.5" high minimum to indicate the type and location of the fire protection device.

8. Fire dampers shall be installed at the following penetration locations:
   a. Fire-rated walls and partitions with a 2-hour rating or more.

   b. Air transfer openings in partitions that are required to have a fire resistance rating and in which other openings are required to be protected.

   c. Fire-rated floors: Where air ducts extend through only one floor and serve only two adjacent floors, the ducts may be enclosed or provided with a fire damper at each floor penetration.

   d. Shafts:
      1. Less than four stories: One-hour rating.

2. Four stories or more: Two-hour rating.

3. Shafts that constitute air ducts or that enclose air ducts used for movement of environmental air shall not enclose the following:
    a. Kitchen hood exhaust ducts.

    b. Ducts used to remove flammable vapors.

    c. Ducts used for moving, conveying, or transporting stock, vapor, or dust.

    d. Ducts used for the removal of nonflammable corrosive fumes and vapors.

    e. Refuse or linen chutes.

    f. Piping containing hazardous materials or combustible piping.

    g. Combustible storage.

4. Exception: A fire damper is not required where the following occur:
    a. Branch ducts connected to enclosed exhaust risers enclosed in shafts.

    b. The airflow moves upward.

    c. Steel subducts at least 22" in length are carried up inside the riser from each inlet.

    d. The riser is appropriately sized to accommodate the flow restriction created by the subduct.

9. Smoke dampers shall be installed at the following penetration locations:
    a. Smoke Barriers: Damper shall be installed within 2 feet of the smoke barrier and prior to any air inlet or outlet.
        1. Exception: Smoke dampers shall not be required on air systems other than where necessary for the proper function of that system where the system is designed specifically to accomplish the following:
            a. Function as an engineered smoke control system.

            b. Provide air to other areas of the building during a fire emergency.

            c. Provide pressure differentials during a fire emergency.

        2. Exception: Smoke dampers shall not be required where ducts serve a single smoke compartment and no other smoke compartment.

b. Smoke dampers shall be installed in air handling systems with a capacity greater than 15,000 CFM to isolate air handling equipment (supply and return).
    1. Exception: Air handling units located on the floor they serve and serving only that floor do not require smoke dampers.
    2. Exception: Air handling units located on the roof and serving only the floor immediately below the roof do not require smoke dampers.

10. Fire/smoke dampers shall be installed at the following penetration locations:
    a. Fire-rate and smoke-rated walls and partitions.

11. Maintenance: At least every 4 years the following shall be performed:
    a. Fusible links shall be removed.

    b. All dampers shall be operated to verify that they close fully.

    c. The latch, if provided, shall be checked.

    d. Moving parts shall be lubricated as necessary.

17.07. HVAC Smoke Detection Systems Control

A. 2015 IMC

1. HVAC systems shall be equipped with smoke detectors listed and labeled for installation in air distribution systems.

2. Smoke detectors shall be installed in accordance with NFPA 72 and manufacturer's installation instructions.

3. Smoke detectors are required at the following locations:
    a. Return Air Systems: Smoke detectors are required in return air systems with design air capacity greater than 2,000 CFM (upstream of filters, exhaust connections, outdoor air connections, etc.).

    b. Common Supply and Return Systems: Smoke detectors are required in the return air system where multiple air handling systems share common supply or return air ducts or plenums with a combined capacity greater than 2,000 CFM.

    c. Return Air Risers: Smoke detectors are required in systems where the return air riser serves two or more floors and serves any portion of a return air system having a design capacity greater than 15,000 CFM. Smoke detectors shall be installed at each floor where the return air duct connects to the riser.

d. Fan Powered Boxes: Smoke detectors are required for fan-powered boxes with a capacity greater than 2,000 CFM.

e. Exception: Smoke detectors are not required where air distribution systems are incapable of spreading smoke beyond the enclosing walls, floors, and ceilings of the room or space in which smoke is generated.

f. Exception: Smoke detectors are not required where the building is equipped throughout with area smoke detectors connected to a fire alarm system.

4. Control/supervision:
   a. Upon detection of smoke, the air distribution system shall be shutdown. Air distribution systems that are part of a smoke control system shall switch to smoke control operation.

   b. All smoke detectors shall be connected to the fire alarm system where a fire alarm system is required.

B. NFPA 90A-2015

1. Smoke detectors shall be installed in accordance with NFPA 72 and the manufacturer's installation instructions.

2. Smoke dampers installed to isolate the air handling system shall be arranged to close automatically when the system is not in operation.

3. Supply Air System: Smoke detectors are required in supply air systems with design air capacity greater than 2,000 CFM (downstream of filters, upstream of supply connections).

4. Return Air Risers: Smoke detectors are required in systems where the return air riser serves two or more floors and serves any portion of a return air system having a design capacity greater than 15,000 CFM. Smoke detectors shall be installed at each floor where the return air duct connects to the riser.
   a. Exception: Return air smoke detectors are not required where the entire space served by the air distribution system is protected by an area smoke detection system.

5. Exception: Smoke detectors are not required for fan units whose sole function is to remove air from the inside of the building to the outside of the building.

6. Smoke detectors shall automatically stop their respective fans.

7. Where the system is functioning as an engineered smoke control system, the smoke detectors are not required to stop the air handling system.

C. Because the IMC and NFPA requirements are different, I recommend meeting both codes by providing smoke detectors in both the supply and return systems with a capacity greater than 2,000 CFM.

17.08. Sound Attenuators

A. Types

1. Rectangular: 3-, 5-, 7-, and 10-foot lengths.

2. Round: Two or three times the diameter.

B. Locating

1. Centrifugal and axial fans:
   a. Discharge: 1 duct diameter from discharge for every 1,000 FPM.

   b. Intake: 0.75 duct diameters from intake for every 1,000 FPM.

2. Elbows: 3 duct diameters up and down stream.

3. Terminal Boxes: 1 duct diameter down stream.

4. Mechanical Equipment Rooms: Install in or close to mechanical equipment room wall opening.

17.09. Terminal Units

A. For diagrammatic examples of air terminal units, see Fig. 17.6.

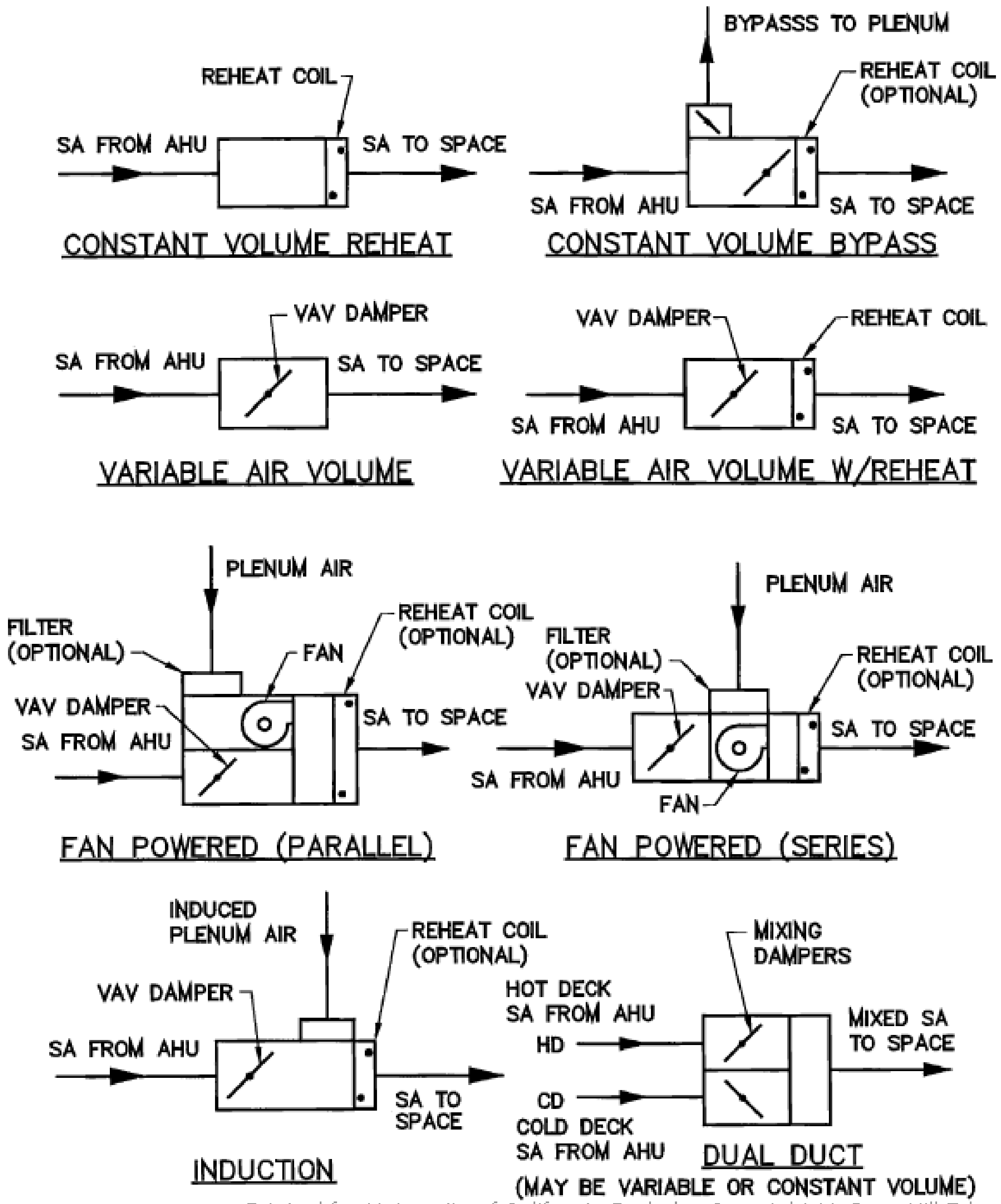


Figure 17.6. AIR TERMINAL UNITS.

B. Variable Air Volume (VAV) Terminal Units

1. VAV w/o reheat:
   a. Controls space temperature by varying the quantity of supply air.
   b. Supply temperature is constant.
   c. The energy savings is due to reduced supply air quantities and therefore reduced horsepower.
2. VAV w/reheat:

a. Integrates heating at the VAV terminal unit to offset heating load, limit maximum humidity, provide reasonable air movement, and provide ventilation air.

3. Minimum CFM for VAV boxes:
   a. Dictated by ASHRAE Standard 62.1.

   b. Typical office building range: 30 percent to 50 percent of design flow.

   c. When interior spaces are occupied or lights are on, the VAV terminal unit will maintain a minimum flow to offset the heat gain. Therefore, the only time a VAV terminal unit serving an interior space will be closed is when the space is unoccupied and the lights are off.

C. Fan-Powered Terminal Units

1. Parallel fan-powered terminal units:
   a. Primary air is modulated in response to cooling demands and the fan is energized at a predetermined reduced primary airflow.

   b. The fan is the first stage of heating by utilizing plenum air for return. The second stage of heating is the reheat coil.

   c. Fan is located outside the primary airstream to allow intermittent fan operation.

2. Series fan-powered terminal units:
   a. A constant volume fan mixes primary air with a varying amount of air from the ceiling plenum.

   b. The fan is located within the primary airstream and runs continuously.

   c. Series fan-powered boxes are generally used with low temperature supply air from the air handling unit.

D. Induction Terminal Units

1. Reduces cooling capacity by reducing primary air and inducing room or ceiling plenum air.

2. Incorporates reduced supply air quantity energy savings of the VAV system and air volume to space is constant to reduce the effect of stagnant air.

E. Constant Volume Reheat (CVR) Terminal Units

1. CVR terminal units provide zone/space control for areas of unequal loading, simultaneous cooling/heating, and close tolerance of temperature control.
2. Conditioned air is delivered to each terminal unit at a fixed temperature, and is then reheated to control space temperature.
3. Energy inefficient system.
4. Energy codes restrict the use of these systems.

F. Constant Volume Bypass Terminal Units

1. Variation of CVR system. Constant volume primary air system with VAV secondary system.
2. Supply air to space varied by dumping air to return air plenum.
3. Energy codes restrict the use of these systems.

G. Dual Duct Terminal Units

1. A constant volume of supply air is delivered to the space.
2. Space temperature is maintained by mixing varying amounts of hot and cold air.
3. Energy inefficient system.
4. Energy codes restrict the use of these systems.

H. VAV Dual Duct Terminal Units

1. A variable volume of supply air is delivered to space.
2. Space temperature is maintained by supplying either hot or cold air in varying amounts and limiting the amount of hot and cold air mixing.
3. More energy efficient than standard dual duct systems.
4. Energy codes restrict the use of these systems.

I. Single Zone Systems

1. Supply unit serves single temperature zone and varies supply air temperature to control space temperature.
2. Single zone systems are generally small capacity systems or serve large open

areas.

J. Multizone Systems

1. Supply unit serves two or more temperature zones and varies supply air temperature to each zone by mixing hot and cold air with zone dampers at the unit to control space temperature.

2. Each zone is served by a separate ductwork system.

3. Similar to dual duct systems, but where mixing occurs at the unit.

4. Limited number of zones, inflexible system, energy inefficient, and not a recommended system.

5. Multizone systems are essentially obsolete.

K. Terminal Unit Types

1. Pressure-independent terminal units: Terminal unit airflow is independent of pressure upstream of the box. Recommend using pressure-independent terminal units.

2. Pressure-dependent terminal units: Terminal unit airflow is dependent on pressure upstream of box.

L. Terminal Unit Installation

1. Locate all terminal units for unobstructed access to unit access panels, controls, and valving.

2. Minimum straight duct length upstream of terminal units:
   a. Manufacturers generally recommend 1.5 duct diameters based on terminal unit inlet size.

   b. 2.0 duct diameters are the recommended minimum.

   c. 3.0 –5.0 duct diameters are preferred.

   d. Best to use 3 feet of straight duct upstream of terminal units because you do not have to concern yourself with box size when producing ductwork layout (the maximum terminal unit inlet size is 16 inches with 2 duct diameters, which results in 32 inches, and most of the time you are not using 16-inch terminal units).

3. Duct runout to the terminal unit should never be smaller than the terminal unit's inlet size; it may be larger than the inlet size, though. Terminal unit inlet and discharge ductwork should be sized based on ductwork sizing criteria and not the terminal unit inlet and discharge connection sizes. The transition from the inlet and discharge connection sizes to the air terminal unit should be made at the terminal unit. A minimum of 3 feet of straight duct should be provided upstream of all terminal units.

M. Zoning

1. Partitioned offices:
   a. One, two, three, or four offices/terminal unit.

   b. Two or three offices/terminal unit most common.

   c. One office/terminal unit; most desirable, also most expensive.

2. Open offices:
   a. 400–1,200 sq.ft./terminal unit.

3. Perimeter and interior spaces should be zoned separately.

4. Group spaces/zones/rooms/areas of similar thermal occupancy:
   a. For example, group offices with offices.

   b. Don't put offices with conference rooms or other dissimilar rooms.

   c. Don't put east offices with south offices, etc.

   d. Corner offices or spaces should be treated separately.

17.10. Process Exhaust Systems

A. **Ductwork material must be selected to suit the material or chemical being exhausted—carbon steel, 304 or 316 stainless steel, Teflon- or Halar-coated stainless steel, fiberglass reinforced plastic (FRP), and polyvinyl chloride (PVC) are some examples. Sprinklers are generally required in FRP and PVC ductwork systems in all sizes larger than 8 inches in diameter.**

B. **Process exhaust ductwork cannot penetrate fire walls, fire separation assemblies, or smoke walls.**

C. **Process exhaust systems should be provided with a blast gate or butterfly damper at each tap for a hood or equipment, at each lateral, and at each submain. At all fans, large laterals, and submains, a tight shutoff—style butterfly damper should be provided for balancing and positive shutoff in addition to the blast gate. Blast gates should be specified with a wiper gasket, of EPDM or other suitable material, to provide as tight a seal as possible for blast gates; otherwise, blast gates tend to experience high leakage rates. Wind loading on blast gates installed on the roof or outside the building must be considered, especially in large blast gates. Blast gate blades will act as a sail in the wind and cause considerable stress on the ductwork system.**

D. **Process exhaust ductwork should be sloped a minimum of 1/8 inch per foot with a drain provided at the low point. The drain should be piped to the appropriate waste system.**

E. **Process exhaust systems are required, in most cases, to undergo a treatment process—scrubbing, abatement, burning, or filtering.**

F. **Duct sizing must be based on capture velocities and entrainment velocities of the material or chemical being exhausted. For most chemical or fume exhaust systems, the mains, risers, submains, and large laterals should be sized for 2,000 to 3,000 feet per minute, and small laterals and branches should be sized for 1,500 to 2,500 feet per minute. Discharge stacks should be sized for 3,000 to 4,000 feet per minute discharge velocity and should terminate a minimum of 8 feet above the roof and a minimum of 10 feet from any openings or intakes. Properly locate discharge stacks and coordinate discharge height to prevent contamination of outside air intakes, cooling tower intakes, and combustion air intakes. Clearly indicate termination heights.**

G. **The connection to a fume hood or other piece of equipment will generally require between 1.0 and 3.0 inches WC negative pressure.**

H. **Branches and laterals should be connected above duct centerline. If branches and laterals are connected below the duct centerline, drains will be required at the low point. Hoods, tools, and equipment must be protected from the possibility of drainage contaminating or entering equipment when taps are connected below the centerline.**

I. **Specify proper pressure class upstream and downstream of scrubbers and other abatement equipment.**

J. **When ductwork is installed outside or in unconditioned spaces, verify if condensation will occur on the outside or the inside of this duct. Insulate the duct and/or heat trace if required.**

K. **Process exhaust fans are required to be on emergency power by code.**

L. **Process exhaust ductwork cannot penetrate fire-rated construction. Fire dampers are generally not desirable. If penetrating fire-rated construction cannot be avoided, process exhaust ductwork must be enclosed in a fire-rated enclosure until it exits the building, or sprinkler protection located inside the duct may be used if approved by authority having jurisdiction.**

M. **Provide pressure ports at the end of all laterals, submains, and mains.**

N. **Generally, drains are required in fan scroll, scrubber, and other abatement equipment.**

O. **Provide flexible connections at fans and specify flexible connection material suitable for application.**

P. **If adjustable or variable frequency drives are required or used, locate and coordinate them with the electrical engineer. Use direct drive fans with adjustable or variable frequency drives.**

17.11. Hazardous Exhaust Systems

A. **Hazardous exhaust systems as defined in the 2015 IMC.**

B. **A hazardous exhaust system shall include exhaust systems containing:**

1. Flammable vapors.
2. Gases.
3. Fumes.
4. Mists.
5. Dusts.

6. Paint residue.

7. Corrosive fumes.

8. Volatile or airborne materials posing a health hazard.

C. **Hazardous Exhaust System Concerns:**

1. Combustibility.

2. Flammability.

3. Toxicity.

4. Corrosiveness.

5. Explosiveness.

6. Microbial.

7. Pathogenic.

D. **Hospital and research laboratory exhaust systems are designed to exhaust different substances. However, these substances may or may not be flammable, toxic, corrosive, or pathogenic. For the classification and identification of hazardous substances, see NFPA 704. NFPA 704 covers the concerns of combustibility, flammability, toxicity, corrosiveness, and explosiveness, but this standard does not address microbial, pathogenic, and other hospital or research exhaust hazards. Laboratory exhaust systems involve the use of chemicals and other hazardous materials for:**

1. Testing.

2. Analysis.

3. Teaching.

4. Research.

5. Development.

6. Nonproduction purposes.

7. 2015 IMC: Laboratory exhaust systems do not have to be independent of other exhaust systems provided that all of the following conditions are met.

a. All hazardous exhaust ductwork and other laboratory exhaust ductwork within both the occupied space and the shaft is under negative pressure while in operation.

b. All hazardous exhaust ductwork manifolded together within the occupied space must originate in the same fire area.

c. Hazardous exhaust ductwork originating in different fire areas and manifolded together in a common shaft shall be equipped with steel exhaust air subducts extending at least 22" vertically in exhaust shafts where there is continuous airflow upward to the outside.

d. Each control branch has a flow regulating device.

e. Perchloric acid hoods must have a separate exhaust system and cannot be manifolded together.

f. Radioisotope hoods are properly filtered.

g. Biological safety cabinets are properly filtered.

h. A provision is made for continuous operation of the negative static pressure in the ductwork with standby fans.

E. **Hazardous exhaust systems are required wherever hazardous materials are present to create any one of the following conditions. The criteria is based on the normal operating conditions and not the conditions that would exist in an accident or unusual condition.**

1. Materials are present in concentrations at room temperature that exceed 25 percent of the lower flammability limit of the substance.

2. Materials are present at any concentration with a health hazard of 4.
   a. Exception: Hazardous exhaust systems are required for laboratories where materials are present with a health hazard of 4 at concentrations exceeding 1 percent of the median lethal concentration for acute inhalation toxicity.

3. Materials are present with a health hazard of 1, 2, or 3 at concentrations exceeding 1 percent of the median lethal concentration for acute inhalation toxicity.

F. **Hazardous exhaust systems must be independent of all other exhaust systems.**

G. **Hazardous exhaust systems must be located in separate shafts from other HVAC duct systems and in separate shafts from other hazardous exhaust systems originating in different fire areas.**

H. **Hazardous exhaust systems must segregate compatible and incompatible material exhaust air streams.**

I. **Ductwork design methods:**
   1. Vapors, gases, and smoke: Constant velocity or equal friction methods.

   2. Dust, fibers, and particulate matter: Constant velocity method.

J. **Exhaust makeup air shall be delivered to the space with hazardous exhaust systems in quantities nearly equal to the exhaust air quantities. Normally, the makeup air is slightly less than the exhaust air quantity to help confine the contaminants.**

K. **Hazardous exhaust systems that penetrate a fire-rated floor/ceiling assembly or fire-rated wall assembly must be enclosed in a fire-resistance-rated shaft enclosure, meeting the fire rating of the highest rated assembly penetrated, from where the exhaust system penetrates the rated enclosure until it terminates outdoors.**

L. **In lieu of enclosing the hazardous exhaust duct that penetrates a fire-rated wall assembly in a fire-rated enclosure, the interior of the duct may be equipped with an approved automatic fire suppression system suitable for the materials being exhausted. Hazardous exhaust systems that penetrate a fire-rated floor/ceiling assembly must be enclosed in a fire-rated shaft, regardless of whether the system is protected by a fire suppression system or not.**

M. **Ducts shall not penetrate a fire wall.**

N. **Fire dampers and smoke dampers are not permitted in hazardous exhaust systems.**

O. **Hazardous exhaust systems shall be protected by an approved automatic fire suppression system. The automatic fire suppression system must be compatible with the materials being exhausted (water, dry chemical, carbon dioxide).**
   1. Except hazardous exhaust systems conveying nonflammable and noncombustible materials at all concentrations.

2. Except in metallic and noncombustible, nonmetallic exhaust ducts in semiconductor fabrication facilities.

3. Except in ducts where the cross-sectional duct diameter is less than 10 inches.

4. Except in laboratory hoods or laboratory exhaust systems.

P. **Ductwork materials for hazardous exhaust systems:**

1. G90 galvanized steel.

2. 304 or 316 stainless steel.

3. Fiberglass reinforced: Chemical exhaust; plastic (FRP).

4. Polyvinyl chloride (PVC): Chemical exhaust, underground ducts; PVC conforming to *NFPA 91, ASTM D1784, D1785, D1927,* and *D2241.*

5. Polyvinyl steel and stainless steel (PVS and PVSS): Chemical exhaust; common type: Halar-coated stainless steel, Teflon-coated stainless steel.

6. Nonmetal ducts must meet the ASTM E 84 flame spread index of 25 or less and a smoke developed index of 50 or less.

7. Ducts shall be constructed of materials that are compatible with the exhaust.

8. Minimum hazardous exhaust duct thickness:

	Minimum Nominal Thickness		
Diameter of Duct or Maximum Side Dimension	**Nonabrasive Materials (Gauge)**	**Nonabrasive/Abrasive Materials (Gauge)**	**Abrasive Materials (Gauge)**
0–8 inches	24	22	20
9–18 inches	22	20	18
19–30 inches	20	18	16
Over 30 inches	18	16	14

Q. **Hazardous exhaust ducts shall be supported at intervals not** exceeding 10 feet. Supports shall be constructed of noncombustible materials.

17.12. Galvanized Rectangular Ductwork Weights—Pound per Lineal Foot

GALVANIZED RECTANGULAR DUCT WEIGHT

	Sheet Metal Gauge						
Width + Depth Inches	26 (12")	24 (24")	22 (48")	20 (60")	18 (60+")	16	Surface Area sq.ft./ln.ft.
38	–	9.15	11.13	13.11	17.07	21.03	6.34
39	–	9.39	11.42	13.46	17.52	21.58	6.50
40	–	9.63	11.72	13.80	17.97	22.13	6.67
41	–	9.87	12.01	14.15	18.42	22.69	6.83
42	–	10.12	12.30	14.49	18.87	23.24	7.00
43	–	10.36	12.60	14.84	19.31	23.79	7.17
44	–	10.60	12.89	15.18	19.76	24.35	7.34
45	–	10.84	13.18	15.53	20.21	24.90	7.50
46	–	11.08	13.47	15.87	20.66	25.45	7.67
47	–	11.32	13.77	16.22	21.11	26.00	7.83
48	–	11.56	14.06	16.56	21.56	26.56	8.00
49	–	11.80	14.35	16.91	22.01	27.11	8.17
50	–	12.04	14.65	17.25	22.46	27.67	8.34
51	–	12.28	14.94	17.60	22.91	28.22	8.50
52	–	12.52	15.23	17.94	23.36	28.77	8.67
53	–	12.76	15.52	18.29	23.81	29.32	8.83
54	–	13.01	15.82	18.63	24.26	29.88	9.00
55	–	13.25	16.11	18.98	24.70	30.43	9.17
56	–	13.49	16.40	19.32	25.15	30.99	9.34
57	–	13.73	16.70	19.67	25.60	31.54	9.50
58	–	13.97	16.99	20.01	26.05	32.09	9.67
59	–	14.21	17.28	20.36	26.50	32.65	9.83
60	–	14.45	17.58	20.70	26.95	33.20	10.00

Notes:

1. **Table includes 25 percent allowance for bracing, hangers, reinforcing, joints, and seams. Add 10 percent for insulated**

Sheet Metal Gauge

Width + Depth Inches	26 (12")	24 (24")	22 (48")	20 (60")	18 (60+")	16	Surface Area sq.ft./ln.ft.
61	–	–	17.87	21.05	27.40	33.75	10.17
62	–	–	18.16	21.39	27.85	34.31	10.34
63	–	–	18.45	21.74	28.30	34.86	10.50
64	–	–	18.75	22.08	28.75	35.41	10.67
65	–	–	19.04	22.43	29.20	35.97	10.83
66	–	–	19.33	22.77	29.65	36.52	11.00
67	–	–	19.63	23.12	30.09	37.07	11.17
68	–	–	19.92	23.46	30.54	37.63	11.34
69	–	–	20.21	23.81	30.99	38.18	11.50
70	–	–	20.50	24.15	31.44	38.73	11.67
71	–	–	20.80	24.50	31.89	39.29	11.83
72	–	–	21.09	24.84	32.34	39.84	12.00
73	–	–	21.38	25.19	32.79	40.39	12.17
74	–	–	21.68	25.53	33.24	40.95	12.34
75	–	–	21.97	25.88	33.69	41.50	12.50
76	–	–	22.26	26.22	34.14	42.05	12.67
77	–	–	22.55	26.57	34.59	42.61	12.83
78	–	–	22.85	26.91	35.04	43.16	13.00
79	–	–	23.14	27.26	35.48	43.71	13.17
80	–	–	23.43	27.60	35.93	44.27	13.34
81	–	–	23.73	27.95	36.38	44.82	13.50
82	–	–	24.02	28.29	36.83	45.37	13.67
83	–	–	24.31	28.64	37.28	45.93	13.83
84	–	–	24.61	28.98	37.73	46.48	14.00
85	–	–	24.90	29.33	39.18	47.03	14.17
86	–	–	25.19	29.67	38.63	48.59	14.34
87	–	–	25.48	30.02	39.08	48.14	14.50
88	–	–	25.78	30.36	39.53	48.69	14.67
89	–	–	26.07	30.71	39.98	49.25	14.83
90	–	–	26.36	31.05	40.43	49.80	15.00
91	–	–	26.66	31.40	40.87	50.35	15.17
92	–	–	26.95	31.74	41.32	50.91	15.34
93	–	–	27.24	32.09	41.77	51.46	15.50
94	–	–	27.53	32.43	42.22	52.01	15.67
95	–	–	27.83	32.78	42.67	52.57	15.83
96	–	–	28.12	33.12	43.12	53.12	16.00
97	–	–	28.41	33.47	43.57	53.67	16.17

Notes:

1. **Table includes 25 percent allowance for bracing, hangers, reinforcing, joints, and seams. Add 10 percent for insulated ductwork systems.**

Width + Depth Inches	Sheet Metal Gauge 26 (12")	24 (24")	22 (48")	20 (60")	18 (60+")	16	Surface Area sq.ft./ln.ft.
98	–	–	28.71	33.81	44.02	54.23	16.34
99	–	–	29.00	34.16	44.47	54.78	16.50
100	–	–	29.29	34.50	44.92	55.33	16.67
101	–	–	29.58	34.85	45.37	55.89	16.83
102	–	–	29.88	35.19	45.82	56.44	17.00
103	–	–	30.17	35.54	46.26	56.99	17.17
104	–	–	30.46	35.88	46.71	57.55	17.34
105	–	–	30.76	36.23	47.16	58.10	17.50
106	–	–	31.05	36.57	47.61	58.65	17.67
107	–	–	31.34	36.92	48.06	59.21	17.83
108	–	–	31.64	37.26	48.51	59.76	18.00
109	–	–	31.93	37.61	48.96	60.31	18.17
110	–	–	32.22	37.95	49.41	60.87	18.34
111	–	–	32.51	38.30	49.86	61.42	18.50
112	–	–	32.81	38.64	50.31	61.97	18.67
113	–	–	33.10	38.99	50.76	62.53	18.83
114	–	–	33.39	39.33	51.21	63.08	19.00
115	–	–	33.69	39.68	51.65	63.63	19.17
116	–	–	33.98	40.02	52.10	64.19	19.34
117	–	–	34.27	40.37	52.55	64.74	19.50
118	–	–	34.56	40.71	53.00	65.29	19.67
119	–	–	34.86	41.06	53.45	65.85	19.83
120	–	–	35.15	41.40	53.90	66.40	20.00
121	–	–	35.44	41.75	54.35	66.95	20.17
122	–	–	35.74	42.09	54.80	67.51	20.34
123	–	–	36.03	42.44	55.25	68.06	20.50
124	–	–	36.32	42.78	55.70	68.61	20.67
125	–	–	36.61	43.13	56.15	69.17	20.83
126	–	–	36.91	43.47	56.60	69.72	21.00
127	–	–	37.20	43.82	57.04	70.27	21.17
128	–	–	37.49	44.16	57.49	70.83	21.34
129	–	–	37.79	44.51	57.94	71.38	21.50
130	–	–	38.08	44.85	58.39	71.93	21.67
131	–	–	38.37	45.20	58.84	72.49	21.83
132	–	–	38.67	45.54	59.29	73.04	22.00
133	–	–	38.96	45.89	59.74	73.59	22.17

Notes:

Width + Depth Inches	Sheet Metal Gauge 26 (12")	24 (24")	22 (48")	20 (60")	18 (60+")	16	Surface Area sq.ft./ln.ft.
134	–	–	39.25	46.23	60.19	74.15	22.34
135	–	–	39.54	46.58	60.64	74.70	22.50
136	–	–	39.84	46.92	61.09	75.25	22.67
137	–	–	40.13	47.27	61.54	75.81	22.83
138	–	–	40.42	47.61	61.99	76.36	23.00
139	–	–	40.72	47.96	62.43	76.91	23.17
140	–	–	41.01	48.30	62.88	77.46	23.34
141	–	–	41.30	48.65	63.33	78.02	23.50
142	–	–	41.59	48.99	63.78	78.57	23.67
143	–	–	41.88	49.34	64.23	79.13	23.83
144	–	–	42.18	49.68	64.68	79.68	24.00
145	–	–	42.47	50.03	65.13	80.23	24.17
146	–	–	42.77	50.37	65.58	80.79	24.34
147	–	–	43.06	50.72	66.03	81.34	24.50
148	–	–	43.35	51.06	66.48	81.89	24.67
149	–	–	43.64	51.41	66.93	82.45	24.83
150	–	–	43.94	51.75	67.38	83.00	25.00
151	–	–	44.23	52.10	67.82	83.55	25.17
152	–	–	44.52	52.44	68.27	84.11	25.34
153	–	–	44.82	52.79	68.72	84.66	25.50
154	–	–	45.11	53.13	69.17	85.21	25.67
155	–	–	45.40	53.48	69.62	85.77	25.83
156	–	–	45.70	53.82	70.07	86.32	26.00
157	–	–	45.99	54.17	70.52	86.87	26.17
158	–	–	46.28	54.51	70.97	87.43	26.34
159	–	–	46.57	54.86	71.42	87.98	26.50
160	–	–	46.87	55.20	71.87	88.53	26.67
161	–	–	47.16	55.55	72.32	89.09	26.83
162	–	–	47.45	55.89	72.77	89.64	27.00
163	–	–	47.75	56.24	73.21	90.19	27.17
164	–	–	48.04	56.58	73.66	90.75	17.34
165	–	–	48.33	56.93	74.11	91.30	27.50
166	–	–	48.62	57.27	74.56	91.85	27.67
167	–	–	48.92	57.62	75.01	92.41	27.83
168	–	–	49.21	57.96	75.46	92.96	28.00
169	–	–	49.50	58.31	75.91	93.51	28.17

Notes:

Width + Depth Inches	Sheet Metal Gauge 26 (12")	24 (24")	22 (48")	20 (60")	18 (60+")	16	Surface Area sq.ft./ln.ft.
170	–	–	49.80	58.65	76.36	94.07	28.34
171	–	–	50.09	59.00	76.81	94.62	28.50
172	–	–	50.38	59.34	77.26	95.17	28.67
173	–	–	50.67	59.69	77.71	95.73	28.83
174	–	–	50.97	60.03	78.16	96.28	29.00
175	–	–	51.26	60.38	78.60	96.83	29.17
176	–	–	51.55	60.72	79.05	97.39	29.34
177	–	–	51.85	61.07	79.50	97.94	29.50
178	–	–	52.14	61.41	79.95	98.49	29.67
179	–	–	52.43	61.76	80.40	99.05	29.83
180	–	–	52.73	62.10	80.85	99.60	30.00
181	–	–	53.02	62.45	81.30	100.15	30.17
182	–	–	53.31	62.79	81.75	100.71	30.34
183	–	–	53.60	63.14	82.20	101.26	30.50
184	–	–	53.90	63.48	82.65	101.81	30.67
185	–	–	54.19	63.83	83.10	102.37	30.83
186	–	–	54.48	64.17	83.55	102.92	31.00
187	–	–	54.78	64.52	83.99	103.47	31.17
188	–	–	55.07	64.86	84.44	104.03	31.34
189	–	–	55.36	65.21	84.89	104.58	31.50
190	–	–	55.65	65.55	85.34	105.13	31.67
191	–	–	55.95	65.90	85.79	105.69	31.83
192	–	–	56.24	66.24	86.24	106.24	32.00
193	–	–	56.53	66.59	86.69	106.79	32.17
194	–	–	56.83	66.93	87.14	107.35	32.34
195	–	–	57.12	67.28	87.59	107.90	32.50
196	–	–	57.41	67.62	88.04	108.45	32.67
197	–	–	57.70	67.97	88.49	109.01	32.83
198	–	–	58.00	68.31	88.94	109.56	33.00
199	–	–	58.29	68.66	89.38	110.11	33.17
200	–	–	58.58	69.00	89.83	110.67	33.34
201	–	–	58.88	69.35	90.28	111.22	33.50
202	–	–	59.17	69.69	90.73	111.77	33.67
203	–	–	59.46	70.04	91.18	112.33	33.83
204	–	–	59.76	70.38	91.63	112.88	34.00
205	–	–	60.05	70.73	92.08	113.43	34.17

Notes:

1. Table includes 25 percent allowance for bracing, hangers, reinforcing, joints, and seams. Add 10 percent for insulated

Width + Depth Inches	26 (12")	24 (24")	22 (48")	20 (60")	18 (60+")	16	Surface Area sq.ft./ln.ft.
			Sheet Metal Gauge				
206	–	–	60.34	71.07	92.53	113.99	34.34
207	–	–	60.63	71.42	92.98	114.54	34.50
208	–	–	60.93	71.76	93.43	115.09	34.67
209	–	–	61.22	72.11	93.88	115.65	34.83
210	–	–	61.51	72.45	94.33	116.20	35.00
211	–	–	61.81	72.80	94.77	116.75	35.17
212	–	–	62.10	73.14	95.22	117.31	35.34
213	–	–	62.39	73.49	95.67	117.86	35.50
214	–	–	62.68	73.83	96.12	118.41	35.67
215	–	–	62.98	74.18	96.57	118.97	35.83
216	–	–	63.27	74.52	97.02	119.52	36.00
217	–	–	63.56	74.87	97.47	120.07	36.17
218	–	–	63.86	75.21	97.92	120.63	36.34
219	–	–	64.15	75.56	98.37	121.18	36.50
220	–	–	64.44	75.90	98.82	121.73	36.67
221	–	–	64.73	76.25	99.27	122.29	36.83
222	–	–	65.03	76.59	99.72	122.84	37.00
223	–	–	65.32	76.94	100.16	123.39	37.17
224	–	–	65.61	77.28	100.61	123.95	37.34
225	–	–	65.91	77.63	101.06	124.50	37.50
226	–	–	66.20	77.97	101.51	125.05	37.67
227	–	–	66.49	78.32	101.96	125.61	37.83
228	–	–	66.79	78.66	102.41	126.16	38.00
229	–	–	67.08	79.01	102.86	126.71	38.17
230	–	–	67.37	79.35	103.31	127.27	38.34
231	–	–	67.66	79.70	103.76	127.82	38.50
232	–	–	67.96	80.04	104.21	128.37	38.67
233	–	–	68.25	80.39	104.66	128.93	38.83
234	–	–	68.54	80.73	105.11	129.48	39.00
235	–	–	68.84	81.08	105.55	130.03	39.17
236	–	–	69.13	81.42	106.00	130.59	39.34
237	–	–	69.42	81.77	106.45	131.14	39.50
238	–	–	69.71	82.11	106.90	131.69	39.67
239	–	–	70.01	82.46	107.35	132.25	39.83
240	–	–	70.30	82.80	107.80	132.80	40.00

Notes:

Width + Depth Inches	Sheet Metal Gauge 26 (12")	24 (24")	22 (48")	20 (60")	18 (60+")	16	Surface Area sq.ft./lin.ft.

1. Table includes 25 percent allowance for bracing, hangers, reinforcing, joints, and seams. Add 10 percent for insulated ductwork systems.
2. The first column is the sum of the width and depth of the duct (i.e., a 20 × 10 duct equals 30 inches).
3. Columns 2 through 7 give the weight of galvanized steel ducts in pounds per lineal foot.
4. Column 8 gives the ductwork surface area used for estimating insulation.
5. Numbers in parentheses below the sheet metal gauges indicate the maximum duct dimension for the indicated gauge.

17.13. Galvanized Round Ductwork Weights—Pound per Lineal Foot

GALVANIZED ROUND DUCT WEIGHT

Diameter	Gauge 26	24	22	20	18	16	Surface Area sq.ft./Lin.ft.
3	0.89	1.13	1.38	1.63	2.12	2.61	0.79
4	1.19	1.51	1.84	2.17	2.82	3.48	1.05
5	1.48	1.89	2.30	2.71	3.53	4.35	1.31
6	1.78	2.27	2.76	3.25	4.23	5.22	1.57
7	2.08	2.65	3.22	3.79	4.94	6.08	1.83
8	2.37	3.03	3.68	4.34	5.64	6.95	2.09
9	2.67	3.40	4.14	4.88	6.35	7.82	2.36
10	2.96	3.78	4.60	5.42	7.06	8.69	2.62
11	3.26	4.16	5.06	5.96	7.76	9.56	2.88
12	3.56	4.54	5.52	6.50	8.47	10.43	3.14
14	4.15	5.30	6.44	7.59	9.88	12.17	3.67
16	4.74	6.05	7.36	8.67	11.29	13.91	4.19

Notes:

1. Table includes 25 percent allowance for bracing, hangers,

Diameter	Gauge 26	24	22	20	18	16	Surface Area sq.ft./Lin.ft.
18	5.34	6.81	8.28	9.75	12.70	15.65	4.71
20	5.93	7.57	9.20	10.84	14.11	17.38	5.24
22	6.52	8.32	10.12	11.92	15.52	19.12	5.76
24	7.12	9.08	11.04	13.01	16.93	20.86	6.28
26	7.71	9.84	11.96	14.09	18.34	22.60	6.81
28	8.30	10.59	12.88	15.17	19.76	24.34	7.33
30	8.89	11.35	13.80	16.26	21.17	26.08	7.85
32	9.49	12.11	14.72	17.34	22.58	27.81	8.38
34	10.08	12.86	15.64	18.43	23.99	29.55	8.90
36	10.67	13.62	16.56	19.51	25.40	31.29	9.42
38	11.27	14.38	17.48	20.59	26.81	33.03	9.95
40	11.86	15.13	18.40	21.68	28.22	34.77	10.47
42	12.45	15.89	19.32	22.76	29.63	36.51	11.00
44	13.05	16.65	20.24	23.84	31.04	38.24	11.52
46	13.64	17.40	21.17	24.93	32.46	39.98	12.04
48	14.23	18.16	22.09	26.01	33.87	41.72	12.57
50	–	18.92	23.01	27.10	35.28	43.46	13.09
52	–	19.67	23.93	28.18	36.69	45.20	13.61
54	–	20.43	24.85	29.26	38.10	46.94	14.14
56	–	21.18	25.77	30.35	39.51	48.67	14.66
58	–	21.94	26.69	31.43	40.92	50.41	15.18
60	–	22.70	27.61	32.52	42.33	52.15	15.71
62	–	23.45	28.53	33.60	43.74	53.89	16.23
64	–	24.21	29.45	34.68	45.16	55.63	16.76
66	–	24.97	30.37	35.77	46.57	57.37	17.28
68	–	25.72	31.29	36.85	47.98	59.10	17.80
70	–	26.48	32.21	37.93	49.39	60.84	18.33
72	–	27.24	33.13	39.02	50.80	62.58	18.85
74	–	27.99	34.05	40.10	52.21	64.32	19.37
76	–	28.75	34.97	41.19	53.62	66.06	19.90
78	–	29.51	35.89	42.27	55.03	67.80	20.42
80	–	30.26	36.81	43.35	56.44	69.53	20.94
82	–	31.02	37.73	44.44	57.86	71.27	21.47
84	–	31.78	38.65	45.52	59.27	73.01	21.99
86	–	32.53	39.57	46.61	60.68	74.75	22.51
88	–	33.29	40.49	47.69	62.09	76.49	23.04
90	–	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Notes:

1. Table includes 25 percent allowance for bracing, hangers, reinforcing, joints, and seams. Add 10 percent for insulated

Diameter	Gauge 26	24	22	20	18	16	Surface Area sq.ft./Lin.ft.
90	–	34.05	41.41	48.77	63.50	78.23	23.56
92	–	34.80	42.33	49.86	64.91	79.96	24.09
94	–	35.56	43.25	50.94	66.32	81.70	24.61
96	–	36.32	44.17	52.02	66.73	83.44	25.13
98	–	37.07	45.09	53.11	69.14	85.18	25.66
100	–	37.83	46.01	54.19	70.55	86.92	26.18
102	–	38.59	46.93	55.28	71.97	88.66	26.70
104	–	39.34	47.85	56.36	73.38	90.39	27.23
106	–	40.10	48.77	57.44	74.79	92.13	27.75
108	–	40.86	49.69	58.53	76.20	93.87	28.27
110	–	41.61	50.61	59.61	77.61	95.61	28.80
112	–	42.37	51.53	60.70	79.02	97.35	29.32
114	–	43.13	52.45	61.78	80.43	99.09	29.85
116	–	43.88	53.37	62.86	81.84	100.82	30.37
118	–	44.64	54.29	63.95	83.25	102.56	30.89
120	–	45.40	55.21	65.03	84.67	104.30	31.42
122	–	46.15	56.13	66.11	86.08	106.04	31.94
124	–	46.91	57.05	67.20	87.49	107.78	32.46
126	–	47.67	57.97	68.28	88.90	109.52	32.99
128	–	48.42	58.89	69.37	90.31	111.25	33.51
130	–	49.18	59.81	70.45	91.72	112.99	34.03
132	–	49.94	60.73	71.53	93.13	114.73	34.56
134	–	50.69	61.66	72.62	94.54	116.47	35.08
136	–	51.45	62.58	73.70	95.95	118.21	35.60
138	–	52.21	63.50	74.79	97.37	119.95	36.12
140	–	52.96	64.42	75.87	98.78	121.68	36.65
142	–	53.72	65.34	76.95	100.19	123.42	37.18
144	–	54.48	66.26	78.04	101.60	125.16	37.70

Notes:

1. **Table includes 25 percent allowance for bracing, hangers, reinforcing, joints, and seams. Add 10 percent for insulated ductwork systems.**

2. **Table gives weight of galvanized steel ducts in pounds per lineal foot.**

17.14. Galvanized Flat Oval Ductwork Weights—Pounds per Lineal Foot

GALVANIZED FLAT OVAL DUCTWORK WEIGHT

Nominal Flat Oval Size	Equiv. Round	Cross Sectional Area sq.ft.	Surface Area sq.ft./ln.ft.	Gauge	Weight lbs./ln.ft.
3 × 8	5.1	0.15	1.57	24	2.3
3 × 9	5.6	0.18	1.83	24	2.6
3 × 11	6.0	0.22	2.09	24	3.1
3 × 12	6.4	0.25	2.36	24	3.4
3 × 14	6.7	0.29	2.62	24	3.8
3 × 15	7.0	0.32	2.88	24	4.2
3 × 17	7.3	0.36	3.14	24	4.5
3 × 19	7.5	0.39	3.40	24	4.9
3 × 22	8.0	0.46	3.93	24	5.7
4 × 7	5.7	0.18	1.57	24	2.3
4 × 9	6.2	0.22	1.83	24	2.6
4 × 10	6.7	0.26	2.09	24	3.1
4 × 12	7.2	0.31	2.36	24	3.4
4 × 13	7.6	0.35	2.62	24	3.8
4 × 15	8.0	0.40	2.88	24	4.2
4 × 17	8.4	0.44	3.14	24	4.5
4 × 18	8.5	0.48	3.40	24	4.9
4 × 20	9.0	0.52	3.68	24	5.3
4 × 21	9.5	0.57	3.93	24	5.7
5 × 8	6.6	0.25	1.83	24	2.6
5 × 10	7.3	0.30	2.09	24	3.0
5 × 11	7.9	0.35	2.36	24	3.4
5 × 13	8.4	0.41	2.62	24	3.8
5 × 14	8.8	0.46	2.88	24	4.2
5 × 16	9.3	0.52	3.14	24	4.5
5 × 18	9.5	0.57	3.40	24	4.9

Notes:

Nominal Flat Oval Size	Equiv. Round	Cross Sectional Area sq.ft.	Surface Area sq.ft./ln.ft.	Gauge	Weight lbs./ln.ft.
5 × 19	10.0	0.63	3.66	24	5.3
5 × 21	10.5	0.68	3.93	24	5.7
6 × 8	6.9	0.26	1.83	24	2.6
6 × 9	7.7	0.33	2.09	24	3.0
6 × 11	8.4	0.39	2.36	24	3.4
6 × 12	8.9	0.46	2.62	24	3.8
6 × 14	9.6	0.53	2.88	24	4.2
6 × 15	10.1	0.59	3.14	24	4.5
6 × 17	10.5	0.65	3.40	24	4.9
6 × 19	11.0	0.72	3.66	24	5.3
6 × 20	11.5	0.79	3.93	24	5.7
6 × 22	11.8	0.85	4.18	24	6.0
6 × 23	12.0	0.92	4.45	24	6.4
6 × 25	12.5	0.98	4.71	22	8.3
6 × 28	13.2	1.11	5.23	22	9.2
6 × 30	13.5	1.18	5.50	22	9.7
6 × 31	13.8	1.24	5.76	22	10.1
6 × 33	14.0	1.31	6.02	22	10.6
6 × 34	14.3	1.38	6.28	22	11.0
6 × 36	14.5	1.44	6.54	22	11.5
6 × 37	14.9	1.50	6.80	22	12.0
6 × 39	15.0	1.57	7.07	22	12.4
6 × 41	15.4	1.64	7.33	22	12.9
6 × 44	15.9	1.77	7.85	22	13.8
6 × 45	16.0	1.83	8.12	22	14.3
6 × 52	17.0	2.09	9.16	20	19.0
6 × 59	18.0	2.42	10.47	20	21.7
7 × 10	8.7	0.42	2.36	24	3.4
7 × 12	9.4	0.50	2.62	24	3.8
7 × 13	10.1	0.57	2.88	24	4.2
7 × 15	10.7	0.65	3.14	24	4.5
7 × 16	11.0	0.73	3.40	24	4.9
7 × 18	11.7	0.80	3.67	24	5.3
7 × 20	12.0	0.88	3.93	24	5.7
7 × 21	12.5	0.95	4.19	24	6.1

Notes:

Nominal Flat Oval Size	Equiv. Round	Cross Sectional Area sq.ft.	Surface Area sq.ft./ln.ft.	Gauge	Weight lbs./ln.ft.
7 × 21	12.5	0.95	4.19	24	6.1
7 × 23	13.0	1.03	4.45	24	6.4
8 × 10	9.0	0.44	2.36	24	3.4
8 × 11	9.8	0.53	2.62	24	3.8
8 × 13	10.6	0.62	2.88	24	4.2
8 × 14	11.2	0.70	3.14	24	4.5
8 × 16	11.5	0.79	3.40	24	4.9
8 × 17	12.0	0.87	3.67	24	5.3
8 × 18	12.4	0.90	3.80	24	5.5
8 × 19	13.0	0.96	3.93	24	5.7
8 × 21	13.5	1.05	4.18	24	6.1
8 × 22	14.0	1.13	4.45	24	6.4
8 × 24	14.4	1.23	4.71	24	6.8
8 × 27	15.2	1.40	5.23	22	9.2
8 × 30	15.9	1.57	5.76	22	10.2
8 × 33	16.6	1.74	6.28	22	11.0
8 × 35	17.0	1.83	6.54	22	11.5
8 × 36	17.3	1.92	6.80	22	12.0
8 × 39	17.9	2.09	7.33	22	12.9
8 × 43	18.6	2.27	7.85	22	13.8
8 × 46	19.1	2.44	8.37	22	14.7
8 × 49	19.6	2.62	8.89	20	18.4
8 × 50	20.0	2.71	9.16	20	19.0
8 × 52	20.2	2.80	9.42	20	19.5
8 × 58	21.0	3.14	10.47	20	21.7
8 × 65	22.0	3.49	11.52	20	23.8
8 × 71	23.0	3.84	12.57	18	33.9
8 × 77	24.0	4.19	13.61	18	36.7
9 × 12	10.8	0.64	2.88	24	4.2
9 × 14	11.5	0.74	3.14	24	4.6
9 × 15	12.0	0.83	3.40	24	4.9
9 × 17	12.9	0.93	3.67	24	5.3
9 × 18	13.5	1.03	3.93	24	5.7
9 × 20	14.0	1.13	4.19	24	6.1
9 × 22	14.5	1.23	4.45	24	6.4

Notes:

Nominal Flat Oval Size	Equiv. Round	Cross Sectional Area sq.ft.	Surface Area sq.ft./ln.ft.	Gauge	Weight lbs./ln.ft.
9 × 22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9 × 23	15.0	1.33	4.71	24	6.8
10 × 12	11.0	0.66	2.88	24	4.2
10 × 13	11.9	0.77	3.14	24	4.5
10 × 15	12.5	0.87	3.40	24	4.9
10 × 16	13.4	1.00	3.66	24	5.3
10 × 18	14.0	1.09	3.93	24	5.7
10 × 19	14.5	1.20	4.19	24	6.1
10 × 20	14.7	1.25	4.18	24	6.1
10 × 21	15.0	1.31	4.45	24	6.4
10 × 23	15.7	1.42	4.71	24	6.8
10 × 24	16.0	1.53	4.97	24	7.2
10 × 26	16.7	1.63	5.23	22	9.2
10 × 27	17.0	1.75	5.50	22	9.7
10 × 29	17.7	1.86	5.76	22	10.2
10 × 30	18.0	1.96	6.02	22	10.6
10 × 32	18.5	2.07	6.28	22	11.1
10 × 34	19.0	2.18	6.54	22	11.5
10 × 35	19.3	2.29	6.80	22	12.0
10 × 38	20.1	2.51	7.33	22	12.9
10 × 41	20.8	2.73	7.85	22	13.8
10 × 43	21.0	2.84	8.12	22	14.3
10 × 45	21.5	2.95	8.37	22	14.7
10 × 48	22.1	3.16	8.89	22	15.6
10 × 51	22.8	3.39	9.42	20	19.5
10 × 52	23.0	3.49	9.69	20	20.1
10 × 54	23.3	3.60	9.95	20	20.6
10 × 57	23.8	3.82	10.56	20	21.9
10 × 60	24.4	4.04	11.00	20	22.8
10 × 63	25.0	4.25	11.52	20	23.8
10 × 67	25.5	4.47	12.05	20	24.9
10 × 70	26.0	4.69	12.51	20	25.9
10 × 73	26.4	4.91	13.10	18	35.3
10 × 76	27.0	5.13	13.61	18	36.7
11 × 14	13.0	0.90	3.40	24	4.9

Notes:

Nominal Flat Oval Size	Equiv. Round	Cross Sectional Area sq.ft.	Surface Area sq.ft./ln.ft.	Gauge	Weight lbs./ln.ft.
11 × 16	13.6	1.02	3.67	24	5.3
11 × 17	14.0	1.14	3.93	24	5.7
11 × 19	15.0	1.26	4.19	24	6.1
11 × 22	16.3	1.50	4.71	24	6.8
11 × 24	17.0	1.62	4.97	24	7.2
12 × 14	13.0	0.92	3.40	24	4.9
12 × 15	13.8	1.05	3.67	24	5.3
12 × 17	14.5	1.18	3.93	24	5.7
12 × 18	15.3	1.31	4.19	24	6.1
12 × 20	16.0	1.44	4.45	24	6.4
12 × 21	16.7	1.57	4.71	24	6.8
12 × 25	18.0	1.83	5.24	22	9.2
12 × 28	19.1	2.09	5.76	22	10.1
12 × 31	20.1	2.36	6.28	22	11.1
12 × 34	20.9	2.62	6.81	22	12.0
12 × 37	21.9	2.88	7.33	22	12.9
12 × 40	22.7	3.14	7.85	22	13.8
12 × 42	23.0	3.27	8.12	22	14.3
12 × 43	23.5	3.40	8.37	22	14.7
12 × 45	24.0	3.53	8.64	22	15.2
12 × 47	24.3	3.67	8.89	22	15.6
12 × 50	25.0	3.93	9.42	20	19.5
12 × 53	25.7	4.19	9.95	20	20.6
12 × 56	26.3	4.45	10.56	20	21.9
12 × 59	26.9	4.71	11.00	20	22.8
12 × 62	27.5	4.98	11.52	20	23.8
12 × 65	28.1	5.23	12.05	20	24.9
12 × 69	28.7	5.51	12.57	20	26.0
12 × 72	29.2	5.76	13.10	18	35.3
12 × 78	30.0	6.28	14.14	18	38.1
12 × 81	31.0	6.54	14.66	18	39.5
14 × 17	16.0	1.37	4.19	24	6.1
14 × 19	17.0	1.53	4.45	24	6.4
14 × 20	17.5	1.68	4.71	24	6.8

Nominal Flat Oval Size	Equiv. Round	Cross Sectional Area sq.ft.	Surface Area sq.ft./ln.ft.	Gauge	Weight lbs./ln.ft.
14 × 22	18.0	1.83	4.97	24	7.2
14 × 25	18.9	1.98	5.23	24	7.6
14 × 27	20.2	2.30	5.76	22	10.1
14 × 28	21.0	2.44	6.02	22	10.6
14 × 30	21.3	2.60	6.28	22	11.0
14 × 31	22.0	2.75	6.54	22	11.5
14 × 33	22.4	2.91	6.80	22	12.0
14 × 34	23.0	3.05	7.07	22	12.4
14 × 36	23.4	3.21	7.33	22	12.9
14 × 38	24.0	3.36	7.59	22	13.3
14 × 39	24.4	3.51	7.85	22	13.8
14 × 41	25.0	3.67	8.12	22	14.3
14 × 42	25.3	3.84	8.37	22	14.7
14 × 45	26.1	4.12	8.89	22	15.6
14 × 49	26.9	4.43	9.42	20	19.5
14 × 52	27.7	4.74	9.95	20	20.6
14 × 55	28.4	5.04	10.56	20	21.9
14 × 58	29.1	5.35	11.00	20	22.8
14 × 61	29.8	5.65	11.52	20	23.9
14 × 64	30.5	5.96	12.05	20	24.9
14 × 67	31.1	6.27	12.57	20	26.0
14 × 71	31.7	6.57	13.10	18	35.9
14 × 77	33.0	7.18	14.14	18	38.1
16 × 19	18.0	1.75	4.71	24	6.8
16 × 21	19.0	1.92	4.97	24	7.2
16 × 22	19.5	2.08	5.23	24	7.6
16 × 24	20.0	2.27	5.50	24	7.9
16 × 25	20.9	2.44	5.76	22	10.2
16 × 29	22.3	2.79	6.28	22	11.0
16 × 30	23.0	2.97	6.54	22	11.5
16 × 32	23.5	3.13	6.80	22	12.0
16 × 33	24.0	3.32	7.07	22	12.4
16 × 35	24.7	3.48	7.33	22	12.9
16 × 36	25.0	3.67	7.59	22	13.3
16 × 38	25.7	3.84	7.85	22	13.8

Notes:

1. Equivalent round is the diameter of the round duct which will have

Nominal Flat Oval Size	Equiv. Round	Cross Sectional Area sq.ft.	Surface Area sq.ft./ln.ft.	Gauge	Weight lbs./ln.ft.
16 × 41	26.8	4.19	8.38	22	14.7
16 × 44	27.7	4.53	8.89	22	15.6
16 × 46	28.0	4.71	9.16	22	16.1
16 × 47	28.6	4.88	9.42	22	16.6
16 × 49	29.0	5.06	9.69	20	20.1
16 × 51	29.4	5.23	9.95	20	20.6
16 × 54	30.2	5.59	10.47	20	21.7
16 × 57	31.0	5.93	11.00	20	22.8
16 × 60	31.8	6.28	11.52	20	23.8
16 × 63	32.5	6.61	12.05	20	24.9
16 × 66	33.3	6.98	12.57	20	26.0
16 × 69	34.0	7.33	13.09	20	27.1
16 × 76	35.0	8.03	14.14	18	38.1
16 × 79	36.0	8.38	14.66	18	39.5
18 × 21	19.9	2.16	5.23	24	7.6
18 × 23	21.0	2.36	5.50	24	7.9
18 × 24	21.6	2.56	5.76	24	8.3
18 × 26	22.0	2.75	6.02	22	10.6
18 × 27	23.1	2.95	6.28	22	11.0
18 × 29	24.0	3.14	6.54	22	11.5
18 × 31	24.5	3.35	6.80	22	12.0
18 × 32	25.0	3.53	7.07	22	12.4
18 × 34	25.7	3.73	7.33	22	12.9
18 × 37	27.0	4.13	7.85	22	13.8
18 × 40	28.1	4.53	8.37	22	14.7
18 × 43	29.1	4.92	8.89	22	15.6
18 × 46	30.2	5.31	9.42	22	16.6
18 × 49	31.1	5.70	9.95	20	20.6
18 × 53	32.0	6.10	10.56	20	21.9
18 × 56	32.9	6.49	11.00	20	22.8
18 × 59	33.7	6.88	11.52	20	23.8
18 × 62	34.5	7.26	12.05	20	24.9
18 × 65	35.3	7.67	12.51	20	25.9
18 × 68	36.0	8.07	13.10	20	27.1

Notes:

1. Equivalent round is the diameter of the round duct which will have

Nominal Flat Oval Size	Equiv. Round	Cross Sectional Area sq.ft.	Surface Area sq.ft./ln.ft.	Gauge	Weight lbs./ln.ft.
18 × 71	37.0	8.44	13.61	18	36.7
18 × 78	38.0	9.23	14.66	18	39.5
20 × 26	23.6	3.05	6.28	22	11.0
20 × 29	25.2	3.49	6.81	22	12.0
20 × 31	26.0	3.71	7.07	22	12.4
20 × 33	26.6	3.93	7.33	22	12.9
20 × 34	27.0	4.15	7.59	22	13.3
20 × 36	28.0	4.36	7.85	22	13.8
20 × 39	29.2	4.81	8.37	22	14.7
20 × 40	30.0	5.02	8.64	22	15.2
20 × 42	30.3	5.23	8.89	22	15.6
20 × 44	31.0	5.45	9.16	22	16.1
20 × 45	31.4	5.67	9.42	22	16.6
20 × 47	32.0	5.89	9.69	22	17.0
20 × 48	32.5	6.11	9.95	22	17.5
20 × 51	33.4	6.55	10.56	20	21.9
20 × 55	34.4	6.98	11.00	20	22.8
20 × 58	35.3	7.41	11.52	20	23.8
20 × 61	36.2	7.86	12.05	20	24.9
20 × 64	37.1	8.29	12.57	20	26.0
20 × 67	37.9	8.71	13.10	20	27.1
20 × 77	40.0	10.04	14.66	18	39.5
22 × 25	23.9	3.12	6.28	22	11.0
22 × 28	25.6	3.60	6.81	22	12.0
22 × 31	27.2	4.08	7.33	22	12.9
22 × 35	28.7	4.56	7.85	22	13.8
22 × 38	30.0	5.04	8.38	22	14.7
22 × 39	31.0	5.28	8.64	22	15.2
22 × 41	31.3	5.52	8.90	22	15.6
22 × 42	32.0	5.76	9.16	22	16.1
22 × 44	32.5	6.00	9.42	22	16.6
22 × 46	33.0	6.24	9.69	22	17.0
22 × 47	33.7	6.48	9.95	22	17.5
22 × 50	34.8	6.96	10.47	20	21.7

Notes:

1. Equivalent round is the diameter of the round duct which will have the capacity and friction equivalent to the flat oval duct size.

Nominal Flat Oval Size	Equiv. Round	Cross Sectional Area sq.ft.	Surface Area sq.ft./ln.ft.	Gauge	Weight lbs./ln.ft.
22 × 53	35.8	7.44	11.00	20	22.8
22 × 57	36.7	7.92	11.52	20	23.8
22 × 60	37.8	8.40	12.04	20	24.9
22 × 63	38.7	8.88	12.57	20	26.0
22 × 66	39.6	9.36	13.09	20	27.1
22 × 69	40.4	9.84	13.61	20	28.2
22 × 75	42.0	10.80	14.66	18	39.5
22 × 82	44.0	11.76	15.71	18	42.3
24 × 27	25.9	3.66	6.81	22	12.0
24 × 30	28.1	4.19	7.33	22	12.9
24 × 33	29.3	4.71	7.85	22	13.8
24 × 37	30.8	5.23	8.38	22	14.7
24 × 40	32.2	5.76	8.90	22	15.6
24 × 41	33.0	6.02	9.16	22	16.1
24 × 43	33.5	6.28	9.42	22	16.6
24 × 44	34.0	6.54	9.69	22	17.1
24 × 46	34.7	6.80	9.95	22	17.5
24 × 49	35.9	7.33	10.47	20	21.7
24 × 52	37.0	7.85	11.00	20	22.8
24 × 55	38.1	8.38	11.52	20	23.8
24 × 59	39.2	8.90	12.04	20	24.9
24 × 62	40.1	9.42	12.57	20	26.0
24 × 65	41.1	9.95	13.09	20	27.1
24 × 68	42.0	10.47	13.61	20	28.2
24 × 74	44.0	11.52	14.66	18	39.5
26 × 29	27.9	4.25	7.33	22	12.9
26 × 32	29.7	4.82	7.85	22	13.8
26 × 35	31.3	5.39	8.38	22	14.7
26 × 39	32.8	5.96	8.90	22	15.6
26 × 42	34.3	6.52	9.42	22	16.6
26 × 45	35.6	7.09	9.95	22	17.5
26 × 48	36.9	7.66	10.47	22	18.4
26 × 51	38.1	8.22	11.00	20	22.8
26 × 54	39.3	8.79	11.52	20	23.8

Nominal Flat Oval Size	Equiv. Round	Cross Sectional Area sq.ft.	Surface Area sq.ft./ln.ft.	Gauge	Weight lbs./ln.ft.
26 × 57	40.4	9.36	12.04	20	24.9
26 × 61	41.5	9.93	12.57	20	26.0
26 × 64	42.5	10.49	13.09	20	27.1
26 × 67	43.5	11.06	13.61	20	28.2
26 × 70	44.4	11.63	14.14	20	29.3
28 × 31	29.9	4.88	7.85	22	13.8
28 × 34	31.7	5.50	8.38	22	14.7
28 × 37	33.4	6.11	8.90	22	15.6
28 × 41	34.9	6.72	9.42	22	16.6
28 × 44	36.4	7.33	9.95	22	17.5
28 × 47	37.8	7.94	10.47	22	18.4
28 × 50	39.1	8.55	11.00	20	22.8
28 × 53	40.3	9.16	11.52	20	23.8
28 × 56	41.5	9.77	12.04	20	24.9
28 × 59	42.6	10.38	12.57	20	26.0
28 × 63	43.8	10.99	13.09	20	27.1
28 × 66	44.8	11.60	13.61	20	28.2
28 × 69	45.8	12.22	14.14	20	29.3
30 × 33	32.0	5.56	8.38	22	14.7
30 × 36	33.7	6.22	8.90	22	15.6
30 × 39	35.4	6.87	9.42	22	16.6
30 × 43	37.0	7.53	9.95	22	17.5
30 × 46	38.5	8.18	10.47	22	18.4
30 × 49	39.9	8.84	11.00	20	22.8
30 × 52	41.2	9.49	11.52	20	23.8
30 × 55	42.5	10.15	12.06	20	25.0
30 × 58	43.7	10.80	12.57	20	26.0
30 × 61	44.9	11.46	13.09	20	27.1
30 × 64	46.0	12.11	13.61	20	28.2
30 × 68	47.1	12.77	14.14	20	29.3
30 × 71	48.2	13.42	14.66	18	39.5
32 × 35	34.0	6.28	8.90	22	15.6
32 × 38	35.8	6.98	9.42	22	16.6
32 × 41	37.4	7.68	9.95	22	17.5

Notes:

1. Equivalent round is the diameter of the round duct which will have the capacity and friction equivalent to the flat oval duct size.

Nominal Flat Oval Size	Equiv. Round	Cross Sectional Area sq.ft.	Surface Area sq.ft./ln.ft.	Gauge	Weight lbs./ln.ft.
32 × 45	39.0	8.38	10.47	22	18.4
32 × 48	40.5	9.08	11.00	22	19.3
32 × 51	42.0	9.77	11.52	20	23.8
32 × 54	43.3	10.47	12.04	20	24.9
32 × 57	44.6	11.17	12.57	20	26.0
32 × 60	45.9	11.87	13.09	20	27.1
32 × 63	47.1	12.57	13.61	20	28.2
32 × 67	48.3	13.26	14.14	20	29.3
32 × 70	49.4	13.96	14.66	20	30.3
34 × 37	36.0	7.05	9.42	22	16.6
34 × 40	37.8	7.79	9.95	22	17.5
34 × 43	39.5	8.52	10.47	22	18.4
34 × 47	41.1	9.27	11.00	22	19.3
34 × 50	42.6	10.01	11.52	20	23.8
34 × 53	44.1	10.75	12.04	20	24.9
34 × 56	45.5	11.50	12.57	20	26.0
34 × 59	46.8	12.24	13.09	20	27.1
34 × 62	48.1	12.98	13.61	20	28.2
34 × 65	49.3	13.72	14.14	20	29.3
34 × 69	50.5	14.46	14.66	20	30.3
34 × 72	51.6	15.20	15.18	18	31.4
36 × 39	38.0	7.85	9.95	22	17.5
36 × 42	39.8	8.64	10.47	22	18.4
36 × 45	41.5	9.42	11.00	22	19.4
36 × 49	43.1	10.21	11.52	20	23.8
36 × 52	44.7	11.00	12.04	20	24.9
36 × 55	46.2	11.78	12.57	20	26.0
36 × 58	47.6	12.57	13.09	20	27.1
36 × 61	48.9	13.35	13.61	20	28.2
36 × 64	50.2	14.14	14.14	20	29.3
36 × 67	51.1	14.92	14.66	20	30.3
36 × 71	52.7	15.71	15.18	18	40.9
38 × 41	40.0	8.70	10.47	22	18.4
38 × 44	41.8	9.53	11.00	22	19.3
38 × 47	43.5	10.36	11.52	22	20.3

Notes:

1. Equivalent round is the diameter of the round duct which will have

Nominal Flat Oval Size	Equiv. Round	Cross Sectional Area sq.ft.	Surface Area sq.ft./ln.ft.	Gauge	Weight lbs./ln.ft.
38 × 47	43.5	10.36	11.52	22	20.3
38 × 51	45.2	11.19	12.04	20	24.9
38 × 54	46.7	12.02	12.57	20	26.0
38 × 57	48.2	12.85	13.09	20	27.1
38 × 60	49.7	13.68	13.61	20	28.2
38 × 63	51.0	14.51	14.14	20	29.3
38 × 66	52.4	15.34	14.66	20	30.3
38 × 69	53.7	16.16	15.18	20	31.4
40 × 43	42.0	9.60	11.00	22	19.3
40 × 46	43.8	10.47	11.52	22	20.3
40 × 49	45.6	11.34	12.04	20	24.9
40 × 53	47.2	12.21	12.57	20	26.0
40 × 56	48.8	13.09	13.09	20	27.1
40 × 59	50.4	13.96	13.61	20	28.2
40 × 62	51.8	14.83	14.14	20	29.3
40 × 65	53.2	15.71	14.66	20	30.3
40 × 68	54.5	16.58	15.18	20	31.4
40 × 71	55.8	17.45	15.71	18	42.3

Notes:

1. **Equivalent round is the diameter of the round duct which will have the capacity and friction equivalent to the flat oval duct size.**
2. **To obtain the rectangular duct size, use the Trane Ductulator and equivalent round duct size.**
3. **Table includes 25 percent allowance for bracing, hangers, reinforcing, joints, and seams. Add 10 percent for insulated ductwork systems.**
4. **Table lists standard sizes as manufactured by United Sheet Metal, a division of United McGill Corporation.**

17.15. Ductwork Cost Ratios

DUCTWORK COST RATIOS

SMACNA Pressure Class	Installed Cost Ratio
± ½"	1.00
± 1"	1.05
± 2"	1.15
± 3"	1.40
± 4"	1.50
± 6"	1.60
± 10"	1.80

Aspect Ratios	Installed Cost Ratio	Operating Cost Ratio
1:1	1.00	1.000
2:1	1.13	1.001
3:1	1.28	1.005
4:1	1.45	1.010
5:1	1.65	1.012
6:1	1.85	1.020
7:1	2.08	1.030

17.16. Friction Loss Correction Factors for Ducts

FRICTION LOSS CORRECTION FACTORS FOR DUCTS

	Material						
Velocity FPM	Galv. Steel Stainless Steel	Duct Liner	Aluminum	Carbon Steel	Fiberous Glass (2)	PVC	Conc or C Blc
500	1.00	1.25	0.98	0.93	1.25	0.93	1.5–1
600	1.00	1.28	0.98	0.92	1.27	0.92	1.5–1
700	1.00	1.30	0.98	0.92	1.30	0.92	1.5–2

Notes:

Velocity FPM	Material						
	Galv. Steel Stainless Steel	Duct Liner	Aluminum	Carbon Steel	Fiberous Glass (2)	PVC	Conc or C Blo
800	1.00	1.31	0.97	0.91	1.31	0.91	1.5–2
900	1.00	1.32	0.97	0.90	1.31	0.90	1.5–2
1,000	1.00	1.33	0.97	0.90	1.32	0.90	1.6–2
1,200	1.00	1.36	0.97	0.89	1.34	0.89	1.6–2
1,400	1.00	1.38	0.96	0.88	1.36	0.88	1.6–2
1,600	1.00	1.40	0.96	0.87	1.38	0.87	1.6–2
1,800	1.00	1.41	0.96	0.86	1.39	0.86	1.6–2
2,000	1.00	1.42	0.96	0.85	1.40	0.85	1.7–2
2,500	1.00	1.45	0.95	0.84	1.42	0.84	1.7–2
3,000	1.00	1.47	0.95	0.83	1.43	0.83	1.7–2
3,500	1.00	1.49	0.95	0.83	1.44	0.83	1.8–2
4,000	1.00	1.50	0.94	0.82	1.45	0.82	1.8–2
4,500	1.00	1.52	0.94	0.81	1.46	0.81	1.8–2
5,000	1.00	1.54	0.94	0.80	1.48	0.80	1.8–2
5,500	1.00	1.55	0.93	0.79	1.49	0.79	1.8–2
6,000	1.00	1.56	0.93	0.78	1.50	0.78	1.8–2

Notes:

1. **First number indicated is for smooth concrete; second number indicat rough concrete.**
2. **Flexible ductwork has a friction loss correction factor of 1.5–2.0 times read from friction loss tables, ductulators, etc.**

17.17. Velocity Pressures

VELOCITIES VS. VELOCITY PRESSURES

Velocity FPM	Velocity Pressure in. W.G.	Velocity FPM	Velocity Pressure in. W.G.	Velocity FPM	Velocity Pressure in. W.G.

Velocity FPM	Velocity Pressure in. W.G.	Velocity FPM	Velocity Pressure in. W.G.	Velocity FPM	Velocity Pressure in. W.G.
50	0.0002	2,050	0.262	4,050	1.023
100	0.0006	2,100	0.275	4,100	1.048
150	0.001	2,150	0.288	4,150	1.074
200	0.002	2,200	0.302	4,200	1.100
250	0.004	2,250	0.316	4,250	1.126
300	0.006	2,300	0.330	4,300	1.153
350	0.008	2,350	0.344	4,350	1.180
400	0.010	2,400	0.359	4,400	1.207
450	0.013	2,450	0.374	4,450	1.235
500	0.016	2,500	0.390	4,500	1.262
550	0.019	2,550	0.405	4,550	1.291
600	0.022	2,600	0.421	4,600	1.319
650	0.026	2,650	0.438	4,650	1.348
700	0.031	2,700	0.454	4,700	1.377
750	0.035	2,750	0.471	4,750	1.407
800	0.040	2,800	0.489	4,800	1.436
850	0.045	2,850	0.506	4,850	1.466
900	0.050	2,900	0.524	4,900	1.497
950	0.056	2,950	0.543	4,950	1.528
1,000	0.062	3,000	0.561	5,000	1.559
1,050	0.069	3,050	0.580	5,050	1.590
1,100	0.075	3,100	0.599	5,100	1.622
1,150	0.082	3,150	0.619	5,150	1.654
1,200	0.090	3,200	0.638	5,200	1.686
1,250	0.097	3,250	0.659	5,250	1.718
1,300	0.105	3,300	0.679	5,300	1.751
1,350	0.114	3,350	0.700	5,350	1.784
1,400	0.122	3,400	0.721	5,400	1.818
1,450	0.131	3,450	0.742	5,450	1.852
1,500	0.140	3,500	0.764	5,500	1.886
1,550	0.150	3,550	0.786	5,550	1.920
1,600	0.160	3,600	0.808	5,600	1.955
1,650	0.170	3,650	0.831	5,650	1.990
1,700	0.180	3,700	0.853	5,700	2.026
1,750	0.191	3,750	0.877	5,750	2.061
1,800	0.202	3,800	0.900	5,800	2.097

Notes:

Velocity FPM	Velocity Pressure in. W.G.	Velocity FPM	Velocity Pressure in. W.G.	Velocity FPM	Velocity Pressure in. W.G.
1,800	0.202	3,800	0.900	5,800	2.097
1,850	0.213	3,850	0.924	5,850	2.134
1,900	0.225	3,900	0.948	5,900	2.170
1,950	0.237	3,950	0.973	5,950	2.207
2,000	0.249	4,000	0.998	6,000	2.244
6,050	2.282	8,050	4.040	10,050	6.297
6,100	2.320	8,100	4.090	10,100	6.360
6,150	2.358	8,150	4.141	10,150	6.423
6,200	2.397	8,200	4.192	10,200	6.486
6,250	2.435	8,250	4.243	10,250	6.550
6,300	2.474	8,300	4.295	10,300	6.614
6,350	2.514	8,350	4.347	10,350	6.678
6,400	2.554	8,400	4.399	10,400	6.743
6,450	2.594	8,450	4.452	10,450	6.808
6,500	2.634	8,500	4.504	10,500	6.873
6,550	2.675	8,550	4.558	10,550	6.939
6,600	2.716	8,600	4.611	10,600	7.005
6,650	2.757	8,650	4.665	10,650	7.071
6,700	2.799	8,700	4.719	10,700	7.138
6,750	2.841	8,750	4.773	10,750	7.205
6,800	2.883	8,800	4.828	10,800	7.272
6,850	2.925	8,850	4.883	10,850	7.339
6,900	2.968	8,900	4.938	10,900	7.407
6,950	3.011	8,950	4.994	10,950	7.475
7,000	3.055	9,000	5.050	11,000	7.544
7,050	3.099	9,050	5.106	11,050	7.612
7,100	3.143	9,100	5.163	11,100	7.681
7,150	3.187	9,150	5.220	11,150	7.751
7,200	3.232	9,200	5.277	11,200	7.820
7,250	3.277	9,250	5.334	11,250	7.890
7,300	3.322	9,300	5.392	11,300	7.961
7,350	3.368	9,350	5.450	11,350	8.031
7,400	3.414	9,400	5.509	11,400	8.102
7,450	3.460	9,450	5.567	11,450	8.173
7,500	3.507	9,500	5.627	11,500	8.245
7,550	3.554	9,550	5.686	11,550	8.317
7,600	3.601	9,600	5.746	11,600	8.389

Notes:

Velocity FPM	Velocity Pressure in. W.G.	Velocity FPM	Velocity Pressure in. W.G.	Velocity FPM	Velocity Pressure in. W.G.
7,650 7,700 7,750	3.649 3.696 3.745	9,650 9,700 9,750	5.807 5.866 5.927	11,650 11,700 11,750	8.461 8.534 8.607
7,800 7,850 7,900 7,950 8,000	3.793 3.842 3.891 3.940 3.990	9,800 9,850 9,900 9,950 10,000	5.988 6.049 6.110 6.172 6.234	11,800 11,850 11,900 11,950 12,000	8.681 8.755 8.829 8.903 8.978

Notes:

1. Velocity Pressure = VP = $\left[\frac{V}{4005}\right]^2 = \frac{(V)^2}{(4005)^2}$

Refer to the online resource for Section 17.18 Equivalent Round/Rectangular Ducts. www.mheducation.com/HVACequations

17.18. Equivalent Round/Rectangular Ducts

		Aspect Ratio							
Duct Dia. in.	**Rect. Size in.**	**1.00**	**1.25**	**1.50**	**1.75**	**2.00**	**2.25**	**2.50**	**2.75**
6	Width Height	– –	6 5						
7	Width Height	6 6	8 6						
8	Width Height	7 7	9 7	9 6	11 6				
9	Width Height	8 8	9 7	11 7	11 6	12 6	14 6		
10	Width Height	9 9	10 8	12 8	12 7	14 7	14 6	15 6	17 6
11	Width Height	10 10	11 9	12 8	14 8	14 7	16 7	18 7	17 6
12	Width	11	13	14	14	16	16	18	19

Duct Dia. in.	Rect. Size in.	Aspect Ratio 1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75
	Height	11	10	9	8	8	7	7	7
13	Width	12	14	15	16	18	18	20	19
	Height	12	11	10	9	9	8	8	7
14	Width	13	14	17	18	18	20	20	22
	Height	13	11	11	10	9	9	8	8
15	Width	14	15	17	18	20	20	23	25
	Height	14	12	11	10	10	9	9	9
16	Width	15	16	18	19	20	23	23	25
	Height	15	13	12	11	10	10	9	9
17	Width	16	18	20	21	22	25	25	28
	Height	16	14	13	12	11	11	10	10
18	Width	16	19	21	23	24	25	28	28
	Height	16	15	14	13	12	11	11	10
19	Width	17	20	21	23	24	27	28	30
	Height	17	16	14	13	12	12	11	11
20	Width	18	20	23	25	26	27	30	30
	Height	18	16	15	14	13	12	12	11
21	Width	19	21	24	26	28	29	30	33
	Height	19	17	16	15	14	13	12	12
22	Width	20	23	26	26	28	32	33	36
	Height	20	18	17	15	14	14	13	13
23	Width	21	24	26	28	30	32	35	36
	Height	21	19	17	16	15	14	14	13
24	Width	22	25	27	30	32	34	35	39
	Height	22	20	18	17	16	15	14	14
25	Width	23	25	29	30	32	36	38	39
	Height	23	20	19	17	16	16	15	14
26	Width	24	26	30	32	34	36	38	41
	Height	24	21	20	18	17	16	15	15
27	Width	25	28	30	33	36	38	40	41
	Height	25	22	20	19	18	17	16	15
28	Width	26	29	32	35	36	38	43	44
	Height	26	23	21	20	18	17	17	16

Duct Dia. in.	Rect. Size in.	Aspect Ratio 1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75
29	Width	27	30	33	35	38	41	43	44
	Height	27	24	22	20	19	18	17	16
30	Width	27	31	35	37	40	43	45	47
	Height	27	25	23	21	20	19	18	17
31	Width	28	31	35	39	40	43	45	50
	Height	28	25	23	22	20	19	18	18
32	Width	29	33	36	39	42	45	48	50
	Height	29	26	24	22	21	20	19	18
33	Width	30	34	38	40	44	47	50	52
	Height	30	27	25	23	22	21	20	19
34	Width	31	35	39	42	44	47	50	52
	Height	31	28	26	24	22	21	20	19
35	Width	32	36	39	42	46	50	53	55
	Height	32	29	26	24	23	22	21	20
36	Width	33	36	41	44	48	50	53	55
	Height	33	29	27	25	24	22	21	20
38	Width	35	39	44	47	50	54	58	61
	Height	35	31	29	27	25	24	23	22
40	Width	37	41	45	49	52	56	60	63
	Height	37	33	30	28	26	25	24	23
42	Width	38	43	48	51	56	59	63	66
	Height	38	34	32	29	28	26	25	24
44	Width	40	45	50	54	58	61	65	69
	Height	40	36	33	31	29	27	26	25
46	Width	42	48	53	56	60	65	68	72
	Height	42	38	35	32	30	29	27	26
48	Width	44	49	54	60	62	68	70	74
	Height	44	39	36	34	31	30	28	27
50	Width	46	51	57	61	66	70	75	77
	Height	46	41	38	35	33	31	30	28
52	Width	48	54	59	63	68	72	78	83
	Height	48	43	39	36	34	32	31	30

Duct Dia. in.	Rect. Size in.	Aspect Ratio 1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75
54	Width	49	55	62	67	70	77	80	85
	Height	49	44	41	38	35	34	32	31
56	Width	51	58	63	68	74	79	83	88
	Height	51	46	42	39	37	35	33	32
58	Width	53	60	66	70	76	81	85	91
	Height	53	48	44	40	38	36	34	33
60	Width	55	61	68	74	78	83	90	94
	Height	55	49	45	42	39	37	36	34
62	Width	57	64	71	75	82	88	93	96
	Height	57	51	47	43	41	39	37	35
64	Width	59	65	72	79	84	90	95	99
	Height	59	52	48	45	42	40	38	36
66	Width	60	68	75	81	86	92	98	105
	Height	60	54	50	46	43	41	39	38
68	Width	62	70	77	82	90	95	100	107
	Height	62	56	51	47	45	42	40	39
70	Width	64	71	80	86	92	99	105	110
	Height	64	57	53	49	46	44	42	40
72	Width	66	74	81	88	94	101	108	113
	Height	66	59	54	50	47	45	43	41
74	Width	68	76	84	91	98	104	110	116
	Height	68	61	56	52	49	46	44	42
76	Width	70	78	86	93	100	106	113	118
	Height	70	62	57	53	50	47	45	43
78	Width	71	80	89	95	102	110	115	121
	Height	71	64	59	54	51	49	46	44
80	Width	73	83	90	98	104	113	118	124
	Height	73	66	60	56	52	50	47	45
82	Width	75	84	93	100	108	115	123	129
	Height	75	67	62	57	54	51	49	47
84	Width	77	86	95	103	110	117	125	132
	Height	77	69	63	59	55	52	50	48
86	Width	[illegible]	[illegible]	[illegible]	105	[illegible]	[illegible]	[illegible]	135

Duct Dia. in.	Rect. Size in.	Aspect Ratio 1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75
86	Width	79	88	98	105	112	119	128	135
	Height	79	70	65	60	56	53	51	49
88	Width	80	90	99	107	116	124	130	138
	Height	80	72	66	61	58	55	52	50
90	Width	82	93	102	110	118	126	133	140
	Height	82	74	68	63	59	56	53	51
92	Width	84	94	104	112	120	128	138	143
	Height	84	75	69	64	60	57	55	52
94	Width	86	96	107	116	124	131	140	146
	Height	86	77	71	66	62	58	56	53
96	Width	88	99	108	117	126	135	143	151
	Height	88	79	72	67	63	60	57	55
98	Width	90	100	111	119	128	137	145	154
	Height	90	80	74	68	64	61	58	56
100	Width	91	103	113	123	132	140	148	157
	Height	91	82	75	70	66	62	59	57
102	Width	93	105	116	124	134	142	153	160
	Height	93	84	77	71	67	63	61	58
104	Width	95	106	117	128	136	146	155	162
	Height	95	85	78	73	68	65	62	59

EQUIVALENT RECTANGULAR DUCT DIMENSIONS

Duct Dia. in.	Rect. Size in.	Aspect Ratio 3.00	3.50	4.00	5.00	6.00	7.00	8.00
6	Width							
	Height							
7	Width							
	Height							
8	Width							
	Height							
9	Width							

Note:

Duct Dia. in.	Rect. Size in.			Aspect Ratio				
		3.00	3.50	4.00	5.00	6.00	7.00	8.00
9	Width Height							
10	Width Height							
11	Width Height	18 6	21 6					
12	Width Height	21 7	21 6	24 6				
13	Width Height	21 7	25 7	24 6	30 6			
14	Width Height	24 8	25 7	28 7	30 6	36 6		
15	Width Height	24 8	28 8	28 7	35 7	36 6	42 6	
16	Width Height	27 9	28 8	32 8	35 7	42 7	42 6	48 6
17	Width Height	27 9	32 9	32 8	35 7	42 7	49 7	48 6
18	Width Height	30 10	32 9	36 9	40 8	42 7	49 7	56 7
19	Width Height	30 10	35 10	36 9	40 8	48 8	49 7	56 7
20	Width Height	33 11	35 10	40 10	45 9	48 8	56 8	56 7
21	Width Height	33 11	39 11	40 10	45 9	54 9	56 8	64 8
22	Width Height	36 12	39 11	44 11	50 10	54 9	56 8	64 8
23	Width Height	39 13	42 12	44 11	50 10	54 9	63 8	64 8
24	Width Height	39 13	42 12	48 12	55 11	60 10	63 9	72 9
25	Width	42	46	48	55	60	70	72

Note:

Duct Dia. in.	Rect. Size in.	Aspect Ratio 3.00	3.50	4.00	5.00	6.00	7.00	8.00
	Height	14	13	12	11	10	10	9
26	Width	42	46	52	55	66	70	72
	Height	14	13	13	11	11	10	9
27	Width	45	49	52	60	66	70	80
	Height	15	14	13	12	11	10	10
28	Width	45	49	56	60	66	77	80
	Height	15	14	14	12	11	11	10
29	Width	48	53	56	65	72	77	88
	Height	16	15	14	13	12	11	11
30	Width	48	53	60	65	72	77	88
	Height	16	15	15	13	12	11	11
31	Width	51	56	60	70	78	84	88
	Height	17	16	15	14	13	12	11
32	Width	54	56	60	70	78	84	96
	Height	18	16	15	14	13	12	12
33	Width	54	60	64	75	78	91	96
	Height	18	17	16	15	13	13	12
34	Width	57	60	64	75	84	91	96
	Height	19	17	16	15	14	13	12
35	Width	57	63	68	75	84	91	104
	Height	19	18	17	15	14	13	13
36	Width	60	63	68	80	90	98	104
	Height	20	18	17	16	15	14	13
38	Width	63	67	72	85	96	105	112
	Height	21	19	18	17	16	15	14
40	Width	66	70	76	90	96	105	120
	Height	22	20	19	18	16	15	15
42	Width	69	74	80	90	102	112	120
	Height	23	21	20	18	17	16	15
44	Width	72	81	84	95	108	119	128
	Height	24	23	21	19	18	17	16
46	Width	75	84	88	100	114	126	136
	Height	25	24	22	20	19	18	17

Note:

Duct Dia. in.	Rect. Size in.	Aspect Ratio 3.00	3.50	4.00	5.00	6.00	7.00	8.00
48	Width	78	88	92	105	120	126	136
	Height	26	25	23	21	20	18	17
50	Width	81	91	96	110	120	133	144
	Height	27	26	24	22	20	19	18
52	Width	84	95	100	115	126	140	152
	Height	28	27	25	23	21	20	19
54	Width	90	98	104	120	132	147	160
	Height	30	28	26	24	22	21	20
56	Width	93	102	108	125	138	147	160
	Height	31	29	27	25	23	21	20
58	Width	96	105	112	130	144	154	168
	Height	32	30	28	26	24	22	21
60	Width	99	109	116	130	144	161	
	Height	33	31	29	26	24	23	
62	Width	102	112	120	135	150	168	
	Height	34	32	30	27	25	24	
64	Width	105	116	124	140	156		
	Height	35	33	31	28	26		
66	Width	108	119	128	145	162		
	Height	36	34	32	29	27		
68	Width	111	123	132	150	168		
	Height	37	35	33	30	28		
70	Width	114	126	136	155			
	Height	38	36	34	31			
72	Width	117	130	140	160			
	Height	39	37	35	32			
74	Width	123	133	144	165			
	Height	41	38	36	33			
76	Width	126	137	148	165			
	Height	42	39	37	33			
78	Width	129	140	152				
	Height	43	40	38				

Note:

1. Shaded areas and bold numbers exceed the recommended

Duct Dia. in.	Rect. Size in.	Aspect Ratio 3.00	3.50	4.00	5.00	6.00	7.00	8.00
80	Width Height	132 44	144 41	156 39				
82	Width Height	135 45	147 42	160 40				
84	Width Height	138 46	151 43	164 41				
86	Width Height	141 47	154 44	168 42				
88	Width Height	144 48	158 45					
90	Width Height	147 49	161 46					
92	Width Height	150 50	165 47					
94	Width Height	153 51	168 48					
96	Width Height	159 53						
98	Width Height	162 54						
100	Width Height	165 55						
102	Width Height	168 56						
104	Width Height							

Note:

1. **Shaded areas and bold numbers exceed the recommended maximum 4:1 aspect ratio.**

ROUND/RECTANGULAR DUCT EQUIVALENTS

A\B	3	3.5	4	4.5	5	5.5	6	7	8	9	10
3.0	3.3										
3.5	3.5	3.8									
4.0		4.1	4.4								
4.5	3.8	4.3	4.6	4.9							
5.0	4.0	4.6	4.9	5.2	5.5						
	4.2										
5.5	4.4	4.8	5.1	5.4	5.7	6.0					
6	4.6	5.0	5.3	5.7	6.0	6.3	6.6				
7	4.9	5.3	5.7	6.1	6.4	6.8	7.1	7.7			
8	5.2	5.7	6.1	6.5	6.9	7.2	7.6	8.2	8.7		
9	5.5	6.0	6.4	6.9	7.3	7.6	8.0	8.7	9.3	9.8	
10	5.7	6.3	6.7	7.2	7.6	8.0	8.4	9.1	9.8	10.4	10.9
11	6.0	6.5	7.0	7.5	8.0	8.4	8.8	9.5	10.2	10.9	11.5
12	6.2	6.8	7.3	7.8	8.3	8.7	9.1	9.9	10.7	11.3	12.0
13	6.4	7.0	7.6	8.1	8.6	9.0	9.5	10.3	11.1	11.8	12.4
14	6.6	7.2	7.8	8.4	8.9	9.3	9.8	10.8	11.4	12.2	12.9
15	6.8	7.5	8.0	8.6	9.1	9.6	10.1	11.0	11.8	12.6	13.3
16	7.0	7.7	8.3	8.8	9.4	9.9	10.4	11.3	12.2	13.0	13.7
17	7.2	7.9	8.5	9.1	9.6	10.2	10.7	11.6	12.5	13.4	14.1
18	7.3	8.0	8.7	9.3	9.9	10.4	11.0	11.9	12.9	13.7	14.5
19	7.5	8.2	8.9	9.5	10.1	10.7	11.2	12.2	13.2	14.1	14.9
20	7.7	8.4	9.1	9.7	10.3	10.9	11.5	12.6	13.5	14.4	15.2
22	8.0	8.7	9.5	10.1	10.8	11.4	12.0	13.0	14.1	15.0	15.9
24	8.3	9.1	9.8	10.5	11.2	11.8	12.4	13.5	14.6	15.6	16.5
26	8.5	9.4	10.1	10.9	11.5	12.2	12.8	14.0	15.1	16.2	17.1
28	8.8	9.6	10.4	11.2	11.9	12.6	13.2	14.5	15.6	16.7	17.7
30	9.0	9.9	10.7	11.5	12.2	13.0	13.6	14.9	16.1	17.2	18.3
32		10.2	11.0	11.8	12.6	13.3	14.0	15.3	16.5	17.7	18.8
34		10.4	11.3	12.2	12.9	13.6	14.4	15.7	17.0	18.2	19.3
36		10.7	11.5	12.4	13.2	14.0	14.7	16.1	17.4	18.6	19.8
38			11.8	12.7	13.5	14.3	15.0	16.5	17.8	19.0	20.2
40			12.0	13.1	13.8	14.7	15.3	16.8	18.2	19.5	20.7
42				13.2	14.0	14.9	15.6	17.1	18.5	19.9	21.1
44				13.4	14.3	15.1	15.9	17.5	18.9	20.3	31.5
46				13.7	14.6	15.4	16.2	17.8	19.3	20.6	21.9
48					14.8	15.7	16.5	18.1	19.6	21.0	22.3

A\B	3	3.5	4	4.5	5	5.5	6	7	8	9	10
48					14.8	15.7	16.5	18.1	19.6	21.0	22.5
50					15.1	15.9	16.8	18.4	19.9	21.4	22.7
52						16.2	17.1	18.7	20.2	21.7	23.1
54						16.4	17.3	19.0	20.6	22.0	23.5
56						16.7	17.6	19.3	20.9	22.4	23.8
58							17.8	19.5	21.2	22.7	24.2
60							18.1	19.8	21.5	23.0	24.5
62								20.1	21.7	23.3	24.8
64								20.3	22.0	23.6	25.1
66								20.6	22.3	23.9	25.5
68								20.8	22.6	24.2	25.8
70								21.1	22.8	24.5	26.1
72									23.1	24.8	26.4
74									23.3	25.1	26.7
76									23.6	25.3	27.0
78									23.8	25.6	27.3
80									24.1	25.8	27.5
82										26.1	27.8
84										26.4	28.1
86										26.6	28.3
88										26.8	28.6
90										27.1	28.9
92											29.1
94											29.4
96											29.6
98											29.9
100											30.1

ROUND/RECTANGULAR DUCT EQUIVALENTS

A\B	12	13	14	15	16	17	18	19	20	22	24
3.0											
3.5											
4.0											
4.5											
5.0											

A\B	12	13	14	15	16	17	18	19	20	22	24
5											
6											
7											
8											
9											
10											
11											
12	13.1										
13	13.7	14.2									
14	14.2	14.7	15.3								
15	14.6	15.3	15.8	16.4							
16	15.1	15.7	16.4	16.9	17.5						
17	15.6	16.2	16.8	17.4	18.0	18.6					
18	16.0	16.7	17.3	17.9	18.5	19.1	19.7				
19	16.4	17.1	17.8	18.4	19.0	19.6	20.2	20.8			
20	16.8	17.5	18.2	18.9	19.5	20.1	20.7	21.3	21.9		
22	17.6	18.3	19.1	19.8	20.4	21.1	21.7	22.3	22.9	24.0	
24	18.3	19.1	19.9	20.6	21.3	22.0	22.7	23.3	23.9	25.1	26.
26	19.0	19.8	20.6	21.4	22.1	22.9	23.5	24.2	24.9	26.1	27.
28	19.6	20.5	21.3	22.1	22.9	23.7	24.4	25.1	25.8	27.1	28.
30	20.2	21.1	22.0	22.9	23.7	24.4	25.2	25.9	26.6	28.0	29.
32	20.8	21.8	22.7	23.5	24.4	25.2	26.0	26.7	27.5	28.9	30.
34	21.4	22.4	23.3	24.2	25.1	25.9	26.7	27.5	28.3	29.7	31.
36	21.9	22.9	23.9	24.8	25.7	26.6	27.4	28.2	29.0	30.5	32.
38	22.4	23.5	24.5	25.4	26.4	27.2	28.1	28.9	29.8	31.3	32.
40	22.9	24.0	25.0	26.0	27.0	27.9	28.8	29.6	30.5	32.1	33.
42	23.4	24.5	25.6	26.6	27.6	28.5	29.4	30.3	31.2	32.8	34.
44	23.9	25.0	26.1	27.1	28.1	29.1	30.0	30.9	31.8	33.5	35.
46	24.4	25.5	26.6	27.7	28.7	29.7	30.6	31.6	32.5	34.2	35.
48	24.8	26.0	27.1	28.2	29.2	30.2	31.2	32.2	33.1	34.9	36.
50	25.2	26.4	27.6	28.7	29.8	30.8	31.8	32.8	33.7	35.5	37.
52	25.7	26.9	28.0	29.2	30.3	31.3	32.3	33.3	34.3	36.2	37.
54	26.1	27.3	28.5	29.7	30.8	31.8	32.9	33.9	34.9	36.8	38.
56	26.5	27.7	28.9	30.1	31.2	32.3	33.4	34.4	35.4	37.4	39.
58	26.9	28.2	29.4	30.6	31.7	32.8	33.9	35.0	36.0	38.0	39.
60	27.3	28.6	29.8	31.0	32.2	33.3	34.4	35.5	36.5	38.5	40.

A\B	12	13	14	15	16	17	18	19	20	22	24
62	27.6	28.9	30.2	31.5	32.6	33.8	34.9	36.0	37.1	39.1	41.
64	28.0	29.3	30.6	31.9	33.1	34.3	35.4	36.5	37.6	39.6	41.
66	28.4	29.7	31.0	32.3	33.5	34.7	35.9	37.0	38.1	40.2	42.
68	28.7	30.1	31.4	32.7	33.9	35.2	36.3	37.5	38.6	40.7	42.
70	29.1	30.4	31.8	33.1	34.4	35.6	36.8	37.9	39.1	41.2	43.
72	29.4	30.8	32.2	33.5	34.8	36.0	37.2	38.4	39.5	41.7	43.
74	29.7	31.2	32.5	33.9	35.2	36.4	37.7	38.8	40.0	42.2	44.
76	30.0	31.5	32.9	34.3	35.6	36.8	38.1	39.3	40.5	42.7	44.
78	30.4	31.8	33.3	34.6	36.0	37.2	38.5	39.7	40.9	43.2	45.
80	30.7	32.2	33.6	35.0	36.3	37.6	38.9	40.2	41.4	43.7	45.
82	31.0	32.5	34.0	35.4	36.7	38.0	39.3	40.6	41.8	44.1	46.
84	31.3	32.8	34.3	35.7	37.1	38.4	39.7	41.0	42.2	44.6	46.
86	31.6	33.1	34.6	36.1	37.4	38.8	40.1	41.4	42.6	45.0	47.
88	31.9	33.4	34.9	36.4	37.8	39.2	40.5	41.8	43.1	45.5	47.
90	32.2	33.8	35.3	36.7	38.2	39.5	40.9	42.2	43.5	45.9	48.
92	32.5	34.1	35.6	37.1	38.5	39.9	41.3	42.6	43.9	46.4	48.
94	32.8	34.4	35.9	37.4	38.9	40.3	41.7	43.0	44.3	46.8	49.
96	33.0	34.7	36.2	37.7	39.2	40.6	42.0	43.3	44.7	47.2	49.
98	33.3	35.0	36.5	38.1	39.5	41.0	42.4	43.7	45.1	47.6	50.
100	33.6	35.2	36.8	38.4	39.8	41.3	42.7	44.1	45.4	48	50.

ROUND/RECTANGULAR DUCT EQUIVALENTS

A\B	28	30	32	34	36	38	40	42	44	46	48
3.0											
3.5											
4.0											
4.5											
5.0											
5.5											
6											
7											
8											
9											
10											
11											

A\B	28	30	32	34	36	38	40	42	44	46	48
12											
13											
14											
15											
16											
17											
18											
19											
20											
22											
24											
26											
28	30.6										
30	31.7	32.8									
32	32.7	33.9	35.0								
34	33.7	34.9	36.1	37.2							
36	34.6	35.9	37.1	38.2	39.4						
38	35.6	36.8	38.1	39.3	40.4	41.5					
40	36.4	37.8	39.0	40.3	41.5	42.6	43.7				
42	37.3	38.7	40.0	41.3	42.5	43.7	44.8	45.9			
44	38.1	39.5	40.9	42.2	43.5	44.7	45.8	47.0	48.1		
46	38.9	40.4	41.8	43.1	44.4	45.7	46.9	48.0	49.2	50.3	
48	39.7	41.2	42.6	44.0	45.3	46.6	47.9	49.1	50.2	51.4	52.
50	40.5	42.0	43.6	44.9	46.2	47.5	48.8	50.0	51.2	52.4	53.
52	41.2	42.8	44.3	45.7	47.1	48.4	49.7	51.0	52.2	53.4	54.
54	41.9	43.5	45.1	46.5	48.0	49.3	50.7	52.0	53.2	54.4	55.
56	42.7	44.3	45.8	47.3	48.8	50.2	51.6	52.9	54.2	55.4	56.
58	43.3	45.0	46.6	48.1	49.6	51.0	52.4	53.8	55.1	56.4	57.
60	44.0	45.7	47.3	48.9	50.4	51.9	53.3	54.7	60.0	57.3	58.
62	44.7	46.4	48.0	49.6	51.2	52.7	54.1	55.5	56.9	58.2	59.
64	45.3	47.1	48.7	50.4	51.9	53.5	54.9	56.4	57.8	59.1	60.
66	46.0	47.7	49.4	51.1	52.7	54.2	55.7	57.2	58.6	60.0	61.
68	46.6	48.4	50.1	51.8	53.4	55.0	56.5	58.0	59.4	60.8	62.
70	47.2	49.0	50.8	52.5	54.1	55.7	57.3	58.8	60.3	61.7	63.
72	47.8	49.6	51.4	53.2	54.8	56.5	58.0	59.6	61.1	62.5	63.
74	48.4	50.3	52.1	53.8	55.5	57.2	58.8	60.3	61.9	63.3	64.

A\B	28	30	32	34	36	38	40	42	44	46	48
76	48.9	50.9	52.7	54.5	56.2	57.9	59.5	61.1	62.6	64.1	65.
78	49.5	51.4	53.3	55.1	56.9	58.6	60.2	61.8	63.4	64.9	66.
80	50.1	52.0	53.9	55.8	57.5	59.3	60.9	62.6	64.1	65.7	67.
82	50.6	52.6	54.6	56.4	58.2	59.9	61.6	63.3	64.9	66.5	68.
84	51.1	53.2	55.1	57.0	58.8	60.6	62.3	64.0	65.6	67.2	68.
86	51.7	53.7	55.7	57.6	59.4	61.2	63.0	64.7	66.3	67.9	69.
88	52.2	54.3	56.3	58.2	60.1	61.9	63.6	65.4	67.0	68.7	70.
90	52.7	54.8	56.8	58.8	60.7	62.5	64.3	66.0	67.7	69.4	71.
92	53.2	55.3	57.4	59.3	61.3	63.1	64.9	66.7	68.4	70.1	71.
94	53.7	55.9	57.9	59.9	61.9	63.7	65.6	67.3	69.1	70.8	72.
96	54.2	56.4	58.4	60.5	62.4	64.3	66.2	68.0	69.7	71.5	73.
98	54.7	56.9	59.0	61.1	63.0	64.9	66.8	68.6	70.4	72.2	73.
100	55.2	57.4	59.5	61.6	63.6	65.5	67.4	69.2	71	72.8	74.

ROUND/RECTANGULAR DUCT EQUIVALENTS

A\B	52	54	56	58	60	62	64	66	68	70	72
50											
52	56.8										
54	57.9	59.0									
56	59.0	60.1	61.2								
58	60.0	61.2	62.3	63.4							
60	61.0	62.2	63.4	64.5	65.6						
62	62.0	63.2	64.4	65.5	66.7	67.8					
64	63.0	64.2	65.4	66.6	67.7	69.9	70.0				
66	63.9	65.2	66.4	67.6	68.8	69.9	71.0	72.1			
68	64.9	66.2	67.4	68.6	69.8	71.0	72.1	73.2	74.3		
70	65.8	67.1	68.3	69.6	70.8	72.0	73.2	74.3	75.4	76.5	
72	66.7	68.0	69.3	70.6	71.8	73.0	74.2	75.4	76.5	77.6	78.
74	67.5	68.9	70.2	71.5	72.7	74.0	75.2	76.4	77.5	78.7	79.
76	68.4	69.8	71.1	72.4	73.7	75.0	76.2	77.4	78.6	79.7	80.
78	69.3	70.6	72.0	73.3	74.6	75.9	77.1	78.4	79.6	80.7	81.
80	70.1	71.6	72.9	74.2	75.4	76.9	78.1	79.4	80.6	81.8	82.
82	70.9	72.3	73.7	75.1	76.4	77.8	79.0	80.3	81.5	82.8	84.
84	71.7	72.6	74.6	76.0	77.3	78.7	80.0	81.3	82.5	83.8	85.
86	72.5	73.3	75.4	76.8	78.2	79.6	80.9	82.2	83.5	84.7	85.
88	73.3	74.0	76.3	77.7	79.1	80.5	81.8	83.1	84.4	85.7	86.
90	74.1	75.6	77.1	78.5	79.9	81.3	82.7	84.0	85.3	86.6	87.
92	74.9	76.4	77.9	79.3	80.8	82.2	83.5	85.4	86.2	87.5	88.
94	75.6	77.2	78.7	80.1	81.6	83.0	84.4	86.0	87.1	88.4	89.
96	76.3	77.9	79.4	80.9	82.4	83.8	85.3	86.6	88.0	89.3	90.
98	77.1	78.7	80.2	81.7	83.2	84.7	86.1	87.5	88.9	90.2	91.
100	77.8	79.4	81	82.5	84	85.5	86.9	88.3	89.7	91.1	92.

ROUND/RECTANGULAR DUCT EQUIVALENTS

A\B	76	78	80	82	84	86	88	90	92	94
70										
72										
74										
76	83.1									
78	84.2	85.3								
80	85.2	86.4	87.5							
82	86.3	87.4	88.5	89.6						
84	87.3	88.5	89.6	90.7	91.8					
86	88.3	89.5	90.7	91.8	92.9	94.0				
88	89.3	90.5	91.7	92.9	94.0	95.1	96.2			
90	90.3	91.5	92.7	93.9	95.0	96.2	97.3	98.4		
92	91.3	92.5	93.7	94.9	96.1	97.2	98.4	99.5	100.6	
94	92.3	93.5	94.7	95.9	97.1	98.3	99.4	100.6	101.1	102.
96	93.2	94.5	95.7	96.9	98.1	99.3	100.5	101.6	102.7	103.
98	94.2	95.5	96.7	97.9	99.1	100.3	101.5	102.7	103.8	104.
100	95.1	96.4	97.6	98.9	100.1	101.3	102.5	103.7	104.8	106

Note:

1. **Shaded areas and bold numbers exceed the recommended maximum**

Part 18: Piping Systems, General

18. Part 18: Piping Systems, General

18.01. Piping Materials and Properties

A. Steel pipe and Type L copper pipe are the most common pipe materials used in HVAC applications.

B. Steel Pipe

1. Standard steel pipe sizes: 1/2", 3/4", 1", 1-1/4", 1-1/2", 2", 2-1/2", 3", 4", 6", 8", 10", 12", 14", 16", 18", 20", 24", 30", 36", 42", 48", 54", 60", 72", 84", and 96".
2. Nonstandard steel pipe sizes: 5", 22", 26", 28", 32", and 34" are not standard sizes and not readily available in all locations.
3. Standard steel pipe is the most common steel pipe used in HVAC applications.
4. Standard and XS steel pipe are available in sizes through 96 inch.
5. XXS steel pipe is available in sizes through 12 inch.
6. Schedule 40 steel pipe is available in sizes through 96 inch.
7. Schedule 80 and 160 steel pipe are available in sizes through 24 inch.
8. Standard and Schedule 40 steel pipe have the same dimensions and flow for 10 inch and smaller.
9. XS and Schedule 80 steel pipe have the same dimensions and flow for 8 inch and smaller.
10. XXS and Schedule 160 have no relationship for dimensions or flow.

11. Steel pipe is manufactured in accordance with ASTM Standards A53 and A106.
12. The ASTM standards refer to steel pipe grades A and B. Grade A steel pipe has a lower tensile strength and is not generally used for HVAC applications.
13. The ASTM standards refer to steel pipe Types E, S, and F.
    a. Type E (also referred to as ERW) steel pipe refers to electric resistance welded steel pipe.
    b. Type S steel pipe refers to seamless steel pipe.
    c. Type F steel pipe refers to furnace-butt welded steel pipe. This type is generally not used in HVAC applications and is only available in Grade A.

C. Copper Pipe

1. Standard copper pipe sizes:1/2",3/4", 1",1-1/4",1-1/2", 2",2-1/2", 3", 4", 6", 8", 10", and 12".
2. Copper pipe is available in Types K, L, and M.
3. Types K, L, and M copper may be hard drawn or annealed (soft) temper.
4. Hard drawn copper pipe has higher allowable stress than annealed copper pipe.
5. Types K, L, and M designate decreasing wall thicknesses (Type K copper pipe has the thickest wall, while type M copper pipe has the thinnest wall).
6. Type K is generally used for higher pressure/temperature applications and for direct burial.
7. Type L copper pipe is the most common copper pipe used in HVAC applications.
8. Type M copper pipe should not be used where subject to external damage.
9. Copper pipe is manufactured in accordance with ASTM Standard B88.

D. Stainless Steel Pipe

1. Standard stainless steel pipe sizes:1/2",3/4", 1",1-1/4",1-1/2", 2",2-1/2", 3", 4", 6", 8", 10", 12", 14", 16", 18", 20", and 24".
2. Schedule 5 and 10 stainless steel pipe are available in sizes through 24 inch.

E. In the following piping tables …

1. Uninsulated piping: Add 20 percent for hangers and supports.

2. Insulated piping: Add 25 percent for hangers, supports, and insulation.

F. Piping installations are generally governed by one of the following three codes …

1. ASME B31.1-1998: Power Piping:
   a. Applicable to electric generating stations, industrial and institutional plants, central and district heating/cooling plants, and geothermal heating.

2. ASME B31.3-1999: Process Piping:
   a. Applicable to petroleum refineries, chemical, pharmaceutical, textile, paper, semiconductor, and cryogenic plants.

3. ASME B31.9-1996: Building Services Piping:
   a. Applicable to industrial, institutional, commercial, and public buildings and multiunit residences.

   b. Most HVAC applications fall under ASME B31.9 requirements.

PROPERTIES OF COPPER PIPE

						Weight (1)		
Pipe Size in.	**Type**	**Inside Dia. in.**	**Wall Thick in.**	**Outside Dia. in.**	**Area, sq.in.**	**Pipe lbs./ft.**	**Water lbs./ft.**	**Tota lbs./f**
1/2	K	0.527	0.049	0.625	0.218	0.301	0.095	0.396
	L	0.545	0.040	0.625	0.233	0.250	0.101	0.351
	M	0.569	0.028	0.625	0.254	0.179	0.110	0.289
3/4	K	0.745	0.065	0.875	0.436	0.562	0.189	0.751
	L	0.785	0.045	0.875	0.484	0.399	0.210	0.609
	M	0.811	0.032	0.875	0.517	0.288	0.224	0.512
1	K	0.995	0.065	1.125	0.778	0.736	0.337	1.073
	L	1.025	0.050	1.125	0.825	0.574	0.357	0.932
	M	1.055	0.035	1.125	0.874	0.407	0.379	0.786
1-1/4	K	1.245	0.065	1.375	1.217	0.909	0.527	1.437
	L	1.265	0.055	1.375	1.257	0.775	0.545	1.320
	M	1.291	0.042	1.375	1.309	0.598	0.567	1.165

Pipe Size in.	Type	Inside Dia. in.	Wall Thick in.	Outside Dia. in.	Area, sq.in.	Weight (1) Pipe lbs./ft.	Water lbs./ft.	Tota lbs./f
	M	1.291	0.042	1.375	1.309	0.598	0.567	1.165
1-1/2	K	1.481	0.072	1.625	1.723	1.194	0.746	1.941
	L	1.505	0.060	1.625	1.779	1.003	0.771	1.774
	M	1.527	0.049	1.625	1.831	0.825	0.793	1.618
2	K	1.959	0.083	2.125	3.014	1.810	1.306	3.116
	L	1.985	0.070	2.125	3.095	1.536	1.341	2.877
	M	2.009	0.058	2.125	3.170	1.280	1.373	2.654
2-1/2	K	2.435	0.095	2.625	4.657	2.567	2.018	4.585
	L	2.465	0.080	2.625	4.772	2.174	2.068	4.242
	M	2.495	0.065	2.625	4.889	1.777	2.118	3.895
3	K	2.907	0.109	3.125	6.637	3.511	2.876	6.387
	L	2.945	0.090	3.125	6.812	2.917	2.951	5.868
	M	2.981	0.072	3.125	6.979	2.348	3.024	5.371
4	K	3.857	0.134	4.125	11.684	5.712	5.062	10.77
	L	3.905	0.110	4.125	11.977	4.717	5.189	9.906
	M	3.935	0.095	4.125	12.161	4.089	5.269	9.358
5	K	4.805	0.160	5.125	18.133	8.484	7.856	16.34
	L	4.875	0.125	5.125	18.665	6.675	8.087	14.76
	M	4.907	0.109	5.125	18.911	5.839	8.193	14.03
6	K	5.741	0.192	6.125	25.886	12.166	11.215	23.38
	L	5.845	0.140	6.125	26.832	8.949	11.625	20.57
	M	5.881	0.122	6.125	27.164	7.822	11.769	19.59
8	K	7.583	0.271	8.125	45.162	22.732	19.566	42.29
	L	7.725	0.200	8.125	46.869	16.928	20.306	37.23
	M	7.785	0.170	8.125	47.600	14.443	20.623	35.06
10	K	9.449	0.338	10.125	70.123	35.330	30.381	65.71
	L	9.625	0.250	10.125	72.760	26.367	31.523	57.89
	M	9.701	0.212	10.125	73.913	22.445	32.023	54.46
12	K	11.315	0.405	12.125	100.554	50.695	43.565	94.25
	L	11.565	0.280	12.125	105.046	35.422	45.511	80.93
	M	11.617	0.254	12.125	105.993	32.203	45.921	78.12

PROPERTIES OF STEEL PIPE

Weight

Pipe Size in.	Schedule		Inside Dia. in.	Wall Thick in.	Outside Dia. in.	Area sq.in.	Weight Pipe lbs./ft.	Weight Water lbs./ft.
1/2	10	–	0.674	0.083	0.840	0.357	0.671	0.155
	40	STD	0.622	0.109	0.840	0.304	0.851	0.132
	80	XS	0.546	0.147	0.840	0.234	1.088	0.101
	160	–	0.466	0.187	0.840	0.171	1.304	0.074
	–	XXS	0.252	0.294	0.840	0.050	1.714	0.022
3/4	10	–	0.884	0.083	1.050	0.614	0.857	0.266
	40	STD	0.824	0.113	1.050	0.533	1.131	0.231
	80	XS	0.742	0.154	1.050	0.432	1.474	0.187
	160	–	0.614	0.218	1.050	0.296	1.937	0.128
	–	XXS	0.434	0.308	1.050	0.148	2.441	0.064
1	10	–	1.097	0.109	1.315	0.945	1.404	0.409
	40	STD	1.049	0.133	1.315	0.864	1.679	0.374
	80	XS	0.957	0.179	1.315	0.719	2.172	0.312
	160	–	0.815	0.250	1.315	0.522	2.844	0.226
	–	XXS	0.599	0.358	1.315	0.282	3.659	0.122
1-1/4	10	–	1.442	0.109	1.660	1.633	1.806	0.708
	40	STD	1.380	0.140	1.660	1.496	2.273	0.648
	80	XS	1.278	0.191	1.660	1.283	2.997	0.556
	160	–	1.160	0.250	1.660	1.057	3.765	0.458
	–	XXS	0.896	0.382	1.660	0.631	5.214	0.273
1-1/2	10	–	1.682	0.109	1.900	2.222	2.085	0.963
	40	STD	1.610	0.145	1.900	2.036	2.718	0.882
	80	XS	1.500	0.200	1.900	1.767	3.631	0.766
	160	–	1.338	0.281	1.900	1.406	4.859	0.609
	–	XXS	1.100	0.400	1.900	0.950	6.408	0.412
2	10	–	2.157	0.109	2.375	3.654	2.638	1.583
	40	STD	2.067	0.154	2.375	3.356	3.653	1.454
	80	XS	1.939	0.218	2.375	2.953	5.022	1.279
	160	–	1.689	0.343	2.375	2.241	7.444	0.971
	–	XXS	1.503	0.436	2.375	1.774	9.029	0.769
2-1/2	10	–	2.635	0.120	2.875	5.453	3.531	2.363
	40	STD	2.469	0.203	2.875	4.788	5.793	2.074
	80	XS	2.323	0.276	2.875	4.238	7.661	1.836

Pipe Size in.	Schedule		Inside Dia. in.	Wall Thick in.	Outside Dia. in.	Area sq.in.	Weight	
							Pipe lbs./ft.	Water lbs./ft.
	160	–	2.125	0.375	2.875	3.547	10.013	1.537
	–	XXS	1.771	0.552	2.875	2.463	13.695	1.067
3	10	–	3.260	0.120	3.500	8.347	4.332	3.616
	40	STD	3.068	0.216	3.500	7.393	7.576	3.203
	80	XS	2.900	0.300	3.500	6.605	10.253	2.862
	160	–	2.626	0.437	3.500	5.416	14.296	2.346
	–	XXS	2.300	0.600	3.500	4.155	18.584	1.800
4	10	–	4.260	0.120	4.500	14.253	5.614	6.175
	40	STD	4.026	0.237	4.500	12.730	10.791	5.515
	80	XS	3.826	0.337	4.500	11.497	14.984	4.981
	160	–	3.438	0.531	4.500	9.283	22.509	4.022
	–	XXS	3.152	0.674	4.500	7.803	27.541	3.381
5	10	–	5.295	0.134	5.563	22.020	7.770	9.540
	40	STD	5.047	0.258	5.563	20.006	14.618	8.667
	80	XS	4.813	0.375	5.563	18.194	20.778	7.882
	160	–	4.313	0.625	5.563	14.610	32.962	6.330
	–	XXS	4.063	0.750	5.563	12.965	38.553	5.617
6	10	–	6.357	0.134	6.625	31.739	9.290	13.751
	40	STD	6.065	0.280	6.625	28.890	18.974	12.517
	80	XS	5.761	0.432	6.625	26.067	28.574	11.293
	160	–	5.189	0.718	6.625	21.147	45.297	9.162
	–	XXS	4.897	0.864	6.625	18.834	53.161	8.160
8	10	–	8.329	0.148	8.625	54.485	13.399	23.605
	20	–	8.125	0.250	8.625	51.849	22.362	22.463
	30	–	8.071	0.277	8.625	51.162	24.697	22.166
	40	STD	7.981	0.322	8.625	50.027	28.554	21.674
	80	XS	7.625	0.500	8.625	45.664	43.388	19.784
	–	XXS	6.875	0.875	8.625	37.122	72.425	16.083
	160	–	6.813	0.906	8.625	36.456	74.691	15.794
10	10	–	10.420	0.165	10.750	85.276	18.653	36.945
	20	–	10.250	0.250	10.750	82.516	28.036	35.750
	30	–	10.136	0.307	10.750	80.691	34.241	34.959
	40	STD	10.020	0.365	10.750	78.854	40.484	34.163
	60	XS	9.750	0.500	10.750	74.662	54.736	32.347
	80	–	9.564	0.593	10.750	71.840	64.328	31.125
	140	XXS	8.750	1.000	10.750	60.132	104.132	26.052
	160	–	8.500	1.125	10.750	56.745	115.647	24.585

Pipe Size in.	Schedule		Inside Dia. in.	Wall Thick in.	Outside Dia. in.	Area sq.in.	Weight Pipe lbs./ft.	Weight Water lbs./ft.
	160		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	10	–	12.390	0.180	12.750	120.568	24.165	52.236
	20	–	12.250	0.250	12.750	117.859	33.376	51.062
	30	–	12.090	0.330	12.750	114.800	43.774	49.737
	–	STD	12.000	0.375	12.750	113.097	49.563	48.999
	40	–	11.938	0.406	12.750	111.932	53.526	48.494
	–	XS	11.750	0.500	12.750	108.434	65.416	46.979
	80	–	11.376	0.687	12.750	101.641	88.510	44.036
	120	XXS	10.750	1.000	12.750	90.763	125.492	39.323
	160	–	10.126	1.312	12.750	80.531	160.274	34.890
14	10	–	13.500	0.250	14.000	143.139	36.713	62.014
	20	–	13.376	0.312	14.000	140.521	45.611	60.880
	30	STD	13.250	0.375	14.000	137.886	54.569	59.739
	40	–	13.126	0.437	14.000	135.318	63.302	58.626
	–	XS	13.000	0.500	14.000	132.732	72.091	57.506
	80	–	12.500	0.750	14.000	122.718	106.134	53.167
	160	–	11.188	1.406	14.000	98.309	189.116	42.592
16	10	–	15.500	0.250	16.000	188.692	42.053	81.750
	20	–	15.376	0.312	16.000	185.685	52.276	80.447
	30	STD	15.250	0.375	16.000	182.654	62.579	79.134
	40	XS	15.000	0.500	16.000	176.715	82.772	76.561
	80	–	14.314	0.843	16.000	160.921	136.465	69.718
	160	–	12.814	1.593	16.000	128.961	245.114	55.872
18	10	–	17.500	0.250	18.000	240.528	47.393	104.208
	20	–	17.376	0.312	18.000	237.132	58.940	102.737
	–	STD	17.250	0.375	18.000	233.705	70.589	101.252
	30	–	17.126	0.437	18.000	230.357	81.971	99.802
	–	XS	17.000	0.500	18.000	226.980	93.452	98.338
	40	–	16.876	0.562	18.000	223.681	104.668	96.909
	80	–	16.126	0.937	18.000	204.241	170.755	88.487
	160	–	14.438	1.781	18.000	163.721	308.509	70.932
20	10	–	19.500	0.250	20.000	298.648	52.733	129.388
	20	STD	19.250	0.375	20.000	291.039	78.600	126.092
	30	XS	19.000	0.500	20.000	283.529	104.132	122.838
	40	–	18.814	0.593	20.000	278.005	122.911	120.445
	80	–	17.938	1.031	20.000	252.719	208.873	109.490
	160	–	16.064	1.968	20.000	202.674	379.008	87.808
22	10		21.500	0.250	22.000	363.050	58.074	157.290

Pipe Size in.	Schedule		Inside Dia. in.	Wall Thick in.	Outside Dia. in.	Area sq.in.	Weight Pipe lbs./ft.	Weight Water lbs./ft.
22	10	–	21.500	0.250	22.000	363.050	58.074	157.290
	20	STD	21.250	0.375	22.000	354.656	86.610	153.654
	30	XS	21.000	0.500	22.000	346.361	114.812	150.060
	80	–	19.750	1.125	22.000	306.354	250.818	132.727
	160	–	17.750	2.125	22.000	247.450	451.072	107.207
24	10	–	23.500	0.250	24.000	433.736	63.414	187.915
	20	STD	23.250	0.375	24.000	424.557	94.620	183.938
	–	XS	23.000	0.500	24.000	415.476	125.492	180.003
	30	–	22.876	0.562	24.000	411.008	140.681	178.068
	40	–	22.626	0.687	24.000	402.073	171.054	174.197
	80	–	21.564	1.218	24.000	365.215	296.359	158.228
	160	–	19.314	2.343	24.000	292.978	541.938	126.932
26	10	–	25.376	0.312	26.000	505.750	85.598	219.115
	–	STD	25.250	0.375	26.000	500.740	102.630	216.944
	20	XS	25.000	0.500	26.000	490.874	136.173	212.670
28	10	–	27.376	0.312	28.000	588.613	92.263	255.015
	–	STD	27.250	0.375	28.000	583.207	110.640	252.673
	20	XS	27.000	0.500	28.000	572.555	146.853	248.058
	30	–	26.750	0.625	28.000	562.001	182.732	243.485
30	10	–	29.376	0.312	30.000	677.759	98.927	293.637
	–	STD	29.250	0.375	30.000	671.957	118.650	291.123
	20	XS	29.000	0.500	30.000	660.520	157.533	286.168
	30	–	28.750	0.625	30.000	649.181	196.082	281.255
	40	–	28.500	0.688	29.876	637.940	214.473	276.385
32	10	–	31.376	0.312	32.000	773.188	105.591	334.981
	–	STD	31.250	0.375	32.000	766.990	126.660	332.296
	20	XS	31.000	0.500	32.000	754.768	168.213	327.001
	30	–	30.750	0.625	32.000	742.643	209.432	321.748
	40	–	30.624	0.688	32.000	736.569	230.080	319.116
34	10	–	33.376	0.312	34.000	874.900	112.256	379.048
	–	STD	33.250	0.375	34.000	868.307	134.671	376.191
	20	XS	33.000	0.500	34.000	855.299	178.893	370.555
	30	–	32.750	0.625	34.000	842.389	222.782	364.962
	40	–	32.624	0.688	34.000	835.919	244.776	362.159
36	10	–	35.376	0.312	36.000	982.895	118.920	425.836
	–	STD	35.250	0.375	36.000	975.906	142.681	422.808
	20	XS	35.000	0.500	36.000	962.113	189.574	416.832

Pipe Size in.	Schedule		Inside Dia. in.	Wall Thick in.	Outside Dia. in.	Area sq.in.	Weight Pipe lbs./ft.	Water lbs./ft.
	30	–	34.750	0.625	36.000	948.417	236.133	[illegible]
	40	–	34.500	0.750	36.000	934.820	282.358	405.008
42	–	STD	41.250	0.375	42.000	1336.404	166.711	578.993
	20	XS	41.000	0.500	42.000	1320.254	221.614	571.996
	30	–	40.750	0.625	42.000	1304.203	276.183	565.042
	40	–	40.500	0.750	42.000	1288.249	330.419	558.130
48	–	STD	47.250	0.375	48.000	1753.450	190.742	759.677
	20	XS	47.000	0.500	48.000	1734.945	253.655	751.659
	30	–	46.750	0.625	48.000	1716.537	316.234	743.684
	40	–	46.500	0.750	48.000	1698.227	378.480	735.751
54	–	STD	53.250	0.375	54.000	2227.046	214.772	964.860
	20	XS	53.000	0.500	54.000	2206.183	285.695	955.822
	30	–	52.750	0.625	54.000	2185.419	356.285	946.826
	40	–	52.500	0.750	54.000	2164.754	426.540	937.873
60	–	STD	59.250	0.375	60.000	2757.189	238.803	1194.54
	20	XS	59.000	0.500	60.000	2733.971	317.736	1184.48
	30	–	58.750	0.625	60.000	2710.851	396.336	1174.46
	40	–	58.500	0.750	60.000	2687.829	474.601	1164.49
72	–	STD	71.250	0.375	72.000	3987.123	286.863	1727.40
	20	XS	71.000	0.500	72.000	3959.192	381.817	1715.30
	30	–	70.750	0.625	72.000	3931.360	476.437	1703.24
	40	–	70.500	0.750	72.000	3903.625	570.723	1691.23
84	–	STD	83.250	0.375	84.000	5443.251	334.924	2358.27
	20	XS	83.000	0.500	84.000	5410.608	445.898	2344.12
	30	–	82.750	0.625	84.000	5378.063	556.539	2330.02
	40	–	82.500	0.750	84.000	5345.616	666.845	2315.97
96	–	STD	95.250	0.375	96.000	7125.574	382.985	3087.13
	20	XS	95.000	0.500	96.000	7088.218	509.980	3070.94
	30	–	94.750	0.625	96.000	7050.961	636.640	3054.80
	40	–	94.500	0.750	96.000	7013.802	762.967	3038.70

PROPERTIES OF STAINLESS STEEL PIPE

Pipe			Inside	Wall	Outside	Area	Weight (1) Pipe	Water

Pipe Size in.	Schedule		Inside Dia. in.	Wall Thick in.	Outside Dia. in.	Area sq.in.	Pipe lbs./ft.	Water Weight (1) lbs./ft.
1/2	5	–	0.710	0.065	0.840	0.396	0.549	0.172
	10	–	0.674	0.083	0.840	0.357	0.684	0.155
3/4	5	–	0.920	0.065	1.050	0.665	0.697	0.288
	10	–	0.884	0.083	1.050	0.614	0.874	0.266
1	5	–	1.185	0.065	1.315	1.103	0.885	0.478
	10	–	1.097	0.109	1.315	0.945	1.432	0.409
1-1/4	5	–	1.530	0.065	1.660	1.839	1.129	0.797
	10	–	1.442	0.109	1.660	1.633	1.842	0.708
1-1/2	5	–	1.770	0.065	1.900	2.461	1.299	1.066
	10	–	1.682	0.109	1.900	2.222	2.127	0.963
2	5	–	2.245	0.065	2.375	3.958	1.636	1.715
	10	–	2.157	0.109	2.375	3.654	2.691	1.583
2-1/2	5	–	2.709	0.083	2.875	5.764	2.524	2.497
	10	–	2.635	0.120	2.875	5.453	3.601	2.363
3	5	–	3.334	0.083	3.500	8.730	3.090	3.782
	10	–	3.260	0.120	3.500	8.347	4.419	3.616
4	5	–	4.334	0.083	4.500	14.753	3.994	6.392
	10	–	4.260	0.120	4.500	14.253	5.726	6.175
5	5	–	5.345	0.109	5.563	22.438	6.476	9.721
	10	–	5.295	0.134	5.563	22.020	7.925	9.540
6	5	–	6.407	0.109	6.625	32.240	7.737	13.968
	10	–	6.357	0.134	6.625	31.739	9.475	13.751
8	5	–	8.407	0.109	8.625	55.510	10.112	24.050
	10	–	8.329	0.148	8.625	54.485	13.667	23.605
10	5	–	10.482	0.134	10.750	86.294	15.497	37.386
	10	–	10.420	0.165	10.750	85.276	19.026	36.945
12	5	–	12.438	0.156	12.750	121.504	21.403	52.641
	10	–	12.390	0.180	12.750	120.568	24.648	52.236
14	5	–	13.688	0.156	14.000	147.153	23.527	63.754
	10	–	13.624	0.188	14.000	145.780	28.287	63.159
16	5		15.670	0.165	16.000	192.854	28.463	83.553

Pipe Size in.	Schedule		Inside Dia. in.	Wall Thick in.	Outside Dia. in.	Area sq.in.	Weight (1) Pipe lbs./ft.	Water lbs./ft.
16	5	–	15.670	0.165	16.000	192.854	28.463	83.553
	10	–	15.624	0.188	16.000	191.723	32.384	83.063
18	5	–	17.670	0.165	18.000	245.224	33.058	106.243
	10	–	17.624	0.188	18.000	243.949	36.480	105.690
20	5	–	19.624	0.188	20.000	302.458	40.576	131.039
	10	–	19.564	0.218	20.000	300.611	46.979	130.239
22	5	–	21.624	0.188	22.000	367.250	44.672	159.110
	10	–	21.564	0.218	22.000	365.215	51.729	158.228
24	5	–	23.564	0.218	24.000	436.102	56.479	188.940
	10	–	23.500	0.250	24.000	433.736	64.682	187.915

18.02. Pipe Support and Pipe Spacing

HORIZONTAL PIPE SUPPORT SPACING

	Maximum Horizontal Hanger Spacing Feet					
	Steel			Copper		
Pipe Size	Recommend	Water Systems	Vapor Systems	Recommend	Water Systems	Vap Syst
1/2	6	7	8	5	5	6
3/4	6	7	9	5	5	7
1	6	7	9	6	6	8
1-1/4	6	7	9	6	7	9
1-1/2	6	9	12	6	8	10
2	7	10	13	7	8	11
2-1/2	10	11	14	8	9	13
3	10	12	15	10	10	14
4	10	14	17	10	12	16
5	10	16	19	10	13	18
6	10	17	21	10	14	20

Note:

1. Recommended pipe support spacing is less than the maximum to mee

Maximum Horizontal Hanger Spacing Feet						
	Steel			Copper		
Pipe Size	Recommend	Water Systems	Vapor Systems	Recommend	Water Systems	Vap Syst
8	12	19	24	10	16	23
10	12	22	26	10	18	25
12	12	23	30	10	19	28
14	12	25	32	–	–	–
16	12	27	35	–	–	–
18	12	28	37	–	–	–
20	12	30	39	–	–	–
22	12	30	39	–	–	–
24	12	32	42	–	–	–
26	12	32	42	–	–	–
28	12	32	42	–	–	–
30	12	33	44	–	–	–
32	12	33	44	–	–	–
34	12	33	44	–	–	–
36	12	33	44	–	–	–
42	12	33	44	–	–	–
48	12	32	42	–	–	–
54	12	33	44	–	–	–
60	12	33	44	–	–	–
72	12	33	44	–	–	–
84	12	33	44	–	–	–
96	12	33	44	–	–	–

Note:

1. **Recommended pipe support spacing is less than the maximum to mor distribute weight over a building's structural system. Consult the stru engineer for additional guidance on pipe support spacing, especially v joist construction.**

VERTICAL PIPE SUPPORT SPACING

Maximum Vertical Support Spacing Feet			
Pipe Size	**Steel**	**Copper**	**Support**
8" and Smaller	**Every other floor and base of all pipe risers**	**Every floor and base of all pipe risers**	**Steel extension pipe clamps**
10"–12"	Every other floor and base of all pipe risers	Every floor and base of all pipe risers	Steel extension pipe clamps
14"–24"	Every other floor and base of all pipe risers	Not applicable	Steel extension pipe clamps
26"–96"	Every floor and base of all pipe risers	Not applicable	Steel extension pipe clamps

PIPE SPACING ON RACKS

Minimum Centerline-to-Centerline Dimensions, Inches

	Pipe Size										
Pipe Size	**1/2**	**3/4**	**1**	**1-1/4**	**1-1/2**	**2**	**2-1/2**	**3**	**4**	**5**	**6**
1/2 3/4 1	7.5 8.0 8.0	– 8.0 8.5	– – 8.5	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –
1-1/4 1-1/2 2	8.5 8.5 9.0	8.5 8.5 9.0	8.5 9.0 9.5	9.0 9.0 9.5	– 9.0 9.5	– – 10.0	– – –	– –– –	– – –	– – –	– – –
2-1/2 3 4	10.0 10.0 11.5	10.0 10.5 11.5	10.5 10.5 12.0	10.5 11.0 12.0	10.5 11.0 12.0	11.0 11.5 12.5	12.0 12.5 13.5	– 12.5 14.0	– – 15.0	– – –	– – –

Minimum Centerline-to-Centerline Dimensions, Inches

Pipe Size

Pipe Size	1/2	3/4	1	1-1/4	1-1/2	2	2-1/2	3	4	5	6
5	12.0	12.0	12.5	12.5	12.5	13.0	14.0	14.5	15.5	16.0	–
6	12.5	12.5	13.0	13.0	13.0	13.5	14.5	14.5	16.0	16.5	17
8	13.5	14.0	14.0	14.5	14.5	15.0	16.0	16.0	17.5	18.0	18
10	15.0	15.0	15.5	15.5	15.5	16.0	17.0	17.5	18.5	19.0	19
12	16.5	16.5	17.0	17.5	17.0	17.5	18.5	19.0	20.0	20.5	21
14	17.5	17.5	18.0	18.0	18.0	18.5	19.5	20.0	21.0	21.5	22
16	18.5	19.0	19.0	19.0	19.5	20.0	21.0	21.0	22.5	23.0	23
18	19.5	19.5	20.0	20.0	20.0	20.5	21.5	22.0	23.0	23.5	24
20	20.5	21.0	21.0	21.0	21.5	22.0	23.0	23.0	24.5	25.0	25
22	22.0	22.0	22.0	22.0	22.5	23.0	24.0	24.0	25.5	26.0	26
24	23.0	23.5	23.5	23.5	23.5	24.0	25.0	25.5	26.5	27.0	27
26	24.0	24.5	24.5	24.5	25.0	25.0	26.0	26.5	28.0	28.0	29
28	25.0	25.5	25.5	25.5	26.0	26.5	27.5	27.5	29.0	29.5	30
30	26.5	27.0	27.0	27.0	27.0	27.5	28.5	29.0	30.0	30.5	31
32	28.0	28.0	28.0	28.0	28.5	29.0	29.5	30.0	31.5	32.0	32
34	29.0	29.0	29.0	29.0	29.5	30.0	31.0	31.0	32.5	33.0	33
36	30.0	30.5	30.5	30.5	30.5	31.0	32.0	32.5	33.5	34.0	34
42	33.5	34.0	34.0	34.0	34.0	34.5	35.5	36.0	37.0	37.5	38
48	36.5	37.0	37.0	37.5	37.5	38.0	39.0	39.0	40.5	41.0	41
54	40.0	40.0	40.5	40.5	41.0	41.5	42.5	42.5	44.0	44.5	45
60	43.5	43.5	44.0	44.0	44.0	44.5	45.5	46.0	47.0	47.5	48
72	50.0	50.5	50.5	51.0	51.0	51.5	52.5	52.5	54.0	54.5	55
84	57.0	57.0	57.5	57.5	57.5	58.0	59.0	59.5	60.5	61.0	61
96	63.5	64.0	64.0	64.5	64.5	65.0	66.0	66.0	67.5	68.0	68

PIPE SPACING ON RACKS

Minimum Centerline-to-Centerline Dimensions, Inches

Pipe Size

Pipe Size	8	10	12	14	16	18	20	22	24	26	2
1/2	–	–	–	–	–	–	–	–	–	–	–
3/4	–	–	–	–	–	–	–	–	–	–	–
1	–	–	–	–	–	–	–	–	–	–	–

Minimum Centerline-to-Centerline Dimensions, Inches

Pipe Size	8	10	12	14	16	18	20	22	24	26	2
1-1/4	–	–	–	–	–	–	–	–	–	–	–
1-1/2	–	–	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–	–	–
2-1/2	–	–	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	–	–	–	–	–
5	–	–	–	–	–	–	–	–	–	–	–
6	–	–	–	–	–	–	–	–	–	–	–
8	19.5	–	–	–	–	–	–	–	–	–	–
10	21.0	22.0	–	–	–	–	–	–	–	–	–
12	22.5	23.5	25.0	–	–	–	–	–	–	–	–
14	23.5	24.5	26.0	27.0	–	–	–	–	–	–	–
16	24.5	26.0	27.5	28.5	30.0	–	–	–	–	–	–
18	25.5	26.5	28.0	29.0	30.5	31.0	–	–	–	–	–
20	26.5	28.0	29.5	30.5	31.5	32.5	33.5	–	–	–	–
22	27.5	29.0	30.5	31.5	32.5	33.5	34.5	35.5	–	–	–
24	29.0	30.0	31.5	32.5	34.0	34.5	36.0	37.0	38.0	–	–
26	30.0	31.0	33.0	34.0	35.0	36.0	37.0	38.0	39.5	40.5	–
28	31.0	32.5	34.0	35.0	36.0	37.0	38.0	39.0	40.5	41.5	42
30	32.5	33.5	35.0	36.0	37.5	38.0	39.5	40.5	41.5	42.5	44
32	34.0	35.0	36.5	37.4	39.0	39.5	41.0	42.0	43.0	44.0	45
34	35.0	36.0	37.5	38.5	40.0	40.5	42.0	43.0	44.0	45.0	46
36	36.0	37.0	38.5	39.5	41.0	41.5	43.0	44.0	45.0	46.5	47
42	39.5	40.5	42.0	41.0	44.5	45.0	46.5	47.5	48.5	50.0	51
48	42.5	44.0	45.5	46.5	47.5	48.5	49.5	51.0	52.0	53.0	54
54	46.0	47.5	49.0	50.0	51.0	52.0	53.0	54.0	55.5	56.5	57
60	49.5	50.5	52.0	53.0	54.5	55.0	56.5	57.5	58.5	60.0	61
72	56.0	57.5	59.0	60.0	61.0	62.0	63.0	64.5	65.5	66.5	67
84	63.0	64.0	65.5	66.5	68.0	68.5	70.0	71.0	72.0	73.5	74
96	69.5	71.0	72.5	73.5	74.5	75.5	76.5	78.0	79.0	80.0	81

PIPE SPACING ON RACKS

Minimum Centerline-to-Centerline Dimensions, Inches

Pipe Size	Pipe Size 30	32	34	36	42	48	54	60	72	84
1/2	–	–	–	–	–	–	–	–	–	–
3/4	–	–	–	–	–	–	–	–	–	–
1	–	–	–	–	–	–	–	–	–	–
1-1/4	–	–	–	–	–	–	–	–	–	–
1-1/2	–	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–	–
2-1/2	–	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	–	–	–	–
5	–	–	–	–	–	–	–	–	–	–
6	–	–	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	–	–	–	–
12	–	–	–	–	–	–	–	–	–	–
14	–	–	–	–	–	–	–	–	–	–
16	–	–	–	–	–	–	–	–	–	–
18	–	–	–	–	–	–	–	–	–	–
20	–	–	–	–	–	–	–	–	–	–
22	–	–	–	–	–	–	–	–	–	–
24	–	–	–	–	–	–	–	–	–	–
26	–	–	–	–	–	–	–	–	–	–
28	–	–	–	–	–	–	–	–	–	–
30	45.0	–	–	–	–	–	–	–	–	–
32	46.5	48.0	–	–	–	–	–	–	–	–
34	47.5	49.0	50.0	–	–	–	–	–	–	–
36	48.5	50.0	51.0	52.0	–	–	–	–	–	–

Notes:

1. Table based on schedule 40 pipe and includes the outside dimensions

Minimum Centerline-to-Centerline Dimensions, Inches

Pipe Size	Pipe Size									
	30	**32**	**34**	**36**	**42**	**48**	**54**	**60**	**72**	**84**
42	52.0	53.5	54.5	55.5	59.0	–	–	–	–	–
48	55.5	57.0	58.0	59.0	62.5	65.5	–	–	–	–
54	58.5	60.0	61.0	62.5	66.0	69.0	72.5	–	–	–
60	62.0	63.5	64.5	65.5	69.0	72.5	76.0	79.0	–	–
72	69.0	70.5	71.5	72.5	76.0	79.0	82.5	86.0	92.5	–
84	75.4	77.0	78.0	79.0	82.5	86.0	89.5	92.5	99.5	106.0
96	82.5	84.0	85.0	86.0	89.5	92.5	96.0	99.5	106.0	113.0

Notes:

1. **Table based on schedule 40 pipe and includes the outside dimensions flanges, fittings, etc.**
2. **Insulation over flanges, fittings, etc., is as follows:**
   Pipe sizes 2" and smaller:1-1/2" Insulation
   Pipe sizes2-1/2" and larger: 2" Insulation
3. **The spaces between fittings are as follows:**
   Space between two pipes 3" and smaller: 1"
   Space between one pipe 3" and smaller, and one pipe 4" and larger:1
   Space between two pipes 4" and larger: 2"
4. **For schedule 80 and 160 pipe and 300 lb. fittings, add the following:**
   Pipe sizes 4" and smaller: 1"
   Pipe sizes 5"–12":1-1/2"
   Pipe sizes 14" and larger: 2"
5. **Tables do not include space for valve handles and stems, expansion joints, expansion loops, or pipe guides.**

18.03. Pipe Expansion

A. Expansion Loops (See Part 3)

1. L-Bends. Anchor force = 500 lbs./dia. in.
2. Z-Bends. Anchor force = 200–500 lbs./dia. in.
3. U-Bends. Anchor force = 200 lbs./dia. in.

4. Locate anchors at beam locations, and avoid anchor locations at steel bar joists if at all possible.
5. The following expansion tables were created using the equations in Part 3.

THERMAL EXPANSION OF METAL PIPE

		Linear Thermal Expansion Inches/100 Feet		
Saturated Steam Pressure Psig	**Temperature °F**	**Carbon Steel**	**Stainless Steel**	**Copper**
–	–30	–0.19	–0.30	–0.32
–	–20	–0.12	–0.20	–0.21
–	–10	–0.06	–0.10	–0.11
–	0	0	0	0
–	10	0.08	0.11	0.12
–	20	0.15	0.22	0.24
–14.6	32	0.24	0.36	0.37
–14.6	40	0.30	0.45	0.45
–14.5	50	0.38	0.56	0.57
–14.4	60	0.46	0.67	0.68
–14.3	70	0.53	0.78	0.79
–14.2	80	0.61	0.90	0.90
–14.0	90	0.68	1.01	1.02
–13.7	100	0.76	1.12	1.13
–13.0	120	0.91	1.35	1.37
–11.8	140	1.06	1.57	1.59
–10.0	160	1.22	1.79	1.80
–7.2	180	1.37	2.02	2.05
–3.2	200	1.52	2.24	2.30
0	212	1.62	2.38	2.43
2.5	220	1.69	2.48	2.52
10.3	240	1.85	2.71	2.76
20.7	260	2.02	2.94	2.99
34.6	280	2.18	3.17	3.22

Saturated Steam Pressure Psig	Temperature °F	Linear Thermal Expansion Inches/100 Feet		
		Carbon Steel	Stainless Steel	Copper
52.3	300	2.35	3.40	3.46
75.0	320	2.53	3.64	3.70
103.3	340	2.70	3.88	3.94
138.3	360	2.88	4.11	4.18
181.1	380	3.05	4.35	4.42
232.6	400	3.23	4.59	4.87
294.1	420	3.41	4.83	4.91
366.9	440	3.60	5.07	5.15
452.2	460	3.78	5.32	5.41
551.4	480	3.97	5.56	5.65
666.1	500	4.15	5.80	5.91
797.7	520	4.35	6.05	6.15
947.8	540	4.54	6.29	6.41
1118	560	4.74	6.54	6.64
1311	580	4.93	6.78	6.92
1528	600	5.13	7.03	7.18
1772	620	5.34	7.28	7.43
2045	640	5.54	7.53	7.69
2351	660	5.75	7.79	7.95
2693	680	5.95	8.04	8.20
3079	700	6.16	8.29	8.47
–	720	6.37	8.55	8.71
–	740	6.59	8.81	9.00
–	760	6.80	9.07	9.26
–	780	7.02	9.33	9.53
–	800	7.23	9.59	9.79
–	820	7.45	9.85	10.07
–	840	7.67	10.12	10.31
–	860	7.90	10.38	10.61
–	880	8.12	10.65	10.97
–	900	8.34	10.91	11.16
–	920	8.56	11.18	11.42
–	940	8.77	11.45	11.71
–	960	8.99	11.73	11.98
–	980	9.20	12.00	12.27
–	1000	9.42	12.27	12.54

Notes:

1. **Table based on ASTM A53, Grade B, steel pipe.**
2. **Temperature range applicable through 400°F.**

Saturated Steam Pressure Psig	Temperature °F	Linear Thermal Expansion Inches/100 Feet		
		Carbon Steel	Stainless Steel	Copper

Notes:

1. Table based on ASTM A53, Grade B, steel pipe.
2. Temperature range applicable through 400°F.
3. Table also applicable to copper tube.
4. For equations and diagrams relating to pipe expansion, see Part 3 Equations.
5. L-bend, Z-bend, and U-bend or loop dimensions are minimum dimensions; we recommend rounding up to nearest 1/2 foot (H = 2W).

PIPE EXPANSION L-BENDS

Pipe Size	Expansion of Longest Leg							
	1"	1-1/2"	2"	2-1/2"	3"	4"	5"	6"
1/2	5'9"	7'0"	8'2"	9'2"	10'0"	11'6"	12'9"	14'0"
3/4	6'6"	8'4"	9'3"	10'4"	11'3"	13'0"	14'8"	16'0"
1	7'2"	8'9"	10'2"	11'4"	12'6"	14'4"	16'0"	17'6"
1-1/4	8'0"	9'10"	11'4"	12'8"	14'0"	16'2"	18'0"	19'8"
1-1/2	8'8"	10'6"	12'2"	13'8"	15'0"	17'2"	19'3"	21'0"
2	9'8"	11'9"	13'8"	15'2"	16'8"	19'3"	21'6"	23'6"
2-1/2	10'8"	13'0"	15'0"	16'9"	18'4"	21'2"	23'8"	26'0"
3	11'8"	14'4"	16'6"	18'6"	20'2"	23'4"	26'2"	28'8"
4	13'3"	16'2"	18'8"	21'0"	23'0"	26'6"	29'8"	32'6"
5	14'8"	18'0"	20'9"	23'3"	25'6"	29'6"	32'10"	36'0"
6	16'2"	19'8"	22'8"	25'4"	27'9"	32'2"	35'10"	39'3"
8	18'4"	22'6"	26'0"	29'0"	31'8"	36'8"	41'0"	44'10"
10	20'6"	25'0"	29'9"	32'4"	35'6"	40'10"	45'8"	50'0"
12	22'3"	27'3"	31'6"	35'2"	38'6"	44'6"	49'9"	54'6"
14	23'4"	28'8"	33'0"	36'10"	40'4"	46'8"	52'2"	57'2"
16	25'0"	30'6"	35'3"	39'6"	43'2"	50'0"	55'8"	61'0"
18	26'6"	32'4"	37'6"	41'9"	45'9"	52'10"	59'2"	64'10"

Pipe Size	1"	1-1/2"	2"	2-1/2"	3"	4"	5"	6"
	Expansion of Longest Leg							
20	27'10"	34'2"	39'6"	44'0"	48'3"	55'8"	62'3"	68'3"
22	29'3"	35'9"	41'4"	46'2"	50'8"	58'6"	65'4"	71'8"
24	30'6"	37'6"	43'2"	48'3"	52'10"	61'0"	68'3"	74'9"
26	31'9"	39'0"	45'0"	50'3"	55'0"	63'6"	71'0"	77'9"
28	33'0"	40'4"	46'8"	52'2"	57'2"	66'0"	73'8"	80'9"
30	34'2"	41'9"	48'3"	54'0"	59'2"	68'3"	76'3"	83'8"
32	35'3"	43'2"	50'0"	55'8"	61'0"	70'6"	78'9"	86'4"
34	36'4"	44'6"	51'4"	57'6"	63'0"	72'8"	81'2"	89'0"
36	37'6"	45'9"	52'10"	59'2"	64'9"	74'9"	83'8"	91'6"
42	40'6"	49'6"	57'2"	63'10"	70'0"	80'9"	90'3"	99'10"
48	43'2"	52'10"	61'0"	68'3"	74'9"	86'4"	96'5"	105'8"
54	45'9"	56'1"	64'9"	72'4"	79'3"	91'6"	102'4"	112'1"
60	48'3"	59'1"	68'3"	76'3"	83'7"	96'6"	107'10"	118'2"
72	52'10"	64'9"	74'9"	83'7"	91'6"	105'8"	118'2"	129'5"
84	57'1"	69'11"	80'9"	90'3"	98'10"	114'2"	127'7"	140'0"
96	61'0"	74'9"	86'4"	96'6"	105'8"	122'0"	136'5"	149'6"

PIPE EXPANSION Z-BENDS

Pipe Size	1"	1-1/2"	2"	2-1/2"	3"	4"	5"	6"
	Anchor-to-Anchor Expansion							
1/2	3'8"	4'6"	5'2"	5'10"	6'5"	7'4"	8'2"	9'0"
3/4	4'2"	5'2"	6'2"	6'8"	7'3"	8'6"	9'4"	10'3"
1	4'8"	5'8"	6'6"	7'4"	8'0"	9'2"	10'4"	11'3"
1-1/4	5'2"	6'4"	7'4"	8'2"	9'0"	10'4"	11'8"	12'8"
1-1/2	5'6"	6'10"	7'10"	8'9"	9'7"	11'0"	12'4"	13'6"
2	6'2"	7'8"	8'9"	9'9"	10'8"	12'4"	13'10"	15'2"
2-1/2	6'10"	8'4"	9'8"	10'9"	11'9"	13'8"	15'2"	16'8"
3	7'6"	9'2"	10'8"	12'0"	13'0"	15'0"	16'9"	18'4"
4	8'6"	10'6"	12'0"	13'6"	14'9"	17'0"	19'0"	20'10"
5	9'6"	11'8"	13'4"	15'0"	16'6"	19'0"	21'2"	23'2"
6	10'4"	12'8"	14'6"	16'4"	18'0"	20'8"	23'0"	25'3"
8	11'9"	14'6"	16'8"	18'8"	20'4"	23'6"	26'4"	28'10"
10	13'2"	16'2"	18'6"	20'9"	22'9"	26'3"	29'4"	32'2"

Pipe Size	Anchor-to-Anchor Expansion 1"	1-1/2"	2"	2-1/2"	3"	4"	5"	6"
12	14'4"	17'6"	20'3"	22'8"	24'9"	28'8"	32'0"	35'0"
14	15'0"	18'4"	21'2"	23'8"	26'0"	30'0"	33'6"	36'8"
16	16'0"	19'8"	22'8"	25'4"	27'9"	32'0"	35'9"	39'3"
18	17'0"	20'10"	24'0"	26'10"	29'6"	34'0"	38'0"	41'8"
20	18'0"	22'0"	25'3"	28'4"	31'0"	35'9"	40'0"	43'10"
22	18'10"	23'0"	26'8"	29'8"	32'6"	37'8"	42'0"	46'0"
24	19'8"	24'0"	27'9"	31'0"	34'0"	39'2"	43'10"	48'0"
26	20'6"	25'0"	28'10"	32'4"	35'4"	40'10"	45'8"	50'0"
28	21'2"	26'0"	30'0"	33'6"	36'8"	42'4"	47'4"	52'0"
30	22'0"	26'10"	31'0"	34'8"	38'0"	43'10"	49'0"	53'8"
32	22'8"	27'9"	32'0"	35'10"	39'3"	45'4"	50'8"	55'6"
34	23'4"	28'8"	33'0"	37'0"	40'6"	46'8"	52'2"	57'2"
36	24'0"	29'6"	34'0"	38'0"	41'8"	48'0"	53'8"	58'10"
42	26'0"	31'9"	36'8"	41'0"	45'0"	52'0"	58'0"	63'6"
48	27'9"	34'0"	39'3"	43'10"	48'0"	55'6"	62'0"	67'11"
54	29'5"	36'0"	41'7"	46'6"	50'11"	58'10"	65'9"	72'0"
60	31'0"	38'0"	43'10"	49'0"	53'8"	62'0"	69'4"	75'11"
72	34'0"	41'7"	48'0"	53'8"	58'10"	67'11"	75'11"	83'2"
84	36'8"	44'11"	51'11"	58'0"	63'6"	73'4"	82'0"	89'10"
96	39'3"	48'0"	55'6"	62'0"	67'11"	78'5"	87'8"	96'0"

PIPE EXPANSION U-BENDS OR LOOPS

	Anchor-to-Anchor Expansion							
	1"		1-1/2"		2"		2-1/2"	
Pipe Size	W	H	W	H	W	H	W	H
1/2	1'2"	2'4"	1'6"	3'0"	1'8"	3'4"	1'10"	3'8"
3/4	1'4"	2'8"	1'8"	3'4"	1'10"	3'8"	2'2"	4'4"
1	1'6"	3'0"	1'9"	3'6"	2'0"	4'0"	2'4"	4'8"
1-1/4	1'8"	3'4"	2'0"	4'0"	2'4"	4'8"	2'8"	5'4"
1-1/2	1'9"	3'6"	2'2"	4'4"	2'6"	5'0"	2'9"	5'6"
2	1'11"	3'10"	2'4"	4'8"	2'9"	5'6"	3'2"	6'4"
2-1/2	2'2"	4'4"	2'8"	5'4"	3'0"	6'0"	3'3"	6'6"

Pipe Size	Anchor-to-Anchor Expansion 1" W	H	1-1/2" W	H	2" W	H	2-1/2" W	H
3	2'4"	4'8"	3'0"	6'0"	3'4"	6'8"	3'9"	7'6"
4	2'8"	5'4"	3'3"	6'6"	3'9"	7'6"	4'2"	8'4"
5	3'0"	6'0"	3'8"	7'4"	4'2"	8'4"	4'8"	9'4"
6	3'3"	6'6"	4'0"	8'0"	4'7"	9'2"	5'2"	10'4"
8	3'8"	7'4"	4'6"	9'0"	5'2"	10'4"	5'10"	11'8"
10	4'2"	8'4"	5'0"	10'0"	5'10"	11'8"	6'6"	13'0"
12	4'6"	9'0"	5'6"	11'0"	6'4"	12'8"	7'2"	14'4"
14	4'8"	9'4"	5'9"	11'6"	6'8"	13'4"	7'6"	15'0"
16	5'0"	10'0"	6'2"	12'4"	7'1"	14'2"	8'0"	16'0"
18	5'4"	10'8"	6'6"	13'0"	7'6"	15'0"	8'6"	17'0"
20	5'8"	11'4"	7'0"	14'0"	7'11"	15'9"	8'10"	17'8"
22	5'10"	11'8"	7'3"	14'6"	8'3"	16'6"	9'3"	18'6"
24	6'1"	12'2"	7'6"	15'0"	8'8"	17'4"	9'8"	19'4"
26	6'5"	13'0"	7'10"	15'8"	9'0"	18'0"	10'2"	20'4"
28	6'8"	13'4"	8'2"	16'4"	9'4"	18'8"	10'6"	21'0"
30	6'10"	13'8"	8'6"	17'0"	9'8"	19'4"	11'0"	21'8"
32	7'1"	14'2"	8'8"	17'4"	10'0"	20'0"	11'2"	22'4"
34	7'4"	14'8"	9'0"	18'0"	10'4"	20'8"	11'6"	23'0"
36	7'6"	15'0"	9'2"	18'4"	10'8"	21'4"	12'0"	23'8"
42	8'1"	16'2"	10'0"	20'0"	11'6"	13'0"	12'9"	25'6"
48	8'8"	17'4"	10'7	21'2"	12'3"	24'6"	13'8"	27'4"
54	9'2"	18'4"	11'3"	22'6"	13'0"	26'0"	14'6"	29'0"
60	9'8"	19'4"	11'10"	23'8"	13'8"	27'4"	15'3"	30'6"
72	10'7"	21'2"	13'0"	26'0"	15'0"	30'0"	16'9"	33'6"
84	11'5"	22'10"	14'0"	28'0"	16'2"	32'4"	18'1"	36'2"
96	12'3"	24'6"	15'0"	30'0"	17'3"	34'6"	19'4"	38'8"

PIPE EXPANSION U-BENDS OR LOOPS

Pipe Size	Anchor-to-Anchor Expansion 3" W	H	4" W	H	5" W	H	6" W	H
1/2	2'0"	4'0"	2'4"	4'8"	2'8"	5'4"	2'10"	5'8"
3/4	2'4"	4'8"	2'8"	5'4"	3'0"	6'0"	3'3"	6'6"

Anchor-to-Anchor Expansion

Pipe Size	3" W	3" H	4" W	4" H	5" W	5" H	6" W	6" H
1	2'6"	5'0"	3'0"	6'0"	3'4"	6'8"	3'6"	7'0"
1-1/4	2'10"	5'8"	3'3"	6'6"	3'8"	7'4"	4'0"	8'0"
1-1/2	3'0"	6'0"	3'6"	7'0"	3'10"	7'8"	4'3"	8'6"
2	3'4"	6'8"	4'0"	8'0"	4'4"	8'8"	4'9"	9'6"
2-1/2	3'8"	7'4"	4'3"	8'6"	4'10"	9'10"	5'2"	10'4"
3	4'1"	8'2"	4'8"	9'4"	5'4"	10'8"	5'9"	11'8"
4	4'7"	9'2"	5'4"	10'8"	5'10"	11'8"	6'6"	13'0"
5	5'2"	10'4"	6'0"	12'0"	6'8"	13'4"	7'3"	14'6"
6	5'7"	11'2"	6'6"	13'0"	7'2"	14'4"	8'0"	16'0"
8	6'4"	12'8"	7'4"	14'8"	8'4"	16'8"	9'0"	18'0"
10	7'1"	14'2"	8'2"	16'4"	9'2"	18'4"	10'0"	20'0"
12	7'9"	15'6"	9'0"	18'0"	10'0"	20'0"	11'0"	22'0"
14	8'1"	16'2"	9'4"	18'8"	10'6"	21'0"	11'6"	23'0"
16	8'8"	17'4"	10'0"	20'0"	11'2"	22'4"	12'3"	24'6"
18	9'2"	18'4"	10'8"	21'4"	11'10"	23'8"	13'0"	26'0"
20	9'8"	19'4"	11'2"	22'4"	12'6"	25'0"	13'8"	27'4"
22	10'2"	20'4"	11'8"	23'4"	13'2"	26'4"	14'4"	28'8"
24	10'8"	21'4"	12'3"	24'6"	13'8"	27'4"	15'0"	30'0"
26	11'0"	22'0"	12'9"	25'6"	14'4"	28'8"	15'7"	31'2"
28	11'6"	23'0"	13'2"	26'4"	14'10"	29'8"	16'2"	32'4"
30	12'0"	23'8"	13'8"	27'4"	15'4"	30'8"	16'9"	33'6"
32	12'3"	24'6"	14'2"	28'4"	15'10"	31'8"	17'3"	34'6"
34	12'8"	25'4"	14'6"	29'0"	16'4"	32'8"	18'0"	36'0"
36	13'0"	26'0"	15'0"	30'0"	16'10"	33'8"	18'4"	36'8"
42	14'0"	28'0"	16'2"	32'4"	18'2"	36'4"	20'0"	40'0"
48	15'0"	30'0"	17'4"	34'8"	19'4"	38'8"	21'2"	42'4"
54	15'11"	31'10"	18'4"	36'8"	20'6"	41'0"	22'5"	44'10"
60	16'9"	33'6"	19'4"	38'8"	21'7"	43'2"	23'8"	47'4"
72	18'4"	36'8"	21'2"	42'4"	23'8"	47'4"	25'11"	51'10"
84	19'10"	39'8"	22'10"	45'8"	25'7"	51'2"	28'0"	56'0"
96	21'2"	42'4"	24'5"	48'10"	27'4"	54'8"	29'11"	59'10"

PIPE EXPANSION U-BENDS OR LOOPS

Anchor-to-Anchor Expansion

Anchor-to-Anchor Expansion

Anchor-to-Anchor Expansion

Pipe Size	7" W	7" H	8" W	8" H	10" W	10" H	12" W	12" H
1/2	3'2"	6'4"	3'3"	6'6"	3'8"	7'4"	4'0"	8'0"
3/4	3'6"	7'0"	3'8"	7'4"	4'2"	8'4"	4'6"	9'0"
1	3'10"	7'8"	4'0"	8'0"	4'7"	9'2"	5'0"	10'0"
1-1/4	4'4"	8'8"	4'7"	9'2"	5'1"	10'2"	5'7"	11'2"
1-1/2	4'8"	9'4"	5'0"	10'0"	5'6"	11'0"	6'0"	12'0"
2	5'2"	10'4"	5'6"	11'0"	6'1"	12'2"	6'8"	13'4"
2-1/2	5'8"	11'4"	6'0"	12'0"	6'8"	13'4"	7'4"	14'8"
3	6'2"	12'4"	6'8"	13'4"	7'6"	15'0"	8'1"	16'2"
4	7'0"	14'0"	7'6"	15'0"	8'6"	17'0"	9'2"	18'4"
5	7'10"	15'8"	8'4"	16'8"	9'4"	18'8"	10'2"	20'4"
6	8'6"	17'0"	9'2"	18'4"	10'2"	20'4"	11'2"	22'4"
8	9'8"	19'4"	10'4"	20'8"	11'7"	23'2"	12'8"	25'4"
10	10'10"	21'8"	11'7"	23'2"	13'0"	26'0"	14'2"	28'4"
12	11'10"	23'8"	12'7"	25'2"	14'0"	28'0"	15'6"	31'0"
14	12'4"	24'8"	13'3"	26'6"	14'9"	29'6"	16'2"	32'4"
16	13'2"	26'4"	14'2"	28'4"	15'9"	31'6"	17'3"	34'6"
18	14'0"	28'0"	15'0"	30'0"	16'9"	33'6"	18'4"	36'8"
20	14'10"	29'8"	15'9"	31'6"	17'8"	35'4"	19'4"	38'8"
22	15'6"	31'0"	16'7"	33'2"	18'6"	37'0"	20'3"	40'6"
24	16'2"	32'4"	17'4"	34'8"	19'4"	38'8"	21'2"	42'4"
26	16'10"	33'8"	18'0"	36'0"	20'0"	40'0"	22'0"	44'0"
28	17'6"	35'0"	18'8"	37'4"	21'0"	42'0"	23'0"	46'0"
30	18'2"	36'4"	19'4"	38'8"	21'7"	43'2"	23'8"	47'4"
32	18'8"	37'4"	20'0"	40'0"	22'4"	44'8"	24'6"	49'0"
34	19'4"	38'8"	20'8"	41'4"	23'0"	46'0"	25'2"	50'4"
36	19'10"	39'8"	21'2"	42'4"	23'8"	47'4"	26'0"	52'0"
42	21'6"	43'0"	23'0"	46'0"	25'6"	51'0"	28'0"	56'0"
48	22'10"	45'8"	24'5"	48'10"	27'4"	54'8"	30'0"	60'0"
54	24'3"	48'6"	25'11"	51'10"	29'0"	58'0"	31'9"	63'6"
60	25'7"	51'2"	27'4"	54'8"	30'6"	61'0"	33'6"	67'0"
72	23'8"	47'4"	29'11"	59'10"	33'5"	66'10"	36'8"	73'4"

	Anchor-to-Anchor Expansion							
	7"		8"		10"		12"	
72	25'8"	47'4"	29'11"	59'10"	33'3"	66'10"	36'8"	73'4"
84	30'3"	60'6"	32'4"	64'8"	36'1"	72'2"	39'7"	69'2"
96	32'4"	64'8"	34'7"	69'2"	38'8"	77'4"	42'4"	84'8"

18.04. *ASME B31 Piping Code* Comparison

ASME B31 PIPING CODE COMPARISON

Item	Power Piping ASME B31.1-1998	Process Piping ASME B31.3-1996	Building Services PipingASME B31.9-1996
Application	Power and auxiliary piping for electric generating stations, industrial and institutional plants, central and district heating/cooling plants, and geothermal heating systems.	Petroleum refineries, chemical, pharmaceutical, textile, paper, semiconductor, and cryogenic plants.	Industrial, institutional, commercial, and public buildings and multiunit residences.
Services	Systems include, but are not limited to, steam, water, oil, gas, and air.	Systems include, but are not limited to, raw, intermediate, and finished chemicals, petroleum products, gas, steam air water, fluidized solids, refrigerants, and cryogenic fluids.	Systems include, but are not limited to, water for heating and cooling, condensing water, steam or other condensate, other nontoxic liquids, steam, vacuum, other nontoxic,

nonflammable gases, and combustible liquids including fuel oil.

Item	Power Piping ASME B31.1-1998	Process Piping ASME B31.3-1996	Building Services PipingASME B31.9-1996
General Limitations	This code does not apply to building services piping within the property limits or buildings of industrial and institutional facilities, which is in the scope of ASME B31.9 except that piping beyond the limitations of material, size, temperature, pressure, and service specified in ASME B31.9 shall conform to the requirements of ASME B31.1. This code excludes power boilers in accordance with the ASME Boiler and Pressure Vessel Code (BPVC) Section I.	This code excludes piping systems for internal gauge pressures above zero but less than 15 psig, provided the fluid is nonflammable, nontoxic, and not damaging to human tissue and its temperature is from –20°F through 366°F. This code excludes power boilers in accordance with the ASME Boiler and Pressure Vessel Code Section I and boiler external piping, which is required to conform to ASME B31.1.	This code prescribes requirements for the design, materials, fabrication, installation, inspection, examination, and testing of piping systems for building services. It includes piping systems in the building or within the property limits. This code excludes power boilers in accordance with the ASME Boiler and Pressure Vessel Code Section I and boiler external piping, which is required to conform to ASME B31.1.
Pipe Size Limitations	No limit	No limit	Carbon steel 30" nominal pipe size and 0.5" wall (30" xs steel pipe)

Item	Power Piping ASME B31.1-1998	Process Piping ASME B31.3-1996	Building Services PipingASME B31.9-1996
			xs steel pipe) Copper—12" nominal pipe size Stainless steel—12" of nominal pipe size and 0.5" wall
Pressure Limitations	No limit	No limit	Steam and condensate—150 psig Liquids—350 psig Vacuum—1 atmosphere external pressure Compressed air and gas—150 psig
Temperature Limitations	No limit	No limit	Steam and condensate—366°F Maximum (150 psig) Other gases and vapors—200°F maximum Nonflammable liquids—250°F maximum Minimum temperature all services—0°F
Bypass Requirements	All bypasses must be in accordance with MSS-SP-45. Pipe weight shall be minimum Schedule 80.	Bypasses not addressed—recommend the following B31.1	Bypasses not addressed—recommend the following B31.1
Class I Boiler Systems—ASME	Boiler external piping is	Boiler external piping is	Boiler external piping is

Item	Power Piping ASME B31.1-1998	Process Piping ASME B31.3-1996	Building Services PipingASME B31.9-1996
BPVC Section I	governed by ASME B31.1. All other piping may be governed by this code within the limitations of the code.	governed by ASME B31.1. All other piping may be governed by this code within the limitations of the code.	governed by ASME B31.1. All other piping may be governed by this code within the limitations of the code.
Class IV Boiler Systems— ASME BPVC Section IV	All piping, including boiler external piping, may be governed by this code within the limitations of the code.	All piping, including boiler external piping, may be governed by this code within the limitations of the code.	All piping, including boiler external piping, may be governed by this code within the limitations of the code.

Class I Boiler Systems

1. Class I Steam Boiler Systems are constructed for Working Pressures above 15 psig.
2. Class I Hot Water Boiler Systems are constructed for Working Pressures above 160 psig and/or Working Temperatures above 250°F.

Class IV Boiler Systems

1. Class IV Steam Boiler Systems are constructed with a maximum Working Pressure of 15 psig.
2. Class IV Hot Water Boiler Systems are constructed with a maximum Working Pressure of 160 psig and a maximum Working Temperature of 250°F.

Class I Boiler External Piping

1. Steam Boiler Piping—ASME Code piping is required from the boiler through the 1st stop check valve to the 2nd stop valve.
2. Steam Boiler Feedwater Piping—ASME Code piping is required from the boiler through the 1st stop valve to the check valve for single boiler feedwater installations and from the boiler through the 1st stop valve and through the check valve to the 2nd stop valve at the feedwater control valve

for multiple boiler installations.

Item | Power Piping ASME B31.1-1998 | Process Piping ASME B31.3-1996 | Building Services PipingASME B31.9-1996

3. Steam Boiler Bottom Blowdown Piping—ASME Code Piping is required from the boiler through the 1st stop valve to the 2nd stop valve.
4. Steam Boiler Surface Blowdown Piping—ASME Code Piping is required from the boiler to the 1st stop valve.
5. Steam and Hot Water Boiler Drain Piping—ASME Code Piping is required from the boiler through the 1st stop valve to the 2nd stop valve.
6. Hot Water Boiler Supply and Return Piping—ASME Code piping is required from the boiler through the 1st stop check valve to the 2nd stop valve on both the supply and return piping.

Class IV Boiler External Piping

1. All Class IV Boiler External Piping is governed by the respective piping system code.

ASME B31 PIPING CODE COMPARISON

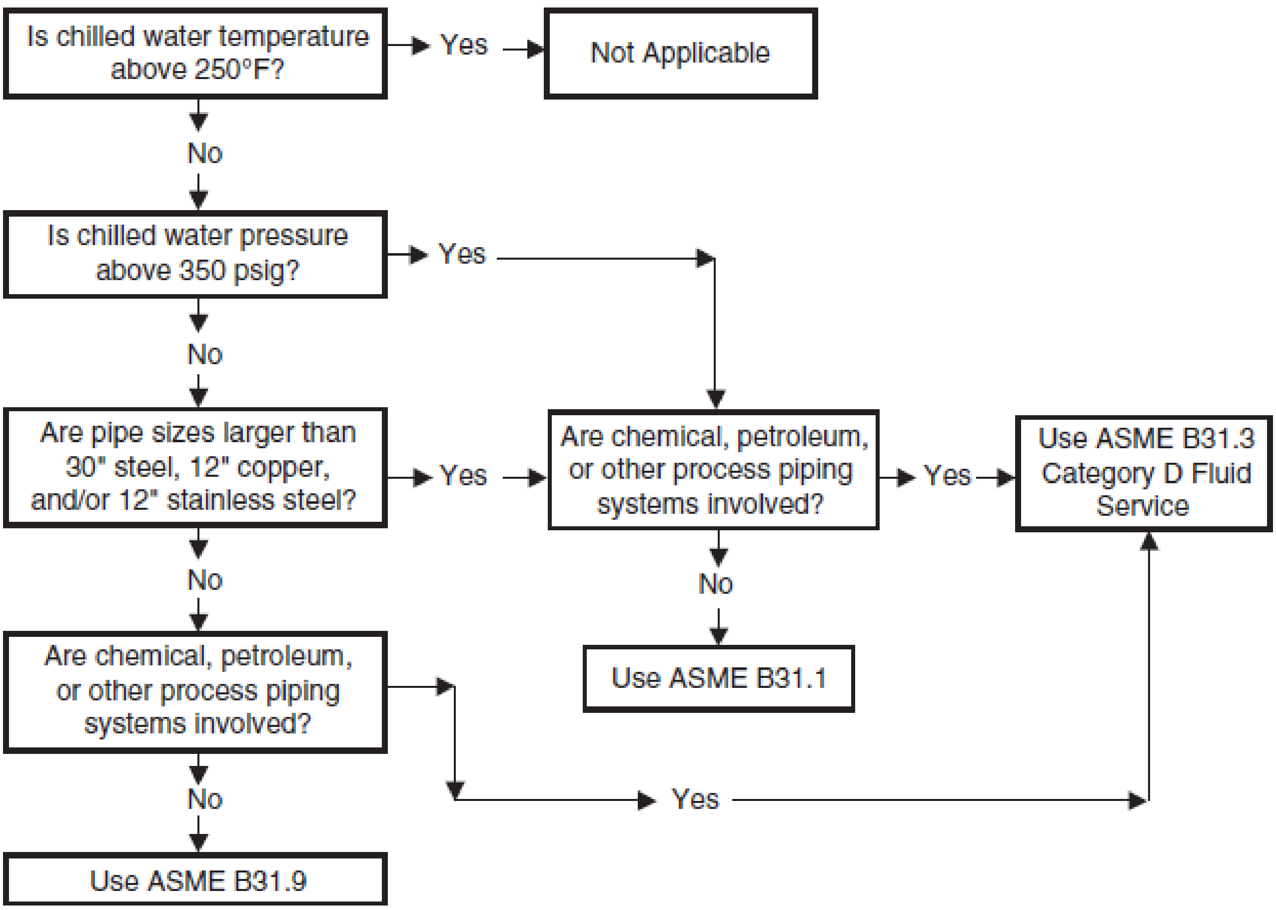
Item	**Power Piping ASME B31.1-1998**	**Process Piping ASME B31.3-1996**	**Building Services Piping ASME B31.9-1996**
Piping Classifications	No classifications required by this code. The code deals with and governs all piping under its jurisdiction the same.		No classifications required by this code. The code deals with and governs all piping under its jurisdiction the same.
Low Temp Chilled Water (0–40°F)		D	
Chilled Water (40–60°F)		D	
Condenser Water (60–110°F)		D	

Item	Power Piping ASME B31.1-1998	Process Piping ASME B31.3-1996	Building Services Piping ASME B31.9-1996
(60–110°F)			
Low Temp Heating Water (110–250°F)		N	
High Temp Heating Water (250–450°F)		N—Except Boiler Ext. Piping B31.1 applicable	
Low Press. Steam (15 psig and Less)		N	
High Press. Steam (Above 15 psig)		N—Except Boiler Ext. Piping B31.1 applicable	
Hydrostatic Pressure Testing	Test Medium—Water, unless subject to freezing	Test Medium—Water, unless subject to freezing	Test Medium—Water, unless subject to freezing
	Boiler External Piping—ASME BPVC Section I	N/A	N/A
	Nonboiler External Piping—1.5 times the design pressure but not to exceed the max. allowable system pressure for a minimum of 10 minutes.	Category D or N Fluid Service—1.5 times the design pressure but not to exceed the max. allowable system pressure for a minimum of 10 minutes.	Nonboiler External Piping—1.5 times the design pressure but not to exceed the max. allowable system pressure for a minimum of 10 minutes.
	All Other Services—1.5 times the design pressure but not to exceed the max. allowable system		All Other Services— 1.5 times the design pressure but not to exceed the max. allowable system

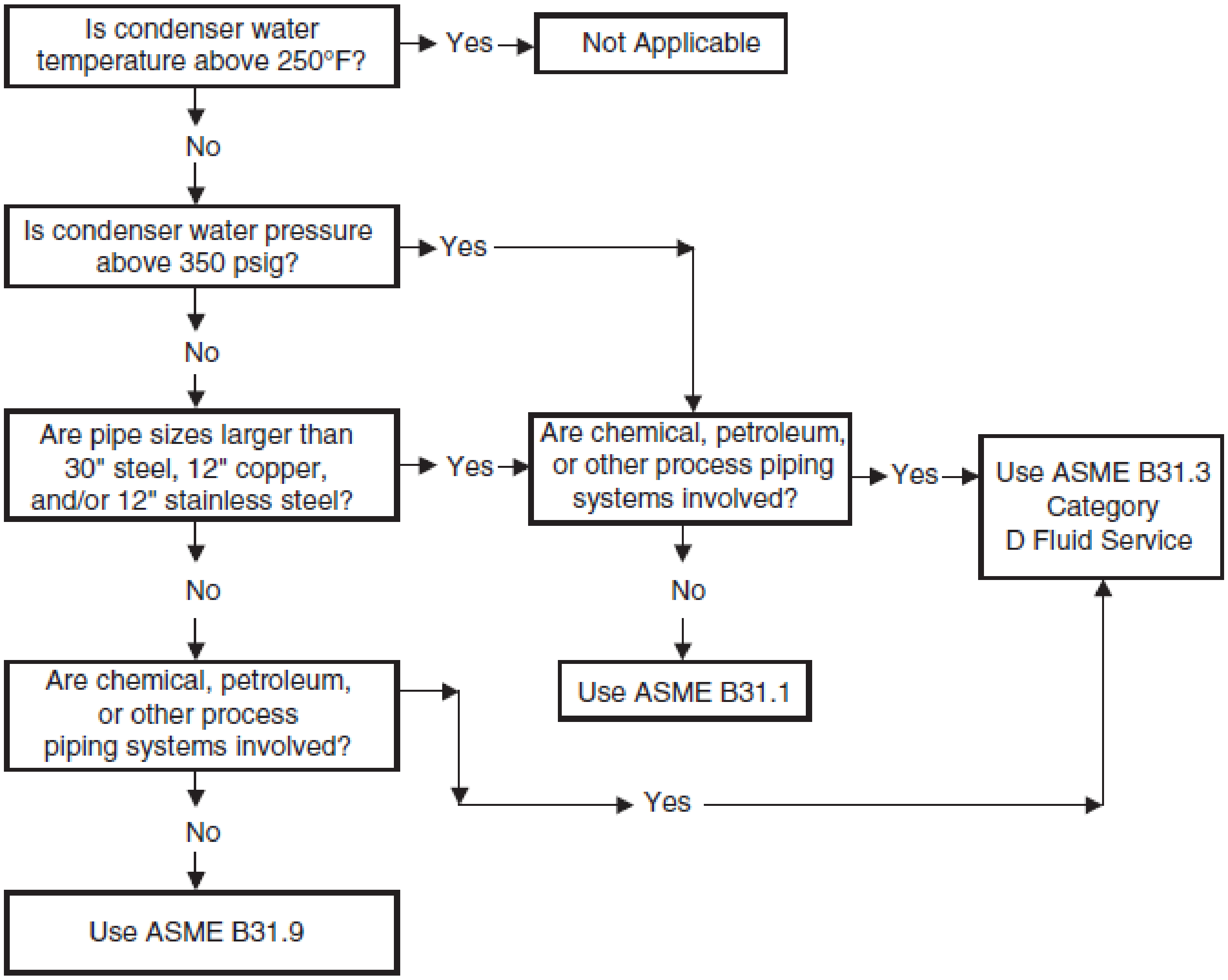
Item	Power Piping ASME B31.1-1998	Process Piping ASME B31.3-1996	Building Services Piping ASME B31.9-1996
	pressure for a minimum of 10 minutes.		pressure for a minimum of 10? minutes.
Examination, Inspection, and Testing Requirements	The degree of examination, inspection, and testing, and the acceptance standards must be mutually agreed upon by the manufacturer, fabricator, erector, or contractor and the owner.	The degree of examination, inspection, and testing, and the acceptance standards must be mutually agreed upon by the manufacturer, fabricator, erector, or contractor and the owner.	The degree of examination, inspection, and testing, and the acceptance standards must be mutually agreed upon by the manufacturer, fabricator, erector, or contractor and the owner.
	Class I Steam & Hot Water Systems—Nondestructive testing and visual examinations are required by this code. Percentage and types of tests performed must be agreed upon.	Category D Fluid Service—Visual Examination.	All Services—Visual Examinations.
	Class IV Steam & Hot Water Systems—Visual Examination only. All other services—Visual Examination only.	Category N Fluid Service—Visual Examination, 5% Random Examination of components, fabrication, welds, and installation. Random	If more rigorous examination or testing is required, it must be mutually agreed upon

Item	Power Piping ASME B31.1-1998	Process Piping ASME B31.3-1996 radiographic or ultrasonic testing of 5% of circumferential butt welds.	Building Services Piping ASME B31.9-1996
	If more rigorous examination or testing is required, it must be mutually agreed upon.	If more rigorous examination or testing is required, it must be mutually agreed upon.	.
Nondestructive Testing	Radiographic Ultrasonic Eddy current Liquid penetrant Magnetic particle Hardness tests	Radiographic Ultrasonic Eddy current Liquid penetrant Magnetic particle Hardness tests	Radiographic Ultrasonic Eddy current Liquid penetrant Magnetic particle Hardness tests

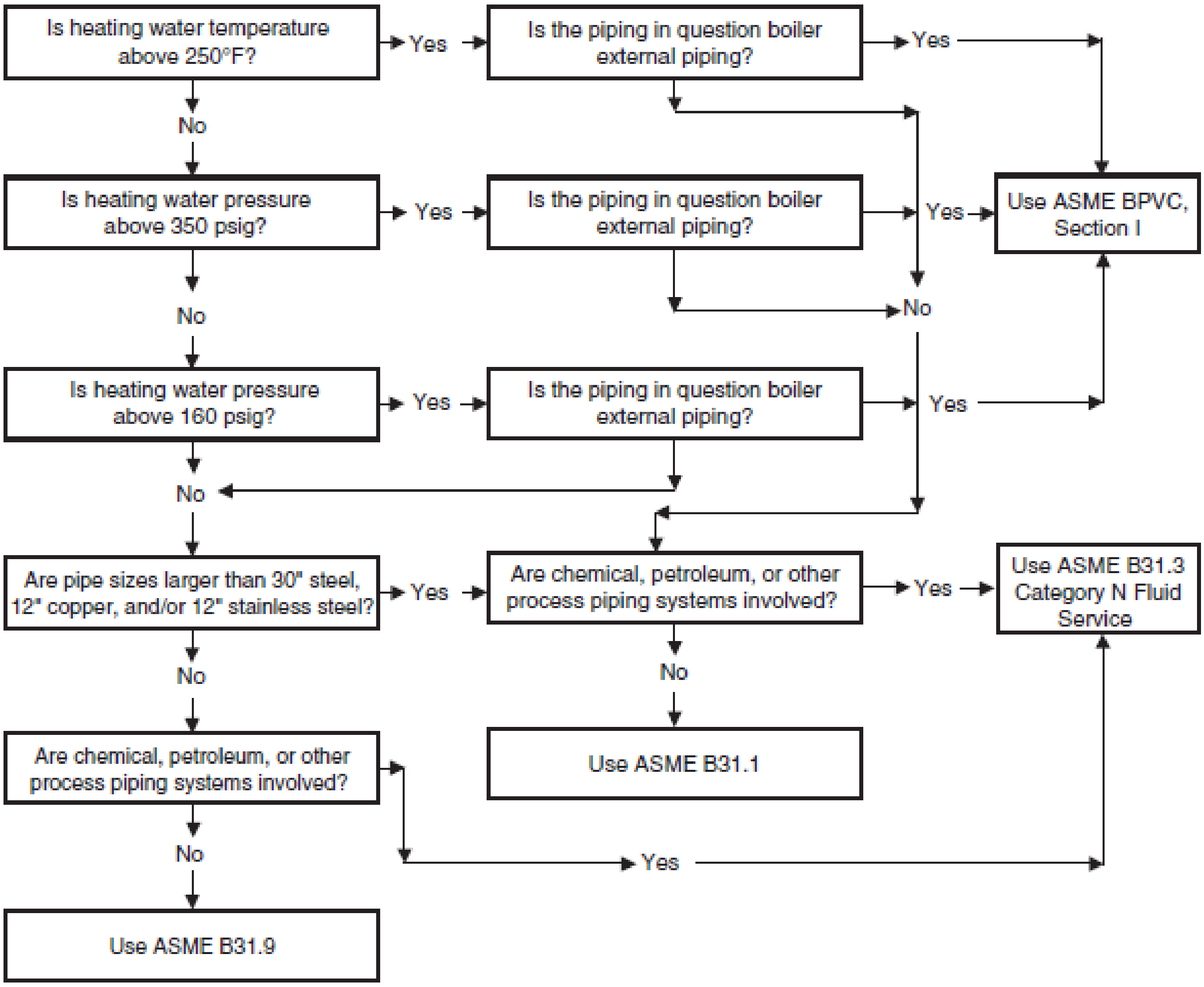
ASME B31 Chilled Water System Decision Diagram Chilled Water Systems (0–60°F)



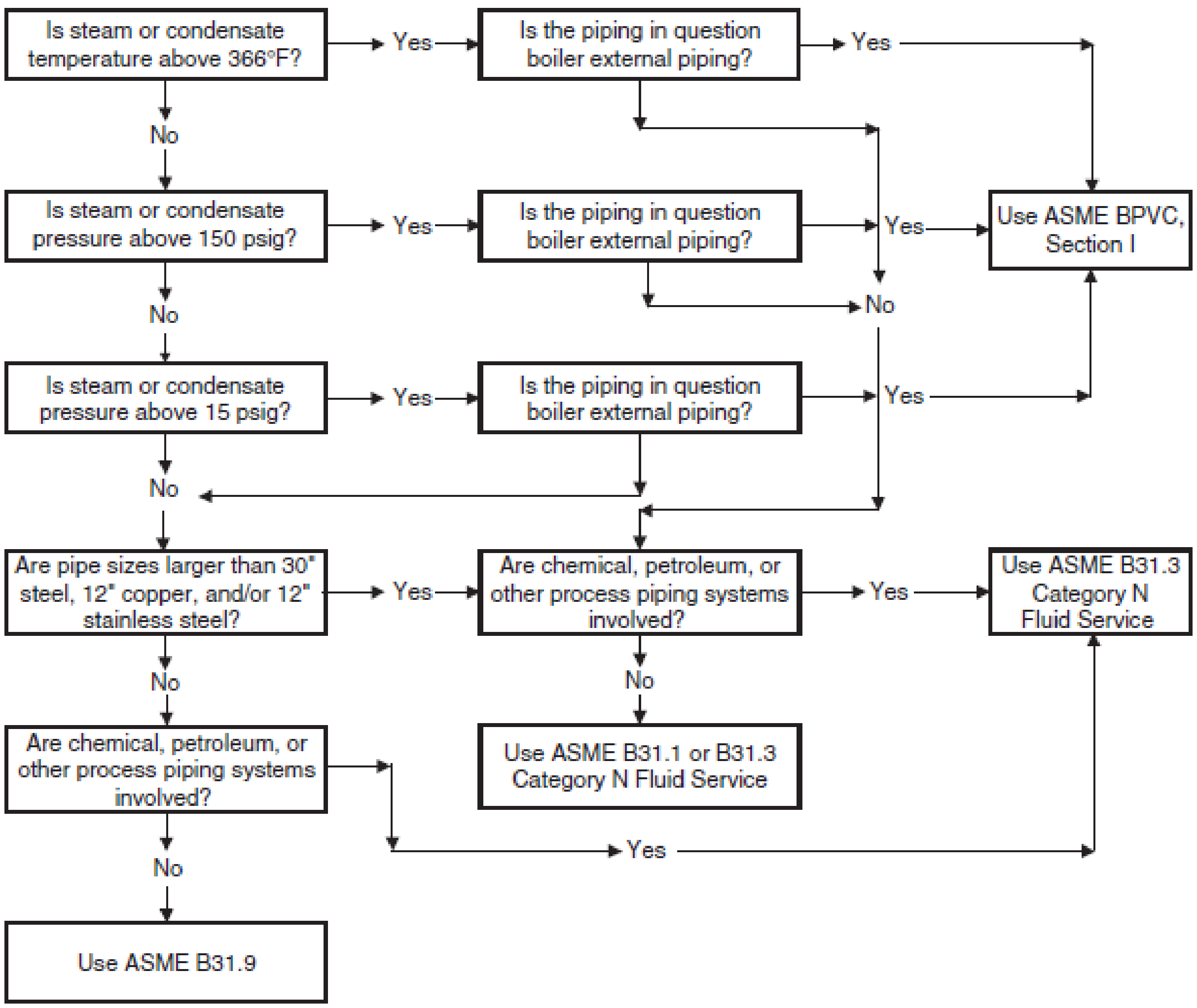
ASME B31 Condenser Water System Decision Diagram Condenser Water Systems (60–110°F)



ASME B31 Heating Water System Decision Diagram Heating Water Systems (110–450°F)



ASME B31 Steam and Steam Condensate System Decision Diagram
Steam and Steam Condensate Systems (0–300 psig)



18.05. Galvanic Action

A. **Galvanic action results from the electrochemical variation in the potential of metallic ions. If two metals of different potentials are placed in an electrolytic medium (i.e., water), the one with the higher potential will act as an anode and will corrode. The metal with the lower potential, being the cathode, will be unchanged. The greater the separation of the two metals on the following chart, the greater the speed and severity of the corrosion. The following list is in order of their anodic-cathodic characteristics (i.e., metals listed in the following will corrode those listed previously—for example, copper will corrode steel).**

Magnesium Alloys

Alclad 3S

Aluminum Alloys

Low-Carbon Steel

Cast Iron

Stainless Steel, Type 410

Stainless Steel, Type 430

Stainless Steel, Type 404

Stainless Steel, Type 304

Stainless Steel, Type 316

Hastelloy A

Lead-Tin Alloys

Brass

Copper

Bronze

90/10 Copper-Nickel

70/30 Copper-Nickel

Inconel

Silver

Stainless Steel (passive)

Monel

Hastelloy C

Titanium

18.06. Piping System Installation Hierarchy (Easiest to Hardest to Install)

A. **Natural Gas, Medical Gases, and Laboratory Gases, Easiest to Install**

B. **Chilled Water, Heating Water, Domestic Cold and Hot Water Systems, and Other Closed HVAC and Plumbing Systems**

C. **Steam and Steam Condensate**

D. **Refrigeration Piping Systems**

E. **Sanitary Systems, Storm Water Systems, AC Condensate Systems, Hardest to Install**

18.07. Valves

A. Valve Types

1. Balancing valves:
   a. Duty: Balancing, shutoff (manual or automatic).

   b. A valve specially designed for system balancing.

2. Ball valves full port:
   a. Duty: Shutoff.

   b. A valve with a sphere-shaped internal flow device that rotates open and closed to permit flow, or obstruct flow, through the valve. The valve goes from full open to full close in a quarter turn. The opening in the spherical flow device is the same size or close to the same size as the pipe.

3. Ball valves, reduced port:
   a. Duty: Balancing, shutoff.

   b. A valve with a sphere-shaped internal flow device that rotates open and closed to permit flow, or obstruct flow, through the valve. The valve goes from full open to full close in a quarter turn. The opening in the spherical flow device is smaller than the pipe size.

4. Butterfly valves:
   a. Duty: Shutoff, balancing.

   b. A valve with a disc-shaped internal flow device that rotates open and closed to permit flow, or obstruct flow, through the valve. The valve goes from full open to full close in a quarter turn.

5. Check valves:

a. Duty: Control flow direction.

b. A valve opened by the flow of fluid in one direction that closes automatically to prevent flow in the reverse direction. (Types: Ball, Disc, Globe, Piston, Stop, Swing.)

6. Gate valves:
   a. Duty: Shutoff.

   b. A valve with a wedge- or gate-shaped internal flow device that moves on an axis perpendicular to the direction of flow.

   c. This valve is obsolete in today's hydronic piping systems (it is replaced by ball and butterfly valves).

7. Globe valves:
   a. Duty: Throttling.

   b. A valve with a disc or plug that moves on an axis perpendicular to the valve seat.

8. Plug valves:
   a. Duty: Shutoff, balancing.

   b. A valve with a cylindrical or cone-shaped internal flow device that rotates open and closed to permit flow, or obstruct flow, through the valve. The valve goes from full open to full close in a quarter turn.

9. Control Valves. Control valves are mechanical devices used to control the flow of steam, water, gas, and other fluids.
   a. *2-Way*. Temperature control, modulate flow to controlled device, variable flow system.

   b. 3-*Way Mixing*. Temperature control, modulate flow to controlled device, constant flow system; two inlets and one outlet.

   c. *3-Way Diverting*. Used to divert flow; generally cannot modulate flow—Two positions; one inlet and two outlets.

   d. *Quick Opening Control Valves*. Quick opening control valves produce a wide free port area with a relatively small percentage of total valve stem stroke. The maximum flow is approached as the valve begins to open.

e. e.*Linear Control Valves*. Linear control valves produce free port areas directly related to valve stem stroke. The opening and flow are related in direct proportion.

f. f.*Equal Percentage Control Valves*. Equal percentage control valves produce an equal percentage increase in the free port area with each equal increment of valve stem stroke. Each equal increment of opening increases flow by an equal percentage over the previous value (most common HVAC control valve).

g. Control valves are normally smaller than line size unless used in two-position applications (open/closed).

h. Control valves should normally be sized to provide 20–60 percent of the total system pressure drop.
   1. Water system control valves should be selected with a pressure drop equal to 2–3 times the pressure drop of the controlled device.
      OR
      Water system control valves should be selected with a pressure drop equal to 10 ft or the pressure drop of the controlled device, whichever is greater.
      OR
      Water system control valves for constant flow systems should be sized to provide 25 percent of the total system pressure drop.
      OR
      Water system control valves for variable flow systems should be sized to provide 10 percent of the total system pressure drop or 50 percent of the total available system pressure.

   2. Steam control valves should be selected with a pressure drop equal to 75 percent of the inlet steam pressure.

10. Specialty valves:
    a. Triple-duty valves: Combination check, balancing, and shutoff.

    b. Backflow preventer: prevent contamination of domestic water system. For HVAC applications, use reduced pressure zone backflow preventers.

11. Valves used for balancing need not be line size. Balancing valves should be selected for the midrange of its adjustment.

B. Valve Terms

1. *Actuator*. A mechanical, hydraulic, electric, or pneumatic device or mechanism used to operate a valve.
2. *Adjustable Travel Stop*. A mechanism used to limit the internal flow device travel.
3. *Back Face*. The side of the flange opposite the gasket.
4. *Blind Flange*. A flange with a sealed end to provide a pressure tight closure of a flanged opening.
5. *Body*. The pressure containing shell of a valve or fitting with ends for connection to the piping system.
6. *Bonnet*. A valve body component that contains an opening for the stem. The bonnet may be bolted (Bolted Bonnet), threaded (Threaded Bonnet), or a union (Union Bonnet).
7. *Bronze Mounted*. The seating surfaces of the valve are made of brass or bronze.
8. *Butt Welding Joints*. A joint made to pipes, valves, and fittings with ends adapted for welding by abutting the ends and welding them together.
9. *Chainwheel*. A manual actuator that uses a chain-driven wheel to turn the valve flow device by turning the stem, handwheel, or gearing.
10. *Cock*. A form of a plug valve.
11. *Cold Working Pressure*. Maximum pressure at which a valve or fitting is allowed to operate at ambient temperature.
12. *Concentric Reducer*. A reducer in which both openings are on the same centerline.
13. *Eccentric Reducer*. A reducer with the small end off-center.
14. *Elbow*, *Long Radius*. An elbow with a centerline turning radius of 1-1/2 times the nominal pipe size of the elbow.
15. *Elbow*, *Short Radius*. An elbow with a centerline turning radius of one times the nominal pipe size of the elbow.
16. *Face-to-Face Dimension*. The dimension from the face of the inlet to the face of the outlet of the valve or fitting.

17. *Female End*. Internally threaded portion of a pipe, valve, or fitting.

18. *Flanged Joint*. A joint made with an annular collar designed to permit a bolted connection.

19. *Grooved Joint* or *Mechanical Joint*. A joint made with a special mechanical device using a circumferential groove cut into or pressed into the pipes, valves, and fittings to retain a coupling member.

20. *Handwheel*. The valve handle shaped in the form of a wheel.

21. *Inside Screw*. The screw mechanism that moves the internal flow device located within the valve body.

22. *Insulating Unions* (*Dielectric Unions*). Used in piping systems to prevent dissimilar metals from coming into direct contact with each other. (See Galvanic Action Paragraph.)

23. *Male End*. Externally threaded portion of pipes, valves, or fittings.

24. *Memory Stop*. A device that allows for the repeatable operation of a valve at a position other than full open or full closed, often used to set or mark a balance position.

25. *Nipple*. A short piece of pipe with both ends externally threaded.

26. *Nominal Pipe Size* (*NPS*). The standard pipe size, but not necessarily the actual dimension.

27. *Nonrising Stem*. When the valve is operated, the stem does not rise through the bonnet; the internal flow device rises on the stem.

28. *Outside Screw and Yoke* (*OS&Y*). The valve packing is located between the stem threads and the valve body. The valve has a threaded stem that is visible.

29. *Packing*. A material that seals around the movable penetration of the valve stem.

30. *Rising Stem*. When the valve is operated, the stem rises through the bonnet and the internal flow device is moved up or down by the moving stem.

31. *Safety-Relief Valves*. A valve that automatically relieves the system pressure when the internal pressure exceeds a set value. Safety-relief valves may operate on pressure only or on a combination of pressure and temperature.
    a. *Safety Valve*. An automatic pressure relieving device actuated by the static pressure upstream of the valve and characterized by full opening pop action. A safety valve is used primarily for gas or vapor service.

    b. *Relief Valve*. An automatic pressure relieving device actuated by the static pressure upstream of the valve that opens further with the increase in pressure over the opening pressure. A relief valve is used primarily for liquid service.

    c. *Safety Relief Valve*. An automatic pressure actuated relieving device suitable for use either as a safety valve or relief valve, depending on application.

    d. Safety, Relief, and Safety Relief Valve testing is dictated by the Insurance Underwriter.

32. *Seat*. The portion of the valve that the internal flow device presses against to form a tight seal for shutoff.

33. *Slow Opening Valve*. A valve that requires at least five 360-degree turns of the operating mechanism to change from fully closed to fully open.

34. *Socket Welding Joint*. A joint made with a socket configuration to fit the ends of the pipes, valves, or fittings, which is then fillet welded in place.

35. *Soldered Joint*. A joint made with pipes, valves, or fittings in which the joining is accomplished by soldering or brazing.

36. *Stem*. A device that operates the internal flow control device.

37. *Threaded Joint*. A joint made with pipes, valves, or fittings in which the joining is accomplished by threading the components.

38. *Union*. A fitting that allows the assembly or disassembly of the piping system without rotating the piping.

C. Valve Abbreviations

TE	Threaded End
FE	Flanged End
SE	Solder End

BWE	Butt Weld End
SWE	Socket Weld End
TB	Threaded Bonnet
BB	Bolted Bonnet
UB	Union Bonnet
TC	Threaded Cap
BC	Bolted Cap
UC	Union Cap
IBBM	Iron Body, Bronze Mounted
DI	Ductile Iron
SB	Silver Brazed
DD	Double Disc
SW	Solid Wedge Disc
RWD	Resilient Wedge Disc
FW	Flexible Wedge
HW	Handwheel
NRS	Non-Rising Stem
RS	Rising Stem
OS&Y	Outside Screw & Yoke
ISNRS	Inside Screw NRS
ISRS	Inside Screw RS
FF	Flat Face
RF	Raised Face
HF	Hard Faced
MJ	Mechanical Joint
RJ	Ring Type Joint
F&D	Face and Drilled Flange
CWP	Cold Working Pressure

CWP	Cold Working Pressure
OWG	Oil, Water, Gas, Pressure
SWP	Steam Working Pressure
WOG	Water, Oil, Gas, Pressure
WWP	Water Working Pressure
FTTG	Fitting
FLG	Flange
DWV	Drainage-Waste-Vent Fitting
NPS	Nominal Pipe Size
IPS	Iron Pipe Size
NPT	National Standard Pipe Thread Taper

18.08. Strainers

A. Strainers shall be full line size.

B. Water Systems

1. Strainer type:

a. 2" and smaller:	"Y" Type.
b. 2-1/2" to 16":	Basket type.
c. 18" and larger:	Multiple basket type.

2. Strainer perforation size:

a. 4" and smaller:	0.057" dia. perforations.
b. 5" and larger:	0.125" dia. perforations.
c. Double perforation diameter for condenser water systems.	

C. Steam Systems

1. Strainer type: "Y" Type.

2. Strainer perforation size:

a. 2" and smaller: 0.033" dia. perforations.

b. 2-1/2" and larger: 3/64" dia. perforations.

D. Strainer Pressure Drops, Water Systems: Pressure drops listed in the following are based on the GPM and pipe sizing of 4.0 ft./100 ft. pressure drop or 10 ft./sec. velocity.

1. 1-1/2" and smaller (Y type and Basket type):
   a. Pressure drop < 1.0 PSI, 2.31 ft. H_2O.

2. 2"–4" (Y type and Basket type):
   a. Pressure drop: 1.0 PSI, 2.31 ft. H_2O.

3. 5" and larger:
   a. Y-type pressure drop 1.5 PSI, 3.46 ft H_2O

   b. Basket-type pressure drop 1.0 PSI, 2.31 ft. H_2O

Part 19: Hydronic (Water) Piping Systems

19. Part 19: Hydronic (Water) Piping Systems

19.01. Hydronic Pipe Sizing

A. **4.0 ft./100 ft. Maximum pressure drop**

B. **8 FPS Maximum velocity occupied areas**

C. **10 FPS Maximum velocity unoccupied areas**

D. **Minimum pipe velocity 1.5 FPS, even under low load/flow conditions.**

E. **Pipe sizing tables are applicable to closed and open hydronic piping systems.**

F. **See the following pipe sizing tables for copper, steel, and stainless steel.**

19.02. Friction Loss Estimate

A. **1.5 × System Length (ft.) × Friction Rate (ft./100 ft.)**

B. **Pipe Friction Estimate: 3.0 to 3.5 ft./100 ft.**

19.03. Pipe Testing

A. **1.5 × System Working Pressure**

B. **100 psi Minimum**

19.04. Hydronic System Pipe Sizing Tables

HYDRONIC PIPING SYSTEMS—TYPE K COPPER PIPE

	Water Flow—GPM							
Pipe Size	Friction Rate—ft./100 ft.			Velocity—ft./sec.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0
1/2	1.0	1.2	1.4		Pressure with these	drop pipe	governs sizes	
3/4	2.4	3.0	3.5					
1	5.2	6.4	7.4					
1-1/4	9	12	13					
1-1/2	15	18	21	21				
2	31	38	44	38				
2-1/2	55	67	78	58	73			
3	87	107	123	83	103	124		
4	183	224	258	146	182	219		
5	324	397	458	226	283	339	452	
6	515	631	729	323	403	484	645	
8	1,064	1,304		563	704	845	1,126	1,408
10	1,887	Velocity with these	governs pipe sizes	874	1,093	1,311	1,749	2,186
12	3,015			1,254	1,567	1,880	2,507	3,134

HYDRONIC PIPING SYSTEMS—TYPE L COPPER PIPE

Water Flow—GPM								
Pipe Size	**Friction Rate—ft./100 ft.**			**Velocity—ft./sec.**				
	2.0	**3.0**	**4.0**	**4.0**	**5.0**	**6.0**	**8.0**	**10.0**
1/2 3/4 1	1.1 2.8 5.7	1.3 3.4 6.9	1.5 4.0 8.0		Pressure with these	drop pipe	governs sizes	
1-1/4 1-1/2 2	10 16 32	12 19 39	14 22 45	 22 39				
2-1/2 3 4	57 90 189	69 111 231	80 128 267	59 85 149	74 106 187	 127 224		
5 6 8	337 540 1,117	412 662 1,368	476 764	233 335 584	291 418 730	349 502 877	465 669 1,169	 1,461
10 12	1,980 3,191	Velocity with these	governs pipe sizes	907 1,310	1,134 1,637	1,361 1,965	1,814 2,619	2,268 3,274

HYDRONIC PIPING SYSTEMS—TYPE M COPPER PIPE

Pipe Size	Friction Rate—ft./100 ft.			Water Flow—GPM Velocity—ft./sec.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0
1/2 3/4 1	1.2 3.1 6.1	1.5 3.7 7.5	1.7 4.3 8.6		Pressure with these	drop pipe	governs sizes	
1-1/4 1-1/2 2	10 16 33	13 20 41	15 23 47	16 23 40				
2-1/2 3 4	58 93 192	72 114 236	83 132 272	61 87 152	76 109 190	131 227		
5 6 8	342 549 1,140	419 672 1,396	484 776	236 339 593	295 423 742	354 508 890	472 677 1,187	1,484
10 12	2,020 3,228	Velocity with these	governs pipe sizes	922 1,321	1,152 1,652	1,382 1,982	1,843 2,643	2,304 3,304

HYDRONIC PIPING SYSTEMS—STANDARD STEEL PIPE

Pipe Size	Friction Rate—ft./100 ft.			Water Flow—GPM Velocity—ft./sec.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	1
1/2 3/4 1	1.5 3.2 6.0	1.9 3.9 7.4	2.1 4.5 8.5		Pressure with these	drop pipe	governs sizes	
1-1/4	12 19	15 23	18 26	19 25				

Pipe Size	Friction Rate—ft./100 ft.			Water Flow—GPM Velocity—ft./sec.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	1
1-1/2	36	44	51	42	52			
2	57	70	80	60	75			
2-1/2	100	123	142	92	115	138		
3	204	250	289	159	198	238		
4								
5	368	451	521	249	312	374	499	
6	595	729	841	360	450	540	720	
8	1,216	1,489		624	780	936	1,247	1,5
10	2,198	governs	with	983	1,229	1,475	1,966	2,4
12	3,512	pipe	sizes	1,410	1,763	2,115	2,820	3,5
14				1,719	2,149	2,579	3,438	4,2
16	Velocity			2,277	2,847	3,416	4,554	5,6
18	these			2,914	3,642	4,371	5,827	7,2
20				3,629	4,536	5,443	7,257	9,0
22				4,422	5,527	6,633	8,843	11
24				5,293	6,616	7,940	10,586	13
26				6,243	7,804	9,364	12,486	15
28				7,271	9,089	10,907	14,542	18
30				8,378	10,472	12,566	16,755	20
32				9,562	11,953	14,344	19,125	23
34				10,826	13,532	16,238	21,651	27
36				12,167	15,209	18,251	24,334	30
42				16,662	20,827	24,992	33,323	41
48				21,861	27,327	32,792	43,722	54
54				27,766	34,707	41,649	55,532	69
60				34,375	42,969	51,563	68,751	85
72				49,710	62,137	74,564	99,419	12
84				67,864	84,830	101,796	135,728	16
96				88,838	111,048	133,257	177,677	22

HYDRONIC PIPING SYSTEMS—XS STEEL PIPE

Water Flow—GPM

Pipe Size	Friction Rate—ft./100 ft.			Water Flow—GPM Velocity—ft./sec.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	1
1/2 3/4 1	1.1 2.4 4.7	1.3 3.0 5.8	1.5 3.4 6.7		Pressure with these	drop pipe	governs sizes	
1- 1/4 1- 1/2 2	10 15 30	12 19 37	14 22 43	22 37				
2- 1/2 3 4	48 87 179	59 106 219	69 123 253	53 82 143	66 103 179	124 215		
5 6 8	325 520 1,080	399 637 1,322	460 736	227 325 569	284 406 712	340 487 854	454 650 1,139	1,4
10 12 14	2,047 3,325	governs pipe	with sizes	931 1,352 1,655	1,164 1,690 2,069	1,396 2,028 2,482	1,862 2,704 3,310	2,3 3,3 4,
16 18 20	Velocity these			2,203 2,830 3,535	2,754 3,537 4,419	3,305 4,245 5,302	4,406 5,660 7,070	5,5 7,0 8,8
22 24 26				4,318 5,180 6,120	5,398 6,475 7,650	6,477 7,770 9,180	8,637 10,360 12,240	10 12 15
28 30 32				7,138 8,235 9,410	8,923 10,294 11,763	10,708 12,353 14,115	14,277 16,470 18,820	17 20 23
34 36 42				10,663 11,995 16,460	13,329 14,994 20,575	15,995 17,993 24,690	21,327 23,990 32,921	26 29 41
48				21,630	27,038	32,446	43,261	54

Pipe Size	Friction Rate—ft./100 ft. 2.0	3.0	4.0	Water Flow—GPM / Velocity—ft./sec. 4.0	5.0	6.0	8.0	1
54 60				27,506 34,086	34,382 42,607	41,258 51,129	55,011 68,172	68 85
72 84 96				49,361 67,457 88,373	61,702 84,321 110,466	74,042 101,185 132,559	98,723 134,914 176,745	12 16 22

HYDRONIC PIPING SYSTEMS—XXS STEEL PIPE

Pipe Size	Friction Rate—ft./100 ft.			Water Flow—GPM Velocity—ft./sec.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0
1/2 3/4 1	0.1 0.6 1.4	0.2 0.7 1.7	0.2 0.8 1.9		Pressure with these	drop pipe	governs sizes	
1-1/4 1-1/2 2	4 7 15	5 8 19	6 10 22	 22				
2-1/2 3 4	24 47 108	29 58 132	34 67 152	31 52 97	 65 122	 146		
5 6 8	209 341 825	256 417 1,010	296 482	162 235 463	202 294 579	242 352 694	 470 926	1,157
10 12	1,545 2,639	Velocity with these	governs pipe sizes	750 1,132	937 1,414	1,125 1,697	1,499 2,263	1,874 2,829

HYDRONIC PIPING SYSTEMS—SCHEDULE 40 STEEL PIPE

Water Flow—GPM

Pipe Size	Friction Rate—ft./100 ft.			Water Flow—GPM Velocity—ft./sec.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	1
1/2 3/4 1	1.5 3.2 6.0	1.9 3.9 7.4	2.1 4.5 8.5		Pressure with these	drop pipe	governs sizes	
1- 1/4 1- 1/2 2	12 19 36	15 23 44	18 26 51	19 25 42	52			
2- 1/2 3 4	57 100 204	70 123 250	80 142 289	60 92 159	75 115 198	138 238		
5 6 8	368 595 1,216	451 729 1,489	521 841	249 360 624	312 450 780	374 540 936	499 720 1,247	1
10 12 14	2,198 3, 65	governs pipe	with sizes	983 1,396 1,687	1,229 1,744 2,109	1,475 2,093 2,531	1,966 2,791 3,374	2 3 4
16 18 20	Velocity these			2,203 2,789 3,466	2,754 3,486 4,333	3,305 4,183 5,199	4,406 5,577 6,932	5 6 8
22 24 26	– 5,013 –			– 6,266 –	– 7,519 –	– 10,026 –	– 12,532 –	
28 30 32	– 7,954 9,183			– 9,942 11,479	– 11,930 13,775	– 15,907 18,366	– 19,884 22,958	
34 36 42	10,422 11,655 16,061			13,027 14,569 20,077	15,633 17,482 24,092	20,844 23,310 32,123	26,055 29,137 40,153	
48 54	21,173 26,989			26,466 33,736	31,759 40,484	42,345 53,978	52,932 67,473	

Pipe Size Friction Rate—ft./100 ft. Velocity—ft./sec.
2.0 3.0 4.0 4.0 5.0 6.0 8.0 1

Pipe Size	Friction Rate—ft./100 ft.			Water Flow—GPM		Velocity—ft./sec.		
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	[illegible]
60	33,511			41,889	50,266	67,021	83,776	
72	48,669			60,836	73,003	97,337	121,671	
84	66,647			83,308	99,970	133,293	166,617	
96	87,445			109,306	131,167	174,890	218,612	

HYDRONIC PIPING SYSTEMS—SCHEDULE 80 STEEL PIPE

Water Flow—GPM

Pipe Size	Friction Rate—ft./100 ft.			Velocity—ft./sec.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0
1/2 3/4 1	1.1 2.4 4.7	1.3 3.0 5.8	1.5 3.4 6.7		Pressure with these	drop pipe	governs sizes	
1-1/4 1-1/2 2	10 15 30	12 19 37	14 22 43	22 37				
2-1/2 3 4	48 87 179	59 106 219	69 123 253	53 82 143	66 103 179	124 215		
5 6 8	325 520 1,080	399 637 1,322	460 736	227 325 569	284 406 712	340 487 854	454 650 1,139	1,423
10 12 14	1,947 3,057	governs pipe	with sizes	896 1,267 1,530	1,120 1,584 1,912	1,344 1,901 2,295	1,791 2,534 3,060	2,239 3,168 3,825
16 18 20	Velocity these			2,006 2,546 3,151	2,508 3,183 3,938	3,009 3,820 4,726	4,013 5,093 6,302	5,016 6,366 7,877
22 24	3,819 4,553			4,774 5,692	5,729 6,830	7,639 9,107	9,549 11,383	

HYDRONIC PIPING SYSTEMS—SCHEDULE 160 STEEL PIPE

Pipe Size	Water Flow—GPM							
	Friction Rate—ft./100 ft.			Velocity—ft./sec.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0
1/2 3/4 1	0.7 1.5 3.1	0.9 1.8 3.8	1.0 2.1 4.4		Pressure with these	drop pipe	governs sizes	
1-1/4 1-1/2 2	8 11 21	10 14 26	11 16 30	28				
2-1/2 3 4	38 67 135	47 82 166	54 95 191	44 68 116	55 84 145	174		
5 6 8	244 396 805	299 485 986	346 560	182 264 455	228 330 568	273 395 682	527 909	1,136
10 12 14	1,433 2,259 2,928	1,755	with sizes	707 1,004 1,226	884 1,255 1,532	1,061 1,506 1,839	1,415 2,008 2,451	1,769 2,510 3,064
16 18 20	Velocity these	governs pipe		1,608 2,041 2,527	2,010 2,551 3,159	2,412 3,062 3,790	3,216 4,082 5,054	4,020 5,103 6,317
22 24	3,085 3,653	3,856 4,566		4,628 5,479	6,170 7,305	7,713 9,132		

HYDRONIC PIPING SYSTEMS—SCHEDULE 5 STAINLESS STEEL PIPE

Pipe Size	Water Flow—GPM Friction Rate—ft./100 ft.			Velocity—ft./sec.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0
1/2 3/4 1	2.2 4.3 8.3	2.6 5.2 10.2	3.0 6.0 11.7		Pressure with these	drop pipe	governs sizes	
1-1/4 1-1/2 2	16 24 44	20 29 54	23 34 63	23 31 49	 62			
2-1/2 3 4	73 125 248	89 153 303	103 176 350	72 109 184	90 136 230	 163 276		
5 6 8	428 686 1,392	524 840 1,705	605 970	280 402 692	350 502 865	420 603 1,038	559 804 1,384	 1,730
10 12 14	2,471	governs pipe	with sizes	1,076 1,515 1,835	1,345 1,894 2,293	1,614 2,272 2,752	2,152 3,030 3,669	2,690 3,787 4,587
16 18 20	Velocity these			2,404 3,057 3,771	3,006 3,822 4,714	3,607 4,586 5,656	4,809 6,115 7,542	6,011 7,643 9,427
22 24				4,579 5,437	5,723 6,796	6,868 8,156	9,157 10,874	11,447 13,593

HYDRONIC PIPING SYSTEMS—SCHEDULE 10 STAINLESS STEEL PIPE

Pipe Size	Water Flow—GPM Friction Rate—ft./100 ft.			Velocity—ft./sec.				
Notes:	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0

Pipe Size	Friction Rate—ft./100 ft. 2.0	3.0	4.0	Water Flow—GPM Velocity—ft./sec. 4.0	5.0	6.0	8.0	10.0
1/2	1.9	2.3	2.7					
3/4	3.8	4.7	5.4					
1	6.8	8.3	9.6					
1-1/4	14	17	20	[illegible]				
1-1/2	21	25	29	28				
2	40	49	56	46	57			
2-1/2	67	83	95	68	85			
3	118	144	166	104	130	156		
4	237	290	335	178	222	267		
5	417	511	590	275	343	412	549	
6	672	823	951	396	495	594	791	
8	1,359	1,664		679	849	1,019	1,359	1,698
10	2,433			1,063	1,329	1,595	2,126	2,658
12				1,503	1,879	2,255	3,006	3,758
14				1,818	2,272	2,726	3,635	4,544
16				2,390	2,988	3,585	4,781	5,976
18				3,041	3,802	4,562	6,083	7,604
20				3,748	4,685	5,622	7,496	9,370
22				4,553	5,692	6,830	9,107	11,383
24				5,408	6,760	8,111	10,815	13,519

Pressure drop governs with these pipe sizes

Velocity governs with these pipe sizes

Notes:

1. **Maximum recommended pressure drop: 4 ft./100 ft.**
2. **Maximum recommended velocity (occupied areas): 8 FPS.**
3. **Maximum recommended velocity (unoccupied areas, shafts, tunnels, etc.): 10 FPS.**
4. **Standard steel pipe and Type L copper pipe are the most common pipe materials used in HVAC applications.**
5. **Tables are applicable to closed and open hydronic piping systems.**
6. **Pipe sizes 5", 22", 26", 28", 32", and 34" are not standard sizes and**

are not readily available in all locations.

7. Types K, L, and M copper pipe are available in sizes up through 12 inch.

8. Standard and XS steel pipe are available in sizes through 96 inch.

9. XXS steel pipe is available in sizes through 12 inch.

10. Schedule 40 steel pipe is available in sizes through 96 inch.

11. Schedule 80 and 160 steel pipe are available in sizes through 24 inch.

12. Schedule 5 and 10 stainless steel pipe are available in sizes through 24 inch.

13. Standard and Schedule 40 steel pipe have the same dimensions and flow for 10 inch and smaller.

14. XS and Schedule 80 steel pipe have the same dimensions and flow for 8 inch and smaller.

15. XXS and Schedule 160 have no relationship for dimensions or flow.

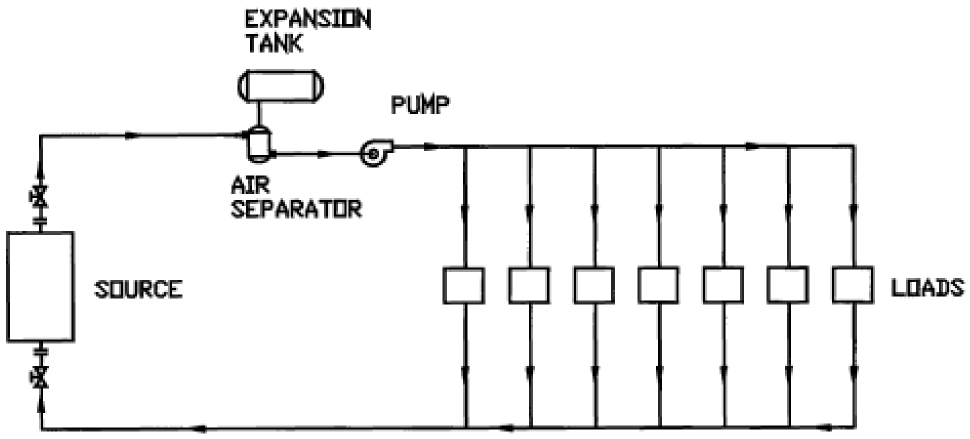
Pipe Size	Friction Rate—ft./100 ft.	Water Flow—GPM						
		Velocity—ft./sec.						
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0

19.05. Hydronic System Designs and Terminology

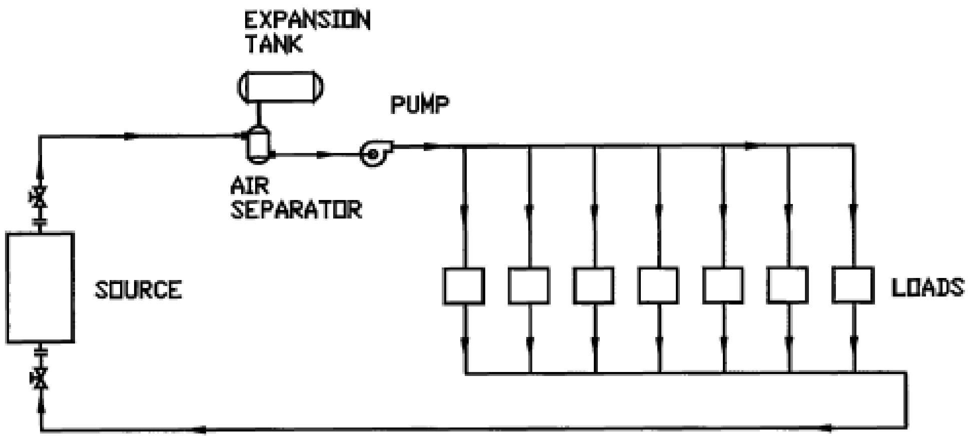
A. ***Closed Piping Systems.*** **Piping systems with no more than one point of interface with a compressible gas (generally air). Examples: Chilled Water and Heating Water Systems.**

B. ***Open Piping Systems*****. Piping systems with more than one point of interface with a compressible gas (generally air). Example: Condenser Water Systems**

C. ***Reverse Return Systems*****. Where the length of supply and return piping is nearly equal. Reverse return systems are nearly self-balancing (see Figs. 19.1 through 19.5).**



DIRECT RETURN HYDRONIC SYSTEM



REVERSE RETURN HYDRONIC SYSTEM

Figure 19.1. HYDRONIC SYSTEM RETURN TYPES.

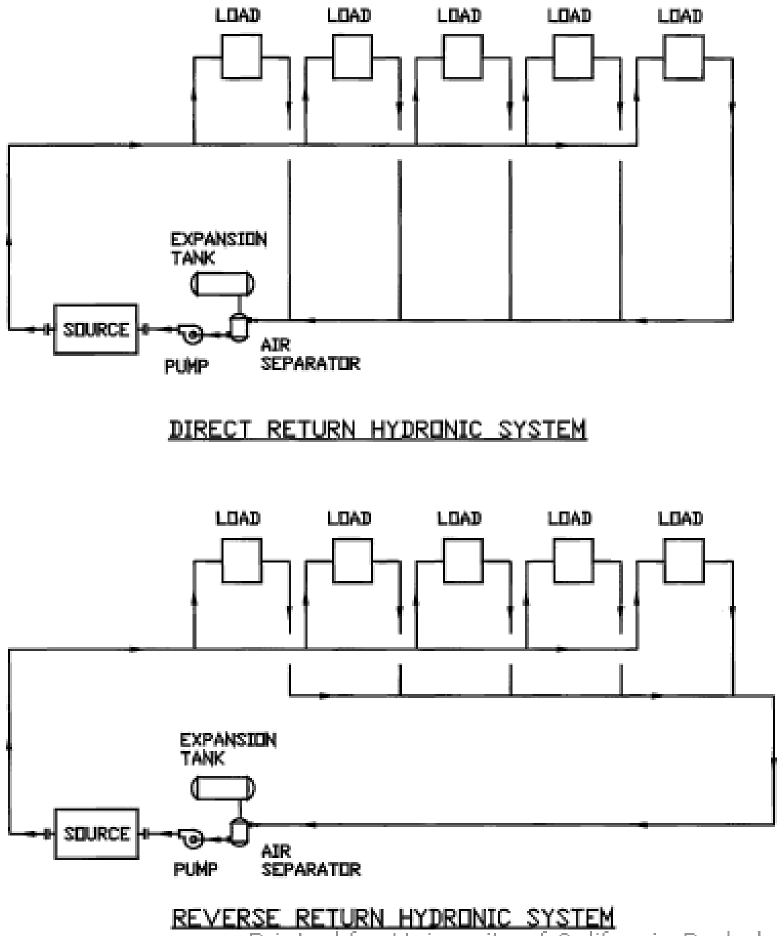


Figure 19.2. HYDRONIC SYSTEM RETURN TYPES.

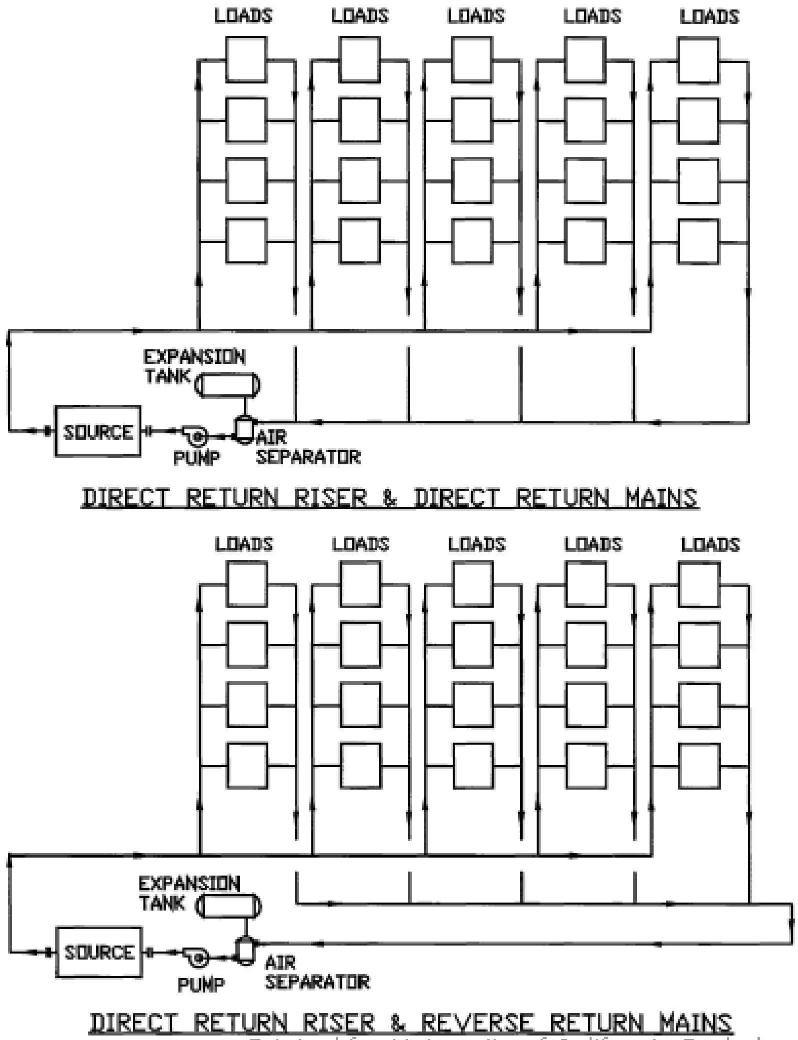


Figure 19.3. HYDRONIC SYSTEM RETURN TYPES.

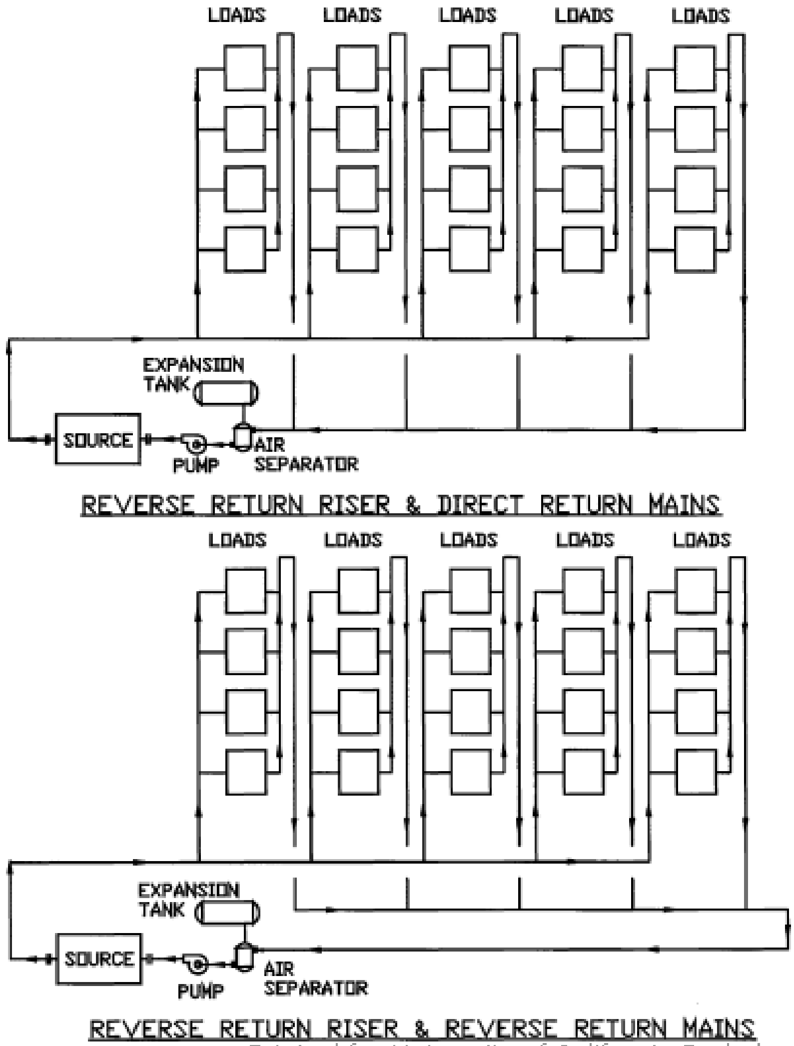


Figure 19.4. HYDRONIC SYSTEM RETURN TYPES.

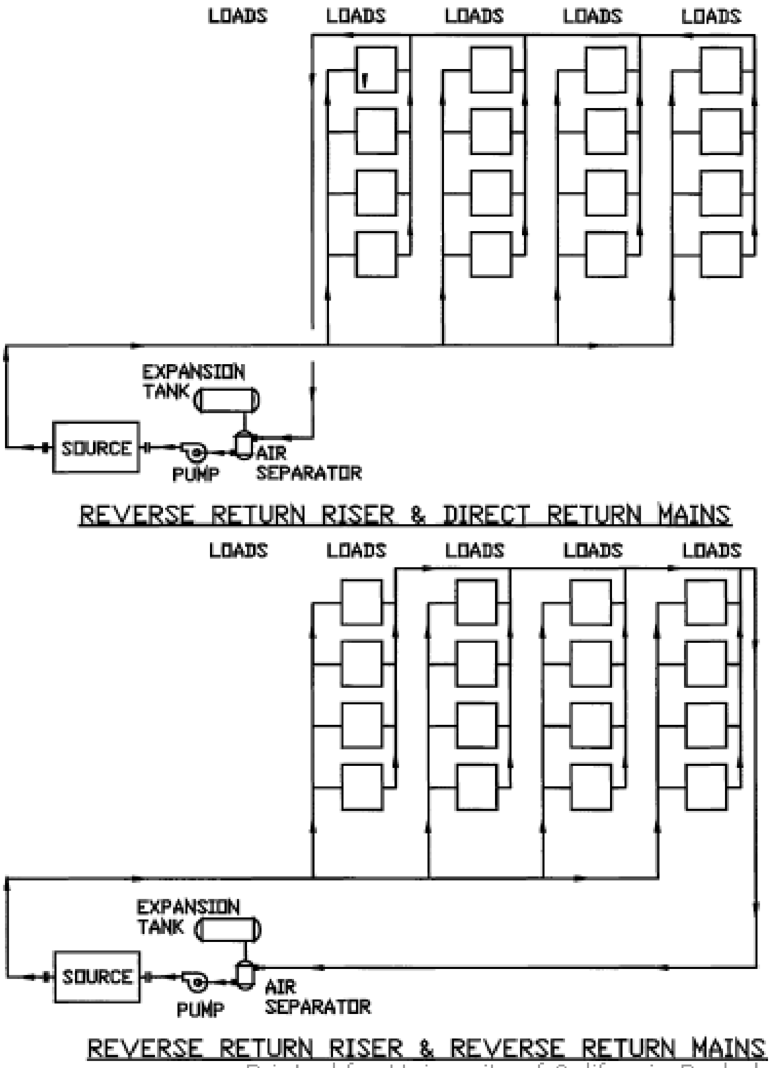


Figure 19.5. HYDRONIC SYSTEM RETURN TYPES.

D. ***Direct Return Systems*. Where the length of supply and return piping is unequal. Direct return systems are more difficult to balance (see Figs. 19.1 through 19.5).**

E. **One-Pipe Systems**

1. One-pipe systems are constant volume flow systems.
2. *All Series Flow Arrangements*. Total circulation flows through every terminal user with lower inlet supply temperatures with each successive terminal device.
3. *Diverted Series Flow Arrangements*. Part of the flow goes through the terminal unit, while the remainder is diverted around the terminal unit using a resistance device (balancing valve, fixed orifice, diverting tees, or flow control devices).

F. **Two-Pipe Systems (See Fig. 19.6)**

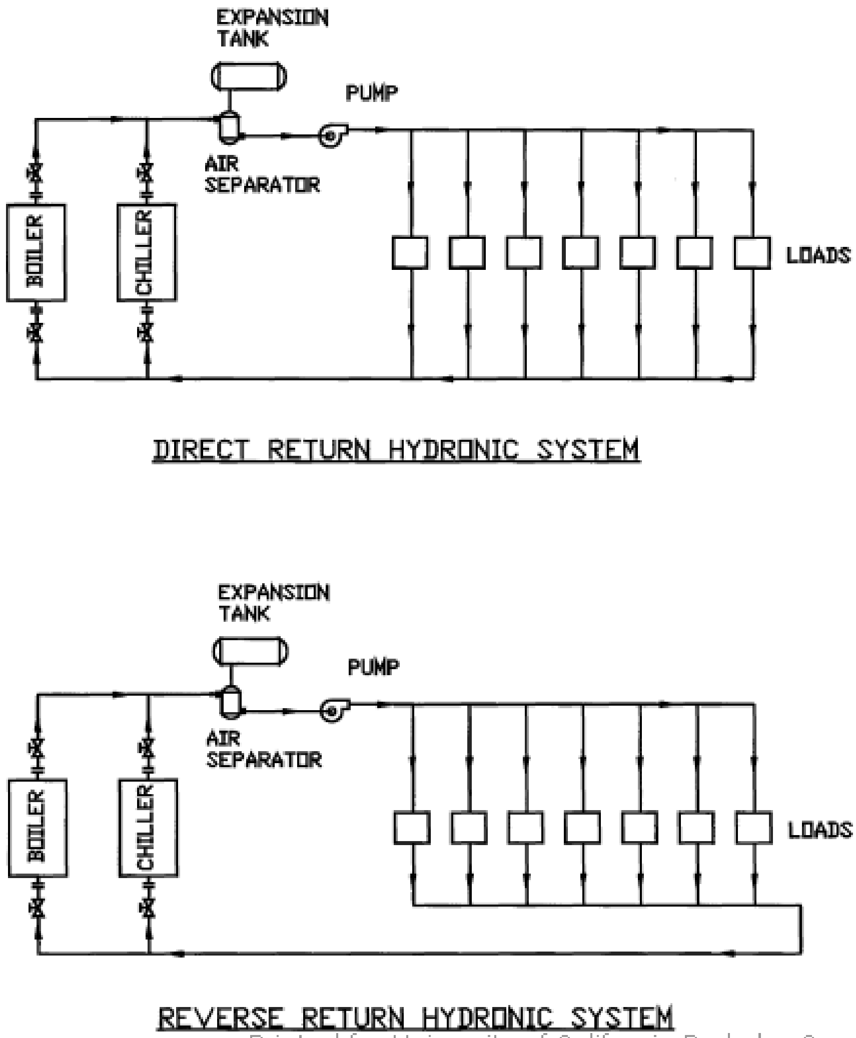
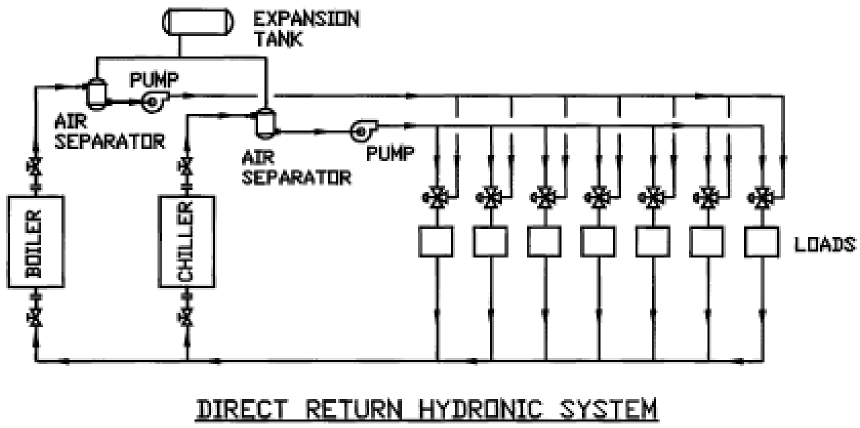


Figure 19.6. TWO-PIPE HYDRONIC SYSTEMS.

1. The same piping is used to circulate chilled water and heating water.
2. Two-pipe systems are either constant volume flow or variable volume flow systems.
3. *Direct Return Systems*. In these systems, it is critical to provide proper balancing devices (balancing valves or flow control devices).
4. *Reverse Return Systems*. Generally limited to small systems, these systems will simplify balancing.

G. **Three-Pipe Systems (Obsolete; See Fig. 19.7)**



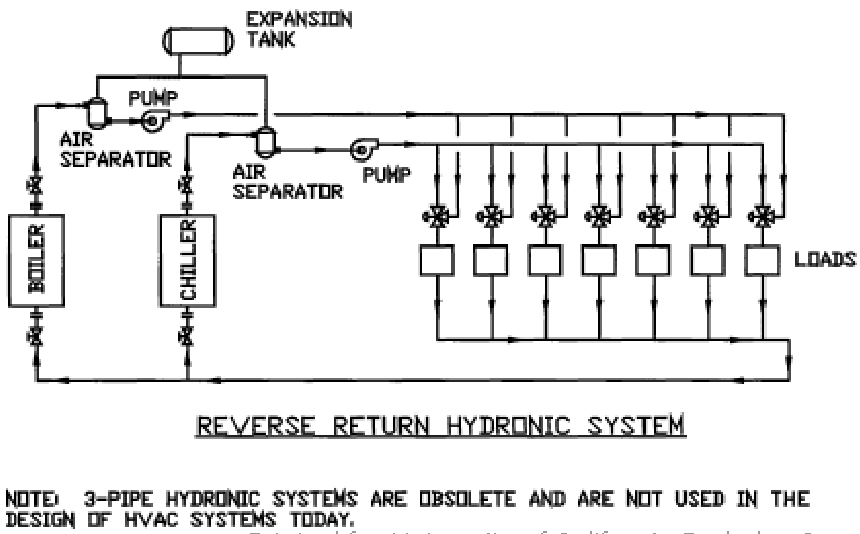
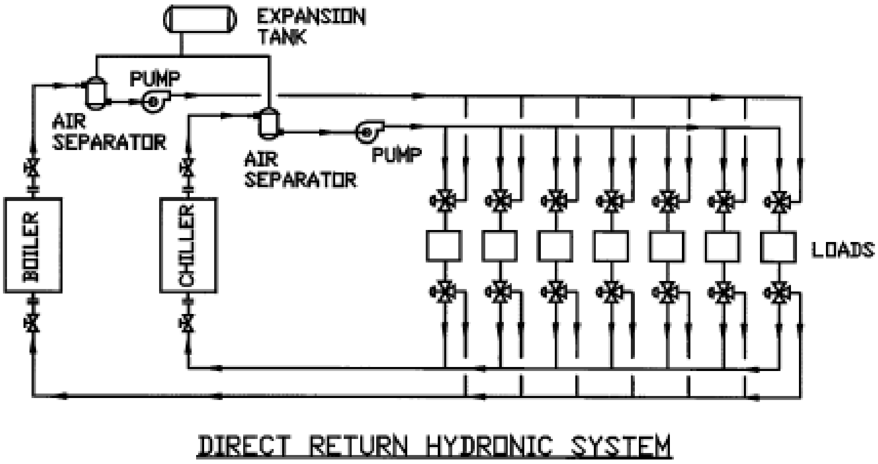


Figure 19.7. THREE-PIPE HYDRONIC SYSTEMS.

1. Separate chilled water and heating water supply piping; common return piping is used to circulate chilled water and heating water.

H. **Four-Pipe Systems (See Figs. 19.8 and 19.9)**



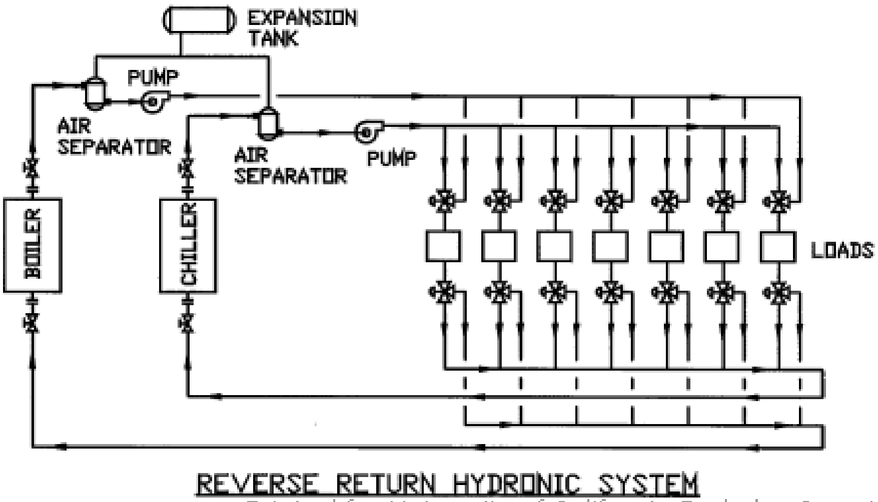


Figure 19.8. FOUR-PIPE HYDRONIC SYSTEMS COMMON LOAD SYSTEMS.

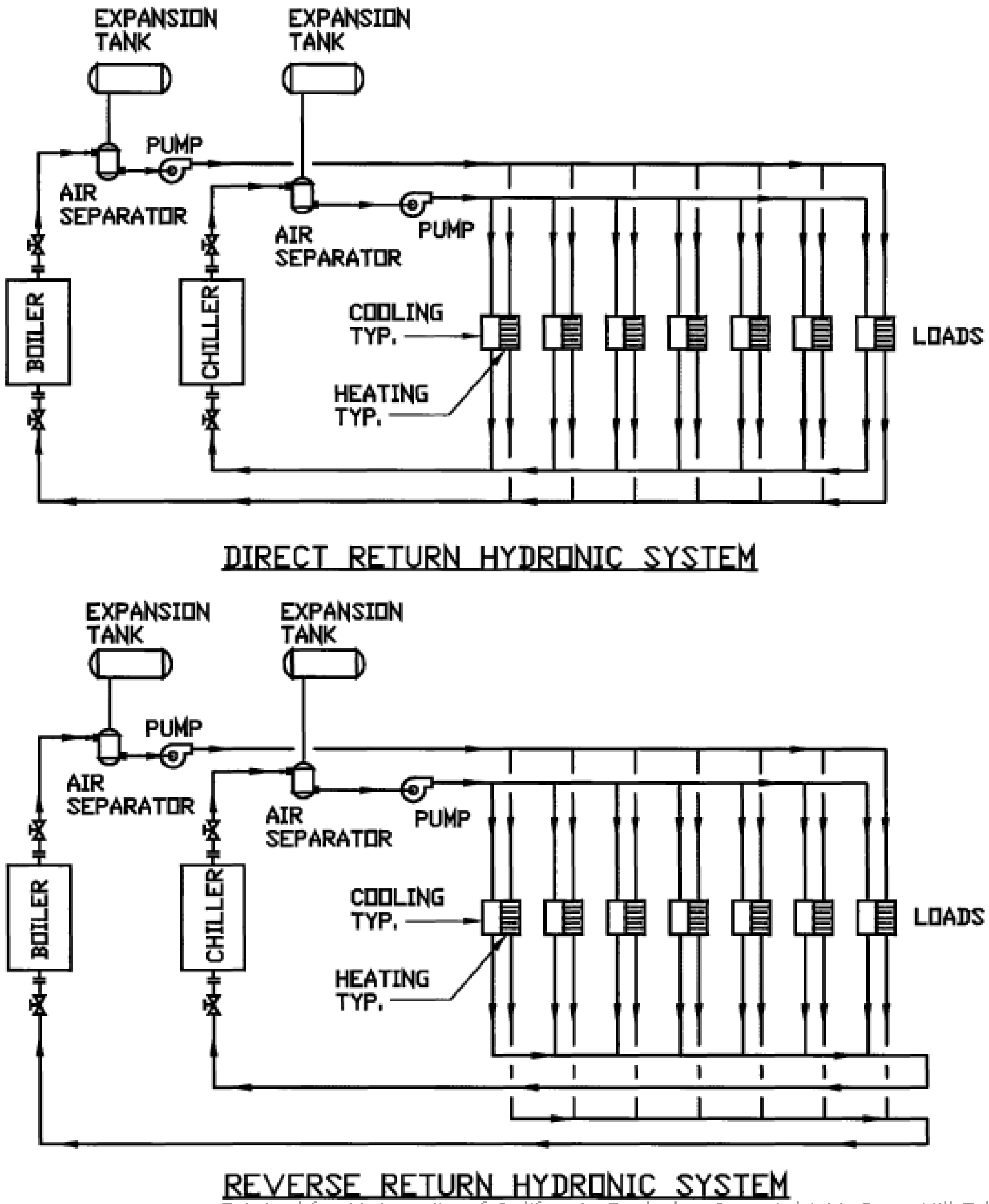


Figure 19.9. FOUR-PIPE HYDRONIC SYSTEMS INDEPENDENT LOAD SYSTEMS.

1. Separate supply and return piping (two separate systems) are used to circulate chilled water and heating water.

2. Four-pipe systems are either constant volume flow or variable volume flow systems.

3. *Direct Return Systems*. In these systems, it is critical to provide proper balancing devices (balancing valves or flow control devices).

4. *Reverse Return Systems*. Generally limited to small systems. These systems will simplify balancing.

I. **Ring or Loop Type Systems**

1. Piping systems that are laid out to form a loop with the supply and return mains parallel to each other.

2. Constant volume flow or variable volume flow systems.

3. They provide flexibility for future additions and provide service reliability.

4. These can be designed with better diversity factors.

5. During shutdown for emergency or scheduled repairs, maintenance, or modifications, loads, especially critical loads, can be fed from other direction or leg.

6. Isolation valves must be provided at critical junctions and between all major lateral connections so mains can be isolated and flow rerouted.

7. Flows and pressure distribution must be estimated by trial and error or by computer.

J. **Constant Volume Flow Systems**

1. *Direct Connected Terminals*. Flow created by a main pump through three-way valves.

2. *Indirect Connected Terminals*. Flow created by a separate pump with a bypass and without output controls.
   a. Permit variable volume flow systems.

   b. Subcircuits can be operated with high pump heads without penalizing the main pump.

   c. Require excess flow in the main circulating system.

3. Constant volume flow systems are limited to (see Figs. 19.10 and 19.11):

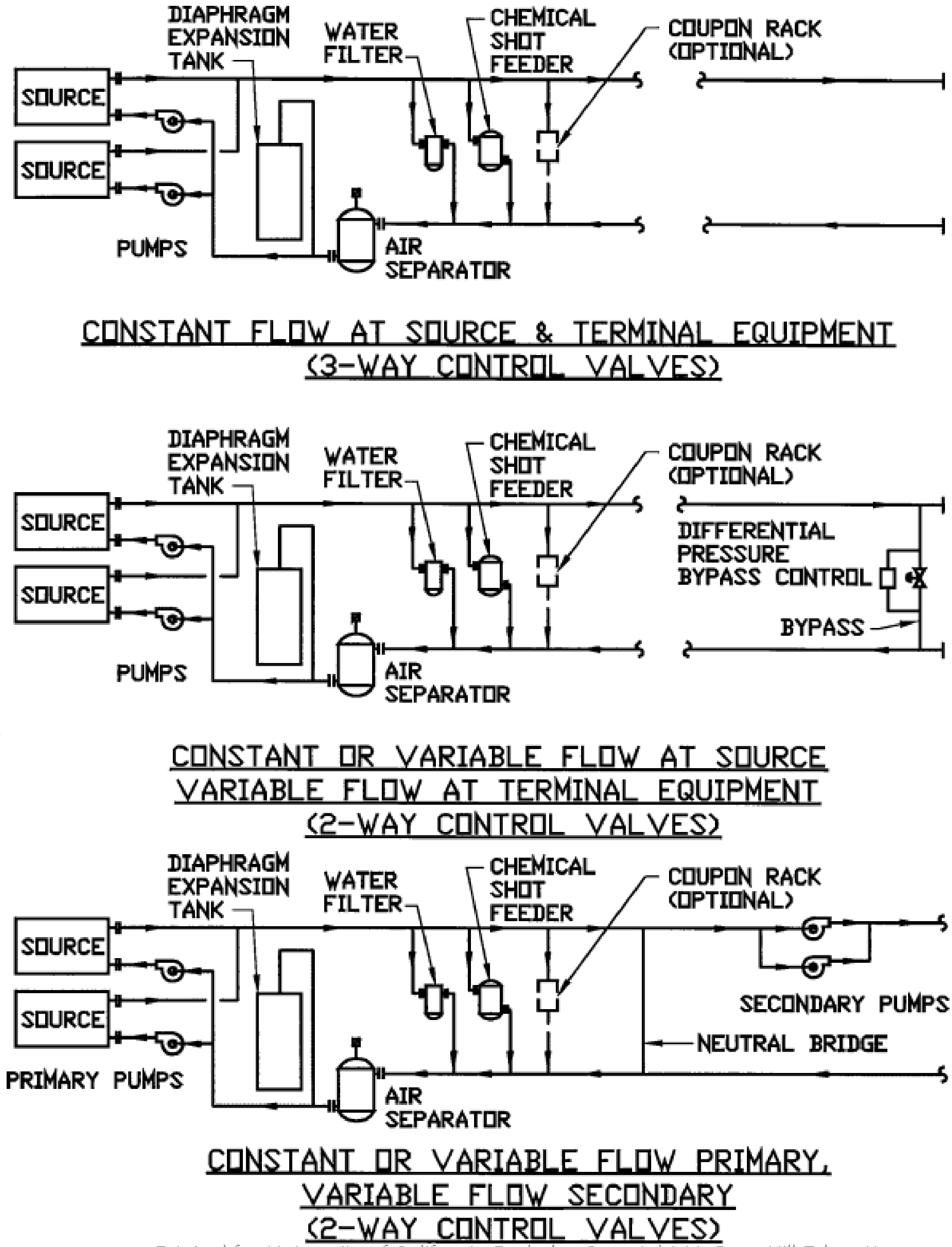


Figure 19.10. COUPLED CONSTANT VS. VARIABLE FLOW SYSTEMS.

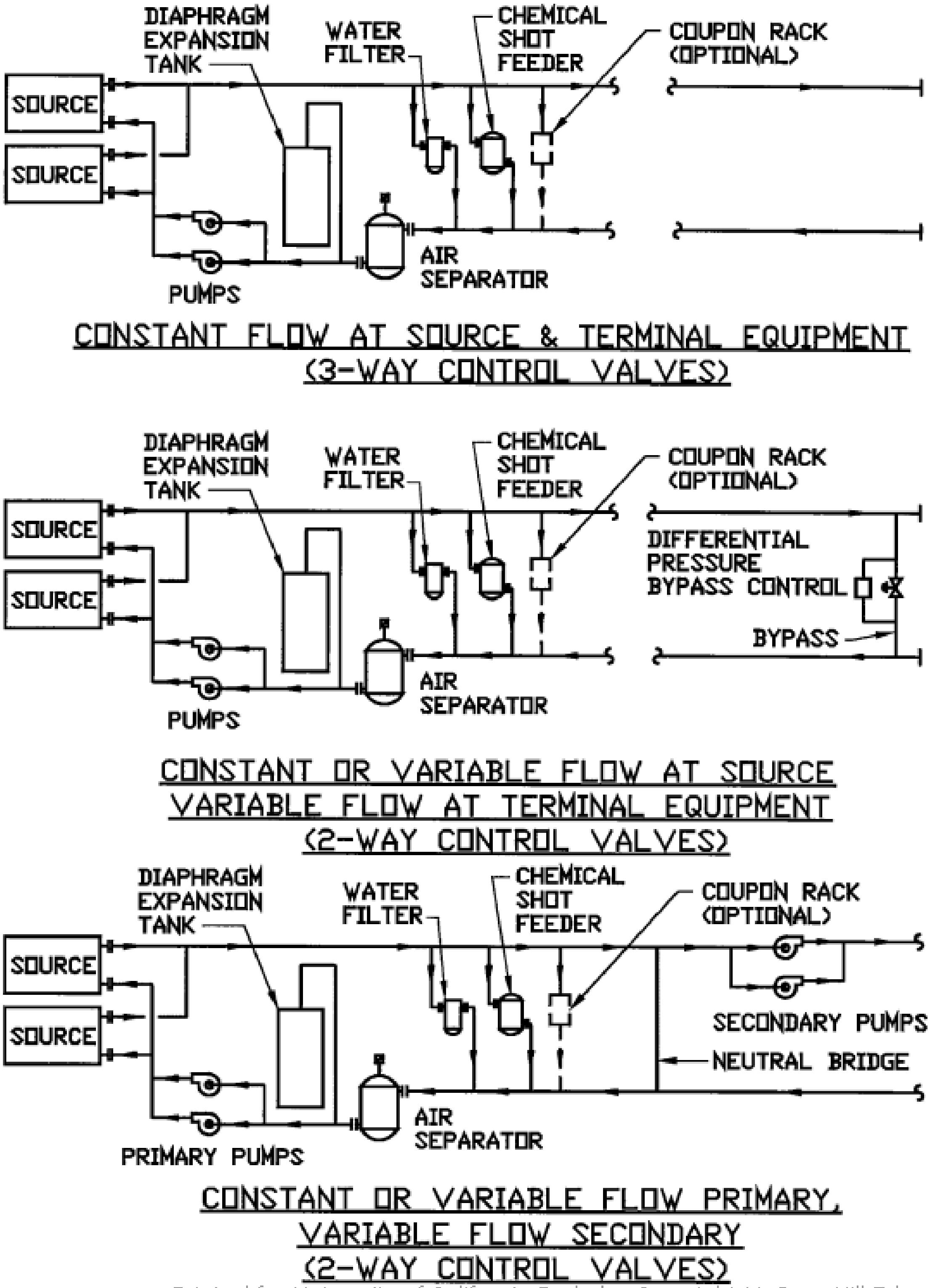


Figure 19.11. HEADERED CONSTANT VS. VARIABLE FLOW SYSTEMS.

a. Small systems with a single boiler or chiller.

b. More than one boiler system if boilers are firetube or firebox boilers.

c. Two chiller systems if chillers are connected in series.

d. Small low-temperature heating water systems with 10–20°F delta T.

e. Small chilled water systems with 7–10°F delta T.

f. Condenser water systems.

g. Large chilled water and heating water systems with primary/secondary pumping systems, constant flow primary circuits.

4. Constant volume flow systems are not suited to (see Figs. 19.10 and 19.11):
   a. Multiple watertube boiler systems.

   b. Parallel chiller systems.

   c. Parallel boiler systems.

5. Constant volume flow systems are generally energy inefficient.

K. **Variable Volume Flow Systems (See Figs. 19.10 and 19.11)**

1. At partial load, the variable volume flow system return temperatures approach the temperature in the secondary medium.

2. Significantly higher pressure differentials occur at part load and must be considered during design unless variable speed pumps are provided.

L. **Primary/Secondary/Tertiary Systems (PST Systems; See Figs. 19.12 through 19.21)**

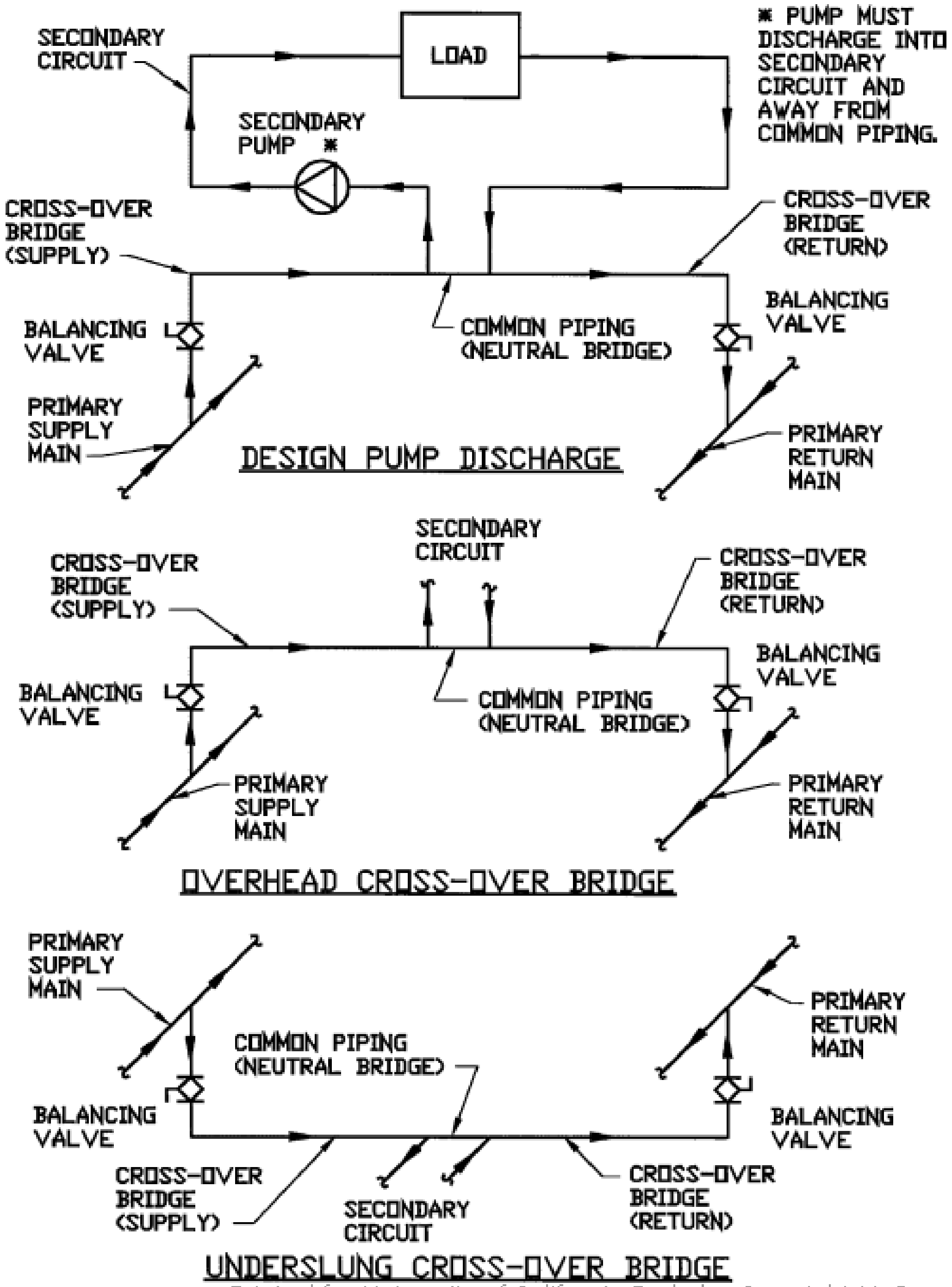


Figure 19.12. PRIMARY-SECONDARY TERMINOLOGY.

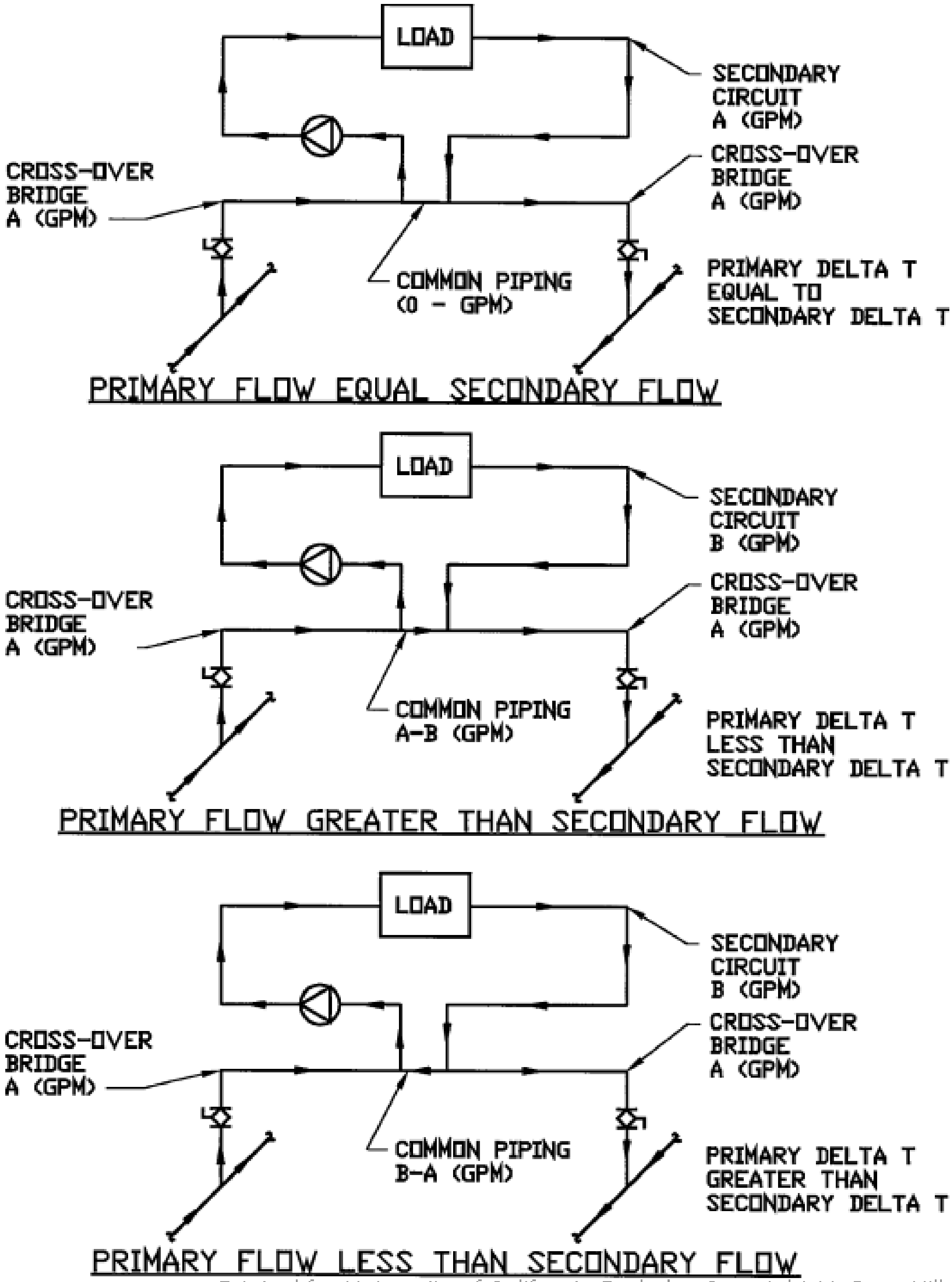


Figure 19.13. PRIMARY-SECONDARY FLOW ANALYSIS.

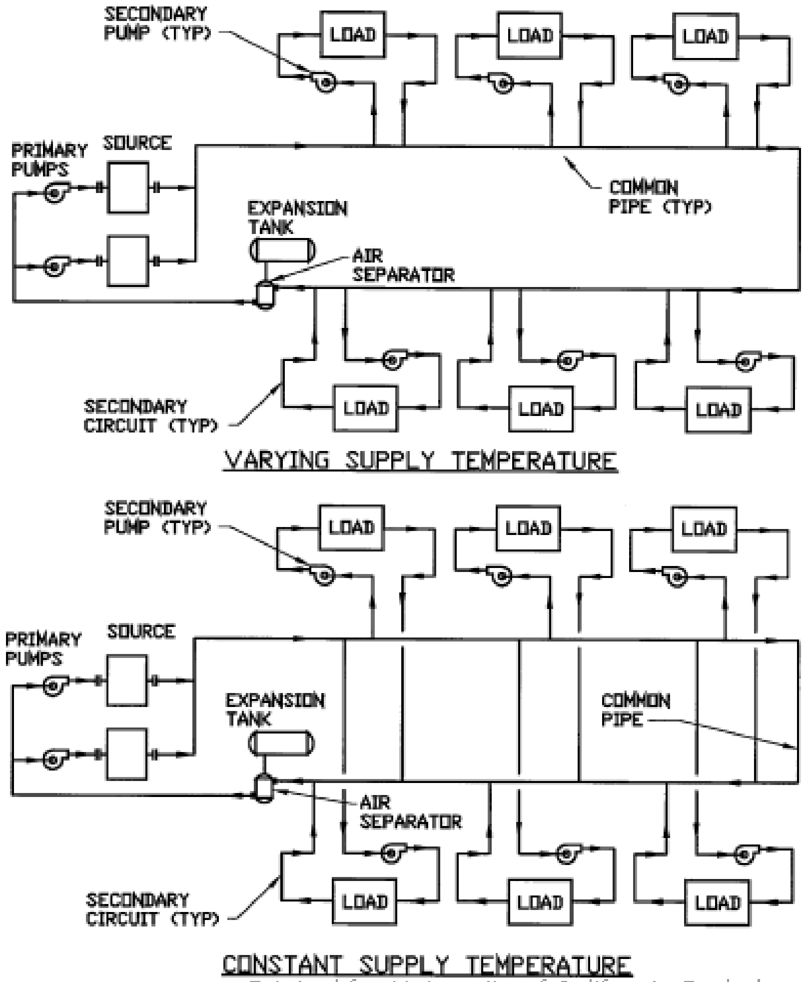


Figure 19.14. COUPLED ONE-PIPE PRIMARY-SECONDARY HYDRONIC SYSTEMS.

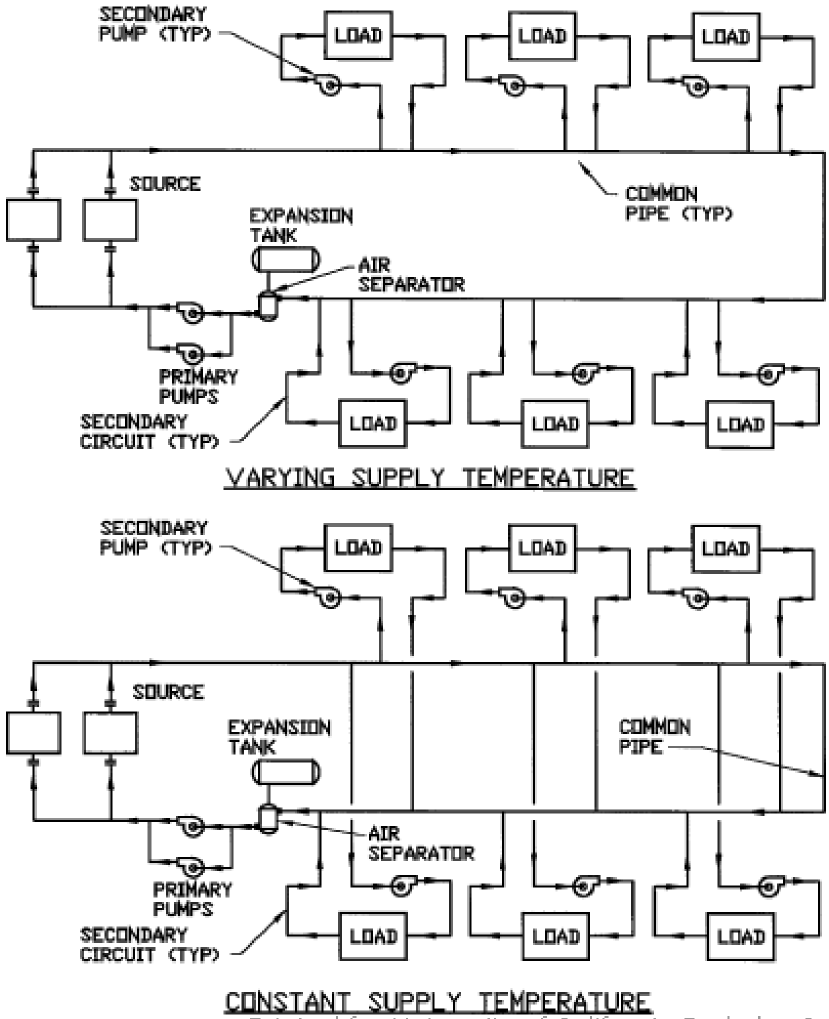


Figure 19.15. HEADERED ONE-PIPE PRIMARY-SECONDARY HYDRONIC SYSTEMS.

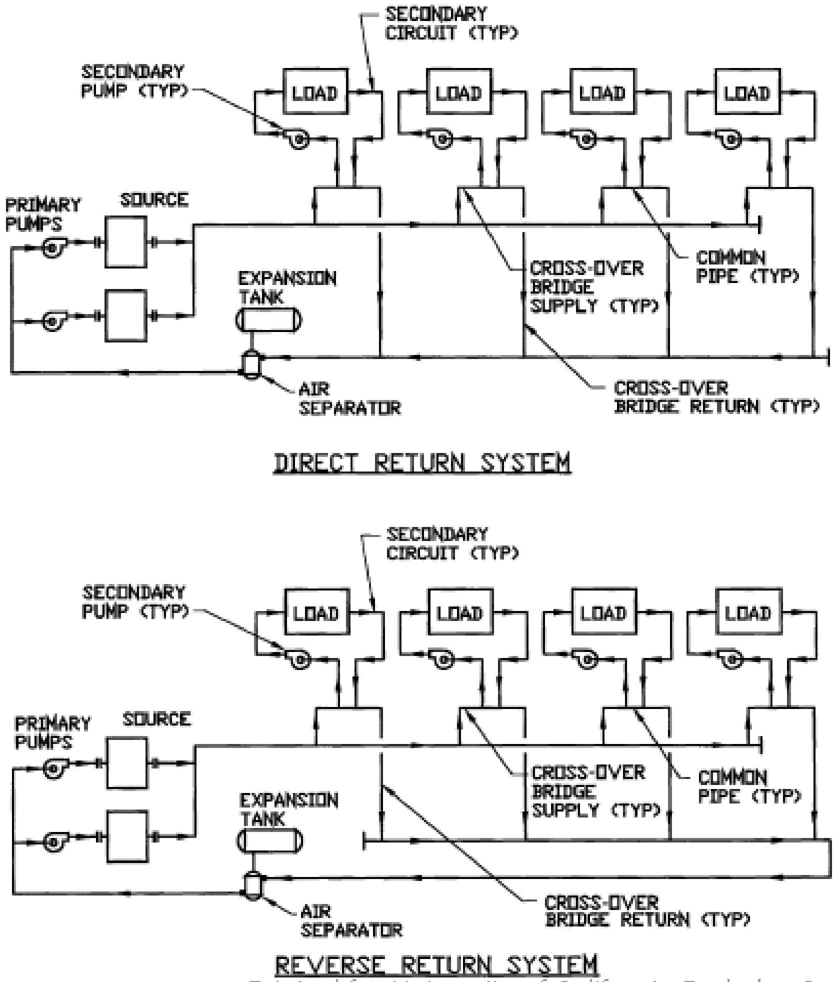


Figure 19.16. COUPLED TWO-PIPE PRIMARY-SECONDARY HYDRONIC SYSTEMS.

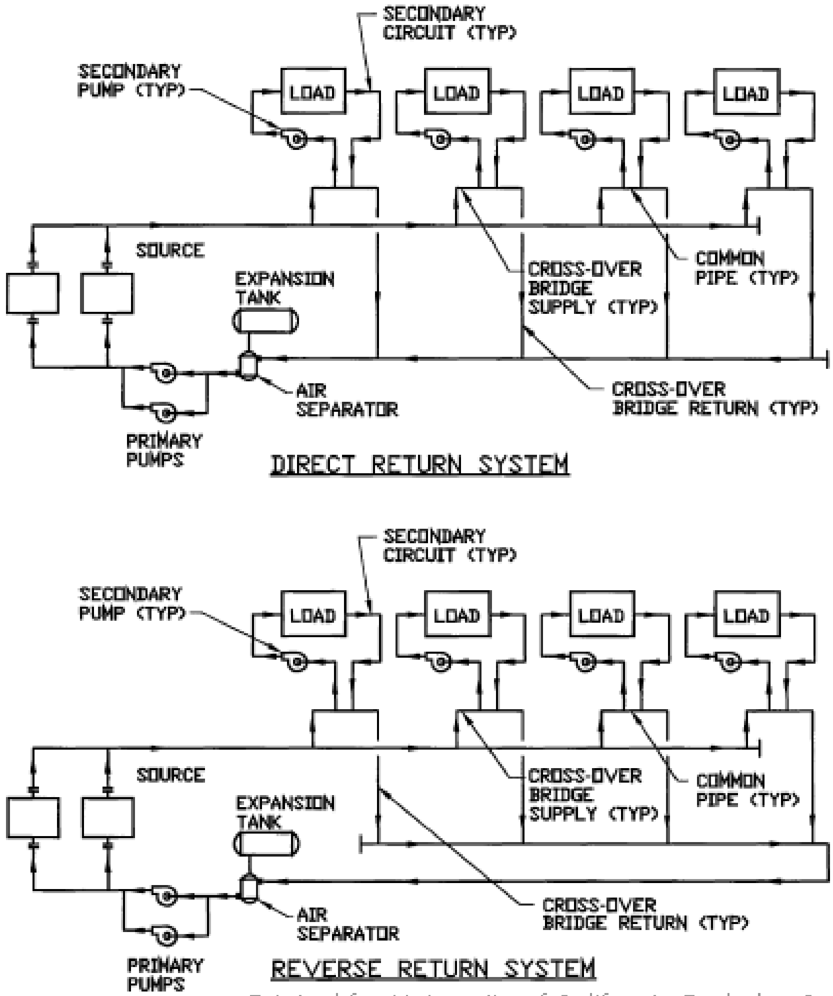


Figure 19.17. HEADERED TWO-PIPE PRIMARY-SECONDARY HYDRONIC SYSTEMS.

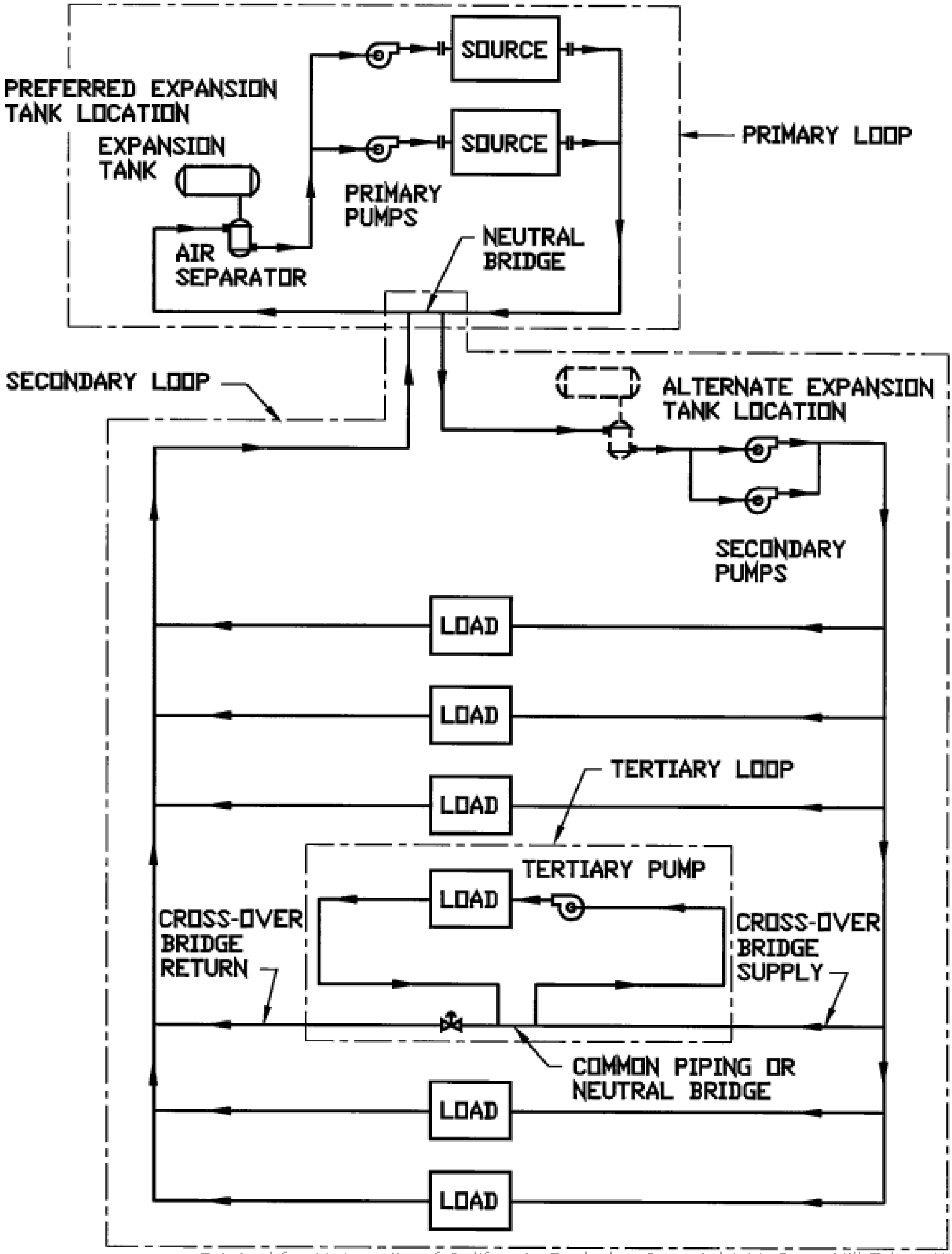


Figure 19.18. COUPLED PRIMARY-SECONDARY-TERTIARY HYDRONIC SYSTEMS.

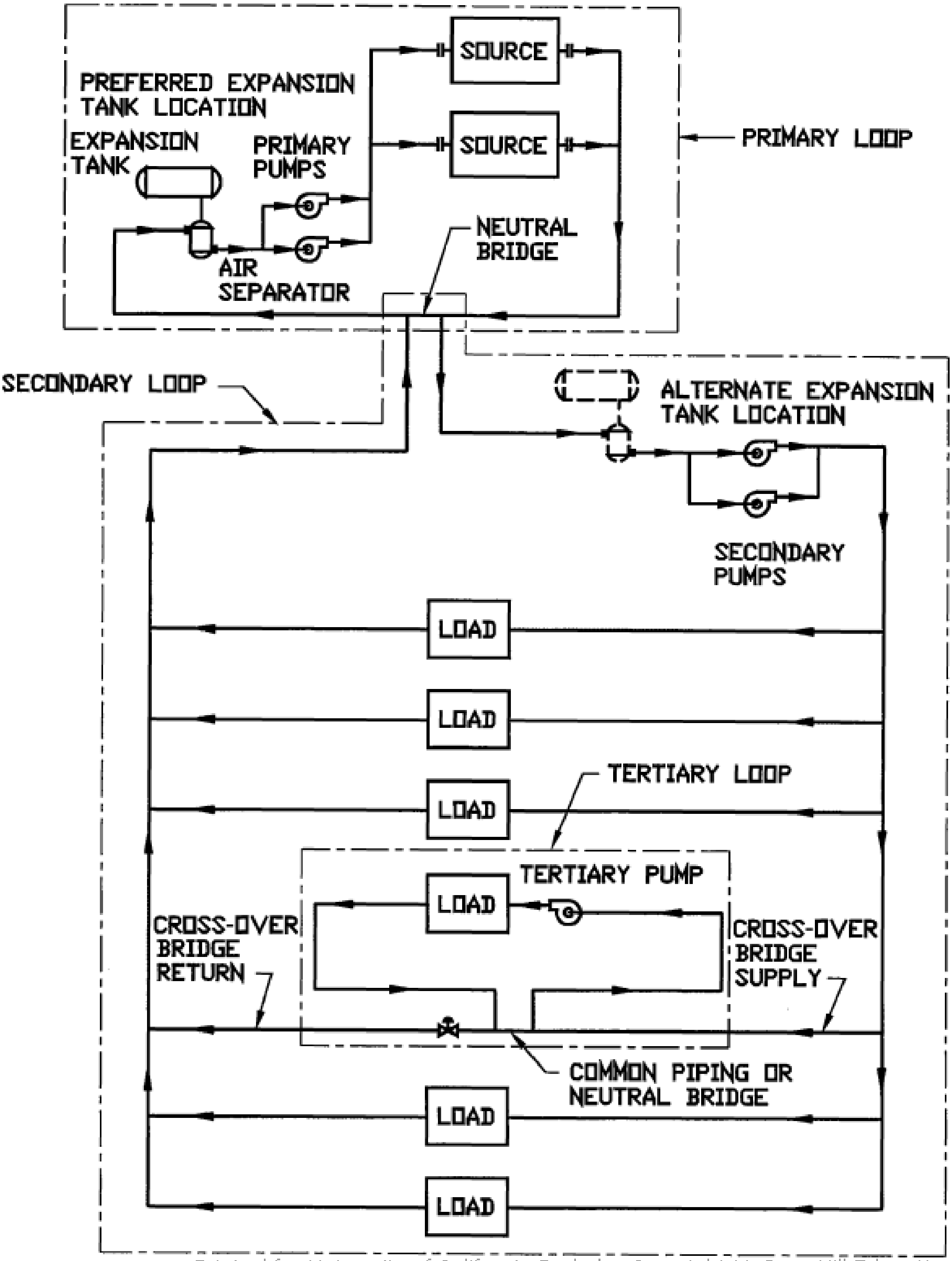


Figure 19.19. HEADERED PRIMARY-SECONDARY-TERTIARY HYDRONIC SYSTEMS.

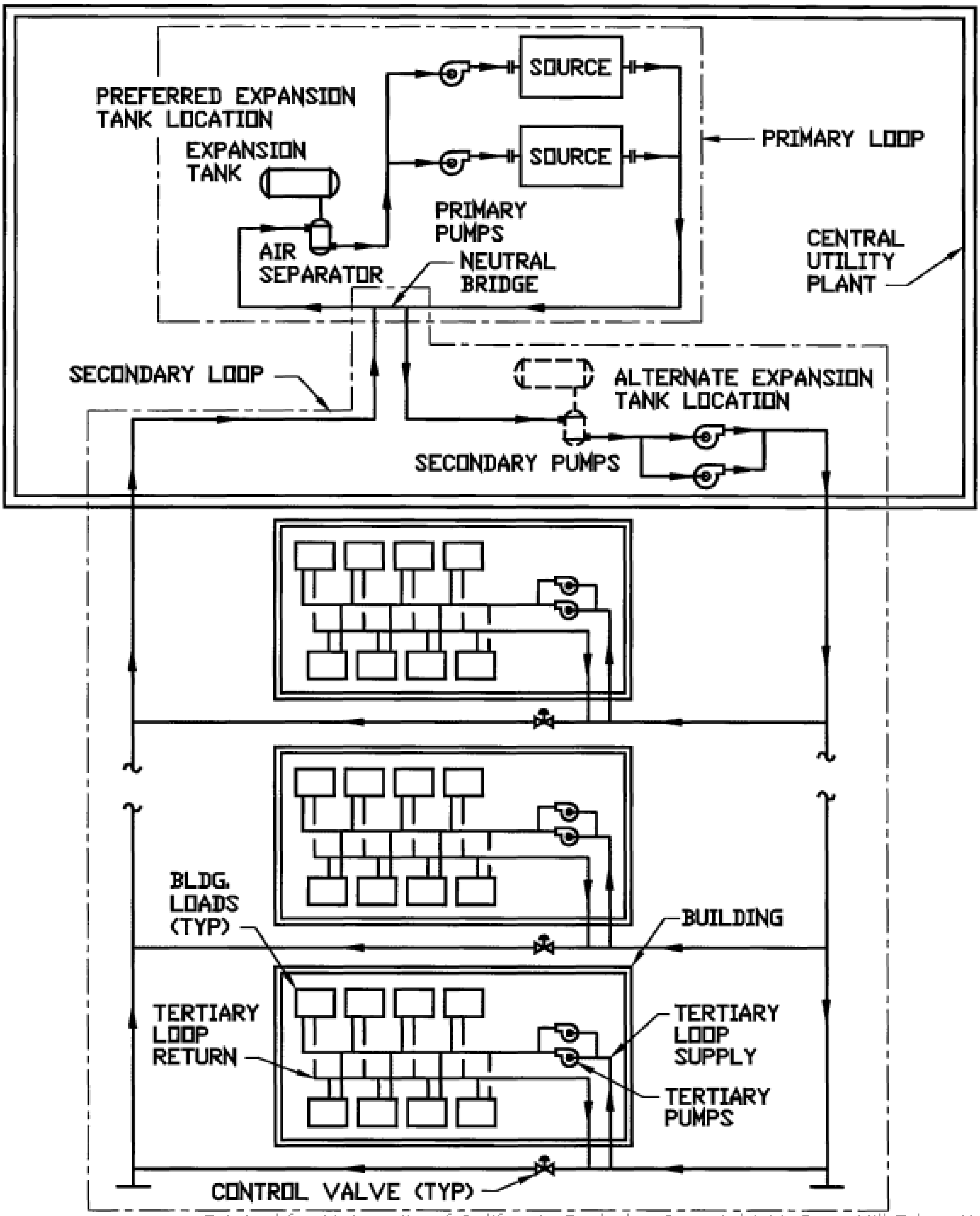


Figure 19.20. COUPLED PRIMARY-SECONDARY-TERTIARY HYDRONIC SYSTEMS.

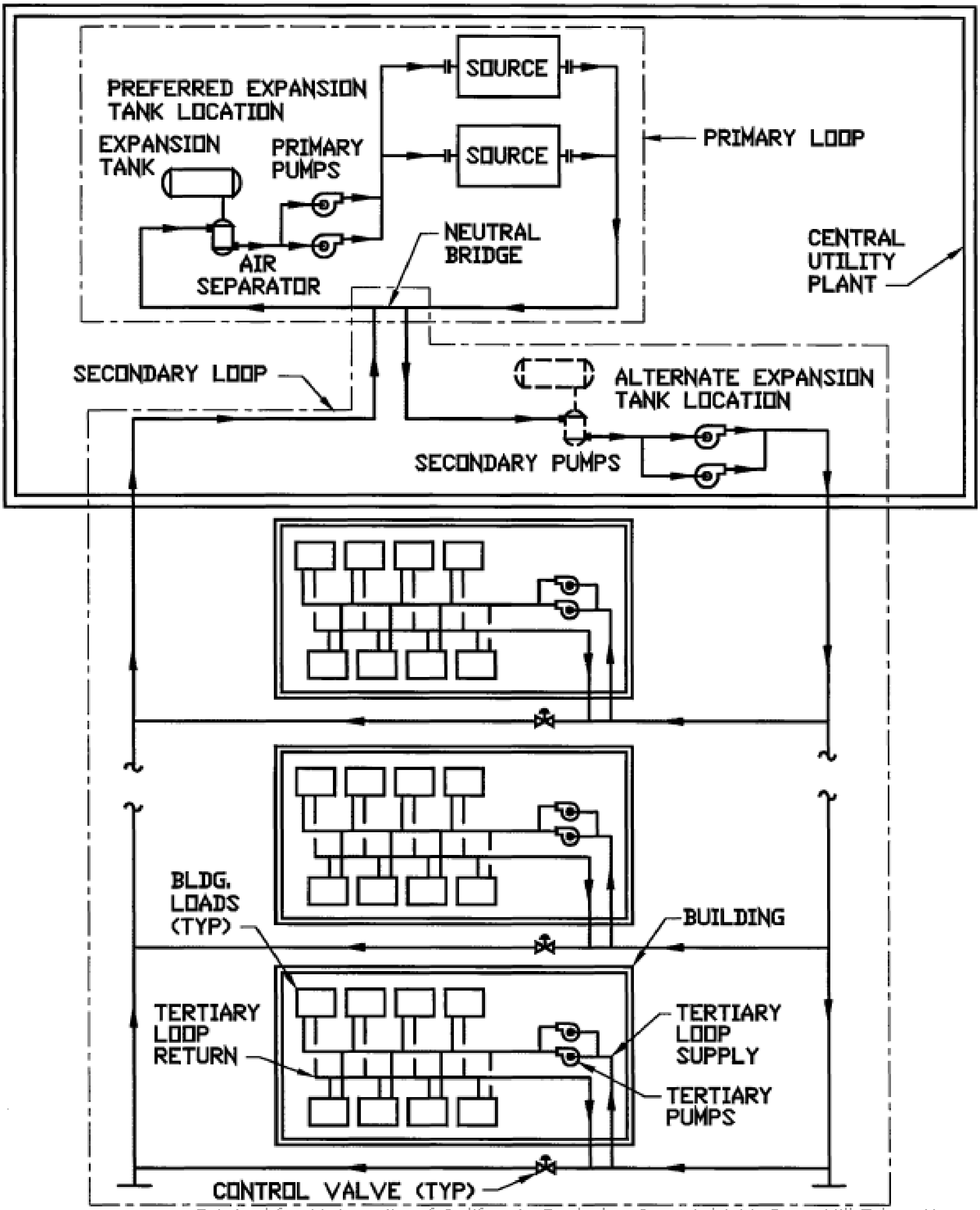


Figure 19.21. HEADERED PRIMARY-SECONDARY-TERTIARY HYDRONIC SYSTEMS.

1. PST systems decouple system circuits hydraulically, thereby making control, operation, and analysis of large systems less complex.

2. Secondary (tertiary) pumps should always discharge into secondary (tertiary) circuits away from the common piping.

3. *Cross-Over Bridge*. Cross-over bridge is the connection between the primary (secondary) supply main and the primary (secondary) return main. Size

cross-over bridge at a pressure drop of 1–4 ft./100 ft.

4. *Common Piping*. Common piping (sometimes called bypass piping) is the length of piping common to both the primary and secondary circuit flow paths and the secondary and tertiary circuit flow paths. Common piping is the interconnection between the primary and secondary circuits and the secondary and tertiary circuits. The common piping is purposely designed to an extremely low or negligible pressure drop and is generally only 6" to 24" long maximum. By designing for an extremely low pressure drop, the common piping ensures hydraulic isolation of the secondary circuit from the primary circuit, and the tertiary circuit from the secondary circuit.

5. Extend common pipe size a minimum of 8 diameters upstream and a minimum of 4 diameters downstream when primary flow rate is considerably less than secondary flow rate (e.g., primary pipe size is smaller than secondary pipe size—use larger pipe size) to prevent any possibility of "jet flow." Common piping (bypass piping) in primary/secondary systems or secondary/tertiary systems should be a minimum of 10 pipe diameters in length and the same size as the larger of the two piping circuits.

6. A one-pipe primary system uses one pipe for supply and return. The secondary circuits are in series. Therefore, this system supplies a different supply water temperature to each secondary circuit, and the secondary circuits must be designed for this temperature change.

7. A two-pipe primary system uses two pipes, one for supply and one for return with a cross-over bridge connecting the two. The secondary circuits are in parallel. Therefore, this system supplies the same supply water temperature to each secondary circuit.

19.06. Hydronic System Design and Piping Installation Guidelines

A. Hydronic systems design principle and goal is to provide the correct water flow at the correct water temperature to the terminal users.

B. Common Design Errors

1. Differential pressure control valves are installed in pump discharge bypasses.

2. Control valves are not selected to provide control with system design pressure differentials at maximum and minimum flows.

3. Control valves are selected with improper pressure drop.

4. Incorrect primary/secondary/tertiary system design.

5. Constant flow secondary or tertiary systems are connected to variable flow primary or secondary systems, respectively.

6. Check valves are not provided in pump discharges when pumps are operating in parallel.

7. Automatic relief valves are oversized, which results in quick, sudden, and sometimes violent system pressure fluctuations.

C. Piping System Arrangements

1. When designing pumping systems for chillers, boilers, and cooling towers, provide either a coupled pumping arrangement (each pump piped directly to each piece of central plant equipment) or provide a headered system (see Fig. 19.22). Hydronic systems should be designed with standby pumps (see Figs. 19.23 and 19.24).

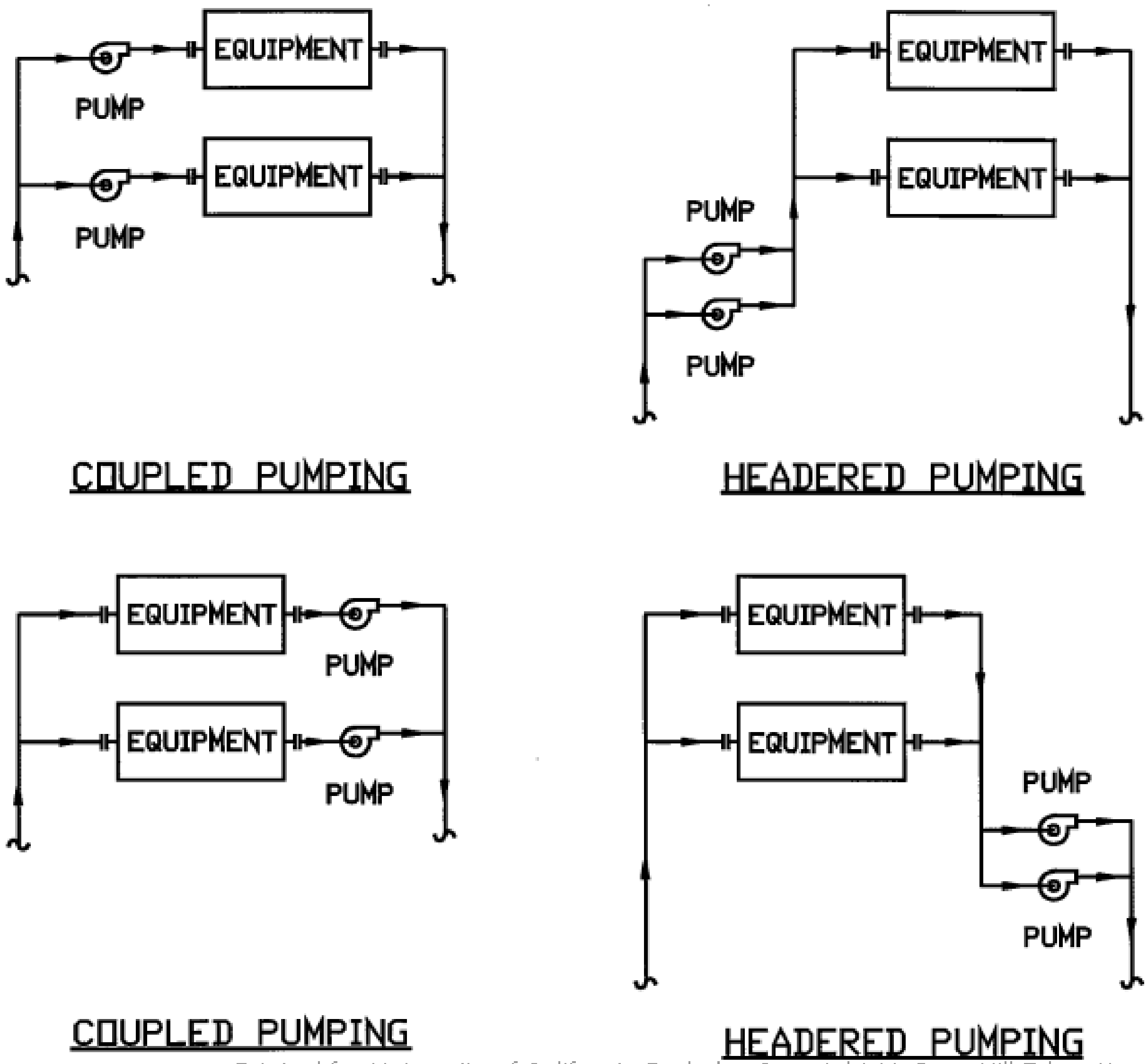
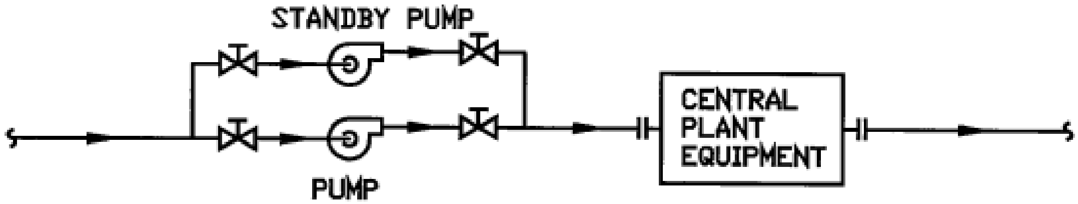
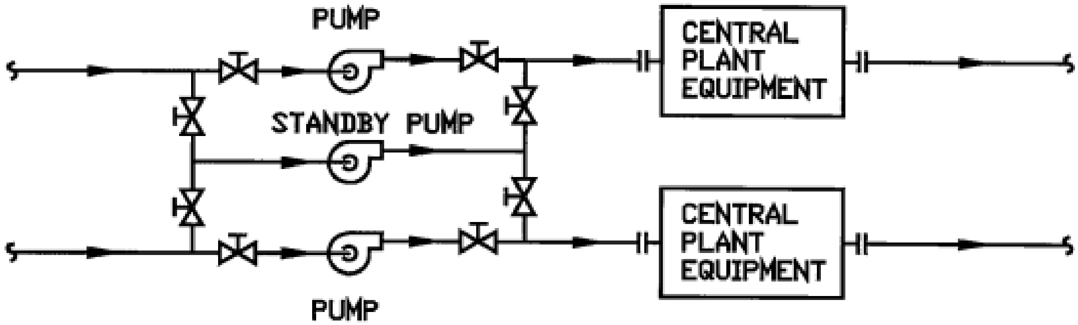


Figure 19.22. COUPLED-HEADERED PUMPING ARRANGEMENTS.

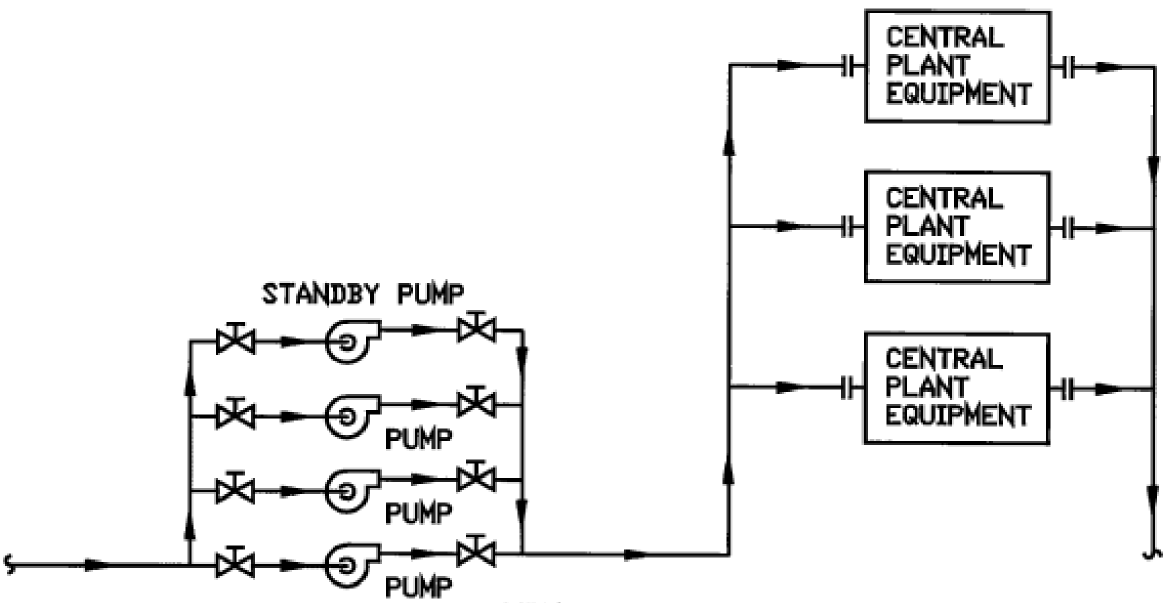


INDIVIDUAL



COUPLED

NOTE: STANDBY PUMP MAY SERVE EITHER PIECE OF CENTRAL PLANT EQUIPMENT.



HEADERED

NOTE: STANDBY PUMP MAY SERVE ANY PIECE OF CENTRAL PLANT EQUIPMENT, PROVIDED ALL EQUIPMENT IS THE SAME CAPACITY.

Figure 19.23. STANDBY PUMPS.

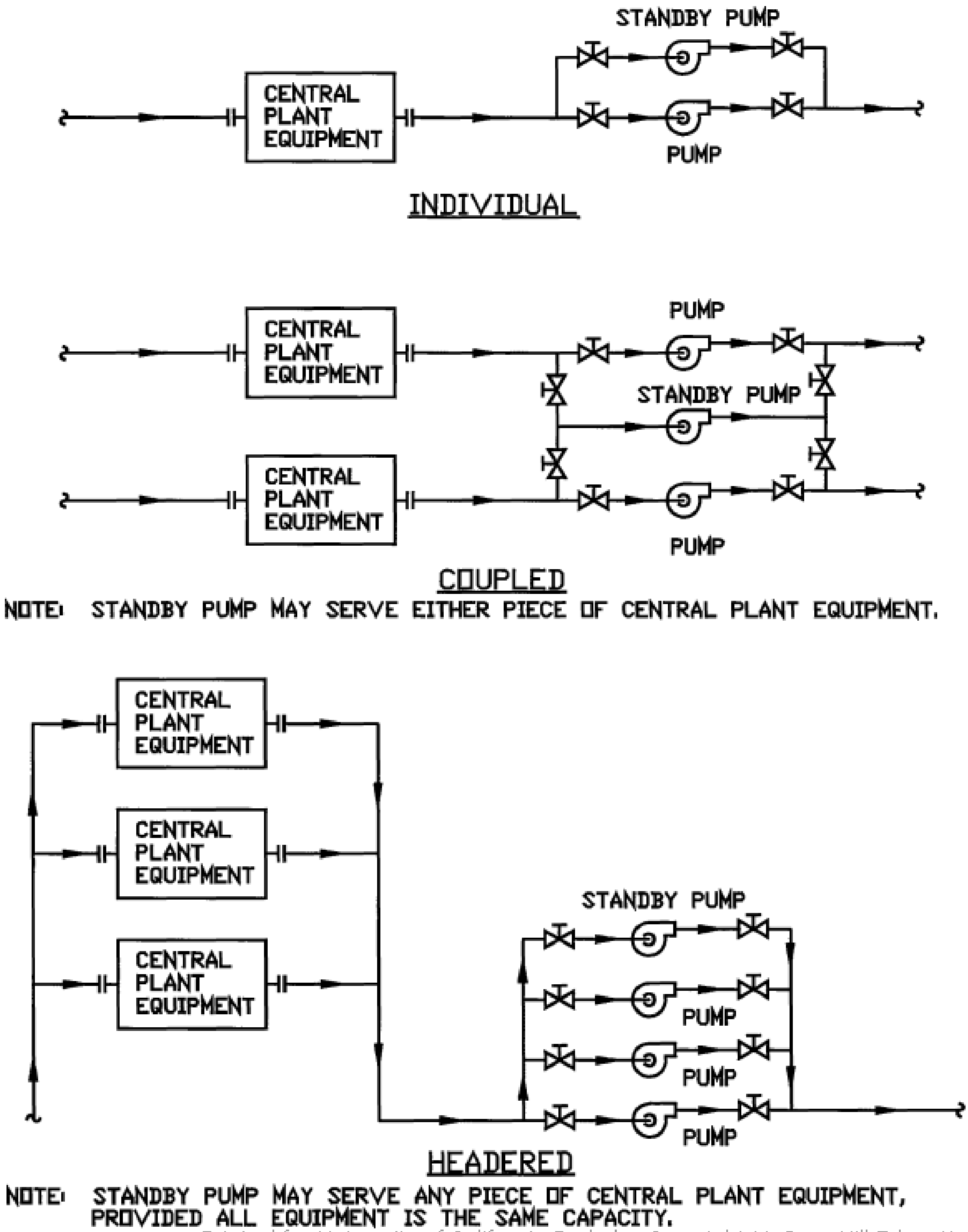


Figure 19.24. STANDBY PUMPS.

2. Coupled system:
   a. A coupled system should only be used when all the equipment in the system is the same capacity (chillers, boilers, cooling towers, and associated pumps).

3. Headered system:

a. A headered system is preferred especially when chillers, cooling towers, boilers, and associated pumps are of unequal capacity. Although, the system is easier to design and operate if the equipment is of equal capacity.

b. When designing a headered system, Griswold valves (flow control devices) must be installed in the supply piping to each piece of equipment to obtain the proper flow through that piece of equipment. In addition to Griswold valves, control valves must be installed to isolate equipment not in service if the system is to be fully automatic. These control valves should be provided with a manual means of opening and closing in case of control system malfunction or failure.

c. Provide adequate provisions for the expansion and contraction of piping in the boiler, chiller, cooling tower, and pump-headered systems. Provide U-shaped header connections for all equipment to accommodate expansion and contraction (first route piping away from the header, then route parallel to the header, and finally route back toward the header; the size of the U-shape will depend on the temperature of the system).

D. The minimum recommended hydronic system pipe size should be 3/4 inch.

E. In general, noise generation in hydronic systems indicates erosion is occurring.

F. Large System Diversities

1. Campus heating: 80 percent.

2. Campus cooling: 65 percent.

3. Constant flow: Load is diversified only; flow is not diversified, resulting in temperature changes.

4. Variable flow: Load and flow are both diversified.

G. When designing a campus or district type heating or cooling system, the controls at the interface between the central system and the building system should be secured so that access is limited to the personnel responsible for operating the central plant and not accessible to the building operators. Building operators may not fully understand the central plant operation and may unknowingly disrupt the central plant operation with system interface tinkering.

H. Differential pressure control of the system pumps should never be accomplished at the pump. The pressure bypass should be provided at the end of the system or at the end of each of the subsystems regardless of whether the system is a bypass flow system or a variable speed pumping system. Bypass flow need not exceed 20 percent of the pump design flow.

I. Central plant equipment (chillers, boilers, cooling towers, and associated pumps) should be of equal size units; however, the system design may include 1/2-sized units or 1/3-sized units with full-sized equipment. For example, a chiller system may be made up of 1,200-ton, 600-ton, and 400-ton chillers. However, 1/3-sized units have limited application. This permits providing multiple units to achieve the capacity of a single unit and having two or three pumps operate to replace the one larger pump.

J. Pump Discharge Check Valves

1. Pump discharge check valves should be center-guided, spring-loaded, disc-type check valves.

2. Pump discharge check valves should be sized so that the check valve is full open at the design flow rate. Generally, this will require the check valve to be one pipe size smaller than the connecting piping.

3. Condenser water system and other open piping system check valves should have globe style bodies to prevent flow reversal and slamming.

4. Installing check valves with 4 to 5 pipe diameters upstream of flow disturbances is recommended by most manufacturers.

K. Install air vents at all high points in water systems. Install drains at all low points in water systems. All automatic air vents, manual air vents, and drains in hydronic systems should be piped to a safe location within 6 inches of the floor, preferably over a floor drain, especially with heating water systems.

L. Thermometers should be installed in both the supply and return piping to all water coils, chillers, boilers, heat exchangers, and other similar equipment. Thermometers should also be installed at each location where major return streams mix at a location approximately 10 pipe diameters downstream of the mixing point. Placing thermometers

upstream of this point is not required, but often desirable, because the other return thermometers located upstream will provide the water temperatures coming into this junction point. Placing thermometers in these locations will provide assistance in troubleshooting system problems. Liquid-filled-type thermometers are more accurate than the dial-type thermometers.

M. Select water coils with tube velocities high enough at design flow so that tube velocities do not end up in the laminar flow region when the flow is reduced in response to low load conditions. Tube velocities become critical with units designed for 100 percent outside air at low loads near 32°F. Higher tube velocity selection results in a higher water pressure drop for the water coil. Sometimes a trade-off between pressure drop and low load flows must be evaluated.

N. Install the manual air vent and drain on a coupon rack to relieve pressure from the coupon rack to facilitate removing coupons. Pipe drain to the floor drain.

O. Make piping connections to mains and branches from piping using the following guidelines (see Fig. 19.25):

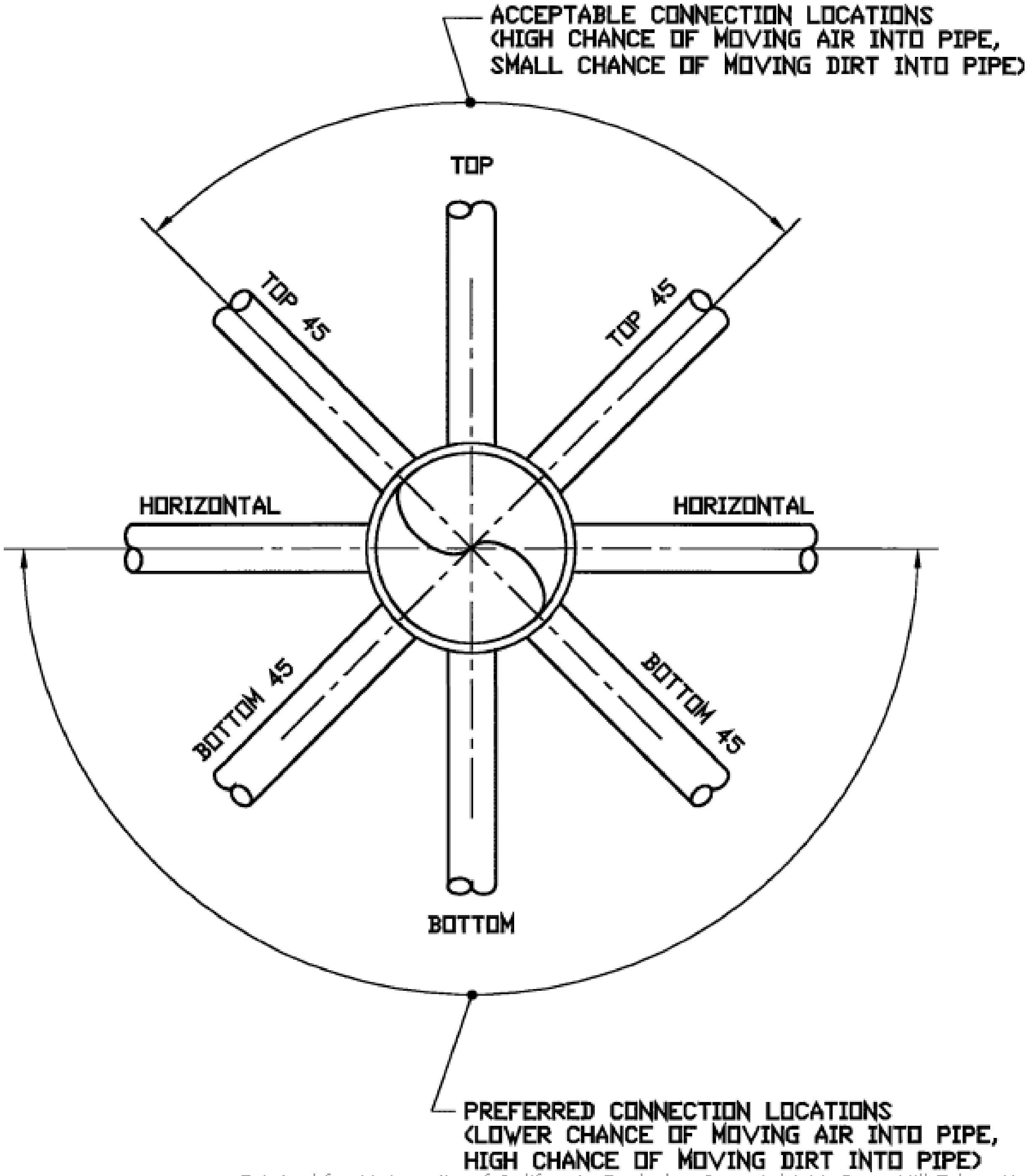


Figure 19.25. HYDRONIC PIPING CONNECTIONS.

1. Top of piping: To prevent dirt from entering the main or branch piping.

2. Bottom or side of piping: To prevent air from entering the main or branch piping.

P. Do not use bull head tees (see Fig. 19.26).

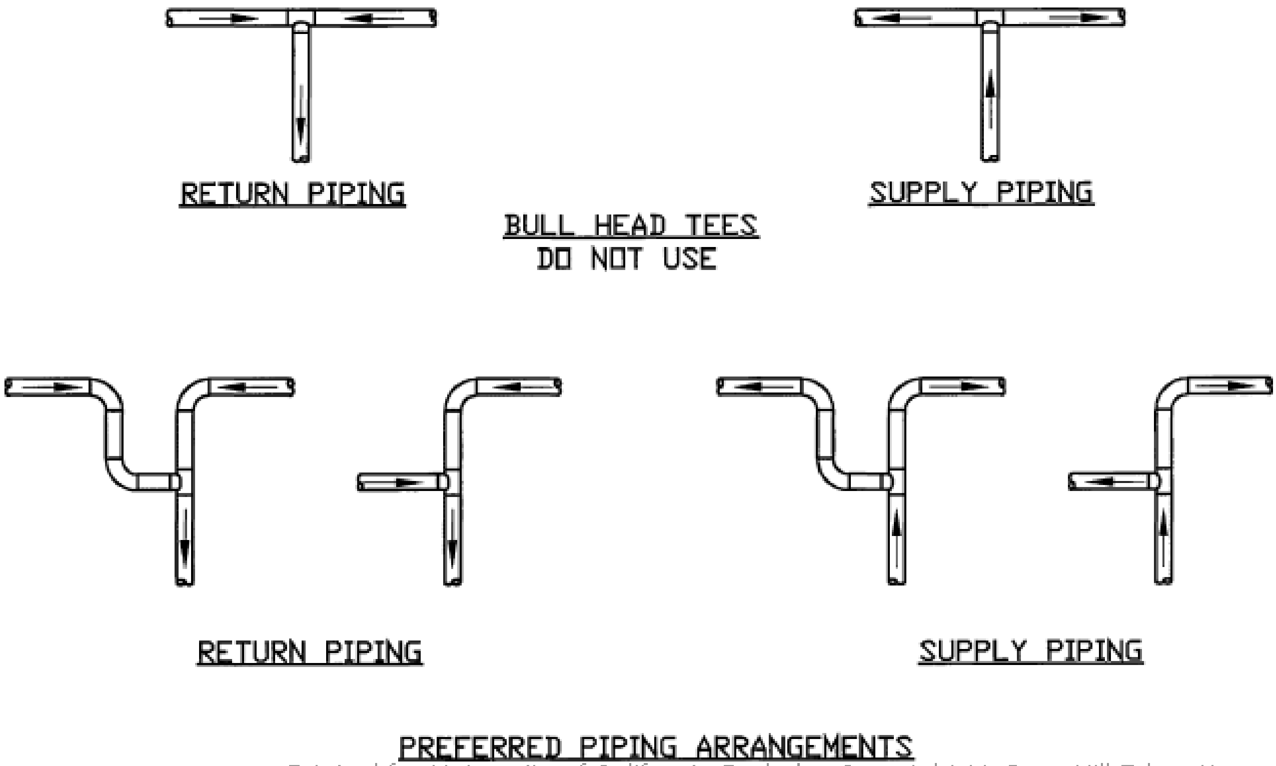


Figure 19.26. PIPING DESIGN—BULL HEAD TEES.

Q. Install the manual air vent on a chemical feed tank and also pipe drain to the floor drain.

R. Provide water meters on all makeup water and all blowdown water connections to hydronic systems (heating water, chilled water, condenser water, and steam systems). System water usage is critical in operating the systems, maintaining chemical levels, and troubleshooting the systems. If the project budget permits, these meter readings should be logged and recorded at the building facilities management and control system.

S. Locate all valves, strainers, unions, and flanges so they are accessible. All valves (except control valves) and strainers should be the full size of the pipe before reducing the size to make connections to the equipment and controls. Union and/or flanges should be installed at each piece of equipment, in bypasses and in long piping runs (100 feet or more) to permit disassembly for alteration and repairs.

T. Provide chainwheel operators for all valves in equipment rooms mounted greater than 7'0" above the floor level. The chain should extend to 5'0" to 7'0" above the floor level.

U. All balancing valves should be provided with position indicators and maximum adjustable stops (memory stops).

V. All valves should be installed so the valve remains in service when equipment or piping on the equipment side of the valve is removed.

W. Locate all flow measuring devices in accessible locations with a straight section of pipe upstream (10 pipe diameters) and downstream (5 pipe diameters) of the device or as recommended by the manufacturer.

X. Provide a bypass around water filters and water softeners. Show water filters and water softener feeding hydronic or steam systems on schematic drawings and plans.

Y. Provide vibration isolators for all piping supports connected to, and within 50 feet of, isolated equipment and throughout mechanical equipment rooms, except at base elbow supports and anchor points.

Z. Do not use malleable iron fittings for glycol systems.

AA. Water in a system should be maintained at a pH of approximately 8 to 9. A pH of 7 is neutral; below 7 is acidic; above 7 is alkaline. Closed system water treatment should be 1,600 to 2,000 ppm Borax-Nitrite additive.

BB. Terminal Systems

1. Design for the largest possible system delta T.
2. Better to have terminal coils *slightly* oversized than undersized. Increasing flow rates in terminal coils to twice the design flow rate only increases coil capacity 5 to 16 percent, and tripling the flow rate only increases coil capacity 7 to 22 percent. Grossly oversized terminal unit coils can lead to serious control problems, so care must be taken in properly sizing coils.

CC. Terminal Unit Control Methods

1. Constant supply temperature, variable flow.
2. Variable supply temperature, constant flow.
3. Flow modulation to a minimum value at constant supply temperature. At minimum flow a pump or fan is started to maintain a constant minimum flow at a variable supply temperature.

4. No primary system control, secondary system control is accomplished by blending supply water with return water, or by utilizing face and bypass damper control.

DD. Terminal Unit Design

1. Terminal unit design should be designed for the largest possible system delta T.

2. Terminal unit design should be designed for the closest approach of primary return water temperature and secondary return temperature.

3. Terminals must be selected for full-load and partial-load performance.

4. Select coils with high water velocities at full load, larger pressure drop. This will result in increased performance at partial loads.

EE. Thermal Storage

1. Peak shaving. Constant supply with variable demand.

2. Space heating/cooling. Variable supply with constant-demand waste heat recovery.

3. Variable supply with variable demand.

FF. Provide stop check valves (located closest to the boiler) and isolation valves with a drain between them on both the supply and return connections to all heating water boilers.

19.07. Chilled Water Systems

A. **Leaving Water Temperature (LWT): 40–48°F (60°F Maximum)**

B. **ΔT Range 10–20°F.**

C. **Chiller Start-up and Shutdown Bypass: When starting a chiller, it takes 5 to 15 minutes from the time the chiller start sequence is initiated until the time the chiller starts to provide chilled water at the design temperature. During this time, the chilled water supply temperature rises above the desired set point. If chilled water temperature is critical and this deviation is unacceptable, the method to correct this problem is to provide the chillers with a bypass that**

runs from the chiller discharge to the primary pump suction header return. The common pipe only needs to be sized for the flow of one chiller because it is unlikely that more than one chiller will be started at the same time. Chiller system operation with a bypass should be as follows:

1. In the chiller start sequence, the primary chilled water pump is started, the bypass valve is opened, and the supply header valve is closed. When the chilled water supply temperature is reached, as sensed in the bypass, the supply header valve is slowly opened. When the supply header valve is fully opened, the bypass valve is slowly closed.

2. In the chiller stop sequence, the bypass valve is slowly opened. When the bypass valve is fully opened, the supply header valve is slowly closed. When the primary chilled water pump stops, the bypass valve is closed.

D. **Large- and campus-chilled water systems should be designed for large delta Ts and for variable flow secondary and tertiary systems.**

E. **Chilled water pump energy must be accounted for in the chiller capacity because they add heat load to the system (motor out, driven equipment in, see Part 12—Motor Heat Gain).**

F. **Methods of Maintaining Constant Chilled Water Flow**

1. Primary/secondary systems.

2. Bypassing-control.

3. Constant volume flow is only applicable to two chillers in series-flow or single chiller applications.

G. **It is best to design chilled water and condenser water systems to pump through the chiller.**

H. **When combining independent chilled water systems into a central plant …**

1. Create a central system concept, control scheme, and flow schematics.

2. The system shall only have a single expansion tank connection point sized to handle entire system expansion and contraction.

3. All systems must be altered, if necessary, to be compatible with the central system concept (temperatures, pressures, flow concepts, variable or constant, control concepts).

4. For constant flow and variable flow systems, the secondary chillers are tied into the main chiller plant return main. Chilled water is pumped from the return main through the chiller and back to the return main.

5. District chilled water systems, due to their size, extensiveness, or both, may require that independent plants feed into the supply main at different points. If this is required, design and layout must enable isolating the plant; provide start-up and shutdown bypasses; and provide adequate flow, temperature, pressure, and other control parameter readings and indicators for proper plant operation, as well as other design issues that affect plant operation and optimization.

I. **In large systems, it may be beneficial to install a steam-to-water or water-to-water heat exchanger to place an artificial load on the chilled water system to test individual chillers or groups of chillers during plant start-up, after repairs, or for troubleshooting chiller or system problems.**

19.08. Low-Temperature Chilled Water Systems (Glycol or Ice Water Systems)

A. **Leaving Water Temperature (LWT): 20–40°F (0°F Minimum)**

B. **ΔT Range 20–40°F**

C. **The design of low-temperature chilled-water systems is the same as chilled-water systems.**

19.09. Heating Water Systems General

A. **From a design and practical standpoint, low-temperature heating water systems are often defined as systems with water temperatures of 210°F and less, and high-temperature heating water systems are defined as systems with water temperatures of 211°F and higher.**

B. **Provide a manual vent on top of a heating water boiler to vent air from the top of the boiler during filling and system operation. Pipe the manual vent discharge to the floor drain.**

C. **Blowdown separators are not required for hot water boilers, but desirable for maintenance purposes. Install the blowdown separator so the inlet to the separator is at or below the boiler drain to enable the use of the blowdown separator during boiler draining for emergency repairs.**

D. **Safety: High temperature hydronic systems when operated at higher system temperatures and higher system pressures will result in a lower chance of water hammer and the damaging effects of pipe leaks. These high-temperature heating water systems are also safer than lower-temperature heating water systems because system leaks subcool to temperatures below scalding due to the sudden decrease in pressure and the production of water vapor.**

E. **Outside air temperature reset of low temperature heating water systems is recommended for energy savings and controllability of terminal units at low load conditions. However, care must be taken with boiler design to prevent thermal shock by low return water temperature or to prevent condensation in the boiler due to low supply water temperature and, therefore, lower combustion stack discharge temperature.**

F. **Circulating hot water through a boiler that is not operating, in order to keep it hot for standby purposes, creates a natural draft of heated air through the boiler and up the stack, especially in natural draft boilers. Forced draft or induced draft boilers have combustion dampers that close when not firing and therefore reduce, but don't eliminate, this heat loss. Although this heat loss is undesirable for standby boilers, circulating hot water through the boiler is more energy efficient than firing the boiler. Operating a standby boiler may be in violation of air permit regulations in many jurisdictions today.**

19.10. Low-Temperature Heating Water Systems

A. **Leaving Water Temperature (LWT): 160–200°F (Recommend 180°F, Range: 140–200°F)**

B. **ΔT Range 20–40°F**

C. **Low Temperature Water 250°F and Less; 160 psig Maximum**

D. **The system ΔT is generally limited by the boiler and the maximum temperature difference the boiler can withstand without thermal shock. The following are some common boiler types and the maximum recommended system temperature difference (consult the boiler manufacturer).**

1. Steel boilers (fire tube, water tube): 40°F.
2. Cast-iron boilers: 40°F.
3. Modular or copper tube boilers: 100°F (some even higher)

19.11. Medium- and High-Temperature Heating Water Systems

A. **Leaving Water Temperature (LWT): 350–450°F**

B. **ΔT Range 20–100°F**

C. **Medium Temperature Water 251–350°F, 160 psig Maximum**

D. **High Temperature Water 351–450°F, 300 psig Maximum**

E. **The submergence or antiflash margin is the difference between the actual system operating pressure and the vapor pressure of water at the system operating temperature. However, submergence or antiflash margin is often expressed in degrees Fahrenheit—the difference between the temperature corresponding to the vapor pressure equal to the actual system pressure and the system operating temperature.**

F. **Provide operators on valves on the discharge of the feedwater pumps for medium- and high-temperature systems to provide positive shutoff because the check valves sometimes leak with the large pressure differential. Interlock the valves to open when the pumps operate. Verify that the valve is open with an end switch or a valve positioner.**

G. **Provide space and racks for spare nitrogen bottles in mechanically pressurized medium- and high-temperature heating water systems.**

H. **Medium- and High-Temperature Heating Water System Design Principles**

1. System pressure must exceed the vapor pressure at the design temperature in all locations in the system. Verify this pressure requirement at the highest location in the system, at the pump suction, and at the control valve when at minimum flow or part load conditions. The greater the elevation difference, above the pressure source (in most cases, the expansion tank), the higher the selected operating temperature should be in the medium- and high-temperature heating water system.

2. Medium- and high-temperature water systems are unforgiving to system design errors in capacity or flow rates.

3. Conversion factors in standard HVAC equations must be adjusted for specific gravity and specific heat at the design temperatures.

4. Thermal expansion and contraction of piping must be considered and are critical in system design.

5. Medium- and high-temperature heating water systems can be transported over essentially unlimited distances.

6. The greater the system delta T, the more economical the system becomes.

7. Use medium- and high-temperature heating water systems when required for process applications because it produces precise temperature control and more uniform surface temperatures in heat transfer devices.

8. The net positive suction head requirements of the medium- and high-temperature system pumps are critical and must be checked for adequate pressure. It is best to locate and design the pumps as follows so cavitation does not occur:
   a. Oversize the pump suction line to reduce resistance.

   b. Locate the pump at a lower level than the expansion tank to take advantage of the static pressure gain.

   c. Elevate the expansion tank above the pumps.

   d. Locate the pumps in the return piping circuit and pump through the boilers, thus reducing the system temperature at the pumps, which reduces the vapor pressure requirements.

9. Either blending fittings or properly designed pipe fittings must be used when blending return water with supply water in large delta T systems or injecting

medium- and high-temperature primary supply water into low-temperature secondary circuits. When connecting piping to create a blending tee, the hotter water must always flow downward and the colder water must always flow upward. The blending pipe must remain vertical for a short length equal to a few pipe diameters on either side of the tee. Since turbulence is required for mixing action, it is not desirable to have straight piping for any great distance (a minimum of 10 pipe diameters is adequate).

I. **Above approximately 300°F, the bearings and gland seals of a pump must be cooled. Consult factory representatives for all pumps for systems above 250°F to determine specification requirements. Cooling water leaving the pump cooling jacket should not fall below 100°F. The best method for cooling seals is to provide a separate heat exchanger (one at each pump or one for a group of pumps) and circulate the water through the seal chamber. The heat exchanger should be constructed of stainless steel. Another method to cool the seals is to take a side stream flow off of the pump discharge, cool the flow, and inject it into the end face. This is not recommended because the amount of energy wasted is quite substantial.**

J. **Medium- and high-temperature heating water systems work well for radiant heating systems.**

K. **Control valves should be placed in the supply to heat exchangers with a check valve in the return. This practice provides a safety shutoff in case of a major leak in the heat exchanger. By placing the control valve in the supply when a leak occurs, the temperature or pressure increases on the secondary side causing the control valve to close while the check valve prevents back flow or pressure from the return. Flashing may occur with the control valve in the supply when a large pressure differential exists or when the system is operated without an antiflash margin. To correct this flashing, control must be split with one control valve in the supply and one control valve in the return.**

L. **If using medium- or high-temperature heating water systems to produce steam, the steam pressure dictates the delta T and thus the return water temperature.**

M. **Medium- and High-Temperature Heating Water Systems in Frequent Use**

1. Cascade systems with integral expansion space:

a. Type 1. Feedwater pump piped to steam boiler.

b. Type 2. Feedwater pump piped to medium- or high-temperature heating water system with steam boiler feedwater provided by medium- and high-temperature heating water system.

2. Flooded generators with external expansion/pressurization provisions.

N. **Medium- and High-Temperature Water System Boiler Types**

1. Natural circulators, fire tube, and water tube boilers.

2. Controlled (forced) circulation.

3. Combustion (natural and forced), corner tube boilers.

O. **Design Requirements**

1. Settling chamber to remove any foreign matter, dirt, and debris; oversized header with flanged openings for cleanout.

2. Generator must never be blown down. Blowdown should only be done at the expansion tank or piping system.

3. Boiler safety relief valves should only be tested when water content is cold; otherwise, flashing water-to-steam mixture will erode the valve seat and after opening once or twice the safety relief valves will leak constantly.

4. Boiler safety relief valves must only be considered protection for the boilers. Another safety relief valve must be provided on the expansion tank.

5. Relief valves should be piped to a blowdown tank.

P. **Medium- and high-temperature heating water systems may be pressurized by steam systems on the generator discharge or by pump or mechanical means on the suction side of the primary pumps pumping through the boilers.**

Q. **Steam Pressurized System Characteristics**

1. Steam pressurized systems are generally continuously operated with rare shutdowns.

2. A system expansion tank is pressurized with steam and contains a large volume of water at a high temperature, resulting in a considerable ability to absorb load fluctuations.

3. Steam pressurized systems improve the operation of combustion control.

4. A steam pressurized system reduces the need to anticipate load changes.

5. The system is closed and the entry of air or gas is prevented, thus reducing or eliminating corrosion or flow restricting accumulations.

6. Generally, these systems can operate at a lower pressure than pump or mechanically pressurized systems.

7. Steam pressurized systems have a higher first cost.

8. These systems require greater space requirements.

9. The large pressurization tank must be located above and over generators.

10. Pipe discharges into a steam pressurized expansion tank should be vertically upward or should not exceed an angle greater than 45 degrees with respect to the vertical.

R. **Mechanically Pressurized System Characteristics**

1. Mechanically pressurized systems have flexibility in their expansion tank location.

2. Mechanically pressurized systems should be designed to pump through the generator. Place the expansion and pressurization means at the pump suction inlet.

3. Mechanically pressurized systems are best suited for intermittently operated systems.

4. A submergence or antiflash margin must be provided.

5. A nitrogen supply must be kept on hand. The system cannot operate without nitrogen.

6. Mechanically pressurized systems have a lower first cost.

7. Mechanically pressurized systems require less expansion tank space.

8. Startup and shutdown of these systems is simplified.

S. **Pumps in medium- and high-temperature heating water systems should be provided with 1/2 to 3/4 inch bypasses around the check valve and shutoff valves on the pump discharge in order to …**

1. Refill the pump piping after repairs have been made.

2. Allow for opening the system shutoff valve (often the gate valve), which becomes difficult to open against the pressure differentials experienced.

3. Allow for a slow warming of the pump and pump seals, and for letting sealing surfaces seat properly.

T. **Double valves should be installed on both the supply and return side of the equipment for isolation on heating water systems above 250°F with a drain between these valves to visually confirm isolation. The double valving of systems ensures isolation because of the large pressure differentials that occur when the system is opened for repairs. Double valve all of the following.**

1. Equipment.

2. Drains.

3. Vents.

4. Gauges.

5. Instrumentation.

6. Double drain and vent valve operation: Fully open the valve closest to the system piping first. Then, open the second valve, modulating the second valve to control flow to the desired discharge rate. Close the second valve first when finished draining or venting. Operating in this fashion keeps the valve closest to the system from being eroded and thus allowing the valve to provide tight shutoff when needed. In addition, this operation allows for the replacement of the second valve with the system in operation since this valve receives most of the wear and tear during operation.

U. **Do not use screw fittings because high- and medium-temperature water is very penetrating. Use welded or flanged fittings in lieu of screwed fittings. Do not use union joints.**

V. **Use of dissimilar metals must be avoided. Use only steel pipe, fittings, valves, flanges, and other devices.**

W. **Do not use cast-iron or bronze body valves.**

X. **Use valves with metal-to-metal seats.**

Y. **Do not use lubricated plug valves.**

19.12. Boiler Warming Techniques

A. **To provide fully automatic heating water system controls, the controls must look at and evaluate the boiler metal temperature (water temperature) and the refractory temperature prior to starting the primary pumps or enabling the boiler to fire.**

B. **First, the boiler system design must circulate system water through the boilers to keep the boiler water temperature at system temperature when the boiler is in standby mode, as discussed for boiler warming pump arrangements in the following.**

C. **Second, the design must look at the water temperature prior to starting the primary pumps to verify the boiler is ready for service.**

D. **Third, the design must look at refractory temperature to prevent the boiler from going to high fire if the refractory is not at the appropriate temperature. However, the refractory temperature is usually handled by the boiler control package.**

E. **Boiler warming pumps should be piped to both the system header and the boiler supply piping, thus allowing the boiler to be kept warm (in standby mode) from the system water flow or to warm the boiler when it has been out of service for repairs without the risk of shocking the boiler with system water temperature (see Figs. 19.27 and 19.28).**

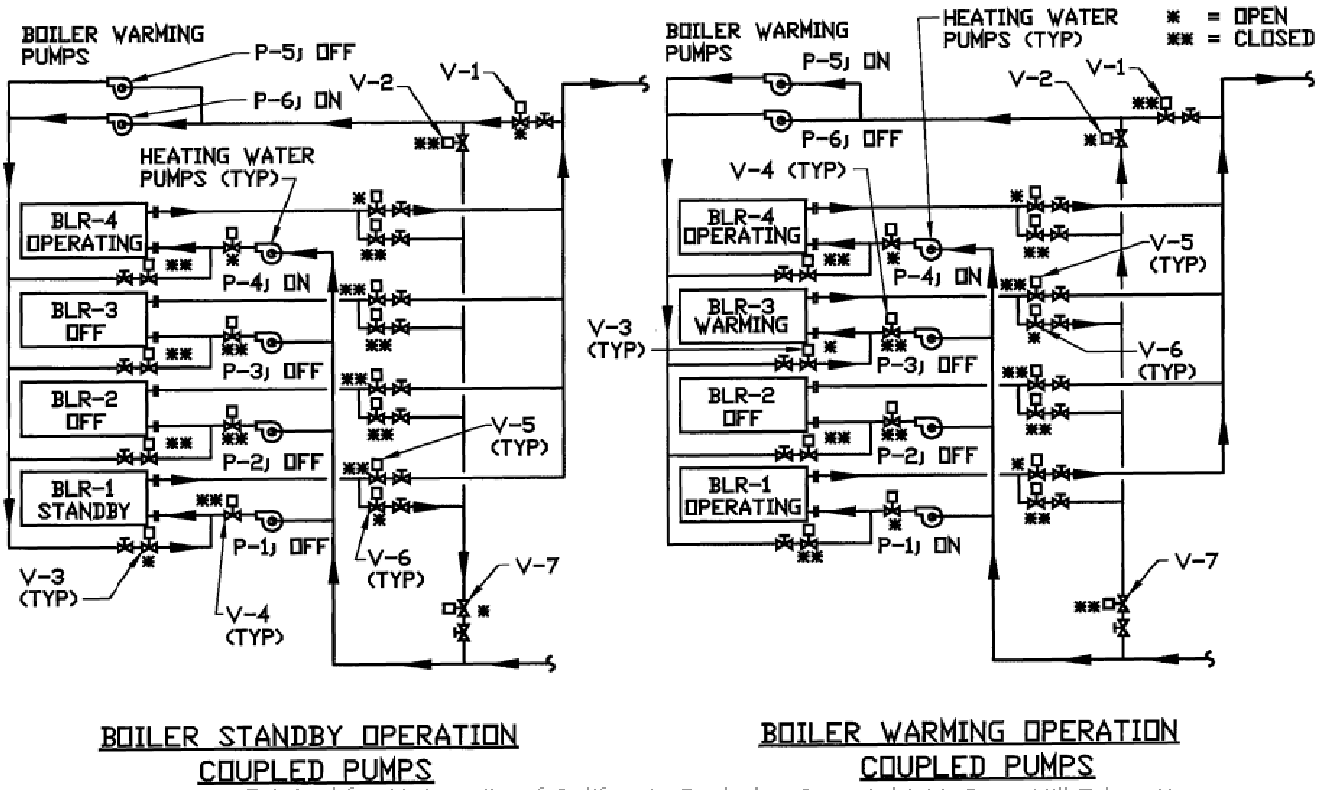


Figure 19.27. BOILER STANDBY AND WARMING DIAGRAM—COUPLED PUMPS.

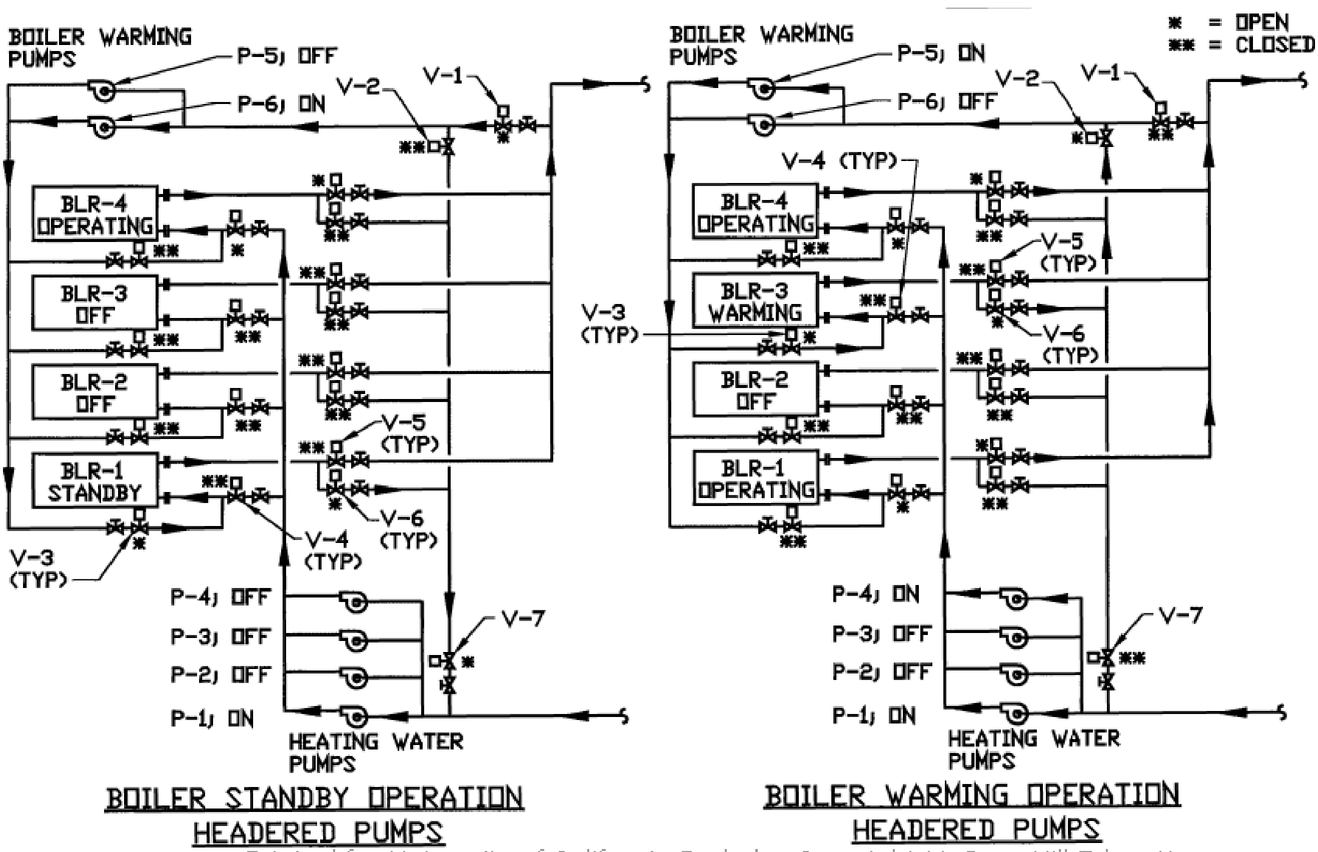


Figure 19.28. BOILER STANDBY AND WARMING DIAGRAM—HEADERED PUMPS.

F. **Boiler warming pumps should be selected for 0.1 GPM/BHP (range 0.05 to 0.1 GPM/BHP). At 0.1 GPM/BHP, it takes 45 to 75 minutes to completely exchange the water in the boiler. This flow rate is sufficient to offset the heat loss by radiation and stack losses on boilers when in standby mode of operation. In addition, this flow rate allows the system to keep the boiler warm without firing the boiler, thus allowing for more efficient system operation. For example, it takes 8 to 16 hours to bring a boiler online from a cold start. Therefore, the standby boiler must be kept warm to enable immediate startup of the boiler upon failure of an operating boiler.**

G. **Heating Water System Warm-Up Procedure**

1. Heating water system startup should not exceed a 120°F temperature rise per hour, but boiler or heat exchanger manufacturer limitations should be consulted.

2. It is recommended that no more than a 25°F temperature rise per hour be used when warming heating water systems. Slow warming of the heating water system allows for system piping, supports, hangers, and anchors to keep up with system expansion.

3. Low-temperature heating water systems (250°F and less) should be warmed slowly at a 25°F temperature rise per hour until the system design temperature is reached.

4. Medium- and high-temperature heating water systems (above 250°F) should be warmed slowly at a 25°F temperature rise per hour until a 250°F system temperature is reached. At this temperature, the system should be permitted to settle for at least eight hours or more (preferably overnight). The temperature and pressure maintenance time gives the system piping, hangers, supports, and anchors a chance to catch up with the system expansion. After allowing the system to settle, the system can be warmed up to 350°F or the system design temperature in 25°F temperature increments and 25 psig pressure increments, semi-alternating between temperature and pressure increases, and allowing the system to settle for an hour before increasing the temperature or pressure to the next increment. When the system reaches 350°F and the design temperature is above 350°F, the system should be allowed to settle for at least eight hours or more (preferably overnight). The temperature and pressure maintenance time gives the system piping, hangers, supports, and anchors a chance to catch up with the system expansion. After allowing the system to settle, the

system can be warmed up to 455°F or the system design temperature in 25°F temperature increments and 25 psig pressure increments, semi-alternating between temperature and pressure increases, and allowing the system to settle for an hour before increasing the temperature or pressure to the next increment.

H. **Provide heating water systems with warm-up valves for in-service startup as shown in the following table. This will allow operators to warm these systems slowly and prevent a sudden shock or catastrophic system failure when large system valves are opened. Providing warming valves also reduces wear on large system valves when they are only opened a small amount in an attempt to control system warm-up speed.**

I. **Heating Water System Warming Valve Procedure**

1. First, open the warming return valve slowly to pressurize the equipment without flow.

2. Once the system pressure has stabilized, slowly open the warming supply valve to establish flow and warm the system.

3. When the system pressure and temperature have stabilized, proceed with the following listed items one at a time:
    a. Slowly open the main return valve.

    b. Close the warming return valve.

    c. Slowly open the main supply valve.

    d. Close the warming supply valve.

Bypass and Warming Valves

Main Valve Nominal Pipe Size	**Nominal Pipe Size**	
	Series A Warming Valves	**Series B Bypass Valves**
4	1/2	1
5	3/4	1-1/4
6	3/4	1-1/4
8	3/4	1-1/2
10	1	1-1/2
12	[illegible]	[illegible]

Notes:

1. ***Series A valve sizes are utilized in steam service for warming up***

Bypass and Warming Valves

Main Valve Nominal Pipe Size	Nominal Pipe Size	
	Series A Warming Valves	Series B Bypass Valves
12	1	2
14 16 18	1 1 1	2 3 3
20 24 30	1 1 1	3 4 4
36 42 48	1 1 1	6 6 8
54 60 72	1 1 1	8 10 10
84 96	1 1	12 12

Notes:

1. ***Series A valve sizes are utilized in steam service for warming up before the main line is opened, and for balancing pressures where lines are of limited volume.***
2. ***Series B valve sizes are utilized in pipe lines conveying gases or liquids where bypassing may facilitate the operation of the main valve through balancing the pressures on both sides of the disc or discs thereof. The valves in the larger sizes may be of the bolted on type.***

19.13. Dual Temperature Water Systems

A. **Leaving Cooling Water Temperature: 40–48 °F (60°F Maximum)**

B. **Cooling ΔT Range: 10–20°F**

C. **Leaving Heating Water Temperature: 160–200 °F (Recommend 180°F, Range: 140–200°F)**

D. **ΔT Range: 20–40°F.**

E. **Two-pipe switch-over systems provide heating or cooling but not both.**

F. **Three-pipe systems provide heating and cooling at the same time with a blended return water temperature causing energy waste.**

G. **Four-Pipe Systems**

1. Hydraulically joined at the terminal user (most common with fan coil systems with a single coil). Must design the heating and cooling systems with a common and single expansion tank connected at the generating end. At the terminal units, the heating and cooling supplies should be connected and the heating and cooling returns should be connected.

2. Hydraulically joined at the generator end (most common with condenser water heat recovery systems).

3. Hydraulically joined at both ends.

H. **Design of dual temperature water systems is the same as chilled water and heating water systems.**

19.14. Condenser Water Systems

A. **Entering Water Temperature (EWT): 85°F**

B. **ΔT Range: 10–20°F**

C. **Normal ΔT: 10°F**

D. **Design of condenser water systems is the same as chilled water systems.**

E. **When using condenser water systems in a waterside economizer operation to produce chilled water, remember to insulate the condenser water piping with the same insulation thickness as the chilled water system.**

19.15. Water Source Heat Pump Loop

A. **Range: 60–90°F**

B. **ΔT Range: 10–20°F**

19.16. Hydronic System Equation Factors

A. **H = 500 × GPM × ΔT**

B. **Substitute the equation factors in the following table for the number 500 in the previous equation for the design water temperatures indicated. Generally, it is acceptable to use 500 for hydronic systems up to 200**°F water.

Water Equation Factors

System Type	System Temperature Range °F	Equation Factor
Low-Temperature (Glycol) Chilled Water	0–40	See Note 2
Chilled Water	40–60	500
Condenser Water Heat Pump Loop	60–110	500
Low-Temperature Heating Water	110–150	490
	151–200	485
	201–250	480
Medium-Temperature Heating Water	251–300	475
	301–350	470
High-Temperature Heating Water	351–400	470
	401–450	470

Notes:

1. ***Water equation corrections for temperature, density, and specific heat.***
2. ***For glycol system equation factors, see Part 20.***

C. **Water Equation Factor Derivations**

1. Standard water conditions:
   a. Temperature: 60°F.

b. Pressure: 14.7 psia (sea level).

c. Density: 62.4 lbs./ft.^{3}

2. Water equation examples:

$H = m \times c_w \times \Delta T$

Water @ 250°F

$$c_w = 1.02\ \text{Btu}/\cancel{\text{Lb H}_2\text{O}}\,°\text{F} \times 62.4\ \cancel{\text{Lbs.H}_2\text{O}/\text{ft}^3} \times 1.0\ \cancel{\text{ft}^3}/7.48052\ \text{gal.} \times 60\ \text{min./h} \times 0.94\ (\text{SG})$$

× 60 min./h × 0.94 (SG)

= 480 Btu min./h °F gal.

$H_{250°F}$ = 480 Btu min./h °F gal. × GPM (gal./min.) × ΔT (°F)

$H_{250°F}$ = 480 × GPM × ΔT (°F)

Water @ 450°F

$$c_w = 1.13\ \text{Btu}/\cancel{\text{Lb H}_2\text{O}}\,°\text{F} \times 62.4\ \cancel{\text{Lbs.H}_2\text{O}/\text{ft}^3} \times 1.0\ \cancel{\text{ft}^3}/7.48052\ \text{gal.} \times 60\ \text{min./h} \times 0.83\ (\text{SG})$$

× 60 min./h × 0.83 (SG)

= 470 Btu min./h °F gal.

$H_{450°F}$ = 470 Btu min./h °F gal. × GPM (gal./min.) × ΔT (°F)

$H_{450°F}$ = 470 × GPM × ΔT (°F)

19.17. Hydronic System Design Temperatures and Pressures

A. **When designing medium- and high-temperature heating water systems, the appropriate system operating pressure or antiflash margin must be maintained to prevent water from becoming steam and creating water hammer.**

B. **Antiflash margin is the difference between the actual system operating pressure and the vapor pressure of water at the system operating temperature. However, antiflash margin is often expressed in degrees Fahrenheit—the difference between the temperature corresponding to the vapor pressure equal to the actual system pressure and the system operating temperature.**

Hydronic System Design Temperatures and Pressures

Hydronic System Design Temperatures and Pressures

Water Temperature °F	Vapor Pressure psig	System Operating Pressure Antiflash Margin 10°F	20°F	30°F	40°F	50°F	60°F	70°F
200	–3.2	–0.6	2.5	6	10	15	21	27
210	–0.6	2.5	6	10	15	21	27	35
212	0.0	3	7	11	16	22	29	36
215	0.9	4	8	13	18	24	31	39
220	2.5	6	10	15	21	27	35	43
225	4.2	8	13	18	24	30	39	48
230	6.1	10	15	21	27	35	43	52
240	10.3	15	21	27	34	43	52	63
250	15.1	21	27	34	43	52	63	75
260	20.7	27	34	43	52	63	75	88
270	27.2	34	43	52	63	75	88	103
275	30.7	39	47	58	69	81	96	111
280	34.5	43	52	63	75	88	103	120
290	42.8	52	63	75	88	103	120	138
300	52.3	63	75	88	103	120	138	159
310	62.9	75	88	103	120	138	159	181
320	74.9	88	103	120	138	159	181	206
325	81.4	96	111	129	148	170	193	219
330	88.3	103	120	138	159	181	206	232
340	103.2	120	138	159	181	206	232	262
350	119.8	138	159	181	206	232	262	294
360	138.2	159	181	206	232	262	294	329
370	158.5	181	206	232	262	294	329	367
375	169.5	193	219	247	277	311	347	387
380	180.9	206	232	262	294	329	367	407
390	205.5	232	262	294	329	367	407	452
400	232.4	262	294	329	367	407	452	500
410	261.8	294	329	367	407	452	500	551
420	293.8	329	367	407	452	500	551	606
425	310.9	347	387	429	475	524	578	635
430	328.6	367	407	452	500	551	606	665
440	366.5	407	452	500	551	606	665	729
450	407.4	452	500	551	606	665	729	797

Notes:

1. ***Safety: High-temperature hydronic systems when operated at***

455	429.1	475	525	578	635	697	762	832

Hydronic System Design Temperatures and Pressures

Water Temperature °F	**Vapor Pressure psig**	**System Operating Pressure Antiflash Margin**						
		10°F	**20°F**	**30°F**	**40°F**	**50°F**	**60°F**	**70°F**

Notes:

1. ***Safety: High-temperature hydronic systems when operated at higher system temperatures and higher system pressures will result in a lower chance of water hammer and the damaging effects of pipe leaks. These high-temperature heating water systems are also safer than lower-temperature heating water systems because system leaks subcool to temperatures below scalding due to the sudden decrease in pressure and the production of water vapor.***
2. ***The antiflash margin of 40°F minimum is recommended for nitrogen or mechanically pressurized systems.***

19.18. Piping Materials

A. **125 Psi (289 ft.) and Less**

1. 2" and smaller:
   a. Pipe: black steel pipe, ASTM A53, Schedule 40, Type E or S, Grade B Fittings: black malleable iron screw fittings, 150 lbs. ANSI/ASME B16.3 Joints: pipe threads, general purpose (American) ANSI/ASME B1.20.1.

   b. Pipe: black steel pipe, ASTM A53, Schedule 40, Type E or S, Grade B Fittings: cast-iron threaded fittings, 150 lbs. ANSI/ASME B16.4 Joints: pipe threads, general purpose (American) ANSI/ASME B1.20.1.

   c. Pipe: type "L" copper tubing, ASTM B88, Hard Drawn Fittings: wrought copper solder joint fittings, ANSI/ASME B16.22 Joints: solder joint with 95-5 tin antimony solder, 96-4 tin silver solder, or 94-6 tin silver solder, ASTM B32.

2. 2-1/2" through 10":
   a. Pipe: black steel pipe, ASTM A53, Schedule 40, Type E or S, Grade B Fittings: steel butt-welding fittings ANSI/ASME B16.9 Joints: welded pipe, ANSI/AWS D1.1 and ANSI/ASME Sec 9.

   b. Pipe: black steel pipe, ASTM A53, Schedule 40, Type E or S, Grade B

Fittings: factory-grooved end fittings equal to Victaulic full-flow. Tees shall be equal to Victaulic Style 20, 25, 27, or 29.
Joints: Mechanical couplings equal to Victaulic couplings Style 75 or 77 with Grade E gaskets, lubricated per the manufacturer's recommendation.

3. 12" and larger:
   a. Pipe: black steel pipe, ASTM A53,3/8" wall, Type E or S, Grade B
      Fittings: steel butt-welding fittings ANSI/ASME B16.9
      Joints: welded pipe, ANSI/AWS D1.1 and ANSI/ASME Sec 9.

   b. Pipe: black steel pipe, ASTM A53,3/8" wall, Type E or S, Grade B
      Fittings: Factory-grooved end fittings equal to Victaulic full-flow. Tees shall be equal to Victaulic Style 20, 25, 27, or 29.
      Joints: mechanical couplings equal to Victaulic couplings Style 75 or 77 with Grade E gaskets, lubricated per manufacturer's recommendation.

4. Mechanical joint manufacturers:
   a. Victaulic.

   b. Anvil Gruvlok.

   c. Grinnell.

B. **126–250 Psig (290–578 ft.)**
1. 1-1/2" and smaller:
   a. Pipe: black steel pipe, ASTM A53, Schedule 40, Type E or S, Grade B
      Fittings: forged steel socket-weld, 300 lbs., ANSI B16.11
      Joints: welded pipe, ANSI/AWS D1.1 and ANSI/ASME Sec 9.

   b. Pipe: carbon steel pipe, ASTM A106, Schedule 80, Grade B
      Fittings: forged steel socket-weld, 300 lbs., ANSI B16.11
      Joints: welded pipe, ANSI/AWS D1.1 and ANSI/ASME Sec 9.

2. 2" and larger:
   a. Pipe: black steel pipe, ASTM A53, Schedule 40, Type E or S, Grade B
      Fittings: steel butt-welding fittings, 300 lbs., ANSI/ASME B16.9
      Joints: welded pipe, ANSI/AWS D1.1 and ANSI/ASME Sec 9.

   b. Pipe: carbon steel pipe, ASTM A106, Schedule 80, Grade B
      Fittings: steel butt-welding fittings, 300 lbs., ANSI/ASME B16.9
      Joints: welded pipe, ANSI/AWS D1.1 and ANSI/ASME Sec 9.

19.19. Expansion Tanks and Air Separators

A. **Minimum (Fill) Pressure**

1. Height of system + 5 to 10 psi or 5–10 psi, whichever is greater.

B. **Maximum (System) Pressure**

1. 150-lbs. systems: 45–125 psi.
2. 250-lbs. systems: 125–225 psi.

C. **System Volume Estimate**

1. 12 gal./ton.
2. 35 gal./BHP.

D. **Connection Location**

1. Suction side of pump(s).
2. Suction side of primary pumps when used in primary/secondary/tertiary systems. An alternate location in primary/secondary/tertiary systems with a single secondary circuit may be the suction side of the secondary pumps.

E. **Expansion Tank Design Considerations**

1. Solubility of air in water. The amount of air that water can absorb and hold in solution is temperature- and pressure-dependent. As temperature increases, maximum solubility decreases, and as pressure increases, maximum solubility increases. Therefore, expansion tanks are generally connected to the suction side of the pump (the lowest pressure point).
2. Expansion tank sizing. If due to space or structural limitations, the expansion tank must be undersized, the minimum expansion tank size should be capable of handling at least 1/2 of the system expansion volume. With less than this capacity, system startup becomes a tedious and extremely sensitive process. If the expansion tank is undersized, an automatic drain should be provided and operated by the control system in addition to the manual drain. Size both the manual and automatic drains to enable a quick dump of a waterlogged tank (especially critical with undersized tanks) within the limits of the nitrogen fill speed and system pressure requirements.
3. System volume changes:
   a. System startup and shutdown result in the largest change in system volume.

b. System volume expansion and contraction must be evaluated at full load and partial load. Variations caused by load changes are described in the following:

   1. In constant flow systems, heating water return temperatures rise and chilled water temperatures drop as load decreases until at no load the return temperature is equal to the supply temperature. Heating systems expand and cooling systems contract at part load.

   2. In variable flow systems, heating water return temperatures drop and chilled water return temperatures rise as load decreases until at no load the return temperature equals the temperature in the secondary medium. Heating systems contract, and cooling systems expand at part load.

4. Expansion tanks are used to accept system volume changes, and a gas cushion (usually air or nitrogen) pressure is maintained by releasing the gas from the tank and readmitting the gas into the tank as the system water expands and contracts, respectively. Expansion tanks are used where constant pressurization in the system must be maintained.

5. Cushion tanks are used in conjunction with expansion tanks and are limited in size. As system water expands, pressure increases in the cushion tank until reaching the relief point, at which time it discharges to a lower-pressure expansion tank. As the system water contracts, pressure decreases in the cushion tank until reaching a low limit, at which time the pump starts and pumps the water from the low pressure expansion tank to the cushion tank, thus increasing the pressure. Cushion tank relief and makeup flow rates are based on the initial expansion of a heating system, or the initial contraction of a cooling system during start-up, because this will be the largest change in system volume for either system.

6. Compression tanks build their own pressure through the thermal expansion of the system contents. Compression tanks are not recommended on medium- or high-temperature heating water systems.

7. When expansion tank level transmitters are provided for building automation control systems, the expansion tank level should be provided from the level transmitter with local readout at the expansion tank, compression tank, or cushion tank. Also provide a sight glass or some other means of visually verifying the level in the tank and the accuracy of transmitter.

8. When expansion tank pressure transmitters are provided for building automation control systems, the expansion tank pressure should be provided from the pressure transmitter with local readout at the expansion tank, compression tank, or cushion tank. Also provide a pressure gauge at the tank to verify the transmitter.

9. Nitrogen relief from the expansion, cushion, or compression tank must be vented to outside (the noise when discharging is quite deafening). The vent can be tied into the vent off of the blowdown separator. Also need to provide nitrogen pressure monitoring and alarms and manual nitrogen relief valves.

10. Expansion tank sizing can be simplified using the following tables and their respective correction factors. These tables can be especially helpful for preliminary sizing.
    a. Low-temperature systems. Tables on pages 253 through 256.
    b. Medium-temperature systems. Tables on pages 257 through 260.
    c. High-temperature systems. Tables on pages 260 through 264.

11. Figure 19.29 is a photograph of an expansion tank in its installed condition.

Figure 19.29. PHOTOGRAPH OF AN EXPANSION TANK.

F. **Air Separators**

1. Air separators shall be full line size.

2. Figure 19.30 is a photograph of an air separator in its installed condition.

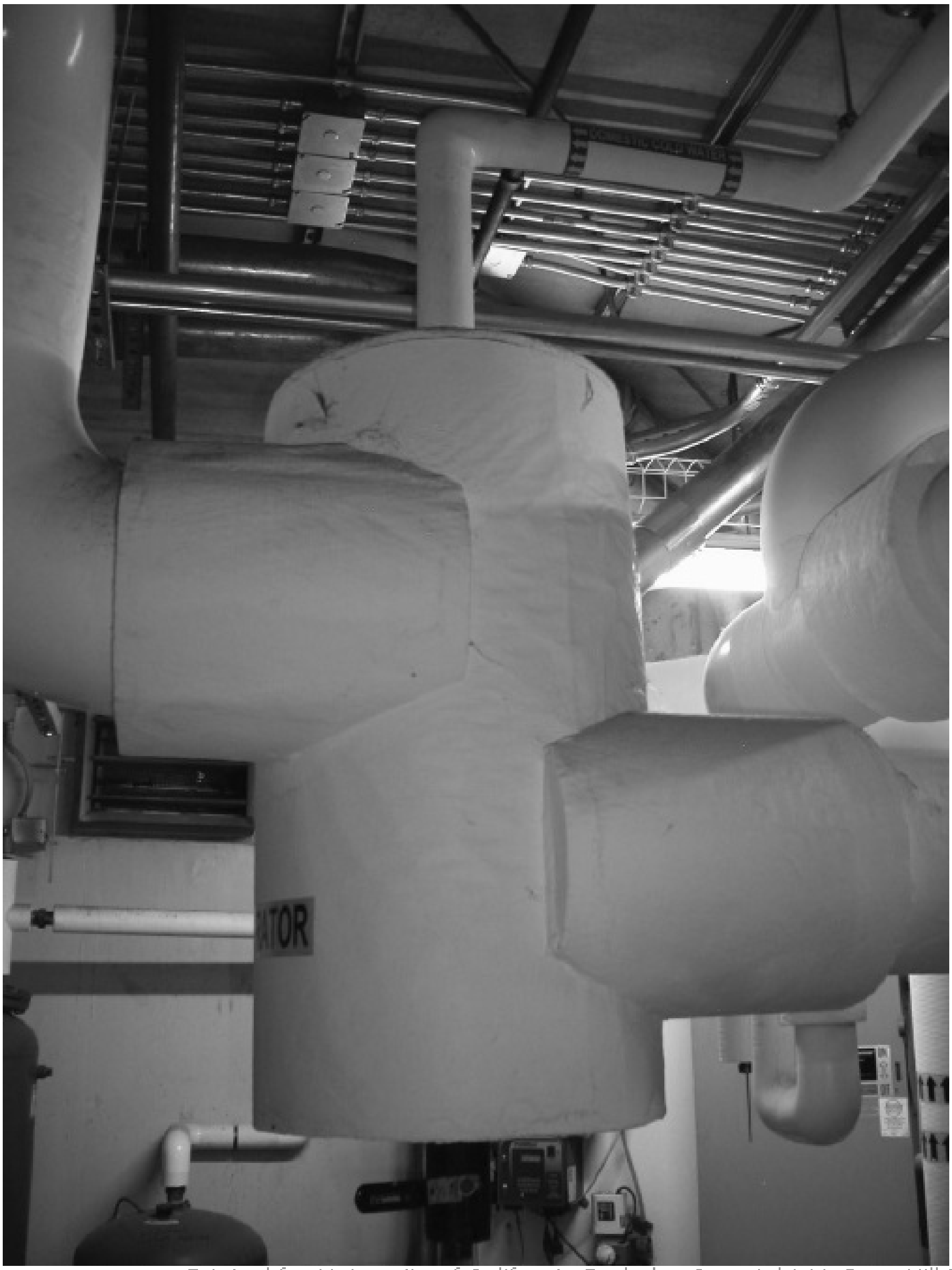


Figure 19.30. PHOTOGRAPH OF AN AIR SEPARATOR.

EXPANSION TANK SIZING—LOW TEMPERATURE SYSTEMS

Tank Size Expressed as a Percentage of System Volume

Maximum System Temperature °F	**Expansion Tank Type**			
			Diaphragm Tank	
	Closed Tank	**Open Tank**	**Tank Volume**	**Acceptance Volume**
100	2.21	1.37	1.32	0.59
[illegible]	3.08	1.87	1.83	0.82

Notes:

Maximum System Temperature °F	Tank Size Expressed as a Percentage of System Volume			
	Expansion Tank Type			
	Closed Tank	Open Tank	Diaphragm Tank	
			Tank Volume	Acceptance Volume
120	3.71	2.24	2.21	0.99
130	4.81	2.87	2.86	1.28
140	5.67	3.37	3.37	1.51
150	6.77	3.99	4.03	1.80
160	7.87	4.61	4.68	2.10
170	9.20	5.36	5.48	2.45
180	10.53	6.11	6.27	2.81
190	11.87	6.86	7.06	3.16
200	13.20	7.61	7.86	3.52
210	14.77	–	8.79	3.93
220	16.34	–	9.72	4.35
230	17.90	–	10.66	4.77
240	19.71	–	11.73	5.25
250	21.51	–	12.80	5.73

Notes:

1. ***Table based on initial temperature: 50°F.***
2. ***Table based on initial pressure: 10 psig.***
3. ***Table based on maximum operating pressure: 30 psig.***
4. ***For initial and maximum pressures different than those listed above, multiply the tank size only (not the Acceptance Volume) by correction factors contained in the Low Temperature System Correction Factor tables that follow.***

CLOSED EXPANSION TANK SIZING LOW TEMPERATURE SYSTEM CORRECTION FACTORS

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increas Maximum Operating Pressure								
	5	10	15	20	25	30	35	40	45

Notes:

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure								
	5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**
5	1.76	1.06	0.83	0.71	0.64	0.59	0.56	0.53	0.51
10	2.66	1.55	1.18	**1.00**	0.89	0.82	0.76	0.72	0.69
15	3.73	2.14	1.60	1.34	1.18	1.07	0.99	0.94	0.89
20	4.99	2.81	2.08	1.72	1.50	1.36	1.25	1.17	1.11
25	6.43	3.57	2.62	2.15	1.86	1.67	1.53	1.43	1.35
30	8.05	4.43	3.22	2.62	2.26	2.02	1.84	1.71	1.61
35	9.85	5.37	3.88	3.14	2.69	2.39	2.18	2.02	1.89
40	11.83	6.41	4.60	3.70	3.16	2.80	2.54	2.35	2.20
45	13.99	7.54	5.39	4.31	3.66	3.23	2.93	2.70	2.52
50	16.34	8.75	6.23	4.96	4.21	3.70	3.34	3.07	2.86
55	18.86	10.06	7.13	5.66	4.78	4.20	3.78	3.46	3.22
60	21.57	11.46	8.09	6.41	5.40	4.72	4.24	3.88	3.60
65	24.46	12.95	9.11	7.20	6.05	5.28	4.73	4.32	4.00
70	27.53	14.53	10.20	8.03	6.73	5.87	5.25	4.78	4.42
75	30.77	16.20	11.34	8.91	7.45	6.48	5.79	5.27	4.86
80	34.21	17.96	12.55	9.84	8.21	7.13	6.36	5.78	5.33
85	37.82	19.81	13.81	10.81	9.01	7.81	6.95	6.31	5.81
90	41.61	21.75	15.13	11.83	9.84	8.52	7.57	6.86	6.31
95	45.59	23.79	16.52	12.89	10.71	9.25	8.22	7.44	6.83
100	49.74	25.91	17.97	13.99	11.61	10.02	8.89	8.04	7.37

Notes:

1. ***Table based on initial temperature: 50°F.***
2. ***Table based on initial pressure: 200 psig.***
3. ***Table based on maximum operating pressure: 300 psig.***

CLOSED EXPANSION TANK SIZING LOW TEMPERATURE SYSTEM CORRECTION FACTORS

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	55	60	65	70	75	80	85	90	95	100
5	0.48	0.47	0.47	0.46	0.45	0.44	0.44	0.43	0.43	0.43
10	0.65	0.63	0.62	0.61	0.59	0.59	0.58	0.57	0.56	0.56
15	0.83	0.80	0.78	0.77	0.75	0.74	0.73	0.72	0.71	0.70
20	1.03	0.99	0.96	0.94	0.92	0.90	0.89	0.87	0.86	0.85
25	1.24	1.19	1.16	1.13	1.10	1.08	1.06	1.04	1.02	1.00
30	1.47	1.41	1.37	1.33	1.29	1.26	1.24	1.21	1.19	1.17
35	1.71	1.65	1.59	1.54	1.50	1.46	1.43	1.40	1.37	1.35
40	1.98	1.89	1.82	1.77	1.71	1.67	1.63	1.59	1.56	1.53
45	2.26	2.16	2.07	2.00	1.94	1.89	1.84	1.80	1.76	1.73
50	2.55	2.44	2.34	2.26	2.18	2.12	2.06	2.01	1.97	1.93
55	2.86	2.73	2.62	2.52	2.44	2.36	2.30	2.24	2.19	2.14
60	3.19	3.04	2.91	2.80	2.70	2.62	2.54	2.48	2.42	2.36
65	3.54	3.36	3.21	3.09	2.98	2.88	2.80	2.72	2.65	2.59
70	3.90	3.70	3.53	3.39	3.27	3.16	3.06	2.98	2.90	2.83
75	4.27	4.05	3.87	3.71	3.57	3.45	3.34	3.24	3.16	3.08
80	4.67	4.42	4.21	4.04	3.88	3.75	3.63	3.52	3.43	3.34
85	5.08	4.81	4.58	4.38	4.21	4.06	3.92	3.81	3.70	3.61
90	5.51	5.21	4.95	4.73	4.54	4.38	4.23	4.10	3.99	3.88
95	5.95	5.62	5.34	5.10	4.89	4.71	4.55	4.41	4.28	4.17
100	6.41	6.05	5.74	5.48	5.26	5.06	4.88	4.73	4.59	4.46

Notes:

1. **Table based on initial temperature: 50°F.**
2. **Table based on initial pressure: 10 psig.**
3. **Table based on maximum operating pressure: 30 psig.**

DIAPHRAGM EXPANSION TANK SIZING LOW TEMPERATURE SYSTEM CORRECTION FACTORS

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	5	10	15	20	25	30	35	40	45	50
5	2.21	1.33	1.04	0.89	0.80	0.74	0.70	0.67	0.64	0.6
10	2.66	1.55	1.18	**1.00**	0.89	0.82	0.76	0.72	0.69	0.6
15	3.11	1.78	1.33	1.11	0.98	0.89	0.83	0.78	0.74	0.7
20	3.55	2.00	1.48	1.22	1.07	0.96	0.89	0.84	0.79	0.7
25	4.00	2.22	1.63	1.34	1.16	1.04	0.95	0.89	0.84	0.8
30	4.45	2.45	1.78	1.45	1.25	1.11	1.02	0.95	0.89	0.8
35	4.89	2.67	1.93	1.56	1.34	1.19	1.08	1.00	0.94	0.8
40	5.34	2.89	2.08	1.67	1.43	1.26	1.15	1.06	0.99	0.9
45	5.79	3.12	2.23	1.78	1.52	1.34	1.21	1.12	1.04	0.9
50	6.24	3.34	2.38	1.89	1.61	1.41	1.27	1.17	1.09	1.0
55	6.68	3.57	2.53	2.01	1.69	1.49	1.34	1.23	1.14	1.0
60	7.13	3.79	2.68	2.12	1.78	1.56	1.40	1.28	1.19	1.1
65	7.58	4.01	2.82	2.23	1.87	1.64	1.47	1.34	1.24	1.1
70	8.03	4.24	2.97	2.34	1.96	1.71	1.53	1.39	1.29	1.2
75	8.47	4.46	3.12	2.45	2.05	1.79	1.59	1.45	1.34	1.2
80	8.92	4.68	3.27	2.57	2.14	1.86	1.66	1.51	1.39	1.2
85	9.37	4.91	3.42	2.68	2.23	1.93	1.72	1.56	1.44	1.3
90	9.82	5.13	3.57	2.79	2.32	2.01	1.79	1.62	1.49	1.3
95	10.26	5.36	3.72	2.90	2.41	2.08	1.85	1.67	1.54	1.4
100	10.71	5.58	3.87	3.01	2.50	2.16	1.91	1.73	1.59	1.4

Notes:

1. **Table based on initial temperature: 50°F.**

2. Table based on initial pressure: 10 psig.

3. Table based on maximum operating pressure: 30 psig.

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure								
	5	10	15	20	25	30	35	40	45	5(

DIAPHRAGM EXPANSION TANK SIZING LOW TEMPERATURE SYSTEM CORRECTION FACTORS

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	55	60	65	70	75	80	85	90	95	100
5	0.61	0.59	0.58	0.57	0.56	0.56	0.55	0.55	0.54	0.54
10	0.65	0.63	0.62	0.61	0.59	0.59	0.58	0.57	0.56	0.56
15	0.69	0.67	0.65	0.64	0.62	0.61	0.60	0.60	0.59	0.58
20	0.73	0.71	0.69	0.67	0.65	0.64	0.63	0.62	0.61	0.60
25	0.77	0.74	0.72	0.70	0.68	0.67	0.66	0.64	0.63	0.63
30	0.81	0.78	0.76	0.73	0.71	0.70	0.68	0.67	0.66	0.65
35	0.85	0.82	0.79	0.77	0.74	0.73	0.71	0.69	0.68	0.67
40	0.89	0.86	0.82	0.80	0.77	0.75	0.74	0.72	0.71	0.69
45	0.93	0.89	0.86	0.83	0.80	0.78	0.76	0.74	0.73	0.71
50	0.97	0.93	0.89	0.86	0.83	0.81	0.79	0.77	0.75	0.74
55	1.01	0.97	0.93	0.89	0.86	0.84	0.81	0.79	0.78	0.76
60	1.06	1.00	0.96	0.92	0.89	0.87	0.84	0.82	0.80	0.78
65	1.10	1.04	1.00	0.96	0.92	0.89	0.87	0.84	0.82	0.80
70	1.14	1.08	1.03	0.99	0.95	0.92	0.89	0.87	0.85	0.83
75	1.18	1.12	1.06	1.02	0.98	0.95	0.92	0.89	0.87	0.85
80	1.22	1.15	1.10	1.05	1.01	0.98	0.95	0.92	0.89	0.87
85	1.26	1.19	1.13	1.08	1.04	1.01	0.97	0.94	0.92	0.89
90	1.30	1.23	1.17	1.12	1.07	1.03	1.00	0.97	0.94	0.92
95	1.34	1.27	1.20	1.15	1.10	1.06	1.02	0.99	0.96	0.94

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	55	60	65	70	75	80	85	90	95	100
100	1.38	1.30	1.24	1.18	1.13	1.09	1.05	1.02	0.99	0.96

Notes:

1. **Table based on initial temperature: 50°F.**
2. **Table based on initial pressure: 10 psig.**
3. **Table based on maximum operating pressure: 30 psig.**

EXPANSION TANK SIZING—MEDIUM TEMPERATURE SYSTEMS

Tank Size Expressed as a Percentage of System Volume

Maximum System Temperature °F	Expansion Tank Type			
	Closed Tank	Open Tank	Diaphragm Tank	
			Tank Volume	Acceptance Volume
250	263.25	–	18.02	5.73
260	285.30	–	19.53	6.21
270	310.23	–	21.24	6.75
280	335.16	–	22.95	7.29
290	360.08	–	24.65	7.83
300	387.88	–	26.56	8.44
310	415.67	–	28.46	9.04
320	443.47	–	30.36	9.65
330	474.13	–	32.46	10.32
340	504.80	–	34.56	10.98
350	538.33	–	36.86	11.71

Notes:

1. **Table based on initial temperature: 50°F.**
2. **Table based on initial pressure: 200 psig.**
3. **Table based on maximum operating pressure: 300 psig.**
4. **For initial and maximum pressures different than those listed above, multiply the tank size only (not the Acceptance Volume) by correction factors contained in the Medium Temperature System Correction Factor tables that follow.**

CLOSED EXPANSION TANK SIZING MEDIUM TEMPERATURE SYSTEM CORRECTION FACTORS

Initial Pressure	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	10	20	30	40	50	60	70	80	90	10
30	0.36	0.21	0.16	0.14	0.13	0.12	0.11	0.10	0.10	0.1
40	0.52	0.30	0.23	0.19	0.17	0.15	0.14	0.14	0.13	0.1
50	072	0.41	0.30	0.25	0.22	0.20	0.18	0.17	0.16	0.1
60	0.94	0.52	0.39	0.32	0.28	0.25	0.23	0.21	0.20	0.1
70	1.19	0.66	0.48	0.39	0.34	0.30	0.28	0.26	0.24	0.2
80	1.47	0.80	0.58	0.47	0.41	0.36	0.33	0.31	0.29	0.2
90	1.78	0.97	0.70	0.56	0.48	0.43	0.39	0.36	0.34	0.3
100	2.12	1.14	0.82	0.66	0.56	0.49	0.45	0.41	0.39	0.3
110	2.49	1.34	0.95	0.76	0.64	0.57	0.51	0.47	0.44	0.4
120	2.88	1.54	1.09	0.87	0.74	0.65	0.58	0.54	0.50	0.4
130	3.31	1.76	1.25	0.99	0.83	0.73	0.66	0.60	0.56	0.5
140	3.77	2.00	1.41	1.11	0.94	0.82	0.73	0.67	0.62	0.5
150	4.26	2.25	1.58	1.25	1.05	0.91	0.82	0.75	0.69	0.6
160	4.78	2.52	1.76	1.39	1.16	1.01	0.90	0.82	0.76	0.7
170	5.32	2.80	1.96	1.54	1.28	1.11	0.99	0.90	0.83	0.7
180	5.90	3.09	2.16	1.69	1.41	1.22	1.09	0.99	0.91	0.8
190	6.50	3.40	2.37	1.85	1.54	1.34	1.19	1.08	0.99	.92
200	7.14	3.73	2.59	2.02	1.68	1.45	1.29	1.17	1.08	1.0
210	7.81	4.07	2.82	2.20	1.83	1.58	1.40	1.27	1.16	1.0
220	8.50	4.42	3.06	2.39	1.98	1.71	1.51	1.37	1.25	1.1
230	9.22	4.79	3.32	2.58	2.13	1.84	1.63	1.47	1.35	1.2
240	9.98	5.18	3.58	2.78	2.30	1.98	1.75	1.58	1.44	1.3
250	10.76	5.58	3.85	2.98	2.47	2.12	1.87	1.69	1.54	1.4
260	11.57	5.99	4.13	3.20	2.64	2.27	2.00	1.80	1.65	1.5

Notes:

1. Table based on initial temperature: 50°F.

2. Table based on initial pressure: 200 psig.
3. Table based on maximum operating pressure: 300 psig.

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	10	20	30	40	50	60	70	80	90	100

CLOSED EXPANSION TANK SIZING MEDIUM TEMPERATURE SYSTEM CORRECTION FACTORS

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	110	120	130	140	150	160	170	180	190	200
30	0.09	0.09	0.09	0.09	0.09	0.08	0.08	0.08	0.08	0.08
40	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.10	0.10
50	0.15	0.15	0.14	0.14	0.14	0.13	0.13	0.13	0.13	0.13
60	0.19	0.18	0.17	0.17	0.17	0.16	0.16	0.16	0.15	0.15
70	0.22	0.21	0.21	0.20	0.20	0.19	0.19	0.18	0.18	0.18
80	0.26	0.25	0.24	0.23	0.23	0.22	0.22	0.21	0.21	0.21
90	0.30	0.29	0.28	0.27	0.26	0.26	0.25	0.25	0.24	0.24
100	0.35	0.33	0.32	0.31	0.30	0.29	0.28	0.28	0.27	0.27
110	0.39	0.38	0.36	0.35	0.34	0.33	0.32	0.31	0.31	0.30
120	0.44	0.42	0.41	0.39	0.38	0.37	0.36	0.35	0.34	0.33
130	0.50	0.47	0.45	0.44	0.42	0.41	0.40	0.39	0.38	0.37
140	0.55	0.52	0.50	0.48	0.47	0.45	0.44	0.43	0.42	0.41
150	0.61	0.58	0.55	0.53	0.51	0.49	0.48	0.47	0.46	0.44
160	0.67	0.63	0.61	0.58	0.56	0.54	0.52	0.51	0.50	0.48
170	0.73	0.69	0.66	0.63	0.61	0.59	0.57	0.55	0.54	0.53
180	0.80	0.76	0.72	0.69	0.66	0.64	0.62	0.60	0.58	0.57
190	0.87	0.82	0.78	0.75	0.72	0.69	0.67	0.65	0.63	0.61
200	0.94	0.89	0.84	0.81	0.77	0.74	0.72	0.70	0.68	0.66
210	1.01	0.96	0.91	0.87	0.83	0.80	0.77	0.75	0.73	0.71
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	110	120	130	140	150	160	170	180	190	200
220	1.09	1.03	0.97	0.93	0.89	0.86	0.83	0.80	0.78	0.75
230	1.17	1.10	1.04	1.00	0.95	0.92	0.88	0.85	0.83	0.81
240	1.25	1.18	1.12	1.06	1.02	0.98	0.94	0.91	0.88	0.86
250	1.33	1.26	1.19	1.13	1.08	1.04	1.00	0.97	0.94	0.91
260	1.42	1.34	1.27	1.20	1.15	1.10	1.06	1.03	0.99	0.96

Notes:

1. **Table based on initial temperature: 50°F.**
2. **Table based on initial pressure: 200 psig.**
3. **Table based on maximum operating pressure: 300 psig.**

DIAPHRAGM EXPANSION TANK SIZING MEDIUM TEMPERATURE SYSTEM CORRECTION FACTORS

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	10	20	30	40	50	60	70	80	90	100
30	1.74	1.03	0.79	0.67	0.60	0.55	0.52	0.50	0.48	0.46
40	2.06	1.19	0.90	0.75	0.67	0.61	0.57	0.54	0.51	0.49
50	2.37	1.35	1.00	0.83	0.73	0.66	0.61	0.57	0.55	0.52
60	2.69	1.50	1.11	0.91	0.79	0.71	0.66	0.61	0.58	0.56
70	3.01	1.66	1.21	0.99	0.86	0.77	0.70	0.65	0.62	0.59
80	3.33	1.82	1.32	1.07	0.92	0.82	0.75	0.69	0.65	0.62
90	3.64	1.98	1.43	1.15	0.98	0.87	0.79	0.73	0.69	0.65
100	3.96	2.14	1.53	1.23	1.05	0.93	0.84	0.77	0.72	0.68
110	4.28	2.30	1.64	1.31	1.11	0.98	0.88	0.81	0.76	0.71
120	4.60	2.46	1.74	1.39	1.17	1.03	0.93	0.85	0.79	0.75
130	4.92	2.62	1.85	1.47	1.24	1.08	0.97	0.89	0.83	0.78
140	5.23	2.78	1.96	1.55	1.30	1.14	1.02	0.93	0.86	0.81
150	5.55	2.93	2.06	1.63	1.36	1.19	1.07	0.97	0.90	0.84

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	10	20	30	40	50	60	70	80	90	100
150	5.55	2.93	2.06	1.63	1.36	1.19	1.07	0.97	0.90	0.84
160	5.87	3.09	2.17	1.71	1.43	1.24	1.11	1.01	0.93	0.87
170	6.19	3.25	2.27	1.79	1.49	1.30	1.16	1.05	0.97	0.90
180	6.50	3.41	2.38	1.86	1.56	1.35	1.20	1.09	1.01	0.94
190	6.82	3.57	2.49	1.94	1.62	1.40	1.25	1.13	1.04	0.97
200	7.14	3.73	2.59	2.02	1.68	1.45	1.29	1.17	1.08	**1.00**
210	7.46	3.89	2.70	2.10	1.75	1.51	1.34	1.21	1.11	1.03
220	7.78	4.05	2.80	2.18	1.81	1.56	1.38	1.25	1.15	1.06
230	8.09	4.21	2.91	2.26	1.87	1.61	1.43	1.29	1.18	1.10
240	8.41	4.36	3.02	2.34	1.94	1.67	1.47	1.33	1.22	1.13
250	8.73	4.52	3.12	2.42	2.00	1.72	1.52	1.37	1.25	1.16
260	9.05	4.68	3.23	2.50	2.06	1.77	1.56	1.41	1.29	1.19

Notes:

1. **Table based on initial temperature: 50°F.**
2. **Table based on initial pressure: 200 psig.**
3. **Table based on maximum operating pressure: 300 psig.**

DIAPHRAGM EXPANSION TANK SIZING MEDIUM TEMPERATURE SYSTEM CORRECTION FACTORS

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	110	120	130	140	150	160	170	180	190	200
30	0.45	0.44	0.43	0.42	0.41	0.41	0.40	0.40	0.39	0.39
40	0.48	0.46	0.45	0.44	0.43	0.43	0.42	0.41	0.41	0.40
50	0.50	0.49	0.48	0.46	0.45	0.45	0.44	0.43	0.43	0.42
60	0.53	0.52	0.50	0.49	0.48	0.47	0.46	0.45	0.44	0.44
70	0.56	0.54	0.52	0.51	0.50	0.49	0.48	0.47	0.46	0.45
80	0.59	0.57	0.55	0.53	0.52	0.51	0.49	0.48	0.48	0.47

Notes:

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	110	120	130	140	150	160	170	180	190	200
80	0.59	0.57	0.55	0.53	0.52	0.51	0.49	0.48	0.48	0.47
90	0.62	0.60	0.57	0.56	0.54	0.53	0.51	0.50	0.49	0.48
100	0.65	0.62	0.60	0.58	0.56	0.55	0.53	0.52	0.51	0.50
110	0.68	0.65	0.62	0.60	0.58	0.57	0.55	0.54	0.53	0.52
120	0.71	0.67	0.65	0.62	0.60	0.59	0.57	0.56	0.54	0.53
130	0.74	0.70	0.67	0.65	0.62	0.61	0.59	0.57	0.56	0.55
140	0.76	0.73	0.70	0.67	0.65	0.63	0.61	0.59	0.58	0.56
150	0.79	0.75	0.72	0.69	0.67	0.64	0.63	0.61	0.59	0.58
160	0.82	0.78	0.74	0.71	0.69	0.66	0.64	0.63	0.61	0.60
170	0.85	0.81	0.77	0.74	0.71	0.68	0.66	0.64	0.63	0.61
180	0.88	0.83	0.79	0.76	0.73	0.70	0.68	0.66	0.64	0.63
190	0.91	0.86	0.82	0.78	0.75	0.72	0.70	0.68	0.66	0.64
200	0.94	0.89	0.84	0.81	0.77	0.74	0.72	0.70	0.68	0.66
210	0.97	0.91	0.87	0.83	0.79	0.76	0.74	0.71	0.69	0.67
220	1.00	0.94	0.89	0.85	0.81	0.78	0.76	0.73	0.71	0.69
230	1.02	0.97	0.92	0.87	0.84	0.80	0.78	0.75	0.73	0.71
240	1.05	0.99	0.94	0.90	0.86	0.82	0.79	0.77	0.74	0.72
250	1.08	1.02	0.96	0.92	0.88	0.84	0.81	0.79	0.76	0.74
260	1.11	1.05	0.99	0.94	0.90	0.86	0.83	0.80	0.78	0.75

Notes:

1. **Table based on initial temperature: 50°F.**
2. **Table based on initial pressure: 200 psig.**
3. **Table based on maximum operating pressure: 300 psig.**

EXPANSION TANK SIZING—HIGH TEMPERATURE SYSTEMS

Tank Sized Expressed as a Percentage of System Volume

Maximum System Temperature °F	Expansion Tank Type			
			Diaphragm Tank	
	Closed Tank	Open Tank	Tank Volume	Acceptance Volume
350	1,995.03	–	47.71	11.71
360	2,119.30	–	50.68	12.44
370	2,243.58	–	53.65	13.17
380	2,378.48	–	56.88	13.96
390	2,524.02	–	60.36	14.82
400	2,669.56	–	63.84	15.67
410	2,815.10	–	67.32	16.53
420	2,981.90	–	71.31	17.51
430	3,138.07	–	75.04	18.42
440	3,315.51	–	79.29	19.46
450	3,492.95	–	83.53	20.51

Notes:

1. **Table based on initial temperature: 50°F.**
2. **Table based on initial pressure: 600 psig.**
3. **Table based on maximum operating pressure: 800 psig.**
4. **For initial and maximum pressures different than those listed above, multiply the tank size (the Acceptance Volume) by correction factors contained in the High Temperature System Correction Factor tables that follow.**

CLOSED EXPANSION TANK SIZING HIGH TEMPERATURE SYSTEM CORRECTION FACTORS

Initial Pressure	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure								
	20	**40**	**60**	**80**	**100**	**120**	**140**	**160**	**180**	**20**
160	0.68	0.37	0.27	0.22	0.19	0.17	0.16	0.15	0.14	0.1
180	0.83	0.46	0.33	0.27	0.23	0.20	0.19	0.17	0.16	0.1
200	1.01	0.55	0.39	0.32	0.27	0.24	0.22	0.20	0.19	0.1
220	1.19	0.64	0.46	0.37	0.31	0.28	0.25	0.23	0.22	0.2
240	1.40	0.75	0.53	0.43	0.36	0.32	0.29	0.26	0.25	0.2
260	1.62	0.86	0.61	0.49	0.41	0.36	0.32	0.30	0.28	0.2
280	1.85	0.98	0.70	0.55	0.46	0.41	0.37	0.33	0.31	0.2
300	2.10	1.11	0.78	0.62	0.52	0.46	0.41	0.37	0.35	0.3
320	2.37	1.25	0.88	0.69	0.58	0.51	0.45	0.41	0.38	0.3
340	2.65	1.40	0.98	0.77	0.64	0.56	0.50	0.46	0.42	0.3
360	2.95	1.55	1.08	0.85	0.71	0.62	0.55	0.50	0.46	0.4
380	3.27	1.71	1.19	0.94	0.78	0.68	0.60	0.55	0.50	0.4
400	3.60	1.88	1.31	1.02	0.85	0.74	0.66	0.59	0.55	0.5
420	3.95	2.06	1.43	1.12	0.93	0.80	0.71	0.65	0.59	0.5
440	4.31	2.25	1.56	1.21	1.01	0.87	0.77	0.70	0.64	0.5
460	4.69	2.44	1.69	1.31	1.09	0.94	0.83	0.75	0.69	0.6
480	5.08	2.64	1.83	1.42	1.17	1.01	0.90	0.81	0.74	0.6
500	5.50	2.85	1.97	1.53	1.26	1.09	0.96	0.87	0.79	0.7
520	5.92	3.07	2.12	1.64	1.36	1.17	1.03	0.93	0.85	0.7
540	6.37	3.29	2.27	1.76	1.45	1.25	1.10	0.99	0.90	0.8
560	6.82	3.53	2.43	1.88	1.55	1.33	1.17	1.05	0.96	0.8
580	7.30	3.77	2.59	2.00	1.65	1.41	1.25	1.12	1.02	0.9
600	7.79	4.02	2.76	2.13	1.75	1.50	1.32	1.19	1.08	**1.0**
620	8.30	4.28	2.93	2.26	1.86	1.59	1.40	1.26	1.15	1.0
640	8.82	4.54	3.11	2.40	1.97	1.69	1.48	1.33	1.21	1.1
660	9.36	4.81	3.30	2.54	2.09	1.78	1.57	1.41	1.28	1.1

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	20	40	60	80	100	120	140	160	180	20
680	9.91	5.10	3.49	2.69	2.20	1.88	1.65	1.48	1.35	1.2
700	10.49	5.39	3.69	2.84	2.33	1.99	1.74	1.56	1.42	1.3

Notes:

1. **Table based on initial temperature: 50°F.**
2. **Table based on initial pressure: 600 psig.**
3. **Table based on maximum operating pressure: 800 psig.**

CLOSED EXPANSION TANK SIZING HIGH TEMPERATURE SYSTEM CORRECTION FACTORS

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	220	240	260	280	300	320	340	360	380	400
160	0.13	0.12	0.12	0.11	0.11	0.11	0.11	0.10	0.10	0.10
180	0.15	0.14	0.14	0.13	0.13	0.13	0.12	0.12	0.12	0.12
200	0.17	0.16	0.16	0.15	0.15	0.14	0.14	0.14	0.13	0.13
220	0.19	0.19	0.18	0.17	0.17	0.16	0.16	0.15	0.15	0.15
240	0.22	0.21	0.20	0.19	0.19	0.18	0.18	0.17	0.17	0.17
260	0.25	0.24	0.23	0.22	0.21	0.20	0.20	0.19	0.19	0.19
280	0.28	0.26	0.25	0.24	0.23	0.23	0.22	0.21	0.21	0.20
300	0.31	0.29	0.28	0.27	0.26	0.25	0.24	0.24	0.23	0.22
320	0.34	0.32	0.31	0.29	0.28	0.27	0.27	0.26	0.25	0.25
340	0.37	0.35	0.33	0.32	0.31	0.30	0.29	0.28	0.27	0.27
360	0.40	0.38	0.37	0.35	0.34	0.32	0.31	0.31	0.30	0.29
380	0.44	0.42	0.40	0.38	0.37	0.35	0.34	0.33	0.32	0.31
400	0.48	0.45	0.43	0.41	0.39	0.38	0.37	0.36	0.35	0.34
420	0.52	0.49	0.46	0.44	0.43	0.41	0.40	0.38	0.37	0.36
440	0.56	0.53	0.50	0.48	0.46	0.44	0.42	0.41	0.40	0.39

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	220	240	260	280	300	320	340	360	380	400
460	0.60	0.56	0.54	0.51	0.49	0.47	0.45	0.44	0.43	0.41
480	0.64	0.60	0.57	0.55	0.52	0.50	0.49	0.47	0.45	0.44
500	0.69	0.65	0.61	0.58	0.56	0.54	0.52	0.50	0.48	0.47
520	0.73	0.69	0.65	0.62	0.59	0.57	0.55	0.53	0.51	0.50
540	0.78	0.73	0.69	0.66	0.63	0.61	0.58	0.56	0.54	0.53
560	0.83	0.78	0.74	0.70	0.67	0.64	0.62	0.60	0.58	0.56
580	0.88	0.83	0.78	0.74	0.71	0.68	0.65	0.63	0.61	0.59
600	0.93	0.87	0.83	0.78	0.75	0.72	0.69	0.66	0.64	0.62
620	0.98	0.92	0.87	0.83	0.79	0.76	0.73	0.70	0.68	0.66
640	1.04	0.97	0.92	0.87	0.83	0.80	0.76	0.74	0.71	0.69
660	1.10	1.03	0.97	0.92	0.88	0.84	0.80	0.77	0.75	0.72
680	1.15	1.08	1.02	0.97	0.92	0.88	0.84	0.81	0.78	0.76
700	1.21	1.14	1.07	1.01	0.87	0.92	0.89	0.85	0.82	0.80

Notes:

1. **Table based on initial temperature: 50°F.**
2. **Table based on initial pressure: 600 psig.**
3. **Table based on maximum operating pressure: 800 psig.**

DIAPHRAGM EXPANSION TANK SIZING HIGH TEMPERATURE SYSTEM CORRECTION FACTORS

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	20	40	60	80	100	120	140	160	180	200
160	2.39	1.32	0.96	0.78	0.67	0.60	0.55	0.51	0.48	0.46
180	2.64	1.44	1.04	0.84	0.72	0.64	0.59	0.54	0.51	0.48
200	2.88	1.56	1.12	0.90	0.77	0.68	0.62	0.57	0.54	0.51
220	3.13	1.69	1.21	0.97	0.82	0.73	0.66	0.61	0.57	0.53
240	3.37	1.81	1.29	1.03	0.87	0.77	0.69	0.64	0.59	0.56

Notes:

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	20	40	60	80	100	120	140	160	180	200
240	3.37	1.81	1.29	1.03	0.87	0.77	0.69	0.64	0.59	0.56
260	3.62	1.93	1.37	1.09	0.92	0.81	0.73	0.67	0.62	0.58
280	3.86	2.05	1.45	1.15	0.97	0.85	0.76	0.70	0.65	0.61
300	4.11	2.18	1.53	1.21	1.02	0.89	0.80	0.73	0.67	0.63
320	4.35	2.30	1.61	1.27	1.07	0.93	0.83	0.76	0.70	0.66
340	4.60	2.42	1.70	1.33	1.12	0.97	0.87	0.79	0.73	0.68
360	4.84	2.55	1.78	1.40	1.17	1.01	0.90	0.82	0.76	0.71
380	5.09	2.67	1.86	1.46	1.21	1.05	0.94	0.85	0.78	0.73
400	5.34	2.79	1.94	1.52	1.26	1.09	0.97	0.88	0.81	0.75
420	5.58	2.91	2.02	1.58	1.31	1.13	1.01	0.91	0.84	0.78
440	5.83	3.04	2.11	1.64	1.36	1.18	1.04	0.94	0.87	0.80
460	6.07	3.16	2.19	1.70	1.41	1.22	1.08	0.97	0.89	0.83
480	6.32	3.28	2.27	1.76	1.46	1.26	1.11	1.00	0.92	0.85
500	6.56	3.40	2.35	1.82	1.51	1.30	1.15	1.04	0.95	0.88
520	6.81	3.53	2.43	1.89	1.56	1.34	1.18	1.07	0.97	0.90
540	7.05	3.65	2.52	1.95	1.61	1.38	1.22	1.10	1.00	0.93
560	7.30	3.77	2.60	2.01	1.66	1.42	1.25	1.13	1.03	0.95
580	7.55	3.90	2.68	2.07	1.71	1.46	1.29	1.16	1.06	0.98
600	7.79	4.02	2.76	2.13	1.75	1.50	1.32	1.19	1.08	1.00
620	8.04	4.14	2.84	2.19	1.80	1.54	1.36	1.22	1.11	1.02
640	8.28	4.26	2.92	2.25	1.85	1.58	1.39	1.25	1.14	1.05
660	8.53	4.39	3.01	2.32	1.90	1.63	1.43	1.28	1.17	1.07
680	8.77	4.51	3.09	2.38	1.95	1.67	1.46	1.31	1.19	1.10
700	9.02	4.63	3.17	2.44	2.00	1.71	1.50	1.34	1.22	1.12

Notes:

1. Table based on initial temperature: 50°F.

2. Table based on initial pressure: 600 psig.

3. Table based on maximum operating pressure: 800 psig.

Initial	Pressure Increase—psig Initial Pressure + Pressure Increase

DIAPHRAGM EXPANSION TANK SIZING HIGH TEMPERATURE SYSTEM CORRECTION FACTORS

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	220	240	260	280	300	320	340	360	380	400
160	0.44	0.42	0.41	0.40	0.39	0.38	0.37	0.36	0.36	0.35
180	0.46	0.44	0.43	0.42	0.40	0.39	0.39	0.38	0.37	0.36
200	0.49	0.47	0.45	0.43	0.42	0.41	0.40	0.39	0.38	0.38
220	0.51	0.49	0.47	0.45	0.44	0.43	0.41	0.41	0.40	0.39
240	0.53	0.51	0.49	0.47	0.45	0.44	0.43	0.42	0.41	0.40
260	0.55	0.53	0.50	0.49	0.47	0.46	0.44	0.43	0.42	0.41
280	0.57	0.55	0.52	0.50	0.49	0.47	0.46	0.45	0.44	0.43
300	0.60	0.57	0.54	0.52	0.50	0.49	0.47	0.46	0.45	0.44
320	0.62	0.59	0.56	0.54	0.52	0.50	0.49	0.47	0.46	0.45
340	0.64	0.61	0.58	0.56	0.54	0.52	0.50	0.49	0.47	0.46
360	0.66	0.63	0.60	0.57	0.55	0.53	0.52	0.50	0.49	0.48
380	0.69	0.65	0.62	0.59	0.57	0.55	0.53	0.51	0.50	0.49
400	0.71	0.67	0.64	0.61	0.58	0.56	0.54	0.53	0.51	0.50
420	0.73	0.69	0.66	0.63	0.60	0.58	0.56	0.54	0.53	0.51
440	0.75	0.71	0.67	0.64	0.62	0.59	0.57	0.56	0.54	0.52
460	0.78	0.73	0.69	0.66	0.63	0.61	0.59	0.57	0.55	0.54
480	0.80	0.75	0.71	0.68	0.65	0.63	0.60	0.58	0.57	0.55
500	0.82	0.77	0.73	0.70	0.67	0.64	0.62	0.60	0.58	0.56
520	0.84	0.79	0.75	0.71	0.68	0.66	0.63	0.61	0.59	0.57
540	0.86	0.81	0.77	0.73	0.70	0.67	0.65	0.62	0.60	0.59
560	0.89	0.83	0.79	0.75	0.72	0.69	0.66	0.64	0.62	0.60

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	220	240	260	280	300	320	340	360	380	400
580	0.91	0.85	0.81	0.77	0.73	0.70	0.67	0.65	0.63	0.61
600	0.93	0.87	0.73	0.78	0.75	0.72	0.69	0.66	0.64	0.62
620	0.95	0.89	0.84	0.80	0.76	0.73	0.70	0.68	0.66	0.64
640	0.98	0.92	0.86	0.82	0.78	0.75	0.72	0.69	0.67	0.65
660	1.00	0.94	0.88	0.84	0.80	0.76	0.73	0.71	0.68	0.66
680	1.02	0.96	0.90	0.85	0.81	0.78	0.75	0.72	0.69	0.67
700	1.04	0.98	0.92	0.87	0.83	0.79	0.76	0.73	0.71	0.68

Notes:

1. **Table based on initial temperature: 50°F.**
2. **Table based on initial pressure: 600 psig.**
3. **Table based on maximum operating pressure: 800 psig.**

Part 20: Glycol Piping Systems

20. Part 20: Glycol Piping Systems

20.01. Glycol System Piping

A. **Glycol piping is a special type of hydronic piping.**

B. **Design and sizing of glycol piping systems are identical to chilled water or heating water piping systems, except that the flows are increased to account for the differences in the thermal properties of glycol versus water.**

20.02. Glycol System Design Considerations

A. **HVAC system glycol applications should use an industrial-grade ethylene glycol (phosphate-based) or propylene glycol (phosphate-based) with corrosion inhibitors without fouling. Specify glycol to have *zero* silicate content.**

B. **Automobile antifreeze solutions should *not* be used for HVAC systems because they contain silicates to protect aluminum engine parts. These silicates can cause fouling in HVAC systems.**

C. **Consider having the antifreeze dyed to facilitate leak detection.**

D. **Glycol systems should be filled with a high-quality water, preferably distilled or deionized (deionized is recommended) water, or filled with prediluted solutions of industrial-grade glycol. Water should have less**

than 25 ppm of chloride and sulfate, and less than 50 ppm of hard-water ions (Ca++, Mg++). City water is treated with chlorine, which is corrosive.

E. **Automatic makeup water systems should be avoided to prevent system contamination or system dilution. A low-level liquid alarm should be used in lieu of an automatic fill line.**

F. **Systems should be clean with little or no corrosion.**

G. **Industrial-grade glycol will last up to 20 years in a system if properly maintained.**

H. **Propylene glycol should be used where low oral toxicity is important or where incidental contact with drinking water is possible.**

I. **Expansion tank sizing is critical to the design of glycol systems. The design should allow for a glycol level of about two-thirds full during operation. Glycol will expand about 6 percent.**

J. **Water quality should be analyzed at each site for careful evaluation of the level of corrosion protection required.**

K. **Foaming of a glycol system is usually caused by air entrainment, improper expansion tank design, contamination by organics (oil, gas) or solids, or improper system operation. Foaming will reduce heat transfer and aggravate cavitation corrosion.**

L. **A buffering agent should be added to maintain fluid alkalinity, minimize acidic corrosive attack, and counteract fluid degradation. Proper buffering agents will reduce fluid maintenance, extend fluid life, and be less sensitive to contamination.**

M. **A nonabsorbent bypass filter, of the sock or cartridge variety, should be installed in each glycol system.**

N. **An annual chemical analysis should be conducted to determine the glycol content, oxidative degradation, foaming agent concentration, inhibitor concentration, buffer concentration, freezing point, and pH, reserve alkalinity.**

Ethylene Glycol Characteristics	Propylene Glycol Characteristics
More effective freeze point depression	Less effective freeze point depression
Better heat transfer efficiency	Lower heat transfer efficiency
Lower viscosity	Higher viscosity
Low flammability	Low flammability
Low chemical oxygen demand (more friendly to the environment)	High chemical oxygen demand (less friendly to the environment)
Biodegrades in a reasonable period of time—10–20 days completely	Greater resistance to complete biodegradation—more than 20 days
Noncarcinogenic	Noncarcinogenic
Higher level of acute (short-term) and chronic (long-term) toxicity to humans and animals when taken orally—targets the kidney	Lower level of acute (short-term) and chronic (long-term) toxicity to humans and animals when taken orally
Mild eye irritant	Mild eye irritant
Less irritating to the skin	More irritating to the skin
No adverse reproductive effects in lifetime or three-generation studies	No adverse reproductive effects in lifetime or three-generation studies
At high concentrations during pregnancy will cause birth defects and is toxic to the fetus	At the same concentrations during pregnancy will not cause birth defects
Relatively nontoxic to both sewage microorganisms needed for biodegradation and to aquatic life	Relatively nontoxic to both sewage microorganisms needed for biodegradation and to aquatic life

20.03. Glycol System Equation Factors and Derivations

A. **$H = 500 \times GPM \times \Delta T$**

B. Substitute the equation factors in the following tables for the number 500 in the preceding equation for the ethylene or propylene glycol indicated.

Ethylene Glycol

% Glycol Solution	Temperature °F Freeze Point	Temperature °F Boiling Point	Specific Heat	Specific Gravity (1)	Equation Factor
0	+32	212	1.00	1.000	500
10	+26	214	0.97	1.012	491
20	+16	216	0.94	1.027	483
30	+4	220	0.89	1.040	463
40	–12	222	0.83	1.055	438
50	–34	225	0.78	1.067	416
60	–60	232	0.73	1.079	394
70	<–60	244	0.69	1.091	376
80	–49	258	0.64	1.101	352
90	–20	287	0.60	1.109	333
100	+10	287+	0.55	1.116	307

Notes:

1. **Specific gravity with respect to water at 60 °F.**

Propylene Glycol

% Glycol Solution	Temperature °F		Specific Heat	Specific Gravity (1)	Equation Factor
Freeze Point	Boiling Point				
0	+32	212	1.000	1.000	500
10	+26	212	0.980	1.008	494
20	+19	213	0.960	1.017	488
30	+8	216	0.935	1.026	480
40	–7	219	0.895	1.034	463
50	–28	222	0.850	1.041	442
60	<–60	225	0.805	1.046	421
70	<–60	230	0.750	1.048	393
80	<–60	230+	0.690	1.048	362
90	<–60	230+	0.645	1.045	337
100	<–60	230+	0.570	1.040	296

Notes:

1. **Specific gravity with respect to water at 60°F.**

A. Glycol Equation Factor Derivations

1. Standard water conditions:

a. Temperature:	60°F.
b. Pressure:	14.7 psia (sea level).
c. Density:	62.4 lbs./ft.^{3}

2. Water equation examples:

$$H = m \times c_g \times \Delta T.$$

30 percent ethylene glycol.

$c_g = 0.89$ Btu/~~Lb H$_2$O~~ [AC1]°F × 62.4 ~~Lbs.H$_2$O/Ft^3~~ × 1.0 ~~Ft^3~~/7.48052 gal. × 60 min./h × 1.040 (SG)

= 463 Btu min./h °F gal.

$H_{30\%EG}$ = 463 Btu min./h °F gal. × GPM (gal/min.) × ΔT (°F).

$H_{30\%EG}$ = 463 × GPM × ΔT (°F).

50 percent propylene glycol.

$c_g = 0.85$ Btu/~~Lb H$_2$O~~ °F × 62.4 ~~Lbs.H$_2$O/Ft^3~~ × 1.0 ~~Ft^3~~ / 7.48052 gal. × 60 min./h × 1.041 (SG)

= 442 Btu min./h °F gal.

$H_{50\%PG}$ = 442 Btu min./h °F gal. × GPM (gal/min.) × ΔT (°F).

$H_{50\%PG}$ = 442 × GPM × ΔT (°F).

Part 21: Steam Piping Systems

21. Part 21: Steam Piping Systems

Printed for University of California Berkeley Copyright McGraw-Hill Education Holdings

21.01. Steam Piping Systems

A. **Steam Pipe -Sizing**

1. Low-pressure steam systems:
   a. Low-pressure steam: 0–15 psig.
   b. 0.2–3 psi total system pressure drop max.
   c. 1/8–1/2 psi/100 ft.
2. Medium-pressure steam systems:
   a. Medium-pressure steam: 16–100 psig.
   b. 3–10 psi total system pressure drop max.
   c. 1/2–2 psi/100 ft.
3. High-pressure steam systems:
   a. High-pressure steam: 101–300 psig.
   b. 10–60 psi total system pressure drop max.
   c. 2–5 psi/100 ft.
4. Steam velocity:
   a. 15,000 FPM maximum.
   b. 6,000–12,000 FPM recommended.
   c. Low pressure systems: 4,000–6,000 FPM.

d. Medium pressure systems: 6,000–8,000 FPM.

e. High pressure systems: 10,000–15,000 FPM.

5. Friction loss estimate:
   a. 2.0 × System Length (ft.) × Friction Rate (ft./100 ft.).

6. Standard steel pipe sizes—1/2",3/4", 1",1-1/4",1-1/2", 2",2-1/2", 3", 4", 6", 8", 10", 12", 14", 16", 18", 20", 24", 30", 36", 42", 48", 54", 60", 72", 84", 96".

7. Total pressure drop in the steam system should not exceed 20 percent of the total maximum steam pressure at the boiler.

8. Steam condensate liquid to steam volume ratio is 1:1600 at 0 psig.

9. Flash steam: Flash steam is formed when hot steam condensate under pressure is released to a lower pressure; the temperature drops to the boiling point of the lower pressure, causing some of the condensate to evaporate, forming steam. Flash steam occurs whenever steam condensate experiences a drop in pressure and thus produces steam at the lower pressure.
   a. Low-pressure steam systems flash steam is negligible and can generally be ignored.

   b. Medium- and high-pressure steam systems flash steam is important to utilize and consider when sizing condensate piping.

   c. Flash steam recovery requirements:
      1. To utilize flash steam recovery, the condensate must be at a reasonably high pressure (medium- and high-pressure steam systems) and the traps supplying the condensate must be capable of operating with the back pressure of the flash steam system.

      2. There must be a use or demand for the flash steam at the reduced pressure. Demand for steam at the lower pressure should be greater than the supply of flash steam. The demand for steam should occur at the same time as the flash steam supply.

      3. The steam equipment should be in close proximity to the flash steam source to minimize installation and radiation losses and to fully take advantage of the flash steam recovery system. Flash steam recovery

systems are especially advantageous when steam is utilized at multiple pressures within the facility and the distribution systems are already in place.

10. Saturated steam:
    a. Saturated steam: Saturated steam is steam that is in equilibrium with the liquid at a given pressure. One pound of steam has a volume of 26.8 cu.ft. at atmospheric pressure (0 psig).

    b. Dry saturated steam: Dry steam is steam which has been completely evaporated and contains no liquid water in the form of mist or small droplets. Steam systems that produce a dry steam supply are superior to systems that produce a wet steam supply.

    c. Wet saturated steam: Wet steam is steam that has not been completely evaporated and contains water in the form of mist or small droplets. Wet steam has a heat content substantially lower than dry steam.

    d. Superheated steam: Superheated steam is dry saturated steam that is heated, which increases the temperature without increasing the system pressure.

11. Steam types:
    a. Plant steam: Steam produced in a conventional boiler system using softened and chemically treated water.

    b. Filtered steam: Plant steam that has been filtered to remove solid particles (no chemical removal).

    c. Clean steam: Steam produced in a clean steam generator using distilled, de-ionized, reverse-osmosis, or ultra-pure water.

    d. Pure steam: Steam produced in a clean steam generator using distilled or de-ionized pyrogen-free water, normally defined uncondensed water for injection.

12. Steam purity versus steam quality:
    a. Steam purity: A qualitative measure of steam contamination caused by dissolved solids, volatiles, or particles in vapor, or by tiny water droplets that may remain in the steam following primary separation in the boiler.

b. Steam quality: The ratio of the weight of dry steam to the weight of dry saturated steam and entrained water [Example: 0.95 quality refers to 95 parts steam (95 percent) and 5 parts water (5 percent)].

B. **Steam System Design and Pipe Installation Guidelines**

1. The minimum recommended steam pipe size is 3/4 inch.

2. Locate all valves, strainers, unions, and flanges so they are accessible. All valves (except control valves) and strainers should be the full size of the pipe before reducing the size to make connections to equipment and controls. Union and/or flanges should be installed at each piece of equipment, in bypasses and in long piping runs (100 feet or more), to permit disassembly for alteration and repairs.

3. Provide chainwheel operators for all valves in equipment rooms mounted greater than 7'0" above floor level. The chain should extend to 5'0–7'0" above the floor level.

4. All valves should be installed so the valve remains in service when equipment or piping on the equipment side of the valve is removed.

5. Locate all flow measuring devices in accessible locations with the straight section of the pipe upstream (10 pipe diameters) and downstream (5 pipe diameters) of the device or as recommended by the manufacturer.

6. Provide vibration isolators for all piping supports connected to, and within 50 feet of, isolated equipment, except at base elbow supports and anchor points, throughout mechanical equipment rooms, and for supports of steam mains within 50 feet of boiler or pressure reducing valves.

7. Pitch steam piping downward in the direction of flow1/4" per 10 ft. (1" per 40 ft.) minimum.

8. Where the length of steam branch lines are less than 8 feet, pitch branch lines downward toward mains1/2" per foot minimum.

9. Connect all branch lines to the top of steam mains (45 degree preferred, 90 degree acceptable; see Fig. 21.1).

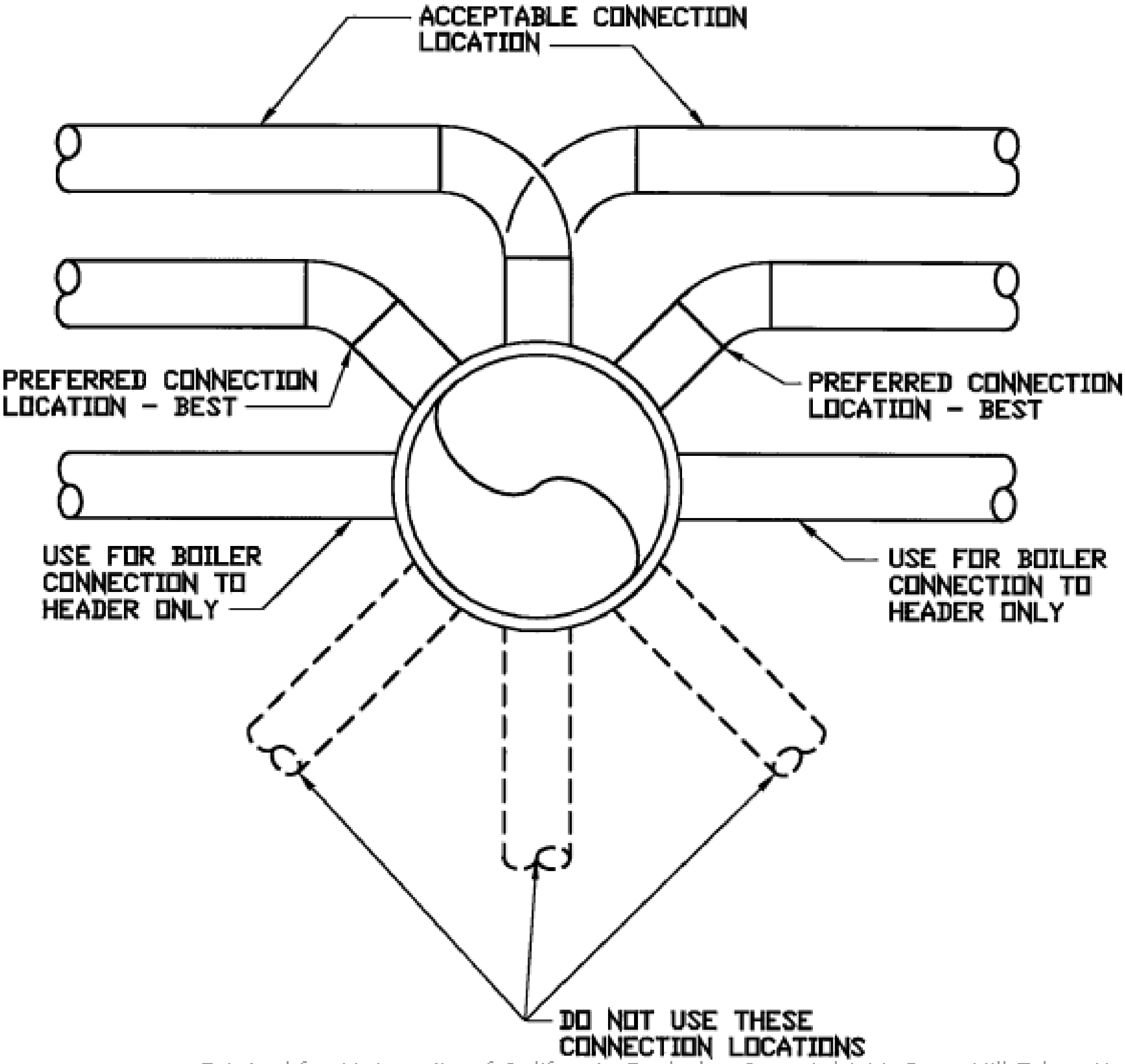


Figure 21.1. STEAM PIPING CONNECTIONS

10. Steam piping should be installed with eccentric reducers (flat on the bottom) to prevent accumulation of condensate in the pipe and thus decreasing the risk of water hammer.

11. Drip leg collection points on steam piping should be the same size as the steam piping to prevent steam condensate from passing over the drip leg and thus decreasing the risk of water hammer. The drip leg collection point should be a minimum of 12 inches long including a minimum 6-inch-long dirt leg with the steam trap outlet above the dirt leg.

12. Drip legs must be installed at all low points, downfed runouts to all equipment, end of mains, bottom of risers, and ahead of all pressure regulators, control valves, isolation valves, and expansion joints.

13. On straight runs with no natural drainage points, install drip legs at intervals not exceeding 200 feet where the pipe is pitched downward in the direction of steam flow, and a maximum of 100 feet where the pipe is pitched up so

that condensate flow is opposite of steam flow.

14. Steam traps used on steam mains and branches shall be a minimum3/4" size.

15. Control of steam systems with more than 2 million Btuh should be accomplished with two or more control valves (see steam PRVs).

16. Double valves should be installed on the supply side of equipment for isolating steam systems, above 100 psig, with a drain between these valves to visually confirm isolation. The reason for the double valving of systems is to ensure isolation because of the large pressure differentials that occur when the system is opened for repairs. Double valve all of the following:
    a. Equipment.
    b. Drains.
    c. Vents.
    d. Gauges.
    e. Instrumentation.

17. Steam in a steam system should be maintained at a pH of approximately 8 to 9. A pH of 7 is neutral; below 7 is acidic; above 7 is alkaline.

18. Provide a stop check valve (located closest to the boiler) and an isolation valve with a drain between these valves on the steam supply connections to all steam boilers.

19. Provide steam systems with warm-up valves for in-service start-up as shown in the following table. This will allow operators to warm these systems slowly and to prevent a sudden shock or catastrophic system failure when large system valves are opened. Providing warming valves also reduces wear on large system valves when they are only opened a small amount in an attempt to control system warm-up speed.

BYPASS AND WARMING VALVES

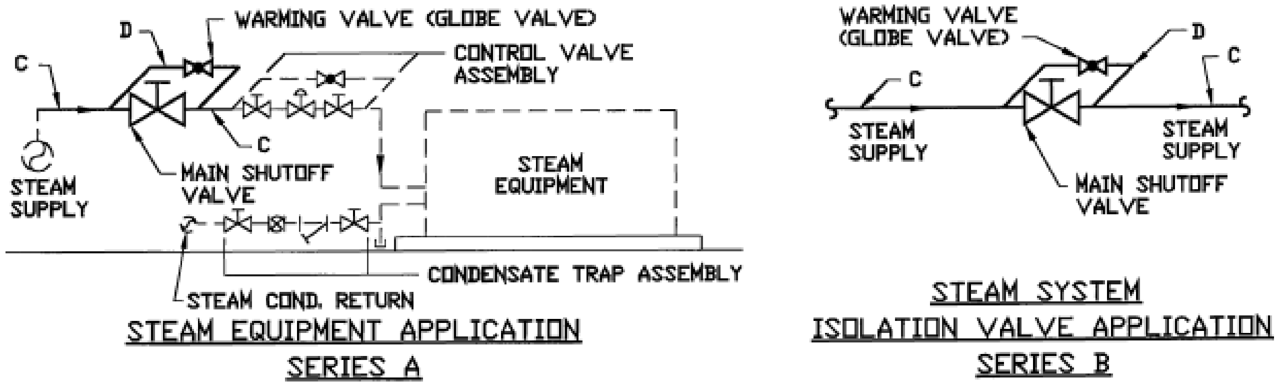
Main Valve Nominal Pipe Size	Nominal Pipe Size	
	Series A Warming Valves	Series B Bypass Valves
4	1/2	1
5	3/4	1-1/4
6	3/4	1-1/4
8	3/4	1-1/2
10	1	1-1/2
12	1	2
14	1	2
16	1	3
18	1	3
20	1	3
24	1	4
30	1	4
36	1	6
42	1	6
48	1	8
54	1	8
60	1	10
72	1	10
84	1	12
96	1	12

Notes:

1. **Series A valve sizes are utilized in steam service for warming up before the main line is opened, and for balancing pressures where lines are of limited volume.**

2. **Series B valve sizes are utilized in pipe lines conveying gases or liquids where by-passing may facilitate the operation of the main valve through balancing the pressures on both sides of the disc or discs thereof. The valves in the larger sizes may be of the bolted-on type.**

20. Steam system warming valve procedure (see Fig. 21.2):



NOTES:

1. SERIES A WARMING VALVES COVER STEAM OR MEDIUM/HIGH TEMPERATURE HEATING WATER SERVICE FOR SYSTEM OR EQUIPMENT WARM-UP BEFORE THE MAIN SHUTOFF VALVE TO THE SYSTEM OR DEVICE IS OPENED. WARMING VALVES ARE ALSO USED FOR BALANCING PRESSURES WHERE LINES ARE OF LIMITED VOLUME.
2. SERIES B WARMING VALVES COVER LINES CONVEYING GASES OR LIQUIDS WHERE BYPASSING MAY FACILITATE THE OPERATION OF THE MAIN VALVE BY BALANCING THE PRESSURES ON BOTH SIDES OF THE MAIN VALVE.

MAIN VALVE SIZE (C)	WARMING VALVE SIZE (D)	
	SERIES A WARMING VALVES	SERIES B WARMING VALVES
4"	1/2"	1"
5", 6"	3/4"	1-1/4"
8"	3/4"	1-1/2"
10"	1"	1-1/2"
12", 14"	1"	2"
16", 18", 20"	1"	3"
24", 30"	1"	4"
36", 42"	1"	6"
48", 54"	1"	8"
60", 72"	1"	10"
84", 96"	1"	12"

Figure 21.2. STEAM SYSTEM WARMING VALVES.

a. Slowly open the warming supply valve to establish flow and to warm the system.

b. Once the system pressure and temperature have stabilized, proceed with the following items, one at a time:
   1. Slowly open the main supply valve.

   2. Close the warming supply valve.

21. Steam system warm-up procedure:
   a. Steam system start-up should not exceed 120°F temperature rise per hour, but the boiler or heat exchanger manufacture limitations should be consulted.

   b. It is recommended that no more than a 25°F temperature rise per hour be used when warming steam systems. Slow warming of the steam system allows for system piping, supports, hangers, and anchors to keep up with system expansion.

c. Low-pressure steam systems (15 psig and less) should be warmed slowly at 25°F temperature rise per hour until system design pressure is reached.

d. Medium- and high-pressure steam systems (above 15 psig) should be warmed slowly at 25°F temperature rise per hour until 250°F-15 psig system temperature-pressure is reached. At this temperature-pressure, the system should be permitted to settle for at least eight hours or more (preferably overnight). The temperature-pressure maintenance time gives the system piping, hangers, supports, and anchors a chance to catch up with the system expansion. After allowing the system to settle, the system can be warmed up to 120 psig or the system design pressure in 25 psig pressure increments. Allow the system to settle for an hour before increasing the pressure to the next increment. When the system reaches 120 psig and the design pressure is above 120 psig, the system should be allowed to settle for at least eight hours or more (preferably overnight). The pressure maintenance time gives the system piping, hangers, supports, and anchors a chance to catch up with the system expansion. After allowing the system to settle, the system can be warmed up to 300 psig or the system design pressure in 25 psig pressure increments; allow the system to settle for an hour before increasing the pressure to the next increment.

C. **Low-Pressure Steam Pipe Materials (0–15 psig):**

1. 2" and smaller:

a. Pipe:	Black Steel Pipe, *ASTM A53, Schedule 40,* Type E or S, Grade B
Fittings:	Black Cast Iron Screw Fittings, 125 lb., *ANSI/ASME B16.4*
Joints:	Pipe Threads, General Purpose (American) *ANSI/ASME B1.20.1.*

2. 2-1/2" through 10":

a. Pipe:	Black Steel Pipe, *ASTM A53, Schedule 40,* Type E or S, Grade B
Fittings:	Steel Butt-Welding Fittings, 125 lb., *ANSI/ASME B16.9*
Joints:	Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*

3. 12" and larger:

a. Pipe:	Black Steel Pipe, *ASTM A53,*3/8" wall, Type E or S, Grade B
Fittings:	Steel Butt-Welding Fittings, 125 lb., *ANSI/ASME B16.9*
Joints:	Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*

D. **Medium-Pressure Steam Pipe (16–100 psig):**

1. 1-1/2" and Smaller:

a. Pipe:	Black Steel Pipe, *ASTM A53, Schedule 40,* Type E or S, Grade B
Fittings:	Forged Steel Socket-Weld, 150 lb., *ANSI B16.11*
Joints:	Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*
b. Pipe:	Carbon Steel Pipe, *ASTM A106, Schedule 40,* Grade B
Fittings:	Forged Steel Socket-Weld, 150 lb., *ANSI B16.11*
Joints:	Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*

2. 2" through 10":

a. Pipe:	Black Steel Pipe, *ASTM A53, Schedule 40,* Type E or S, Grade B
Fittings:	Steel Butt-Welding Fittings, 150 lb., *ANSI/ASME B16.9*
Joints:	Welded pipe, ANSI/AWS D1.1 and ANSI/ASME Sec. 9
b. Pipe:	Carbon Steel Pipe, *ASTM A106, Schedule 40,* Grade B
Fittings:	Steel Butt-Welding Fittings, 150 lb., *ANSI/ASME B16.9*
Joints:	Welded pipe, ANSI/AWS D1.1 and ANSI/ASME Sec. 9.

3. 12" and larger:

a. Pipe:	Black Steel Pipe, *ASTM A53, 3/8*" *wall*, Type E or S, Grade B
Fittings:	Steel Butt-Welding Fittings, 150 lb., *ANSI/ASME B16.9*
Joints:	Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*
b. Pipe:	Carbon Steel Pipe, *ASTM A106, 3/8*" *wall,* Grade B
Fittings:	Steel Butt-Welding Fittings, 150 lb., *ANSI/ASME B16.9*
Joints:	Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*

E. **High-Pressure Steam Pipe (100–300 psig):**

1. 1-1/2" and smaller:

a. Pipe:	Black Steel Pipe, *ASTM A53, Schedule 80,* Type E or S, Grade B
Fittings:	Forged Steel Socket-Weld, 300 lb., *ANSI B16.11*
Joints:	Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*
b. Pipe: Carbon Steel Pipe, *ASTM A106, Schedule 80,* Grade B	
Fittings:	Forged Steel Socket-Weld, 300 lb., *ANSI B16.11*
Joints:	Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*

2. 2" and larger:

a. Pipe:	Black Steel Pipe, *ASTM A53, Schedule 80,* Type E or S, Grade B
Fittings:	Steel Butt-Welding Fittings, 300 lb., *ANSI/ASME B16.9*
Joints: Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*	
b. Pipe:	Carbon Steel Pipe, *ASTM A106, Schedule 80,* Grade B
Fittings:	Steel Butt-Welding Fittings, 300 lb., *ANSI/ASME B16.9*
Joints:	Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*

F. **Pipe Testing**

1. 1.5 × System Working Pressure.

2. 100 psi minimum.

G. **Steam Pressure Reducing Valves (PRV)**

1. PRV types:

a. Direct acting:
   1. Low cost.
   2. Limited ability to respond to changing load and pressure.
   3. Suitable for systems with low flow requirements.
   4. Suitable for systems with constant loads.
   5. Limited control of downstream pressure.
b. Pilot-operated:
   1. Close control of downstream pressure over a wide range of upstream pressures.
   2. Suitable for systems with varying loads.
   3. Ability to respond to changing loads and pressures.
   4. Types:
      a. Pressure-operated-pilot.
      b. Temperature-pressure-operated-pilot.

2. Use multiple stage reduction where greater than 100 psig reduction is required or where greater than 50 psig reduction is required to deliver a pressure less than 25 psig operating pressure or when intermediate steam pressure is required.

3. Use multiple PRVs where system steam capacity exceeds 2" PRV size, when normal operation calls for 10 percent of design load for sustained periods, or when there are two distinct load requirements (i.e., summer/winter). Provide the number of PRVs to suit the project.
   a. If the system capacity for a single PRV exceeds the 2" PRV size but is not larger than the 4" PRV size, use two PRVs with 1/3 and 2/3 capacity split.
   b. If system capacity for a single PRV exceeds the 4" PRV size, use three PRVs with 25 percent, 25 percent, and 50 percent, or 15 percent, 35 percent, and 50 percent capacity split to suit the project.

4. The smallest PRV should be no greater than 1/3 of the system capacity. The maximum size PRV should be 4" (6" when 4" PRV will require more than three valves per stage).

5. The PRV bypass should be two pipe sizes smaller than the largest PRV.

6. Provide 10 pipe diameters from the PRV inlet to the upstream header.

7. Provide 20 pipe diameters from the PRV outlet to the downstream header.

8. Maximum pipe velocity upstream and downstream of PRV:
   a. 8" and smaller: 10,000 FPM.

   b. 10" and larger: 8,000 FPM.

   c. Where low sound levels are required, reduce velocities by 25–50 percent.

   d. If the outlet velocity exceeds the preceding listings, use a noise suppressor.

9. Avoid abrupt changes in pipe size. Use concentric reducers.

10. Limit pipe diameter changes to two pipe sizes per stage of expansion.

H. **Safety Relief Valves**

1. The safety relief valve must be capable of handling the volume of steam as determined by the high pressure side of the largest PRV, or the bypass, whichever is greater.

2. Use multiple safety relief valves if the capacity of a 4" safety relief valve is exceeded. Each valve must have a separate connection to the pipeline.

3. Safety, relief, and safety relief valve testing is dictated by the insurance underwriter.

I. **Steam -Systems**

1. Residential steam systems are low-pressure steam systems normally with gravity return condensate systems (see Figs. 21.3 through 21.5).

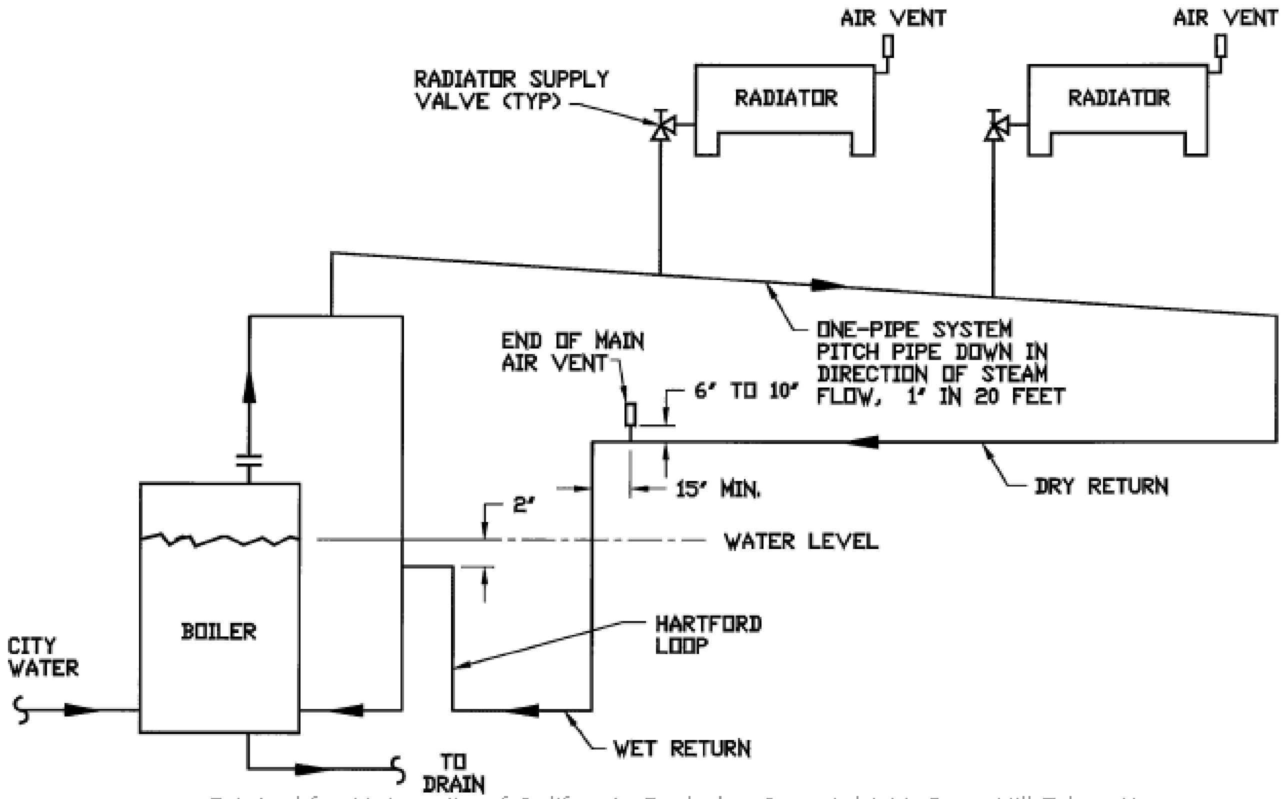


Figure 21.3. RESIDENTIAL LP STEAM SYSTEMS 1.

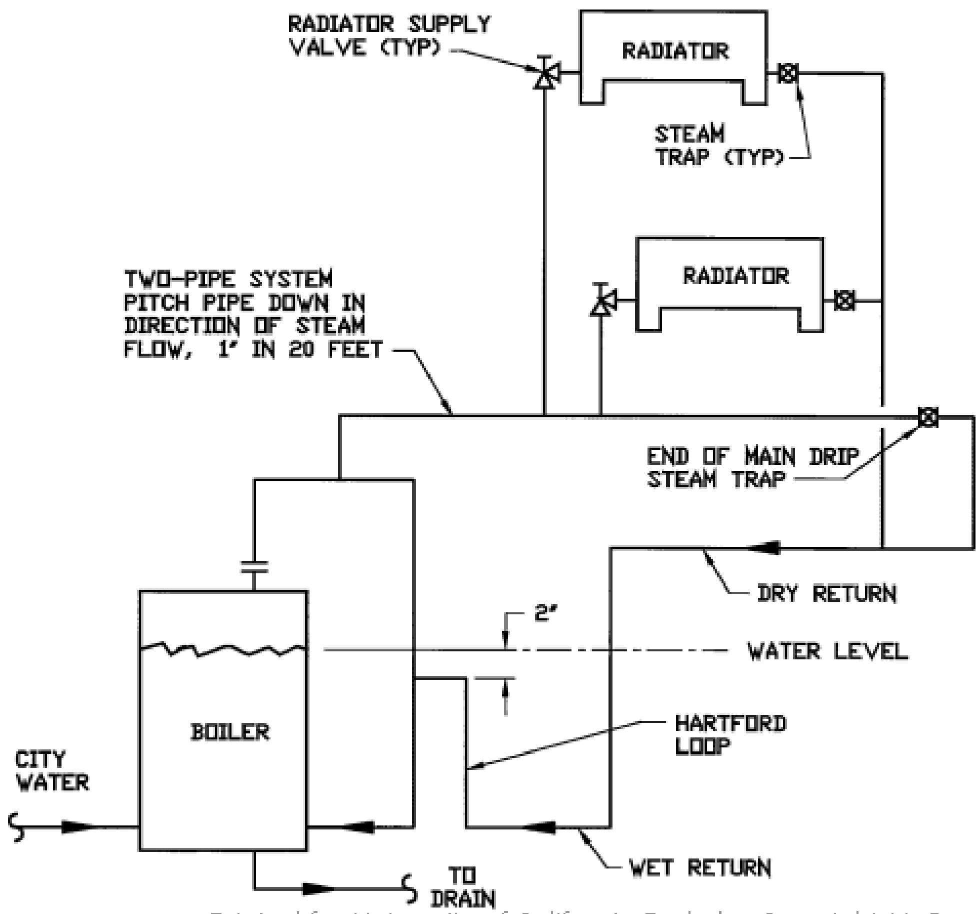


Figure 21.4. RESIDENTIAL LP STEAM SYSTEMS 2.

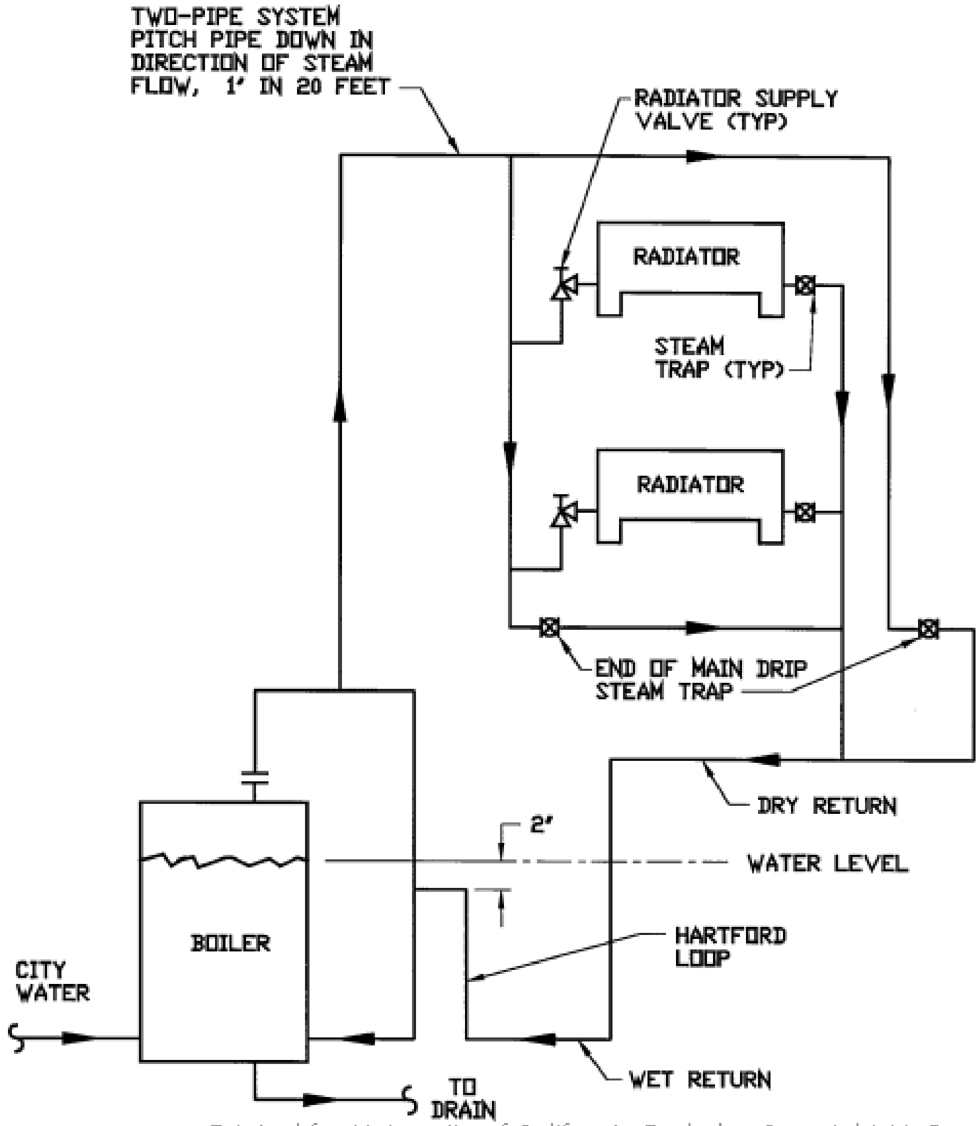


Figure 21.5. RESIDENTIAL LP STEAM SYSTEMS 3.

2. Commercial low-pressure steam systems may be provided with either gravity or pumped condensate return systems (see Figs. 21.6 and 21.7).

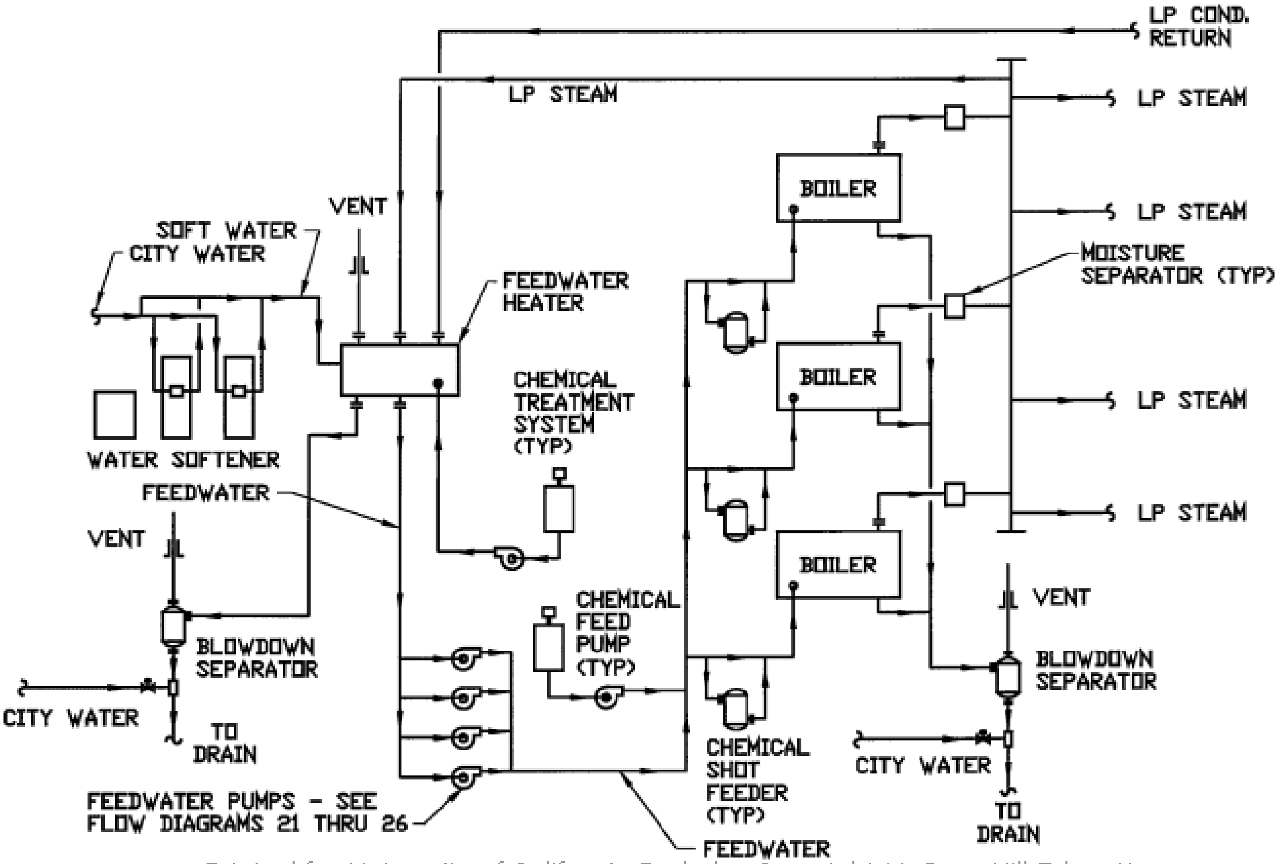


Figure 21.6. LOW-PRESSURE STEAM SYSTEMS–GRAVITY RETURN.

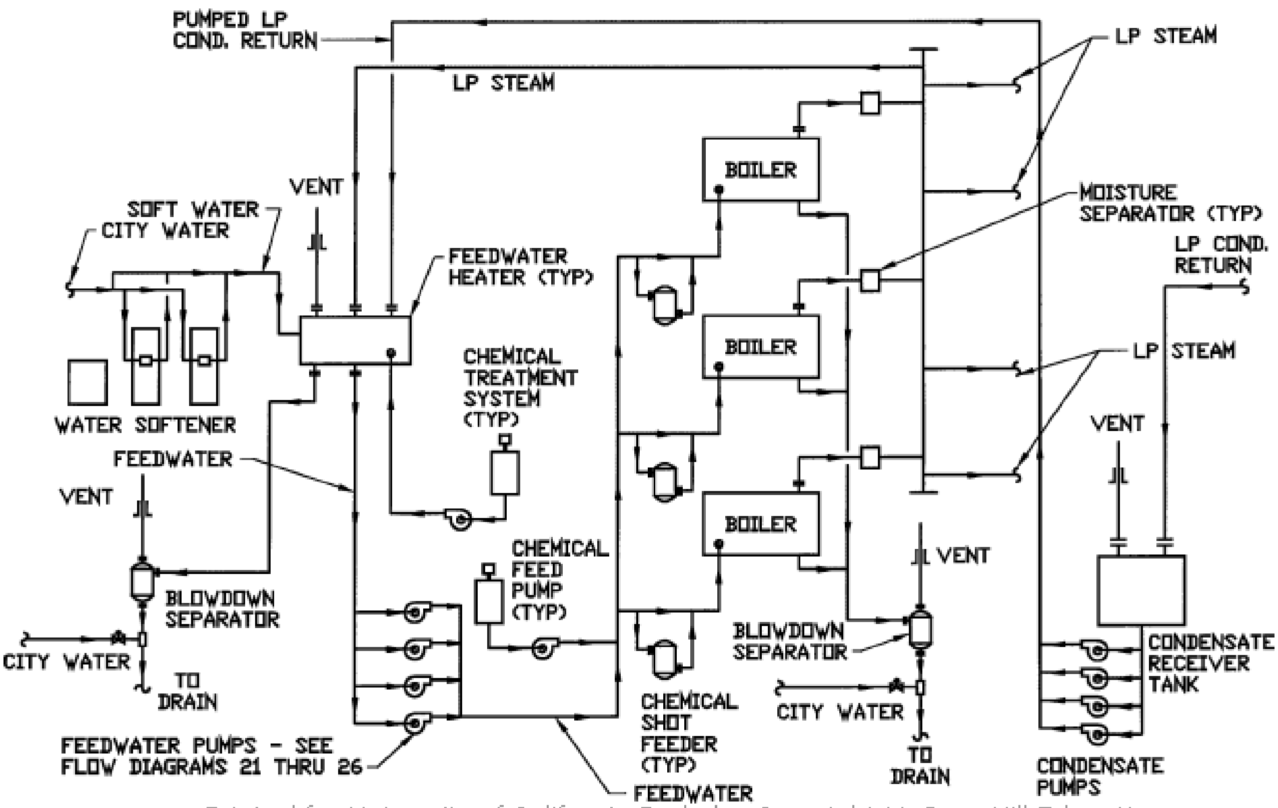


Figure 21.7. LOW-PRESSURE STEAM SYSTEMS–PUMPED RETURN.

3. Commercial and industrial medium- and high-pressure steam systems are generally provided with pumped condensate return systems (see Figs. 21.8 and 21.9).

HIGH PRESSURE STEAM SYSTEM KEYED NOTES:

1. BOILER
2. DEAERATOR OR FEEDWATER HEATER
3. BLOWDOWN FLASH TANK
4. FEEDWATER PUMPS – SEE FLOW DIAGRAMS 21 THROUGH 26
5. CONDENSATE RECEIVER TANK
6. CONDENSATE PUMPS
7. BLOWDOWN SEPARATOR
8. BLOWDOWN HEAT EXCHANGER
9. SAMPLE COOLER
10. FLASH TANK
11. CHEMICAL TREATMENT SYSTEMS
12. CHEMICAL FEED PUMPS
13. CHEMICAL SHOT FEEDER
14. WATER TREATMENT SYSTEM
15. MOISTURE SEPARATOR
16. PRV STATION
17. TEMPERATURE CONTROL
18. LEVEL CONTROL
19. TOP BLOWDOWN CONTROLLER
20. TO DRAIN
21. EXHAUST HEAD
22. VENT, TERMINATE A MINIMUM OF 7'-6' ABOVE ROOF
23. STEAM SYSTEM #1 (LOW PRESSURE STEAM)
24. STEAM SYSTEM #2 (MEDIUM PRESSURE STEAM)
25. STEAM SYSTEM #3 (HIGH PRESSURE STEAM)
26. FLASH STEAM TO LP STEAM SYSTEM
27. COMBINED HIGH-PRESSURE & MEDIUM-PRESSURE CONDENSATE RETURNS
28. LOW PRESSURE CONDENSATE RETURN
29. MEDIUM-PRESSURE CONDENSATE RETURN
30. HIGH-PRESSURE CONDENSATE RETURN
31. PUMPED CONDENSATE RETURN
32. CITY WATER
33. TREATED WATER
34. HEATED SOFT WATER
35. FEEDWATER

Figure 21.8. HP STEAM SYSTEM FLOW DIAGRAM NOTES.

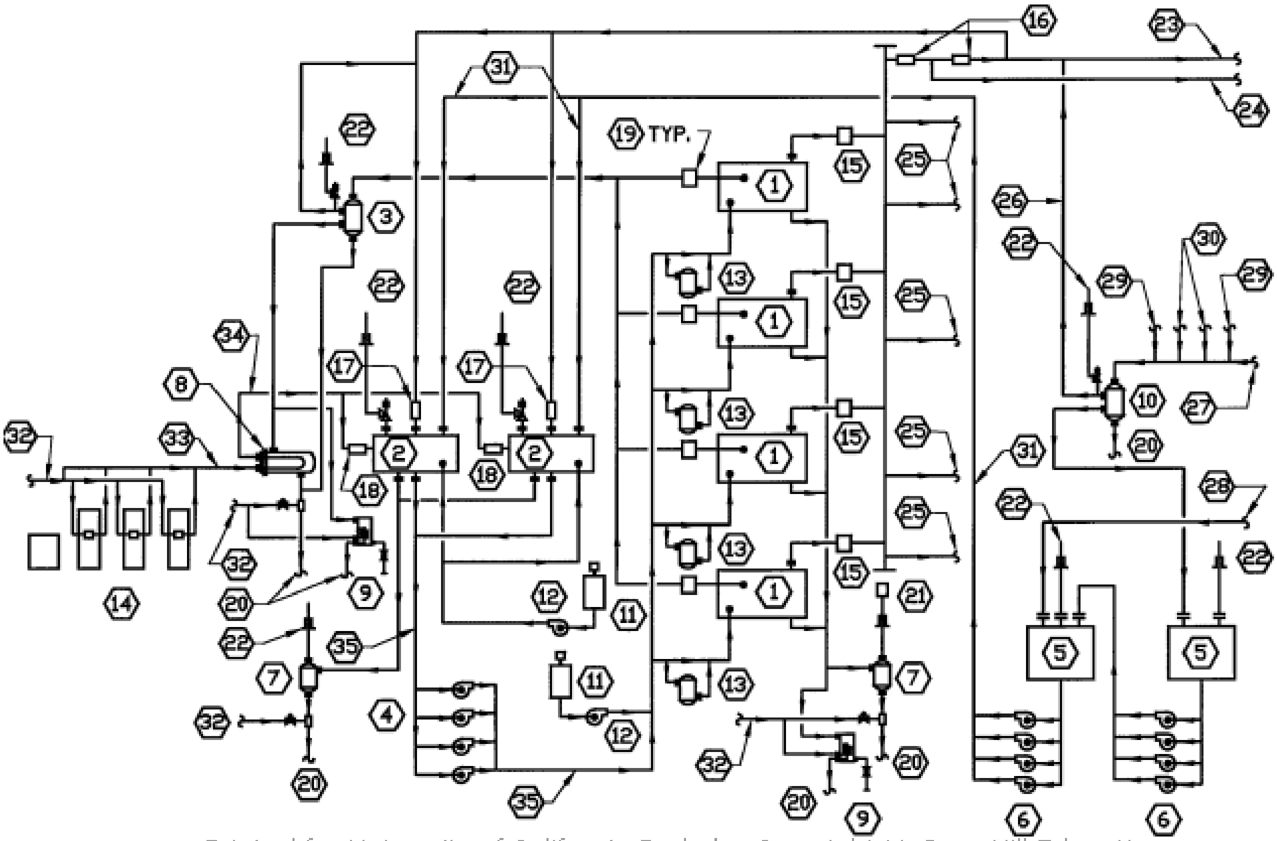


Figure 21.9. HIGH-PRESSURE STEAM SYSTEMS–PUMPED RETURN.

21.02. Steam System Design Criteria

STEAM SYSTEM DESIGN CRITERIA

System Type	Initial Steam Pressure psig	Maximum Pressure Drop psig/100 ft.	Maximum Total System Pressure Drop psig	Maximum Velocity FPM
Low Pressure	1	1/8	0.2	4,000
	3	1/8	0.6	4,000
	5	1/4	1.0	6,000
	7	1/4	1.5	6,000
	10	1/2	2.0	6,000
Velocity Range	12	1/2	2.5	6,000
4,000–6,000	15	1/2	3	6,000

System Type	Initial Steam Pressure psig	Maximum Pressure Drop psig/100 ft.	Maximum Total System Pressure Drop psig	Maximum Velocity FPM
FPM				
Medium	20	1/2	4	8,000
Pressure	25	1/2–1	5	8,000
	30	1/2–1	5–6	8,000
	40	1	6–8	10,000
	50	1	8–10	10,000
	60	1	10–12	12,000
	75	1–2	12–15	12,000
Velocity Range	85	1–2	12–15	12,000
6,000–12,000 FPM	100	1–2	15–20	12,000
High	120	2	20–24	15,000
Pressure	125	2	20–24	15,000
	150	2	24–30	15,000
	175	2	24–30	15,000
	200	2–5	30–40	15,000
	225	2–5	30–40	15,000
	250	2–5	30–50	15,000
Velocity Range	275	2–5	30–50	15,000
6,000–15,000 FPM	300	2–5	40–60	15,000

21.03. Steam Tables

STEAM TABLES

Steam Pressure psig	Steam Pressure psia	Saturation Temperature °F	Specific Volume cu.ft./lb.	Heat Content (above 32°F) Btu/lb.		
				Sensible	Latent	Tot

Steam Pressure psig	Steam Pressure psia	Saturation Temperature °F	Specific Volume cu.ft./lb.	Heat Content (above 32°F) Btu/lb.		
				Sensible	Latent	Total
0	14.7	212.0	26.800	180.2	970.4	1,150
1	15.7	215.3	25.212	183.5	968.2	1,151
2	16.7	218.5	23.798	186.7	966.2	1,152
3	17.7	221.5	22.536	189.7	964.3	1,154
4	18.7	224.4	21.407	192.6	962.4	1,155
5	19.7	227.1	20.387	195.4	960.6	1,156
6	20.7	229.8	19.467	198.1	958.9	1,157
7	21.7	232.3	18.626	200.7	957.3	1,158
8	22.7	234.8	17.855	203.1	955.7	1,158
9	23.7	237.1	17.147	205.5	954.2	1,159
10	24.7	239.4	16.496	207.8	952.7	1,160
11	25.7	241.6	15.895	210.1	951.2	1,161
12	26.7	243.7	15.337	212.2	949.8	1,162
13	27.7	245.8	14.817	214.4	948.4	1,162
14	28.7	247.8	14.334	216.4	947.1	1,163
15	29.7	249.8	13.881	218.3	945.8	1,164
16	30.7	251.7	13.458	220.3	944.5	1,164
17	31.7	253.5	13.059	222.2	943.3	1,165
18	32.7	255.3	12.685	224.0	942.1	1,166
19	33.7	257.1	12.332	225.8	940.9	1,166
20	34.7	258.8	11.998	227.5	939.7	1,167
21	35.7	260.5	11.684	229.2	938.5	1,167
22	36.7	262.1	11.385	230.9	937.4	1,168
23	37.7	263.7	11.102	232.5	936.3	1,168
24	38.7	265.3	10.833	234.1	935.2	1,169
25	39.7	266.8	10.577	235.7	934.1	1,169
26	40.7	268.3	10.333	237.3	933.1	1,170
27	41.7	269.8	10.101	238.7	932.1	1,170
28	42.7	271.2	9.879	240.2	931.1	1,171
29	43.7	272.6	9.666	241.7	930.1	1,171
30	44.7	274.0	9.463	243.1	929.1	1,172
31	45.7	275.4	9.269	244.5	928.2	1,172
32	46.7	276.8	9.082	245.9	927.2	1,173
33	47.7	278.1	8.904	247.2	926.3	1,173
34	48.7	279.4	8.732	248.5	925.4	1,173
35	49.7	280.6	8.567	249.9	924.5	1,174

Steam Pressure psig	Steam Pressure psia	Saturation Temperature °F	Specific Volume cu.ft./lb.	Heat Content (above 32°F) Btu/lb.		
				Sensible	Latent	Total
35	49.7	280.6	8.567	249.9	924.5	1,174
36	50.7	281.9	8.408	251.1	923.6	1,174
37	51.7	283.1	8.255	252.4	922.7	1,175
38	52.7	284.4	8.109	253.7	921.8	1,175
39	53.7	285.6	7.966	254.9	921.0	1,175
40	54.7	286.7	7.843	256.1	920.1	1,176
41	55.7	287.9	7.697	257.3	919.3	1,176
42	56.7	289.1	7.570	258.5	918.4	1,176
43	57.7	290.2	7.447	259.6	917.6	1,177
44	58.7	291.3	7.327	260.8	916.8	1,177
45	59.7	292.4	7.212	261.9	916.0	1,177
46	60.7	293.5	7.100	263.0	915.2	1,178
47	61.7	294.6	6.992	264.2	914.4	1,178
48	62.7	295.6	6.887	265.3	913.6	1,178
49	63.7	296.7	6.785	266.3	912.9	1,179
50	64.7	297.7	6.686	267.4	912.1	1,179
51	65.7	298.7	6.591	268.4	911.4	1,179
52	66.7	299.7	6.498	269.4	910.6	1,180
53	67.7	300.7	6.407	270.5	909.9	1,180
54	68.7	301.7	6.391	271.5	909.2	1,180
55	69.7	302.7	6.234	272.5	908.5	1,181
56	70.7	303.6	6.151	273.5	907.7	1,181
57	71.7	304.6	6.070	274.5	907.0	1,181
58	72.7	305.5	5.991	275.4	906.3	1,181
59	73.7	306.4	5.915	276.4	905.6	1,182
60	74.7	307.4	5.840	277.3	905.0	1,182
61	75.7	308.3	5.768	278.3	904.3	1,182
62	76.7	309.2	5.696	279.2	903.6	1,182
63	77.7	310.1	5.627	280.1	902.9	1,183
64	78.7	310.9	5.560	281.0	902.3	1,183
65	79.7	311.8	5.494	281.9	901.6	1,183
66	80.7	312.7	5.430	282.8	901.0	1,183
67	81.7	313.5	5.367	283.7	900.3	1,184
68	82.7	314.4	5.306	284.6	899.7	1,184
69	83.7	315.2	5.246	285.5	899.0	1,184
70	84.7	316.0	5.187	286.3	898.4	1,184
71	85.7	316.9	5.130	287.2	897.8	1,185

Steam Pressure psig	Steam Pressure psia	Saturation Temperature °F	Specific Volume cu.ft./lb.	Heat Content (above 32°F) Btu/lb.		
				Sensible	Latent	Total
72	86.7	317.7	5.075	288.0	897.1	1,185
73	87.7	318.5	5.020	288.9	896.5	1,185
74	88.7	319.3	4.966	289.7	895.9	1,185
75	89.7	320.1	4.914	290.5	895.3	1,185
76	90.7	320.9	4.863	291.3	894.7	1,186
77	91.7	321.6	4.813	292.1	894.1	1,186
78	92.7	322.4	4.764	292.9	893.5	1,186
79	93.7	323.2	4.715	293.7	892.9	1,186
80	94.7	323.9	4.668	294.5	892.3	1,186
81	95.7	324.7	4.623	295.3	891.7	1,187
82	96.7	325.4	4.578	296.1	891.1	1,187
83	97.7	326.2	4.533	296.9	890.6	1,187
84	98.7	326.9	4.489	297.6	890.0	1,187
85	99.7	327.6	4.447	298.4	889.4	1,187
86	100.7	328.4	4.405	299.1	888.8	1,187
87	101.7	329.1	4.364	299.9	888.3	1,188
88	102.7	329.8	4.324	300.6	887.7	1,188
89	103.7	330.5	4.284	301.4	887.1	1,188
90	104.7	331.2	4.245	302.1	886.6	1,188
91	105.7	331.9	4.207	302.8	886.1	1,188
92	106.7	332.6	4.170	303.5	885.5	1,189
93	107.7	333.3	4.133	304.3	885.0	1,189
94	108.7	333.9	4.098	305.0	884.4	1,189
95	109.7	334.6	4.062	305.7	883.9	1,189
96	110.7	335.3	4.048	306.4	883.3	1,189
97	111.7	336.0	3.993	307.1	882.8	1,189
98	112.7	336.6	3.959	307.8	882.2	1,190
99	113.7	337.3	3.926	308.4	881.8	1,190
100	114.7	337.9	3.894	309.1	881.2	1,190
101	115.7	338.6	3.862	309.8	880.7	1,190
102	116.7	339.2	3.830	310.5	880.2	1,190
103	117.7	339.9	3.799	311.1	879.7	1,190
104	118.7	340.5	3.769	311.8	879.2	1,191
105	119.7	341.1	3.739	312.5	878.7	1,191
106	120.7	341.7	3.710	313.1	878.1	1,191
107	121.7	342.4	3.681	313.8	877.6	1,191

Steam Pressure psig	Steam Pressure psia	Saturation Temperature °F	Specific Volume cu.ft./lb.	Heat Content (above 32°F) Btu/lb.		
				Sensible	Latent	Tota
108	122.7	343.0	3.652	314.4	877.1	1,191
109	123.7	343.6	3.624	315.1	876.6	1,191
110	124.7	344.2	3.596	315.7	876.1	1,191
111	125.7	344.8	3.569	316.3	875.6	1,191
112	126.7	345.4	3.543	317.0	875.1	1,192
113	127.7	346.0	3.516	317.6	874.6	1,192
114	128.7	346.6	3.490	318.2	874.2	1,192
115	129.7	347.2	3.465	318.9	873.7	1,192
116	130.7	347.8	3.440	319.5	873.2	1,192
117	131.7	348.4	3.415	320.1	872.7	1,192
118	132.7	348.9	3.390	320.7	872.2	1,192
119	133.7	349.5	3.366	321.3	871.7	1,193
120	134.7	350.1	3.342	321.9	871.3	1,193
121	135.7	350.7	3.319	322.5	870.8	1,193
122	136.7	351.2	3.296	323.1	870.3	1,193
123	137.7	351.8	3.273	323.7	869.8	1,193
124	138.7	352.4	3.251	324.3	869.4	1,193
125	139.7	352.9	3.228	324.9	868.9	1,193
126	140.7	353.5	3.206	325.5	868.4	1,193
127	141.7	354.0	3.185	326.0	868.0	1,194
128	142.7	354.6	3.163	326.6	867.5	1,194
129	143.7	355.1	3.142	327.2	867.0	1,194
130	144.7	355.7	3.121	327.8	866.6	1,194
131	145.7	356.2	3.101	328.4	866.1	1,194
132	146.7	356.7	3.081	328.9	865.7	1,194
133	147.7	357.3	3.061	329.5	865.2	1,194
134	148.7	357.8	3.042	330.0	864.8	1,194
135	149.7	358.3	3.022	330.6	864.3	1,194
136	150.7	358.8	3.003	331.1	863.9	1,195
137	151.7	359.4	2.984	331.7	863.4	1,195
138	152.7	359.9	2.965	332.2	863.0	1,195
139	153.7	360.4	2.947	332.8	862.5	1,195
140	154.7	360.9	2.928	333.3	862.1	1,195
141	155.7	361.4	2.910	333.9	861.6	1,195
142	156.7	361.9	2.893	334.4	861.2	1,195
143	157.7	362.4	2.875	334.9	860.8	1,195
144	158.7	362.9	2.858	335.5	860.4	1,195

Steam Pressure psig	Steam Pressure psia	Saturation Temperature °F	Specific Volume cu.ft./lb.	Heat Content (above 32°F) Btu/lb. Sensible	Latent	Total
144	158.7	362.9	2.858	335.5	860.4	1,195
145	159.7	363.4	2.841	336.0	859.9	1,195
146	160.7	363.9	2.824	336.5	859.5	1,196
147	161.7	364.4	2.807	337.1	859.0	1,196
148	162.7	364.9	2.791	337.6	858.6	1,196
149	163.7	365.4	2.775	338.1	858.2	1,196
150	164.7	365.9	2.759	338.6	857.8	1,196
151	165.7	366.4	2.743	339.1	857.3	1,196
152	166.7	366.9	2.727	339.7	856.9	1,196
153	167.7	367.4	2.712	340.2	856.5	1,196
154	168.7	367.9	2.696	340.7	856.1	1,196
155	169.7	368.3	2.681	341.2	855.7	1,196
156	170.7	368.8	2.666	341.7	855.3	1,197
157	171.7	369.3	2.651	342.2	854.8	1,197
158	172.7	369.7	2.636	342.7	854.4	1,197
159	173.7	370.2	2.621	343.2	854.0	1,197
160	174.7	370.7	2.607	343.7	853.6	1,197
161	175.7	371.1	2.593	344.2	853.2	1,197
162	176.7	371.6	2.579	344.7	852.8	1,197
163	177.7	372.1	2.565	345.2	852.4	1,197
164	178.7	372.5	2.551	345.7	852.0	1,197
165	179.7	373.0	2.537	346.1	851.6	1,197
166	180.7	373.4	2.524	346.6	851.2	1,197
167	181.7	373.9	2.511	347.1	850.8	1,197
168	182.7	374.4	2.498	347.6	850.4	1,198
169	183.7	374.8	2.484	348.1	850.0	1,198
170	184.7	375.2	2.471	348.5	849.6	1,198
171	185.7	375.7	2.459	349.0	849.2	1,198
172	186.7	376.1	2.446	349.5	848.8	1,198
173	187.7	376.6	2.434	350.0	848.4	1,198
174	188.7	377.0	2.421	350.4	848.1	1,198
175	189.7	377.4	2.409	350.9	847.7	1,198
176	190.7	377.9	2.397	351.4	847.2	1,198
177	191.7	378.3	2.385	351.8	846.9	1,198
178	192.7	378.8	2.373	352.3	846.5	1,198
179	193.7	379.2	2.361	352.8	846.1	1,198
180	194.7	379.6	2.349	353.2	845.7	1,198

Steam Pressure psig	Steam Pressure psia	Saturation Temperature °F	Specific Volume cu.ft./lb.	Heat Content (above 32°F) Btu/lb.		
				Sensible	Latent	Total
180	194.7	379.6	2.349	353.2	845.7	1,198
181	195.7	380.0	2.337	353.7	845.3	1,199
182	196.7	380.5	2.326	354.1	844.9	1,199
183	197.7	380.9	2.315	354.6	844.5	1,199
184	198.7	381.3	2.304	355.1	844.1	1,199
185	199.7	381.7	2.292	355.5	843.8	1,199
186	200.7	382.2	2.281	355.9	843.4	1,199
187	201.7	382.6	2.271	356.3	843.1	1,199
188	202.7	383.0	2.260	356.8	842.7	1,199
189	203.7	383.4	2.249	357.2	842.3	1,199
190	204.7	383.8	2.238	357.7	841.9	1,199
191	205.7	384.2	2.228	358.1	841.6	1,199
192	206.7	384.6	2.218	358.5	841.2	1,199
193	207.7	385.0	2.207	359.0	840.8	1,199
194	208.7	385.4	2.197	359.4	840.5	1,199
195	209.7	385.8	2.187	359.9	840.1	1,200
196	210.7	386.3	2.177	360.3	839.7	1,200
197	211.7	386.7	2.167	360.7	839.4	1,200
198	212.7	387.1	2.158	361.2	838.9	1,200
199	213.7	387.5	2.148	361.6	838.6	1,200
200	214.7	387.9	2.138	362.1	838.2	1,200
201	215.7	388.2	2.128	362.5	837.8	1,200
202	216.7	388.6	2.119	362.9	837.5	1,200
203	217.7	389.0	2.110	363.3	837.1	1,200
204	218.7	389.4	2.100	363.8	836.8	1,200
205	219.7	389.8	2.091	364.2	836.4	1,200
206	220.7	390.2	2.082	364.6	836.0	1,200
207	221.7	390.6	2.073	365.0	835.7	1,200
208	222.7	391.0	2.064	365.4	835.3	1,200
209	223.7	391.4	2.055	365.8	835.0	1,200
210	224.7	391.8	2.046	366.2	834.6	1,200
211	225.7	392.1	2.037	366.6	834.2	1,200
212	226.7	392.5	2.028	367.0	833.9	1,200
213	227.7	392.9	2.020	367.5	833.5	1,201
214	228.7	393.3	2.011	367.9	833.2	1,201
215	229.7	393.6	2.003	368.3	832.8	1,201
216	230.7	394.0	1.994	368.7	832.5	1,201

Steam Pressure psig	Steam Pressure psia	Saturation Temperature °F	Specific Volume cu.ft./lb.	Heat Content (above 32°F) Btu/lb.		
				Sensible	Latent	Total
217	231.7	394.4	1.986	369.1	832.1	1,201
218	232.7	394.8	1.978	369.5	831.8	1,201
219	233.7	395.2	1.970	369.9	831.4	1,201
220	234.7	395.5	1.961	370.3	831.1	1,201
221	235.7	395.9	1.953	370.7	830.8	1,201
222	236.7	396.3	1.945	371.1	830.4	1,201
223	237.7	396.6	1.937	371.5	830.1	1,201
224	238.7	397.0	1.929	371.9	829.7	1,201
225	239.7	397.4	1.921	372.3	829.4	1,201
226	240.7	397.7	1.914	372.7	829.0	1,201
227	241.7	398.1	1.906	373.0	828.7	1,201
228	242.7	398.4	1.898	373.4	828.3	1,201
229	243.7	398.8	1.891	373.8	828.0	1,201
230	244.7	399.2	1.883	374.2	827.6	1,201
231	245.7	399.5	1.876	374.6	827.3	1,201
232	246.7	399.9	1.869	375.0	826.9	1,201
233	247.7	400.2	1.862	375.3	826.6	1,201
234	248.7	400.6	1.854	375.7	826.2	1,201
235	249.7	400.9	1.847	376.1	825.9	1,202
236	250.7	401.3	1.840	376.5	825.6	1,202
237	251.7	401.6	1.833	376.8	825.3	1,202
238	252.7	402.0	1.826	377.2	824.9	1,202
239	253.7	402.3	1.819	377.6	824.6	1,202
240	254.7	402.7	1.812	378.0	824.3	1,202
241	255.7	403.0	1.805	378.4	824.0	1,202
242	256.7	403.4	1.798	378.7	823.7	1,202
243	257.7	403.7	1.791	379.1	823.3	1,202
244	258.7	404.1	1.785	379.5	822.9	1,202
245	259.7	404.4	1.778	379.9	822.6	1,202
246	260.7	404.7	1.771	380.3	822.3	1,202
247	261.7	405.1	1.765	380.6	822.0	1,202
248	262.7	405.4	1.758	381.0	821.6	1,202
249	263.7	405.8	1.752	381.3	821.3	1,202
250	264.7	406.1	1.745	381.7	821.0	1,202
251	265.7	406.4	1.739	382.1	820.7	1,202
252	266.7	406.8	1.733	382.4	820.4	1,202

Steam Pressure psig	Steam Pressure psia	Saturation Temperature °F	Specific Volume cu.ft./lb.	Heat Content (above 32°F) Btu/lb. Sensible	Latent	Total
253	267.7	407.1	1.726	382.8	820.0	1,202
254	268.7	407.4	1.720	383.2	819.6	1,202
255	269.7	407.8	1.714	383.6	819.3	1,202
256	270.7	408.1	1.707	383.9	819.0	1,202
257	271.7	408.4	1.701	384.3	818.7	1,203
258	272.7	408.8	1.695	384.6	818.4	1,203
259	273.7	409.1	1.689	385.0	818.0	1,203
260	274.7	409.4	1.683	385.3	817.7	1,203
261	275.7	409.7	1.677	385.7	817.4	1,203
262	276.7	410.1	1.671	386.0	817.1	1,203
263	277.7	410.4	1.666	386.4	816.7	1,203
264	278.7	410.7	1.660	386.7	816.4	1,203
265	279.7	411.1	1.654	387.1	816.1	1,203
266	280.7	411.4	1.648	387.5	815.8	1,203
267	281.7	411.7	1.642	387.8	815.5	1,203
268	282.7	412.0	1.637	388.2	815.2	1,203
269	283.7	412.3	1.631	388.5	814.9	1,203
270	284.7	412.7	1.625	388.9	814.6	1,203
271	285.7	413.0	1.620	389.2	814.3	1,203
272	286.7	413.3	1.614	389.5	814.0	1,203
273	287.7	413.6	1.609	389.9	813.6	1,203
274	288.7	413.9	1.603	390.3	813.3	1,203
275	289.7	414.2	1.598	390.6	813.0	1,203
276	290.7	414.5	1.593	390.9	812.7	1,203
277	291.7	414.9	1.587	391.3	812.3	1,203
278	292.7	415.2	1.582	391.6	812.0	1,203
279	293.7	415.5	1.577	392.0	811.7	1,203
280	294.7	415.8	1.571	392.3	811.4	1,203
281	295.7	416.1	1.566	392.6	811.1	1,203
282	296.7	416.4	1.561	393.0	810.8	1,203
283	297.7	416.7	1.556	393.3	810.5	1,203
284	298.7	417.0	1.551	393.7	810.2	1,203
285	299.7	417.3	1.546	394.0	809.9	1,203
286	300.7	417.6	1.541	394.3	809.6	1,203
287	301.7	417.9	1.536	394.7	809.3	1,204
288	302.7	418.2	1.531	395.0	809.0	1,204
289	303.7	418.5	1.526	395.3	808.7	1,204

Steam Pressure psig	Steam Pressure psia	Saturation Temperature °F	Specific Volume cu.ft./lb.	Heat Content (above 32°F) Btu/lb.		
				Sensible	Latent	Total
289	303.7	418.5	1.526	395.3	808.7	1,204
290	304.7	418.8	1.521	395.7	808.4	1,204
291	305.7	419.2	1.516	396.0	808.1	1,204
292	306.7	419.5	1.511	396.3	807.8	1,204
293	307.7	419.8	1.507	396.6	807.5	1,204
294	308.7	420.1	1.502	397.0	807.2	1,204
295	309.7	420.4	1.497	397.3	806.9	1,204
296	310.7	420.6	1.492	397.6	806.6	1,204
297	311.7	420.9	1.488	397.9	806.3	1,204
298	312.7	421.2	1.483	398.3	806.0	1,204
299	313.7	421.5	1.478	398.6	805.7	1,204
300	314.7	421.8	1.474	398.9	805.4	1,204
310	324.7	424.7	1.429	402.1	802.4	1,204
320	334.7	427.6	1.387	405.3	799.4	1,204
330	344.7	430.4	1.347	408.3	796.5	1,204
340	354.7	433.1	1.310	411.3	793.7	1,205
350	364.7	435.7	1.274	414.3	790.9	1,205
360	374.7	438.3	1.240	417.1	788.1	1,205
370	384.7	440.9	1.208	420.0	785.4	1,205
380	394.7	443.4	1.178	422.8	782.6	1,205
390	404.7	445.8	1.149	425.5	780.0	1,205
400	414.7	448.2	1.121	428.2	777.4	1,205
410	424.7	450.6	1.095	430.8	774.8	1,205
420	434.7	452.9	1.069	433.4	772.2	1,205
430	444.7	455.2	1.045	436.0	769.6	1,205
440	454.7	457.4	1.022	438.6	767.0	1,205
450	464.7	459.6	1.000	441.0	764.5	1,205
460	474.7	461.8	0.979	443.5	762.0	1,205
470	484.7	463.9	0.958	445.9	759.5	1,205
480	494.7	466.0	0.939	448.3	757.1	1,205
490	504.7	468.1	0.920	450.6	754.7	1,205
500	514.7	470.1	0.901	453.0	752.2	1,205
510	524.7	472.1	0.884	455.2	749.9	1,205
520	534.7	474.1	0.867	457.5	747.5	1,205
530	544.7	476.0	0.851	459.8	745.1	1,204
540	554.7	478.0	0.835	461.9	742.8	1,204
550	564.7	479.[illegible]	0.820	464.1	740.5	1,204

Steam Pressure psig	Steam Pressure psia	Saturation Temperature °F	Specific Volume cu.ft./lb.	Heat Content (above 32°F) Btu/lb.		
				Sensible	Latent	Total
550	564.7	479.9	0.820	464.1	740.5	1,204
560	574.7	481.7	0.805	466.3	738.2	1,204
570	584.7	483.6	0.791	468.4	735.9	1,204
580	594.7	485.4	0.777	470.6	733.6	1,204
590	604.7	487.2	0.764	472.7	731.3	1,204
600	614.7	488.9	0.751	474.7	729.1	1,203
610	624.7	490.7	0.739	476.7	726.9	1,203
620	634.7	492.4	0.727	478.7	724.7	1,203
630	644.7	494.1	0.715	480.7	722.5	1,203
640	654.7	495.8	0.704	482.7	720.3	1,203
650	664.7	497.5	0.693	484.7	718.1	1,202
660	674.7	499.2	0.682	486.7	715.9	1,202
670	684.7	500.8	0.671	488.6	713.8	1,202
680	694.7	502.4	0.661	490.5	711.6	1,202
690	704.7	504.0	0.651	492.4	709.5	1,201
700	714.7	505.5	0.642	494.3	707.3	1,201
710	724.7	507.1	0.632	496.2	705.2	1,201
720	734.7	508.7	0.623	498.0	703.1	1,201
730	744.7	510.2	0.614	499.8	701.0	1,200
740	754.7	511.7	0.606	501.6	698.9	1,200
750	764.7	513.2	0.597	503.4	696.8	1,200
760	774.7	514.7	0.589	505.2	694.8	1,200
770	784.7	516.1	0.581	507.0	692.7	1,199
780	794.7	517.6	0.573	508.8	690.7	1,199
790	804.7	519.0	0.566	510.5	688.6	1,199
800	814.7	520.5	0.558	512.3	686.5	1,198
810	824.7	521.9	0.551	514.0	684.6	1,198
820	834.7	523.3	0.544	515.7	682.6	1,198
830	844.7	524.7	0.537	517.4	680.6	1,198
840	854.7	526.0	0.530	519.0	678.6	1,197
850	864.7	527.4	0.523	520.7	676.6	1,197
860	874.7	528.7	0.517	522.4	674.6	1,197
870	884.7	530.1	0.511	524.1	672.6	1,196
880	894.7	531.4	0.504	525.7	670.6	1,196
890	904.7	532.7	0.498	527.4	668.6	1,196
900	914.7	534.0	0.492	529.0	666.6	1,195
910	924.7	535.3	0.486	530.6	664.7	1,195

Steam Pressure psig	Steam Pressure psia	Saturation Temperature °F	Specific Volume cu.ft./lb.	Heat Content (above 32°F) Btu/lb.		
				Sensible	Latent	Total
920	934.7	536.6	0.481	532.2	662.7	1,194
930	944.7	537.9	0.475	533.8	660.7	1,194
940	954.7	539.1	0.470	535.4	658.7	1,194
950	964.7	540.4	0.464	536.9	656.8	1,193
960	974.7	541.6	0.459	538.5	654.9	1,193
970	984.7	542.9	0.454	540.0	653.0	1,193
980	994.7	544.1	0.449	541.6	651.0	1,192
990	1,004.7	545.3	0.444	543.1	649.1	1,192
1,000	1,014.7	546.5	0.439	544.6	647.2	1,191
1,050	1,064.7	552.4	0.416	552.2	637.6	1,189
1,100	1,114.7	558.1	0.395	559.5	628.2	1,187
1,150	1,164.7	563.6	0.375	566.7	618.9	1,185
1,200	1,214.7	568.9	0.357	573.7	609.6	1,183
1,250	1,264.7	574.0	0.341	580.6	600.3	1,180
1,300	1,314.7	579.0	0.325	587.4	591.1	1,178
1,350	1,364.7	583.9	0.311	594.0	581.9	1,175
1,400	1,414.7	588.6	0.298	600.5	572.8	1,173
1,450	1,464.7	593.2	0.285	607.0	563.6	1,170
1,500	1,514.7	597.7	0.274	613.4	554.5	1,167
1,550	1,564.7	602.0	0.263	619.6	545.4	1,165
1,600	1,614.7	606.3	0.252	625.8	536.2	1,162
1,650	1,664.7	610.4	0.242	632.0	527.1	1,159
1,700	1,714.7	614.5	0.233	638.0	517.9	1,155
1,750	1,764.7	618.5	0.224	644.1	508.7	1,152
1,800	1,814.7	622.3	0.216	650.0	499.4	1,149
1,850	1,864.7	626.1	0.208	655.9	490.0	1,145
1,900	1,914.7	629.8	0.200	661.8	480.6	1,142
1,950	1,964.7	633.5	0.193	667.7	471.2	1,138
2,000	2,014.7	637.0	0.187	673.6	461.5	1,135
2,050	2,064.7	640.5	0.179	679.4	451.8	1,131
2,100	2,114.7	643.9	0.173	685.3	442.1	1,127
2,150	2,164.7	647.3	0.167	691.1	432.1	1,123
2,200	2,214.7	650.6	0.161	697.0	422.0	1,119
2,250	2,264.7	653.8	0.155	702.8	411.7	1,114
2,300	2,314.7	657.0	0.150	708.7	401.3	1,110
2,350	2,364.7	660.1	0.144	714.6	390.6	1,105

Steam Pressure psig	Steam Pressure psia	Saturation Temperature °F	Specific Volume cu.ft./lb.	Heat Content (above 32°F) Btu/lb. Sensible	Latent	Total
2,400	2,414.7	663.2	0.139	720.6	379.7	1,100
2,450	2,464.7	666.2	0.134	726.6	368.5	1,095
2,500	2,514.7	669.2	0.129	732.7	357.1	1,089

21.04. Steam Flow through Orifices

STEAM FLOW THROUGH ORIFICES

Orifice Dia. Inches	Steam Flow lbs./h Steam Pressure psig									
	2	5	10	15	25	50	75	100	125	150
1/32	0.3	0.5	0.6	0.7	0.9	1.5	2.1	2.7	3.3	3.9
1/16	1.3	1.9	2.3	2.8	3.8	6.1	8.5	10.8	13.2	15.6
3/32	2.8	4.2	5.3	6.3	8.5	13.8	19.1	24.4	29.7	35.1
1/8	4.5	7.5	9.4	11.2	15.0	24.5	34.0	43.4	52.9	62.4
5/32	7.8	11.7	14.6	17.6	23.5	38.3	53.1	67.9	82.7	97.4
3/16	11.2	16.7	21.0	25.3	33.8	55.1	76.4	97.7	119	140
7/32	15.3	22.9	28.7	34.4	46.0	75.0	104	133	162	191
1/4	20.0	29.8	37.4	45.0	60.1	98.0	136	173	212	250
9/32	25.2	37.8	47.4	56.9	76.1	124	172	220	268	316
5/16	31.2	46.6	58.5	70.3	94.0	153	212	272	331	390
11/32	37.7	56.4	70.7	85.1	114	185	257	329	400	472
3/8	44.9	67.1	84.2	101	135	221	306	391	476	561
13/32	52.7	78.8	98.8	119	159	259	359	459	559	659
7/16	61.1	91.4	115	138	184	300	416	532	648	764
15/32	70.2	105	131	158	211	344	478	611	744	877
1/2	79.8	119	150	180	241	392	544	695	847	998

Note:

1. **team leaks and energy wasted: A1/8" diameter hole in a steam pipe c lbs.Stm./h at 150 psig, resulting in 30 tons of coal, 4800 gallons of oil gas to be wasted each year (assuming 8400 hour per year operation).**

21.05. Flash Steam

FLASH STEAM

Flash Steam Flow lbs. Steam/h per 100 lbs. of S
Flash Steam Flow lbs. Steam/h per 100 lbs. of S

Condensate Pressur
Condensate Pressur

Steam Press.psig	0	1	3	5	7	10	12	15	20	25
0	0.0									
1	0.3	0.0								
3	1.0	0.6	0.0							
5	1.6	1.2	0.6	0.0						
7	2.1	1.8	1.1	0.6	0.0					
10	2.8	2.5	1.9	1.3	0.7	0.0				
12	3.3	3.0	2.3	1.7	1.2	0.5	0.0			
15	3.9	3.6	3.0	2.4	1.8	1.1	0.6	0.0		
20	4.9	4.5	3.9	3.3	2.8	2.1	1.6	1.0	0.0	
25	5.7	5.4	4.8	4.2	3.7	2.9	2.5	1.8	0.9	0.0
30	6.5	6.2	5.5	5.0	4.4	3.7	3.3	2.6	1.7	0.8
40	7.8	7.5	6.9	6.3	5.8	5.1	4.6	4.0	3.0	2.2
50	9.0	8.7	8.1	7.5	7.0	6.3	5.8	5.2	4.2	3.4
60	10.0	9.7	9.1	8.5	8.0	7.3	6.9	6.2	5.3	4.5
75	11.4	11.1	10.5	9.9	9.4	8.7	8.2	7.6	6.7	5.9
85	12.2	11.9	11.3	10.7	10.2	9.5	9.1	8.5	7.5	6.7
100	13.3	13.0	12.4	11.8	11.3	10.6	10.2	9.6	8.7	7.9
120	14.6	14.3	13.7	13.2	12.7	12.0	11.5	11.0	10.0	9.2
125	14.9	14.6	14.0	13.5	13.0	12.3	11.9	11.3	10.4	9.5
150	16.3	16.0	15.4	14.9	14.4	13.7	13.3	12.7	11.8	11.
175	17.6	17.3	16.7	16.2	15.7	15.0	14.6	14.0	13.1	12.
200	18.7	18.4	17.9	17.4	16.9	16.2	15.8	15.2	14.3	13.
225	19.8	19.5	18.9	18.4	17.9	17.3	16.9	16.3	15.4	14.
250	20.8	20.5	19.9	19.4	18.9	18.3	17.8	17.3	16.4	15.
275	21.7	21.4	20.8	20.3	19.8	19.2	18.8	18.2	17.4	16.

300	22.5	22.2	21.7	21.2	20.7	20.1	19.7	19.1	18.2	17

Flash Steam Flow lbs. Steam/h per 100 lbs. of S

21.06. Warm-up Loads

LOW-PRESSURE STEAM PIPING WARM-UP LOADS

Pipe Size	Pounds of Steam per 100 Feet of Pipe — Steam Pressure psig							
	0	1	3	5	7	10	12	15
1/2"	1	1	2	2	2	2	2	2
3/4"	2	2	2	2	2	2	2	2
1"	3	3	3	3	3	3	4	4
1-1/4"	4	4	4	4	4	5	5	5
1-1/2"	5	5	5	5	5	6	6	6
2"	6	6	7	7	7	7	8	8
2-1/2"	10	10	10	11	11	12	12	13
3"	13	13	14	14	15	15	16	17
4"	18	19	19	20	21	22	23	24
5"	25	25	26	27	28	30	31	32
6"	32	33	34	36	37	39	40	42
8"	48	49	51	54	56	58	60	62
10"	68	70	73	76	79	83	85	89
12"	83	85	89	93	96	101	104	108
14"	92	94	98	103	106	111	115	119
16"	105	108	113	118	122	128	132	137
18"	119	122	127	133	137	144	149	154
20"	132	135	142	148	153	160	166	172
22"	146	150	157	164	169	177	183	190
24"	159	163	170	178	184	193	199	207
26"	173	177	185	194	200	210	217	225
28"	187	191	200	209	216	226	234	243
30"	200	205	214	224	232	243	251	260
32"	214	219	229	239	247	259	268	278

Pipe Size	Pounds of Steam per 100 Feet of Pipe Steam Pressure psig							
	0	1	3	5	7	10	12	15
34"	227	233	243	254	263	275	284	295
36"	241	246	258	269	278	292	301	313
42"	281	288	301	314	325	341	352	366
48"	321	328	343	358	371	389	402	417
54"	361	370	387	404	418	438	453	470
60"	402	411	430	449	465	487	503	523
72"	483	494	517	539	558	585	604	628
84"	564	577	603	629	652	683	706	733
96"	645	660	690	720	745	781	807	838
Corr. Factor	1.50	1.49	1.46	1.44	1.43	1.41	1.40	1.39

Notes:

1. **Table based on 70°F ambient temperature, standard weight steel pipe to 250 psig, and extra-strong weight steel pipe above 250 psig.**
2. **For ambient temperatures of 0°F, multiply table values by correction factor.**

MEDIUM-PRESSURE STEAM PIPING WARM-UP LOADS

Pipe Size	Pounds of Steam per 100 Feet of Pipe Steam Pressure psig								
	20	25	30	40	50	60	75	85	100
1/2"	2	2	2	2	2	3	3	3	3
3/4"	3	3	3	3	3	3	4	4	4
1"	4	4	4	5	5	5	5	6	6
1-1/4"	5	6	6	6	7	7	7	8	8
1-1/2"	6	7	7	7	8	8	9	9	10
2"	8	9	9	10	11	11	12	12	13
2-1/2"	13	14	15	16	17	17	19	19	20
3"	18	18	19	21	22	23	24	25	27
4"	25	26	27	29	31	32	35	36	38
5"	34	35	37	40	42	44	47	49	51

Pipe Size	Pounds of Steam per 100 Feet of Pipe — Steam Pressure psig								
	20	**25**	**30**	**40**	**50**	**60**	**75**	**85**	**100**
6"	44	46	48	51	55	57	61	63	66
8"	66	69	72	77	82	86	92	95	100
10"	94	98	102	110	116	122	130	135	142
12"	115	120	125	134	142	149	159	165	173
14"	126	132	138	148	157	164	175	182	191
16"	145	152	158	170	180	188	201	209	219
18"	163	171	178	191	203	213	227	235	247
20"	182	191	198	213	226	237	252	262	275
22"	201	211	220	236	250	262	279	290	304
24"	219	229	239	257	272	285	304	316	331
26"	238	250	260	279	296	310	331	344	360
28"	257	269	280	301	319	334	356	370	388
30"	275	289	300	323	342	358	382	397	416
32"	294	308	321	344	365	382	408	424	444
34"	312	327	341	366	388	407	434	450	472
36"	331	347	361	388	411	431	459	477	500
42"	386	405	422	453	480	503	536	557	584
48"	441	463	482	517	548	574	612	636	667
54"	497	521	542	583	617	647	690	717	751
60"	552	579	603	648	686	719	767	797	835
72"	664	696	724	778	825	864	921	957	1,003
84"	775	812	846	908	963	1,009	1,075	1,117	1,171
96"	886	929	967	1,039	1,101	1,153	1,230	1,278	1,340
Corr. Factor	1.37	1.36	1.35	1.32	1.31	1.29	1.28	1.27	1.26

Notes:

1. **Table based on 70°F ambient temperature, standard weight steel pipe to 250 psig, and extra-strong weight steel pipe above 250 psig.**

2. **For ambient temperatures of 0°F, multiply table values by the correction factor.**

HIGH-PRESSURE STEAM PIPING WARM-UP LOADS

Pipe Size	Pounds of Steam per 100 Feet of Pipe — Steam Pressure psig								
	120	125	150	175	200	225	250	275	300
1/2"	3	3	3	4	4	4	4	4	5
3/4"	4	4	4	5	5	5	5	6	7
1"	6	6	7	7	7	8	8	8	11
1-1/4"	8	9	9	9	10	10	11	11	15
1-1/2"	10	10	11	11	12	12	13	13	18
2"	14	14	14	15	16	17	17	18	25
2-1/2"	21	22	23	24	25	26	27	28	39
3"	28	28	30	32	33	34	36	37	52
4"	40	40	43	45	47	49	51	53	75
5"	54	55	58	61	64	66	69	71	104
6"	70	71	75	79	83	86	89	92	144
8"	106	107	113	119	125	129	134	139	218
10"	150	152	161	169	177	184	191	197	275
12"	183	186	197	206	216	225	233	241	329
14"	202	204	217	227	238	247	257	266	362
16"	231	234	248	261	273	284	295	305	416
18"	261	264	280	294	308	320	332	343	470
20"	290	294	312	327	343	356	370	382	523
22"	322	326	345	362	380	394	409	423	578
24"	350	354	375	394	413	429	445	460	631
26"	381	386	409	429	449	467	485	501	384
28"	410	416	440	462	484	503	522	540	739
30"	440	446	472	496	519	540	560	579	794
32"	469	476	504	529	554	576	598	618	844
34"	499	506	536	562	589	612	635	657	900
36"	528	536	567	596	624	648	673	696	955
42"	617	626	663	696	729	757	786	813	1,116
48"	705	714	757	794	832	865	898	928	1,275
54"	794	805	852	895	937	974	1,011	1,045	1,436
60"	883	894	948	995	1,042	1,083	1,124	1,162	1,597
72"	1,060	1,075	1,139	1,195	1,252	1,301	1,350	1,396	1,946

Notes:

Pipe Size	120	125	150	175	200	225	250	275	300
	Pounds of Steam per 100 Feet of Pipe — Steam Pressure psig								
84"	1,238	1,254	1,329	1,395	1,461	1,518	1,576	1,630	2,241
96"	1,415	1,435	1,520	1,595	1,671	1,737	1,803	1,864	2,510
Corr. Factor	1.25	1.25	1.24	1.23	1.22	1.22	1.21	1.21	1.20

Notes:

1. **Table based on 70°F ambient temperature, standard weight steel pipe to 250 psig, and extra-strong weight steel pipe above 250 psig.**
2. **For ambient temperatures of 0°F, multiply table values by the correction factor.**

21.07. Steam Operating Loads

LOW-PRESSURE STEAM PIPING OPERATING LOADS

Pipe Size	Pounds of Steam per Hour per 100 Feet of Pipe — Steam Pressure psig							
	0	1	3	5	7	10	12	15
1/2"	2	2	2	2	3	3	3	3
3/4"	3	3	3	3	3	3	3	4
1"	3	3	3	4	4	4	4	4
1-1/4"	4	4	4	4	5	5	5	5
1-1/2"	4	4	5	5	5	6	6	6
2"	5	5	6	6	6	7	7	7
2-1/2"	6	6	7	7	7	8	8	9
3"	7	8	8	8	9	9	10	10
4"	9	9	10	10	11	12	12	13
5"	11	11	12	13	13	14	15	15
6"	13	13	14	15	15	16	17	18
8"	16	17	18	19	19	21	22	23
10"	20	20	21	23	24	25	26	28
12"	23	24	25	26	28	29	31	32
14"	25	26	27	29	30	32	33	35

Notes:

1. **Table based on 70°F ambient temperature, standard weight steel**

Pipe Size	Pounds of Steam per Hour per 100 Feet of Pipe — Steam Pressure psig 0	1	3	5	7	10	12	15
16"	28	29	31	32	34	36	38	40
18"	31	32	34	36	38	40	42	44
20"	34	35	37	39	41	44	46	48
22"	37	38	41	43	45	48	50	53
24"	40	41	44	47	49	52	54	57
26"	47	48	51	54	57	60	63	66
28"	50	52	55	58	61	65	68	72
30"	54	56	59	62	65	70	73	77
32"	57	59	63	67	70	74	78	82
34"	61	63	67	71	74	79	83	87
36"	65	67	71	75	78	84	87	92
42"	75	78	83	87	92	98	102	107
48"	86	89	94	100	105	112	117	123
54"	97	100	106	112	118	125	131	138
60"	108	111	118	125	131	139	146	153
72"	129	133	141	150	157	167	175	184
84"	151	156	165	175	183	195	204	215
96"	172	178	189	200	209	223	233	245
Corr. Factor	1.70	1.68	1.66	1.64	1.60	1.58	1.57	1.55

Notes:

1. **Table based on 70°F ambient temperature, standard weight steel pipe to 250 psig, and extra-strong weight steel pipe above 250 psig.**

2. **For ambient temperatures of 0°F, multiply the table values by the correction factor.**

3. **Table values include convection and radiation loads with 80 percent efficient insulation.**

MEDIUM-PRESSURE STEAM PIPING OPERATING LOADS

Pounds of Steam per Hour per 100 Feet of Pipe

Pipe

Notes:

Steam Pressure psig

Pounds of Steam per Hour per 100 Feet of Pipe

Pipe Size	Steam Pressure psig 20	25	30	40	50	60	75	85	100
1/2"	3	3	4	4	4	5	5	5	6
3/4"	4	4	4	5	5	6	6	6	7
1"	5	5	5	6	6	7	7	8	8
1-1/4"	6	6	6	7	8	8	9	9	10
1-1/2"	6	7	7	8	9	9	10	11	11
2"	8	8	9	10	11	11	12	13	14
2-1/2"	9	10	10	12	12	13	14	15	16
3"	11	12	12	14	15	16	17	18	19
4"	14	15	16	17	18	20	21	23	24
5"	17	18	19	21	22	24	26	27	29
6"	19	21	22	24	26	28	30	32	34
8"	25	26	28	30	33	35	38	40	43
10"	30	32	34	37	40	43	47	49	53
12"	35	37	39	43	47	50	54	57	61
14"	38	40	43	47	51	54	59	62	67
16"	43	45	48	53	57	61	67	70	75
18"	47	50	53	59	64	68	74	78	84
20"	52	56	59	65	70	75	82	86	92
22"	57	60	64	70	76	81	89	94	101
24"	61	65	69	76	83	88	96	102	109
26"	72	77	81	89	97	103	113	110	117
28"	77	82	87	96	104	111	122	129	138
30"	83	88	93	103	112	119	131	138	148
32"	88	94	100	110	119	127	139	147	157
34"	94	100	106	117	127	135	148	156	167
36"	99	106	112	124	134	143	157	166	177
42"	116	124	131	144	157	167	183	193	207
48"	132	141	149	165	179	191	209	221	236
54"	149	159	168	186	201	215	235	248	266
60"	165	177	187	206	224	239	261	276	295
72"	199	212	224	247	268	287	314	331	354
84"	232	247	261	289	313	334	366	386	413
96"	265	283	299	330	358	382	418	442	472

Notes:

1. Table based on 70°F ambient temperature, standard weight steel pipe to 250 psig, and extra strong weight steel pipe above 250

Pipe Size	Pounds of Steam per Hour per 100 Feet of Pipe — Steam Pressure psig								
	20	25	30	40	50	60	75	85	100
Corr. Factor	1.52	1.51	1.50	1.48	1.47	1.45	1.43	1.42	1.41

Notes:

1. **Table based on 70°F ambient temperature, standard weight steel pipe to 250 psig, and extra-strong weight steel pipe above 250 psig.**
2. **For ambient temperatures of 0°F, multiply the table values by the correction factor.**
3. **Table values include convection and radiation loads with 80 percent efficient insulation.**

HIGH-PRESSURE STEAM PIPING OPERATING LOADS

Pipe Size	Pounds of Steam per Hour per 100 Feet of Pipe — Steam Pressure psig								
	120	125	150	175	200	225	250	275	300
1/2"	6	6	7	7	8	8	8	9	9
3/4"	7	7	8	9	9	10	10	11	11
1"	9	9	10	10	11	12	12	13	14
1-1/4"	11	11	12	13	14	14	15	16	17
1-1/2"	12	12	13	14	15	16	17	18	19
2"	15	15	16	18	19	20	21	22	23
2-1/2"	18	18	19	21	22	23	25	26	27
3"	21	21	23	25	26	28	29	31	32
4"	26	27	29	31	33	35	37	38	40
5"	31	32	35	37	40	42	44	46	49
6"	37	38	41	44	46	49	52	54	57
8"	47	48	52	55	59	62	66	69	72
10"	57	58	63	67	72	76	80	84	88
12"	66	68	73	79	84	89	93	98	103
14"	72	74	80	85	91	96	102	107	112
16"	81	83	90	96	103	109	115	121	126
18"	91	92	100	107	115	121	128	134	141

Notes:

Pipe Size	Pounds of Steam per Hour per 100 Feet of Pipe								
	Steam Pressure psig								
	120	125	150	175	200	225	250	275	300
18"	91	92	100	107	115	121	128	134	141
20"	100	102	110	118	126	134	141	148	155
22"	109	111	120	129	138	146	154	161	169
24"	118	120	130	140	140	158	167	175	183
26"	127	129	140	150	161	170	179	188	197
28"	149	152	165	177	189	182	192	201	211
30"	160	163	177	190	203	214	226	237	249
32"	170	174	189	202	216	229	241	253	265
34"	181	185	200	215	230	243	256	269	282
36"	192	195	212	228	243	257	271	285	299
42"	224	228	248	265	284	300	317	332	348
48"	256	261	283	303	324	343	362	380	398
54"	287	293	318	341	365	386	407	427	448
60"	319	326	354	379	406	429	452	475	498
72"	383	391	425	455	487	514	543	570	597
84"	447	456	495	531	568	600	633	665	697
96"	511	521	566	607	649	686	724	760	796
Corr. Factor	1.39	1.39	1.39	1.38	1.37	1.37	1.36	1.36	1.35

Notes:

1. **Table based on 70°F ambient temperature, standard weight steel pipe to 250 psig, and extra-strong weight steel pipe above 250 psig.**
2. **For ambient temperatures of 0°F, multiply the table values by the correction factor.**
3. **Table values include convection and radiation loads with 80 percent efficient insulation.**

21.08. Boiling Points of Water

BOILING POINTS OF WATER

Psia	Boiling Point °F	Psia	Boiling Point °F	Psia	Boiling Point °F

Psia	Boiling Point °F	Psia	Boiling Point °F	Psia	Boiling Point °F
0.5	79.6	44	273.1	150	358.5
1	101.7	46	275.8	175	371.8
2	126.0	48	278.5	200	381.9
3	141.4	50	281.0	225	391.9
4	152.9	52	283.5	250	401.0
5	162.2	54	285.9	275	409.5
6	170.0	56	288.3	300	417.4
7	176.8	58	290.5	325	424.8
8	182.8	60	292.7	350	431.8
9	188.3	62	294.9	375	438.4
10	193.2	64	297.0	400	444.7
11	197.7	66	299.0	425	450.7
12	201.9	68	301.0	450	456.4
13	205.9	70	303.0	475	461.9
14	209.6	72	304.9	500	467.1
14.69	212.0	74	306.7	525	472.2
15	213.0	76	308.5	550	477.1
16	216.3	78	310.3	575	481.8
17	219.4	80	312.1	600	486.3
18	222.4	82	313.8	625	490.7
19	225.2	84	315.5	650	495.0
20	228.0	86	317.1	675	499.2
22	233.0	88	318.7	700	503.2
24	237.8	90	320.3	725	507.2
26	242.3	92	321.9	750	511.0
28	246.4	94	323.4	775	514.7
30	250.3	96	324.9	800	518.4

Psia	Boiling Point °F	Psia	Boiling Point °F	Psia	Boiling Point °F
32	254.1	98	326.4	825	521.9
34	257.6	100	327.9	850	525.4
36	261.0	105	331.4	875	528.8
38	264.2	110	334.8	900	532.1
40	267.3	115	338.1	950	538.6
42	270.2	120	341.3	1000	544.8

21.09. Steam Heating Units of Measure

COMPARISON OF COMMON STEAM HEATING UNITS OF MEASURE

MBH (1000 Btuh)	Steam lbs./h	EDR sq.ft.	Boiler hp	Condensate Flow Rate GPM	Cond. Pump Capacity GPM (2)
10	10.6	42	0.3	0.02	0.06
25	26.4	104	0.7	0.05	0.15
50	52.9	208	1.5	0.10	0.30
75	79.3	313	2.2	0.16	0.48
100	105.8	417	2.9	0.21	0.63
200	211.5	833	5.8	0.41	1.23
300	317.3	1,250	8.7	0.62	1.86
400	423.0	1,667	11.6	0.83	2.49
500	528.8	2,083	14.5	1.03	3.09
750	793.1	3,125	21.7	1.55	4.65
1,000	1,058	4,167	29.0	2.07	6.21
1,250	1,322	5,208	36.2	2.58	7.74
1,500	1,418	6,250	43.5	3.10	9.30
1,750	1,851	7,292	50.7	3.62	10.8
2,000	2,115	8,333	58.0	4.13	12.4

Notes:

MBH (1000 Btuh)	Steam lbs./h	EDR sq.ft.	Boiler hp	Condensate Flow Rate GPM	Cond. Pump Capacity GPM (2)
2,500	2,644	10,417	72.5	5.17	15.5
3,000	3,173	12,500	87.0	6.20	18.6
4,000	4,230	16,667	115.9	8.27	24.8
5,000	5,288	20,833	144.9	10.3	30.9
7,500	7,931	31,250	217.4	15.5	46.5
10,000	10,575	41,667	289.9	20.7	62.1
15,000	15,862	62,500	434.8	31.0	93.0
20,000	21,150	83,333	579.7	41.3	124
25,000	26,438	104,167	724.6	51.7	155
30,000	31,725	125,000	869.6	62.0	186
35,000	37,014	145,833	1,015	72.3	217
40,000	42,301	166,667	1,159	82.7	248
50,000	52,876	208,333	1,449	103.3	310

Notes:

1. **Steam flow rate is based on 15 psig steam with an enthalpy of 945.6 Btu/lb.**
2. **Condensate pump capacity is equal to three times the condensate flow rate.**

21.10. Low-Pressure Steam Pipe Sizing Tables (15 psig and Less)

1 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./h						
	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h			
	0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)
1/2	4	6	9		Pressure drop governs these pipe sizes		
3/4	10	14	20	18			
1	20	28	40	29			
1-1/4	44	62	87	49	[illegible]		
1-1/2	68	96	135	67	135		
2	137	194	274	111	222		
2-1/2	226	320	452	158	317		
3	414	585	822	245	489	734	
4	874	1,236	1,748	421	842	1,263	1,685
5	1,608	2,274	3,217	659	1,318	1,978	2,637
6	2,654	3,753	5,308	956	1,912	2,867	3,823
8	5,525	7,813		1,655	3,310	4,965	6,620
10	10,082	14,258	Velocity governs these pipe sizes	2,609	5,218	7,826	10,435
12	16,181			3,742	7,483	11,225	14,967
14	20,959			4,562	9,123	13,685	18,247
16	30,212			6,043	12,086	18,128	24,171
18	41,576			7,732	15,463	23,195	30,927
20	55,192			9,629	19,257	28,886	38,514
22				11,733	23,466	35,200	46,933
24				14,046	28,092	42,137	56,183
26				16,566	33,132	49,698	66,265
28				19,294	38,589	57,883	77,178
30				22,231	44,461	66,692	88,922
32				25,375	50,749	76,124	101,498
34				28,726	57,453	86,179	114,906
36				32,286	64,572	96,859	129,145
42				44,213	88,425	132,638	176,851
48				58,010	116,020	174,030	232,040
54				73,678	147,356	221,034	294,712
60				91,217	182,434	273,651	364,868
72				131,907	263,815	395,722	527,629
84				180,081	360,162	540,243	720,324

Notes:

96				235,738	471,475	707,213	942,951

Notes:

1. Maximum recommended pressure drop/velocity: 0.125 psig/100 ft./4,0

2. Table based on Standard Weight Steel Pipe using steam equations in

Steam Flow lbs./h
Pipe Size | Pressure Drop psig/100 ft. | Velocity FPM (mph)
0.125 | 0.25 | 0.5 | 2,000 (23) | 4,000 (45) | 6,000 (68) | 8,000 (91)

3 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

	Steam Flow lbs./h						
Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)
1/2	5	6	9		Pressure	drop	governs
3/4	10	15	21	20	these	pipe	sizes
1	21	30	42	32			
1-1/4	46	65	92	55			
1-1/2	72	101	143	75			
2	145	205	290	124	248		
2-1/2	239	338	478	177	354		
3	437	619	870	274	547	821	
4	924	1,307	1,849	471	942	1,413	
5	1,701	2,405	3,402	737	1,475	2,212	2,949
6	2,807	3,969	5,614	1,069	2,138	3,207	4,276
8	5,843	8,263		1,851	3,702	5,553	7,404
10	10,662	15,078	with	2,918	5,835	8,753	11,670
12	17,112	24,200	sizes	4,185	8,369	12,554	16,738
14	22,165			5,102	10,204	15,305	20,407
16	31,951	governs		6,758	13,516	20,275	27,033
18	43,968	pipe		8,647	17,294	25,941	34,588
20	58,368			10,768	21,537	32,305	43,074

Notes:

1. Maximum recommended pressure drop/velocity: 0.125 psig/100 ft./4,0

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Steam Flow lbs./h — Velocity FPM (mph) 2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)
22	75,290			13,122	26,245	39,367	52,489
24				15,709	31,417	47,126	62,834
26				18,527	37,055	55,582	74,110
28	Velocity			21,579	43,157	64,736	86,315
30	these			24,862	49,725	74,587	99,450
32				28,379	56,757	85,136	113,515
34				32,127	64,255	96,382	128,509
36				36,109	72,217	108,326	144,434
42				49,447	98,894	148,341	197,788
48				64,878	129,755	194,633	259,511
54				82,401	164,801	247,202	329,603
60				102,016	204,032	306,048	408,064
72				147,524	295,047	442,571	590,094
84				201,400	402,801	604,201	805,601
96				263,646	527,292	790,939	1,054,585

Notes:

1. Maximum recommended pressure drop/velocity: 0.125 psig/100 ft./4,0

2. Table based on Standard Weight Steel Pipe using steam equations in

5 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Steam Flow lbs./h — Velocity FPM (mph) 2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)
1/2	5	7	10		Pressure	drop	governs
3/4	11	15	22	22	these	pipe	sizes
1	22	31	44	35			
1- 1/4	48 75	69 106	97 150	61 83			
1- 1/2	153	216	305	137	275		

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./6,0

2. Table based on Standard Weight Steel Pipe using steam equations in

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Steam Flow lbs./h Velocity FPM (mph) 2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)
1/2							
2							
2	251	355	503	196	392		
1/2	460	651	914	302	605	907	
3	972	1,375	1,944	521	1,042	1,563	
4							
5	1,789	2,529	3,577	815	1,631	2,446	3,261
6	2,952	4,174	5,903	1,182	2,364	3,546	4,728
8	6,144	8,689		2,047	4,094	6,141	8,188
10	11,212	15,856		3,226	6,453	9,679	12,906
12	17,995	25,449		4,628	9,255	13,883	18,510
14	23,309	32,964		5,642	11,284	16,926	22,567
16	33,599			7,474	14,947	22,421	29,894
18	46,237			9,562	19,125	28,687	38,250
20	61,380			11,908	23,817	35,725	47,633
22	79,175			14,511	29,023	43,534	58,045
24	99,764			17,371	34,743	52,114	69,486
26				20,489	40,977	61,466	81,955
28				23,863	47,726	71,589	95,452
30				27,494	54,988	82,483	109,977
32				31,383	62,765	94,148	125,531
34	Velocity	governs	with	35,528	71,056	106,585	142,113
36	these	pipe	sizes	39,931	79,862	119,792	159,723
42				54,681	109,362	164,044	218,725
48				71,745	143,491	215,236	286,981
54				91,123	182,247	273,370	364,493
60				112,815	225,630	338,445	451,260
72							163,140
84							222,720
96							291,555

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./6,0**
2. **Table based on Standard Weight Steel Pipe using steam equations in**

7 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h Velocity FPM (mp			
	0.125	0.25	0.5	2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)
1/2	5	7	10		Pressure	drop	governs
3/4	11	16	23		these	pipe	sizes
1	23	33	46	39			
1-1/4	51	72	101	67			
1-1/2	79	111	157	91			
2	160	226	319	150	300		
2-1/2	263	372	526	214	429		
3	481	680	956	331	662		
4	1,016	1,438	2,033	570	1,139	1,709	
5	1,870	2,645	3,741	892	1,783	2,675	3,567
6	3,087	4,365	6,174	1,293	2,586	3,879	5,171
8	6,426	9,087	12,851	2,239	4,477	6,716	8,955
10	11,726	16,583	with	3,529	7,057	10,586	14,115
12	18,819	26,614	sizes	5,061	10,122	15,183	20,244
14	24,376	34,473		6,170	12,341	18,511	24,682
16	35,138	governs		8,174	16,348	24,521	32,695
18	48,354	pipe		10,458	20,917	31,375	41,833
20	64,191			13,024	26,048	39,072	52,096
22	82,801			15,871	31,742	47,613	63,483
24	104,332			18,999	37,998	56,997	75,996
26	128,924			22,408	44,816	67,224	89,633
28	Velocity			26,099	52,197	78,296	104,394
30	these			30,070	60,140	90,210	120,280
32				34,323	68,646	102,968	137,291

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./6,00

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Steam Flow lbs./h Velocity FPM (mph) 2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)
34				38,857	77,715	116,570	155,427
36				43,672	87,344	131,015	174,687
42				59,804	119,608	179,412	239,216
48				78,467	156,934	235,401	313,868
54				99,660	199,321	298,981	398,641
60				123,384	246,768	370,153	493,537
72				178,424	356,847	535,271	713,695
84				243,585	487,171	730,756	974,342
96				318,869	637,739	956,608	1,275,478

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./6,0**
2. **Table based on Standard Weight Steel Pipe using steam equations in**

10 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft. 0.25	0.5	1	Steam Flow lbs./h Velocity FPM (mph) 2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)
1/2	8	11	15	15	Pressure	drop pipe	governs
3/4	17	24	34	27	these		sizes
1	35	49	69	44			
1-1/4	76	108	152	76	151		
1-1/2	118	167	236	103	206		
2	240	339	479	169	339		
2-1/2	395	558	790	242	484	725	
3	723	1,016	1,445	373	747	1,120	
4	1,527	2,160	3,054	643	1,286	1,929	2,572
5	2,810	3,974	5,620	1,006	2,013	3,019	4,025

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h			
				Velocity FPM (mp			
	0.25	0.5	1	2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)
6	4,637	6,558		1,459	2,918	4,377	5,836
8	9,654	13,652		2,526	5,053	7,579	10,105
10	17,616	24,912	with	3,982	7,964	11,946	15,929
12	28,273		sizes	5,711	11,423	17,134	22,846
14	36,621			6,963	13,927	20,890	27,853
16	52,789	governs		9,224	18,448	27,672	36,896
18		pipe		11,802	23,604	35,406	47,208
20				14,697	29,395	44,092	58,790
22	Velocity			17,910	35,820	53,730	71,641
24	these			21,440	42,880	64,320	85,760
26				25,287	50,575	75,862	101,150
28				29,452	58,904	88,356	117,808
30				33,934	67,868	101,802	135,735
32				38,733	77,466	116,199	154,932
34				43,849	87,699	131,548	175,398
36				49,283	98,567	147,850	197,133
42				67,488	134,977	202,465	269,954
48				88,549	177,098	265,648	354,197
54				112,466	224,932	337,397	449,863
60				139,238	278,476	417,714	556,952
72				201,350	402,699	604,049	805,399
84				274,884	549,768	824,653	1,099,53
96				359,841	719,683	1,079,524	1,439,36

Notes:

1. **Maximum recommended pressure drop/velocity: 0.5 psig/100 ft./6,00**
2. **Table based on Standard Weight Steel Pipe using steam equations in**

12 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.	Steam Flow lbs./h
		Velocity FPM (mp

Pipe Size	Pressure Drop psig/100 ft. 0.25	0.5	1	Steam Flow lbs./h Velocity FPM (mph) 2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)
1/2	8	11	16		Pressure	drop pipe	governs
3/4	18	25	36	29	these		sizes
1	36	51	72	47			
1-1/4	79	112	158	81			
1-1/2	123	173	245	111	221		
2	249	352	497	182	365		
2-1/2	410	579	819	260	520	780	
3	750	1,054	1,499	402	803	1,205	
4	1,584	2,240	3,168	692	1,383	2,075	2,767
5	2,915	4,122	5,830	1,083	2,165	3,248	4,331
6	4,810	6,803		1,570	3,139	4,709	6,279
8	10,013	14,161		2,718	5,436	8,154	10,873
10	18,272			4,284	8,569	12,853	17,138
12	29,326			6,145	12,290	18,435	24,580
14	37,986			7,492	14,984	22,475	29,967
16	54,755	governs	with	9,924	19,848	29,773	39,697
18	75,351	pipe	sizes	12,698	25,396	38,094	50,792
20				15,813	31,626	47,439	63,252
22	Velocity			19,270	38,539	57,809	77,079
24	these			23,068	46,135	69,203	92,270
26				27,207	54,414	81,621	108,828
28				31,688	63,375	95,063	126,750
30				36,510	73,019	109,529	146,039
32				41,673	83,346	125,019	166,693
34				47,178	94,356	141,534	188,712
36				53,024	103,048	159,073	212,097
42				72,611	145,223	217,834	290,445
48				95,271	190,542	285,812	381,093
54				121,003	242,006	363,008	484,011
60				149,807	299,615	449,422	599,229

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h		Velocity FPM (mp	
	0.25	0.5	1	2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)
72				216,634	433,267	649,901	866,535
84				295,750	591,500	887,250	1,183,00
96				387,156	774,312	1,161,469	1,548,63

Notes:

1. **Maximum recommended pressure drop/velocity: 0.5 psig/100 ft./8,000**
2. **Table based on Standard Weight Steel Pipe using steam equations in**

15 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h		Velocity FPM (mp	
	0.25	0.5	1	2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)
1/2	8	12	16		Pressure	drop pipe	governs
3/4	19	26	37	32	these		sizes
1	38	53	75	52			
1-1/4	83	117	166	90			
1-1/2	129	182	258	122	244		
2	261	370	523	201	403		
2-1/2	430	609	861	287	575	862	
3	788	1,107	1,575	444	887	1,331	
4	1,665	2,354	3,329	764	1,528	2,291	3,055
5	3,063	4,332	6,126	1,196	2,391	3,587	4,782
6	5,055	7,149	10,110	1,733	3,467	5,200	6,934
8	10,522	14,881		3,002	6,003	9,005	12,006
10	19,201	27,155	with	4,731	9,463	14,194	18,925
12	30,817		sizes	6,786	13,572	20,358	27,143
14	39,918			8,273	16,546	24,820	33,093
16	57,540	governs		10,959	21,918	32,878	43,837

Notes:

Pipe Size	Pressure Drop psig/100 ft. 0.25	0.5	1	Steam Flow lbs./h Velocity FPM (mp 2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)
18	79,183	pipe		14,022	28,045	42,067	56,089
20				17,462	34,925	52,387	69,849
22	Velocity			21,279	42,559	63,838	85,118
24	these			25,473	50,947	76,420	101,894
26				30,044	60,089	90,133	120,178
28				34,992	69,985	104,977	139,970
30				40,317	80,635	120,952	161,270
32				46,019	92,039	138,058	184,078
34				52,098	104,197	156,295	208,394
36				58,554	117,109	175,663	234,218
42				80,184	160,368	240,553	320,737
48					105,207	210,414	315,621
54					133,623	267,245	400,868
60					165,431	330,863	496,294
72	239,227				478,455	717,682	956,909
84	326,595				653,190	979,785	1,306,38
96	427,534				855,069	1,282,603	1,710,13

Notes:

1. **Maximum recommended pressure drop/velocity: 0.5 psig/100 ft./6,00(**
2. **Table based on Standard Weight Steel Pipe using steam equations in**

21.11. Medium-Pressure Steam Pipe Sizing Tables (20–100 psig)

20 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft. 0.25	0.5	1	Steam Flow lbs./h Velocity FPM (n 4,000 (45)	6,000 (68)	8,000 (91)	10,0 (11(
1/2	9	13	18		Pressure	drop pipe	gover
3/4	20	29	40		these		sizes

Notes:

1. **Maximum recommended pressure drop/velocity: 0.5 psig/100 ft./8,000**

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h		Velocity FPM (m	
	0.25	0.5	1	4,000 (45)	6,000 (68)	8,000 (91)	10,0 (11
1	41	57	81				
1-1/4	89	126	178				
1-1/2	139	196	277				
2	281	397	562	466			
2-1/2	463	655	926	665			
3	847	1,191	1,695	1,026	1,540		
4	1,790	2,532	3,581	1,767	2,651	3,535	
5	3,295	4,659	6,589	2,766	4,150	5,533	
6	5,437	7,689	10,874	4,011	6,016	8,022	10,02
8	11,318	16,006	22,636	6,945	10,418	13,891	17,36
10	20,653	29,208	with	10,948	16,421	21,895	27,36
12	33,148	46,878	sizes	15,702	23,553	31,403	39,25
14	42,936	60,720		19,143	28,715	38,286	47,85
16	61,891	87,527		25,358	38,038	50,717	63,39
18	85,170	120,449		32,446	48,669	64,892	81,11
20	113,063			40,406	60,609	80,812	101,0
22	145,843	governs		49,238	73,857	98,476	123,0
24	183,768	pipe		58,943	88,414	117,885	147,3
26	227,082			69,519	104,279	139,039	173,7
28	276,022			80,969	121,453	161,937	202,4
30	330,813			93,290	139,935	186,580	233,2
32	397,670			106,484	159,726	212,968	266,2
34	Velocity			120,550	180,825	241,100	301,3
36	these			135,488	203,232	270,977	338,7
42				185,537	278,306	371,075	463,8
48				243,437	365,156	486,875	608,5
54				309,188	463,782	618,376	772,9
60				382,790	574,185	765,580	956,9
72				553,546	830,318	1,107,091	1,383,
84				755,705	1,133,557	1,511,409	1,889,
96				989,267	1,483,901	1,978,534	2,473,

Notes:

Steam Flow lbs./h

1. Maximum recommended pressure drop/velocity: 0.5 psig/100 ft./8,00(

Pressure Drop psig/100 ft.

Pipe Size

Velocity FPM (n

2. Table based on Standard Weight Steel Pipe using steam equations in

4,000 6,000 8,000 10,0

25 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

	Steam Flow lbs./h						
Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (r			
	0.25	0.5	1	4,000 (45)	6,000 (68)	8,000 (91)	10 (1
1/2	9	13	19		Pressure	drop pipe	gove
3/4	21	30	43		these		size:
1	43	61	86				
1-1/4	95	134	190				
1-1/2	148	209	295				
2	299	423	599	529			
2-1/2	493	697	986	754			
3	902	1,269	1,805	1,164	1,747		
4	1,907	2,697	3,814	2,005	3,008		
5	3,509	4,963	7,018	3,138	4,708	6,277	
6	5,791	8,190	11,582	4,550	6,825	9,100	11,3
8	12,055	17,048	24,110	7,879	11,819	15,759	19,6
10	21,998	31,110	43,996	12,420	18,629	24,839	31,0
12	35,306	49,930		17,813	26,719	35,626	44,5
14	45,731	64,674		21,717	32,576	43,434	54,2
16	65,920	93,225	with	28,768	43,152	52,536	71,9
18	90,715	128,291	sizes	36,809	55,213	73,617	92,0
20	120,424	170,306		45,839	68,758	91,677	114,
22	155,339	governs		55,858	83,788	111,717	139,
24	195,732	pipe		66,868	100,302	133,735	167,

Notes:

Pipe Size	Pressure Drop psig/100 ft. 0.25	0.5	1	Steam Flow lbs./h Velocity FPM (... 4,000 (45)	6,000 (68)	8,000 (91)	10... (1...
26	241,867			78,867	118,300	157,733	197,...
28	293,993			91,855	137,783	183,710	229,...
30	352,351			105,833	158,750	211,667	264,...
32	417,171			120,801	181,201	241,602	302,...
34	488,677			136,758	205,137	273,517	341,...
36	567,084			153,705	230,558	307,410	384,...
42				210,484	315,725	420,967	526,...
48	Velocity			276,168	414,253	552,337	690,...
54	these			350,760	526,140	701,519	876,...
60				434,257	651,386	868,515	1,08...
72				627,972	941,958	1,255,944	1,56...
84				857,312	1,285,968	1,714,624	2,14...
96				1,122,278	1,683,417	2,244,556	2,80...

Notes:

1. **Maximum recommended pressure drop/velocity: 0.5 psig/100 ft./8,00...**
2. **Table based on Standard Weight Steel Pipe using steam equations in...**

30 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft. 0.25	0.5	1	Steam Flow lbs./h Velocity FPM (... 4,000 (45)	6,000 (68)	8,000 (91)	10... (1...
1/2	10	14	20		Pressure	drop pipe	gove...
3/4	23	32	45		these		size...
1	46	65	91				
1-1/4	101	142	201				
1-1/2	156	221	312				
2	317	448	633	591			
...	521	727	1,043	843			

Pipe Size	Pressure Drop psig/100 ft. 0.25	0.5	1	Steam Flow lbs./h — Velocity FPM (… 4,000 (45)	6,000 (68)	8,000 (91)	10… (1…
2-1/2	521	737	1,043	843			
3	954	1,342	1,909	1,302			
4	2,017	2,852	4,034	2,243	3,364		
5	3,711	5,249	7,423	3,310	5,266	7,621	
6	6,125	8,662	12,249	5,090	7,634	10,179	
8	12,749	18,030	25,499	8,813	13,220	17,626	22,0
10	23,265	32,902	46,530	13,891	20,837	27,783	34,7
12	37,340	52,806	74,679	19,924	29,886	39,848	49,8
14	48,365	68,399		24,291	36,436	48,582	60,7
16	69,717	98,595	with	32,178	48,266	64,355	80,4
18	95,940	135,680	sizes	41,171	61,757	82,342	102,
20	127,361	180,116		51,271	76,907	102,543	128,
22	164,286	232,336		62,479	93,718	124,957	156,
24	207,006			74,793	112,189	149,586	186,
26	255,799			88,214	132,321	176,428	220,
28	310,927	governs		102,742	154,113	205,483	256,
30	372,647	pipe		118,376	177,565	236,753	295,
32	441,200			135,118	202,677	270,236	337,
34	516,825			152,967	229,450	305,933	382,
36	599,748			171,922	257,883	343,844	429,
42				235,430	353,145	470,860	588,
48	Velocity			308,900	463,349	617,799	772,
54	these			392,331	588,497	784,662	980,
60				485,725	728,587	971,450	1,21
72				702,398	1,053,597	1,404,796	1,75
84				958,919	1,438,379	1,917,839	2,39
96				1,255,289	1,882,933	2,510,577	3,13

Notes:

1. Maximum recommended pressure drop/velocity: 0.5 psig/100 ft./8,00(

2. Table based on Standard Weight Steel Pipe using steam equations in

40 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h			
				Velocity FPM (…			
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	10… (1…
1/2 3/4 1	16 35 71	22 50 100	31 71 142		Pressure these	drop pipe	gove… size…
1-1/4 1-1/2 2	156 242 492	221 343 695	312 485 984	 433 713			
2-1/2 3 4	810 1,473 3,133	1,145 2,097 4,430	1,620 2,965 6,265	1,017 1,571 2,705	1,526 2,356 4,058	 5,410	
5 6 8	5,764 9,513 19,802	8,152 13,453 28,005	11,529 19,026 39,605	4,234 6,139 10,631	6,352 9,209 15,946	8,469 12,278 21,261	10,5… 15,3… 26,5…
10 12 14	36,136 57,996 75,122	51,103 82,019 106,239	with sizes	16,757 24,033 29,301	25,135 36,050 43,951	33,513 48,066 58,602	41,8… 60,0… 73,2…
16 18 20	108,286 149,016 197,819	governs pipe		38,814 49,662 61,846	58,221 74,493 92,769	77,628 99,325 123,692	97,0… 124,… 154,…
22 24 26	255,172 321,526 397,311			75,364 90,218 106,407	113,047 135,327 159,611	150,729 180,437 212,815	188,… 225,… 266,…
28 30 32	Velocity these			123,932 142,791 162,985	185,897 214,186 244,478	247,863 285,582 325,971	309,… 356,… 407,…
34 36 42				184,515 207,380 283,986	276,773 311,070 425,979	369,030 414,760 567,972	461,… 518,… 709,…

Notes:

1. Maximum recommended pressure drop/velocity: 1.0 psig/100 ft./10,00…

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h		Velocity FPM (	
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	10 (1
42				[illegible]	[illegible]	[illegible]	[illegible]
48				372,608	558,912	745,216	931,
54				473,247	709,871	946,494	1,18
60				585,903	878,854	1,171,805	1,46
72				847,264	1,270,895	1,694,527	2,11
84				1,156,691	1,735,036	2,313,382	2,89
96				1,514,184	2,271,277	3,028,369	3,78

Notes:

1. **Maximum recommended pressure drop/velocity: 1.0 psig/100 ft./10,0(**
2. **Table based on Standard Weight Steel Pipe using steam equations in**

50 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h		Velocity FPM (	
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	10 (1
1/2	17	24	34		Pressure	drop pipe	gove
3/4	38	54	76		these		size
1	77	109	154				
1-1/4	169	239	338				
1-1/2	263	371	525	508			
2	533	753	1,065	837			
2-1/2	877	1,241	1,755	1,194		6,348	
3	1,569	2,271	3,212	1,843	2,765		
4	3,393	4,799	6,786	3,174	4,761		
5	6,244	8,830	12,488	4,968	7,453	9,937	12,4
6	10,304	14,573	20,609	7,203	10,805	14,407	18,0
8	21,450	30,335	42,900	12,473	18,710	24,947	31,1

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h Velocity FPM (			
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	10 (1
10	39,142	55,355	with	19,661	29,492	39,322	49,1
12	62,822	88,844	sizes	28,199	42,298	56,398	70,4
14	81,373	115,078		34,380	51,570	68,759	85,9
16	117,296	165,882		45,542	68,313	91,084	113,
18	161,415			58,270	87,406	116,541	145,
20	214,279			72,566	108,849	145,132	181,
22	276,404	governs		88,428	132,641	176,855	221,
24	348,279	pipe		105,856	158,784	211,712	264,
26	430,370			124,851	187,277	249,703	312,
28	523,121			145,413	218,120	290,826	363,
30	626,961			167,541	251,312	335,083	418,
32				191,236	286,854	382,473	478,
34	Velocity			216,498	324,747	432,996	541,
36	these			243,326	364,989	486,652	608,
42				333,210	499,815	666,420	833,
48				437,194	655,790	874,387	1,09
54				555,277	832,915	1,110,553	1,38
60				687,459	1,031,189	1,374,918	1,71
72				994,123	1,491,184	1,988,245	2,48
84				1,357,184	2,035,776	2,714,368	3,39
96				1,776,643	2,664,965	3,553,286	4,44

Notes:

1. **Maximum recommended pressure drop/velocity: 1.0 psig/100 ft./10,0(**

2. **Table based on Standard Weight Steel Pipe using steam equations in**

60 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h Velocity FPM (			
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	10 (1
1/2	18	25	36		Pressure	drop pipe	gove

Notes:

Pipe Size	Pressure Drop psig/100 ft. 0.5	1	2	Velocity FPM (… 4,000 (45)	6,000 (68)	8,000 (91)	10… (1…
					Steam Flow lbs./h		
3/4	41	58	82		these		sizes
1	82	116	164				
1-1/4	181	256	362				
1-1/2	281	397	562				
2	570	806	1,140	957			
2-1/2	938	1,327	1,877	1,366			
3	1,707	2,429	3,436	2,109	3,164		
4	3,630	5,133	7,260	3,632	5,449		
5	6,680	9,446	13,359	5,686	8,529	11,371	
6	11,023	15,589	22,046	8,243	12,365	16,487	20,6
8	22,946	32,451	45,893	14,274	21,412	28,549	35,6
10	41,873	59,217	83,745	22,500	33,750	45,000	56,2
12	67,204	95,041		32,270	48,406	64,541	80,6
14	87,049	123,106		39,344	59,015	78,687	98,3
16	125,479	177,454	with	52,117	78,176	104,235	130,
18	172,676	244,200	sizes	66,684	100,026	133,368	166,
20	229,227	324,176		83,043	124,565	166,086	207,
22	295,686	governs		101,195	151,793	202,391	252,
24	372,575	pipe		121,140	181,710	242,280	302,
26	460,392			142,878	214,317	285,756	357,
28	559,614			166,408	249,613	332,817	416,
30	670,697			191,732	287,598	383,464	479,
32	794,082			218,848	328,272	437,696	547,
34	Velocity			247,757	371,635	495,514	619,
36	these			278,459	417,688	556,917	696,
42				381,321	571,981	762,641	953,
48				500,318	750,477	1,000,636	1,25
54				635,450	953,176	1,270,901	1,58
60				786,718	1,180,077	1,573,436	1,96
72				1,137,659	1,706,489	2,275,318	2,84
84				1,553,141	2,329,711	3,106,282	3,88
96				2,033,164	3,049,746	4,066,328	5,08

Notes:

1. Maximum recommended pressure drop/velocity: 1.0 psig/100 ft./12,0(

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h Velocity FPM (			
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	10 (1

Notes:

1. Maximum recommended pressure drop/velocity: 1.0 psig/100 ft./12,0
2. Table based on Standard Weight Steel Pipe using steam equations in

75 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h Velocity FPM			
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	1
1/2	20	28	39		Pressure	drop pipe	go
3/4	45	63	89		these		siz
1	90	127	179				
1-1/4	197	279	394				
1-1/2	306	433	612				
2	621	879	1,243	1,138			
2-1/2	1,023	1,447	2,046	1,624			
3	1,862	2,649	3,746	2,507			
4	3,957	5,597	7,915	4,318	6,477		
5	7,283	10,299	14,565	6,758	10,138	13,517	
6	12,018	16,997	24,036	9,799	14,698	19,597	
8	25,018	35,380	50,035	16,967	25,451	33,935	42
10	45,652	64,562	91,304	26,745	40,117	53,489	66
12	73,270	103,620		38,359	57,538	76,718	95
14	94,906	134,218		46,766	70,150	93,533	11
16	136,805	193,471	with	61,950	92,925	123,900	15
18	188,261	266,242	sizes	79,265	118,897	158,530	19
20	249,917	353,436		98,711	148,066	197,422	24
22	322,374	governs		120,288	180,431	240,575	30
24	406,203	pipe		142,906	215,993	287,991	35

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h		Velocity FPM	
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	1
24 26	406,203 501,947	pipe		143,996 169,834	215,993 254,752	287,991 339,669	35 42
28 30 32	610,125 731,235 865,756			197,804 227,905 260,138	296,707 341,858 390,206	395,609 455,811 520,275	49 56 65
34 36 42	1,014,152 1,176,871			294,501 330,995 453,264	441,751 496,492 679,896	589,001 661,990 906,527	73 82 1,:
48 54 60	Velocity these			594,712 755,340 935,147	892,068 1,133,009 1,402,720	1,189,424 1,510,679 1,870,293	1, 1, 2,:
72 84 96				1,352,299 1,846,169 2,416,757	2,028,449 2,769,254 3,625,136	2,704,598 3,692,339 4,833,514	3,: 4,(6,(

Notes:

1. **Maximum recommended pressure drop/velocity: 1.0 psig/100 ft./12,0(**
2. **Table based on Standard Weight Steel Pipe using steam equations in**

85 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h		Velocity FP	
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	
1/2 3/4 1	21 47 94	29 66 133	41 94 188		Pressure these	drop pipe	g s
1-1/4 1-1/2 2	207 322 653	293 455 924	415 644 1,306	1,258			
2-	1,076	1,521	2,151	1,794			

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h		Velocity FP	
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	
1/2	1,957	2,784	3,938	2,771			
3	4,160	5,883	8,320	4,771	7,157		
4							
5	7,655	10,826	15,311	7,468	11,202	14,936	
6	12,633	17,866	25,267	10,828	16,241	21,655	
8	26,298	37,192	52,597	18,749	28,124	37,499	4
10	47,989	67,867	95,979	29,553	44,330	59,107	7
12	77,021	108,925	154,043	42,387	63,580	84,774	1
14	99,765	141,089		51,678	77,516	103,355	1
16	143,808	203,376		68,456	102,684	136,911	1
18	197,899	279,872		87,589	131,383	175,178	2
20	262,712	371,531		109,077	163,615	218,153	2
22	338,879	479,247		132,919	199,379	265,839	3
24	426,999			159,117	238,675	318,234	3
26	527,645			187,669	281,504	375,338	4
28	641,361			218,576	327,865	437,153	5
30	768,671			251,838	377,758	503,677	6
32	910,079			287,455	431,183	574,910	7
34	1,066,072	governs	with	325,427	488,140	650,854	8
36	1,237,121	pipe	sizes	365,753	548,630	731,507	9
42	1,845,105			500,862	751,293	1,001,724	1
48	Velocity			657,164	985,746	1,314,328	1
54	these			834,660	1,251,989	1,669,319	2
60				1,033,349	1,550,023	2,066,697	2
72	1,494,307			2,241,461	2,988,614	3,735,768	4
84	2,040,040			3,060,060	4,080,080	5,100,099	6
96	2,670,546			4,005,820	5,341,093	6,676,366	8

Notes:

1. Maximum recommended pressure drop/velocity: 1.0 psig/100 ft./12,0(

2. Table based on Standard Weight Steel Pipe using steam equations in

100 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

					Steam Flow lbs./h		
Pipe Size	Pressure Drop psig/100 ft.					Velocity FP	
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	
1/2	22	31	44		Pressure	drop pipe	g
3/4	50	71	100		these		s
1	101	142	201				
1-1/4	222	313	443				
1-1/2	344	486	688				
2	698	987	1,396				
2-1/2	1,149	1,625	2,299	2,049			
3	2,091	2,975	4,208	3,164			
4	4,446	6,287	8,891	5,449	8,173		
5	8,181	11,569	16,362	8,529	12,793		
6	13,501	19,093	27,001	12,365	18,548	24,730	
8	28,104	39,744	56,207	21,412	32,117	42,823	5
10	51,283	72,526	102,567	33,750	50,624	67,499	8
12	82,308	116,402	164,617	48,406	72,608	96,811	1
14	106,613	150,773	213,226	59,015	88,523	118,031	1
16	153,680	217,336	with	78,176	117,264	156,352	1
18	211,483	299,083	sizes	100,026	150,039	200,052	2
20	280,745	397,033		124,565	186,847	249,129	3
22	362,139	512,142		151,793	227,689	303,586	3
24	456,309	645,318		181,710	272,565	363,421	4
26	563,863	797,422		214,317	321,475	428,634	5
28	685,384	governs		249,613	374,419	499,225	6
30	821,433	pipe		287,598	431,397	575,195	7
32	972,548			328,272	492,408	656,544	8
34	1,139,248			371,635	557,453	743,271	9
36	1,322,038			417,688	626,532	835,376	1
42	1,971,754			571,981	857,971	1,143,962	1

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h			Velocity FP
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	
48	2,783,057			750,477	1,125,715	1,500,954	1
54				953,176	1,429,763	1,906,351	2
60				1,180,077	1,770,116	2,360,154	2
72	Velocity			1,706,489	2,559,733	3,412,977	4
84	these			2,329,711	3,494,567	4,659,423	5
96				3,049,746	4,574,618	6,099,491	7

Notes:

1. **Maximum recommended pressure drop/velocity: 1.0 psig/100 ft./12,0(**

2. **Table based on Standard Weight Steel Pipe using steam equations in**

21.12. High-Pressure Steam Pipe Sizing Tables (120–300 psig)

120 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h			Velocity FPI
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)	1
1/2	34	48	75		Pressure	drop pipe	go
3/4	76	108	171		these		siz
1	154	217	344				
1-1/4	338	478	756	746			
1-1/2	525	743	1,174	1,015			
2	1,065	1,507	2,382	1,673			
2-1/2	1,755	2,481	3,923	2,387	3,581	12,696	
3	3,212	4,542	7,181	3,686	5,530		
4	6,786	9,597	15,175	6,348	9,522		
5	12,488	17,661	27,924	9,937	14,905	19,873	24
6	20,609	29,145	46,083	14,407	21,610	28,813	36
8	42,900	60,670		24,947	37,420	49,894	62

Notes:

1. **Maximum recommended pressure drop/velocity: 2.0 psig/100 ft./15,0(**

Pipe Size	Pressure Drop psig/100 ft. 1	2	5	Steam Flow lbs./h Velocity FPM 4,000 (45)	6,000 (68)	8,000 (91)	1…
10	78,284	110,711	with	39,322	58,983	78,644	98…
12	125,644	177,688	sizes	56,398	84,597	112,796	14…
14	162,745	230,156		68,759	103,139	137,519	17…
16	234,593	331,764		91,084	136,625	182,167	22…
18	322,831			116,541	174,811	233,082	29…
20	428,558			145,132	217,697	290,263	36…
22	552,808	governs		176,855	265,283	353,711	44…
24	696,558	pipe		211,712	317,568	423,425	52…
26	860,739			249,703	374,554	499,405	62…
28	1,046,243			290,826	436,239	581,652	72…
30	1,253,922			335,083	502,624	670,165	83…
32				382,473	573,709	764,945	95…
34	Velocity			432,996	649,493	865,991	1,…
36	these			486,652	729,978	973,304	1,…
42				666,420	999,630	1,332,840	1,…
48				874,387	1,311,581	1,748,775	2,…
54				1,110,553	1,665,830	2,221,107	2,…
60				1,374,918	2,062,378	2,749,837	3,…
72				1,998,245	2,982,368	3,976,491	4,…
84				2,714,368	4,071,552	5,428,736	6,…
96				3,553,286	5,329,929	7,106,572	8,…

Notes:

1. **Maximum recommended pressure drop/velocity: 2.0 psig/100 ft./15,00**
2. **Table based on Standard Weight Steel Pipe using steam equations in**

125 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft. 1	2	5	Steam Flow lbs./h Velocity FPM 4,000 (45)	6,000 (68)	8,000 (91)	1…
1/2	34	48	77		Pressure	drop pipe	go…

Notes:

Pipe Size	Pressure Drop psig/100 ft. 1	2	5	Steam Flow lbs./h Velocity FPM 4,000 (45)	6,000 (68)	8,000 (91)	1
3/4	78	110	174		these		siz
1	156	221	350				
1-1/4	344	487	770	1,051			
1-1/2	534	756	1,195	1,733			
2	1,084	1,533	2,424				
2-1/2	1,785	2,525	3,992	2,472	3,708	13,146	
3	3,268	4,622	7,308	3,817	5,726		
4	6,905	9,766	15,441	6,573	9,860		
5	12,707	17,971	28,414	10,289	15,433	20,578	25
6	20,971	29,657	46,892	14,917	22,376	29,834	37
8	43,654	61,735		25,831	38,746	51,661	64
10	79,659	112,655	with	40,715	61,073	81,430	10
12	127,850	180,808	sizes	58,396	87,594	116,792	14
14	165,603	234,198		71,195	106,793	142,391	17
16	238,712	337,590		94,310	141,466	188,621	23
18	328,499			120,670	181,005	241,339	30
20	436,083			150,273	225,410	300,546	37
22	562,515	governs		183,121	274,681	366,242	45
24	708,789	pipe		219,213	328,819	438,426	54
26	875,854			258,549	387,823	517,098	64
28	1,064,614			301,129	451,694	602,259	75
30	1,275,940			346,954	520,431	693,908	86
32				396,023	594,034	792,045	99
34	Velocity			448,336	672,504	896,671	1,:
36	these			503,893	755,839	1,007,786	1,:
42				690,030	1,035,045	1,380,060	1,:
48				905,365	1,358,047	1,810,730	2,:
54				1,149,898	1,724,847	2,299,796	2,:
60				1,423,629	2,135,443	2,847,258	3,:
72				2,058,684	3,088,027	4,117,369	5,:
84				2,810,532	4,215,798	5,621,064	7,(
96				3,679,171	5,518,757	7,358,343	9,:

Notes:

1. Maximum recommended pressure drop/velocity: 2.0 psig/100 ft./15,00

Notes:

Steam Flow lbs./h

Pipe Size | Pressure Drop psig/100 ft. | Velocity FP[cut off]

1. Maximum recommended pressure drop/velocity: 2.0 psig/100 ft./15,0[cut off]

2. Table based on Standard Weight Steel Pipe using steam equations in [cut off]

	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)	1

150 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h		Velocity F	
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)	
1/2	37	52	83		Pressure	drop pipe	g
3/4	84	119	188		these		s
1	169	239	378				
1-1/4	372	526	832	1,230			
1-1/2	578	817	1,292	2,027			
2	1,173	1,658	2,622				
2-1/2	1,931	2,731	4,318	2,893	6,700	15,382	
3	3,535	4,999	7,905	4,466	11,537		
4	7,470	10,564	16,703	7,691			
5	13,746	19,439	30,736	12,039	18,059	24,078	3
6	22,684	32,080	50,724	17,455	26,182	34,909	4
8	47,221	66,780	105,589	30,225	45,337	60,449	7
10	86,168	121,861		47,641	71,462	95,282	1
12	138,298	195,583		68,330	102,494	136,659	1
14	179,135	253,336		83,306	124,960	166,613	2
16	258,219	365,176		110,354	165,530	220,707	2
18	355,343	502,531		141,197	211,795	282,394	3
20	471,718			175,836	263,754	351,672	4
22	608,481			214,272	321,407	428,543	5
24	766,709			256,503	384,755	513,006	6

Notes:

Pipe Size	Pressure Drop psig/100 ft. 1	2	5	Steam Flow lbs./h 4,000 (45)	6,000 (68)	8,000 (91)	Velocity F
24	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]
26	947,425			302,531	453,796	605,061	7
28	1,151,610	governs	with	352,354	528,532	704,709	8
30	1,380,205	pipe	sizes	405,074	608,061	811,048	1
32	1,634,114			463,390	695,085	926,780	1
34	1,914,211			524,602	786,903	1,049,204	1
36				589,610	884,415	1,179,220	1
42				807,411	1,211,116	1,614,822	2
48	Velocity			1,059,376	1,589,065	2,118,753	2
54	these			1,345,507	2,018,260	2,691,013	3
60				1,665,802	2,498,703	3,331,604	4
72				2,408,887	3,613,330	4,817,773	6
84				3,288,631	4,932,946	6,577,262	8
96				4,305,034	6,457,551	8,610,068	1

Notes:

1. **Maximum recommended pressure drop/velocity: 2.0 psig/100 ft./15,0(**
2. **Table based on Standard Weight Steel Pipe using steam equations in**

175 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft. 1	2	5	Steam Flow lbs./h 4,000 (45)	6,000 (68)	8,000 (91)	Velocity F
1/2	40	56	89		Pressure	drop pipe	
3/4	90	127	201		these		
1	181	256	405				
1-1/4	398	563	891	2,322			
1-1/2	618	875	1,383				
2	1,255	1,775	2,806				
2-	2,067	2,923	4,621	3,312	7,672	17,614	

Notes:

Pipe Size	Pressure Drop psig/100 ft. 1	2	5	Steam Flow lbs./h 4,000 (45)	6,000 (68)	Velocity F… 8,000 (91)
1/2	3,783	5,350	8,459	5,114	13,211	
3	7,993	11,304	17,874	8,807		
4						
5	14,709	20,802	32,891	13,786	20,679	27,572
6	24,274	34,329	54,279	19,987	29,981	39,974
8	50,531	71,461	112,990	34,610	51,916	69,221
10	92,208	130,402	with	54,554	81,831	109,108
12	147,992	209,292	sizes	78,245	117,367	156,489
14	191,692	271,093		95,394	143,092	190,789
16	276,318	390,773		126,366	189,549	252,732
18	380,251	537,756		161,685	242,527	323,370
20	504,783	713,872		201,351	302,026	402,701
22	651,133	governs		245,363	368,045	490,726
24	820,451	pipe		293,723	440,584	587,445
26	1,013,835			346,429	519,643	692,858
28	1,232,333			403,482	605,223	806,964
30	1,476,951			464,882	697,324	929,765
32	1,748,657			530,630	795,944	1,061,259
34	2,048,388			600,724	901,085	1,201,447
36	2,377,048			675,165	1,012,747	1,350,329
42				924,569	1,386,853	1,849,138
48	Velocity			1,213,095	1,819,643	2,426,191
54	these			1,540,744	2,311,117	3,081,489
60				1,907,515	2,861,273	3,815,031
72	2,758,425			4,137,637	5,516,849	6,896,061
84	3,765,823			5,648,734	7,531,645	9,414,556
96	4,929,710			7,394,564	9,859,419	12,324,274

Notes:

1. **Maximum recommended pressure drop/velocity: 2.0 psig/100 ft./15,0**
2. **Table based on Standard Weight Steel Pipe using steam equations in**

200 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

				Steam Flow lbs./h		
Pipe Size	Pressure Drop psig/100 ft.					Velocity
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)
1/2 3/4 1	42 96 192	59 135 272	94 214 430		Pressure these	drop pipe
1-1/4 1-1/2 2	423 656 1,332	598 928 1,884	946 1,468 2,978	2,616		
2-1/2 3 4	2,194 4,015 8,485	3,102 5,679 11,999	4,905 8,979 18,972	3,732 5,763 9,923	8,644 14,885	
5 6 8	15,613 25,766 53,637	22,081 36,439 75,854	34,913 57,616 119,935	15,533 22,520 38,996	23,299 33,780 58,494	31,066 45,040 77,992
10 12 14	97,876 157,089 203,475	138,418 222,157 287,757	218,858	61,467 88,159 107,482	92,200 132,239 161,224	122,934 176,319 214,965
16 18 20	293,303 403,625 535,812	414,794 570,811 757,753	with sizes	142,379 182,173 226,865	213,568 273,260 340,297	284,758 364,346 453,730
22 24 26	691,157 870,884 1,076,154	977,444 1,231,615		276,455 330,942 390,327	414,682 496,413 585,491	552,909 661,884 780,654
28 30 32	1,308,083 1,567,737 1,856,146	governs pipe		454,610 523,791 597,869	681,915 785,686 896,804	909,220 1,047,581 1,195,738
34 36 42	2,174,300 2,523,162 3,763,171			676,845 760,719 1,041,727	1,015,268 1,141,078 1,562,590	1,353,690 1,521,438 2,083,454
[illegible]	Velocit			1,366,815	2,050,222	2,733,630

Pipe Size	Pressure Drop psig/100 ft. 1	2	5	Steam Flow lbs./h 4,000 (45)	6,000 (68)	Velocity 8,000 (91)
48	Velocity			1,366,815	2,050,222	2,733,629
54	these			1,735,982	2,603,973	3,471,964
60				2,149,229	3,223,844	4,298,458
72				3,107,962	4,661,943	6,215,925
84				4,243,014	6,364,521	8,486,028
96				5,554,385	8,331,577	11,108,770

Notes:

1. Maximum recommended pressure drop/velocity: 2.0 psig/100 ft./15,0(

2. Table based on Standard Weight Steel Pipe using steam equations in

225 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft. 1	2	5	Steam Flow lbs./h 4,000 (45)	6,000 (68)	Velocity 8,000 (91)
1/2	44	63	99		Pressure	drop pipe
3/4	101	143	225		these	
1	203	287	453			
1-1/4	446	631	998	2,912		
1-1/2	693	980	1,549			
2	1,405	1,987	3,142			
2-1/2	2,314	3,273	5,175	4,154	16,568	
3	4,236	5,991	9,473	6,414		
4	8,952	12,660	20,017	11,046		
5	16,473	23,296	36,834	17,290	25,935	34,579
6	27,185	38,445	60,787	25,067	37,601	50,134
8	56,589	80,029	126,536	43,407	65,110	86,814
10	103,263	146,036	230,904	68,419	102,629	136,838
12	165,735	234,384		98,131	147,196	196,262

Notes:

1. Maximum recommended pressure drop/velocity: 5.0 psig/100 ft./15,0(

Pipe Size	Pressure Drop psig/100 ft. 1	2	5	Steam Flow lbs./h 4,000 (45)	6,000 (68)	Velocity 8,000 (91)
14	214,674	303,595		119,639	179,459	239,279
16	309,447	437,623	with	158,483	237,724	316,966
18	425,840	602,228	sizes	202,778	304,167	405,556
20	565,302	799,458		252,525	378,787	505,050
22	729,198	1,031,241		307,724	461,585	615,447
24	918,816	1,299,402		368,374	552,561	736,748
26	1,135,385	1,605,676		434,476	651,714	868,952
28	1,380,078	governs		506,029	759,044	1,012,059
30	1,654,023	pipe		583,035	874,552	1,166,070
32	1,958,305			665,492	998,238	1,330,984
34	2,293,971			753,401	1,130,101	1,506,802
36	2,662,034			846,761	1,270,142	1,693,523
42	3,970,291			1,159,553	1,739,330	2,319,107
48	5,603,917			1,521,411	2,282,116	3,042,821
54				1,932,333	2,898,500	3,864,666
60				2,392,321	3,588,482	4,784,643
72	Velocity			3,459,494	5,189,240	6,918,987
84	these			4,722,928	7,084,391	9,445,855
96				6,182,623	9,273,934	12,365,246

Notes:

1. **Maximum recommended pressure drop/velocity: 5.0 psig/100 ft./15,0(**
2. **Table based on Standard Weight Steel Pipe using steam equations in**

250 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft. 1	2	5	Steam Flow lbs./h 4,000 (45)	6,000 (68)	Velocity 8,000 (91
1/2	47	66	104		Pressure	drop pipe
3/4	106	150	236		these	
1	213	301	476			
	468	662	1,047	3,205		

Notes:

Pipe Size	Pressure Drop psig/100 ft.				Steam Flow lbs./h	Velocity
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91
1- 1/4 1- 1/2 2	468 727 1,474	662 1,028 2,085	1,047 1,625 3,297	3,205		
2- 1/2 3 4	2,428 4,445 9,392	3,434 6,286 13,283	5,430 9,939 21,002	4,573 7,061 12,160	18,239	
5 6 8	17,283 28,522 59,374	24,442 40,337 83,967	38,647 63,778 132,764	19,033 27,595 47,784	28,550 41,393 71,676	38,066 55,190 95,568
10 12 14	108,345 173,891 225,238	153,223 245,919 318,535	242,267 388,831	75,319 108,027 131,705	112,978 162,040 197,557	150,638 216,054 263,409
16 18 20	324,675 446,796 593,122	459,160 631,865 838,801		174,465 223,227 277,991	261,698 334,841 416,986	348,930 446,455 555,982
22 24 26	765,083 964,032 1,191,259	1,081,991 1,363,348 1,684,694		338,756 405,522 478,291	508,134 608,284 717,436	677,512 811,045 956,581
28 30 32	1,447,994 1,735,421 2,054,677	2,047,773		557,060 641,831 732,604	835,590 962,747 1,098,905	1,114,120 1,283,662 1,465,207
34 36 42	2,406,861 2,793,037 4,165,676	governs pipe	with sizes	829,378 932,153 1,276,489	1,244,067 1,398,230 1,914,733	1,658,755 1,864,306 2,552,977
48 54 60	5,879,695 7,959,549			1,674,837 2,127,200 2,633,575	2,512,256 3,190,800 3,950,363	3,349,675 4,254,399 5,267,151
72 84 96	Velocity these			3,808,367 5,199,212 6,806,111	5,712,550 7,798,818 10,209,166	7,616,734 10,398,42 13,612,22

Notes:

1. **Maximum recommended pressure drop/velocity: 5.0 psig/100 ft./15,00**

Steam Flow lbs./h

2. Table based on Standard Weight Steel Pipe using steam equations in

Pipe Pressure Drop psig/100 ft. Velocity

275 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

				Steam Flow lbs./h		
Pipe Size	Pressure Drop psig/100 ft.					Velocity
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91
1/2 3/4 1	49 110 222	69 156 314	109 247 497		Pressure these	drop pipe
1-1/4 1-1/2 2	489 759 1,541	692 1,074 2,179	1,094 1,689 3,445			
2-1/2 3 4	2,537 4,645 9,815	3,589 6,569 13,880	5,674 10,386 21,946	4,994 7,711 13,278	19,916	
5 6 8	18,061 29,805 62,044	25,542 42,151 87,743	40,385 66,646 138,734	20,783 30,133 52,178	31,175 45,199 78,267	60,265 104,356
10 12 14	113,217 181,710 235,367	160,113 256,977 332,859	253,161 406,316 526,296	82,245 117,961 143,816	123,368 176,941 215,723	164,490 235,921 287,631
16 18 20	339,275 466,887 619,793	479,807 660,278 876,519	with sizes	190,508 243,754 303,554	285,762 365,632 455,331	381,017 487,509 607,108
22 24 26	799,486 1,007,382 1,244,826	1,130,644 1,424,653 1,760,450		369,907 442,813 522,272	554,860 664,219 783,408	739,813 885,625 1,044,545
28	1,513,106	2,139,855		608,285	912,428	1,216,570

Notes:

Pipe Size	Pressure Drop psig/100 ft. 1	2	5	Steam Flow lbs./h Velocity 4,000 (45)	6,000 (68)	8,000 (91
30	1,813,457	2,564,616		700,851	1,051,277	1,401,703
32	2,147,070			799,971	1,199,956	1,599,942
34	2,515,091	governs		905,644	1,358,466	1,811,288
36	2,918,632	pipe		1,017,870	1,526,805	2,035,741
42	4,352,994			1,393,869	2,090,804	2,787,739
48	6,144,088			1,828,849	2,743,273	3,657,698
54	8,317,466			2,322,809	3,484,213	4,645,617
60				2,875,748	4,313,623	5,751,497
72	Velocity			4,158,569	6,237,854	8,317,138
84	these			5,677,311	8,515,966	11,354,62
96				7,431,974	11,147,960	14,863,94

Notes:

1. Maximum recommended pressure drop/velocity: 5.0 psig/100 ft./15,00

2. Table based on Standard Weight Steel Pipe using steam equations in

300 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft. 1	2	5	Steam Flow lbs./h Velocity 4,000 (45)	6,000 (68)	8,000 (9
1/2	51	72	113		Pressure	drop pipe
3/4	115	163	257		these	
1	232	327	518			
1-1/4	509	720	1,139			
1-1/2	791	1,118	1,768			
2	1,604	2,269	3,587			
2-1/2	2,642	3,736	5,908	5,413	21,591	
3	4,836	6,839	10,814	8,359		
4	10,219	14,451	22,850	14,394		

Notes:

1. Maximum recommended pressure drop/velocity: 5.0 psig/100 ft./15,00

2. Table based on Standard Weight Steel Pipe using steam equations in

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs/h			Veloci…
	1	2	5	4,000 (45)	6,000 (68)	8,000 (9…	
5	18,804	26,593	42,048	22,530	33,796	65,331	
6	31,032	43,886	69,390	32,665	48,998	113,128	
8	64,598	91,356	144,446	56,564	84,846		
10	117,879	166,706	263,586	89,158	133,737	178,316	
12	189,193	267,559	423,047	127,875	191,813	255,751	
14	245,059	346,565	547,968	155,904	233,855	311,807	
16	353,245	499,564	with	206,521	309,781	413,042	
18	486,113	687,467	sizes	264,242	396,364	528,485	
20	645,315	912,613		329,068	493,602	658,136	
22	832,408	1,177,203		400,998	601,497	801,996	
24	1,048,864	1,483,318		480,032	720,048	960,064	
26	1,296,086	1,832,942		566,170	849,256	1,132,34…	
28	1,575,413	2,227,971		659,413	989,119	1,318,82…	
30	1,888,133	2,670,223		759,760	1,139,639	1,519,51…	
32	2,235,482	3,161,450		867,210	1,300,816	1,734,42…	
34	2,618,658	governs		981,766	1,472,648	1,963,53…	
36	3,038,816	pipe		1,103,425	1,655,137	2,206,84…	
42	4,532,243			1,511,028	2,266,541	3,022,05…	
48	6,397,091			1,982,568	2,973,852	3,965,13…	
54	8,659,966			2,518,046	3,777,069	5,036,09…	
60	11,345,797			3,117,462	4,676,193	6,234,92…	
72	Velocity			4,508,107	6,762,160	9,016,21…	
84	these			6,154,503	9,231,754	12,309,0…	
96				8,056,649	12,084,973	16,113,2…	

Notes:

1. **Maximum recommended pressure drop/velocity: 5.0 psig/100 ft./15,0…**
2. **Table based on Standard Weight Steel Pipe using steam equations in**

Part 22: Steam Condensate Piping Systems

22. Part 22: Steam Condensate Piping Systems

22.01. Steam Condensate Piping

A. **Steam Condensate Pipe Sizing**

1. Steam condensate pipe sizing criteria limits:
   a. Pressure drop: 1/16–1.0 psig/100 ft.

   b. Velocity–liquid systems: 150 ft./min. max.

   c. Velocity–vapor systems: 5,000 ft./min. max.

2. Recommended steam condensate pipe sizing criteria:
   a. Low-pressure systems:
      1. Pressure drop: 1/8–1/4 psig/100 ft.

      2. Velocity–vapor systems: 5,000 ft. per minute.

   b. Medium-pressure systems:
      1. Pressure drop: 1/8–1/4 psig/100 ft.

      2. Velocity–vapor systems: 5,000 ft. per minute.

   c. High-pressure systems:
      1. Pressure drop: 1/4–1/2 psig/100 ft.

      2. Velocity–vapor systems: 5,000 ft. per minute.

3. *Wet Returns*. Return pipes contain only liquid, no vapor. Wet condensate returns connect to the boiler below the waterline so the piping is always flooded.

4. *Dry Returns*. Return pipes contain saturated liquid and saturated vapor (most common). Dry condensate returns connect to the boiler above the waterline so the piping is not flooded and must be pitched in the direction of flow. Dry condensate returns often carry steam, air, and condensate.

5. *Open Returns*. The return system is vented to the atmosphere and condensate lines are essentially at atmospheric pressure (gravity flow lines).

6. *Closed Returns*. The return system is not vented to the atmosphere.

7. Steam traps and steam condensate piping should be selected to discharge at four times the condensate rating of air handling heating coils and three times the condensate rating of all other equipment for system startup.

8. Steam condensate liquid to steam volume ratio is 1:1600 at 0 psig.

9. *Flash Steam*. Flash steam is formed when hot steam condensate under pressure is released to a lower pressure; the temperature drops to the boiling point of the lower pressure, causing some of the condensate to evaporate forming steam. Flash steam occurs whenever steam condensate experiences a drop in pressure and thus produces steam at the lower pressure.
   a. Low-pressure steam systems' flash steam is negligible and can be generally be ignored.

   b. Medium- and high-pressure steam systems' flash steam is important to utilize and consider when sizing condensate piping.

   c. Flash steam recovery requirements:
      1. To utilize flash steam recovery, the condensate must be at a reasonably high pressure (medium- and high-pressure steam systems) and the traps supplying the condensate must be capable of operating with the back pressure of the flash steam system.

      2. There must be a use or demand for the flash steam at the reduced pressure. Demand for steam at the lower pressure should be greater than the supply of flash steam. The demand for steam should occur at the same time as the flash steam supply.

      3. The steam equipment should be in close proximity to the flash steam source to minimize installation and radiation losses and to fully take advantage of the flash steam recovery system. Flash steam recovery

systems are especially advantageous when steam is utilized at multiple pressures within the facility and the distribution systems are already in place.

B. **Steam Condensate System Design and Pipe Installation Guidelines**

1. The minimum recommended steam condensate pipe size is 3/4 in.

2. Locate all valves, strainers, unions, and flanges so they are accessible. All valves (except control valves) and strainers should be the full size of the pipe before reducing the size to make connections to equipment and controls. Union and/or flanges should be installed at each piece of equipment, in bypasses and in long piping runs (100 ft. or more), to permit disassembly for alteration and repairs.

3. Provide chainwheel operators for all valves in equipment rooms mounted greater than 7'0" above floor level. The chain should extend to 5'0"–7'0" above the floor level.

4. All valves should be installed so the valve remains in service when equipment or piping on the equipment side of the valve is removed.

5. Locate all flow measuring devices in accessible locations with a straight section of pipe upstream (10 pipe diameters) and downstream (5 pipe diameters) of the device, or as recommended by the manufacturer.

6. Provide vibration isolators for all piping supports connected to, and within 50 ft. of, isolated equipment, except at base elbow supports and anchor points, throughout mechanical equipment rooms, and for supports of steam mains within 50 ft. of the boiler or pressure reducing valves.

7. Drip leg collection points on steam piping should be the same size as the steam piping to prevent steam condensate from passing over the drip leg and thus decreasing the risk of water hammer. The drip leg collection point should be a minimum of 12 in. long, including a minimum 6-in.-long dirt leg with the steam trap outlet above the dirt leg.

8. Pitch all steam return lines downward in the direction of condensate flow 1/2" per 10 ft. (1" per 20 ft.) minimum.

9. Drip legs must be installed at all low points, downfed runouts to all equipment, at the end of mains, the bottom of risers, and ahead of all pressure regulators, control valves, isolation valves, and expansion joints.

10. On straight runs with no natural drainage points, install drip legs at intervals not exceeding 200 ft. where the pipe is pitched downward in the direction of steam flow, and a maximum of 100 ft. where the pipe is pitched up so that condensate flow is opposite of steam flow.

11. Steam traps used on steam mains and branches shall be at minimum 3/4" size.

12. When elevating steam condensate to an overhead return main, it requires 1 psi to elevate condensate 2 ft. Try to avoid elevating condensate.

13. Steam condensate in a steam system should be maintained at a pH of approximately 8–9. A pH of 7 is neutral; below 7 is acidic; above 7 is alkaline.

C. **Low-Pressure Steam Condensate Pipe Materials (0–15 psig)**

1. 2" and smaller:

a. Pipe:	black steel pipe, *ASTM A53, Schedule 80,* Type E or S, Grade B.
Fittings:	black cast iron screw fittings, 250 lbs., *ANSI/ASME B16.4.*
Joints:	pipe threads, general purpose (American) *ANSI/ASME B1.20.1.*

2. 2-1/2" and larger:

a. Pipe:	black steel pipe, *ASTM A53, Schedule 80,* Type E or S, Grade B.
Fittings:	steel butt-welding fittings, 250 lbs., *ANSI/ASME B16.9.*
Joints:	welded pipe, ANSI/AWS D1.1 and ANSI/ASME Sec. 9.

D. **Medium-Pressure Steam Condensate Pipe Materials (16–100 psig)**

1. 2" and smaller:

a. Pipe:	black steel pipe, *ASTM A53, Schedule 80,* Type E or S, Grade B.
Fittings:	black cast iron screw fittings, 250 lbs., *ANSI/ASME B16.4.*
Joints:	pipe threads, general purpose (American) *ANSI/ASME B1.20.1.*

2. 2-1/2" and larger:

a. Pipe:	black steel pipe, *ASTM A53, Schedule 80,* Type E or S, Grade B.
Fittings:	steel butt-welding fittings, 250 lbs., *ANSI/ASME B16.9.*
Joints:	welded pipe, ANSI/AWS D1.1 and ANSI/ASME Sec. 9.

E. **High-Pressure Steam Condensate Pipe Materials (100–300 psig)**

1. 1-1/2" and smaller:

a. Pipe	black steel pipe, *ASTM A53, Schedule 80,* Type E or S, Grade B.
Fittings	forged steel socket-weld, 300 lbs., *ANSI B16.11.*
Joints	welded pipe, ANSI/AWS D1.1 and ANSI/ASME Sec. 9.
b. Pipe	carbon steel pipe, *ASTM A106, Schedule 80,* Grade B.
Fittings	forged steel socket-weld, 300 lbs., *ANSI B16.11.*
Joints	welded pipe, ANSI/AWS D1.1 and ANSI/ASME Sec. 9.

2. 2" and larger:

a. Pipe	black steel pipe, *ASTM A53, Schedule 80,* Type E or S, Grade B.
Fittings	steel butt-welding fittings, 300 lbs., *ANSI/ASME B16.9.*
Joints	welded pipe, ANSI/AWS D1.1 and ANSI/ASME Sec. 9.
b. Pipe	carbon steel pipe, *ASTM A106, Schedule 80,* Grade B.
Fittings	steel butt-welding fittings, 300 lbs., *ANSI/ASME B16.9.*
Joints	welded pipe, ANSI/AWS D1.1 and ANSI/ASME Sec. 9.

F. **Pipe Testing**

1. 1.5 × system working pressure.
2. 100 psi minimum.

G. **Steam Traps**

1. Steam trap types:
   a. A steam trap is a self-actuated valve that closes in the presence of steam and opens in the presence of steam condensate or noncondensable gases.

   b. Thermostatic traps: React to differences in temperature between steam and cooled condensate. Condensate must be subcooled for the trap to operate properly. Thermostatic traps work best in drip and tracing services and where steam temperature and pressure are constant and predictable.
      1. Liquid expansion thermostatic trap.
      2. Balanced pressure thermostatic trap:
         a. Balanced pressure traps change their actuation temperature automatically with changes in steam pressure. Balanced pressure traps are used in applications where system pressure varies.

b. During startup and operation, this trap discharges air and other noncondensables very well. This trap is often used as a standalone air vent in steam systems.

c. The balanced pressure trap will cause condensate to back up in the system.

3. Bimetal thermostatic trap:
   a. Bimetal traps are rugged and resist damage from steam system events such as water hammer, freezing, superheated steam, and vibration.

   b. Bimetal traps cannot compensate for steam system pressure changes.

   c. Bimetal traps have a slow response time to changing process pressure and temperature conditions.

4. Bellows thermostatic trap.

5. Capsule thermostatic trap.

c. Mechanical traps: Operate according to the difference in density between steam and condensate (buoyancy operated).
   1. Float and thermostatic (F&T) traps:
      a. Process or modulating applications—will work in almost any application—heat exchangers, coils, humidifiers, etc.

      b. The simplest type of mechanical trap.

      c. The F&T trap is the only trap that provides continuous, immediate, and modulating condensate discharge.

      d. A thermostat valve opens when cold or when below saturation (steam) temperature in order to allow air to bleed out during system startup and operation. The valve closes when the system reaches steam temperature.

   2. Inverted bucket traps:
      a. Work best in applications with constant load and constant pressure—drips.

      b. When the inverted bucket is filled with steam, it rises and closes the discharge valve preventing the discharge of steam. When the inverted bucket is filled with condensate, it drops, opening the valve and discharging the condensate.

c. Inverted bucket traps are poor at removing air and other noncondensable gases.

d. Kinetic traps: Rely on the difference in flow characteristics of steam and condensate and the pressure created by flash steam.

1. Thermodynamic traps:

a. Thermodynamic traps work best in drip and tracing services.

b. Thermodynamic traps can remove air and other noncondensables during startup only if the system pressures are increased slowly. Because of this, thermodynamic traps often require a separate air vent.

c. These traps snap open and snap shut and the sound can be annoying if used in noise-sensitive areas.

d. The thermodynamic trap is rugged because it has only one moving part and is resistant to water hammer, superheated steam, freezing, and vibration.

2. Impulse or piston traps.

3. Orifice traps.

2. Steam trap selection:

a. HVAC equipment steam traps should be selected to discharge three to four times the condensate rating of the equipment for system startup.

b. Boiler header steam traps should be selected to discharge three to five times the condensate carryover rating of the boilers (typically 10 percent).

c. Steam main piping steam traps should be selected to discharge two to three times the condensate generated during the start-up mode caused by radiation losses.

d. Steam branch piping steam traps should be selected to discharge three times the condensate generated during the startup mode caused by radiation losses.

e. Use float and thermostatic (F&T) traps for all steam-supplied equipment.

1. Thermostatic traps may be used for steam radiators, steam finned

tube, and other noncritical equipment, in lieu of F&T traps.

2. A combination of an inverted bucket trap and an F&T trap, in parallel with an F&T trap installed above an inverted bucket trap, may be used in lieu of F&T traps.

f. Use inverted bucket traps for all pipeline drips.

3. Steam trap functions:

a. Steam traps allow condensate to flow from the heat exchanger or other device to minimize fouling, prevent damage, and to allow the heat transfer process to continue.

b. Steam traps prevent steam escape from the heat exchanger or other devices.

c. Steam traps vent air or other noncondensable gases to prevent corrosion and allow heat transfer.

4. Common steam trap problems:

a. Steam leakage: Like all valves, the steam trap seat is subject to damage, corrosion, and/or erosion. When the trap seat is damaged, the valve will not seal; thus, the steam trap will leak live steam.

b. Air binding: Air, carbon dioxide, hydrogen, and other noncondensable gases trapped in a steam system will reduce heat transfer and can defeat steam trap operation.

c. Insufficient pressure difference: Steam traps rely on a positive pressure difference between the upstream steam pressure and the downstream condensate pressure to discharge condensate. When this is not maintained, the discharge of condensate is impeded.

1. Overloading of the condensate return system is one cause: too much back pressure.

2. Steam pressure that is too low is another cause.

d. Dirt: Steam condensate often contains dirt, particles of scale and corrosion, and other impurities from the system that can erode and damage the steam traps. Strainers should always be placed upstream of the steam traps to extend life.

e. Freezing: Freezing is normally only a problem when the steam system is shut down or idles, and liquid condensate remains in the trap.

f. Noise: Thermodynamic traps are generally the only trap that produces noise when they operate. All other traps operate relatively quietly.

g. Maintenance: Steam traps, as with all valves, must be maintained. Most steam traps can be maintained inline without removing the body from the connecting piping.

5. Steam trap characteristics are given in the following table.

STEAM TRAP COMPARISON

	Steam Trap Type		
Characteristic	**Inverted Bucket**	**Float & Thermostatic**	**Liquid Expansion Thermostatic**
Method of Operation	Intermittent, condensate drainage is continuous; discharge is intermittent	Continuous	Intermittent
No Load	Small dribble	No action	No action
Light Load	Intermittent	Usually continuous but may cycle at high pressures	Continuous; usually dribble action
Normal Load	Intermittent	Usually continuous but may cycle at high pressures	May blast at high pressures
Full or Overload	Continuous	Continuous	Continuous
Energy Conservation	Excellent	Good	Fair
Resistance to Wear	Excellent	Good	Fair
Corrosion	Excellent	Good	Good

Characteristic	Steam Trap Type		
	Inverted Bucket	Float & Thermostatic	Liquid Expansion Thermostatic
Corrosion Resistance	Excellent	Good	Good
Resistance to Hydraulic Shock	Excellent	Poor	Poor
Vent Air and CO_2 at Steam Temperature	Yes	No	No
Capability to Vent Air at Very Low Pressure (1/4 psig)	Poor	Excellent	Good
Capability to Handle Startup Air Loads	Fair	Excellent	Excellent
Operation Against Back Pressure	Excellent	Excellent	Excellent
Resistance to Damage from Freezing; Cast Iron Trap Not Recommended	Good	Poor	Good
Capability to Purge System	Excellent	Fair	Good
Performance on Very Light Loads	Excellent	Excellent	Excellent
Responsiveness to Slugs of Condensate	Immediate	Immediate	Delayed
Capability to Handle Dirt	Excellent	Poor	Fair
Comparative Physical Size	Large	Large	Small

Characteristic	Steam Trap Type		
	Inverted Bucket	Float & Thermostatic	Liquid Expansion Thermostatic
Capability to Handle Flash Steam	Fair	Poor	Poor
Usual Mechanical Failure Mode	Open	Closed with air vent open	Open or closed depending on design
Subcooling	No	No	Yes
Venting	Fair	Excellent	Excellent
Seat Pressure Rating	Yes	Yes	N/a
Advantages	Rugged	Continuous condensate discharge	Utilizes sensible heat of condensate
	Tolerates water hammer without damage	Handles rapid pressure changes	Allows discharge of noncondensables at startup to the set point temperature
		High noncondensable capacity	Not affected by superheated steam, water hammer, or vibration
			Resists freezing
Disadvantages	Discharges noncondensables slowly (additional air vent required)	Float can be damaged by water hammer	Element subject to corrosion damage
	Level of condensate can freeze, damaging the trap body	Level of condensate in chamber can freeze, damaging float	Condensate backs up into the drain line and/or process

	Steam Trap Type		
Characteristic	**Inverted Bucket**	**Float & Thermostatic**	**Liquid Expansion Thermostatic**
		and body	
	Must have water seal to operate; subject to losing prime	Some thermostatic air vent designs are susceptible to corrosion	
	Pressure fluctuations and superheated steam can cause loss of the water seal		
Recommended Services	Continuous operation where noncondensable venting is not critical and rugged construction is important	Heat exchangers with high and variable heat transfer rates	Ideal for tracing used for freeze protection
		When condensate pump is required	Freeze protection—water and condensate lines and traps
		Batch processes that require frequent startup of an air-filled system	Noncritical temperature control of heated tanks

STEAM TRAP COMPARISON

	Steam Trap Type		
Characteristic	**Balanced Pressure Thermostatic**	**Bimetal Thermostatic**	**Thermodynami**

Characteristic	Steam Trap Type Balanced Pressure Thermostatic	Bimetal Thermostatic	Thermodynami
Method of Operation	Intermittent	Intermittent	Intermittent
No Load	No action	No action	No action
Light Load	Continuous; usually dribble action	Continuous; usually dribble action	Intermittent
Normal Load	May blast at high pressures	May blast at high pressures	Intermittent
Full or Overload	Continuous	Continuous	Continuous
Energy Conservation	Fair	Fair	Poor
Resistance to Wear	Fair	Fair	Poor
Corrosion Resistance	Good	Good	Excellent
Resistance to Hydraulic Shock	Good	Good	Excellent
Vent Air and CO_2 at Steam Temperature	No	No	No
Capability to Vent Air at Very Low Pressure (1/4 psig)	Good	Good	Not recommended fo low-pressure applications
Capability to Handle Startup Air Loads	Excellent	Excellent	Poor
Operation Against Back Pressure	Excellent	Excellent	Poor
Resistance to Damage from	Good	Good	Good

Characteristic	Steam Trap Type		
	Balanced Pressure Thermostatic	Bimetal Thermostatic	Thermodynamic
Freezing; Cast Iron Trap Not Recommended			
Capability to Purge System	Good	Good	Excellent
Performance on Very Light Loads	Excellent	Excellent	Poor
Responsiveness to Slugs of Condensate	Delayed	Delayed	Delayed
Capability to Handle Dirt	Fair	Fair	Poor
Comparative Physical Size	Small	Small	Small
Capability to Handle Flash Steam	Poor	Poor	Poor
Usual Mechanical Failure Mode	Open or closed depending on design	Open or closed depending on design	Open, dirt can cause to fail closed
Subcooling	Yes	Yes	No
Venting	Excellent	Excellent	Fair
Seat Pressure Rating	N/a	N/a	N/a
Advantages	Small and lightweight	Small and lightweight	Rugged, withstands corrosion, water hammer, high pressure, and superheated steam
	Maximum discharge of	Maximum discharge of	Handles wide pressure range

Characteristic	Steam Trap Type		
	Balanced Pressure Thermostatic	Bimetal Thermostatic	Thermodynamic
	noncondensables at startup	noncondensables at startup	
	Unlikely to freeze	Unlikely to freeze and unlikely to be damaged if it does freeze	Compact and simple
		Rugged; withstands corrosion, water hammer, high pressure, and superheated steam	Audible operations warn when repair is needed
Disadvantages	Some types of damage by water hammer, corrosion, and superheated steam	Responds slowly to load and pressure changes	Poor operation with very low-pressure steam or high back pressure
	Condensate backs up into the drain line and/or process	More condensate backup than balance pressure thermostatic trap	Requires slow pressure buildup to remove air at startup to prevent air binding
		Back pressure changes operating characteristics	Noisy operation
Recommended Services	Batch processing requiring rapid discharge of noncondensables at startup	Drip legs on constant-pressure steam mains	Steam main drips, tracers
	Drip legs on steam mains and tracing	Installations subject to ambient	Constant-pressure, constant-load

Characteristic	Steam Trap Type: Balanced Pressure Thermostatic	Bimetal Thermostatic	Thermodynamic
	tracing	ambient conditions below freezing	constant-load applications
	Installations subject to ambient conditions below freezing		Installations subject to ambient conditions below freezing

6. Steam trap inspection:
   a. Method #1 is shown in the following table:

Trap Failure Rate	Steam Trap Inspection Frequency
Over 10%	Every 2 months
5–10%	Every 3 months
Less than 5%	Every 6 months

   b. Method #2 is shown in the following table:

System Pressure	Steam Trap Inspection Frequency
0–30 psig	Annually
30–100 psig	Semi-annually
100–250 psig	Quarterly or monthly
Over 250 psig	Monthly or weekly

22.02. Steam Condensate System Design Criteria

System Type	Initial Steam Pressure psig	MaximumSystem Back Pressure psig	Maximum Pressure Drop psig/100 ft.	Maximum Velocity FPM
Low Pressure	1 3 5	0 0 0	1/8 1/8 1/8	5,000 5,000 5,000
	7 10 12 15	0 3 4 5	1/8 1/4 1/4 1/4	5,000 5,000 5,000 5,000
Medium Pressure	20 25 30	6 8 10	1/4 1/4 1/4	5,000 5,000 5,000
	40 50 60	13 16 20	1/4 1/4 1/4	5,000 5,000 5,000
	75 85 100	25 28 33	1/4 1/4 1/4	5,000 5,000 5,000
High Pressure	120 125 150	40 41 50	1/4 1/4 1/4	5,000 5,000 5,000
	175 200 225	58 66 75	1/4 1/2 1/2	5,000 5,000 5,000
	250 275 300	83 91 100	1/2 1/2 1/2	5,000 5,000 5,000

22.03. Low-Pressure Steam Condensate System Pipe Sizing Tables (15 psig and Less)

1 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

	Pressure Drop psig/100 ft.				Velocity FPM (mph)	
Pipe Size	**0.125**	**0.25**	**0.5**	**2,000 (23)**	**3,000 (34)**	**4,000 (45)**
Steam Condensate Flow lbs./h 0 psig Back Pressure						
1/2 3/4 1	843 2,067 4,329	1,192 2,923 6,122	1,686 4,134 8,658	3,954 6,577	Pressure with these	drop pipe
1-1/4 1-1/2 2	9,965 15,758 32,660	14,093 22,285 46,189	19,930 31,515 65,321	11,729 16,158 27,000	17,594 24,237 40,500	54,000
2-1/2 3 4	54,310 100,865 216,701	76,806 142,645		38,753 60,396 105,124	58,130 90,594 157,686	77,507 120,792 210,247
5 6 8	405,300			166,358 238,345 417,533	249,536 357,518 626,299	332,715 476,690 835,065
10 12 14				682,684 991,486 1,213,661	1,024,026 1,487,228 1,820,491	1,365,369 1,982,971 2,427,322
16 18 20	Velocity these	governs pipe	with sizes	1,615,821 2,075,432 2,592,495	2,423,731 3,113,148 3,888,742	3,231,642 4,150,864 5,184,990
22 24 26				3,167,009 3,798,974 4,488,391	4,750,513 5,698,462 6,732,587	6,334,018 7,597,949 8,976,782
28 30 32				5,235,260 6,039,579 6,901,350	7,852,889 9,059,369 10,352,026	10,470,519 12,079,159 13,802,701
34 36 42				7,820,573 8,797,247 12,071,977	11,730,859 13,195,870 18,107,966	15,641,146 17,594,494 24,143,954

Notes:

1. Maximum recommended pressure drop/velocity: 0.125 psig/100 ft./5,0

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
42				12,071,977	18,107,966	24,143,954
48 54 60				15,863,770 20,172,626 24,998,544	23,795,655 30,258,938 37,497,816	31,727,540 40,345,251 49,997,088
72 84 96				36,201,568 49,472,844 64,812,370	54,302,353 74,209,266 97,218,554	72,403,137 98,945,687 129,624,739

Notes:

1. **Maximum recommended pressure drop/velocity: 0.125 psig/100 ft./5,(**
2. **Table based on heavy weight steel pipe using steam equations in Part**

3 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5
Steam Condensate Flow lbs./h 0 psig Back Pressure							
1/2 3/4 1	293 718 1,504	414 1,015 2,127	586 1,436 3,008	 1,373 2,285	Pressure with these	drop pipe	
1-1/4 1-1/2 2	3,462 5,474 11,345	4,895 7,741 16,045	6,923 10,947 22,690	4,074 5,613 9,379	6,112 8,419 14,069	 18,758	
2-1/2 3 4	18,866 35,037 75,275	26,680 49,550	with sizes	13,462 20,980 36,517	20,193 31,469 54,775	26,923 41,959 73,033	
5 6 8	140,788	governs pipe		57,787 82,794 145,038	86,681 124,190 217,556	115,575 165,587 290,075	
10	Velocity			237,143	355,714	474,286	

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
12 14	these			344,411 421,588	516,616 632,381	688,822 843,175
16 18 20				561,285 720,940 900,551	841,928 1,081,409 1,350,826	1,122,570 1,441,879 1,801,102
22 24 26				1,100,119 1,319,644 1,559,125	1,650,178 1,979,466 2,338,688	2,200,238 2,639,287 3,118,251
28 30 32				1,818,564 2,097,959 2,397,311	2,727,846 3,146,939 3,595,967	3,637,128 4,195,918 4,794,622
34 36 42				2,716,620 3,055,886 4,193,424	4,074,930 4,583,829 6,290,135	5,433,240 6,111,771 8,386,847
48 54 60				5,510,573 7,007,333 8,683,705	8,265,859 10,511,000 13,025,557	11,021,145 14,014,666 17,367,409
72 84 96				12,575,282 17,185,304 22,513,770	18,862,922 25,777,955 33,770,656	25,150,563 34,370,607 45,027,541
Steam Condensate Flow lbs./h 1 psig Back Pressure						
1/2 3/4 1	461 1,132 2,370	653 1,601 3,352	923 2,264 4,741	 2,232 3,713	Pressure with these	drop pipe
1-1/4 1-1/2 2	5,456 8,628 17,882	7,716 12,201 25,289	10,912 17,255 35,764	6,621 9,121 15,242	9,932 13,682 22,862	 30,483
2-1/2 3 4	29,736 55,226 118,648	42,053 78,101	with sizes	21,876 34,093 59,342	32,814 51,140 89,014	43,753 68,187 118,685
5 6	221,910	governs pipe		93,909 134,546	140,863 201,819	187,818 269,092

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
8				235,697	353,546	471,394
10	Velocity			385,375	578,063	770,751
12	these			559,694	839,541	1,119,388
14				685,112	1,027,668	1,370,224
16				912,131	1,368,197	1,824,262
18				1,171,582	1,757,373	2,343,163
20				1,463,464	2,195,195	2,926,927
22				1,787,777	2,681,665	3,575,554
24				2,144,521	3,216,782	4,289,043
26				2,533,697	3,800,546	5,067,395
28				2,955,305	4,432,957	5,910,609
30				3,409,343	5,114,015	6,818,686
32				3,895,813	5,843,720	7,791,626
34				4,414,714	6,622,071	8,829,429
36				4,966,047	7,449,070	9,932,094
42				6,814,632	10,221,949	13,629,265
48				8,955,100	13,432,650	17,910,200
54				11,387,450	17,081,174	22,774,899
60				14,111,681	21,167,521	28,223,362
72				20,435,790	30,653,684	40,871,579
84				27,927,426	41,891,139	55,854,852
96				36,586,590	54,879,885	73,173,180

Notes:

1. **Maximum recommended pressure drop/velocity: 0.125 psig/100 ft./5,0**

2. **Table based on heavy weight steel pipe using steam equations in Par**

5 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
Steam Condensate Flow lbs./h 0 psig Back Pressure						

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1/2	193	259	366		Pressure	drop pipe
3/4	449	635	898	858	with these	
1	940	1,329	1,880	1,428		
1-1/4	2,163	3,060	4,327	2,546	3,820	
1-1/2	3,421	4,838	6,842	3,508	5,262	
2	7,091	10,028	14,182	5,862	8,793	11,724
2-1/2	11,791	16,675		8,414	12,620	16,827
3	21,898	30,969		13,112	19,668	26,224
4	47,047			22,823	34,234	45,646
5	87,993			36,117	54,176	72,234
6				51,746	77,619	103,492
8				90,649	135,973	181,297
10	Velocity	governs	with	148,214	222,322	296,429
12	these	pipe	sizes	215,257	322,885	430,513
14				263,492	395,238	526,984
16				350,803	526,205	701,606
18				450,587	675,881	901,174
20				562,844	844,266	1,125,689
22				687,574	1,031,361	1,375,149
24				824,777	1,237,166	1,649,555
26				974,453	1,461,680	1,948,907
28				1,136,602	1,704,904	2,273,205
30				1,311,224	1,966,837	2,622,449
32				1,498,319	2,247,479	2,996,639
34				1,697,888	2,546,831	3,395,775
36				1,909,929	2,864,893	3,819,857
42				2,620,890	3,931,335	5,241,780
48				3,444,108	5,166,162	6,888,216
54				4,379,583	6,569,375	8,759,166
60				5,427,315	8,140,973	10,854,631
72				7,859,551	11,789,327	15,719,102
84				10,740,815	16,111,222	21,481,629

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
96				14,071,107	21,106,660	28,142,213	
Steam Condensate Flow lbs./h 1 psig Back Pressure							
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	
1/2 3/4 1	240 590 1,235	340 834 1,746	481 1,179 2,470	 1,163 1,934	Pressure with these	drop pipe	
1-1/4 1-1/2 2	2,843 4,495 9,317	4,020 6,357 13,176	5,685 8,990 18,634	3,450 4,752 7,941	5,175 7,128 11,911	 15,882	
2-1/2 3 4	15,493 28,773 61,817	21,910 40,691	with sizes	11,398 17,763 30,918	17,097 26,644 46,377	22,795 35,526 61,836	
5 6 8	115,617	governs pipe		48,927 70,100 122,800	73,391 105,149 184,200	97,855 140,199 245,600	
10 12 14	Velocity these			200,784 291,605 356,949	301,176 437,408 535,423	401,568 583,210 713,898	
16 18 20				475,228 610,404 762,477	712,842 915,606 1,143,715	950,456 1,220,808 1,524,954	
22 24 26				931,447 1,117,314 1,320,078	1,397,170 1,675,971 1,980,116	1,862,894 2,234,627 2,640,155	
28 30 32				1,539,739 1,776,296 2,029,751	2,309,608 2,664,445 3,044,627	3,079,477 3,552,593 4,059,503	
34 36 42				2,300,103 2,587,352 3,550,481	3,450,155 3,881,028 5,325,721	4,600,207 5,174,704 7,100,962	
48 54 60				4,665,682 5,932,957 7,352,304	6,998,524 8,899,435 11,028,457	9,331,365 11,865,914 14,704,609	

Notes:

1. Maximum recommended pressure drop/velocity: 0.125 psig/100 ft./5,0

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
72				10,647,218	15,970,827	21,294,436
84				14,550,424	21,825,635	29,100,847
96				19,061,921	28,592,881	38,123,842

Notes:

1. **Maximum recommended pressure drop/velocity: 0.125 psig/100 ft./5,0**
2. **Table based on heavy weight steel pipe using steam equations in Part**

7 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	**0.25**	**0.5**	**2,000 (23)**	**3,000 (34)**	**4,000 (45)**
Steam Condensate Flow lbs./h 0 psig Back Pressure						
1/2 3/4 1	136 333 697	192 471 986	271 666 1,394	 636 1,059	Pressure with these	drop pipe
1-1/4 1-1/2 2	1,604 2,537 5,258	2,269 3,587 7,435	3,208 5,073 10,515	1,888 2,601 4,346	2,832 3,902 6,520	 8,693
2-1/2 3 4	8,743 16,237 34,884	12,364 22,962	with sizes	6,238 9,722 16,922	9,358 14,583 25,384	12,477 19,444 33,845
5 6 8	65,243	governs pipe		26,780 38,368 67,213	40,169 57,552 100,819	53,559 76,736 134,425
10 12 14	Velocity these			109,896 159,605 195,370	164,843 239,408 293,055	219,791 319,210 390,740
16				260,108	390,162	520,215

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5
18 20				334,094 417,328	501,141 625,993	668,188 834,657	8 1
22 24 26				509,811 611,542 722,522	764,717 917,313 1,083,782	1,019,622 1,223,084 1,445,043	2 1 1
28 30 32				842,749 972,225 1,110,949	1,264,124 1,458,337 1,666,424	1,685,498 1,944,450 2,221,898	2 2 2
34 36 42				1,258,921 1,416,142 1,943,294	1,888,382 2,124,213 2,914,941	2,517,843 2,832,284 3,886,588	3 3 4
48 54 60				2,553,680 3,247,301 4,024,156	3,830,520 4,870,951 6,036,234	5,107,360 6,494,601 8,048,312	6 8 1
72 84 96				5,827,570 7,963,921 10,433,211	8,741,354 11,945,882 15,649,816	11,655,139 15,927,842 20,866,421	1 1 2
Steam Condensate Flow lbs./h 1 psig Back Pressure							
1/2 3/4 1	166 408 854	235 577 1,208	333 816 1,709	 805 1,338	Pressure with these	drop pipe	g s
1-1/4 1-1/2 2	1,967 3,110 6,446	2,781 4,398 9,116	3,933 6,220 12,892	2,387 3,288 5,494	3,580 4,932 8,241	 10,988	
2-1/2 3 4	10,719 19,907 42,769	15,159 28,153	with sizes	7,886 12,289 21,391	11,828 18,434 32,086	15,771 24,579 42,782	1 3 5
5 6 8	79,991	governs pipe		33,851 48,499 84,961	50,776 72,749 127,441	67,702 96,998 169,921	8 1 2
10 12	***Notes:*** Velocity these			138,914 201,750	208,372 302,625	277,829 403,500	3 5

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5
14				246,959	370,438	493,918	6
16				328,791	493,187	657,583	8
18				422,314	633,471	844,629	
20				527,528	791,291	1,055,055	1
22				644,431	966,647	1,288,862	1
24				773,025	1,159,538	1,546,050	1
26				913,310	1,369,964	1,826,619	2
28				1,065,284	1,597,926	2,130,568	2
30				1,228,949	1,843,424	2,457,899	3
32				1,404,305	2,106,457	2,808,609	3
34				1,591,351	2,387,026	3,182,701	3
36				1,790,087	2,685,130	3,580,173	4
42				2,456,437	3,684,656	4,912,875	6
48				3,228,001	4,842,002	6,456,002	8
54				4,104,778	6,157,167	8,209,557	1
60				5,086,769	7,630,153	10,173,537	1
72				7,366,389	11,049,584	14,732,779	1
84				10,066,863	15,100,294	20,133,726	2
96				13,188,190	19,782,284	26,376,379	3

Notes:

1. **Maximum recommended pressure drop/velocity: 0.125 psig/100 ft./5,0**
2. **Table based on heavy weight steel pipe using steam equations in Part**

10 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5
Steam Condensate Flow lbs./h 0 psig Back Pressure							
1/2	101	143	202		Pressure	drop pipe	g
3/4	247	350	494	473	with these		s
1	518	732	1,035	786			

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1 1-1/4 1-1/2 2	1,191 1,884 3,905	1,685 2,664 5,523	2,383 3,768 7,810	1,402 1,932 3,228	2,104 2,898 4,842	6,457
2-1/2 3 4	6,494 12,060 25,910	9,183 17,055	with sizes	4,634 7,221 12,569	6,950 10,832 18,854	9,267 14,442 25,138
5 6 8	48,460	governs pipe		19,891 28,498 49,922	29,836 42,747 74,884	39,781 56,996 99,845
10 12 14	Velocity these			81,625 118,547 145,112	122,438 177,821 217,667	163,251 237,094 290,223
16 18 20				193,196 248,149 309,972	289,794 372,224 464,958	386,392 496,299 619,944
22 24 26				378,664 454,225 536,655	567,996 681,338 804,983	757,328 908,450 1,073,311
28 30 32				625,955 722,124 825,161	938,932 1,083,185 1,237,742	1,251,910 1,444,247 1,650,323
34 36 42				935,068 1,051,845 1,443,389	1,402,603 1,577,767 2,165,083	1,870,137 2,103,689 2,886,777
48 54 60				1,896,755 2,411,944 2,988,956	2,845,133 3,617,917 4,483,435	3,793,510 4,823,889 5,977,913
72 84 96				4,328,448 5,915,231 7,749,305	6,492,673 8,872,847 11,623,958	8,656,897 11,830,463 15,498,610
Steam Condensate Flow lbs./h 1 psig Back Pressure						
Notes:	118	167	235		Pressure	drop pipe

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1/2	118	167	235		Pressure	drop pipe
3/4	289	408	578	569	with these	
1	605	855	1,210	947		
1-1/4	1,392	1,969	2,784	1,689	2,534	
1-1/2	2,201	3,113	4,403	2,327	3,491	
2	4,563	6,452	9,125	3,889	5,833	7,778
2-1/2	7,587	10,730		5,582	8,372	11,163
3	14,091	19,927		8,699	13,048	17,397
4	30,272			15,141	22,711	30,282
5	56,619	governs	with	23,960	35,940	47,921
6		pipe	sizes	34,329	51,493	68,657
8				60,137	90,205	120,273
10	Velocity			98,326	147,489	196,652
12	these			142,803	214,204	285,605
14				174,802	262,203	349,604
16				232,725	349,087	465,450
18				298,922	448,383	597,844
20				373,394	560,091	746,788
22				456,141	684,211	912,281
24				547,162	820,743	1,094,324
26				646,458	969,687	1,292,916
28				754,028	1,131,043	1,508,057
30				869,874	1,304,810	1,739,747
32				993,993	1,490,990	1,987,987
34				1,126,388	1,689,582	2,252,776
36				1,267,057	1,900,586	2,534,114
42				1,738,713	2,608,069	3,477,426
48				2,284,840	3,427,261	4,569,681
54				2,905,440	4,358,160	5,810,880
60				3,600,511	5,400,767	7,201,022
72				5,214,070	7,821,105	10,428,140
84				7,125,516	10,688,274	14,251,032
96				9,334,850	14,002,275	18,669,700

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Steam Condensate Flow lbs./h 3 psig Back Pressure

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)
1/2 3/4 1	167 408 855	236 578 1,210	333 817 1,711	 1,417	Pressure with these	drop pipe
1- 1/4 1- 1/2 2	1,969 3,113 6,453	2,784 4,403 9,126	3,938 6,227 12,906	2,527 3,481 5,817	3,791 5,222 8,726	 11,635
2- 1/2 3 4	10,730 19,928 42,814	15,175 28,183	with sizes	8,350 13,013 22,649	12,524 19,519 33,974	16,699 26,025 45,299
5 6 8	80,076	governs pipe		35,842 51,352 89,959	53,764 77,029 134,939	71,685 102,705 179,918
10 12 14	Velocity these			147,087 213,620 261,488	220,631 320,429 392,232	294,174 427,239 522,976
16 18 20				348,135 447,160 558,564	522,203 670,740 837,845	696,270 894,321 1,117,127
22 24 26				682,345 818,504 967,042	1,023,517 1,227,757 1,450,563	1,364,690 1,637,009 1,934,084
28 30 32				1,127,958 1,301,252 1,486,924	1,691,937 1,951,878 2,230,386	2,255,916 2,602,504 2,973,848
34 36 42				1,684,974 1,895,403 2,600,957	2,527,461 2,843,104 3,901,435	3,369,949 3,790,805 5,201,913
48 54 60				3,417,914 4,346,274 5,386,038	5,126,871 6,519,411 8,079,057	6,835,828 8,692,549 10,772,076

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
72 84 96				7,799,775 10,659,126 13,964,089	11,699,663 15,988,688 20,946,133	15,599,551 21,318,251 27,928,178

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00**
2. **Table based on heavy weight steel pipe using steam equations in Part**

12 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
Steam Condensate Flow lbs./h 0 psig Back Pressure						
1/2 3/4 1	87 213 446	123 301 631	174 426 893	 408 678	Pressure with these	drop pipe
1-1/4 1-1/2 2	1,028 1,625 3,368	1,453 2,298 4,763	2,055 3,250 6,736	1,210 1,666 2,784	1,814 2,499 4,177	 5,569
2-1/2 3 4	5,601 10,402 22,347	7,921 14,710	with sizes	3,996 6,228 10,841	5,995 9,342 16,261	7,993 12,457 21,682
5 6 8	41,797	governs pipe		17,156 24,579 43,058	25,733 36,869 64,587	34,311 49,159 86,116
10 12 14	Velocity these			70,402 102,247 125,159	105,603 153,370 187,738	140,804 204,494 250,318
16 18				166,632 214,029	249,947 321,043	333,263 428,058

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5
20				267,351	401,027	534,702	6
22				326,598	489,897	653,196	8
24				391,769	587,654	783,538	9
26				462,865	694,298	925,731	1
28				539,886	809,829	1,079,772	1
30				622,832	934,247	1,245,663	1
32				711,702	1,067,553	1,423,404	1
34				806,497	1,209,745	1,612,993	2
36				907,216	1,360,824	1,814,432	2
42				1,244,923	1,867,384	2,489,845	3
48				1,635,951	2,453,927	3,271,903	4
54				2,080,302	3,120,453	4,160,604	5
60				2,577,975	3,866,962	5,155,950	6
72				3,733,287	5,599,930	7,466,573	9
84				5,101,887	7,652,831	10,203,774	1
96				6,683,776	10,025,663	13,367,551	1
Steam Condensate Flow lbs./h 1 psig Back Pressure							
1/2 3/4 1	100 245 512	141 346 724	199 489 1,024	482 802	Pressure with these	drop pipe	g s
1-1/4 1-1/2 2	1,179 1,864 3,863	1,667 2,636 5,463	2,357 3,728 7,726	1,430 1,970 3,293	2,146 2,956 4,939	6,585	
2-1/2 3 4	6,424 11,930 25,631	9,085 16,872	with sizes	4,726 7,365 12,820	7,089 11,048 19,229	9,452 14,730 25,639	1 1 3
5 6 8	47,939	governs pipe		20,287 29,066 50,917	30,430 43,598 76,376	40,574 58,131 101,834	5 7 1
10 12 14	Velocity these			83,252 120,909 [illegible]	124,878 181,364 [illegible]	166,504 241,819 [illegible]	2 3

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5
14				148,003	222,003	296,006	3
16				197,046	295,569	394,091	4
18				253,094	379,641	506,189	6
20				316,149	474,223	632,298	7
22				386,210	579,314	772,419	9
24				463,276	694,915	926,553	1
26				547,349	821,024	1,094,699	1
28				638,428	957,642	1,276,856	1
30				736,513	1,104,770	1,473,026	1
32				841,604	1,262,406	1,683,208	2
34				953,701	1,430,552	1,907,403	2
36				1,072,805	1,609,207	2,145,609	2
42				1,472,151	2,208,226	2,944,301	3
48				1,934,551	2,901,827	3,869,102	4
54				2,460,007	3,690,010	4,920,013	6
60				3,048,516	4,572,775	6,097,033	7
72				4,414,700	6,622,050	8,829,400	1
84				6,033,102	9,049,654	12,066,205	1
96				7,903,723	11,855,585	15,807,447	1
Steam Condensate Flow lbs./h 3 psig Back Pressure							
1/2 3/4 1	134 329 688	189 465 973	268 657 1,376	1,140	Pressure with these	drop pipe	g s
1- 1/4 1- 1/2 2	1,584 2,504 5,191	2,240 3,542 7,341	3,168 5,009 10,382	2,033 2,801 4,680	3,049 4,201 7,020	9,359	
2- 1/2 3 4	8,632 16,031 34,442	12,207 22,671	with sizes	6,717 10,468 18,220	10,075 15,702 27,330	13,434 20,936 36,440	1 2 4
5 6 8	64,417	governs pipe		28,833 41,310 72,367	43,250 61,965 108,551	57,666 82,620 144,734	7 1 1

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)	5
10 12 14	Velocity these			118,323 171,845 210,353	177,485 257,768 315,529	236,647 343,690 420,705	2 4 5
16 18 20				280,055 359,716 449,333	420,083 539,573 674,000	560,111 719,431 898,667	7 8 1
22 24 26				548,909 658,441 777,932	823,363 987,662 1,166,898	1,097,817 1,316,883 1,555,863	1 1 1
28 30 32				907,380 1,046,785 1,196,148	1,361,069 1,570,177 1,794,222	1,814,759 2,093,570 2,392,296	2 2 2
34 36 42				1,355,468 1,524,746 2,092,325	2,033,202 2,287,119 3,138,488	2,710,936 3,049,492 4,184,650	3 3 5
48 54 60				2,749,522 3,496,336 4,332,768	4,124,283 5,244,504 6,499,153	5,499,044 6,992,672 8,665,537	6 8 1
72 84 96				6,274,486 8,574,674 11,233,334	9,411,729 12,862,012 16,850,001	12,548,972 17,149,349 22,466,667	1 2 2

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0**
2. **Table based on heavy weight steel pipe using steam equations in Par**

15 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)	5
Steam Condensate Flow lbs./h 0 psig Back Pressure							
1/2	73	103	146		Pressure	drop pipe	

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
3/4 1	179 375	253 530	358 750	342 570	with these	
1-1/4 1-1/2 2	863 1,365 2,829	1,221 1,930 4,001	1,726 2,730 5,658	1,016 1,400 2,339	1,524 2,099 3,508	4,677
2-1/2 3 4	4,704 8,736 18,769	6,652 12,355	with sizes	3,357 5,231 9,105	5,035 7,847 13,658	6,713 10,462 18,210
5 6 8	35,105	governs pipe		14,409 20,644 36,164	21,613 30,966 54,246	28,818 41,288 72,328
10 12 14	Velocity these			59,130 85,877 105,120	88,695 128,815 157,680	118,260 171,753 210,240
16 18 20				139,953 179,762 224,547	209,929 269,643 336,820	279,906 359,524 449,094
22 24 26				274,308 329,045 388,758	411,462 493,568 583,137	548,616 658,090 777,517
28 30 32				453,448 523,113 597,755	680,172 784,670 896,632	906,895 1,046,226 1,195,510
34 36 42				677,372 761,966 1,045,604	1,016,059 1,142,949 1,568,406	1,354,745 1,523,933 2,091,209
48 54 60				1,374,027 1,747,235 2,165,228	2,061,041 2,620,853 3,247,842	2,748,055 3,494,471 4,330,456
72 84 96				3,135,569 4,285,049 5,613,670	4,703,353 6,427,574 8,420,505	6,271,138 8,570,099 11,227,340

Steam Condensate Flow lbs/h/1 psig Back Pressure

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1/2 3/4 1	82 202 422	116 285 597	164 403 845	 298 661	Pressure with these	drop pipe
1-1/4 1-1/2 2	972 1,537 3,186	1,375 2,174 4,506	1,944 3,074 6,372	1,180 1,625 2,715	1,769 2,438 4,073	 5,431
2-1/2 3 4	5,298 9,839 21,139	7,492 13,915	with sizes	3,897 6,074 10,572	5,846 9,111 15,859	7,795 12,148 21,145
5 6 8	39,536	governs pipe		16,731 23,971 41,992	25,096 35,956 62,988	33,462 47,942 83,984
10 12 14	Velocity these			68,659 99,716 122,060	102,988 149,573 183,090	137,318 199,431 244,120
16 18 20				162,506 208,730 260,732	243,759 313,095 391,098	325,012 417,460 521,464
22 24 26				318,512 382,070 451,406	477,768 573,105 677,109	637,024 764,140 902,812
28 30 32				526,520 607,412 694,082	789,780 911,118 1,041,122	1,053,040 1,214,823 1,388,163
34 36 42				786,530 884,755 1,214,101	1,179,794 1,327,133 1,821,152	1,573,059 1,769,511 2,428,202
48 54 60				1,595,449 2,028,798 2,514,150	2,393,173 3,043,198 3,771,225	3,190,898 4,057,597 5,028,300
1				3,640,859	5,461,289	7,281,718

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
72 84 96				[illegible] 4,975,576 6,518,301	[illegible] 7,463,364 9,777,451	[illegible] 9,951,152 13,036,601
Steam Condensate Flow lbs./h 3 psig Back Pressure						
1/2 3/4 1	105 258 541	149 366 766	211 517 1,083	897	Pressure with these	drop pipe
1-1/4 1-1/2 2	1,246 1,970 4,084	1,762 2,786 5,775	2,492 3,941 8,168	1,599 2,203 3,682	2,399 3,305 5,522	7,363
2-1/2 3 4	6,791 12,612 27,096	9,604 17,836	with sizes	5,284 8,235 14,334	7,926 12,353 21,501	10,568 16,470 28,668
5 6 8	50,677	governs pipe		22,683 32,499 56,932	34,025 48,749 85,398	45,367 64,999 113,864
10 12 14	Velocity these			93,087 135,193 165,487	139,630 202,789 248,231	186,173 270,386 330,975
16 18 20				220,323 282,993 353,497	330,485 424,490 530,245	440,647 565,986 706,993
22 24 26				431,834 518,005 612,009	647,751 777,007 918,014	863,667 1,036,009 1,224,018
28 30 32				713,848 823,520 941,025	1,070,771 1,235,279 1,411,538	1,427,695 1,647,039 1,882,051
34 36 42				1,066,365 1,199,538 1,646,060	1,599,547 1,799,307 2,469,090	2,132,730 2,399,076 3,292,120
48				2,163,085	3,244,628	4,326,171

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
54 60				2,750,614 3,408,646	4,125,921 5,112,970	5,501,228 6,817,293
72 84 96				4,936,221 6,745,810 8,837,413	7,404,332 10,118,715 13,256,119	9,872,443 13,491,620 17,674,826
Steam Condensate Flow lbs./h 5 psig Back Pressure						
1/2 3/4 1	138 338 708	195 478 1,001	276 676 1,416	 1,233	Pressure with these	drop pipe
1-1/4 1-1/2 2	1,630 2,577 5,342	2,305 3,645 7,554	3,260 5,154 10,683	2,200 3,030 5,063	 4,545 7,595	 10,126
2-1/2 3 4	8,883 16,497 35,442	12,562 23,330	17,765	7,267 11,326 19,713	10,901 16,988 29,569	14,534 22,651 39,426
5 6 8	66,288 107,770	governs pipe	with sizes	31,196 44,695 78,296	46,793 67,042 117,445	62,391 89,390 156,593
10 12 14	Velocity these			128,018 185,925 227,588	192,027 278,888 341,382	256,036 371,850 455,176
16 18 20				303,002 389,189 486,149	454,502 583,783 729,224	606,003 778,377 972,298
22 24 26				593,883 712,390 841,671	890,825 1,068,586 1,262,507	1,187,766 1,424,781 1,683,342
28 30 32				981,725 1,132,553 1,294,154	1,472,588 1,698,829 1,941,230	1,963,450 2,265,105 2,588,307
34 36				1,466,528 1,649,675	2,199,792 2,474,513	2,933,056 3,299,351

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
42				2,263,759	3,395,638	4,527,517
48				2,974,802	4,462,204	5,949,605
54				[illegible]	[illegible]	[illegible]
60				4,687,772	7,031,657	9,375,543
72				6,788,583	10,182,874	13,577,165
84				9,277,236	13,915,854	18,554,472
96				12,153,731	18,230,597	24,307,462

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0**
2. **Table based on heavy weight steel pipe using steam equations in Par**

22.04. Medium-Pressure Steam Condensate System Pipe Sizing Tables (20–100 psig)

20 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
Steam Condensate Flow lbs./h 0 psig Back Pressure						
1/2 3/4 1	59 144 302	83 204 427	118 288 604	 276 459	Pressure with these	drop pipe
1-1/4 1-1/2 2	695 1,099 2,279	983 1,555 3,222	1,390 2,199 4,557	818 1,127 1,884	1,227 1,691 2,826	 3,767
2-1/2 3 4	3,789 7,037 15,119	5,359 9,952	with sizes	2,704 4,214 7,334	4,056 6,320 11,001	5,407 8,427 14,668

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0**
2. **Table based on heavy weight steel pipe using steam equations in Par**

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5
6 8	23,277	grams pipe		11,606 16,629 29,130	17,410 24,943 43,695	23,213 33,257 58,260	2 4 7
10 12 14	Velocity these			47,629 69,173 84,674	71,444 103,760 127,011	95,258 138,347 169,348	1 1 2
16 18 20				112,732 144,798 180,872	169,098 217,196 271,308	225,463 289,595 361,743	2 3 4
22 24 26				220,954 265,045 313,144	331,431 397,567 469,715	441,908 530,089 626,287	5 6 7
28 30 32				365,251 421,366 481,490	547,876 632,049 722,234	730,501 842,732 962,979	9 1 1
34 36 42				545,621 613,761 842,231	818,432 920,642 1,263,346	1,091,243 1,227,523 1,684,462	1 1 2
48 54 60				1,106,775 1,407,392 1,744,084	1,660,162 2,111,089 2,616,127	2,213,549 2,814,785 3,488,169	2 3 4
72 84 96				2,525,691 3,451,594 4,521,793	3,788,536 5,177,391 6,782,690	5,051,382 6,903,187 9,043,586	6 8 1
Steam Condensate Flow lbs./h 5 psig Back Pressure							
1/2 3/4 1	98 241 505	139 341 714	197 482 1,010	880	Pressure with these	drop pipe	g s
1-1/4 1-1/2 2	1,163 1,839 3,811	1,644 2,600 5,389	2,325 3,677 7,622	1,569 2,162 3,612	3,242 5,418	7,224	
Notes: 1- 1/2	6,337 11,769	8,962 16,644	12,674	5,184 8,080	7,776 12,119	10,369 16,159	2 3

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)
1/2	11,769	16,644		8,080	12,119	16,159
3	25,284			14,063	21,095	28,126
4						
5	47,290	governs	with	22,255	33,382	44,510
6	76,883	pipe	sizes	31,885	47,828	63,770
8				55,856	83,785	111,713
10	Velocity			91,328	136,991	182,655
12	these			132,638	198,957	265,276
14				162,360	243,540	324,720
16				216,160	324,240	432,320
18				277,646	416,468	555,291
20				346,817	520,225	693,634
22				423,674	635,510	847,347
24				508,216	762,324	1,016,432
26				600,445	900,667	1,200,889
28				700,358	1,050,538	1,400,717
30				807,958	1,211,937	1,615,916
32				923,243	1,384,865	1,846,487
34				1,046,215	1,569,322	2,092,429
36				1,176,871	1,765,307	2,353,742
42				1,614,956	2,422,433	3,229,911
48				2,122,211	3,183,317	4,244,422
54				2,698,638	4,047,957	5,397,276
60				3,344,236	5,016,354	6,688,472
72				4,842,945	7,264,418	9,685,891
84				6,618,340	9,927,509	13,236,679
96				8,670,419	13,005,628	17,340,838
Steam Condensate Flow lbs./h 7 psig Back Pressure						
1/2	123	174	246		Pressure	drop pipe
3/4	301	426	602		with these	
1	631	892	1,262	1,150		
1	1,452	2,053	2,904	2,050		
1/4	2,296	3,247	4,592	2,824	4,236	
1-	4,759	6,730	9,518	4,719	7,079	9,438
1/2						

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

2. Table based on heavy weight steel pipe using steam equations in Part

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
2						
2	7,913	11,191	15,827	6,773	10,160	13,547
1/2	14,697	20,785		10,556	15,834	21,112
3	31,575	44,654		18,374	27,560	36,747
4						
5	59,055	governs	with	29,076	43,614	58,152
6	96,011	pipe	sizes	41,658	62,487	83,316
8				72,976	109,464	145,953
10	Velocity			119,320	178,979	238,639
12	these			173,292	259,938	346,584
14				212,124	318,185	424,247
16				282,413	423,620	564,826
18				362,744	544,116	725,488
20				453,116	679,674	906,232
22				553,530	830,294	1,107,059
24				663,985	995,977	1,327,969
26				784,481	1,176,721	1,568,962
28				915,018	1,372,528	1,830,037
30				1,055,597	1,583,396	2,111,195
32				1,206,218	1,809,327	2,412,435
34				1,366,879	2,050,319	2,733,759
36				1,537,582	2,306,374	3,075,165
42				2,109,940	3,164,909	4,219,879
48				2,772,669	4,159,003	5,545,338
54				3,525,771	5,288,656	7,051,541
60				4,369,244	6,553,866	8,738,489
72				6,327,308	9,490,963	12,654,617
84				8,646,861	12,970,292	17,293,722
96				11,327,903	16,991,854	22,655,806

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0…**

2. **Table based on heavy weight steel pipe using steam equations in Par…**

25 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
Steam Condensate Flow lbs./h 0 psig Back Pressure							
1/2 3/4 1	50 123 257	71 174 364	100 246 515	235 391	Pressure with these	drop pipe	gc si:
1-1/4 1-1/2 2	593 937 1,942	838 1,325 2,746	1,185 1,874 3,884	697 961 1,605	1,046 1,441 2,408	3,211	
2-1/2 3 4	3,229 5,997 12,885	4,567 8,482	with sizes	2,304 3,591 6,251	3,456 5,387 9,376	4,609 7,182 12,501	5, 8, 15
5 6 8	24,099	governs pipe		9,892 14,172 24,826	14,837 21,258 37,239	19,783 28,344 49,653	24 35 62
10 12 14	Velocity these			40,592 58,953 72,164	60,888 88,430 108,245	81,184 117,906 144,327	10 14 18
16 18 20				96,076 123,404 154,148	144,114 185,106 231,223	192,152 246,808 308,297	24 30 38
22 24 26				188,309 225,885 266,877	282,463 338,827 400,316	376,617 451,770 533,755	47 56 66
28 30 32				311,286 359,110 410,351	466,929 538,665 615,526	622,571 718,220 820,701	77 89 1,
34				465,007	697,511	930,014	1,

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
36 42				523,080 717,793	784,619 1,076,690	1,046,159 1,435,586	1, 1,
48 54 60				943,251 1,199,453 1,486,400	1,414,877 1,799,180 2,229,600	1,886,502 2,398,907 2,972,800	2, 2, 3,
72 84 96				2,152,526 2,941,629 3,853,708	3,228,789 4,412,443 5,780,563	4,305,051 5,883,257 7,707,417	5, 7, 9,
Steam Condensate Flow lbs./h 5 psig Back Pressure							
1/2 3/4 1	78 192 402	111 272 569	157 384 805	701	Pressure with these	drop pipe	go si
1-1/4 1-1/2 2	926 1,464 3,035	1,310 2,071 4,293	1,852 2,929 6,071	1,250 1,722 2,877	2,583 4,316	5,754	
2-1/2 3 4	5,047 9,374 20,140	7,138 13,257	10,095	4,129 6,436 11,202	6,194 9,653 16,803	8,259 12,871 22,403	16 28
5 6 8	37,668	governs pipe	with sizes	17,727 25,397 44,491	26,590 38,096 66,737	35,453 50,795 88,982	44 63 11
10 12 14	Velocity these			72,745 105,650 129,324	109,117 158,475 193,986	145,490 211,300 258,648	18 26 32
16 18 20				172,177 221,152 276,249	258,266 331,728 414,373	344,354 442,304 552,497	43 55 69
22 24 26				337,467 404,807 478,270	506,201 607,211 717,405	674,934 809,615 956,539	84 1, 1,
28 30				557,854 643,560	836,781 965,340	1,115,708 1,287,119	1, 1,

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
30				[illegible]	[illegible]	[illegible]	1,
32				735,387	1,103,081	1,470,775	1,
34				833,337	1,250,006	1,666,674	2,
36				937,409	1,406,113	1,874,817	2,
42				1,286,354	1,929,531	2,572,708	3,
48				1,690,396	2,535,595	3,380,793	4,
54				2,149,535	3,224,303	4,299,071	5,
60				2,663,771	3,995,656	5,327,542	6,
72				3,857,532	5,786,298	7,715,064	9,
84				5,271,680	7,907,520	10,543,360	13
96				6,906,214	10,359,322	13,812,429	17
Steam Condensate Flow lbs./h 7 psig Back Pressure							
1/2	94	133	188		Pressure	drop pipe	gc
3/4	231	326	461		with these		si
1	483	683	966	880			
1-1/4	1,112	1,572	2,224	1,570			
1-1/2	1,758	2,486	3,516	2,162	3,244		
2	3,644	5,153	7,288	3,613	5,420	7,227	
2-1/2	6,059	8,569	12,119	5,186	7,780	10,373	20
3	11,254	15,915		8,083	12,124	16,166	35
4	24,178	34,192		14,069	21,103	28,138	
5	45,220	governs	with	22,264	33,396	44,528	55
6	73,517	pipe	sizes	31,898	47,847	63,796	79
8				55,879	83,819	111,758	13
10	Velocity			91,365	137,047	182,729	22
12	these			132,692	199,038	265,384	33
14				162,426	243,639	324,852	40
16				216,248	324,372	432,495	54
18				277,758	416,637	555,516	69
20				346,957	520,436	693,915	86
22				423,846	635,768	847,691	1,
24				508,422	762,634	1,016,845	1,

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
26				600,688	901,032	1,201,376	1,
28 30 32				700,643 808,286 923,618	1,050,964 1,212,429 1,385,427	1,401,285 1,616,572 1,847,236	1, 2, 2,
34 36 42				1,046,639 1,177,349 1,615,611	1,569,959 1,766,023 2,423,416	2,093,278 2,354,698 3,231,222	2, 2, 4,
48 54 60				2,123,072 2,699,733 3,345,593	3,184,608 4,049,599 5,018,389	4,246,144 5,399,466 6,691,186	5, 6, 8,
72 84 96				4,844,910 6,621,025 8,673,937	7,267,366 9,931,538 13,010,905	9,689,821 13,242,050 17,347,874	12 16 21

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0(**
2. **Table based on heavy weight steel pipe using steam equations in Par(**

30 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
Steam Condensate Flow lbs./h 0 psig Back Pressure							
1/2 3/4 1	44 108 227	63 153 321	88 217 454	207 345	Pressure with these	drop pipe	go si:
1-1/4 1-1/2 2	523 827 1,714	739 1,169 2,423	1,046 1,653 3,427	615 848 1,417	923 1,272 2,125	2,833	
2	2,849	4,030	with	2,033	3,050	4,066	5,

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
1/2	5,293	7,484	sizes	3,169	4,753	6,337	7,
3	11,369			5,515	8,273	11,030	13
4							
5	21,264	governs		8,728	13,092	17,456	21
6		pipe		12,505	18,757	25,009	31
8				21,906	32,858	43,811	54
10	Velocity			35,817	53,725	71,633	89
12	these			52,018	78,026	104,035	13
14				63,674	95,511	127,348	15
16				84,773	127,159	169,546	21
18				108,886	163,329	217,772	27
20				136,013	204,020	272,026	34
22				166,155	249,232	332,309	41
24				199,310	298,965	398,621	49
26				235,480	353,220	470,960	58
28				274,664	411,996	549,328	68
30				316,862	475,293	633,724	79
32				362,074	543,111	724,148	90
34				410,300	615,450	820,601	1,
36				461,541	692,311	923,082	1,
42				633,347	950,020	1,266,694	1,
48				832,280	1,248,421	1,664,561	2,
54				1,058,341	1,587,512	2,116,682	2,
60				1,311,529	1,967,294	2,623,059	3,
72				1,899,287	2,848,931	3,798,575	4,
84				2,595,555	3,893,332	5,191,109	6,
96				3,400,331	5,100,496	6,800,662	8,
Steam Condensate Flow lbs./h 5 psig Back Pressure							
1/2	66	94	132		Pressure	drop pipe	go
3/4	162	230	325		with these		si
1	340	481	680	592			
1-	782	1,107	1,565	1,056			
1/4	1,237	1,750	2,475	1,455	2,182		
1-	2,564	3,627	5,129	2,431	3,646	4,861	
1/2							

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
1/2							
2							
2-1/2	4,264	6,031	8,529	3,489	5,233	6,978	13
3	7,920	11,200		5,437	8,156	10,874	3
4	17,015			9,464	14,196	18,928	
5	31,824	governs	with	14,977	22,465	29,953	37
6	51,739	pipe	sizes	21,457	32,186	42,915	53
8				37,589	56,383	75,178	93
10	Velocity			61,459	92,189	122,919	15
12	these			89,260	133,889	178,519	22
14				109,261	163,892	218,523	27
16				145,466	218,199	290,932	36
18				186,843	280,265	373,686	46
20				233,392	350,089	466,785	58
22				285,114	427,671	570,227	71
24				342,007	513,011	684,014	85
26				404,073	606,109	808,145	1,
28				471,310	706,966	942,621	1,
30				543,720	815,580	1,087,441	1,
32				621,302	931,953	1,242,604	1,
34				704,056	1,056,084	1,408,113	1,
36				791,983	1,187,974	1,583,965	1,
42				1,086,794	1,630,191	2,173,588	2,
48				1,428,155	2,142,232	2,856,309	3,
54				1,816,064	2,724,097	3,632,129	4,
60				2,250,523	3,375,785	4,501,047	5,
72				3,259,089	4,888,633	6,518,178	8,
84				4,453,851	6,680,777	8,907,702	11
96				5,834,810	8,752,215	11,669,620	14
Steam Condensate Flow lbs./h 7 psig Back Pressure							
1/2	78	110	155		Pressure	drop pipe	go
3/4	190	269	381		with these		si
1	399	564	797	727			
1-	918	1,298	1,836	1,296			

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
1 1/4 1 1/2 2	[illegible] 1,451 3,008	[illegible] 2,052 4,254	[illegible] 2,903 6,016	[illegible] 1,785 2,983	2,678 4,474	5,966	
2- 1/2 3 4	5,002 9,290 19,958	7,074 13,137 28,225	10,004	4,281 6,672 11,613	6,422 10,008 17,420	8,562 13,344 23,227	 16 29
5 6 8	37,328 60,686	governs pipe	with sizes	18,378 26,331 46,127	27,567 39,496 69,190	36,756 52,662 92,253	45 65 11
10 12 14	Velocity these			75,419 109,534 134,078	113,128 164,300 201,117	150,838 219,067 268,156	18 27 33
16 18 20				178,506 229,282 286,404	267,760 343,922 429,605	357,013 458,563 572,807	44 57 71
22 24 26				349,873 419,688 495,851	524,809 629,533 743,777	699,745 839,377 991,702	87 1, 1,
28 30 32				578,361 667,217 762,421	867,541 1,000,826 1,143,631	1,156,721 1,334,434 1,524,841	1, 1, 1,
34 36 42				863,971 971,868 1,333,641	1,295,956 1,457,802 2,000,462	1,727,942 1,943,736 2,667,282	2, 2, 3,
48 54 60				1,752,536 2,228,553 2,761,692	2,628,804 3,342,830 4,142,538	3,505,072 4,457,106 5,523,384	4, 5, 6,
72 84 96				3,999,336 5,465,469 7,160,089	5,999,005 8,198,203 10,740,134	7,998,673 10,930,938 14,320,179	9, 13 17
Steam Condensate Flow lbs./h 10 psig Back Pressure							
Notes: 1/2 3/4	99 243	139 343	197 484		Pressure with th	drop pipe	go si

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
3/4 1	242 506	342 716	484 1,013	 981	with these		si
1-1/4 1-1/2 2	1,166 1,842 3,821	1,649 2,607 5,403	2,331 3,687 7,641	1,749 2,409 4,026	 3,614 6,039		
2-1/2 3 4	6,353 11,800 25,350	8,985 16,687 35,851	12,707	5,778 9,005 15,675	8,668 13,508 23,512	11,557 18,011 31,350	 22 39
5 6 8	47,413 77,083			24,805 35,539 62,257	37,208 53,309 93,386	49,610 71,078 124,515	62 88 15
10 12 14				101,794 147,838 180,966	152,690 221,758 271,450	203,587 295,677 361,933	25 36 45
16 18 20	Velocity these	governs pipe	with sizes	240,932 309,463 386,562	361,398 464,195 579,842	481,863 618,927 773,123	60 77 96
22 24 26				472,226 566,457 669,255	708,339 849,686 1,003,882	944,452 1,132,914 1,338,510	1, 1, 1,
28 30 32				780,619 900,549 1,029,046	1,170,928 1,350,824 1,543,569	1,561,237 1,801,098 2,058,092	1, 2, 2,
34 36 42				1,166,109 1,311,739 1,800,028	1,749,164 1,967,609 2,700,041	2,332,219 2,623,479 3,600,055	2, 3, 4,
48 54 60				2,365,414 3,007,899 3,727,481	3,548,121 4,511,848 5,591,222	4,730,828 6,015,797 7,454,963	5, 7, 9,
72 84 96				5,397,941 7,376,794 9,664,039	8,096,912 11,065,190 14,496,058	10,795,882 14,753,587 19,328,077	13 18 24

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0C**
2. **Table based on heavy weight steel pipe using steam equations in Par**

40 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	**0.25**	**0.5**	**2,000 (23)**	**3,000 (34)**	**4,000 (45)**	**5,**
Steam Condensate Flow lbs./h 0 psig Back Pressure							
1/2 3/4 1	37 90 188	52 127 266	73 180 376	 172 286	Pressure with these	drop pipe	gc si:
1- 1/4 1- 1/2 2	433 685 1,420	613 969 2,008	867 1,370 2,840	510 703 1,174	765 1,054 1,761	 2,348	
2- 1/2 3 4	2,361 4,385 9,422	3,339 6,202	with sizes	1,685 2,626 4,571	2,527 3,939 6,856	3,370 5,252 9,141	4, 6, 11
5 6 8	17,622	governs pipe		7,233 10,363 18,154	10,849 15,544 27,230	14,466 20,726 36,307	18 25 45
10 12 14	Velocity these			29,682 43,108 52,768	44,523 64,662 79,152	59,364 86,216 105,536	74 10 13
16 18 20				70,253 90,236 112,717	105,380 135,354 169,076	140,506 180,472 225,434	17 22 28
22				137,696	206,544	275,392	34

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
24 26				165,173 195,147	247,759 292,721	330,346 390,295	41 48
28 30 32				227,620 262,590 300,059	341,430 393,886 450,088	455,240 525,181 600,117	56 65 75
34 36 42				340,025 382,489 524,869	510,037 573,733 787,303	680,050 764,978 1,049,737	85 95 1,
48 54 60				689,729 877,071 1,086,893	1,034,594 1,315,606 1,630,340	1,379,458 1,754,141 2,173,786	1, 2, 2,
72 84 96				1,573,981 2,150,993 2,817,929	2,360,972 3,226,490 4,226,894	3,147,962 4,301,986 5,635,858	3, 5, 7,
Steam Condensate Flow lbs./h 5 psig Back Pressure							
1/2 3/4 1	52 128 267	74 180 378	104 255 534	465	Pressure with these	drop pipe	go si
1-1/4 1-1/2 2	615 972 2,015	870 1,375 2,850	1,230 1,945 4,031	830 1,143 1,910	1,715 2,865	3,820	
2-1/2 3 4	3,351 6,224 13,371	4,739 8,802	6,702	2,742 4,273 7,437	4,112 6,409 11,156	5,483 8,545 14,874	10 18
5 6 8	25,008 40,658	governs pipe	with sizes	11,769 16,862 29,539	17,654 25,293 44,308	23,538 33,724 59,077	29 42 73
10 12 14	Velocity these			48,297 70,143 85,861	72,445 105,215 128,791	96,594 140,286 171,722	12 17 21
16 18				114,312 146,827	171,468 220,241	228,624 293,655	28 36

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
18 20				146,827 183,407	220,241 275,111	293,655 366,814	36 45
22 24 26				224,051 268,760 317,533	336,077 403,140 476,300	448,103 537,520 635,067	56 67 79
28 30 32				370,371 427,273 488,239	555,556 640,909 732,359	740,742 854,546 976,478	92 1, 1,
34 36 42				553,270 622,365 854,037	829,905 933,548 1,281,056	1,106,540 1,244,730 1,708,075	1, 1, 2,
48 54 60				1,122,290 1,427,121 1,768,533	1,683,434 2,140,682 2,652,800	2,244,579 2,854,243 3,537,066	2, 3, 4,
72 84 96				2,561,096 3,499,979 4,585,180	3,841,644 5,249,968 6,877,770	5,122,193 6,999,957 9,170,361	6, 8, 11
Steam Condensate Flow lbs./h 7 psig Back Pressure							
1/2 3/4 1	59 146 305	84 206 432	119 291 610	556	Pressure with these	drop pipe	go si
1-1/4 1-1/2 2	702 1,111 2,302	993 1,571 3,256	1,405 2,221 4,604	992 1,366 2,283	2,049 3,424	4,566	
2-1/2 3 4	3,828 7,110 15,275	5,414 10,055 21,602	7,656	3,277 5,106 8,888	4,915 7,660 13,332	6,553 10,213 17,777	12 22
5 6 8	28,568 46,446	governs pipe	with sizes	14,066 20,152 35,303	21,098 30,228 52,954	28,131 40,304 70,605	35 50 88
10 12	Velocity these			57,721 83,831	86,582 125,746	115,443 167,661	14 20

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	**0.25**	**0.5**	**2,000 (23)**	**3,000 (34)**	**4,000 (45)**	**5,**
14				102,616	153,924	205,232	25
16				136,619	204,928	273,237	34
18				175,479	263,219	350,958	43
20				219,197	328,795	438,394	5
22				267,772	401,659	535,545	66
24				321,206	481,808	642,411	80
26				379,496	569,244	758,992	94
28				442,644	663,966	885,289	1,
30				510,650	765,975	1,021,300	1,
32				583,513	875,270	1,167,026	1,
34				661,234	991,851	1,322,468	1,
36				743,812	1,115,719	1,487,625	1,
42				1,020,693	1,531,039	2,041,386	2,
48				1,341,291	2,011,937	2,682,582	3,
54				1,705,607	2,558,411	3,411,215	4,
60				2,113,642	3,170,462	4,227,283	5,
72				3,060,864	4,591,296	6,121,728	7,
84				4,182,958	6,274,437	8,365,916	10
96				5,479,924	8,219,886	10,959,848	13
Steam Condensate Flow lbs./h 10 psig Back Pressure							
1/2 3/4 1	72 177 370	102 250 523	144 353 740	 717	Pressure with these	drop pipe	go si
1- 1/4 1- 1/2 2	852 1,347 2,792	1,205 1,905 3,949	1,704 2,694 5,585	1,278 1,761 2,942	 2,641 4,414		
2- 1/2 3 4	4,643 8,624 18,527	6,567 12,196 26,202	9,287	4,223 6,582 11,456	6,335 9,872 17,184	8,446 13,163 22,912	 16 28
5 6 8	34,652 56,336	governs pipe	with sizes	18,129 25,974 45,501	27,193 38,961 68,251	36,258 51,948 91,002	45 64 11

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)	5,
10 12 14	Velocity these			74,396 108,048 13[illegible]	111,594 162,071 198,389	148,792 216,095 264,518	18 27 33
16 18 20				176,085 226,171 282,518	264,127 339,256 423,777	352,169 452,342 565,036	44 56 70
22 24 26				345,126 413,995 489,124	517,689 620,992 733,686	690,252 827,989 978,248	86 1, 1,
28 30 32				570,514 658,165 752,077	855,771 987,248 1,128,116	1,141,029 1,316,331 1,504,154	1, 1, 1,
34 36 42				852,250 958,683 1,315,548	1,278,375 1,438,025 1,973,322	1,704,500 1,917,366 2,631,096	2, 2, 3,
48 54 60				1,728,760 2,198,319 2,724,225	2,593,140 3,297,479 4,086,338	3,457,520 4,396,638 5,448,451	4, 5, 6,
72 84 96				3,945,079 5,391,321 7,062,952	5,917,619 8,086,982 10,594,427	7,890,158 10,782,642 14,125,903	9, 13 17
Steam Condensate Flow lbs./h 12 psig Back Pressure							
1/2 3/4 1	82 201 421	116 284 595	164 402 842		Pressure with these	drop pipe	go si
1- 1/4 1- 1/2 2	969 1,533 3,177	1,371 2,167 4,492	1,938 3,065 6,353	1,508 2,077 3,471	 5,207		
2- 1/2 3 4	5,282 9,810 21,076	7,470 13,873 29,806	10,564	4,982 7,765 13,515	7,474 11,647 20,273	9,965 15,530 27,031	 19 33

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
5	39,419			21,388	32,082	42,776	53
6	64,086			30,643	45,965	61,286	76
8				53,680	80,521	107,361	13
10	Velocity	governs	with	87,770	131,655	175,540	2
12	these	pipe	sizes	127,471	191,207	254,942	31
14				156,035	234,053	312,070	39
16				207,739	311,609	415,478	51
18				266,829	400,244	533,659	66
20				333,306	499,959	666,612	83
22				407,169	610,753	814,338	1,
24				488,418	732,627	976,836	1,
26				577,053	865,580	1,154,106	1,
28				673,075	1,009,612	1,346,150	1,
30				776,483	1,164,724	1,552,966	1,
32				887,277	1,330,916	1,774,554	2,
34				1,005,458	1,508,186	2,010,915	2,
36				1,131,024	1,696,537	2,262,049	2,
42				1,552,042	2,328,064	3,104,085	3,
48				2,039,537	3,059,305	4,079,074	5,
54				2,593,508	3,890,262	5,187,016	6,
60				3,213,956	4,820,934	6,427,911	8,
72				4,654,281	6,981,421	9,308,561	11
84				6,360,512	9,540,767	12,721,023	15
96				8,332,649	12,498,973	16,665,297	20

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00**
2. **Table based on heavy weight steel pipe using steam equations in Part**

50 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000	3,000 (34)	4,000 (45)	5

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
Steam Condensate Flow lbs./h 0 psig Back Pressure							
1/2	32	45	64		Pressure	drop pipe	go
3/4	78	111	156	150	with these		si
1	164	232	328	249			
1-1/4	377	533	754	444	666		
1-1/2	596	843	1,193	611	917		
2	1,236	1,748	2,472	1,022	1,533	2,044	
2-1/2	2,055	2,907	with	1,467	2,200	2,933	3,
3	3,817	5,398	sizes	2,286	3,428	4,571	5,
4	8,201			3,978	5,967	7,957	9,
5	15,338	governs		6,296	9,443	12,591	1
6		pipe		9,020	13,530	18,040	2
8				15,801	23,702	31,602	3
10	Velocity			25,836	38,753	51,671	6
12	these			37,522	56,283	75,044	9
14				45,930	68,895	91,860	1
16				61,149	91,724	122,298	1
18				78,543	117,814	157,085	1
20				98,110	147,166	196,221	2
22				119,852	179,779	239,705	2
24				143,769	215,653	287,537	3
26				169,859	254,788	339,718	4
28				198,123	297,185	396,247	4
30				228,562	342,843	457,124	5
32				261,175	391,762	522,350	6
34				295,962	443,943	591,924	7
36				332,923	499,385	665,847	8
42				456,852	685,279	913,705	1,
48				600,349	900,524	1,200,698	1,
54				763,414	1,145,120	1,526,827	1,
60				946,046	1,419,069	1,892,092	2,

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
72 84 96				1,370,013 1,872,252 2,452,762	2,055,020 2,808,378 3,679,143	2,740,027 3,744,504 4,905,523	3, 4, 6,
Steam Condensate Flow lbs./h 5 psig Back Pressure							
1/2 3/4 1	44 108 225	62 152 318	88 215 450	392	Pressure with these	drop pipe	g si
1- 1/4 1- 1/2 2	518 820 1,699	733 1,159 2,403	1,037 1,639 3,398	700 964 1,610	1,446 2,416	3,221	
2- 1/2 3 4	2,825 5,247 11,273	3,995 7,420	5,650	2,311 3,602 6,270	3,467 5,403 9,405	4,623 7,204 12,540	9, 1
5 6 8	21,083 34,277	governs pipe	with sizes	9,922 14,215 24,903	14,883 21,323 37,354	19,844 28,431 49,805	2 3 6
10 12 14	Velocity these			40,717 59,135 72,386	61,075 88,702 108,578	81,434 118,269 144,771	1 1 1
16 18 20				96,371 123,784 154,622	144,557 185,675 231,934	192,743 247,567 309,245	2 3 3
22 24 26				188,888 226,580 267,698	283,332 339,870 401,547	377,776 453,159 535,396	4 5 6
28 30 32				312,243 360,215 411,613	468,365 540,322 617,419	624,486 720,429 823,225	7 9 1,
34 36 42				466,437 524,688 720,001	699,656 787,033 1,080,002	932,875 1,049,377 1,440,002	1, 1, 1,

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
48 54 60				946,152 1,203,143 1,490,972	1,419,229 1,804,714 2,236,458	1,892,305 2,406,285 2,981,944	2, 3, 3,
72 84 96				2,159,146 2,950,676 3,865,562	3,238,720 4,426,015 5,798,343	4,318,293 5,901,353 7,731,123	5, 7, 9,
Steam Condensate Flow lbs./h 7 psig Back Pressure							
1/2 3/4 1	49 121 253	70 171 358	99 242 507	462	Pressure with these	drop pipe	g si
1- 1/4 1- 1/2 2	583 923 1,912	825 1,305 2,704	1,167 1,845 3,824	824 1,135 1,896	1,702 2,844	3,792	
2- 1/2 3 4	3,180 5,905 12,687	4,497 8,351 17,942	6,359	2,722 4,241 7,382	4,082 6,362 11,074	5,443 8,483 14,765	1(1
5 6 8	23,728 38,577	governs pipe	with sizes	11,683 16,738 29,322	17,524 25,107 43,983	23,365 33,476 58,644	2 4 7
10 12 14	Velocity these			47,942 69,628 85,231	71,914 104,443 127,847	95,885 139,257 170,462	1 1 2
16 18 20				113,473 145,750 182,062	170,210 218,625 273,092	226,947 291,500 364,123	2 3(4
22 24 26				222,408 266,788 315,204	333,612 400,183 472,806	444,815 533,577 630,407	5 6(7
28 30 32				367,654 424,138 484,657	551,480 636,207 726,986	735,307 848,276 969,314	9 1, 1,
34				549,211	823,816	1,098,422	1,

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
36 42				617,799 847,772	926,699 1,271,658	1,235,598 1,695,544	1, 2,
48 54 60				1,114,056 1,416,651 1,755,558	1,671,084 2,124,977 2,633,338	2,228,112 2,833,303 3,511,117	2, 3, 4,
72 84 96				2,542,307 3,474,301 4,551,541	3,813,460 5,211,452 6,827,312	5,084,614 6,948,602 9,103,082	6, 8, 1
Steam Condensate Flow lbs./h 10 psig Back Pressure							
1/2 3/4 1	58 143 300	83 203 424	117 286 600	581	Pressure with these	drop pipe	go si
1- 1/4 1- 1/2 2	690 1,092 2,263	976 1,544 3,200	1,381 2,184 4,526	1,036 1,427 2,384	2,140 3,577		
2- 1/2 3 4	3,763 6,989 15,015	5,322 9,883 21,234	7,526	3,422 5,334 9,284	5,134 8,001 13,926	6,845 10,668 18,568	1 2
5 6 8	28,082 45,655	governs pipe	with sizes	14,692 21,049 36,874	22,038 31,574 55,311	29,383 42,098 73,748	3 5 9
10 12 14	Velocity these			60,291 87,562 107,183	90,436 131,343 160,775	120,581 175,124 214,366	1 2 2
16 18 20				142,699 183,290 228,953	214,049 274,934 343,430	285,399 366,579 457,907	3 4 5
22 24 26				279,691 335,502 396,387	419,536 503,254 594,581	559,382 671,005 792,775	6 8 9
28				462,346	693,520	924,693	1,

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
30 32				533,379 609,485	800,068 914,228	1,066,758 1,218,971	1, 1,
34 36 42				690,666 776,919 1,066,124	1,035,998 1,165,379 1,599,186	1,381,331 1,553,839 2,132,247	1, 1, 2,
48 54 60				1,400,992 1,781,524 2,207,720	2,101,488 2,672,286 3,311,579	2,801,984 3,563,048 4,415,439	3, 4, 5,
72 84 96				3,197,103 4,369,141 5,723,835	4,795,654 6,553,712 8,585,752	6,394,205 8,738,282 11,447,670	7, 1 1
Steam Condensate Flow lbs./h 12 psig Back Pressure							
1/2 3/4 1	65 160 335	92 226 474	130 320 670		Pressure with these	drop pipe	g si
1-1/4 1-1/2 2	771 1,219 2,526	1,090 1,724 3,573	1,542 2,438 5,052	1,199 1,652 2,761	4,141		
2-1/2 3 4	4,201 7,802 16,762	5,941 11,033 23,704	8,402	3,962 6,175 10,749	5,944 9,263 16,123	7,925 12,351 21,497	 1 2
5 6 8	31,349 50,967	governs pipe	with sizes	17,010 24,370 42,691	25,514 36,555 64,037	34,019 48,740 85,383	4 6 1
10 12 14	Velocity these			69,802 101,376 124,093	104,704 152,065 186,140	139,605 202,753 248,186	1 2 3
16 18 20				165,213 212,207 265,075	247,819 318,310 397,612	330,426 424,413 530,150	4 5 6
22 24				323,817 388,434	485,726 582,651	647,634 776,868	8 9

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
26 28 30 32				458,925 535,290 617,520 705,642	688,387 802,934 926,293 1,058,464	917,849 1,070,579 1,235,058 1,411,285	1, 1, 1, 1,
34 36 42				799,630 899,492 1,234,324	1,199,445 1,349,238 1,851,485	1,599,260 1,798,984 2,468,647	1, 2, 3,
48 54 60				1,622,023 2,062,591 2,556,026	2,433,035 3,093,886 3,834,040	3,244,046 4,125,181 5,112,053	4, 5, 6,
72 84 96				3,701,502 5,058,450 6,626,871	5,552,253 7,587,675 9,940,306	7,403,004 10,116,901 13,253,742	9, 1 1
Steam Condensate Flow lbs./h 15 psig Back Pressure							
1/2 3/4 1	77 188 394	108 266 557	153 376 788		Pressure with these	drop pipe	g si
1- 1/4 1- 1/2 2	907 1,434 2,973	1,283 2,028 4,204	1,814 2,869 5,946	1,483 2,044 3,415	5,122		
2- 1/2 3 4	4,943 9,181 19,724	6,991 12,984 27,894	9,887 18,362	4,901 7,638 13,295	7,352 11,458 19,943	9,802 15,277 26,590	3
5 6 8	36,890 59,976 126,990	52,171	with sizes	21,040 30,144 52,806	31,559 45,216 79,209	42,079 60,288 105,613	5 7 1
10 12 14	Velocity these	governs pipe		86,341 125,395 153,494	129,511 188,093 230,242	172,681 250,791 306,989	2 3 3
16 18 20				204,356 262,484 327,878	306,535 393,727 491,818	408,713 524,969 655,757	5 6 8

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
22				400,539	600,808	801,077	1,
24				480,465	720,697	960,929	1,
26				567,657	851,485	1,135,313	1,
28				662,115	993,172	1,324,229	1,
30				763,839	1,145,758	1,527,678	1,
32				872,829	1,309,243	1,745,658	2,
34				989,085	1,483,627	1,978,170	2,
36				1,112,607	1,668,910	2,225,214	2,
42				1,526,769	2,290,154	3,053,539	3,
48				2,006,326	3,009,488	4,012,651	5,
54				2,551,276	3,826,914	5,102,552	6,
60				3,161,620	4,742,431	6,323,241	7,
72				4,578,491	6,867,737	9,156,983	1
84				6,256,938	9,385,408	12,513,877	15
96				8,196,962	12,295,443	16,393,924	20

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00**
2. **Table based on heavy weight steel pipe using steam equations in Part**

60 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
Steam Condensate Flow lbs./h 0 psig Back Pressure							
1/2	29	41	57		Pressure	drop pipe	g
3/4	70	99	141	134	with these		si
1	147	208	294	224			
1-	339	479	677	399	598		
1/4	536	757	1,071	549	824		
1-	1,110	1,570	2,220	918	1,376	1,835	

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00**

Pipe Size	Pressure Drop psig/100 ft.				Velocity FPM (mph)		
1/2 2	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5
2- 1/2 3 4	1,846 3,428 7,365	2,610 4,848	with sizes	1,317 2,053 3,573	1,976 3,079 5,359	2,634 4,105 7,145	3, 5, 8,
5 6 8	13,774	governs pipe		5,654 8,100 14,190	8,481 12,150 21,285	11,308 16,201 28,380	14 20 35
10 12 14	Velocity these			23,201 33,696 41,247	34,802 50,544 61,870	46,403 67,392 82,494	58 84 10
16 18 20				54,915 70,535 88,107	82,372 105,802 132,161	109,829 141,070 176,215	13 17 22
22 24 26				107,633 129,110 152,541	161,449 193,666 228,811	215,265 258,221 305,081	26 32 38
28 30 32				177,923 205,259 234,546	266,885 307,888 351,820	355,847 410,517 469,093	44 51 58
34 36 42				265,787 298,980 410,273	398,680 448,469 615,410	531,573 597,959 820,546	66 74 1,
48 54 60				539,139 685,578 849,590	808,709 1,028,368 1,274,385	1,078,279 1,371,157 1,699,180	1, 1, 2,
72 84 96				1,230,331 1,681,363 2,202,686	1,845,497 2,522,045 3,304,029	2,460,663 3,362,727 4,405,372	3, 4, 5,
Steam Condensate Flow lbs./h 5 psig Back Pressure							
1/2 3/4 1	39 95 198	55 134 280	77 189 396	 345	Pressure with these	drop pipe	go si
Note	456	644	911	615			

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
1-1/4 1-1/2 2	456 721 1,494	644 1,019 2,112	911 1,441 2,987	615 847 1,416	1,271 2,124	2,831	
2-1/2 3 4	2,484 4,613 9,910	3,512 6,523	4,967	2,032 3,167 5,512	3,048 4,750 8,268	4,064 6,333 11,024	7, 1
5 6 8	18,535 30,133	governs pipe	with sizes	8,723 12,497 21,892	13,084 18,746 32,839	17,445 24,994 43,785	2 3 5
10 12 14	Velocity these			35,795 51,986 63,636	53,693 77,980 95,454	71,590 103,973 127,271	8 1 1
16 18 20				84,722 108,821 135,932	127,083 163,231 203,898	169,444 217,642 271,864	2 2 3
22 24 26				166,055 199,191 235,339	249,083 298,786 353,009	332,110 398,382 470,678	4 4 5
28 30 32				274,499 316,672 361,857	411,749 475,008 542,786	548,999 633,344 723,715	6 7 9
34 36 42				410,055 461,265 632,968	615,082 691,897 949,452	820,110 922,529 1,265,936	1, 1, 1,
48 54 60				831,782 1,057,708 1,310,744	1,247,674 1,586,562 1,966,117	1,663,565 2,115,416 2,621,489	2, 2, 3,
72 84 96				1,898,151 2,594,001 3,398,296	2,847,226 3,891,002 5,097,444	3,796,301 5,188,002 6,796,592	4, 6, 8,
Steam Condensate Flow lbs./h 7 psig Back Pressure							
1/2	43	61	86		Pressure	drop pipe	g

Notes:

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)	5,
3/4 1	105 221	149 312	211 441	402	with these		si
1-1/4 1-1/2 2	508 803 1,665	718 1,136 2,355	1,016 1,607 3,330	717 988 1,651	1,482 2,477	3,302	
2-1/2 3 4	2,769 5,142 11,047	3,915 7,272 15,623	5,537	2,370 3,693 6,428	3,555 5,540 9,642	4,740 7,386 12,857	9, 1
5 6 8	20,662 33,591	governs pipe	with sizes	10,173 14,575 25,532	15,259 21,862 38,298	20,346 29,150 51,064	2 3 6
10 12 14	Velocity these			41,746 60,630 74,216	62,619 90,944 111,323	83,493 121,259 148,431	1 1 1
16 18 20				98,808 126,913 158,531	148,212 190,370 237,797	197,615 253,826 317,063	2 3 3
22 24 26				193,663 232,308 274,466	290,495 348,462 411,699	387,326 464,616 548,932	4 5 6
28 30 32				320,137 369,321 422,019	480,205 553,982 633,028	640,274 738,643 844,037	8 9 1,
34 36 42				478,229 537,953 738,203	717,344 806,930 1,107,305	956,459 1,075,906 1,476,407	1, 1, 1,
48 54 60				970,072 1,233,559 1,528,665	1,455,108 1,850,339 2,292,998	1,940,144 2,467,119 3,057,330	2, 3, 3,
72 84 96				2,213,732 3,025,273 3,963,287	3,320,598 4,537,909 5,944,931	4,427,464 6,050,545 7,926,574	5, 7, 9,

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Steam Condensate Flow lbs./h 10 psig Back Pressure

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
1/2 3/4 1	50 123 257	71 174 364	100 246 514	498	Pressure with these	drop pipe	go si
1-1/4 1-1/2 2	592 936 1,941	837 1,324 2,744	1,184 1,873 3,881	888 1,224 2,045	1,836 3,067		
2-1/2 3 4	3,227 5,993 12,876	4,564 8,476 18,209	6,454	2,935 4,574 7,961	4,402 6,861 11,942	5,870 9,148 15,923	1 1
5 6 8	24,082 39,152			12,599 18,051 31,621	18,898 27,076 47,432	25,198 36,102 63,243	3 4 7
10 12 14	Velocity these	governs pipe	with sizes	51,702 75,089 91,915	77,554 112,634 137,873	103,405 150,178 183,831	1 1 2
16 18 20				122,373 157,181 196,340	183,559 235,771 294,510	244,745 314,361 392,680	3 3 4
22 24 26				239,850 287,711 339,924	359,775 431,567 509,885	479,700 575,423 679,847	5 7 8
28 30 32				396,487 457,401 522,667	594,730 686,102 784,000	792,974 914,802 1,045,333	9 1, 1,
34 36 42				592,283 666,250 914,259	888,424 999,375 1,371,388	1,184,566 1,332,501 1,828,517	1, 1, 2,
48 54 60				1,201,426 1,527,753 1,893,239	1,802,139 2,291,629 2,839,858	2,402,852 3,055,506 3,786,477	3, 3, 4,
[illegible]				[illegible]	[illegible]	[illegible]	[illegible]

Pipe Size	Pressure Drop psig/100 ft.				Velocity FPM (mph)		
72 84 96				2,741,688 3,746,774 4,908,497	4,112,532 5,620,161 7,362,746	5,483,376 7,493,549 9,816,995	6, 9, 1
Steam Condensate Flow lbs./h 12 psig Back Pressure	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
1/2 3/4 1	55 136 284	78 192 402	111 271 568		Pressure with these	drop pipe	g si
1-1/4 1-1/2 2	654 1,033 2,142	924 1,462 3,029	1,307 2,067 4,284	1,017 1,401 2,341	3,511		
2-1/2 3 4	3,562 6,615 14,213	5,037 9,356 20,100	7,124	3,360 5,236 9,114	5,040 7,854 13,671	6,720 10,472 18,228	1 2
5 6 8	26,582 43,216	governs pipe	with sizes	14,423 20,664 36,199	21,634 30,996 54,299	28,846 41,328 72,398	3 5 9
10 12 14	Velocity these			59,187 85,960 105,222	88,781 128,940 157,833	118,375 171,919 210,444	1 2 2
16 18 20				140,088 179,936 224,764	210,132 269,903 337,146	280,177 359,871 449,528	3 4 5
22 24 26				274,573 329,363 389,134	411,860 494,045 583,701	549,146 658,726 778,268	6 8 9
28 30 32				453,886 523,619 598,333	680,829 785,428 897,499	907,772 1,047,238 1,196,666	1, 1, 1,
34 36 42				678,027 762,703 1,046,615	1,017,041 1,144,055 1,569,923	1,356,055 1,525,406 2,093,231	1, 1, 2,
48				1,375,356	2,063,034	2,750,712	3,

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5
54 60				1,748,925 2,167,322	2,623,387 3,250,983	3,497,850 4,334,644	4, 5,
72 84 96				3,138,601 4,289,193 5,619,098	4,707,901 6,433,789 8,428,647	6,277,202 8,578,386 11,238,196	7, 1 1
Steam Condensate Flow lbs./h 15 psig Back Pressure							
1/2 3/4 1	64 157 328	90 221 464	128 313 656		Pressure with these	drop pipe	go si
1-1/4 1-1/2 2	755 1,194 2,474	1,067 1,688 3,499	1,510 2,387 4,948	1,235 1,701 2,842	4,263		
2-1/2 3 4	4,114 7,640 16,415	5,818 10,805 23,214	8,228 15,281	4,079 6,357 11,064	6,118 9,535 16,596	8,158 12,713 22,129	2
5 6 8	30,700 49,912 105,681	43,417	with sizes	17,509 25,086 43,946	26,264 37,629 65,918	35,018 50,172 87,891	4 6 1
10 12 14	Velocity these	governs pipe		71,853 104,354 127,739	107,779 156,532 191,608	143,706 208,709 255,477	1 2 3
16 18 20				170,066 218,440 272,862	255,099 327,661 409,292	340,132 436,881 545,723	4 5 6
22 24 26				333,330 399,844 472,406	499,994 599,766 708,609	666,659 799,688 944,812	8 9 1,
28 30 32				551,014 635,669 726,371	826,521 953,504 1,089,557	1,102,028 1,271,338 1,452,742	1, 1, 1,
34 ***Notes:*** 36				823,120 925,915	1,234,680 1,388,873	1,646,240 1,851,831	2, 2,

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
42				1,270,583	1,905,874	2,541,165	3,
48 54 60				1,669,671 2,123,181 2,631,111	2,504,506 3,184,771 3,946,667	3,339,342 4,246,361 5,262,222	4, 5, 6,
72 84 96				3,810,236 5,207,045 6,821,539	5,715,354 7,810,568 10,232,309	7,620,472 10,414,091 13,643,079	9, 1 1
Steam Condensate Flow lbs./h 20 psig Back Pressure							
1/2 3/4 1	81 198 415	114 280 587	162 396 830		Pressure with these	drop pipe	g si
1-1/4 1-1/2 2	956 1,511 3,132	1,352 2,137 4,430	1,911 3,022 6,265	1,681 2,316 3,870	5,805		
2-1/2 3 4	5,209 9,673 20,782	7,366 13,680 29,391	10,417 19,347	5,555 8,657 15,068	8,332 12,985 22,602	17,314 30,136	3
5 6 8	38,870 63,194 133,803	54,970	with sizes	23,845 34,163 59,847	35,767 51,244 89,770	47,689 68,326 119,693	5 8 1
10 12 14	Velocity these	governs pipe		97,852 142,114 173,959	146,778 213,170 260,938	195,704 284,227 347,918	2 3 4
16 18 20				231,602 297,480 371,592	347,403 446,220 557,389	463,204 594,960 743,185	5 7 9
22 24 26				453,940 544,522 643,339	680,910 816,783 965,008	907,880 1,089,044 1,286,677	1, 1, 1,
28 30				750,390 865,677	1,125,585 1,298,515	1,500,781 1,731,353	1, 2,

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5.00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
32				989,198	1,483,796	1,978,395	2,
34				1,120,953	1,681,430	2,241,907	2,
36				1,260,944	1,891,416	2,521,888	3,
42				1,730,324	2,595,486	3,460,648	4,
48				2,273,816	3,410,724	4,547,633	5,
54				2,891,421	4,337,132	5,782,843	7,
60				3,583,139	5,374,709	7,166,278	8,
72				5,188,913	7,783,369	10,377,825	1:
84				7,091,137	10,636,705	14,182,273	11
96				9,289,811	13,934,716	18,579,622	2:

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0(**
2. **Table based on heavy weight steel pipe using steam equations in Part**

75 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
Steam Condensate Flow lbs./h 0 psig Back Pressure							
1/2 3/4 1	25 62 130	36 87 183	50 124 259	 118 197	Pressure with these	drop pipe	gı si
1- 1/4 1- 1/2 2	298 471 977	422 667 1,382	596 943 1,954	351 483 808	526 725 1,212	 1,616	
2- 1/2 3 4	1,625 3,018 6,483	2,298 4,268	with sizes	1,159 1,807 3,145	1,739 2,710 4,718	2,319 3,614 6,290	2, 4, 7,

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0(**
2. **Table based on heavy weight steel pipe using steam equations in Part**

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
5 6 8	12,126	grams pipe.		4,977 7,131 12,492	7,466 10,696 18,738	9,954 14,262 24,984	1 1 3
10 12 14	Velocity these			20,425 29,664 36,311	30,637 44,496 54,466	40,850 59,327 72,622	5 7 9
16 18 20				48,343 62,094 77,563	72,514 93,140 116,345	96,686 124,187 155,127	1 1 1
22 24 26				94,752 113,659 134,286	142,128 170,489 201,428	189,504 227,319 268,571	2 2 3
28 30 32				156,631 180,695 206,477	234,946 271,042 309,716	313,261 361,389 412,955	3 4 5
34 36 42				233,979 263,200 361,174	350,969 394,799 541,761	467,958 526,399 722,349	5 6 9
48 54 60				474,619 603,533 747,917	711,928 905,299 1,121,875	949,237 1,207,066 1,495,833	1, 1, 1,
72 84 96				1,083,093 1,480,149 1,939,083	1,624,640 2,220,223 2,908,624	2,166,186 2,960,297 3,878,165	2, 3, 4,
Steam Condensate Flow lbs./h 5 psig Back Pressure							
1/2 3/4 1	33 81 170	47 115 241	66 163 341	 297	Pressure with these	drop pipe	g si
1-1/4 1-1/2 2	392 621 1,286	555 878 1,819	785 1,241 2,573	530 730 1,219	 1,094 1,829	 2,438	
Notes: 1-1/2	2,139 3,972	3,025 5,618	4,278	1,750 2,727	2,625 4,091	3,500 5,454	 6

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
1/2 3 4	3,972 8,534	5,618		2,727 4,747	4,091 7,120	5,454 9,494	6, 1
5 6 8	15,963 25,951	governs pipe	with sizes	7,512 10,762 18,854	11,268 16,144 28,281	15,024 21,525 37,707	1 2 4
10 12 14	Velocity these			30,827 44,771 54,803	46,240 67,156 82,204	61,653 89,541 109,606	7 1 1
16 18 20				72,963 93,716 117,064	109,444 140,574 175,596	145,925 187,433 234,129	1 2 2
22 24 26				143,007 171,543 202,674	214,510 257,315 304,011	286,013 343,086 405,347	3 4 5
28 30 32				236,399 272,718 311,631	354,598 409,077 467,447	472,797 545,435 623,262	5 6 7
34 36 42				353,139 397,240 545,111	529,708 595,861 817,667	706,277 794,481 1,090,222	8 9 1,
48 54 60				716,330 910,897 1,128,811	1,074,495 1,366,345 1,693,217	1,432,660 1,821,793 2,257,623	1, 2, 2,
72 84 96				1,634,685 2,233,951 2,926,608	2,452,027 3,350,926 4,389,912	3,269,370 4,467,901 5,853,216	4, 5, 7,
Steam Condensate Flow lbs./h 7 psig Back Pressure							
1/2 3/4 1	37 90 188	52 127 266	73 180 377	 343	Pressure with these	drop pipe	g si
1 1/4 1- 1/2	433 685 1,420	613 969 2,009	867 1,370 2,840	612 843 1,408	 1,264 2,113	 2,817	

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

2. Table based on heavy weight steel pipe using steam equations in Part

2 Pipe Size	Pressure Drop psig/100 ft 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)	5
2 1/2 3 4	2,362 4,386 9,423	3,340 6,203 13,327	4,723	2,021 3,150 5,483	3,032 4,726 8,225	4,043 6,301 10,967	 7, 1
5 6 8	17,625 28,654	governs pipe	with sizes	8,677 12,432 21,779	13,016 18,649 32,669	17,355 24,865 43,558	2 3 5
10 12 14	Velocity these			35,610 51,717 63,306	53,415 77,576 94,960	71,220 103,435 126,613	8 1 1
16 18 20				84,284 108,258 135,228	126,425 162,386 202,843	168,567 216,515 270,457	2 2 3
22 24 26				165,196 198,160 234,121	247,794 297,240 351,182	330,392 396,320 468,242	4 4 5
28 30 32				273,079 315,034 359,985	409,618 472,550 539,977	546,158 630,067 719,970	6 7 8
34 36 42				407,933 458,878 629,692	611,899 688,316 944,539	815,866 917,755 1,259,385	1, 1, 1,
48 54 60				827,478 1,052,234 1,303,962	1,241,217 1,578,352 1,955,942	1,654,956 2,104,469 2,607,923	2, 2, 3,
72 84 96				1,888,328 2,580,578 3,380,710	2,832,492 3,870,867 5,071,066	3,776,656 5,161,155 6,761,421	4, 6, 8,
Steam Condensate Flow lbs./h 10 psig Back Pressure							
1/2 3/4 1	42 103 216	60 146 306	84 206 432	 419	Pressure with these	drop pipe	g si
1 1/4	498 787	704 1,113	995 1,574	747 1,028	 1,543		

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
1/4	787	1,113	1,574	1,028	1,543		
1-1/2	1,631	2,306	3,262	1,718	2,578		
2							
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
2-	2,712	3,835	5,424	2,466	3,700	4,933	
1/2	5,037	7,123		3,844	5,766	7,688	9,
3	10,821	15,303		6,691	10,036	13,381	1(
4							
5	20,238	governs	with	10,588	15,882	21,176	2(
6	32,902	pipe	sizes	15,170	22,755	30,339	3'
8				26,574	39,861	53,148	6(
10	Velocity			43,450	65,175	86,900	1(
12	these			63,104	94,656	126,208	1!
14				77,244	115,867	154,489	1!
16				102,840	154,260	205,681	2!
18				132,093	198,139	264,185	3:
20				165,001	247,502	330,003	4:
22				201,567	302,350	403,134	5(
24				241,789	362,683	483,578	6(
26				285,667	428,501	571,335	7:
28				333,202	499,804	666,405	8:
30				384,394	576,591	768,788	9(
32				439,242	658,863	878,484	1,
34				497,747	746,620	995,494	1,
36				559,908	839,862	1,119,816	1,
42				768,331	1,152,497	1,536,662	1,
48				1,009,663	1,514,494	2,019,326	2,
54				1,283,903	1,925,855	2,567,807	3,
60				1,591,053	2,386,580	3,182,106	3,
72				2,304,079	3,456,118	4,608,158	5,
84				3,148,740	4,723,110	6,297,480	7,
96				4,125,037	6,187,556	8,250,074	1(
Steam Condensate Flow lbs./h 12 psig Back Pressure							
1/2	46	65	92		Pressure	drop pipe	g
3/4	113	159	225		with these		si

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
1	236	334	472				
1-1/4	543	768	1,087	845			
1-1/2	859	1,215	1,719	1,165			
2	1,781	2,519	3,562	1,946	2,919		
2-1/2	2,961	4,188	5,923	2,793	4,190	5,587	
3	5,500	7,778		4,353	6,530	8,707	1
4	11,817	16,711		7,578	11,366	15,155	1
5	22,101			11,991	17,987	23,983	2
6	35,931			17,180	25,771	34,361	4
8				30,097	45,145	60,193	7
10				49,209	73,814	98,419	1
12				71,468	107,203	142,937	1
14				87,483	131,225	174,967	2
16	Velocity	governs	with	116,472	174,708	232,944	2
18	these	pipe	sizes	149,602	224,403	299,203	3
20				186,873	280,309	373,745	4
22				228,285	342,427	456,570	5
24				273,838	410,758	547,677	6
26				323,533	485,300	647,066	8
28				377,369	566,053	754,738	9
30				435,346	653,019	870,692	1,
32				497,464	746,197	994,929	1,
34				563,724	845,586	1,127,448	1,
36				634,125	951,187	1,268,250	1,
42				870,174	1,305,262	1,740,349	2,
48				1,143,495	1,715,243	2,286,990	2,
54				1,454,087	2,181,130	2,908,174	3,
60				1,801,950	2,702,924	3,603,899	4,
72				2,609,488	3,914,232	5,218,976	6,
84				3,566,111	5,349,166	7,132,221	8,
96				4,671,817	7,007,726	9,343,634	1

Notes: Condensate Flow lbs./h 15 psig Back Pressure

Steam Condensate Flow lbs./h 15 psig Back Pressure

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)	5,
1/2 3/4 1	52 128 268	74 181 379	104 256 536		Pressure with these	drop pipe	go si
1-1/4 1-1/2 2	617 975 2,022	872 1,379 2,859	1,234 1,951 4,043	1,009 1,390 2,322	3,483		
2-1/2 3 4	3,362 6,243 13,414	4,754 8,830 18,970	6,723 12,487	3,333 5,195 9,041	5,000 7,792 13,562	6,666 10,389 18,083	2
5 6 8	25,088 40,787 86,360	35,479	with sizes	14,308 20,500 35,911	21,462 30,749 53,867	28,616 40,999 71,822	3 5 8
10 12 14	Velocity these	governs pipe		58,716 85,276 104,385	88,075 127,914 156,577	117,433 170,552 208,769	1 2 2
16 18 20				138,974 178,504 222,976	208,460 267,756 334,463	277,947 357,008 445,951	3 4 5
22 24 26				272,388 326,743 386,038	408,583 490,114 579,057	544,777 653,485 772,076	6 8 9
28 30 32				450,275 519,453 593,572	675,412 779,179 890,358	900,549 1,038,905 1,187,144	1, 1, 1,
34 36 42				672,633 756,634 1,038,288	1,008,949 1,134,952 1,557,432	1,345,265 1,513,269 2,076,575	1, 1, 2,
48 54 60				1,364,413 1,735,009 2,150,077	2,046,619 2,602,514 3,225,116	2,728,825 3,470,018 4,300,154	3, 4, 5,
72				3,113,628	4,670,442	6,227,256	7,

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
84 96				4,255,065 5,574,388	6,382,597 8,361,582	8,510,130 11,148,776	10 13
Steam Condensate Flow lbs./h 20 psig Back Pressure							
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
1/2 3/4 1	64 157 328	90 222 464	128 313 656		Pressure with these	drop pipe	go si
1-1/4 1-1/2 2	755 1,195 2,476	1,068 1,689 3,502	1,511 2,389 4,952	1,329 1,831 3,059	4,589		
2-1/2 3 4	4,117 7,647 16,428	5,823 10,814 23,233	8,234 15,293	4,391 6,843 11,911	6,586 10,264 17,866	13,686 23,821	29
5 6 8	30,726 49,953 105,768	43,453	with sizes	18,849 27,005 47,307	28,273 40,508 70,961	37,697 54,010 94,615	47 67 11
10 12 14	Velocity these	governs pipe		77,350 112,337 137,510	116,024 168,506 206,265	154,699 224,675 275,021	19 28 34
16 18 20				183,076 235,151 293,735	274,614 352,726 440,602	366,152 470,301 587,470	45 58 73
22 24 26				358,829 430,432 508,544	538,243 645,647 762,816	717,657 860,863 1,017,088	89 1, 1,
28 30 32				593,166 684,297 781,937	889,748 1,026,445 1,172,906	1,186,331 1,368,593 1,563,874	1, 1, 1,
34 36 42				886,087 996,746 1,367,780	1,329,130 1,495,119 2,051,670	1,772,174 1,993,492 2,735,559	2, 2, 3,
48 54				1,797,398 2,285,600	2,696,096 3,428,400	3,594,795 4,571,200	4, 5,

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
60				2,832,386	4,248,579	5,664,773	7,
72				4,101,712	6,152,568	8,203,424	1(
84				5,605,375	8,408,062	11,210,749	1
96				7,343,374	11,015,061	14,686,749	1
Steam Condensate Flow lbs./h 25 psig Back Pressure							
1/2	78	110	156		Pressure	drop pipe	go
3/4	191	270	381		with these		si
1	399	565	799				
1-1/4	919	1,300	1,839	1,723			
1-1/2	1,454	2,056	2,908	2,373			
2	3,014	4,262	6,027	3,966	5,948		
2-1/2	5,011	7,087	10,022	5,692	8,538		
3	9,307	13,162	18,614	8,871	13,306	17,741	
4	19,995	28,277		15,440	23,160	30,880	3
5	37,397	52,888	with	24,434	36,651	48,868	6
6	60,799	85,983	sizes	35,007	52,510	70,014	8
8	128,734			61,325	91,988	122,650	1
10	246,797	governs		100,269	150,404	200,539	2
12		pipe		145,625	218,437	291,249	3
14				178,257	267,385	356,513	4
16	Velocity			237,324	355,986	474,648	5
18	these			304,829	457,244	609,659	7
20				380,773	571,160	761,546	9
22				465,155	697,732	930,310	1,
24				557,975	836,962	1,115,950	1,
26				659,233	988,850	1,318,466	1,
28				768,929	1,153,394	1,537,859	1,
30				887,064	1,330,596	1,774,128	2,
32				1,013,637	1,520,455	2,027,273	2,
34				1,148,648	1,722,971	2,297,295	2,
36				1,292,097	1,938,145	2,584,193	3,
42				1,773,073	2,659,610	3,546,146	4,

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
48 54 60				2,329,993 2,962,857 3,671,664	3,494,990 4,444,285 5,507,496	4,659,986 5,925,714 7,343,329	5, 7, 9,
72 84 96				5,317,110 7,266,330 9,519,325	7,975,665 10,899,495 14,278,988	10,634,220 14,532,660 19,038,650	1 1 2

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0**
2. **Table based on heavy weight steel pipe using steam equations in Par**

85 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
Steam Condensate Flow lbs./h 0 psig Back Pressure							
1/2 3/4 1	24 58 121	33 82 171	47 115 242	110 184	Pressure with these	drop pipe	g si
1-1/4 1-1/2 2	278 440 912	393 622 1,290	556 880 1,824	327 451 754	491 677 1,131	1,508	
2-1/2 3 4	1,516 2,816 6,050	2,144 3,982	with sizes	1,082 1,686 2,935	1,623 2,529 4,402	2,164 3,372 5,870	2, 4, 7,
5 6 8	11,315	governs pipe		4,644 6,654 11,657	6,967 9,981 17,486	9,289 13,309 23,314	1 1 2

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5
10 12 14	Velocity these			19,060 27,681 33,884	28,590 41,522 50,826	38,119 55,362 67,768	47 69 84
16 18 20				45,112 57,944 72,379	67,668 86,915 108,569	90,223 115,887 144,759	1 14 18
22 24 26				88,419 106,063 125,310	132,629 159,094 187,966	176,838 212,125 250,621	22 26 31
28 30 32				146,162 168,618 192,677	219,243 252,927 289,016	292,324 337,235 385,355	36 42 48
34 36 42				218,341 245,608 337,035	327,511 368,413 505,552	436,682 491,217 674,070	54 61 84
48 54 60				442,897 563,195 697,929	664,346 844,793 1,046,893	885,794 1,126,390 1,395,858	1, 1, 1,
72 84 96				1,010,704 1,381,222 1,809,482	1,516,056 2,071,832 2,714,224	2,021,407 2,762,443 3,618,965	2, 3, 4,
Steam Condensate Flow lbs./h 5 psig Back Pressure							
1/2 3/4 1	31 75 157	43 106 223	61 150 315	274	Pressure with these	drop pipe	go si
1- 1/4 1- 1/2 2	362 573 1,188	512 810 1,680	725 1,146 2,375	489 674 1,126	1,010 1,689	2,251	
2- 1/2 3 4	1,975 3,668 7,880	2,793 5,187	3,950	1,616 2,518 4,383	2,424 3,777 6,574	3,231 5,036 8,766	6, 10
5	14,738	governs	with	6,936	10,404	13,871	17

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
6 8	2?,960 Pressure	pipe	sizes	9,937 17,408	14,906 26,111	19,874 34,815	24 43
10 12 14	Velocity these			28,461 41,337 50,600	42,693 62,005 75,899	56,925 82,674 101,199	71 10 12
16 18 20				67,366 86,528 108,086	101,050 129,793 162,128	134,733 173,057 216,171	16 21 27
22 24 26				132,038 158,386 187,129	198,057 237,579 280,693	264,076 316,772 374,258	33 39 46
28 30 32				218,267 251,801 287,729	327,401 377,701 431,594	436,534 503,601 575,459	54 62 71
34 36 42				326,053 366,772 503,302	489,080 550,159 754,953	652,107 733,545 1,006,603	81 91 1,
48 54 60				661,388 841,032 1,042,233	992,082 1,261,548 1,563,349	1,322,776 1,682,064 2,084,465	1, 2, 2,
72 84 96				1,509,306 2,062,609 2,702,140	2,263,959 3,093,913 4,053,210	3,018,612 4,125,217 5,404,280	3, 5, 6,
Steam Condensate Flow lbs./h 7 psig Back Pressure							
1/2 3/4 1	34 83 173	48 117 245	67 165 346	315	Pressure with these	drop pipe	g si
1-1/4 1-1/2 2	398 630 1,305	563 891 1,846	797 1,260 2,611	562 775 1,294	1,162 1,942	2,589	
2-1/2 3	2,171 4,031 8,661	3,070 5,701 12,248	4,341	1,858 2,896 5,040	2,787 4,343 7,560	3,716 5,791 10,080	7, 1

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5
3	8,661	12,249		5,040	7,560	10,080	
4							
5	16,199	governs	with	7,976	11,964	15,952	19
6	26,337	pipe	sizes	11,427	17,141	22,854	3
8				20,018	30,027	40,036	50
10	Velocity			32,730	49,096	65,461	81
12	these			47,536	71,303	95,071	11
14				58,187	87,281	116,375	14
16				77,468	116,203	154,937	19
18				99,504	149,256	199,008	24
20				124,294	186,441	248,588	31
22				151,838	227,757	303,676	37
24				182,137	273,206	364,274	45
26				215,190	322,785	430,380	53
28				250,998	376,497	501,996	62
30				289,560	434,340	579,120	72
32				330,876	496,315	661,753	82
34				374,947	562,421	749,895	93
36				421,773	632,659	843,546	1,
42				578,776	868,163	1,157,551	1,
48				760,568	1,140,853	1,521,137	1,
54				967,151	1,450,726	1,934,302	2,
60				1,198,524	1,797,785	2,397,047	2,
72				1,735,638	2,603,457	3,471,277	4,
84				2,371,913	3,557,869	4,743,826	5,
96				3,107,347	4,661,020	6,214,694	7,
Steam Condensate Flow lbs./h 10 psig Back Pressure							
1/2	38	54	77	382	Pressure	drop pipe	go
3/4	94	133	188		with these		si
1	197	279	395				
1	454	642	908	681	1,408		
1/4	718	1,016	1,436	939	2,353		
1-1/2	1,489	2,105	2,977	1,569			
2							

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

2. Table based on heavy weight steel pipe using steam equations in Part

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
2 1/2 3 4	2,475 4,597 9,877	3,501 6,502 13,968	4,951	2,251 3,509 6,107	3,377 5,263 9,161	4,503 7,018 12,215	8, 15
5 6 8	18,473 30,033	governs pipe	with sizes	9,665 13,847 24,257	14,497 20,770 36,386	19,329 27,694 48,514	24 34 60
10 12 14	Velocity these			39,661 57,601 70,509	59,492 86,402 105,764	79,323 115,203 141,018	99 14 17
16 18 20				93,873 120,575 150,614	140,809 180,862 225,921	187,746 241,149 301,228	23 30 37
22 24 26				183,991 220,706 260,758	275,986 331,059 391,137	367,982 441,411 521,516	45 55 65
28 30 32				304,148 350,876 400,942	456,223 526,314 601,413	608,297 701,752 801,884	76 87 1,
34 36 42				454,345 511,086 701,335	681,518 766,629 1,052,003	908,690 1,022,172 1,402,671	1, 1, 1,
48 54 60				921,624 1,171,952 1,452,319	1,382,436 1,757,927 2,178,478	1,843,248 2,343,903 2,904,638	2, 2, 3,
72 84 96				2,103,171 2,874,181 3,765,348	3,154,757 4,311,272 5,648,023	4,206,343 5,748,362 7,530,697	5, 7, 9,
Steam Condensate Flow lbs./h 12 psig Back Pressure							
1/2 3/4 1	42 102 214	59 145 303	83 205 429		Pressure with these	drop pipe	go si
1 1/4	494 781	698 1,104	987 1,561	768 1,058	2,652		

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.50	2,000 (23)	3,000 (34)	4,000 (45)	5,
1-1/2 2	1,618	2,288	3,235	1,768			
2-1/2 3 4	2,6[illegible] 4,996 10,734	3,8[illegible] 7,065 15,180	5,0[illegible]0	2,537 3,954 6,883	3,806 5,932 10,325	5,075 7,909 13,766	5, 17
5 6 8	20,075 32,638	governs pipe	with sizes	10,892 15,606 27,338	16,339 23,409 41,008	21,785 31,212 54,677	27 39 68
10 12 14	Velocity these			44,699 64,919 79,466	67,049 97,378 119,199	89,399 129,837 158,931	11 16 19
16 18 20				105,798 135,891 169,746	158,696 203,837 254,619	211,595 271,782 339,493	26 33 42
22 24 26				207,363 248,742 293,882	311,045 373,113 440,823	414,726 497,484 587,764	51 62 73
28 30 32				342,784 395,448 451,873	514,176 593,172 677,810	685,568 790,896 903,746	85 98 1,
34 36 42				512,060 576,009 790,425	768,090 864,013 1,185,638	1,024,120 1,152,018 1,580,851	1, 1, 1,
48 54 60				1,038,697 1,320,824 1,636,806	1,558,045 1,981,236 2,455,209	2,077,394 2,641,647 3,273,611	2, 3, 4,
72 84 96				2,370,335 3,239,286 4,243,658	3,555,503 4,858,929 6,365,486	4,740,671 6,478,572 8,487,315	5, 8, 10
Steam Condensate Flow lbs./h 15 psig Back Pressure							
1/2 3/4 1	47 115 242	67 163 342	94 231 483		Pressure with these	drop pipe	go si

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
1-1/4 1-1/2 2	556 879 1,822	786 1,243 2,577	1,112 1,758 3,645	909 1,253 2,093	3,140		
2-1/2 3 4	3,030 5,628 12,091	4,285 7,959 17,099	6,060 11,255	3,004 4,682 8,150	4,507 7,023 12,225	6,009 9,364 16,300	2
5 6 8	22,613 36,764 77,843	31,980	with sizes	12,897 18,478 32,369	19,345 27,717 48,554	25,794 36,956 64,739	3 4 8
10 12 14	Velocity these	governs pipe		52,925 76,865 94,090	79,388 115,298 141,134	105,851 153,731 188,179	1 1 2
16 18 20				125,267 160,899 200,984	187,901 241,348 301,476	250,534 321,797 401,968	3 4 5
22 24 26				245,524 294,517 347,964	368,285 441,775 521,946	491,047 589,034 695,929	6 7 8
28 30 32				405,866 468,221 535,030	608,798 702,331 802,545	811,731 936,442 1,070,060	1, 1, 1,
34 36 42				606,293 682,010 935,885	909,440 1,023,015 1,403,827	1,212,586 1,364,020 1,871,770	1, 1, 2,
48 54 60				1,229,845 1,563,891 1,938,022	1,844,768 2,345,836 2,907,033	2,459,690 3,127,782 3,876,044	3, 3, 4,
72 84 96				2,806,541 3,835,402 5,024,605	4,209,811 5,753,103 7,536,907	5,613,082 7,670,803 10,049,209	7, 9, 1
Steam Condensate Flow lbs./h 20 psig Back Pressure							

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)	5,
1/2	57	80	114		Pressure	drop pipe	go
3/4	139	197	278		with these		si
1	292	412	583				
1-1/4	671	949	1,343	1,181	[illegible]		
1-1/2	1,061	1,501	2,123	1,627			
2	2,200	3,111	4,400	2,718			
2-1/2	3,658	5,174	7,317	3,902	5,852	12,161	2
3	6,795	9,609	13,589	6,080	9,121	21,167	
4	14,598	20,644		10,584	15,875		
5	27,302	38,611	with	16,748	25,123	33,497	4
6	44,387		sizes	23,996	35,994	47,992	5
8	93,983			42,036	63,054	84,072	1
10	Velocity	governs		68,731	103,096	137,462	1
12	these	pipe		99,820	149,730	199,640	2
14				122,188	183,282	244,377	3
16				162,677	244,015	325,353	4
18				208,949	313,424	417,898	5
20				261,006	391,509	522,011	6
22				318,846	478,269	637,693	7
24				382,471	573,706	764,942	9
26				451,880	677,819	903,759	1,
28				527,072	790,609	1,054,145	1,
30				608,049	912,074	1,216,099	1,
32				694,810	1,042,215	1,389,620	1,
34				787,355	1,181,033	1,574,710	1,
36				885,684	1,328,526	1,771,368	2,
42				1,215,376	1,823,063	2,430,751	3,
48				1,597,123	2,395,685	3,194,247	3,
54				2,030,928	3,046,392	4,061,856	5,
60				2,516,789	3,775,183	5,033,578	6,
72				3,644,681	5,467,021	7,289,361	9,
84				4,980,798	7,471,197	9,961,597	1

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
96				6,525,142	9,787,713	13,050,284	1(
Steam Condensate Flow lbs./h 25 psig Back Pressure							
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
1/2 3/4 1	68 167 349	96 236 494	136 333 698		Pressure with these	drop pipe	g(si
1-1/4 1-1/2 2	804 1,271 2,634	1,136 1,797 3,725	1,607 2,542 5,268	1,506 2,074 3,466	5,199		
2-1/2 3 4	4,380 8,134 17,476	6,194 11,504 24,714	8,760 16,268	4,975 7,753 13,495	7,462 11,629 20,242	15,506 26,989	3:
5 6 8	32,685 53,139 112,514	46,224 75,150	with sizes	21,355 30,596 53,598	32,033 45,894 80,398	42,710 61,192 107,197	5: 7(1:
10 12 14	215,701	governs pipe		87,636 127,276 155,797	131,454 190,915 233,695	175,271 254,553 311,594	2: 3: 3:
16 18 20	Velocity these			207,422 266,422 332,797	311,133 399,633 499,195	414,844 532,844 665,594	5: 6(8:
22 24 26				406,547 487,672 576,172	609,820 731,508 864,258	813,094 975,344 1,152,344	1, 1, 1,
28 30 32				672,047 775,297 885,922	1,008,070 1,162,945 1,328,883	1,344,094 1,550,593 1,771,843	1, 1, 2,
34 36 42				1,003,922 1,129,297 1,549,672	1,505,883 1,693,945 2,324,507	2,007,843 2,258,593 3,099,343	2, 2, 3,
48 54 60				2,036,422 2,589,546 3,209,046	3,054,632 3,884,320 4,813,569	4,072,843 5,179,093 6,418,093	5, 6, 8,

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0(

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
72 84 96				4,647,171 6,350,796 8,31[illegible],920	6,970,757 9,526,194 12,479,881	9,294,342 12,701,592 16,639,841	1 1 2(

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0(**
2. **Table based on heavy weight steel pipe using steam equations in Par**

100 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
Steam Condensate Flow lbs./h 0 psig Back Pressure							
1/2 3/4 1	22 53 111	31 75 157	43 106 222	101 168	Pressure with these	drop pipe	g(si
1-1/4 1-1/2 2	255 403 836	361 571 1,182	510 807 1,672	300 414 691	450 621 1,037	1,382	
2-1/2 3 4	1,390 2,582 5,548	1,966 3,652		992 1,546 2,691	1,488 2,319 4,037	1,984 3,092 5,383	2, 3, 6,
5 6 8	10,376			4,259 6,102 10,689	6,388 9,153 16,034	8,518 12,204 21,379	1(1! 2(
10 12 14				17,478 25,383 31,071	26,216 38,075 46,607	34,955 50,767 62,142	4: 6: 7
16	Velocity	governs	with	41,367	62,051	82,734	1(

Notes:

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)	5,
16 18 20	Velocity these	governs pipe	with sizes	41,367 53,134 66,371	62,051 79,700 99,557	82,734 106,267 132,742	1 1 1
22 24 26				81,079 97,258 114,908	121,619 145,888 172,363	162,159 194,517 229,817	3 2 2
28 30 32				134,029 154,621 176,683	201,044 231,931 265,025	268,058 309,241 353,366	3 3 4
34 36 42				200,216 225,220 309,058	300,325 337,831 463,586	400,433 450,441 618,115	5 5 7
48 54 60				406,132 516,444 639,994	609,198 774,666 959,991	812,264 1,032,889 1,279,988	1, 1, 1,
72 84 96				926,805 1,266,566 1,659,277	1,390,208 1,899,849 2,488,916	1,853,610 2,533,132 3,318,554	2, 3, 4,
Steam Condensate Flow lbs./h 5 psig Back Pressure							
1/2 3/4 1	28 68 143	39 96 202	56 136 285	248	Pressure with these	drop pipe	g si
1-1/4 1-1/2 2	328 519 1,076	464 734 1,522	657 1,038 2,152	443 610 1,020	915 1,530	2,039	
2-1/2 3 4	1,789 3,323 7,138	2,530 4,699	3,578	1,464 2,281 3,970	2,195 3,422 5,956	2,927 4,562 7,941	5, 9,
5 6 8	13,351 21,706	governs pipe	with sizes	6,283 9,002 15,769	9,425 13,503 23,654	12,566 18,004 31,539	1 2 3
10	Velocity			25,784	38,676	51,568	6

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5
12 14	these			37,447 45,838	56,170 68,757	74,893 91,676	9 1
16 18 20				61,027 78,385 97,914	91,540 117,578 146,871	122,053 156,771 195,828	1 1 2
22 24 26				119,612 143,481 169,519	179,419 215,221 254,278	239,225 286,961 339,037	2 3 4
28 30 32				197,727 228,104 260,652	296,590 342,156 390,978	395,453 456,209 521,304	4 5 6
34 36 42				295,369 332,257 455,937	443,054 498,385 683,906	590,739 664,513 911,875	7 8 1,
48 54 60				599,147 761,885 944,151	898,720 1,142,827 1,416,226	1,198,293 1,523,769 1,888,302	1, 1, 2,
72 84 96				1,367,270 1,868,502 2,447,849	2,050,904 2,802,753 3,671,774	2,734,539 3,737,004 4,895,698	3, 4, 6,
Steam Condensate Flow lbs./h 7 psig Back Pressure							
1/2 3/4 1	30 74 156	43 105 221	61 149 312	284	Pressure with these	drop pipe	g si
1-1/4 1-1/2 2	359 568 1,177	508 803 1,664	718 1,135 2,353	507 698 1,167	1,047 1,750	2,333	
2-1/2 3 4	1,956 3,634 7,806	2,767 5,139 11,040	3,913	1,675 2,610 4,543	2,512 3,915 6,814	3,349 5,220 9,085	6, 1
Notes: 5 6	14,600 23,737	governs pipe	with sizes	7,189 10,299	10,783 15,449	14,377 20,598	1 2

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
8				18,042	27,063	36,084	45
10 12 14	Velocity these			29,500 42,8[illegible] 52,4[illegible]	44,249 64,265 78,666	58,999 85,687 104,888	7 10 13
16 18 20				69,822 89,682 112,025	104,733 134,523 168,038	139,643 179,364 224,050	17 22 28
22 24 26				136,851 164,159 193,949	205,276 246,238 290,924	273,701 328,317 387,898	34 41 48
28 30 32				226,222 260,978 298,216	339,333 391,467 447,324	452,445 521,956 596,432	56 65 74
34 36 42				337,937 380,140 521,646	506,905 570,210 782,468	675,874 760,281 1,043,291	84 95 1,
48 54 60				685,494 871,685 1,080,219	1,028,241 1,307,527 1,620,329	1,370,988 1,743,370 2,160,438	1, 2, 2,
72 84 96				1,564,316 2,137,785 2,800,625	2,346,474 3,206,677 4,200,938	3,128,632 4,275,570 5,601,251	3, 5, 7,
Steam Condensate Flow lbs./h 10 psig Back Pressure							
1/2 3/4 1	34 84 176	49 119 250	69 169 353	342	Pressure with these	drop pipe	ge si
1-1/4 1-1/2 2	406 642 1,331	574 908 1,883	812 1,285 2,663	609 840 1,403	1,259 2,104		
2-1/2 3 4	2,214 4,112 8,834	3,131 5,815 12,493	4,428	2,014 3,138 5,462	3,020 4,707 8,193	4,027 6,276 10,924	7, 1

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)	5,
4							
5	16,522	governs	with	8,644	12,966	17,288	21
6	26,861	pipe	sizes	12,384	18,576	24,769	30
8				21,695	32,542	43,390	5
10	Velocity			35,472	53,208	70,944	88
12	these			51,517	77,276	103,034	12
14				63,061	94,592	126,123	15
16				83,957	125,936	167,915	20
18				107,839	161,758	215,677	26
20				134,705	202,058	269,410	33
22				164,557	246,835	329,113	41
24				197,393	296,090	394,787	49
26				233,215	349,823	466,430	58
28				272,022	408,033	544,044	68
30				313,814	470,721	627,629	78
32				358,592	537,887	717,183	89
34				406,354	609,531	812,708	1,
36				457,102	685,652	914,203	1,
42				627,255	940,883	1,254,511	1,
48				824,276	1,236,413	1,648,551	2,
54				1,048,162	1,572,243	2,096,324	2,
60				1,298,915	1,948,372	2,597,830	3,
72				1,881,020	2,821,530	3,762,040	4,
84				2,570,590	3,855,886	5,141,181	6,
96				3,367,626	5,051,440	6,735,253	8,
Steam Condensate Flow lbs./h 12 psig Back Pressure							
1/2	37	53	74		Pressure	drop pipe	go
3/4	91	129	182		with these		si
1	191	270	382				
1-1/4	439	621	878	683	2,359		
1-1/2	694	982	1,389	941			
2	1,439	2,035	2,878	1,573			
[illegible]	2.393	3.384	4.786	2.257	3.386	4.514	8.

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
1/2	4,444	6,285		3,518	5,277	7,036	15
3	9,548	13,503		6,123	9,185	12,246	
4							
5	17,859	governs	with	9,690	14,534	19,379	24
6	29,034	pipe	sizes	13,883	20,824	27,765	34
8				24,320	36,479	48,639	60
10	Velocity			39,764	59,645	79,527	9
12	these			57,750	86,625	115,500	14
14				70,691	106,036	141,382	17
16				94,115	141,173	188,230	2
18				120,886	181,328	241,771	3
20				151,002	226,504	302,005	3
22				184,466	276,698	368,931	4
24				221,275	331,912	442,550	5
26				261,431	392,146	522,861	6
28				304,933	457,399	609,866	7
30				351,781	527,672	703,562	8
32				401,976	602,964	803,952	1,
34				455,517	683,275	911,034	1,
36				512,404	768,606	1,024,808	1,
42				703,144	1,054,716	1,406,288	1,
48				924,001	1,386,001	1,848,001	2,
54				1,174,974	1,762,461	2,349,948	2,
60				1,456,065	2,184,097	2,912,129	3,
72				2,108,596	3,162,893	4,217,191	5,
84				2,881,594	4,322,391	5,763,188	7,
96				3,775,060	5,662,589	7,550,119	9,
Steam Condensate Flow lbs./h 15 psig Back Pressure							
1/2	41	59	83		Pressure	drop pipe	g
3/4	102	144	203		with these		si
1	213	301	426				
1	490	694	981	802	2,770		
1/4	776	1,097	1,551	1,105			
1-	1,608	2,273	3,215	1,847			
1/2							

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.				Velocity FPM (mph)		
1/2 2	**0.125**	**0.25**	**0.5**	**2,000 (23)**	**3,000 (34)**	**4,000 (45)**	**5,**
2- 1/2 3 4	2,673 4,964 10,666	3,780 7,021 15,084	5,346 9,929	2,650 4,130 7,189	3,975 6,196 10,784	5,301 8,261 14,379	1
5 6 8	19,948 32,432 68,670	28,211	with sizes	11,377 16,300 28,555	17,066 24,451 42,832	22,754 32,601 57,110	2 4 7
10 12 14	Velocity these	governs pipe		46,689 67,807 83,002	70,033 101,711 124,503	93,377 135,615 166,004	1 1 2
16 18 20				110,505 141,938 177,300	165,758 212,907 265,950	221,011 283,876 354,600	2 3 4
22 24 26				216,591 259,811 306,960	324,886 389,716 460,440	433,182 519,621 613,919	5 6 7
28 30 32				358,038 413,045 471,981	537,057 619,567 707,972	716,076 826,090 943,962	8 1, 1,
34 36 42				534,847 601,641 825,599	802,270 902,462 1,238,398	1,069,693 1,203,282 1,651,198	1, 1, 2,
48 54 60				1,084,918 1,379,600 1,709,643	1,627,378 2,069,400 2,564,464	2,169,837 2,759,199 3,419,285	2, 3, 4,
72 84 96				2,475,814 3,383,433 4,432,498	3,713,721 5,075,149 6,648,747	4,951,628 6,766,865 8,864,996	6, 8, 1
Steam Condensate Flow lbs./h 20 psig Back Pressure							
1/2 3/4 1	49 121 253	70 171 358	99 242 507		Pressure with these	drop pipe	g si
1	583	825	1,166	1,026	3,543		

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,[illegible]
1 1/4 1- 1/2 2	[illegible] 922 1,912	[illegible] 1,304 2,703	[illegible] 1,845 3,823	[illegible] 1,413 2,362	[illegible]		
2- 1/2 3 4	3,179 5,904 12,683	4,495 8,349 17,937	6,357 11,807	3,390 5,283 9,196	5,085 7,925 13,794	10,566 18,392	2[illegible]
5 6 8	23,722 38,567 81,659	33,548	with sizes	14,552 20,849 36,524	21,828 31,274 54,786	29,105 41,699 73,048	3[illegible] 5[illegible] 9[illegible]
10 12 14	Velocity these	governs pipe		59,718 86,731 106,166	89,578 130,097 159,249	119,437 173,462 212,332	1[illegible] 2[illegible] 2[illegible]
16 18 20				141,345 181,550 226,781	212,018 272,325 340,171	282,691 363,100 453,561	3[illegible] 4[illegible] 5[illegible]
22 24 26				277,037 332,318 392,626	415,555 498,478 588,939	554,074 664,637 785,252	6[illegible] 8[illegible] 9[illegible]
28 30 32				457,959 528,317 603,701	686,938 792,476 905,552	915,918 1,056,635 1,207,403	1,[illegible] 1,[illegible] 1,[illegible]
34 36 42				684,111 769,547 1,056,006	1,026,167 1,154,320 1,584,010	1,368,222 1,539,093 2,112,013	1,[illegible] 1,[illegible] 2,[illegible]
48 54 60				1,387,697 1,764,618 2,186,769	2,081,545 2,646,926 3,280,153	2,775,393 3,529,235 4,373,538	3,[illegible] 4,[illegible] 5,[illegible]
72 84 96				3,166,763 4,327,679 5,669,517	4,750,144 6,491,518 8,504,275	6,333,526 8,655,358 11,339,034	7,[illegible] 1[illegible] 1[illegible]
Steam Condensate Flow lbs./h 25 psig Back Pressure							
1/2	58	82	116		Pressure	drop pipe	g[illegible]

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
3/4 1	142 298	201 422	285 596		with these		si
1-1/4 1-1/2 2	686 1,086 2,250	971 1,535 3,182	1,373 2,171 4,500	1,286 1,772 2,961	4,441		
2-1/2 3 4	3,741 6,948 14,928	5,291 9,827 21,112	7,483 13,897	4,250 6,623 11,527	6,374 9,934 17,291	13,246 23,055	28
5 6 8	27,920 45,392 96,112	39,486 64,195		18,242 26,136 45,785	27,363 39,204 68,677	36,484 52,272 91,570	45 65 11
10 12 14	184,257			74,860 108,722 133,085	112,291 163,084 199,628	149,721 217,445 266,171	18 27 33
16 18 20	Velocity these	governs pipe	with sizes	177,185 227,584 284,283	265,777 341,376 426,424	354,369 455,168 568,566	44 56 71
22 24 26				347,282 416,581 492,179	520,923 624,871 738,269	694,564 833,161 984,359	86 1, 1,
28 30 32				574,078 662,277 756,775	861,117 993,415 1,135,163	1,148,156 1,324,553 1,513,550	1, 1, 1,
34 36 42				857,573 964,672 1,323,766	1,286,360 1,447,008 1,985,649	1,715,147 1,929,343 2,647,532	2, 2, 3,
48 54 60				1,739,559 2,212,051 2,741,243	2,609,338 3,318,077 4,111,864	3,479,118 4,424,102 5,482,485	4, 5, 6,
72 84 96				3,969,722 5,424,999 7,107,071	5,954,584 8,137,498 10,660,606	7,939,445 10,849,997 14,214,142	9, 11 17

Steam Condensate Flow lbs/h 30 psig Back Pressure

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)	5,
1/2 3/4 1	68 167 349	96 236 493	136 333 698		Pressure with these	drop pipe	go si
1-1/4 1-1/2 2	803 1,269 2,631	1,135 1,795 3,721	1,606 2,539 5,262	1,590 2,191 3,661			
2-1/2 3 4	4,375 8,126 17,458	6,188 11,492 24,689	8,751 16,252 34,916	5,254 8,188 14,252	7,881 12,282 21,379	28,505	
5 6 8	32,652 53,085 112,400	46,177 75,073	with sizes	22,554 32,314 56,608	33,832 48,471 84,912	45,109 64,628 113,216	5[illegible] 8[illegible] 1[illegible]
10 12 14	215,482	governs pipe		92,557 134,423 164,545	138,835 201,635 246,818	185,113 268,846 329,090	2[illegible] 3[illegible] 4[illegible]
16 18 20	Velocity these			219,069 281,382 351,484	328,603 422,073 527,226	438,138 562,764 702,968	5[illegible] 7[illegible] 8[illegible]
22 24 26				429,375 515,055 608,525	644,063 772,583 912,787	858,750 1,030,111 1,217,050	1, 1, 1,
28 30 32				709,783 818,831 935,668	1,064,675 1,228,247 1,403,502	1,419,567 1,637,662 1,871,336	1, 2, 2,
34 36 42				1,060,294 1,192,709 1,636,689	1,590,441 1,789,063 2,455,033	2,120,587 2,385,418 3,273,377	2, 2, 4,
48 54 60				2,150,770 2,734,954 3,389,240	3,226,155 4,102,431 5,083,860	4,301,541 5,469,908 6,778,480	5, 6, 8,
Notes:				4,908,118	7,362,177	9,816,236	1[illegible]

Pipe Size	Pressure Drop psig/100 ft.				Velocity FPM (mph)			
84 96				6,707,405 8,787,099	10,061,107 13,180,649	13,414,809 17,574,198	1(2
Notes:	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0(

2. Table based on heavy weight steel pipe using steam equations in Par

22.05. High-Pressure Steam Condensate System Pipe Sizing Tables (120–300 psig)

120 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	**0.25**	**0.5**	**2,000 (23)**	**3,000 (34)**	**4,000 (45)**	
Steam Condensate Flow lbs./h 0 psig Back Pressure							
1/2 3/4 1	20 48 101	28 68 143	39 96 202	92 153	Pressure with these	drop pipe	
1-1/4 1-1/2 2	232 367 761	328 519 1,076	464 734 1,521	273 376 629	410 564 943	1,258	
2-1/2 3 4	1,265 2,349 5,047	1,789 3,322	with sizes	903 1,407 2,448	1,354 2,110 3,672	1,805 2,813 4,896	
5 6 8	9,439	governs pipe		3,874 5,551 9,724	5,811 8,326 14,586	7,748 11,101 19,448	
10 12	Velocity these			15,899 23,090	23,848 34,636	31,798 46,181	

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
14 16 18 20				28,265 37,630 48,334 60,376	42,397 56,445 72,501 90,564	56,529 75,261 96,668 120,751
22 24 26				73,755 88,473 104,529	110,633 132,709 156,793	147,511 176,946 209,057
28 30 32				121,922 140,654 160,723	182,883 210,980 241,085	243,844 281,307 321,446
34 36 42				182,130 204,876 281,140	273,196 307,314 421,710	364,261 409,752 562,280
48 54 60				369,446 469,793 582,182	554,168 704,689 873,273	738,891 939,586 1,164,364
72 84 96				843,085 1,152,155 1,509,392	1,264,628 1,728,233 2,264,088	1,686,170 2,304,310 3,018,784
Steam Condensate Flow lbs./h 5 psig Back Pressure						
1/2 3/4 1	25 61 128	35 87 181	50 122 256	223	Pressure with these	drop pipe
1-1/4 1-1/2 2	295 467 967	417 660 1,368	590 933 1,934	398 549 917	823 1,375	1,833
2-1/2 3 4	1,608 2,986 6,416	2,274 4,223	3,216	1,316 2,050 3,569	1,973 3,075 5,353	2,631 4,100 7,137
5 6 8	12,000 19,509	governs pipe	with sizes	5,647 8,091 14,174	8,471 12,137 21,261	11,295 16,182 28,348

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
8				14,174	21,261	28,348
10 12 14	Velocity these			23,175 33,658 41,200	34,762 50,486 61,800	46,350 67,315 82,399
16 18 20				54,852 70,454 88,006	82,278 105,681 132,010	109,703 140,908 176,013
22 24 26				107,509 128,962 152,366	161,264 193,444 228,549	215,019 257,925 304,732
28 30 32				177,719 205,023 234,278	266,579 307,535 351,416	355,439 410,047 468,555
34 36 42				265,482 298,637 409,803	398,223 447,955 614,704	530,964 597,274 819,606
48 54 60				538,522 684,793 848,616	807,782 1,027,189 1,272,925	1,077,043 1,369,585 1,697,233
72 84 96				1,228,921 1,679,436 2,200,162	1,843,382 2,519,155 3,300,242	2,457,843 3,358,873 4,400,323
Steam Condensate Flow lbs./h 7 psig Back Pressure						
1/2 3/4 1	27 67 139	38 94 197	54 133 279	254	Pressure with these	drop pipe
1-1/4 1-1/2 2	321 508 1,052	454 718 1,488	642 1,015 2,105	453 624 1,043	937 1,565	2,087
2-1/2 3 4	1,750 3,250 6,982	2,475 4,596 9,874	3,500	1,498 2,334 4,063	2,247 3,501 6,094	2,995 4,668 8,126

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00**
2. **Table based on heavy weight steel pipe using steam equations in Part**

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)
6 8	10,058 21,230	given pipe	with sizes	6,429 9,211 16,137	9,644 13,817 24,205	12,859 18,423 32,273
10 12 14	Velocity these			26,384 38,319 46,905	39,576 57,478 70,358	52,768 76,637 93,810
16 18 20				62,448 80,211 100,194	93,672 120,316 150,291	124,896 160,421 200,388
22 24 26				122,398 146,822 173,466	183,596 220,232 260,199	244,795 293,643 346,932
28 30 32				202,331 233,416 266,721	303,496 350,124 400,082	404,662 466,832 533,443
34 36 42				302,247 339,993 466,554	453,371 509,990 699,831	604,494 679,987 933,109
48 54 60				613,098 779,626 966,137	919,648 1,169,439 1,449,205	1,226,197 1,559,252 1,932,273
72 84 96				1,399,108 1,912,012 2,504,850	2,098,662 2,868,018 3,757,275	2,798,216 3,824,024 5,009,700
Steam Condensate Flow lbs./h 10 psig Back Pressure						
1/2 3/4 1	31 75 157	43 106 222	61 150 313	303	Pressure with these	drop pipe
1-1/4 1-1/2 2	361 570 1,182	510 807 1,672	721 1,141 2,364	541 745 1,246	1,118 1,868	
2-1/2	1,966 3,651	2,780 5,163	3,931	1,788 2,786	2,682 4,179	3,575 5,572

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1/2 3 4	3,651 7,843	5,163 11,091		2,786 4,849	4,179 7,274	5,572 9,699
5 6 8	14,669 23,848			7,674 10,995 19,261	11,511 16,493 28,892	15,348 21,990 38,522
10 12 14	Velocity these	governs pipe	with sizes	31,493 45,738 55,987	47,239 68,607 83,981	62,985 91,476 111,974
16 18 20				74,539 95,741 119,594	111,808 143,612 179,390	149,078 191,482 239,187
22 24 26				146,096 175,249 207,053	219,144 262,874 310,579	292,193 350,499 414,105
28 30 32				241,506 278,610 318,364	362,259 417,915 477,546	483,012 557,220 636,728
34 36 42				360,768 405,823 556,888	541,152 608,734 835,333	721,537 811,646 1,113,777
48 54 60				731,806 930,577 1,153,200	1,097,710 1,395,865 1,729,800	1,463,613 1,861,154 2,306,399
72 84 96				1,670,003 2,282,216 2,989,838	2,505,004 3,423,324 4,484,758	3,340,006 4,564,431 5,979,677
Steam Condensate Flow lbs./h 12 psig Back Pressure						
1/2 3/4 1	33 80 168	46 114 238	66 161 337		Pressure with these	drop pipe
1- 1/4 1- 1/2	388 613 1,271	549 867 1,798	776 1,227 2,542	603 831 1,389	2,084	

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

2. Table based on heavy weight steel pipe using steam equations in Part

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
2 2 1/2 3 4	2,114 3,926 8,434	2,989 5,552 11,928	4,228	1,994 3,107 5,409	2,991 4,661 8,113	3,988 6,215 10,817
5 6 8	15,775 25,646	governs pipe	with sizes	8,559 12,263 21,482	12,839 18,394 32,223	17,118 24,526 42,964
10 12 14	Velocity these			35,124 51,012 62,443	52,686 76,517 93,664	70,248 102,023 124,885
16 18 20				83,134 106,780 133,383	124,700 160,171 200,075	166,267 213,561 266,766
22 24 26				162,942 195,456 230,926	244,413 293,184 346,390	325,883 390,912 461,853
28 30 32				269,353 310,735 355,073	404,029 466,102 532,609	538,705 621,469 710,145
34 36 42				402,366 452,616 621,100	603,549 678,924 931,650	804,733 905,232 1,242,200
48 54 60				816,187 1,037,876 1,286,168	1,224,280 1,556,814 1,929,252	1,632,373 2,075,752 2,572,336
72 84 96				1,862,561 2,545,364 3,334,579	2,793,841 3,818,046 5,001,868	3,725,122 5,090,729 6,669,157
Steam Condensate Flow lbs./h 15 psig Back Pressure						
1/2 3/4 1	36 89 187	51 126 264	73 178 373		Pressure with these	drop pipe
1	430	608	860	703	2,428	

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
1/4	680	961	1,360	969		
1-1/2	1,409	1,992	2,818	1,618		
2	**0.125**	**0.25**	**0.5**	**2,000 (23)**	**3,000 (34)**	**4,000 (45)**
2-	2,343	3,313	4,686	2,323	3,484	4,646
1/2	4,351	6,153	8,702	3,620	5,430	7,240
3	9,348	13,220		6,301	9,452	12,602
4						
5	17,484	24,726	with	9,971	14,957	19,943
6	28,425		sizes	14,286	21,430	28,573
8	60,185			25,027	37,540	50,054
10	Velocity	governs		40,920	61,380	81,840
12	these	pipe		59,430	89,144	118,859
14				72,747	109,120	145,494
16				96,852	145,278	193,705
18				124,401	186,602	248,803
20				155,394	233,091	310,788
22				189,831	284,746	379,661
24				227,711	341,566	455,421
26				269,034	403,551	538,068
28				313,801	470,702	627,603
30				362,012	543,019	724,025
32				413,667	620,500	827,334
34				468,765	703,148	937,530
36				527,307	790,960	1,054,614
42				723,594	1,085,391	1,447,189
48				950,874	1,426,312	1,901,749
54				1,209,147	1,813,721	2,418,294
60				1,498,413	2,247,619	2,996,825
72				2,169,922	3,254,883	4,339,844
84				2,965,402	4,448,103	5,930,805
96				3,884,854	5,827,280	7,769,707
Steam Condensate Flow lbs./h 20 psig Back Pressure						
1/2	43	60	85		Pressure	drop pipe
3/4	105	148	209		with these	

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1 1-1/4 1-1/2 2	219 504 797 1,652	310 713 1,127 2,337	438 1,008 1,594 3,305	887 1,222 2,042	3,062	
2-1/2 3 4	2,748 5,103 10,964	3,886 7,217 15,505	5,495 10,206	2,930 4,567 7,949	4,395 6,850 11,923	9,134 15,898
5 6 8	20,505 33,337 70,587	28,999	with sizes	12,579 18,022 31,572	18,869 27,034 47,357	25,158 36,045 63,143
10 12 14	Velocity these	governs pipe		51,621 74,971 91,771	77,431 112,456 137,656	103,242 149,942 183,541
16 18 20				122,180 156,933 196,031	183,270 235,400 294,046	244,360 313,866 392,062
22 24 26				239,472 287,258 339,388	359,209 430,888 509,083	478,945 574,517 678,777
28 30 32				395,863 456,681 521,844	593,794 685,022 782,765	791,725 913,362 1,043,687
34 36 42				591,350 665,201 912,819	887,026 997,802 1,369,229	1,182,701 1,330,403 1,825,638
48 54 60				1,199,534 1,525,347 1,890,258	1,799,302 2,288,021 2,835,387	2,399,069 3,050,695 3,780,516
72 84 96				2,737,371 3,740,875 4,900,769	4,106,057 5,611,312 7,351,153	5,474,743 7,481,750 9,801,538

Notes: Condensate Flow lbs./h 25 psig Back Pressure

Steam Condensate Flow lbs./h 15 psig Back Pressure

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1/2 3/4 1	49 121 254	70 171 359	99 243 508		Pressure with these	drop pipe
1-1/4 1-1/2 2	585 924 1,916	827 1,307 2,709	1,169 1,849 3,832	1,095 1,509 2,521	3,782	
2-1/2 3 4	3,186 5,917 12,712	4,505 8,367 17,977	6,372 11,833	3,619 5,639 9,816	5,428 8,459 14,724	11,279 19,631
5 6 8	23,775 38,652 81,840	33,622 54,662	With Sizes	15,533 22,255 38,986	23,300 33,383 58,479	31,067 44,510 77,973
10 12 14	156,896	governs pipe		63,744 92,578 113,323	95,616 138,867 169,985	127,489 185,156 226,646
16 18 20	Velocity these			150,874 193,789 242,069	226,311 290,684 363,104	301,748 387,579 484,138
22 24 26				295,713 354,722 419,095	443,570 532,083 628,642	591,427 709,444 838,190
28 30 32				488,832 563,934 644,400	733,248 845,901 966,600	977,664 1,127,868 1,288,800
34 36 42				730,231 821,426 1,127,197	1,095,346 1,232,139 1,690,796	1,460,461 1,642,852 2,254,395
48 54 60				1,481,249 1,883,580 2,334,190	2,221,873 2,825,369 3,501,285	2,962,497 3,767,159 4,668,381
72				3,380,251	5,070,376	6,760,502

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
84 96				4,619,430 6,051,729	6,929,146 9,077,593	9,238,861 12,103,457
Steam Condensate Flow lbs./h 30 psig Back Pressure						
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1/2 3/4 1	57 139 292	80 197 413	114 279 584		Pressure with these	drop pipe
1-1/4 1-1/2 2	672 1,063 2,204	951 1,504 3,117	1,345 2,127 4,408	1,332 1,835 3,066		
2-1/2 3 4	3,665 6,806 14,622	5,183 9,625 20,679	7,329 13,612 29,244	4,401 6,858 11,937	6,601 10,287 17,906	23,875
5 6 8	27,348 44,462 94,142	38,676 62,879	with sizes	18,891 27,065 47,413	28,336 40,598 71,119	37,781 54,130 94,826
10 12 14	180,480	governs pipe		77,522 112,588 137,817	116,283 168,882 206,725	155,044 225,176 275,634
16 18 20	Velocity these			183,484 235,675 294,390	275,226 353,513 441,585	366,968 471,350 588,780
22 24 26				359,629 431,392 509,678	539,443 647,087 764,517	719,258 862,783 1,019,356
28 30 32				594,489 685,823 783,681	891,733 1,028,734 1,175,522	1,188,977 1,371,646 1,567,362
34 36 42				888,063 998,969 1,370,830	1,332,095 1,498,454 2,056,246	1,776,127 1,997,939 2,741,661
48 54				1,801,407 2,290,698	2,702,110 3,436,047	3,602,813 4,581,395

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
60 72 84 96				2,838,704 4,110,860 5,617,877 7,359,753	4,258,056 6,166,291 8,426,815 11,039,630	5,677,407 8,221,721 11,235,754 14,719,506
Steam Condensate Flow lbs./h 40 psig Back Pressure						
1/2 3/4 1	74 182 381	105 257 538	148 363 761		Pressure with these	drop pipe
1-1/4 1-1/2 2	876 1,385 2,871	1,239 1,959 4,060	1,752 2,770 5,742	2,626 4,387		
2-1/2 3 4	4,774 8,866 19,048	6,751 12,539 26,939	9,548 17,733 38,097	6,297 9,814 17,081	9,446 14,721 25,622	34,163
5 6 8	35,627 57,921 122,639	50,384 81,913	with sizes	27,031 38,729 67,845	40,547 58,093 101,767	54,063 77,457 135,689
10 12 14	235,113 383,762	governs pipe		110,929 161,106 197,207	166,393 241,659 295,810	221,858 322,212 394,414
16 18 20	Velocity these			262,554 337,236 421,253	393,830 505,853 631,879	525,107 674,471 842,506
22 24 26				514,605 617,293 729,316	771,908 925,939 1,093,974	1,029,210 1,234,586 1,458,631
28 30 32				850,674 981,367 1,121,396	1,276,011 1,472,051 1,682,094	1,701,348 1,962,734 2,242,792
34 36 42				1,270,760 1,429,459 1,961,568	1,906,140 2,144,188 2,942,351	2,541,519 2,858,918 3,923,135

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)
48 54 60				2,577,693 3,277,837 4,061,997	3,866,540 4,916,755 6,092,995	5,155,387 6,555,673 8,123,994
72 84 96				5,882,369 8,038,810 10,531,319	8,823,553 12,058,214 15,796,979	11,764,738 16,077,619 21,062,638

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0**
2. **Table based on heavy weight steel pipe using steam equations in Par**

125 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)
Steam Condensate Flow lbs./h 0 psig Back Pressure						
1/2 3/4 1	19 47 99	27 67 140	38 94 197	90 150	Pressure with these	drop pipe
1-1/4 1-1/2 2	227 359 745	321 508 1,053	455 719 1,490	267 369 616	401 553 924	1,232
2-1/2 3 4	1,239 2,300 4,942	1,752 3,253	with sizes	884 1,377 2,397	1,326 2,066 3,596	1,768 2,755 4,795
5 6 8	9,243	governs pipe		3,794 5,436 9,522	5,691 8,153 14,283	7,588 10,871 19,044
10	Velocity			15,569	23,354	31,138

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
12 14	these			22,612 27,679	33,917 41,518	45,223 55,357
16 18 20				36,850 47,332 59,124	55,275 70,998 88,686	73,700 94,664 118,248
22 24 26				72,226 86,639 102,361	108,339 129,958 153,542	144,452 173,277 204,723
28 30 32				119,394 137,737 157,391	179,091 206,606 236,086	238,789 275,475 314,782
34 36 42				178,354 200,628 275,311	267,532 300,942 412,967	356,709 401,257 550,622
48 54 60				361,786 460,053 570,112	542,679 690,079 855,168	723,572 920,106 1,140,224
72 84 96				825,606 1,128,268 1,478,098	1,238,409 1,692,402 2,217,147	1,651,212 2,256,536 2,956,197
Steam Condensate Flow lbs./h 5 psig Back Pressure						
1/2 3/4 1	24 60 125	34 85 177	49 120 250	218	Pressure with these	drop pipe
1-1/4 1-1/2 2	288 456 945	408 645 1,336	576 911 1,889	389 536 895	804 1,343	1,791
2-1/2 3 4	1,571 2,917 6,267	2,221 4,126	3,142	1,285 2,003 3,486	1,928 3,004 5,229	2,570 4,005 6,972
Notes: 5 6	11,722 19,057	governs pipe	with sizes	5,516 7,904	8,275 11,855	11,033 15,807

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
				13,845	20,768	27,691
10	Velocity			22,638	33,957	45,276
12	these			32,878	49,317	65,756
14				40,245	60,368	80,491
16				53,581	80,371	107,162
18				68,822	103,233	137,644
20				85,968	128,952	171,935
22				105,019	157,528	210,037
24				125,975	188,962	251,950
26				148,836	223,254	297,672
28				173,602	260,404	347,205
30				200,274	300,411	400,548
32				228,850	343,275	457,701
34				259,332	388,998	518,664
36				291,719	437,578	583,437
42				400,309	600,464	800,619
48				526,046	789,069	1,052,092
54				668,929	1,003,393	1,337,858
60				828,957	1,243,436	1,657,915
72				1,200,452	1,800,678	2,400,904
84				1,640,531	2,460,796	3,281,061
96				2,149,193	3,223,789	4,298,385
Steam Condensate Flow lbs./h 7 psig Back Pressure						
1/2	27	37	53	248	Pressure	drop pipe
3/4	65	92	130		with these	
1	136	192	272			
1-1/4	313	443	627	442	914	2,037
1-1/2	495	701	991	609	1,527	
2	1,027	1,452	2,054	1,018		
2-1/2	1,708	2,415	3,415	1,462	2,192	2,923
3	3,171	4,485		2,278	3,417	4,556
4	6,813	9,635		3,965	5,947	7,929

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)
4 5 6 8	12,743 20,717	governs pipe	with sizes	6,274 8,989 15,747	9,411 13,483 23,620	12,548 17,978 31,494
10 12 14	Velocity these			25,747 37,393 45,772	38,620 56,090 68,658	51,494 74,786 91,544
16 18 20				60,939 78,273 97,774	91,409 117,410 146,661	121,879 156,546 195,548
22 24 26				119,441 143,275 169,276	179,162 214,913 253,914	238,882 286,550 338,552
28 30 32				197,444 227,778 260,279	296,165 341,667 390,418	394,887 455,556 520,558
34 36 42				294,947 331,781 455,285	442,420 497,672 682,927	589,893 663,562 910,570
48 54 60				598,289 760,794 942,800	897,434 1,141,191 1,414,200	1,196,579 1,521,589 1,885,600
72 84 96				1,365,313 1,865,828 2,444,346	2,047,969 2,798,743 3,666,519	2,730,626 3,731,657 4,888,692
Steam Condensate Flow lbs./h 10 psig Back Pressure						
1/2 3/4 1	30 73 153	42 103 216	59 146 305	296	Pressure with these	drop pipe
1-1/4 1-1/2 2	351 556 1,152	497 786 1,629	703 1,111 2,304	527 726 1,214	1,089 1,820	
2-	1,915	2,709	3,830	1,742	2,613	3,484

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1/2	3,537	5,030		2,715	4,072	5,429
3	7,642	10,807		4,725	7,088	9,450
4						
5	14,293			7,478	11,216	14,955
6	23,237			10,713	16,070	21,427
8				18,768	28,151	37,535
10				30,686	46,029	61,372
12				44,566	66,849	89,132
14				54,553	81,829	109,105
16	Velocity	governs	with	72,629	108,944	145,259
18	these	pipe	sizes	93,288	139,932	186,577
20				116,530	174,794	233,059
22				142,353	213,530	284,707
24				170,760	256,139	341,519
26				201,748	302,622	403,496
28				235,319	352,978	470,638
30				271,472	407,208	542,944
32				310,208	465,312	620,416
34				351,526	527,289	703,051
36				395,426	593,139	790,852
42				542,621	813,932	1,085,243
48				713,058	1,069,587	1,426,116
54				906,736	1,360,104	1,813,473
60				1,123,656	1,685,484	2,247,312
72				1,627,219	2,440,828	3,254,438
84				2,223,747	3,335,621	4,447,495
96				2,913,241	4,369,862	5,826,483
Steam Condensate Flow lbs./h 12 psig Back Pressure						
1/2	32	45	64		Pressure	drop pipe
3/4	78	111	157		with these	
1	164	232	328			
1	378	534	755	587	2,028	
1-1/4	597	844	1,194	809		
1-1/2	1,237	1,750	2,475	1,352		

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

1/2 Pipe 2 Size	Pressure Drop psig/100 ft.				Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
2- 1/2 3 4	2,058 3,821 8,210	2,910 5,404 11,610	4,115	1,941 3,025 5,265	2,911 4,537 7,897	3,882 6,049 10,529
5 6 8	15,355 24,963	governs pipe	with sizes	8,331 11,936 20,910	12,497 17,905 31,365	16,662 23,873 41,820
10 12 14	Velocity these			34,189 49,654 60,780	51,283 74,481 91,171	68,378 99,308 121,561
16 18 20				80,921 103,938 129,833	121,381 155,907 194,749	161,841 207,876 259,665
22 24 26				158,604 190,253 224,779	237,907 285,380 337,169	317,209 380,507 449,559
28 30 32				262,183 302,463 345,621	393,274 453,695 518,431	524,365 604,926 691,242
34 36 42				391,656 440,568 604,567	587,483 660,851 906,850	783,311 881,135 1,209,133
48 54 60				794,460 1,010,248 1,251,931	1,191,690 1,515,373 1,877,897	1,588,921 2,020,497 2,503,863
72 84 96				1,812,981 2,477,608 3,245,814	2,719,471 3,716,412 4,868,722	3,625,961 4,955,217 6,491,629
Steam Condensate Flow lbs./h 15 psig Back Pressure						
1/2 3/4 1	35 87 181	50 123 257	71 173 363		Pressure with these	drop pipe
Notes:	418	591	836	683	2,359	

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1 1/4 1- 1/2 2	418 661 1,369	591 934 1,936	836 1,321 2,739	683 941 1,573	2,339	
2- 1/2 3 4	2,277 4,229 9,085	3,220 5,980 12,848	4,554 8,457	2,258 3,518 6,124	3,386 5,277 9,186	4,515 7,036 12,248
5 6 8	16,992 27,625 58,492	24,030	with sizes	9,691 13,884 24,323	14,536 20,827 36,484	19,382 27,769 48,645
10 12 14	Velocity these	governs pipe		39,769 57,757 70,700	59,653 86,636 106,049	79,537 115,514 141,399
16 18 20				94,127 120,900 151,021	141,190 181,351 226,531	188,253 241,801 302,042
22 24 26				184,488 221,302 261,463	276,732 331,953 392,194	368,976 442,604 522,926
28 30 32				304,970 351,824 402,025	457,455 527,737 603,038	609,941 703,649 804,051
34 36 42				455,573 512,467 703,231	683,359 768,701 1,054,846	911,146 1,024,934 1,406,461
48 54 60				924,114 1,175,119 1,456,244	1,386,171 1,762,678 2,184,365	1,848,229 2,350,237 2,912,487
72 84 96				2,108,855 2,881,948 3,775,524	3,163,282 4,322,922 5,663,285	4,217,710 5,763,896 7,551,047
Steam Condensate Flow lbs./h 20 psig Back Pressure						
Notes: 1/2	41	58	83		Pressure	drop pipe

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)
3/4 1	101 212	143 300	203 425		with these	
1- 1/4 1- 1/2 2	489 773 1,602	691 1,093 2,265	977 1,545 3,203	860 1,184 1,979	2,968	
2- 1/2 3 4	2,663 4,946 10,626	3,766 6,995 15,027	5,326 9,892	2,840 4,426 7,704	4,260 6,639 11,556	8,852 15,408
5 6 8	19,874 32,310 68,413	28,106	with sizes	12,192 17,467 30,599	18,287 26,201 45,899	24,383 34,935 61,198
10 12 14	Velocity these	governs pipe		50,031 72,662 88,944	75,047 108,993 133,416	100,062 145,323 177,888
16 18 20				118,417 152,100 189,993	177,625 228,149 284,989	236,833 304,199 379,986
22 24 26				232,097 278,411 328,935	348,145 417,616 493,402	464,193 556,821 657,870
28 30 32				383,670 442,615 505,770	575,505 663,922 758,656	767,340 885,230 1,011,541
34 36 42				573,136 644,713 884,704	859,704 967,069 1,327,055	1,146,273 1,289,425 1,769,407
48 54 60				1,162,588 1,478,365 1,832,036	1,743,882 2,217,548 2,748,054	2,325,176 2,956,731 3,664,073
72 84 96				2,653,058 3,625,653 4,749,821	3,979,587 5,438,479 7,124,732	5,306,116 7,251,306 9,499,642

Steam Condensate Flow lbs/h 25 psig Back Pressure

Pipe Size	**Pressure Drop psig/100 ft.**			**Velocity FPM (mph)**		
	0.125	**0.25**	**0.5**	**2,000 (23)**	**3,000 (34)**	**4,000 (45)**
1/2 3/4 1	48 117 245	68 166 347	96 234 491		Pressure with the	drop pipe
1-1/4 1-1/2 2	565 893 1,851	799 1,263 2,618	1,130 1,786 3,703	1,058 1,458 2,436	3,654	
2-1/2 3 4	3,079 5,718 12,284	4,354 8,086 17,372	6,157 11,435	3,497 5,450 9,486	5,245 8,175 14,228	10,899 18,971
5 6 8	22,975 37,352 79,088	32,491 52,824	with sizes	15,011 21,507 37,675	22,516 32,260 56,513	30,022 43,013 75,350
10 12 14	151,620	governs pipe		61,600 89,464 109,512	92,401 134,197 164,268	123,201 178,929 219,024
16 18 20	Velocity these			145,800 187,272 233,928	218,700 280,908 350,892	291,600 374,544 467,856
22 24 26				285,768 342,792 405,000	428,652 514,188 607,500	571,536 685,583 809,999
28 30 32				472,392 544,968 622,727	708,587 817,451 934,091	944,783 1,089,935 1,245,455
34 36 42				705,671 793,799 1,089,287	1,058,507 1,190,699 1,633,931	1,411,343 1,587,599 2,178,574
48 54 60				1,431,431 1,820,231 2,255,686	2,147,146 2,730,346 3,383,529	2,862,862 3,640,461 4,511,372
70 ***Notes:***				3,266,565	4,899,848	6,533,131

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
72 84 96				[illegible] 4,464,068 5,848,195	[illegible] 6,696,102 8,772,293	[illegible] 8,928,137 11,696,390
Steam Condensate Flow lbs./h 30 psig Back Pressure						
1/2 3/4 1	55 134 281	77 190 398	110 269 563		Pressure with these	drop pipe
1-1/4 1-1/2 2	648 1,024 2,123	916 1,449 3,002	1,295 2,049 4,246	1,283 1,768 2,954		
2-1/2 3 4	3,530 6,556 14,086	4,993 9,272 19,921	7,061 13,113 28,172	4,239 6,607 11,499	6,359 9,910 17,249	22,999
5 6 8	26,345 42,831 90,689	37,258 60,573	with sizes	18,198 26,073 45,674	27,297 39,109 68,511	36,396 52,145 91,348
10 12 14	173,861	governs pipe		74,679 108,459 132,763	112,018 162,688 199,144	149,358 216,918 265,525
16 18 20	Velocity these			176,755 227,032 283,593	265,132 340,548 425,390	353,510 454,064 567,187
22 24 26				346,440 415,570 490,986	519,659 623,356 736,479	692,879 831,141 981,972
28 30 32				572,686 660,671 754,940	859,029 991,006 1,132,410	1,145,372 1,321,341 1,509,880
34 36 42				855,494 962,332 1,320,556	1,283,241 1,443,498 1,980,833	1,710,987 1,924,665 2,641,111
48				1,735,340	2,603,011	3,470,681

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	**0.25**	**0.5**	**2,000 (23)**	**3,000 (34)**	**4,000 (45)**
54 60				2,206,687 2,734,595	3,310,030 4,101,892	4,413,374 5,469,189
72 84 96				3,960,095 5,411,842 7,089,836	5,940,143 8,117,764 10,634,753	7,920,191 10,823,685 14,179,671
Steam Condensate Flow lbs./h 40 psig Back Pressure						
1/2 3/4 1	71 174 364	100 246 515	142 348 728		Pressure with these	drop pipe
1- 1/4 1- 1/2 2	838 1,325 2,746	1,185 1,873 3,883	1,675 2,649 5,491	2,511 4,196		
2- 1/2 3 4	4,566 8,480 18,218	6,457 11,992 25,764	9,132 16,959 36,436	6,022 9,386 16,337	9,034 14,079 24,505	32,673
5 6 8	34,073 55,395 117,291	48,187 78,341	with sizes	25,853 37,040 64,886	38,779 55,560 97,329	51,705 74,080 129,773
10 12 14	224,861 367,028	governs pipe		106,092 154,081 188,608	159,138 231,121 282,912	212,184 308,162 377,216
16 18 20	Velocity these			251,105 322,531 402,884	376,658 483,796 604,326	502,210 645,061 805,768
22 24 26				492,166 590,376 697,514	738,249 885,564 1,046,271	984,332 1,180,752 1,395,028
28 30 32				813,581 938,575 1,072,498	1,220,371 1,407,863 1,608,747	1,627,161 1,877,150 2,144,996
34 36				1,215,349 1,367,128	1,823,023 2,050,692	2,430,697 2,734,256

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
42				1,876,034	2,814,051	3,752,068
48				2,465,294	3,697,941	4,930,588
54				[illegible]	[illegible]	[illegible]
60				3,884,875	5,827,312	7,769,750
72				5,625,870	8,438,805	11,251,740
84				7,688,280	11,532,420	15,376,560
96				10,072,105	15,108,157	20,144,209

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0**

2. **Table based on heavy weight steel pipe using steam equations in Par**

150 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	**0.25**	**0.5**	**2,000 (23)**	**3,000 (34)**	**4,000 (45)**
Steam Condensate Flow lbs./h 0 psig Back Pressure						
1/2 3/4 1	18 43 90	25 61 128	35 86 180	137 82	Pressure with these	drop pipe
1-1/4 1-1/2 2	208 328 680	294 464 962	415 657 1,361	244 337 563	367 505 844	1,125
2-1/2 3 4	1,131 2,101 4,515	1,600 2,972	with sizes	807 1,258 2,190	1,211 1,887 3,285	1,615 2,516 4,380
5 6 8	8,444	governs pipe		3,466 4,966 8,699	5,199 7,448 13,048	6,932 9,931 17,397
10				14,223	21,334	28,445

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
10 12 14	velocity these			14,223 20,656 25,285	21,334 30,984 37,927	28,445 41,312 50,569
16 18 20				33,663 43,238 54,010	50,494 64,857 81,015	67,326 86,476 108,021
22 24 26				65,979 79,145 93,508	98,969 118,718 140,262	131,959 158,291 187,016
28 30 32				109,068 125,825 143,778	163,602 188,737 215,667	218,136 251,649 287,556
34 36 42				162,929 183,276 251,500	244,393 274,914 377,249	325,857 366,552 502,999
48 54 60				330,495 420,263 520,803	495,743 630,395 781,204	660,990 840,526 1,041,606
72 84 96				754,199 1,030,684 1,350,258	1,131,299 1,546,026 2,025,387	1,508,399 2,061,368 2,700,515
Steam Condensate Flow lbs./h 5 psig Back Pressure						
1/2 3/4 1	22 54 113	31 76 160	44 108 226	197	Pressure with these	drop pipe
1-1/4 1-1/2 2	261 412 854	369 583 1,208	521 824 1,708	352 485 810	727 1,215	1,619
2-1/2 3 4	1,420 2,638 5,668	2,009 3,731	2,841	1,162 1,811 3,152	1,743 2,717 4,729	2,324 3,622 6,305
5	10,601	governs	with	4,989	7,483	9,977

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
6 8	17,234	pipe	sizes	7,147 12,521	10,721 18,781	14,295 25,042
10 12 14	Velocity these			20,472 29,732 36,395	30,708 44,599 54,592	40,944 59,465 72,790
16 18 20				48,455 62,238 77,743	72,682 93,356 116,615	96,910 124,475 155,486
22 24 26				94,972 113,923 134,597	142,457 170,884 201,895	189,943 227,846 269,194
28 30 32				156,994 181,114 206,956	235,491 271,670 310,434	313,988 362,227 413,912
34 36 42				234,522 263,810 362,012	351,782 395,715 543,018	469,043 527,620 724,023
48 54 60				475,719 604,932 749,651	713,579 907,398 1,124,476	951,438 1,209,864 1,499,301
72 84 96				1,085,604 1,483,580 1,943,579	1,628,407 2,225,370 2,915,368	2,171,209 2,967,161 3,887,157
Steam Condensate Flow lbs./h 7 psig Back Pressure						
1/2 3/4 1	24 59 123	34 83 173	48 117 245	223	Pressure with these	drop pipe
1-1/4 1-1/2 2	282 446 925	399 631 1,308	564 892 1,850	398 549 917	823 1,376	1,834
2-1/2 3	1,538 2,856 6,136	2,175 4,039 8,678	3,076	1,316 2,051 3,571	1,975 3,077 5,356	2,633 4,103 7,142

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
4 5 6 8	11,477 18,659	governs pipe	with sizes	5,651 8,096 14,182	8,476 12,144 21,274	11,301 16,192 28,365
10 12 14	Velocity these			23,189 33,678 41,225	34,784 50,517 61,837	46,378 67,356 82,450
16 18 20				54,885 70,497 88,060	82,328 105,746 132,090	109,770 140,994 176,121
22 24 26				107,575 129,041 152,459	161,363 193,562 228,688	215,150 258,082 304,918
28 30 32				177,828 205,149 234,421	266,742 307,723 351,631	355,656 410,297 468,842
34 36 42				265,644 298,819 410,054	398,467 448,229 615,080	531,289 597,639 820,107
48 54 60				538,851 685,211 849,135	808,276 1,027,817 1,273,703	1,077,702 1,370,423 1,698,270
72 84 96				1,229,673 1,680,463 2,201,507	1,844,509 2,520,695 3,302,260	2,459,345 3,360,926 4,403,014
Steam Condensate Flow lbs./h 10 psig Back Pressure						
1/2 3/4 1	27 65 137	38 92 193	53 131 273	265	Pressure with these	drop pipe
1-1/4 1-1/2 2	315 497 1,031	445 704 1,458	629 995 2,062	472 650 1,087	975 1,630	

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
2 1/2 3 4	1,715 3,184 6,841	2,425 4,503 9,675	3,429	1,559 2,430 4,230	2,339 3,646 6,345	3,119 4,861 8,461
5 6 8	12,796 20,803	governs pipe	with sizes	6,694 9,591 16,802	10,042 14,387 25,203	13,389 19,182 33,604
10 12 14	Velocity these			27,472 39,898 48,839	41,208 59,847 73,258	54,944 79,797 97,678
16 18 20				65,022 83,517 104,324	97,533 125,276 156,486	130,044 167,035 208,649
22 24 26				127,443 152,874 180,617	191,165 229,311 270,925	254,887 305,748 361,234
28 30 32				210,672 243,038 277,717	316,007 364,557 416,575	421,343 486,076 555,433
34 36 42				314,707 354,009 485,787	472,060 531,014 728,681	629,414 708,018 971,575
48 54 60				638,372 811,765 1,005,964	957,559 1,217,647 1,508,946	1,276,745 1,623,529 2,011,928
72 84 96				1,456,784 1,990,832 2,608,108	2,185,176 2,986,248 3,912,162	2,913,568 3,981,664 5,216,217
Steam Condensate Flow lbs./h 12 psig Back Pressure						
1/2 3/4 1	28 70 146	40 99 207	57 140 292		Pressure with these	drop pipe
1- 1/4 1-	337 532 1,103	476 753 1,560	673 1,065 2,206	524 721 1,206	1,808	

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
1 1/2 2	1,103	1,560	2,206	1,200		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
2- 1/2 3 4	1,835 3,407 7,320	2,594 4,818 10,352	3,669	1,730 2,697 4,694	2,596 4,045 7,041	3,461 5,394 9,388
5 6 8	13,691 22,258	governs pipe	with sizes	7,428 10,643 18,644	11,142 15,964 27,966	14,856 21,285 37,287
10 12 14	Velocity these			30,483 44,272 54,193	45,725 66,408 81,289	60,967 88,544 108,385
16 18 20				72,150 92,673 115,761	108,225 139,009 173,641	144,300 185,345 231,521
22 24 26				141,414 169,632 200,416	212,121 254,449 300,625	282,828 339,265 400,833
28 30 32				233,766 269,680 308,160	350,649 404,521 462,240	467,531 539,361 616,321
34 36 42				349,206 392,816 539,040	523,808 589,224 808,560	698,411 785,632 1,078,080
48 54 60				708,352 900,752 1,116,239	1,062,528 1,351,127 1,674,359	1,416,704 1,801,503 2,232,479
72 84 96				1,616,479 2,209,070 2,894,013	2,424,718 3,313,605 4,341,020	3,232,958 4,418,140 5,788,027
Steam Condensate Flow lbs./h 15 psig Back Pressure						
1/2 3/4 1	31 77 161	44 109 227	63 154 322		Pressure with these	drop pipe

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1-1/4 1-1/2 2	370 585 1,213	524 828 1,716	740 1,171 2,427	605 834 1,394	2,091	
2-1/2 3 4	2,018 3,747 8,050	2,853 5,299 11,385	4,035 7,494	2,000 3,118 5,426	3,001 4,676 8,140	4,001 6,235 10,853
5 6 8	15,057 24,479 51,830	21,293		8,587 12,303 21,553	12,881 18,455 32,329	17,174 24,606 43,105
10 12 14				35,240 51,180 62,648	52,859 76,769 93,972	70,479 102,359 125,296
16 18 20	Velocity these	governs pipe	with sizes	83,407 107,132 133,822	125,111 160,698 200,734	166,815 214,264 267,645
22 24 26				163,478 196,100 231,687	245,217 294,150 347,530	326,957 392,200 463,374
28 30 32				270,240 311,758 356,242	405,359 467,637 534,363	540,479 623,516 712,484
34 36 42				403,691 454,106 623,145	605,537 681,160 934,718	807,383 908,213 1,246,290
48 54 60				818,874 1,041,294 1,290,404	1,228,312 1,561,941 1,935,605	1,637,749 2,082,588 2,580,807
72 84 96				1,868,694 2,553,746 3,345,560	2,803,041 3,830,619 5,018,339	3,737,389 5,107,493 6,691,119
Steam Condensate Flow lbs./h 20 psig Back Pressure						
Notes:	36	51	72		Pressure	drop pipe

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1/2 3/4 1	36 89 186	51 126 263	72 178 372		Pressure with these	drop pipe
1-1/4 1-1/2 2	428 677 1,404	606 958 1,986	857 1,355 2,808	754 1,038 1,735	2,602	
2-1/2 3 4	2,335 4,336 9,316	3,302 6,132 13,174	4,669 8,672	2,490 3,880 6,754	3,735 5,821 10,131	7,761 13,508
5 6 8	17,423 28,326 59,977	24,640	with sizes	10,688 15,313 26,826	16,032 22,970 40,239	21,377 30,627 53,652
10 12 14	Velocity these	governs pipe		43,862 63,702 77,976	65,792 95,552 116,964	87,723 127,403 155,952
16 18 20				103,814 133,344 166,564	155,722 200,016 249,847	207,629 266,688 333,129
22 24 26				203,476 244,079 288,373	305,214 366,119 432,560	406,952 488,158 576,746
28 30 32				336,359 388,035 443,403	504,538 582,053 665,104	672,717 776,070 886,805
34 36 42				502,462 565,212 775,609	753,692 847,817 1,163,413	1,004,923 1,130,423 1,551,217
48 54 60				1,019,226 1,296,065 1,606,124	1,528,840 1,944,097 2,409,185	2,038,453 2,592,129 3,212,247
72 84 96				2,325,903 3,178,565 4,164,110	3,488,855 4,767,848 6,246,164	4,651,806 6,357,130 8,328,219

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Steam Condensate Flow lbs./h 25 psig Back Pressure

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1/2 3/4 1	41 102 213	59 144 301	83 203 425		Pressure with these	drop pipe
1- 1/4 1- 1/2 2	490 774 1,605	692 1,095 2,270	979 1,549 3,210	917 1,264 2,112	3,168	
2- 1/2 3 4	2,669 4,956 10,649	3,774 7,009 15,059	9,913 5,338	3,031 4,724 8,223	4,547 7,086 12,334	16,445 9,448
5 6 8	19,916 32,379 68,558	28,166 45,791	with sizes	13,012 18,643 32,659	19,519 27,965 48,989	26,025 37,286 65,318
10 12 14	131,433	governs pipe		53,399 77,553 94,932	80,099 116,330 142,397	106,798 155,106 189,863
16 18 20	Velocity these			126,388 162,339 202,783	189,582 243,508 304,174	252,776 324,677 405,566
22 24 26				247,721 297,153 351,078	371,581 445,729 526,618	495,442 594,306 702,157
28 30 32				409,498 472,411 539,818	614,247 708,617 809,727	818,996 944,822 1,079,636
34 36 42				611,719 688,114 944,261	917,579 1,032,171 1,416,391	1,223,438 1,376,227 1,888,521
48 54 60				1,240,852 1,577,887 1,955,366	1,861,277 2,366,830 2,933,050	2,481,703 3,155,774 3,910,733

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00**

Pipe Size 72 84 96	Pressure Drop psig/100 ft. 0.125	0.25	0.5	2,831,658 3,869,727 5,069,573 2,000 (23)	Velocity FPM (mph) 4,247,487 5,804,590 7,604,359 3,000 (34)	5,663,316 7,739,454 10,139,145 4,000 (45)	
Steam Condensate Flow lbs./h 30 psig Back Pressure							
1/2 3/4 1	47 115 241	66 163 341	94 230 482		Pressure with these	drop pipe	
1- 1/4 1- 1/2 2	555 877 1,818	785 1,241 2,572	1,110 1,755 3,637	1,099 1,514 2,530			
2- 1/2 3 4	3,024 5,616 12,065	4,276 7,942 17,063	6,048 11,232 24,131	3,631 5,659 9,850	5,447 8,488 14,775	19,700	
5 6 8	22,566 36,687 77,679	31,913 51,883	with sizes	15,587 22,332 39,122	23,381 33,499 58,683	31,175 44,665 78,244	
10 12 14	148,920	governs pipe		63,966 92,900 113,717	95,949 139,350 170,576	127,932 185,800 227,434	
16 18 20	Velocity these			151,398 194,463 242,910	227,098 291,694 364,366	302,797 388,926 485,821	
22 24 26				296,741 355,955 420,551	445,111 533,932 630,827	593,482 711,909 841,102	
28 30 32				490,531 565,894 646,640	735,796 848,841 969,959	981,062 1,131,787 1,293,279	
34 36 42				732,768 824,280 1,131,115	1,099,153 1,236,421 1,696,672	1,465,537 1,648,561 2,262,229	
48 ***Notes:***				1,486,396	2,229,594	2,972,792	

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
48 54 60				1,486,396 1,890,125 2,342,302	2,229,594 2,835,188 3,513,453	2,972,792 3,780,251 4,684,604
72 84 96				3,391,998 4,635,484 6,072,760	5,087,997 6,953,226 9,109,140	6,783,996 9,270,968 12,145,519
Steam Condensate Flow lbs./h 40 psig Back Pressure						
1/2 3/4 1	59 145 304	84 205 429	118 290 607		Pressure with these	drop pipe
1-1/4 1-1/2 2	699 1,105 2,290	988 1,562 3,238	1,397 2,209 4,580	2,094 3,499		
2-1/2 3 4	3,808 7,072 15,193	5,385 10,001 21,486	7,615 14,143 30,385	5,022 7,827 13,624	7,534 11,741 20,436	27,248
5 6 8	28,415 46,196 97,814	40,185 65,331	with sizes	21,560 30,889 54,111	32,339 46,333 81,167	43,119 61,778 108,222
10 12 14	187,520 306,079	governs pipe		88,474 128,494 157,287	132,711 192,741 235,931	176,948 256,988 314,575
16 18 20	Velocity these			209,406 268,971 335,981	314,110 403,456 503,971	418,813 537,942 671,962
22 24 26				410,437 492,338 581,685	615,655 738,507 872,527	820,873 984,676 1,163,369
28 30 32				678,477 782,715 894,398	1,017,715 1,174,072 1,341,597	1,356,954 1,565,429 1,788,796
34				1,013,527	1,520,291	2,027,054

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
36 42				1,140,102 1,564,499	1,710,153 2,346,748	2,280,203 3,128,997
48 54 60				2,055,906 2,614,323 3,239,750	3,083,859 3,921,484 4,859,625	4,111,812 5,228,646 6,479,500
72 84 96				4,691,635 6,411,560 8,399,525	7,037,452 9,617,339 12,599,287	9,383,270 12,823,119 16,799,049
Steam Condensate Flow lbs./h 50 psig Back Pressure						
1/2 3/4 1	74 180 378	104 255 534	147 361 755		Pressure with these	drop pipe
1- 1/4 1- 1/2 2	869 1,374 2,849	1,229 1,944 4,029	1,738 2,749 5,697	4,715		
2- 1/2 3 4	4,737 8,797 18,900	6,699 12,441 26,729	9,474 17,595 37,801	6,767 10,546 18,357	15,819 27,535	36,713
5 6 8	35,350 57,471 121,686	49,992 81,276 172,090	70,699	29,049 41,620 72,910	43,574 62,430 109,364	58,099 83,240 145,819
10 12 14	233,285 380,779 495,895	governs pipe	with sizes	119,210 173,133 211,930	178,816 259,700 317,894	238,421 346,266 423,859
16 18 20	Velocity these			282,155 362,412 452,701	423,232 543,618 679,052	564,309 724,824 905,403
22 24 26				553,023 663,377 783,763	829,535 995,065 1,175,644	1,106,046 1,326,754 1,567,526
28 30				914,181 1,054,631	1,371,272 1,581,947	1,828,362 2,109,263

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
32				1,205,114	1,807,671	2,410,228
34 36 42				1,365,629 1,936,175 2,108,009	2,048,443 2,904,263 3,162,013	2,731,257 3,872,351 4,216,018
48 54 60				2,770,132 3,522,544 4,365,246	4,155,198 5,283,816 6,547,869	5,540,264 7,045,089 8,730,493
72 84 96				6,321,519 8,638,949 11,317,537	9,482,278 12,958,423 16,976,306	12,643,037 17,277,898 22,635,075

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0…**
2. **Table based on heavy weight steel pipe using steam equations in Part…**

175 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5…
Steam Condensate Flow lbs./h 0 psig Back Pressure							
1/2 3/4 1	16 40 84	23 57 118	33 80 167	76 127	Pressure with these	drop pipe	g si
1-1/4 1-1/2 2	193 305 631	272 431 893	385 609 1,263	227 312 522	340 469 783	1,044	
2-1/2 3 4	1,050 1,950 4,189	1,485 2,758	with sizes	749 1,168 2,032	1,124 1,751 3,048	1,498 2,335 4,065	1 2 5

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0…**
2. **Table based on heavy weight steel pipe using steam equations in Part…**

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5
5 6 8	7,835	governs pipe		3,216 4,608 8,672	4,824 6,912 12,108	6,432 9,215 16,144	8 1 2
10 12 14	Velocity these			13,198 19,168 23,463	19,797 28,751 35,194	26,396 38,335 46,925	3 4 5
16 18 20				31,237 40,123 50,119	46,856 60,184 75,178	62,475 80,245 100,237	7 1 1
22 24 26				61,225 73,442 86,770	91,838 110,164 130,155	122,450 146,885 173,541	1 1 2
28 30 32				101,209 116,758 133,418	151,813 175,137 200,127	202,418 233,516 266,836	2 2 3
34 36 42				151,189 170,070 233,377	226,783 255,105 350,066	302,377 340,140 466,755	3 4 5
48 54 60				306,681 389,980 483,276	460,021 584,971 724,914	613,362 779,961 966,552	7 9 1
72 84 96				699,855 956,417 1,252,963	1,049,782 1,434,626 1,879,445	1,399,709 1,912,834 2,505,926	1 2 3
Steam Condensate Flow lbs./h 5 psig Back Pressure							
1/2 3/4 1	20 50 104	29 70 147	41 100 209	182	Pressure with these	drop pipe	g si
1-1/4 1-1/2 2	240 380 787	339 537 1,113	480 759 1,573	324 446 746	669 1,118	1,491	
2-	1,308	1,850	2,616	1,070	1,605	2,140	4

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5
1/2	2,420	3,436		1,668	2,502	3,336	7
3	5,219			2,903	4,355	5,806	
4							
5	9,762	governs	with	4,594	6,891	9,188	1
6	15,871	pipe	sizes	6,582	9,873	13,164	1
8				11,530	17,296	23,061	2
10	Velocity			18,853	28,279	37,706	4
12	these			27,381	41,071	54,761	6
14				33,516	50,274	67,032	8
16				44,622	66,933	89,244	1
18				57,315	85,972	114,629	1
20				71,594	107,391	143,187	1
22				87,459	131,189	174,919	2
24				104,912	157,367	209,823	2
26				123,950	185,925	247,901	3
28				144,576	216,863	289,151	3
30				166,787	250,181	333,575	4
32				190,586	285,879	381,172	4
34				215,971	323,956	431,942	5
36				242,943	364,414	485,885	6
42				333,377	500,065	666,753	8
48				438,090	657,135	876,180	1
54				557,082	835,623	1,114,164	1
60				690,353	1,035,530	1,380,707	1
72				999,733	1,499,600	1,999,467	2
84				1,366,230	2,049,344	2,732,459	3
96				1,789,842	2,684,763	3,579,684	4
Steam Condensate Flow lbs./h 7 psig Back Pressure							
1/2	22	31	44	205	Pressure	drop pipe	g
3/4	54	76	107		with these		si
1	113	159	225				
1-1/4	259	366	518	366	756	1,684	
1/4	410	579	819	504	1,263		
1-1/2	849	1,201	1,698	842			

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0

Pipe Size	Pressure Drop psig/100 ft.				Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5
1/2 2 2- 1/2 3 4	1,412 2,622 5,634	1,997 3,709 7,968	2,824	1,209 1,883 3,278	1,813 2,825 4,918	2,417 3,767 6,557	4 8
5 6 8	10,537 17,131	governs pipe	with sizes	5,188 7,433 13,021	7,782 11,149 19,532	10,376 14,866 26,042	1 1 3
10 12 14	Velocity these			21,290 30,920 37,849	31,935 46,380 56,773	42,580 61,840 75,698	5 7 9
16 18 20				50,391 64,724 80,849	75,586 97,086 121,273	100,781 129,448 161,698	1 1 2
22 24 26				98,766 118,474 139,974	148,148 177,711 209,961	197,531 236,948 279,948	2 2 3
28 30 32				163,266 188,349 215,224	244,898 282,523 322,836	326,531 376,698 430,448	4 4 5
34 36 42				243,891 274,349 376,474	365,836 411,523 564,711	487,781 548,698 752,948	6 6 9
48 54 60				494,724 629,099 779,599	742,086 943,648 1,169,398	989,448 1,258,198 1,559,198	1 1 1
72 84 96				1,128,974 1,542,849 2,021,224	1,693,461 2,314,273 3,031,835	2,257,948 3,085,697 4,042,447	2 3 5
Steam Condensate Flow lbs./h 10 psig Back Pressure							
1/2 3/4 1	24 60 125	34 84 177	49 119 250	242	Pressure with these	drop pipe	g si
1	288	407	575	431	891		

Notes:

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)	5
1-1/4	[illegible]	[illegible]	[illegible]	594	1,490		
1-1/2	942	[illegible]	1,885	993			
2							
2-1/2	1,567	2,216	3,135	1,425	2,138	2,851	5
3	2,911	4,116		2,221	3,332	4,443	9
4	6,253	8,844		3,867	5,800	7,733	
5	11,696	governs	with	6,119	9,178	12,238	1
6	19,015	pipe	sizes	8,767	13,150	17,534	2
8				15,358	23,037	30,715	3
10	Velocity			25,111	37,666	50,221	6
12	these			36,469	54,703	72,938	9
14				44,641	66,961	89,282	1
16				59,433	89,150	118,866	1
18				76,339	114,508	152,677	1
20				95,357	143,036	190,715	2
22				116,489	174,734	232,978	2
24				139,734	209,601	279,468	3
26				165,092	247,638	330,184	4
28				192,564	288,845	385,127	4
30				222,148	333,222	444,296	5
32				253,846	380,769	507,692	6
34				287,657	431,485	575,313	7
36				323,581	485,371	647,161	8
42				444,032	666,048	888,064	1
48				583,502	875,253	1,167,004	1
54				741,990	1,112,986	1,483,981	1
60				919,497	1,379,246	1,838,995	2
72				1,331,568	1,997,351	2,663,135	3
84				1,819,712	2,729,568	3,639,424	4
96				2,383,931	3,575,897	4,767,863	5
Steam Condensate Flow lbs./h 12 psig Back Pressure							
Notes: 1/2	26	37	52		Pressure	drop pipe	g
3/4	64	90	127		with these		si

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5
3/4	64	90	127		with these		s
1	133	188	267				
1-1/4	307	434	614	477	1,648		
1-1/2	485	686	970	658			
2	1,005	1,422	2,011	1,099			
2-1/2	1,672	2,364	3,344	1,577	2,365	3,154	6
3	3,105	4,391		2,458	3,686	4,915	1
4	6,671	9,434		4,278	6,417	8,555	
5	12,476	governs	with	6,769	10,154	13,539	1
6	20,284	pipe	sizes	9,699	14,548	19,398	2
8				16,990	25,486	33,981	4
10	Velocity			27,780	41,670	55,560	6
12	these			40,346	60,519	80,692	1
14				49,387	74,080	98,774	1
16				65,752	98,627	131,503	1
18				84,454	126,681	168,909	2
20				105,495	158,242	210,990	2
22				128,873	193,310	257,746	3
24				154,589	231,884	309,179	3
26				182,643	273,965	365,287	4
28				213,035	319,553	426,070	5
30				245,765	368,647	491,530	6
32				280,832	421,249	561,665	7
34				318,238	477,357	636,476	7
36				357,981	536,972	715,962	8
42				491,238	736,856	982,475	1
48				645,535	968,302	1,291,070	1
54				820,872	1,231,309	1,641,745	2
60				1,017,251	1,525,876	2,034,501	2
72				1,473,128	2,209,693	2,946,257	3
84				2,013,168	3,019,753	4,026,337	5
96				2,637,370	3,956,056	5,274,741	6

Steam Condensate Flow lbs./h 15 psig Back Pressure

Pipe Size	**Pressure Drop psig/100 ft.**			**Velocity FPM (mph)**			
	0.125	**0.25**	**0.5**	**2,000 (23)**	**3,000 (34)**	**4,000 (45)**	**5**
1/2 3/4 1	28 70 146	40 99 206	57 139 292		Pressure with these	drop pipe	g si
1-1/4 1-1/2 2	336 531 1,101	475 751 1,557	672 1,062 2,202	549 757 1,264	1,897		
2-1/2 3 4	1,830 3,400 7,304	2,589 4,808 10,329	3,661 6,799	1,815 2,828 4,923	2,722 4,243 7,385	3,630 5,657 9,846	1
5 6 8	13,660 22,208 47,023	19,318	with sizes	7,791 11,162 19,553	11,686 16,743 29,330	15,581 22,324 39,107	1 2 4
10 12 14	Velocity these	governs pipe		31,971 46,432 56,837	47,956 69,648 85,255	63,942 92,864 113,674	7 1 1
16 18 20				75,670 97,194 121,409	113,506 145,792 182,113	151,341 194,389 242,818	1 2 3
22 24 26				148,314 177,910 210,196	222,471 266,864 315,293	296,628 355,819 420,391	3 4 5
28 30 32				245,172 282,839 323,197	367,758 424,259 484,795	490,344 565,678 646,394	6 7 8
34 36 42				366,245 411,983 565,342	549,367 617,975 848,013	732,490 823,967 1,130,684	9 1 1
48 54 60				742,915 944,703 1,170,706	1,114,373 1,417,055 1,756,058	1,485,831 1,889,406 2,341,411	1 2 2
72				1,695,354	2,543,031	3,390,708	4

Notes:

Pipe Size 84 96	**Pressure Drop psig/100 ft.**			2,316,860 3,035,225	**Velocity FPM (mph)** 3,475,290 4,552,837	4,633,721 6,070,450	5 7
Steam Condensate Flow lbs./h 20 psig Back Pressure	**0.125**	**0.25**	**0.5**	**2,000 (23)**	**3,000 (34)**	**4,000 (45)**	**5**
1/2 3/4 1	33 80 168	46 113 237	65 160 335		Pressure with these	drop pipe	g si
1-1/4 1-1/2 2	386 610 1,264	545 862 1,788	771 1,220 2,528	678 935 1,562	2,343		
2-1/2 3 4	2,102 3,904 8,387	2,973 5,521 11,861	4,204 7,808	2,242 3,494 6,081	3,363 5,240 9,121	6,987 12,162	1
5 6 8	15,687 25,503 53,998	22,184		9,623 13,787 24,152	14,434 20,680 36,228	19,246 27,574 48,304	2 3 6
10 12 14				39,490 57,352 70,204	59,234 86,028 105,306	78,979 114,704 140,408	9 1 1
16 18 20	Velocity these	governs pipe	with sizes	93,467 120,053 149,962	140,200 180,079 224,943	186,933 240,105 299,924	2 3 3
22 24 26				183,195 219,750 259,629	274,792 329,625 389,444	366,389 439,501 519,259	4 5 6
28 30 32				302,832 349,357 399,206	454,248 524,036 598,809	605,663 698,715 798,412	7 8 9
34 36 42				452,378 508,874 698,299	678,567 763,310 1,047,449	904,757 1,017,747 1,396,598	1 1 1
Notes: 48 54				917,634 1,166,878	1,376,451 1,750,318	1,835,268 2,333,757	2 2

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5
54 60				1,166,878 1,446,032	1,750,318 2,169,048	2,333,757 2,892,064	2 3
72 84 96				2,094,067 2,861,739 3,749,048	3,141,100 4,292,609 5,623,573	4,188,134 5,723,478 7,498,097	5 7 9
Steam Condensate Flow lbs./h 25 psig Back Pressure							
1/2 3/4 1	37 91 190	52 128 269	74 181 380		Pressure with these	drop pipe	g si
1- 1/4 1- 1/2 2	437 692 1,434	619 978 2,027	875 1,383 2,867	819 1,129 1,886	2,830		
2- 1/2 3 4	2,384 4,427 9,512	3,371 6,261 13,451	4,768 8,854	2,708 4,220 7,345	4,061 6,330 11,017	8,439 14,689	1
5 6 8	17,790 28,922 61,238	25,158 40,902	with sizes	11,623 16,653 29,172	17,435 24,979 43,758	23,246 33,305 58,344	2 4 7
10 12 14	117,400	governs pipe		47,698 69,273 84,796	71,546 103,909 127,194	95,395 138,546 169,591	1 1 2
16 18 20	Velocity these			112,894 145,006 181,132	169,340 217,508 271,697	225,787 290,011 362,263	2 3 4
22 24 26				221,272 265,426 313,593	331,907 398,138 470,390	442,543 530,851 627,187	5 6 7
28 30 32				365,775 421,971 482,181	548,663 632,957 723,272	731,551 843,943 964,363	9 1 1
34 36				546,405 614,643	819,608 921,965	1,092,811 1,229,286	1 1

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)	5
42				843,441	1,265,162	1,686,882	2
48 54 60				1,108,365 1,409,415 1,746,590	1,662,547 2,114,122 2,619,885	2,216,730 2,818,829 3,493,181	2 3 4
72 84 96				2,529,320 3,456,553 4,528,290	3,793,980 5,184,829 6,792,435	5,058,639 6,913,106 9,056,580	6 8 1
Steam Condensate Flow lbs./h 30 psig Back Pressure							
1/2 3/4 1	42 102 214	59 144 302	83 204 427		Pressure with these	drop pipe	g si
1-1/4 1-1/2 2	492 777 1,611	695 1,099 2,278	983 1,554 3,222	974 1,341 2,241			
2-1/2 3 4	2,679 4,975 10,689	3,788 7,036 15,116	5,358 9,950 21,377	3,217 5,013 8,726	4,825 7,520 13,089	17,452	
5 6 8	19,991 32,501 68,816	28,272 45,963	with sizes	13,809 19,784 34,658	20,713 29,676 51,987	27,618 39,568 69,316	3 4 8
10 12 14	131,928	governs pipe		56,667 82,300 100,742	85,001 123,450 151,113	113,335 164,600 201,484	1 2 2
16 18 20	Velocity these			134,124 172,275 215,194	201,186 258,412 322,791	268,248 344,549 430,389	3 4 5
22 24 26				262,883 315,340 372,566	394,324 473,010 558,849	525,765 630,680 745,133	6 7 9
28 30 32				434,561 501,325 572,858	651,842 751,988 859,287	869,123 1,002,650 1,145,716	1 1 1

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5
34 36 42				649,159 730,230 [illegible]	[illegible] 1,095,345 1,503,081	[illegible] 1,460,460 2,004,108	1 1 2
48 54 60				1,316,798 1,674,462 2,075,045	1,975,197 2,511,693 3,112,567	2,633,596 3,348,924 4,150,090	3 4 5
72 84 96				3,004,970 4,106,574 5,379,857	4,507,456 6,159,861 8,069,785	6,009,941 8,213,148 10,759,713	7 1 1
Steam Condensate Flow lbs./h 40 psig Back Pressure							
1/2 3/4 1	51 126 264	73 178 374	103 252 528		Pressure with these	drop pipe	g si
1- 1/4 1- 1/2 2	608 961 1,993	860 1,360 2,818	1,216 1,923 3,985	1,822 3,045			
2- 1/2 3 4	3,314 6,154 13,221	4,686 8,703 18,698	6,627 12,308 26,443	4,371 6,812 11,856	6,556 10,217 17,784	23,712	
5 6 8	24,728 40,202 85,123	34,971 56,855	with sizes	18,762 26,881 47,090	28,143 40,322 70,636	37,524 53,762 94,181	4 6 1
10 12 14	163,190 266,367	governs pipe		76,995 111,822 136,880	115,492 167,734 205,320	153,990 223,645 273,760	1 2 3
16 18 20	Velocity these			182,237 234,073 292,389	273,355 351,109 438,583	364,473 468,146 584,777	4 5 7
22 24 26				357,184 428,459 506,213	535,776 642,688 759,319	714,368 856,917 1,012,426	8 1 1

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5
28 30 32				590,447 681,160 778,353	885,670 1,021,740 1,167,529	1,180,893 1,362,320 1,556,706	1 1 1
34 36 42				882,025 992,177 1,361,510	1,323,038 1,488,266 2,042,265	1,764,050 1,984,354 2,723,020	2 2 3
48 54 60				1,789,159 2,275,123 2,819,403	2,683,738 3,412,684 4,229,104	3,578,317 4,550,246 5,638,806	4 5 7
72 84 96				4,082,910 5,579,680 7,309,713	6,124,365 8,369,520 10,964,569	8,165,820 11,159,360 14,619,426	1 1 1
Steam Condensate Flow lbs./h 50 psig Back Pressure							
1/2 3/4 1	63 154 322	89 217 455	125 307 644		Pressure with these	drop pipe	g si
1- 1/4 1- 1/2 2	741 1,172 2,429	1,048 1,657 3,435	1,482 2,344 4,858	4,020			
2- 1/2 3 4	4,039 7,501 16,116	5,712 10,609 22,792	8,078 15,003 32,233	5,770 8,993 15,653	13,489 23,479	31,305	
5 6 8	30,143 49,005 103,761	42,628 69,303 146,740	60,285	24,770 35,489 62,170	37,155 53,234 93,254	49,540 70,978 124,339	8 1
10 12 14	198,921 324,688 422,847	governs pipe	with sizes	101,650 147,630 180,711	152,475 221,445 271,067	203,300 295,260 361,422	2 3 4
16 18 20	Velocity these			240,592 309,027 386,016	360,888 463,540 579,024	481,184 618,054 772,032	6 7 9
22				471,560	707,340	943,120	1

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5
22				[illegible]	[illegible]	[illegible]	1
24				565,658	848,487	1,131,316	1
26				668,310	1,002,466	1,336,621	1
28				779,517	1,169,276	1,559,035	1
30				899,279	1,348,918	1,798,557	2
32				1,027,594	1,541,391	2,055,188	2
34				1,164,464	1,746,696	2,328,928	2
36				1,309,889	1,964,833	2,619,777	3
42				1,797,488	2,696,232	3,594,976	4
48				2,362,077	3,543,115	4,724,153	5
54				3,003,655	4,505,482	6,007,309	7
60				3,722,222	5,583,333	7,444,444	9
72				5,390,325	8,085,487	10,780,650	1
84				7,366,385	11,049,578	14,732,771	1
96				9,650,403	14,475,605	19,300,806	2

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0(**
2. **Table based on heavy weight steel pipe using steam equations in Part**

200 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
Steam Condensate Flow lbs./h 0 psig Back Pressure						
1/2	15	22	31	72	Pressure	drop pipe
3/4	38	53	75	119	with these	
1	79	111	157			
1-1/4	181	256	362	213	319	980
1-1/2	286	404	572	293	440	
2	593	838	1,185	490	735	

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
2-	985	1,393		703	1,055	1,406
1/2	1,830	2,588		1,096	1,644	2,191
3	3,931			1,907	2,861	3,814
4						
5	7,353			3,018	4,527	6,036
6				4,324	6,486	8,648
8				7,575	11,362	15,150
10				12,385	18,578	24,770
12				17,987	26,981	35,975
14				22,018	33,027	44,036
16	Velocity	governs	with	29,314	43,971	58,628
18	these	pipe	sizes	37,652	56,478	75,304
20				47,033	70,549	94,065
22				57,455	86,183	114,911
24				68,920	103,381	137,841
26				81,428	122,141	162,855
28				94,977	142,466	189,954
30				109,569	164,354	219,138
32				125,203	187,805	250,406
34				141,880	212,819	283,759
36				159,598	239,397	319,196
42				219,008	328,512	438,016
48				287,798	431,697	575,596
54				365,968	548,953	731,937
60				453,519	680,279	907,039
72				656,763	985,144	1,313,526
84				897,528	1,346,292	1,795,056
96				1,175,815	1,763,723	2,351,631
Steam Condensate Flow lbs./h 5 psig Back Pressure						
1/2	19	27	38	169	Pressure	drop pipe
3/4	46	66	93		with these	
1	97	138	195			
1-	224	317	448	302	624	1,391
1/4	354	501	708	416	1,043	
1-	734	1,038	1,468	696		

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size 1/2 1	Pressure Drop psig/100 ft.				Velocity FPM (mph)	
2-1/2 3 4	**0.125** / 1,212 2,266 4,869	**0.25** / 1,726 3,205	**0.5** / 2,445	**2,000 (23)** / 998 1,556 2,708	**3,000 (34)** / 1,497 2,334 4,062	**4,000 (45)** / 1,997 3,112 5,416
5 6 8	9,106 14,805	governs pipe	with sizes	4,285 6,140 10,756	6,428 9,210 16,134	8,571 12,280 21,512
10 12 14	Velocity these			17,586 25,541 31,264	26,379 38,312 46,896	35,172 51,082 62,529
16 18 20				41,624 53,464 66,784	62,436 80,196 100,175	83,248 106,928 133,567
22 24 26				81,583 97,863 115,622	122,375 146,794 173,434	163,166 195,726 231,245
28 30 32				134,862 155,582 177,781	202,293 233,372 266,672	269,724 311,163 355,562
34 36 42				201,461 226,620 310,978	302,191 339,930 466,467	402,921 453,240 621,956
48 54 60				408,656 519,654 643,971	612,984 779,481 965,957	817,312 1,039,307 1,287,942
72 84 96				932,565 1,274,437 1,669,589	1,398,847 1,911,656 2,504,383	1,865,129 2,548,875 3,339,177
Steam Condensate Flow lbs./h 7 psig Back Pressure						
1/2 3/4 1	20 50 105	29 71 148	41 100 209	191	Pressure with these	drop pipe

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1-1/4 1-1/2 2	241 381 790	341 539 1,118	482 762 1,580	340 469 784	703 1,175	1,567
2-1/2 3 4	1,314 2,440 5,243	1,858 3,451 7,415	2,628	1,125 1,753 3,051	1,687 2,629 4,576	2,249 3,506 6,102
5 6 8	9,806 15,942	governs pipe	with sizes	4,828 6,917 12,118	7,242 10,376 18,176	9,656 13,834 24,235
10 12 14	Velocity these			19,813 28,775 35,223	29,719 43,162 52,834	39,625 57,549 70,445
16 18 20				46,894 60,233 75,239	70,341 90,349 112,858	93,788 120,465 150,477
22 24 26				91,912 110,253 130,261	137,868 165,379 195,391	183,824 220,505 260,522
28 30 32				151,936 175,279 200,289	227,904 262,918 300,433	303,872 350,558 400,578
34 36 42				226,966 255,311 350,349	340,450 382,967 525,524	453,933 510,622 700,699
48 54 60				460,394 585,444 725,500	690,590 878,166 1,088,250	920,787 1,170,888 1,451,001
72 84 96				1,050,631 1,435,786 1,880,965	1,575,947 2,153,679 2,821,448	2,101,262 2,871,572 3,761,931
Steam Condensate Flow lbs./h 10 psig Back Pressure						
1/2 ***Notes:***	23	32	45	224	Pressure	drop pipe

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
3/4 1	55 116	78 164	111 232		with these	
1-1/4 1-1/2 2	267 422 874	377 596 1,236	533 843 1,748	400 551 921	827 1,382	
2-1/2 3 4	1,453 2,699 5,800	2,056 3,818 8,202	2,907	1,322 2,060 3,586	1,983 3,090 5,379	2,644 4,120 7,172
5 6 8	10,847 17,635	governs pipe	with sizes	5,675 8,130 14,243	8,512 12,196 21,364	11,350 16,261 28,486
10 12 14	Velocity these			23,288 33,822 41,401	34,932 50,733 62,101	46,576 67,643 82,801
16 18 20				55,119 70,798 88,436	82,679 106,196 132,653	110,238 141,595 176,871
22 24 26				108,034 129,591 153,109	162,050 194,387 229,663	216,067 259,183 306,218
28 30 32				178,586 206,023 235,420	267,879 309,035 353,130	357,172 412,046 470,840
34 36 42				266,777 300,093 411,802	400,165 450,140 617,702	533,554 600,187 823,603
48 54 60				541,148 688,132 852,755	811,722 1,032,199 1,279,132	1,082,296 1,376,265 1,705,510
72 84 96				1,234,915 1,687,627 2,210,892	1,852,372 2,531,440 3,316,337	2,469,829 3,375,254 4,421,783

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00**

Steam Condensate Flow lbs./h 12 psig Back Pressure

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	**0.25**	**0.5**	**2,000 (23)**	**3,000 (34)**	**4,000 (45)**
1/2 3/4 1	24 59 123	34 83 174	48 118 247		Pressure with these	drop pipe
1- 1/4 1- 1/2 2	284 449 930	401 635 1,316	568 898 1,861	442 608 1,017	1,525	
2- 1/2 3 4	1,547 2,873 6,172	2,188 4,063 8,729	3,094	1,459 2,274 3,958	2,189 3,411 5,937	2,918 4,548 7,916
5 6 8	11,544 18,768	governs pipe	with sizes	6,264 8,974 15,721	9,396 13,461 23,581	12,527 17,948 31,442
10 12 14	Velocity these			25,704 37,331 45,697	38,557 55,997 68,545	51,409 74,663 91,394
16 18 20				60,839 78,144 97,613	91,258 117,216 146,419	121,678 156,288 195,225
22 24 26				119,244 143,039 168,997	178,866 214,558 253,495	238,488 286,078 337,994
28 30 32				197,118 227,402 259,850	295,677 341,103 389,774	394,236 454,804 519,699
34 36 42				294,460 331,234 454,534	441,690 496,851 681,801	588,920 662,468 909,068
48 54 60				597,303 759,540 941,245	895,954 1,139,310 1,411,868	1,194,605 1,519,079 1,882,490

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
72 84 96				1,363,061 1,862,752 2,440,315	2,044,592 2,794,127 3,660,473	2,726,123 3,725,503 4,880,631
Steam Condensate Flow lbs./h 15 psig Back Pressure						
1/2 3/4 1	26 64 135	37 91 190	52 128 269		Pressure with these	drop pipe
1- 1/4 1- 1/2 2	310 490 1,015	438 693 1,435	619 979 2,030	507 698 1,166	1,749	
2- 1/2 3 4	1,688 3,135 6,735	2,387 4,433 9,524	3,376 6,269	1,674 2,608 4,540	2,510 3,912 6,809	3,347 5,216 9,079
5 6 8	12,596 20,478 43,360	17,814	with sizes	7,184 10,293 18,031	10,776 15,439 27,046	14,368 20,585 36,061
10 12 14	Velocity these	governs pipe		29,481 42,816 52,410	44,221 64,224 78,615	58,961 85,632 104,820
16 18 20				69,777 89,624 111,953	104,665 134,437 167,929	139,554 179,249 223,906
22 24 26				136,762 164,053 193,824	205,144 246,079 290,737	273,525 328,106 387,649
28 30 32				226,077 260,810 298,024	339,115 391,215 447,036	452,153 521,620 596,049
34 36 42				337,720 379,896 521,310	506,579 569,844 781,965	675,439 759,791 1,042,620
48				685,053	1,027,579	1,370,106

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
54 60				871,124 1,079,524	1,306,686 1,619,286	1,742,248 2,159,048
72 84 96				1,563,310 2,136,409 2,798,824	2,344,964 3,204,614 4,198,235	3,126,619 4,272,819 5,597,647
Steam Condensate Flow lbs./h 20 psig Back Pressure						
1/2 3/4 1	30 73 154	42 104 217	60 147 307		Pressure with these	drop pipe
1-1/4 1-1/2 2	354 559 1,159	500 791 1,639	707 1,118 2,318	622 857 1,432	2,148	
2-1/2 3 4	1,927 3,579 7,689	2,725 5,061 10,874	3,854 7,158	2,055 3,203 5,575	3,083 4,804 8,362	6,406 11,150
5 6 8	14,381 23,381 49,505	20,338	with sizes	8,822 12,640 22,142	13,233 18,960 33,214	17,644 25,280 44,285
10 12 14	Velocity these	governs pipe		36,204 52,580 64,362	54,306 78,870 96,543	72,407 105,160 128,724
16 18 20				85,689 110,063 137,484	128,534 165,095 206,226	171,379 220,126 274,967
22 24 26				167,951 201,465 238,026	251,926 302,198 357,039	335,902 402,930 476,052
28 30 32				277,633 320,287 365,988	416,450 480,431 548,983	555,266 640,575 731,977
34				414,736	622,104	829,472

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
36				466,530	699,796	933,061
42				640,194	960,291	1,280,388
48				841,278	1,261,917	1,682,556
54				1,069,783	1,604,674	2,139,566
60				1,325,708	1,988,562	2,651,417
72				1,919,821	2,879,731	3,839,641
84				2,623,615	3,935,423	5,247,230
96				3,437,092	5,155,638	6,874,184
Steam Condensate Flow lbs./h 25 psig Back Pressure						
1/2	34	48	67		Pressure	drop pipe
3/4	83	117	165		with these	
1	173	245	346			
1-1/4	399	564	797	747	2,579	
1-1/2	630	891	1,261	1,029		
2	1,307	1,848	2,613	1,719		
2-1/2	2,173	3,072	4,345	2,468	3,702	7,692
3	4,035	5,706	8,070	3,846	5,769	13,388
4	8,669	12,259		6,694	10,041	
5	16,213	22,929		10,593	15,890	21,186
6	26,359	37,278		15,177	22,766	30,354
8	55,812			26,587	39,881	53,174
10	106,997			43,471	65,207	86,942
12				63,135	94,702	126,269
14				77,282	115,923	154,564
16	Velocity	governs	with	102,890	154,336	205,781
18	these	pipe	sizes	132,157	198,236	264,314
20				165,082	247,623	330,164
22				201,665	302,498	403,330
24				241,907	362,860	483,814
26				285,807	428,710	571,613
28				333,365	500,047	666,730
30				384,582	576,872	769,163

Notes:

1. Maximum recommended pressure drop/velocity 0.25 psig/100 ft/5,0

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
32 34 36 42				439,456 497,990 560,181 768,706	659,185 746,984 840,272 1,153,059	878,913 995,979 1,120,362 1,537,412
48 54 60				1,010,155 1,284,530 1,591,829	1,515,233 1,926,795 2,387,744	2,020,311 2,569,060 3,183,658
72 84 96				2,305,203 3,150,276 4,127,049	3,457,804 4,725,414 6,190,574	4,610,405 6,300,552 8,254,098
Steam Condensate Flow lbs./h 30 psig Back Pressure						
1/2 3/4 1	38 92 193	53 131 274	75 185 387		Pressure with these	drop pipe
1- 1/4 1- 1/2 2	445 704 1,459	630 996 2,064	891 1,408 2,919	882 1,215 2,030		
2- 1/2 3 4	2,427 4,507 9,683	3,432 6,374 13,693	4,853 9,014 19,365	2,914 4,541 7,905	4,371 6,812 11,857	15,809
5 6 8	18,110 29,442 62,339	25,611 41,637	with sizes	12,509 17,922 31,396	18,764 26,883 47,094	25,018 35,844 62,792
10 12 14	119,511	governs pipe		51,334 74,554 91,260	77,001 111,831 136,890	102,668 149,108 182,521
16 18 20	Velocity these			121,500 156,061 194,941	182,251 234,091 292,411	243,001 312,121 389,881
22 24 26				238,141 285,661 337,501	357,211 428,492 506,252	476,282 571,322 675,002

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)
28 30 32				393,661 454,142 518,942	590,492 681,212 778,413	787,323 908,283 1,037,884
34 36 42				588,062 661,502 907,743	882,093 992,254 1,361,615	1,176,124 1,323,005 1,815,486
48 54 60				1,192,864 1,516,865 1,879,747	1,789,296 2,275,298 2,819,620	2,385,728 3,033,731 3,759,493
72 84 96				2,722,150 3,720,073 4,873,517	4,083,224 5,580,110 7,310,276	5,444,299 7,440,146 9,747,034
Steam Condensate Flow lbs./h 40 psig Back Pressure						
1/2 3/4 1	46 113 236	65 160 334	92 226 472		Pressure with these	drop pipe
1-1/4 1-1/2 2	544 860 1,782	769 1,216 2,520	1,087 1,720 3,564	1,630 2,723		
2-1/2 3 4	2,963 5,504 11,824	4,191 7,784 16,722	5,927 11,008 23,649	3,909 6,092 10,603	5,863 9,138 15,905	21,207
5 6 8	22,115 35,955 76,129	31,276 50,848	with sizes	16,780 24,041 42,115	25,170 36,061 63,172	33,560 48,082 84,230
10 12 14	145,947 238,222	governs pipe		68,860 100,007 122,417	103,289 150,011 183,626	137,719 200,014 244,834
16 18 20	Velocity these			162,981 209,341 261,495	244,472 314,011 392,242	325,963 418,681 522,989

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
22 24 26				319,444 383,187 452,726	479,165 574,781 679,089	638,887 766,375 905,452
28 30 32				528,060 609,188 696,112	792,090 913,783 1,044,168	1,056,120 1,218,377 1,392,224
34 36 42				788,830 887,343 1,217,652	1,183,245 1,331,015 1,826,478	1,577,660 1,774,687 2,435,305
48 54 60				1,600,115 2,034,733 2,521,504	2,400,173 3,052,099 3,782,256	3,200,231 4,069,465 5,043,007
72 84 96				3,651,508 4,990,129 6,537,366	5,477,262 7,485,193 9,806,049	7,303,016 9,980,258 13,074,732
Steam Condensate Flow lbs./h 50 psig Back Pressure						
1/2 3/4 1	55 136 284	78 192 401	111 271 568		Pressure with these	drop pipe
1- 1/4 1- 1/2 2	653 1,033 2,142	924 1,461 3,029	1,307 2,067 4,283	3,545		
2- 1/2 3 4	3,561 6,614 14,210	5,037 9,354 20,096	7,123 13,229 28,420	5,088 7,929 13,801	11,894 20,702	27,603
5 6 8	26,578 43,209 91,489	37,586 61,107 129,385	53,155	21,841 31,292 54,817	32,761 46,938 82,225	43,681 62,584 109,634
10 12 14	175,395 286,288 372,838	governs pipe	with sizes	89,628 130,170 159,339	134,442 195,255 239,008	179,256 260,340 318,678
Notes:	Velocity			212,137	318,206	424,275

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
16 18 20	Velocity these			212,137 272,479 340,363	318,206 408,718 510,544	424,275 544,957 680,725
22 24 26				415,789 498,759 589,271	623,684 748,138 883,906	831,579 997,517 1,178,541
28 30 32				687,325 792,922 906,062	1,030,988 1,189,384 1,359,094	1,374,650 1,585,845 1,812,125
34 36 42				1,026,745 1,154,970 1,584,902	1,540,118 1,732,455 2,377,353	2,053,490 2,309,941 3,169,804
48 54 60				2,082,718 2,648,418 3,282,001	3,124,077 3,972,627 4,923,002	4,165,436 5,296,835 6,564,003
72 84 96				4,752,821 6,495,176 8,509,067	7,129,231 9,742,764 12,763,601	9,505,642 12,990,352 17,018,134
Steam Condensate Flow lbs./h 60 psig Back Pressure						
1/2 3/4 1	66 161 337	93 227 476	131 321 673		Pressure with these	drop pipe
1- 1/4 1- 1/2 2	775 1,225 2,539	1,096 1,733 3,591	1,549 2,450 5,078	4,497		
2- 1/2 3 4	4,222 7,842 16,848	5,971 11,090 23,826	8,445 15,684 33,695	6,454 10,059 17,508	15,088 26,262	
5 6 8	31,510 51,229 108,469	44,562 72,448 153,399	63,021	27,706 39,696 69,539	41,560 59,544 104,308	55,413 79,392 139,078
10 ***Notes:***	207,948	governs	with	113,699	170,549	227,399

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
12	339,422	pipe	sizes	165,129	247,694	330,259
14	442,035			202,132	303,198	404,264
16	Velocity			269,111	403,666	538,221
18	these			345,658	518,487	691,316
20				431,773	647,660	863,546
22				527,457	791,186	1,054,914
24				632,709	949,064	1,265,419
26				747,530	1,121,295	1,495,060
28				871,919	1,307,878	1,743,838
30				1,005,876	1,508,814	2,011,752
32				1,149,402	1,724,103	2,298,804
34				1,302,496	1,953,744	2,604,992
36				1,465,158	2,197,738	2,930,317
42				2,010,556	3,015,834	4,021,113
48				2,642,069	3,963,104	5,284,139
54				3,359,698	5,039,547	6,719,396
60				4,163,442	6,245,163	8,326,884
72				6,029,277	9,043,915	12,058,553
84				8,239,573	12,359,359	16,479,146
96				10,794,331	16,191,496	21,588,662

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0**
2. **Table based on heavy weight steel pipe using steam equations in Par**

225 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
Steam Condensate Flow lbs./h 0 psig Back						
1/2	14	20	29	68	Pressure	drop pipe
3/4	36	50	71	113	with these	
1	74	105	149			

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0**

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1-1/4	171	242	342	201	302	928
1-1/2	271	383	541	278	416	
2	561	793	1,122	464	696	
2-1/2	933	1,319		666	999	1,331
3	1,733	2,450		1,038	1,556	2,075
4	3,723			1,806	2,709	3,612
5	6,962			2,858	4,287	5,716
6				4,094	6,142	8,189
8				7,173	10,759	14,345
10				11,728	17,591	23,455
12				17,032	25,548	34,065
14				20,849	31,273	41,698
16	Velocity	governs	with	27,757	41,636	55,515
18	these	pipe	sizes	35,653	53,479	71,306
20				44,535	66,803	89,071
22				54,405	81,607	108,809
24				65,261	97,891	130,522
26				77,104	115,656	154,208
28				89,934	134,901	179,868
30				103,751	155,627	207,502
32				118,555	177,833	237,110
34				134,346	201,519	268,692
36				151,124	226,686	302,248
42				207,379	311,069	414,758
48				272,517	408,775	545,033
54				346,537	519,805	693,073
60				429,439	644,158	858,878
72				621,891	932,836	1,243,781
84				849,872	1,274,808	1,699,744
96				1,113,383	1,670,074	2,226,765
Steam Condensate Flow lbs./h 5 psig Back Pressure						

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1/2 3/4 1	18 44 92	25 62 130	36 88 183	160	Pressure with these	drop pipe
1-1/4 1-1/2 2	211 334 691	298 472 978	422 667 1,383	285 392 655	588 983	1,311
2-1/2 3 4	1,150 2,136 4,588	1,626 3,020	2,300	941 1,466 2,552	1,411 2,199 3,828	1,881 2,932 5,104
5 6 8	8,581 13,951	governs pipe	with sizes	4,038 5,786 10,136	6,057 8,679 15,203	8,077 11,572 20,271
10 12 14	Velocity these			16,572 24,068 29,462	24,858 36,102 44,192	33,144 48,137 58,923
16 18 20				39,224 50,381 62,933	58,836 75,572 94,399	78,448 100,762 125,866
22 24 26				76,879 92,220 108,956	115,319 138,330 163,434	153,758 184,440 217,911
28 30 32				127,086 146,611 167,530	190,629 219,916 251,295	254,172 293,222 335,061
34 36 42				189,844 213,553 293,047	284,767 320,330 439,571	379,689 427,106 586,095
48 54 60				385,093 489,691 606,840	577,640 734,536 910,260	770,186 979,381 1,213,680
72 84				878,793 1,200,954	1,318,190 1,801,430	1,757,587 2,401,907

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
96				1,573,321	2,359,981	3,146,642
Steam Condensate Flow lbs./h 7 psig Back Pressure						
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1/2 3/4 1	19 47 99	27 67 139	38 94 197	180	Pressure with these	drop pipe
1- 1/4 1- 1/2 2	227 359 743	321 507 1,051	454 717 1,486	320 441 737	662 1,106	1,474
2- 1/2 3 4	1,236 2,295 4,931	1,748 3,246 6,974	2,472	1,058 1,649 2,870	1,587 2,473 4,304	2,116 3,297 5,739
5 6 8	9,223 14,995	governs pipe	with sizes	4,541 6,506 11,397	6,812 9,759 17,096	9,082 13,012 22,794
10 12 14	Velocity these			18,635 27,064 33,129	27,952 40,596 49,693	37,270 54,128 66,258
16 18 20				44,106 56,652 70,766	66,160 84,978 106,150	88,213 113,305 141,533
22 24 26				86,449 103,699 122,518	129,673 155,549 183,777	172,897 207,398 245,036
28 30 32				142,905 164,860 188,384	214,357 247,290 282,575	285,810 329,720 376,767
34 36 42				213,475 240,135 329,524	320,213 360,203 494,287	426,951 480,270 659,049
48 54 60				433,028 550,645 682,376	649,541 825,967 1,023,564	866,055 1,101,290 1,364,752

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
[illegible]				[illegible]	[illegible]	[illegible]
72 84 96				988,181 1,350,442 1,769,160	1,482,272 2,025,663 2,653,739	1,976,362 2,700,884 3,538,319
Steam Condensate Flow lbs./h 10 psig Back Pressure						
1/2 3/4 1	21 52 109	30 73 154	42 104 217	210	Pressure with these	drop pipe
1-1/4 1-1/2 2	250 396 820	354 559 1,159	500 791 1,640	375 517 864	776 1,296	
2-1/2 3 4	1,363 2,532 5,440	1,928 3,581 7,693	2,727	1,240 1,932 3,364	1,860 2,899 5,045	2,480 3,865 6,727
5 6 8	10,174 16,541	governs pipe	with sizes	5,323 7,626 13,360	7,984 11,440 20,040	10,646 15,253 26,720
10 12 14	Velocity these			21,844 31,725 38,834	32,766 47,587 58,250	43,688 63,449 77,667
16 18 20				51,701 66,408 82,952	77,552 99,611 124,428	103,403 132,815 165,904
22 24 26				101,335 121,556 143,615	152,002 182,334 215,423	202,670 243,112 287,230
28 30 32				167,513 193,249 220,823	251,269 289,873 331,234	335,025 386,497 441,645
34 36 42				250,235 281,486 386,267	375,353 422,229 579,401	500,470 562,971 772,535

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
48 54 60				507,593 645,464 799,879	761,390 968,196 1,199,818	1,015,187 1,290,928 1,599,758
72 84 96				1,158,342 1,582,984 2,073,803	1,737,514 2,374,476 3,110,704	2,316,685 3,165,967 4,147,606
Steam Condensate Flow lbs./h 12 psig Back Pressure						
1/2 3/4 1	22 55 115	32 78 163	45 110 231		Pressure with these	drop pipe
1-1/4 1-1/2 2	266 420 871	376 594 1,232	532 840 1,742	413 570 952	1,428	
2-1/2 3 4	1,448 2,690 5,779	2,048 3,804 8,173	2,897	1,366 2,129 3,706	2,049 3,194 5,559	2,732 4,258 7,412
5 6 8	10,809 17,573	governs pipe	with sizes	5,865 8,402 14,719	8,797 12,604 22,079	11,729 16,805 29,439
10 12 14	Velocity these			24,067 34,953 42,785	36,100 52,430 64,178	48,134 69,906 85,571
16 18 20				56,963 73,166 91,394	85,444 109,748 137,091	113,926 146,331 182,787
22 24 26				111,647 133,926 158,230	167,471 200,889 237,345	223,294 267,852 316,460
28 30 32				184,560 212,914 243,295	276,839 319,372 364,942	369,119 425,829 486,589
Notes: 1				275,700	413,550	551,400

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
34 36 42				275,700 310,131 425,576	413,550 465,196 638,363	551,400 620,262 851,151
48 54 60				559,248 711,149 881,278	838,873 1,066,724 1,321,917	1,118,497 1,422,299 1,762,557
72 84 96				1,276,221 1,744,075 2,284,842	1,914,331 2,616,113 3,427,264	2,552,441 3,488,151 4,569,685
Steam Condensate Flow lbs./h 15 psig Back Pressure						
1/2 3/4 1	24 60 126	35 85 178	49 120 251		Pressure with these	drop pipe
1-1/4 1-1/2 2	289 457 948	409 647 1,340	578 915 1,896	473 652 1,089	1,633	
2-1/2 3 4	1,576 2,927 6,289	2,229 4,140 8,894	3,152 5,854	1,563 2,435 4,239	2,344 3,653 6,358	3,125 4,871 8,478
5 6 8	11,762 19,122 40,488	16,634	with sizes	6,708 9,611 16,836	10,062 14,416 25,254	13,416 19,222 33,673
10 12 14	Velocity these	governs pipe		27,528 39,980 48,939	41,292 59,970 73,408	55,056 79,960 97,878
16 18 20				65,155 83,688 104,538	97,733 125,532 156,807	130,310 167,376 209,076
22 24 26				127,704 153,187 180,987	191,556 229,781 271,480	255,408 306,374 361,973
28				211,103	316,654	422,206

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
30 32				243,536 278,285	365,303 417,428	487,071 556,570
34 36 42				315,351 354,734 486,782	473,027 532,101 730,172	630,702 709,468 973,563
48 54 60				639,679 813,426 1,008,023	959,519 1,220,139 1,512,035	1,279,358 1,626,853 2,016,046
72 84 96				1,459,766 1,994,907 2,613,447	2,189,649 2,992,361 3,920,170	2,919,531 3,989,814 5,226,894
Steam Condensate Flow lbs./h 20 psig Back Pressure						
1/2 3/4 1	28 68 143	39 96 202	56 136 286		Pressure with these	drop pipe
1- 1/4 1- 1/2 2	329 520 1,077	465 735 1,523	657 1,039 2,155	578 797 1,331	1,996	
2- 1/2 3 4	1,791 3,327 7,148	2,533 4,705 10,108	3,583 6,654	1,910 2,977 5,182	2,866 4,466 7,773	5,955 10,364
5 6 8	13,368 21,734 46,018	18,905	with sizes	8,201 11,749 20,583	12,301 17,624 30,874	16,401 23,499 41,165
10 12 14	Velocity these	governs pipe		33,653 48,876 59,828	50,480 73,314 89,743	67,307 97,752 119,657
16 18 20				79,653 102,310 127,799	119,480 153,465 191,699	159,306 204,620 255,598
22 24				156,120 187,273	234,180 280,910	312,240 374,547

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
26				221,259	331,888	442,518
28				258,076	387,114	516,152
30				[illegible]	[illegible]	[illegible]
32				340,207	510,311	680,415
34				385,521	578,282	771,043
36				433,667	650,501	867,334
42				595,098	892,646	1,190,195
48				782,017	1,173,025	1,564,034
54				994,425	1,491,638	1,988,851
60				1,232,323	1,848,484	2,464,645
72				1,784,585	2,676,877	3,569,169
84				2,438,802	3,658,204	4,877,605
96				3,194,976	4,792,465	6,389,953
Steam Condensate Flow lbs./h 25 psig Back Pressure						
1/2	31	44	62		Pressure	drop pipe
3/4	77	108	153		with these	
1	160	227	320			
1-1/4	369	522	738	691	2,386	
1-1/2	583	825	1,167	952		
2	1,209	1,710	2,418	1,591		
2-1/2	2,010	2,843	4,021	2,283	3,425	7,117
3	3,734	5,280	7,467	3,559	5,338	12,388
4	8,021	11,344		6,194	9,291	
5	15,003	21,217		9,802	14,703	19,604
6	24,391	34,494		14,044	21,066	28,088
8	51,644			24,602	36,903	49,204
10	99,008			40,225	60,338	80,450
12				58,420	87,631	116,841
14				71,511	107,267	143,023
16				95,208	142,811	190,415
18				122,289	183,433	244,578
20				152,755	229,133	305,510

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
20				152,755	229,133	305,510
22 24 26				186,607 223,843 264,465	279,910 335,765 396,698	373,214 447,687 528,931
28 30 32	Velocity these	governs pipe	with sizes	308,472 355,865 406,642	462,709 533,797 609,963	616,945 711,729 813,284
34 36 42				460,804 518,352 711,306	691,207 777,528 1,066,959	921,609 1,036,704 1,422,612
48 54 60				934,726 1,188,613 1,472,966	1,402,090 1,782,920 2,209,450	1,869,453 2,377,226 2,945,933
72 84 96				2,133,072 2,915,043 3,818,880	3,199,608 4,372,565 5,728,320	4,266,144 5,830,086 7,637,760
Steam Condensate Flow lbs./h 30 psig Back Pressure						
1/2 3/4 1	35 85 178	49 120 252	69 170 356		Pressure with these	drop pipe
1- 1/4 1- 1/2 2	410 648 1,344	580 917 1,901	820 1,297 2,688	812 1,119 1,870		
2- 1/2 3 4	2,235 4,151 8,918	3,161 5,870 12,612	4,470 8,302 17,836	2,684 4,183 7,281	4,026 6,274 10,921	14,561
5 6 8	16,680 27,118 57,418	23,589 38,350	with sizes	11,522 16,507 28,917	17,282 24,761 43,376	23,043 33,015 57,835
10 12 14	110,076	governs pipe		47,281 68,668 84,056	70,922 103,002 126,083	94,563 137,336 168,111

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
16 18 20	Velocity these			111,908 143,740 179,551	167,862 215,610 269,326	223,817 287,480 359,101
22 24 26				219,340 263,109 310,856	329,010 394,663 466,285	438,680 526,218 621,713
28 30 32				362,583 418,288 477,973	543,874 627,432 716,959	725,166 836,577 955,945
34 36 42				541,636 609,278 836,079	812,454 913,918 1,254,119	1,083,272 1,218,557 1,672,159
48 54 60				1,098,691 1,397,113 1,731,346	1,648,036 2,095,669 2,597,018	2,197,381 2,794,226 3,462,691
72 84 96				2,507,243 3,426,383 4,488,766	3,760,865 5,139,575 6,733,149	5,014,486 6,852,766 8,977,532
Steam Condensate Flow lbs./h 40 psig Back Pressure						
1/2 3/4 1	42 103 215	59 146 305	84 206 431		Pressure with these	drop pipe
1-1/4 1-1/2 2	496 784 1,626	701 1,109 2,299	992 1,569 3,251	1,487 2,484		
2-1/2 3 4	2,703 5,021 10,786	3,823 7,100 15,254	5,407 10,041 21,573	3,566 5,557 9,673	5,349 8,336 14,509	19,345
5 6 8	20,174 32,799 69,446	28,531 46,384		15,307 21,931 38,418	22,960 32,896 57,627	30,614 43,861 76,836
10 Notes:	133,136			62,815	94,223	125,630

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
10 12 14	133,136 217,311			62,815 91,229 111,671	94,223 136,843 167,507	125,630 182,457 223,343
16 18 20	Velocity these	governs pipe	with sizes	148,675 190,965 238,541	223,012 286,447 357,811	297,350 381,929 477,081
22 24 26				291,403 349,551 412,986	437,104 524,327 619,479	582,806 699,103 825,972
28 30 32				481,707 555,714 635,007	722,560 833,571 952,511	963,414 1,111,428 1,270,015
34 36 42				719,587 809,453 1,110,767	1,079,380 1,214,179 1,666,151	1,439,174 1,618,905 2,221,534
48 54 60				1,459,658 1,856,124 2,300,167	2,189,487 2,784,186 3,450,250	2,919,316 3,712,249 4,600,334
72 84 96				3,330,980 4,552,097 5,963,518	4,996,470 6,828,145 8,945,277	6,661,960 9,104,194 11,927,036
Steam Condensate Flow lbs./h 50 psig Back Pressure						
1/2 3/4 1	50 122 256	71 173 362	100 245 513		Pressure with these	drop pipe
1-1/4 1-1/2 2	590 933 1,933	834 1,319 2,734	1,180 1,866 3,867	3,200		
2-1/2 3 4	3,215 5,971 12,828	4,547 8,444 18,142	6,430 11,942 25,657	4,593 7,158 12,459	10,737 18,689	24,919
5	23,993	33,932	47,987	19,717	29,576	39,434

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
6 8	39,008 82,593	55,165 116,805		28,249 49,487	42,374 74,230	56,498 98,975
10 12 14	158,340 258,451 336,585	governs pipe	with sizes	80,913 117,513 143,845	121,370 176,269 215,768	161,826 235,025 287,691
16 18 20	Velocity these			191,510 245,984 307,267	287,265 368,976 460,901	383,020 491,968 614,535
22 24 26				375,360 450,262 531,973	563,040 675,392 797,959	750,720 900,523 1,063,945
28 30 32				620,493 715,822 817,961	930,739 1,073,733 1,226,942	1,240,986 1,431,645 1,635,922
34 36 42				926,909 1,042,666 1,430,793	1,390,364 1,563,999 2,146,190	1,853,818 2,085,333 2,861,587
48 54 60				1,880,204 2,390,898 2,962,874	2,820,306 3,586,346 4,444,312	3,760,408 4,781,795 5,925,749
72 84 96				4,290,678 5,863,615 7,681,684	6,436,017 8,795,422 11,522,526	8,581,356 11,727,229 15,363,368
Steam Condensate Flow lbs./h 60 psig Back Pressure						
1/2 3/4 1	58 143 300	83 203 425	117 287 601		Pressure with these	drop pipe
1-1/4 1-1/2 2	692 1,094 2,267	978 1,547 3,205	1,383 2,187 4,533	4,014		
2-1/2 3	3,769 7,000 15,039	5,330 9,899 21,268	7,538 14,000 30,077	5,761 8,979 15,628	13,468 23,442	

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
4						
5	28,127	39,778	56,254	24,732	37,097	49,463
6	45,728	64,670		35,434	53,151	70,867
8	96,823	136,929		62,073	93,109	124,145
10	185,621	governs	with	101,492	152,237	202,983
12	302,979	pipe	sizes	147,400	221,099	294,799
14	394,575			180,429	270,644	360,859
16	572,625			240,217	360,325	480,433
18				308,545	462,818	617,090
20				385,414	578,122	770,829
22	Velocity			470,825	706,237	941,650
24	these			564,776	847,164	1,129,553
26				667,269	1,000,903	1,334,537
28				778,302	1,167,453	1,556,605
30				897,877	1,346,815	1,795,754
32				1,025,992	1,538,989	2,051,985
34				1,162,649	1,743,974	2,325,298
36				1,307,847	1,961,770	2,615,693
42				1,794,686	2,692,029	3,589,372
48				2,358,395	3,537,592	4,716,789
54				2,998,973	4,498,459	5,997,945
60				3,716,420	5,574,630	7,432,840
72				5,381,923	8,072,884	10,763,845
84				7,354,903	11,032,354	14,709,806
96				9,635,361	14,453,041	19,270,721
Steam Condensate Flow lbs./h 75 psig Back Pressure						
1/2	73	104	147		Pressure	drop pipe
3/4	180	254	359		with these	
1	376	532	753			
1-1/4	866	1,225	1,732	5,481		
1-1/2	1,370	1,937	2,739			
2	2,839	4,015	5,678			

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
2 1/2 3 4	4,721 8,767 18,836	6,676 12,399 26,638	9,441 17,535 37,672	7,867 12,260 21,339	32,009	
5 6 8	35,229 57,275 121,271	49,822 80,999 171,504	70,459 114,550	33,769 48,382 84,756	50,654 72,573 127,133	67,538 96,764 169,511
10 12 14	232,491 379,483 494,206	328,792	with sizes	138,579 201,263 246,363	207,869 301,895 369,544	277,158 402,527 492,726
16 18 20	717,216 992,077	governs pipe		327,998 421,295 526,255	491,997 631,943 789,382	655,996 842,591 1,052,509
22 24 26	Velocity these			642,876 771,160 911,106	964,314 1,156,740 1,366,659	1,285,752 1,542,320 1,822,211
28 30 32				1,062,714 1,225,984 1,400,916	1,594,071 1,838,976 2,101,374	2,125,427 2,451,968 2,801,832
34 36 42				1,587,511 1,785,767 2,450,510	2,381,266 2,678,651 3,675,765	3,175,021 3,571,534 4,901,020
48 54 60				3,220,212 4,094,874 5,074,495	4,830,318 6,142,310 7,611,742	6,440,424 8,189,747 10,148,989
72 84 96				7,348,614 10,042,572 13,156,367	11,022,922 15,063,858 19,734,550	14,697,229 20,085,144 26,312,734

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0(**

2. **Table based on heavy weight steel pipe using steam equations in Par(**

250 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
Steam Condensate Flow lbs./h 0 psig Back Pressure						
1/2 3/4 1	14 34 71	20 48 100	28 68 142	65 108	Pressure with these	drop pipe
1- 1/4 1- 1/2 2	163 258 535	231 365 756	326 516 1,070	192 265 442	288 397 663	884
2- 1/2 3 4	889 1,652 3,549	1,258 2,336	with sizes	635 989 1,722	952 1,484 2,582	1,269 1,978 3,443
5 6 8	6,638	governs pipe		2,724 3,903 6,838	4,087 5,855 10,257	5,449 7,807 13,676
10 12 14	Velocity these			11,180 16,238 19,876	16,771 24,357 29,815	22,361 32,475 39,753
16 18 20				26,463 33,990 42,458	39,694 50,985 63,687	52,925 67,979 84,915
22 24 26				51,867 62,216 73,507	77,800 93,325 110,261	103,733 124,433 147,014
28 30 32				85,739 98,911 113,025	128,608 148,367 169,537	171,477 197,822 226,049
34 36				128,079 144,074	192,118 216,111	256,158 288,148

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
42				197,705	296,557	395,410
48 54 60				259,804 330,371 409,405	389,706 495,556 614,108	519,607 660,741 818,811
72 84 96				592,879 810,225 1,061,443	889,319 1,215,338 1,592,165	1,185,759 1,620,450 2,122,887
Steam Condensate Flow lbs./h 5 psig Back Pressure						
1/2 3/4 1	17 42 87	24 59 123	34 83 174	152	Pressure with these	drop pipe
1-1/4 1-1/2 2	200 317 657	283 448 929	401 634 1,313	270 372 622	559 934	1,245
2-1/2 3 4	1,092 2,028 4,357	1,544 2,868	2,184	893 1,392 2,423	1,340 2,088 3,635	1,787 2,784 4,846
5 6 8	8,148 13,247	governs pipe	with sizes	3,835 5,494 9,624	5,752 8,241 14,436	7,669 10,988 19,248
10 12 14	Velocity these			15,736 22,854 27,975	23,604 34,281 41,963	31,472 45,708 55,950
16 18 20				37,245 47,839 59,757	55,867 71,759 89,636	74,490 95,678 119,515
22 24 26				73,000 87,567 103,458	109,500 131,351 155,187	146,000 175,134 206,916
28 30 32				120,674 139,213 159,077	181,011 208,820 238,616	241,347 278,427 318,155

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
32				[illegible]	[illegible]	[illegible]
34 36 42				180,266 202,778 278,261	270,398 304,167 417,392	360,531 405,556 556,523
48 54 60				365,663 464,983 576,221	548,494 697,474 864,331	731,326 929,965 1,152,442
72 84 96				834,453 1,140,358 1,493,937	1,251,679 1,710,537 2,240,905	1,668,905 2,280,716 2,987,874
Steam Condensate Flow lbs./h 7 psig Back Pressure						
1/2 3/4 1	18 45 93	26 63 132	36 89 187	170	Pressure with these	drop pipe
1-1/4 1-1/2 2	215 340 705	304 481 996	430 680 1,409	304 418 699	627 1,048	1,397
2-1/2 3 4	1,172 2,176 4,675	1,657 3,077 6,612	2,343	1,003 1,563 2,720	1,504 2,344 4,081	2,006 3,126 5,441
5 6 8	8,744 14,216	governs pipe	with sizes	4,305 6,168 10,805	6,458 9,252 16,208	8,610 12,336 21,611
10 12 14	Velocity these			17,667 25,659 31,408	26,501 38,488 47,113	35,334 51,317 62,817
16 18 20				41,816 53,710 67,091	62,724 80,565 100,637	83,632 107,420 134,182
22 24 26				81,959 98,314 116,155	122,939 147,471 174,233	163,918 196,627 232,310

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
28 30 32				135,483 156,298 178,600	203,225 234,448 267,900	270,967 312,597 357,200
34 36 42				202,389 227,664 312,411	303,583 341,496 468,616	404,778 455,328 624,822
48 54 60				410,539 522,048 646,938	615,808 783,072 970,407	821,078 1,044,096 1,293,876
72 84 96				936,861 1,280,309 1,677,281	1,405,292 1,920,463 2,515,921	1,873,722 2,560,617 3,354,561
Steam Condensate Flow lbs./h 10 psig Back Pressure						
1/2 3/4 1	20 49 103	28 69 145	40 98 206	199	Pressure with these	drop pipe
1- 1/4 1- 1/2 2	237 374 776	335 529 1,097	473 748 1,551	355 489 817	734 1,226	
2- 1/2 3 4	1,290 2,395 5,146	1,824 3,387 7,277	2,579	1,173 1,828 3,182	1,759 2,742 4,773	2,346 3,656 6,364
5 6 8	9,624 15,647	governs pipe	with sizes	5,035 7,214 12,638	7,553 10,821 18,956	10,070 14,428 25,275
10 12 14	Velocity these			20,663 30,010 36,734	30,995 45,015 55,102	41,326 60,019 73,469
16 18 20				48,907 62,818 78,468	73,360 94,227 117,702	97,814 125,636 156,936
22				95,857	143,786	191,715

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
22 24 26				95,837 114,985 135,852	143,786 172,478 203,778	191,715 229,971 271,704
28 30 32				158,458 182,803 208,886	237,687 274,204 313,329	316,916 365,605 417,773
34 36 42				236,709 266,270 365,388	355,063 399,405 548,082	473,418 532,541 730,776
48 54 60				480,156 610,574 756,642	720,234 915,861 1,134,963	960,312 1,221,148 1,513,285
72 84 96				1,095,729 1,497,417 1,961,705	1,643,594 2,246,125 2,942,558	2,191,459 2,994,834 3,923,411
Steam Condensate Flow lbs./h 12 psig Back Pressure						
1/2 3/4 1	21 52 109	30 74 154	42 104 218		Pressure with these	drop pipe
1-1/4 1-1/2 2	251 397 823	355 561 1,163	502 794 1,645	391 538 899	1,349	
2-1/2 3 4	1,368 2,541 5,459	1,935 3,593 7,720	2,736	1,290 2,011 3,500	1,936 3,017 5,251	2,581 4,022 7,001
5 6 8	10,209 16,598	governs pipe	with sizes	5,539 7,936 13,903	8,309 11,905 20,855	11,079 15,873 27,806
10 12 14	Velocity these			22,732 33,015 40,413	34,098 49,522 60,619	45,464 66,029 80,825
16				53,804	80,706	107,608

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
18 20				69,108 86,325	103,662 129,488	138,216 172,651
22 24 26				105,456 126,499 149,455	158,183 189,748 224,183	210,911 252,998 298,910
28 30 32				174,324 201,107 229,802	261,487 301,660 344,703	348,649 402,214 459,604
34 36 42				260,411 292,932 401,974	390,616 439,398 602,962	520,821 585,864 803,949
48 54 60				528,234 671,711 832,405	792,351 1,007,566 1,248,608	1,056,468 1,343,422 1,664,810
72 84 96				1,205,445 1,647,354 2,158,131	1,808,167 2,471,031 3,237,197	2,410,890 3,294,707 4,316,263
Steam Condensate Flow lbs./h 15 psig Back Pressure						
1/2 3/4 1	23 57 118	33 80 167	46 113 237		Pressure with these	drop pipe
1- 1/4 1- 1/2 2	273 431 893	385 610 1,263	545 862 1,787	446 614 1,026	1,539	
2- 1/2 3 4	1,485 2,759 5,927	2,101 3,901 8,382	2,971 5,517	1,473 2,295 3,995	2,209 3,443 5,993	2,946 4,591 7,990
5 6 8	11,085 18,022 38,159	15,677	With Sizes	6,322 9,058 15,868	9,483 13,587 23,802	12,644 18,116 31,735
Notes: 10 12	Velocity these	governs pipe		25,944 37,680	38,917 56,520	51,889 75,360

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
14				46,123	69,185	92,247
16 18 20				61,407 78,874 98,524	92,110 118,311 147,786	122,814 157,748 197,048
22 24 26				120,358 144,375 170,575	180,536 216,562 255,862	240,715 288,749 341,150
28 30 32				198,959 229,526 262,276	298,438 344,288 393,414	397,917 459,051 524,552
34 36 42				297,210 334,327 458,778	445,815 501,490 688,167	594,419 668,654 917,557
48 54 60				602,880 766,632 950,034	904,320 1,149,948 1,425,051	1,205,760 1,533,264 1,900,068
72 84 96				1,375,789 1,880,145 2,463,102	2,063,684 2,820,217 3,694,653	2,751,578 3,760,290 4,926,203
Steam Condensate Flow lbs./h 20 psig Back Pressure						
1/2 3/4 1	26 64 134	37 91 190	52 128 268		Pressure with these	drop pipe
1- 1/4 1- 1/2 2	309 488 1,012	436 690 1,431	617 976 2,023	543 748 1,250	1,875	
2- 1/2 3 4	1,682 3,124 6,712	2,379 4,418 9,492	3,364 6,248	1,794 2,796 4,866	2,691 4,194 7,299	5,592 9,733
5 6 8	12,553 20,409 [illegible]	17,753	with sizes	7,701 11,033 [illegible]	11,551 16,550 [illegible]	15,402 22,066 [illegible]

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
8	43,215			19,328	28,992	38,656
10 12 14	Velocity these	governs pipe		31,602 45,897 56,181	47,403 68,845 84,272	63,204 91,793 112,362
16 18 20				74,798 96,073 120,008	112,196 144,110 180,013	149,595 192,146 240,017
22 24 26				146,603 175,857 207,771	219,905 263,786 311,656	293,206 351,715 415,542
28 30 32				242,344 279,576 319,468	363,516 419,365 479,203	484,688 559,153 638,937
34 36 42				362,020 407,231 558,821	543,030 610,846 838,231	724,040 814,462 1,117,641
48 54 60				734,345 933,805 1,157,201	1,101,518 1,400,708 1,735,801	1,468,691 1,867,611 2,314,401
72 84 96				1,675,797 2,290,134 3,000,211	2,513,695 3,435,200 4,500,317	3,351,593 4,580,267 6,000,423
Steam Condensate Flow lbs./h 25 psig Back Pressure						
1/2 3/4 1	29 72 150	41 101 212	58 143 300		Pressure with these	drop pipe
1-1/4 1-1/2 2	345 546 1,131	488 772 1,600	690 1,091 2,262	647 891 1,488	2,233	
2-1/2 3 4	1,881 3,493 7,505	2,660 4,940 10,614	3,762 6,987	2,136 3,330 5,795	3,205 4,994 8,693	6,659 11,591

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00**
2. **Table based on heavy weight steel pipe using steam equations in Part**

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
5 6 8	14,037 22,821 48,319	19,851 32,273	with sizes	9,171 13,140 23,018	13,757 19,709 34,527	18,342 26,279 46,036
10 12 14	92,633	governs pipe		37,635 54,659 66,907	56,453 81,989 100,361	75,271 109,318 133,815
16 18 20	Velocity these			89,078 114,415 142,920	133,617 171,623 214,380	178,155 228,831 285,841
22 24 26				174,592 209,432 247,438	261,889 314,147 371,157	349,185 418,863 494,876
28 30 32				288,612 332,953 380,461	432,918 499,429 570,691	577,224 665,906 760,922
34 36 42				431,136 484,979 665,510	646,704 727,468 998,264	862,272 969,958 1,331,019
48 54 60				874,545 1,112,086 1,378,132	1,311,818 1,668,129 2,067,197	1,749,091 2,224,172 2,756,263
72 84 96				1,995,737 2,727,362 3,573,007	2,993,606 4,091,043 5,359,510	3,991,474 5,454,725 7,146,014
Steam Condensate Flow lbs./h 30 psig Back Pressure						
1/2 3/4 1	32 79 166	46 112 235	65 159 332		Pressure with these	drop pipe
1-1/4 1-1/2 2	382 605 1,253	541 855 1,772	765 1,209 2,506	757 1,043 1,743		
Notes: 2- 1/2	2,084 [illegible]	2,947 [illegible]	4,167 [illegible]	2,502 [illegible]	3,753 [illegible]	13,574

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1/2	3,870	5,472	7,739	3,899	5,849	
3	8,313	11,757	16,627	6,787	10,180	
4						
5	15,549	21,989	with	10,740	16,110	21,480
6	25,279	35,749	sizes	15,388	23,082	30,775
8	53,524			26,956	40,434	53,912
10	102,611	governs		44,075	66,112	88,149
12	167,486	pipe		64,011	96,017	128,022
14				78,355	117,532	156,710
16	Velocity			104,319	156,478	208,637
18	these			133,991	200,987	267,983
20				167,373	251,060	334,747
22				204,464	306,697	408,929
24				245,265	367,897	490,529
26				289,774	434,661	579,548
28				337,992	506,988	675,984
30				389,920	584,879	779,839
32				445,556	668,334	891,112
34				504,902	757,353	1,009,804
36				567,957	851,935	1,135,913
42				779,375	1,169,063	1,558,751
48				1,024,176	1,536,265	2,048,353
54				1,302,359	1,953,539	2,604,718
60				1,613,924	2,420,886	3,227,848
72				2,337,199	3,505,799	4,674,398
84				3,194,002	4,791,003	6,388,004
96				4,184,333	6,276,499	8,368,666
Steam Condensate Flow lbs./h 40 psig Back Pressure						
1/2	39	55	78		Pressure	drop pipe
3/4	95	135	190		with these	
1	199	282	399			
1-	459	649	918	1,375		
1/4	726	1,026	1,451	2,298		
1-	1,504	2,127	3,008			
1/2						

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

2. Table based on heavy weight steel pipe using steam equations in Part

2 **Pipe Size**	**Pressure Drop psig/100 ft.**				**Velocity FPM (mph)**	
	0.125	**0.25**	**0.5**	**2,000 (23)**	**3,000 (34)**	**4,000 (45)**
2- 1/2 3 4	2,501 4,645 9,979	3,537 6,569 14,113	5,002 9,290 19,958	3,299 5,141 8,949	4,948 7,712 13,423	17,897
5 6 8	18,664 30,344 64,249	26,395 42,913	with sizes	14,161 20,289 35,543	21,242 30,434 53,314	28,323 40,579 71,086
10 12 14	123,172 201,047	governs pipe		58,114 84,401 103,314	87,171 126,601 154,971	116,228 168,802 206,628
16 18 20	Velocity these			137,548 176,673 220,688	206,322 265,009 331,032	275,096 353,346 441,376
22 24 26				269,594 323,391 382,078	404,391 485,086 573,117	539,188 646,781 764,156
28 30 32				445,656 514,124 587,483	668,483 771,186 881,224	891,311 1,028,248 1,174,966
34 36 42				665,732 748,873 1,027,637	998,599 1,123,309 1,541,455	1,331,465 1,497,745 2,055,273
48 54 60				1,350,416 1,717,211 2,128,021	2,025,624 2,575,816 3,192,031	2,700,832 3,434,421 4,256,041
72 84 96				3,081,687 4,211,415 5,517,204	4,622,530 6,317,122 8,275,806	6,163,374 8,422,829 11,034,407
Steam Condensate Flow lbs./h 50 psig Back Pressure						
1/2 3/4 1	46 112 235	65 159 333	92 225 470		Pressure with these	drop pipe
1-	541	766	1,083	2,937		

Notes:

Pipe Size	Pressure Drop psig/100 ft.				Velocity FPM (mph)	
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1/4 1-1/2 2	856 1,774	1,211 2,509	1,712 3,549			
2-1/2 3 4	2,951 5,480 11,773	4,173 7,750 16,650	5,901 10,960 23,547	4,215 6,570 11,435	9,854 17,152	22,870
5 6 8	22,020 35,800 75,801	31,141 50,629 107,199	44,040	18,095 25,926 45,417	27,143 38,889 68,125	36,191 51,852 90,834
10 12 14	145,319 237,196 308,904			74,259 107,849 132,016	111,388 161,773 198,023	148,518 215,697 264,031
16 18 20				175,760 225,754 281,998	263,641 338,632 422,997	351,521 451,509 563,996
22 24 26	Velocity these	governs pipe	with sizes	344,490 413,232 488,223	516,736 619,848 732,335	688,981 826,464 976,447
28 30 32				569,464 656,953 750,692	854,195 985,430 1,126,038	1,138,927 1,313,907 1,501,384
34 36 42				850,680 956,918 1,313,125	1,276,020 1,435,377 1,969,688	1,701,361 1,913,835 2,626,251
48 54 60				1,725,576 2,194,271 2,719,209	2,588,365 3,291,406 4,078,813	3,451,153 4,388,542 5,438,417
72 84 96				3,937,814 5,381,393 7,049,945	5,906,721 8,072,089 10,574,917	7,875,628 10,762,785 14,099,889
Steam Condensate Flow lbs./h 60 psig Back Pressure						
Notes: 1/2 3/4	53 131	75 185	106 261		Pressure with these	drop pipe

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1	273	387	547			
1-1/4	629	890	1,259	3,653		
1-1/2	[illegible]	[illegible]	[illegible]			
2	2,063	2,917	4,125			
2-1/2	3,430	4,850	6,859	5,243	12,256	
3	6,370	9,008	12,739	8,170	21,332	
4	13,685	19,353	27,369	14,221		
5	25,595	36,196	51,189	22,505	33,757	45,010
6	41,611	58,847		32,243	48,365	64,487
8	88,105	124,600		56,484	84,726	112,968
10	168,908	governs	with	92,353	138,530	184,707
12	275,699	pipe	sizes	134,128	201,192	268,256
14	359,048			164,184	246,276	328,368
16	521,067			218,588	327,882	437,176
18				280,764	421,146	561,528
20				350,712	526,069	701,425
22	Velocity			428,433	642,649	856,865
24	these			513,925	770,887	1,027,850
26				607,189	910,783	1,214,378
28				708,225	1,062,338	1,416,450
30				817,034	1,225,550	1,634,067
32				933,614	1,400,421	1,867,228
34				1,057,966	1,586,949	2,115,932
36				1,190,090	1,785,136	2,380,181
42				1,633,096	2,449,643	3,266,191
48				2,146,049	3,219,073	4,292,098
54				2,728,950	4,093,425	5,457,900
60				3,381,800	5,072,700	6,763,600
72				4,897,343	7,346,015	9,794,687
84				6,692,680	10,039,020	13,385,360
96				8,767,809	13,151,713	17,535,618

Notes: Condensate Flow lbs./h 75 psig Back Pressure

Steam Condensate Flow lbs./h 75 psig Back Pressure

Pipe Size	**Pressure Drop psig/100 ft.**			**Velocity FPM (mph)**		
	0.125	**0.25**	**0.5**	**2,000 (23)**	**3,000 (34)**	**4,000 (45)**
1/2 3/4 1	66 161 338	93 228 477	131 322 675		Pressure with these	drop pipe
1-1/4 1-1/2 2	777 1,229 2,546	1,099 1,737 3,601	1,554 2,457 5,093	4,916		
2-1/2 3 4	4,234 7,864 16,895	5,988 11,121 23,893	8,468 15,727 33,789	7,056 10,996 19,140	28,710	
5 6 8	31,598 51,372 108,772	44,687 72,650 153,827	63,196 102,743	30,289 43,395 76,020	45,433 65,093 114,030	60,577 86,791 152,040
10 12 14	208,528 340,369 443,268	294,903	with sizes	124,296 180,519 220,970	186,444 270,779 331,455	248,592 361,038 441,941
16 18 20	643,292 889,824	governs pipe		294,191 377,872 472,014	441,287 566,808 708,020	588,382 755,745 944,027
22 24 26	Velocity these			576,615 691,676 817,198	864,922 1,037,514 1,225,797	1,153,230 1,383,353 1,634,396
28 30 32				953,180 1,099,622 1,256,524	1,429,769 1,649,432 1,884,785	1,906,359 2,199,243 2,513,047
34 36 42				1,423,886 1,601,708 2,197,935	2,135,828 2,402,562 3,296,903	2,847,771 3,203,416 4,395,871
48 54 60				2,888,304 3,672,814 4,551,465	4,332,456 5,509,221 6,827,198	5,776,609 7,345,629 9,102,931
72 ***Notes:***				6,591,191	9,886,787	13,182,383

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
84				9,007,482	13,511,223	18,014,964
96				11,800,338	17,700,507	23,600,676

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0**
2. **Table based on heavy weight steel pipe using steam equations in Par**

275 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	**0.25**	**0.5**	**2,000 (23)**	**3,000 (34)**	**4,000 (45)**
Steam Condensate Flow lbs./h 0 psig Back Pressure						
1/2	13	19	26	62	Pressure	drop pipe
3/4	32	46	65	103	with these	
1	68	96	136			
1-1/4	156	221	313	184	276	847
1-1/2	247	350	494	253	380	
2	512	724	1,025	423	635	
2-1/2	852	1,205	with	608	912	1,216
3	1,582	2,237	sizes	947	1,421	1,895
4	3,399			1,649	2,473	3,298
5	6,357	governs		2,609	3,914	5,218
6		pipe		3,738	5,607	7,477
8				6,549	9,823	13,098
10	Velocity			10,708	16,061	21,415
12	these			15,551	23,326	31,102
14				19,036	28,553	38,071
16				25,343	38,015	50,686
18				32,552	48,828	65,104
20				40,662	60,993	81,324

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0**

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)
22 24 26				49,673 59,585 70,398	74,509 89,377 105,597	99,345 119,169 140,796
28 30 32				82,112 94,727 108,244	123,168 142,091 162,365	164,224 189,454 216,487
34 36 42				122,661 137,980 189,342	183,992 206,969 284,013	245,322 275,959 378,684
48 54 60				248,814 316,396 392,087	373,221 474,594 588,131	497,628 632,791 784,175
72 84 96				567,800 775,952 1,016,544	851,700 1,163,929 1,524,816	1,135,601 1,551,905 2,033,088
Steam Condensate Flow lbs./h 5 psig Back Pressure						
1/2 3/4 1	16 40 83	23 56 117	32 79 166	145	Pressure with these	drop pipe
1-1/4 1-1/2 2	191 302 627	270 428 886	382 605 1,253	258 355 594	533 891	1,188
2-1/2 3 4	1,042 1,935 4,158	1,474 2,737	2,084	853 1,329 2,313	1,279 1,993 3,469	1,705 2,657 4,625
5 6 8	7,777 12,643	governs pipe	with sizes	3,660 5,243 9,185	5,490 7,865 13,778	7,319 10,487 18,371
10 12 14	Velocity these			15,019 21,812 26,700	22,528 32,718 40,049	30,037 43,624 53,399
[illegible]				[illegible]	[illegible]	[illegible]

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
16				35,547	53,320	71,094
18				45,658	68,487	91,316
20				57,033	85,549	114,066
22				69,672	104,508	139,343
24				83,574	125,362	167,149
26				98,741	148,112	197,482
28				115,172	172,757	230,343
30				132,866	199,299	265,732
32				151,824	227,737	303,649
34				172,047	258,070	344,093
36				193,533	290,299	387,065
42				265,574	398,361	531,148
48				348,991	523,486	697,981
54				443,782	665,673	887,564
60				549,949	824,923	1,099,897
72				796,406	1,194,610	1,592,813
84				1,088,364	1,632,546	2,176,728
96				1,425,822	2,138,733	2,851,644
Steam Condensate Flow lbs./h 7 psig Back Pressure						
1/2	17	25	35	162	Pressure	drop pipe
3/4	43	60	85		with these	
1	89	126	178			
1-1/4	205	290	410	289	598	1,332
1-1/2	324	458	648	399	999	
2	672	950	1,343	666		
2-1/2	1,117	1,579	2,234	956	1,434	1,912
3	2,074	2,933		1,490	2,235	2,979
4	4,456	6,302		2,593	3,889	5,186
5	8,334			4,103	6,155	8,207
6	13,550			5,879	8,819	11,758
8				10,299	15,448	20,598
10				16,839	25,259	33,678

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
12 14				24,456 29,936	36,684 44,905	48,912 59,873
16 18 20	Velocity these	governs pipe	with sizes	39,856 51,193 63,947	59,784 76,789 95,920	79,712 102,386 127,894
22 24 26				78,118 93,706 110,711	117,177 140,559 166,067	156,236 187,412 221,423
28 30 32				129,134 148,973 170,230	193,701 223,460 255,345	258,267 297,946 340,460
34 36 42				192,903 216,994 297,769	289,355 325,491 446,654	385,807 433,988 595,538
48 54 60				391,298 497,581 616,618	586,947 746,372 924,927	782,596 995,162 1,233,236
72 84 96				892,953 1,220,305 1,598,672	1,339,430 1,830,457 2,398,008	1,785,907 2,440,610 3,197,344
Steam Condensate Flow lbs./h 10 psig Back Pressure						
1/2 3/4 1	19 47 98	27 66 138	38 93 196	189	Pressure with these	drop pipe
1-1/4 1-1/2 2	225 356 738	318 503 1,043	450 712 1,476	338 465 777	698 1,166	
2-1/2 3 4	1,227 2,279 4,895	1,735 3,222 6,923	2,454	1,116 1,739 3,027	1,674 2,609 4,540	2,232 3,478 6,054
5 6	9,156 14,885	governs pipe	with sizes	4,790 6,863	7,185 10,294	9,580 13,726

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
8				12,022	18,034	24,045
10	Velocity			19,657	29,486	39,314
12	these			28,549	42,823	57,097
14				34,946	52,419	69,892
16				46,526	69,788	93,051
18				59,760	89,639	119,519
20				74,648	111,972	149,296
22				91,190	136,785	182,381
24				109,387	164,080	218,774
26				129,238	193,857	258,476
28				150,743	226,115	301,486
30				173,903	260,854	347,805
32				198,716	298,074	397,432
34				225,184	337,776	450,368
36				253,306	379,960	506,613
42				347,598	521,397	695,197
48				456,779	685,168	913,557
54				580,847	871,270	1,161,694
60				719,804	1,079,705	1,439,607
72				1,042,381	1,563,572	2,084,763
84				1,424,512	2,136,768	2,849,024
96				1,866,196	2,799,293	3,732,391
Steam Condensate Flow lbs./h 12 psig Back Pressure						
1/2	20	29	40		Pressure	drop pipe
3/4	49	70	99		with these	
1	104	147	207			
1-1/4	238	337	477	371	1,281	
1-1/2	377	533	754	511		
2	782	1,105	1,563	854		
2-1/2	1,300	1,838	2,600	1,226	1,839	2,452
3	2,414	3,414		1,911	2,866	3,821
4	5,186	7,335		3,326	4,989	6,652

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
4 5 6 8	9,700 15,770	governs pipe	with sizes	5,263 7,541 13,209	7,895 11,311 19,814	10,526 15,081 26,419
10 12 14	Velocity these			21,598 31,368 38,397	32,397 47,051 57,595	43,196 62,735 76,793
16 18 20				51,120 65,660 82,019	76,680 98,491 123,028	102,239 131,321 164,037
22 24 26				100,195 120,188 141,999	150,292 180,282 212,999	200,389 240,376 283,998
28 30 32				165,628 191,074 218,338	248,442 286,611 327,507	331,255 382,148 436,676
34 36 42				247,419 278,318 381,921	371,129 417,477 572,881	494,838 556,636 763,841
48 54 60				501,882 638,201 790,878	752,822 957,301 1,186,317	1,003,763 1,276,401 1,581,756
72 84 96				1,145,308 1,565,171 2,050,467	1,717,962 2,347,756 3,075,700	2,290,616 3,130,341 4,100,934
Steam Condensate Flow lbs./h 15 psig Back Pressure						
1/2 3/4 1	22 54 112	31 76 159	44 107 225		Pressure with these	drop pipe
1-1/4 1-1/2 2	258 409 847	366 578 1,198	517 817 1,694	423 582 973	1,460	
1	1,409	1,992	2,817	1,397	2,095	2,793

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	**0.25**	**0.5**	**2,000 (23)**	**3,000 (34)**	**4,000 (45**
2-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1/2	2,616	3,700	5,232	2,177	3,265	4,353
3	5,621	7,949		3,789	5,683	7,577
4						
5	10,513	14,867	with	5,996	8,993	11,991
6	17,091		sizes	8,590	12,885	17,180
8	36,188			15,048	22,572	30,096
10	Velocity	governs		24,604	36,906	49,209
12	these	pipe		35,734	53,601	71,467
14				43,741	65,611	87,482
16				58,235	87,353	116,470
18				74,800	112,200	149,599
20				93,435	140,152	186,870
22				114,141	171,211	228,281
24				136,917	205,376	273,834
26				161,764	242,646	323,528
28				188,682	283,022	377,363
30				217,670	326,504	435,339
32				248,728	373,093	497,457
34				281,858	422,786	563,715
36				317,057	475,586	634,115
42				435,081	652,621	870,161
48				571,739	857,608	1,143,478
54				727,032	1,090,548	1,454,064
60				900,961	1,351,441	1,801,922
72				1,304,724	1,957,086	2,609,448
84				1,783,028	2,674,542	3,566,055
96				2,335,872	3,503,809	4,671,745
Steam Condensate Flow lbs./h 20 psig Back Pressure						
1/2	25	35	49		Pressure	drop pipe
3/4	61	86	121		with these	
1	127	179	254			
1-	292	413	584	513	1,772	
1/4	461	653	923	707		
1-	956	1,353	1,913	1,182		

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

1/2 Pipe 2 Size	Pressure Drop psig/100 ft.				Velocity FPM (mph)	
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
2- 1/2 3 4	1,590 2,954 6,346	2,249 4,177 8,974	3,181 5,907	1,696 2,643 4,601	2,544 3,965 6,901	5,286 9,201
5 6 8	11,868 19,295 40,855	16,784	with sizes	7,281 10,431 18,273	10,921 15,647 27,410	14,561 20,862 36,546
10 12 14	Velocity these	governs pipe		29,878 43,392 53,116	44,816 65,088 79,673	59,755 86,784 106,231
16 18 20				70,716 90,831 113,460	106,074 136,246 170,190	141,432 181,661 226,920
22 24 26				138,603 166,261 196,433	207,905 249,392 294,650	277,207 332,522 392,867
28 30 32				229,120 264,321 302,036	343,680 396,481 453,054	458,240 528,641 604,072
34 36 42				342,265 385,009 528,327	513,398 577,514 792,490	684,531 770,018 1,056,654
48 54 60				694,274 882,850 1,094,055	1,041,411 1,324,275 1,641,082	1,388,548 1,765,699 2,188,110
72 84 96				1,584,352 2,165,166 2,836,497	2,376,528 3,247,749 4,254,745	3,168,704 4,330,332 5,672,993
Steam Condensate Flow lbs./h 25 psig Back Pressure						
1/2 3/4 1	28 67 141	39 95 200	55 135 283		Pressure with these	drop pipe
Notes:	325	460	651	609	2,104	

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1- 1/4 1- 1/2 2	325 514 1,066	460 727 1,508	651 1,029 2,132	609 840 1,403	2,104	
2- 1/2 3 4	1,773 3,293 7,074	2,507 4,656 10,004	3,546 6,585	2,014 3,138 5,462	3,020 4,707 8,193	6,276 10,925
5 6 8	13,230 21,509 45,543	18,710 30,419	with sizes	8,644 12,385 21,695	12,966 18,577 32,543	17,288 24,769 43,391
10 12 14	87,311	governs pipe		35,473 51,519 63,063	53,209 77,278 94,595	70,946 103,037 126,126
16 18 20	Velocity these			83,960 107,842 134,709	125,939 161,762 202,063	167,919 215,683 269,417
22 24 26				164,561 197,398 233,221	246,841 296,098 349,832	329,122 394,797 466,442
28 30 32				272,029 313,823 358,601	408,044 470,734 537,901	544,059 627,645 717,202
34 36 42				406,365 457,114 627,272	609,547 685,670 940,908	812,729 914,227 1,254,544
48 54 60				824,297 1,048,190 1,298,949	1,236,446 1,572,284 1,948,424	1,648,594 2,096,379 2,597,898
72 84 96				1,881,069 2,570,658 3,367,715	2,821,604 3,855,987 5,051,572	3,762,138 5,141,316 6,735,429
Steam Condensate Flow lbs./h 30 psig Back Pressure						
1/2 ***Notes:***	30	43	61		Pressure	drop pipe

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45
3/4 1	75 156	105 221	149 312		with these	
1-1/4 1-1/2 2	350 568 1,177	508 803 1,665	718 1,136 2,355	712 980 1,638		
2-1/2 3 4	1,958 3,636 7,812	2,769 5,142 11,047	3,916 7,272 15,623	2,351 3,664 6,377	3,526 5,496 9,566	12,755
5 6 8	14,610 23,753 50,294	20,662 33,592	with sizes	10,092 14,459 25,330	15,138 21,689 37,995	20,184 28,919 50,659
10 12 14	96,419	governs pipe		41,415 60,149 73,627	62,123 90,223 110,440	82,830 120,297 147,254
16 18 20	Velocity these			98,024 125,906 157,274	147,036 188,860 235,911	196,048 251,813 314,548
22 24 26				192,127 230,465 272,289	288,191 345,698 408,434	384,254 460,931 544,578
28 30 32				317,598 366,392 418,672	476,397 549,588 628,008	635,196 732,784 837,343
34 36 42				474,437 533,687 732,349	711,655 800,530 1,098,523	948,873 1,067,373 1,464,698
48 54 60				962,379 1,223,776 1,516,541	1,443,568 1,835,664 2,274,812	1,924,757 2,447,552 3,033,083
72 84 96				2,196,175 3,001,279 3,931,855	3,294,262 4,501,919 5,897,782	4,392,350 6,002,559 7,863,709

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Steam Condensate Flow lbs./h 40 psig Back Pressure

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	**0.25**	**0.5**	**2,000 (23)**	**3,000 (34)**	**4,000 (45)**
1/2 3/4 1	36 89 186	51 126 263	72 178 372		Pressure with these	drop pipe
1-1/4 1-1/2 2	429 678 1,405	606 958 1,986	857 1,355 2,809	1,284 2,146		
2-1/2 3 4	2,336 4,338 9,319	3,303 6,134 13,179	4,671 8,675 18,638	3,081 4,801 8,357	4,621 7,202 12,535	16,713
5 6 8	17,429 28,336 59,997	24,649 40,073		13,224 18,947 33,191	19,836 28,420 49,786	26,448 37,894 66,382
10 12 14	115,022 187,744			54,269 78,816 96,477	81,403 118,224 144,716	108,537 157,632 192,955
16 18 20	Velocity these	governs pipe	with sizes	128,446 164,982 206,085	192,669 247,473 309,127	256,893 329,964 412,170
22 24 26				251,755 301,992 356,795	377,632 452,987 535,193	503,510 603,983 713,591
28 30 32				416,166 480,104 548,609	624,249 720,156 822,913	832,332 960,208 1,097,217
34 36 42				621,680 699,319 959,637	932,520 1,048,978 1,439,455	1,243,360 1,398,638 1,919,274
48 54 60				1,261,057 1,603,581 1,987,207	1,891,586 2,405,372 2,980,811	2,522,115 3,207,162 3,974,415
72				2,877,769	4,316,653	5,755,537

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
72 84 96				2,877,769 3,932,741 5,152,125	4,316,653 5,899,112 7,728,187	5,755,537 7,865,482 10,304,250
Steam Condensate Flow lbs./h 50 psig Back Pressure						
1/2 3/4 1	42 104 218	60 147 309	85 208 436		Pressure with these	drop pipe
1- 1/4 1- 1/2 2	502 794 1,646	710 1,123 2,328	1,005 1,589 3,293	2,725		
2- 1/2 3 4	2,738 5,084 10,923	3,871 7,190 15,447	5,475 10,168 21,846	3,911 6,095 10,609	9,142 15,913	21,217
5 6 8	20,429 33,214 70,325	28,892 46,971 99,455	40,859	16,788 24,053 42,136	25,182 36,080 63,204	33,577 48,106 84,272
10 12 14	134,821 220,061 286,589	governs pipe	with sizes	68,894 100,058 122,479	103,341 150,086 183,718	137,789 200,115 244,957
16 18 20	Velocity these			163,063 209,446 261,626	244,595 314,169 392,439	326,127 418,892 523,252
22 24 26				319,604 383,380 452,954	479,406 575,070 679,431	639,209 766,760 905,908
28 30 32				528,325 609,495 696,462	792,488 914,242 1,044,693	1,056,651 1,218,990 1,392,924
34 36 42				789,227 887,790 1,218,265	1,183,840 1,331,685 1,827,397	1,578,454 1,775,579 2,436,530
48				1,600,920	2,401,381	3,201,841

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
54 60				2,035,756 2,522,772	3,053,634 3,784,158	4,071,512 5,045,544
72 84 96				3,653,345 4,992,639 6,540,655	5,480,018 7,488,959 9,810,982	7,306,690 9,985,279 13,081,309
Steam Condensate Flow lbs./h 60 psig Back Pressure						
1/2 3/4 1	49 120 252	69 170 356	98 241 504		Pressure with these	drop pipe
1-1/4 1-1/2 2	580 917 1,900	820 1,297 2,688	1,160 1,834 3,801	3,366		
2-1/2 3 4	3,160 5,869 12,610	4,469 8,300 17,833	6,321 11,739 25,219	4,831 7,529 13,104	11,293 19,656	
5 6 8	23,584 38,342 81,185	33,353 54,224 114,812	47,168	20,737 29,711 52,047	31,106 44,566 78,070	41,474 59,421 104,094
10 12 14	155,640 254,042 330,844	governs pipe	with sizes	85,099 123,592 151,287	127,648 185,388 226,930	170,198 247,184 302,574
16 18 20	480,136			201,417 258,709 323,163	302,126 388,064 484,745	402,835 517,419 646,326
22 24 26	Velocity these			394,778 473,555 559,493	592,167 710,332 839,239	789,556 947,109 1,118,986
28 30 32				652,592 752,853 860,276	978,889 1,129,280 1,290,414	1,305,185 1,505,707 1,720,552
34 36				974,860 1,096,606	1,462,290 1,644,909	1,949,720 2,193,212

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
42				1,504,812	2,257,218	3,009,623
48 54 60				1,977,471 2,514,584 3,116,151	2,966,207 3,771,876 4,674,226	3,954,942 5,029,169 6,232,302
72 84 96				4,512,645 6,166,953 8,079,076	6,768,967 9,250,430 12,118,613	9,025,290 12,333,906 16,158,151
Steam Condensate Flow lbs./h 75 psig Back Pressure						
1/2 3/4 1	60 147 308	85 208 435	120 294 615		Pressure with these	drop pipe
1-1/4 1-1/2 2	708 1,119 2,320	1,001 1,583 3,281	1,416 2,239 4,640	4,479		
2-1/2 3 4	3,858 7,165 15,392	5,456 10,132 21,768	7,715 14,329 30,785	6,428 10,019 17,438	26,157	
5 6 8	28,789 46,804 99,101	40,714 66,191 140,150	57,578 93,608	27,596 39,537 69,261	41,393 59,306 103,891	55,191 79,074 138,522
10 12 14	189,987 310,107 403,857	268,683	with sizes	113,245 164,469 201,324	169,867 246,703 301,985	226,489 328,938 402,647
16 18 20	586,096 810,709	governs pipe		268,034 344,275 430,046	402,052 516,413 645,069	536,069 688,551 860,093
22 24 26	Velocity these			525,347 630,179 744,540	788,021 945,268 1,116,810	1,050,695 1,260,357 1,489,080
28 30				868,431 1,001,853	1,302,647 1,502,779	1,736,863 2,003,706

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45
32				1,144,805	1,717,207	2,289,609
34 36 42				1,297,286 1,459,298 2,002,515	1,945,930 2,188,947 3,003,772	2,594,573 2,918,597 4,005,029
48 54 60				2,631,502 3,346,260 4,146,790	3,947,253 5,019,391 6,220,185	5,263,004 6,692,521 8,293,579
72 84 96				6,005,161 8,206,617 10,751,157	9,007,742 12,309,926 16,126,735	12,010,323 16,413,234 21,502,314
Steam Condensate Flow lbs./h 85 psig Back Pressure						
1/2 3/4 1	68 166 349	96 235 493	136 333 697		Pressure with these	drop pipe
1- 1/4 1- 1/2 2	802 1,269 2,630	1,135 1,795 3,720	1,605 2,538 5,260			
2- 1/2 3 4	4,374 8,123 17,451	6,185 11,487 24,680	8,747 16,246 34,902	7,661 11,940 20,782	31,174	
5 6 8	32,639 53,064 112,355	46,159 75,044 158,894	65,278 106,128	32,888 47,120 82,544	49,332 70,680 123,817	94,240 165,089
10 12 14	215,397 351,582 457,871	304,618	with sizes	134,964 196,012 239,935	202,446 294,019 359,903	269,927 392,025 479,871
16 18 20	664,484 919,137 1,225,107	governs pipe		319,441 410,304 512,525	479,161 615,456 768,787	638,881 820,608 1,025,050
22 24 26	Velocity these			626,104 751,041 887,335	939,156 1,126,561 1,331,003	1,252,207 1,502,081 1,774,670

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)
28 30 32				1,034,988 1,193,998 1,364,367	1,552,482 1,790,997 2,046,550	2,069,976 2,387,997 2,728,733
34 36 42				1,546,093 1,739,177 2,386,577	2,319,139 2,608,766 3,579,865	3,092,186 3,478,354 4,773,154
48 54 60				3,136,198 3,988,039 4,942,102	4,704,296 5,982,059 7,413,153	6,272,395 7,976,079 9,884,205
72 84 96				7,156,891 9,780,564 12,813,121	10,735,337 14,670,846 19,219,681	14,313,782 19,561,128 25,626,242

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00**
2. **Table based on heavy weight steel pipe using steam equations in Part**

300 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)
Steam Condensate Flow lbs./h 0 psig Back Pressure						
1/2 3/4 1	13 31 65	18 44 92	25 62 131	60 99	Pressure with these	drop pipe
1-1/4 1-1/2 2	150 238 493	213 336 697	301 476 986	177 244 407	265 366 611	815
2-1/2 3	819 1,522 3,270	1,159 2,152		585 911 1,586	877 1,367 2,379	1,170 1,823 3,172

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00**

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
3	3,270			1,586	2,379	3,172
4						
5	6,116			2,510	3,765	5,020
6				3,596	5,395	7,193
8				6,300	9,450	12,600
10				10,301	15,452	20,602
12				14,961	22,441	29,921
14				18,313	27,470	36,626
16	Velocity	governs	with	24,381	36,572	48,763
18	these	pipe	sizes	31,317	46,975	62,633
20				39,119	58,678	78,237
22				47,788	71,681	95,575
24				57,323	85,985	114,647
26				67,726	101,589	135,452
28				78,996	118,494	157,991
30				91,132	136,698	182,264
32				104,136	156,203	208,271
34				118,006	177,009	236,012
36				132,743	199,115	265,486
42				182,156	273,234	364,312
48				239,371	359,057	478,742
54				304,388	456,582	608,776
60				377,207	565,811	754,414
72				546,251	819,377	1,092,503
84				746,504	1,119,756	1,493,008
96				977,964	1,466,947	1,955,929
Steam Condensate Flow lbs./h 5 psig Back Pressure						
1/2	16	22	31	139	Pressure	drop pipe
3/4	38	54	76		with these	
1	80	113	159			
1-1/4	183	259	367	248	511	1,140
1-1/2	290	410	580	341	855	
2	601	850	1,202	570		

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

2. Table based on heavy weight steel pipe using steam equations in Par

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
2- 1/2 3 4	1,000 1,856 3,988	1,414 2,625	1,999	818 1,274 2,218	1,227 1,912 3,327	1,636 2,549 4,437
5 6 8	7,459 12,127	governs pipe	with sizes	3,510 5,030 8,811	5,266 7,544 13,216	7,021 10,059 17,622
10 12 14	Velocity these			14,406 20,922 25,611	21,609 31,383 38,416	28,812 41,845 51,221
16 18 20				34,097 43,796 54,707	51,145 65,694 82,060	68,194 87,591 109,413
22 24 26				66,830 80,166 94,714	100,245 120,249 142,071	133,660 160,332 189,428
28 30 32				110,474 127,447 145,632	165,711 191,170 218,448	220,948 254,894 291,264
34 36 42				165,029 185,639 254,742	247,544 278,459 382,114	330,059 371,278 509,485
48 54 60				334,757 425,682 527,518	502,135 638,523 791,277	669,513 851,364 1,055,037
72 84 96				763,924 1,043,974 1,367,668	1,145,886 1,565,961 2,051,502	1,527,848 2,087,948 2,735,336
Steam Condensate Flow lbs./h 7 psig Back Pressure						
1/2 3/4 1	17 41 85	23 58 121	33 81 171	155	Pressure with these	drop pipe
1- 1/4	196 310	278 439	393 621	277 382	573 957	1,276

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,0

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1- 1/2 2	643	910	1,287	638		
2- 1/2 3 4	1,070 1,987 4,269	1,513 2,810 6,038	2,140	916 1,427 2,484	1,374 2,141 3,727	1,832 2,855 4,969
5 6 8	7,985 12,982	governs pipe	with sizes	3,932 5,633 9,868	5,897 8,449 14,801	7,863 11,266 19,735
10 12 14	Velocity these			16,134 23,432 28,683	24,201 35,148 43,024	32,268 46,864 57,365
16 18 20				38,187 49,049 61,269	57,281 73,574 91,903	76,374 98,098 122,538
22 24 26				74,847 89,782 106,075	112,270 134,673 159,113	149,693 179,564 212,150
28 30 32				123,726 142,735 163,101	185,589 214,102 244,652	247,452 285,469 326,202
34 36 42				184,825 207,907 285,300	277,238 311,861 427,949	369,651 415,814 570,599
48 54 60				374,912 476,744 590,796	562,368 715,116 886,194	749,824 953,488 1,181,592
72 84 96				855,559 1,169,202 1,531,724	1,283,339 1,753,803 2,297,587	1,711,119 2,338,404 3,063,449
Steam Condensate Flow lbs./h 10 psig Back Pressure						
1/2 3/4 1	18 45 94	26 63 132	36 89 187	181	Pressure with these	drop pipe

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1 1/4 1- 1/2 2	215 341 706	305 482 998	431 681 1,412	323 445 744	668 1,116	
2- 1/2 3 4	1,174 2,180 4,683	1,660 3,082 6,622	2,347	1,067 1,663 2,895	1,601 2,495 4,343	2,135 3,327 5,791
5 6 8	8,758 14,239	governs pipe	with sizes	4,582 6,565 11,500	6,873 9,847 17,250	9,164 13,130 23,000
10 12 14	Velocity these			18,803 27,309 33,428	28,205 40,963 50,142	37,607 54,617 66,856
16 18 20				44,505 57,164 71,406	66,757 85,746 107,108	89,010 114,328 142,811
22 24 26				87,230 104,636 123,625	130,844 156,954 185,437	174,459 209,272 247,250
28 30 32				144,196 166,349 190,085	216,294 249,524 285,128	288,392 332,699 380,171
34 36 42				215,404 242,305 332,501	323,106 363,457 498,752	430,808 484,609 665,002
48 54 60				436,939 555,619 688,540	655,409 833,429 1,032,811	873,879 1,111,238 1,377,081
72 84 96				997,108 1,362,642 1,785,142	1,495,662 2,043,962 2,677,712	1,994,216 2,725,283 3,570,283
Steam Condensate Flow lbs./h 12 psig Back Pressure						

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45
1/2 3/4 1	19 47 99	27 67 140	39 95 198		Pressure with these	drop pipe
1-1/4 1-1/2 2	228 360 747	322 510 1,056	456 721 1,494	355 488 816	1,224	
2-1/2 3 4	1,242 2,307 4,956	1,756 3,262 7,008	2,484	1,172 1,826 3,178	1,757 2,739 4,767	2,343 3,652 6,356
5 6 8	9,269 15,069			5,029 7,205 12,622	7,544 10,808 18,933	10,058 14,411 25,244
10 12 14	Velocity these	governs pipe	with sizes	20,638 29,973 36,690	30,957 44,960 55,034	41,276 59,946 73,379
16 18 20				48,847 62,741 78,372	73,271 94,112 117,559	97,694 125,483 156,745
22 24 26				95,740 114,845 135,686	143,610 172,267 203,529	191,481 229,690 271,373
28 30 32				158,265 182,580 208,631	237,397 273,869 312,947	316,529 365,159 417,263
34 36 42				236,420 265,945 364,942	354,630 398,918 547,413	472,840 531,890 729,884
48 54 60				479,570 609,829 755,719	719,355 914,743 1,133,578	959,139 1,219,657 1,511,437
72 84				1,094,392 1,495,589	1,641,587 2,243,383	2,188,783 2,991,178

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

96				1,959,311	2,938,966	3,918,621

Steam Condensate Flow lbs./h 15 psig Back Pressure

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1/2 3/4 1	21 51 107	29 72 152	42 102 214		Pressure with these	drop pipe
1-1/4 1-1/2 2	247 390 808	349 551 1,143	493 780 1,616	403 556 928	1,393	
2-1/2 3 4	1,344 2,496 5,362	1,901 3,530 7,584	2,688 4,992	1,333 2,077 3,615	1,999 3,115 5,422	2,665 4,153 7,229
5 6 8	10,029 16,306 34,525	14,184	with sizes	5,720 8,195 14,357	8,580 12,293 21,535	11,440 16,391 28,713
10 12 14	Velocity these	governs pipe		23,474 34,091 41,731	35,210 51,137 62,596	46,947 68,183 83,461
16 18 20				55,559 71,362 89,141	83,338 107,043 133,711	111,117 142,724 178,282
22 24 26				108,895 130,625 154,330	163,343 195,937 231,495	217,790 261,249 308,659
28 30 32				180,010 207,666 237,297	270,015 311,499 355,946	360,020 415,332 474,595
34 36 42				268,904 302,486 415,085	403,356 453,729 622,628	537,808 604,972 830,170
48 54 60				545,463 693,619 859,555	818,194 1,040,429 1,289,332	1,090,926 1,387,239 1,719,109

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
72 84 96				1,244,761 1,701,083 2,228,521	1,867,142 2,551,625 3,342,781	2,489,523 3,402,167 4,457,041
	0.125	**0.25**	**0.5**	**2,000 (23)**	**3,000 (34)**	**4,000 (45**
Steam Condensate Flow lbs./h 20 psig Back Pressure						
1/2 3/4 1	23 58 121	33 81 171	47 115 241		Pressure with these	drop pipe
1-1/4 1-1/2 2	278 439 910	393 621 1,287	555 878 1,820	488 673 1,124	1,687	
2-1/2 3 4	1,513 2,811 6,038	2,140 3,975 8,539	3,027 5,621	1,614 2,515 4,378	2,421 3,773 6,567	5,030 8,756
5 6 8	11,294 18,361 38,876	15,972	with sizes	6,928 9,926 17,388	10,392 14,889 26,082	13,856 19,852 34,777
10 12 14	Velocity these	governs pipe		28,431 41,291 50,543	42,646 61,936 75,815	56,861 82,582 101,087
16 18 20				67,292 86,432 107,966	100,937 129,648 161,948	134,583 172,865 215,931
22 24 26				131,891 158,210 186,921	197,837 237,315 280,382	263,783 316,420 373,842
28 30 32				218,025 251,521 287,410	327,037 377,281 431,115	436,049 503,042 574,820
34 36 42				325,691 366,365 502,743	488,537 549,548 754,114	651,382 732,731 1,005,486

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
48 54 60				660,654 840,098 1,041,075	990,981 1,260,147 1,561,613	1,321,307 1,680,196 2,082,151
72 84 96				1,507,630 2,060,319 2,699,140	2,261,446 3,090,478 4,048,710	3,015,261 4,120,637 5,398,280
Steam Condensate Flow lbs./h 25 psig Back Pressure						
1/2 3/4 1	26 64 134	37 91 190	52 128 268		Pressure with these	drop pipe
1-1/4 1-1/2 2	309 488 1,012	437 690 1,431	617 976 2,024	578 797 1,332	1,997	
2-1/2 3 4	1,683 3,125 6,714	2,380 4,420 9,495	3,365 6,250	1,911 2,979 5,185	2,867 4,468 7,777	5,957 10,369
5 6 8	12,557 20,415 43,227	17,759 28,872	with sizes	8,204 11,755 20,592	12,307 17,632 30,888	16,409 23,510 41,184
10 12 14	82,870	governs pipe		33,669 48,898 59,856	50,503 73,348 89,784	67,338 97,797 119,712
16 18 20	Velocity these			79,690 102,357 127,858	119,534 153,535 191,786	159,379 204,714 255,715
22 24 26				156,192 187,359 221,360	234,288 281,039 332,040	312,383 374,718 442,720
28 30 32				258,194 297,862 340,363	387,292 446,793 510,545	516,389 595,724 680,727
34				385,698	578,547	771,396

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
36 42				433,866 595,370	650,799 893,055	867,732 1,190,740
48 54 60				782,375 994,881 1,232,887	1,173,563 1,492,321 1,849,331	1,564,750 1,989,762 2,465,775
72 84 96				1,785,402 2,439,920 3,196,440	2,678,103 3,659,880 4,794,660	3,570,804 4,879,839 6,392,880
Steam Condensate Flow lbs./h 30 psig Back Pressure						
1/2 3/4 1	29 71 148	41 100 209	58 141 295		Pressure with these	drop pipe
1- 1/4 1- 1/2 2	340 538 1,115	481 761 1,576	680 1,076 2,229	674 928 1,551		
2- 1/2 3 4	1,853 3,442 7,396	2,621 4,868 10,459	3,707 6,885 14,791	2,226 3,469 6,038	3,339 5,203 9,056	12,075
5 6 8	13,832 22,488 47,615	19,562 31,803		9,554 13,689 23,980	14,332 20,533 35,970	19,109 27,378 47,961
10 12 14	91,283	governs pipe	with sizes	39,209 56,944 69,705	58,813 85,417 104,557	78,418 113,889 139,409
16 18 20	Velocity these			92,802 119,199 148,896	139,203 178,799 223,343	185,604 238,398 297,791
22 24 26				181,892 218,188 257,783	272,838 327,282 386,675	363,784 436,376 515,567
28 30				300,678 346,873	451,018 520,310	601,357 693,746

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
[illegible] 32				[illegible] 396,368	[illegible] 594,551	[illegible] 792,735
34 36 42				449,162 505,255 693,334	673,742 757,883 1,040,001	898,323 1,010,511 1,386,668
48 54 60				911,109 1,158,581 1,435,750	1,366,664 1,737,872 2,153,625	1,822,219 2,317,163 2,871,500
72 84 96				2,079,177 2,841,391 3,722,391	3,118,766 4,262,086 5,583,587	4,158,354 5,682,782 7,444,782
Steam Condensate Flow lbs./h 40 psig Back Pressure						
1/2 3/4 1	34 84 175	48 118 248	68 167 351		Pressure with these	drop pipe
1-1/4 1-1/2 2	404 638 1,323	571 903 1,871	807 1,276 2,646	1,210 2,022		
2-1/2 3 4	2,200 4,085 8,777	3,111 5,778 12,413	4,400 8,171 17,554	2,902 4,522 7,871	4,352 6,783 11,806	15,742
5 6 8	16,416 26,689 56,510	23,216 37,744	with sizes	12,456 17,846 31,262	18,683 26,768 46,893	24,911 35,691 62,523
10 12 14	108,336 176,832	governs pipe		51,114 74,235 90,870	76,671 111,353 136,305	102,229 148,470 181,740
16 18 20	Velocity these			120,981 155,393 194,107	181,471 233,089 291,160	241,961 310,786 388,213
22 24				237,122 284,439	355,683 426,658	474,244 568,878

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
26				336,057	504,086	672,114
28 30 32				391,977 452,199 516,722	587,966 678,298 775,082	783,954 904,397 1,033,443
34 36 42				585,546 658,672 903,860	878,319 988,008 1,355,789	1,171,092 1,317,344 1,807,719
48 54 60				1,187,761 1,510,376 1,871,704	1,781,641 2,265,564 2,807,557	2,375,521 3,020,751 3,743,409
72 84 96				2,710,503 3,704,157 4,852,667	4,065,755 5,556,236 7,279,000	5,421,007 7,408,315 9,705,333
Steam Condensate Flow lbs./h 50 psig Back Pressure						
1/2 3/4 1	40 98 204	56 138 289	80 195 409		Pressure with these	drop pipe
1- 1/4 1- 1/2 2	471 744 1,542	666 1,052 2,181	941 1,488 3,085	2,553		
2- 1/2 3 4	2,565 4,763 10,234	3,627 6,736 14,472	5,129 9,527 20,467	3,664 5,710 9,939	8,565 14,909	19,878
5 6 8	19,140 31,117 65,886	27,068 44,006 93,177	38,280	15,729 22,535 39,477	23,593 33,802 59,215	31,457 45,070 78,953
10 12 14	126,311 206,171 268,500	governs pipe	with sizes	64,546 93,742 114,748	96,819 140,613 172,122	129,092 187,484 229,496
16 18 20	Velocity these			152,771 196,226 245,113	229,157 294,339 367,669	305,542 392,452 490,226

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
22				299,432	449,147	598,863
24				359,182	538,773	718,364
26				424,364	636,547	848,729
28				494,979	742,468	989,957
30				571,025	856,537	1,142,050
32				652,503	978,754	1,305,006
34				739,413	1,109,119	1,478,825
36				831,754	1,247,631	1,663,509
42				1,141,371	1,712,056	2,282,741
48				1,499,874	2,249,811	2,999,747
54				1,907,264	2,860,895	3,814,527
60				2,363,540	3,545,310	4,727,080
72				3,422,754	5,134,131	6,845,508
84				4,677,515	7,016,272	9,355,029
96				6,127,822	9,191,734	12,255,645
Steam Condensate Flow lbs./h 60 psig Back Pressure						
1/2	46	65	91		Pressure	drop pipe
3/4	112	158	224		with these	
1	235	332	469			
1-1/4	540	764	1,081	3,136		
1-1/2	854	1,208	1,709			
2	1,771	2,504	3,542			
2-1/2	2,945	4,164	5,889	4,501	10,522	
3	5,469	7,734	10,937	7,015	18,314	
4	11,749	16,616	23,498	12,210		
5	21,974	31,076	43,949	19,322	28,982	38,643
6	35,725	50,523		27,683	41,524	55,365
8	75,643	106,976		48,494	72,741	96,989
10	145,016			79,290	118,935	158,581
12	236,702			115,156	172,734	230,312
14	308,261			140,961	211,441	281,921

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
16 18 20	447,364	governs pipe	with sizes	187,669 241,051 301,105	281,504 361,576 451,658	375,339 482,102 602,210
22 24 26	Velocity these			367,832 441,231 521,304	551,748 661,847 781,956	735,664 882,463 1,042,607
28 30 32				608,049 701,466 801,557	912,073 1,052,199 1,202,335	1,216,097 1,402,933 1,603,113
34 36 42				908,320 1,021,755 1,402,098	1,362,479 1,532,633 2,103,148	1,816,639 2,043,511 2,804,197
48 54 60				1,842,496 2,342,947 2,903,453	2,763,744 3,514,421 4,355,180	3,684,992 4,685,895 5,806,906
72 84 96				4,204,627 5,746,018 7,527,625	6,306,941 8,619,027 11,291,438	8,409,254 11,492,036 15,055,251
Steam Condensate Flow lbs./h 75 psig Back Pressure						
1/2 3/4 1	55 136 284	78 192 402	111 271 568		Pressure with these	drop pipe
1-1/4 1-1/2 2	654 1,034 2,142	924 1,462 3,030	1,307 2,067 4,285	4,136		
2-1/2 3 4	3,562 6,616 14,214	5,038 9,356 20,102	7,125 13,232 28,428	5,936 9,251 16,103	24,154	
5 6 8	26,585 43,220 91,513	37,596 61,123 129,419	53,169 86,441	25,483 36,510 63,958	38,224 54,765 95,936	50,965 73,019 127,915
10	175,440	248,110	with	104,574	156,860	209,147

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3000 (34)	4,000 (45)
12 14	286,362 372,934		sizes	151,876 185,909	227,814 278,863	303,752 371,817
16 18 20	541,120 748,634	governs pipe		247,911 317,915 397,118	371,867 476,872 595,678	495,823 635,829 794,237
22 24 26	Velocity these			485,122 581,927 687,532	727,684 872,890 1,031,298	970,245 1,163,854 1,375,064
28 30 32				801,937 925,143 1,057,149	1,202,906 1,387,714 1,585,723	1,603,874 1,850,286 2,114,298
34 36 42				1,197,955 1,347,562 1,849,186	1,796,933 2,021,344 2,773,778	2,395,911 2,695,125 3,698,371
48 54 60				2,430,012 3,090,043 3,829,277	3,645,019 4,635,065 5,743,916	4,860,025 6,180,086 7,658,554
72 84 96				5,545,357 7,578,251 9,927,959	8,318,035 11,367,376 14,891,939	11,090,713 15,156,501 19,855,919
Steam Condensate Flow lbs./h 85 psig Back Pressure						
1/2 3/4 1	62 153 320	88 216 452	125 305 640		Pressure with these	drop pipe
1-1/4 1-1/2 2	736 1,164 2,413	1,041 1,646 3,412	1,472 2,328 4,826			
2-1/2 3 4	4,012 7,452 16,010	5,674 10,539 22,641	8,025 14,904 32,020	7,029 10,954 19,066	28,599	
5 6	29,944 48,682	42,347 68,846	59,887 97,363	30,172 43,228	45,258 64,842	86,457 151,455

Notes:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
6	48,682	68,846	97,363	43,228	64,842	131,455
8	103,076	145,772		75,727	113,591	
10	197,608	279,460	with	123,817	185,726	247,635
12	322,546		sizes	179,824	269,736	359,649
14	420,057			220,120	330,180	440,240
16	609,606	governs		293,059	439,589	586,118
18	843,229	pipe		376,418	564,627	752,836
20	1,123,929			470,197	705,295	940,394
22	Velocity			574,396	861,594	1,148,791
24	these			689,014	1,033,521	1,378,029
26				814,053	1,221,079	1,628,106
28				949,511	1,424,267	1,899,022
30				1,095,389	1,643,084	2,190,779
32				1,251,688	1,877,531	2,503,375
34				1,418,406	2,127,608	2,836,811
36				1,595,544	2,393,315	3,191,087
42				2,189,476	3,284,215	4,378,953
48				2,877,188	4,315,782	5,754,377
54				3,658,679	5,488,019	7,317,358
60				4,533,949	6,800,923	9,067,897
72				6,565,824	9,848,737	13,131,649
84				8,972,816	13,459,224	17,945,632
96				11,754,923	17,632,384	23,509,846
Steam Condensate Flow lbs./h 100 psig Back Pressure						
1/2	74	104	148		Pressure	drop pipe
3/4	181	256	362		with these	
1	379	536	758			
1-1/4	872	1,234	1,745			
1-1/2	1,380	1,951	2,759			
2	2,859	4,044	5,719			
2-1/2	4,755	6,724	9,509	8,900	36,215	
3	8,830	12,488	17,660	13,871		
	18,971	26,829	37,942	24,144		

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45
4						
5	35,482	50,179	70,964	38,207	57,310	109,480
6	57,686	81,580	115,371	54,740	82,110	191,788
8	122,141	172,733		95,894	143,841	
10	234,157	331,149	with	156,791	235,186	313,581
12	382,203	540,517	sizes	227,712	341,569	455,425
14	497,750			278,739	418,108	557,478
16	722,357	governs		371,102	556,653	742,204
18	999,190	pipe		476,660	714,990	953,320
20	1,331,807			595,413	893,119	1,190,825
22	1,723,555			727,360	1,091,040	1,454,720
24	2,177,597			872,502	1,308,753	1,745,004
26				1,030,839	1,546,259	2,061,678
28	Velocity			1,202,371	1,803,556	2,404,741
30	these			1,387,097	2,080,646	2,774,194
32				1,585,018	2,377,527	3,170,036
34				1,796,134	2,694,201	3,592,268
36				2,020,445	3,030,667	4,040,889
42				2,772,545	4,158,817	5,545,089
48				3,643,397	5,465,096	7,286,795
54				4,633,003	6,949,504	9,266,006
60				5,741,361	8,612,042	11,482,722
72				8,314,335	12,471,503	16,628,671
84				11,362,320	17,043,480	22,724,640
96				14,885,316	22,327,974	29,770,631

Notes:

1. **Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,00**
2. **Table based on heavy weight steel pipe using steam equations in Par**

Citation

EXPORT

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. Part 22: Steam Condensate Piping Systems, Chapter

Part 23: AC Condensate Piping

23. Part 23: AC Condensate Piping

23.01. Air Conditioning (AC) Condensate Piping

A. AC Condensate Flow

1. Range:	0.02–0.08 GPM/ton.
2. Average:	0.04 GPM/ton.
3. Unitary packaged AC equipment:	0.006 GPM/ton.
4. Air handling units (100 percent outside air):	0.100 GPM/1000 CFM.
5. Air handling units (50 percent outdoor air):	0.065 GPM/1000 CFM.
6. Air handling units (25 percent outdoor air):	0.048 GPM/1000 CFM.
7. Air handling units (15 percent outdoor air):	0.041 GPM/1000 CFM.
8. Air handling units (0 percent outdoor air):	0.030 GPM/1000 CFM.

B. AC Condensate Pipe Sizing

1. Minimum pipe sizes are provided in the following table.

2. Pipe size shall not be smaller than the drain pan outlet. The minimum size below grade and below ground floor shall be2-1/2" (4" Allegheny Co., PA). The drain shall have a slope of not less than1/8" per foot.

3. Some localities require AC condensate to be discharged to storm sewers. Some require AC condensate to be discharged to sanitary sewers, while some permit AC condensate to be discharged to either storm or sanitary sewers. Verify pipe sizing and discharge requirements with local authorities and codes.

AC Tons	**Minimum Drain Size**
0–20	1"
21–40	1-1/4"
41–60	1-1/2"
61–100	2"
101–250	3"
251 and larger	4"

Part 24: Refrigerant Piping Systems

24. Part 24: Refrigerant Piping Systems

24.01. Refrigerant Systems and Piping

A. Refrigeration System Design Considerations

1. Refrigeration load and system size:
   a. Conduction heat gains, sensible.

   b. Radiation heat gains, sensible.

   c. Convection/infiltration heat gains, sensible and latent.

   d. Internal heat gains, lights, people, equipment.

   e. Product load, sensible and latent.

2. Part load performance, minimum versus maximum load.

3. Piping layout and design:
   a. Ensure proper refrigerant flow to feed evaporators.

   b. Size piping to limit excessive pressure drop and temperature rise and to minimize first cost.

   c. Ensure proper lubricating oil flow to compressors and protect compressors for loss of lubricating oil flow.

   d. To prevent liquid (oil or refrigerant) from entering the compressors.

   e. Maintain a clean and dry system.

f. To prevent refrigeration system leaks.

4. Refrigerant type selection and refrigerant limitations.

5. System operation, partial year or year round regardless of ambient conditions.

6. Load variations during short time periods.

7. Evaporator frost control.

8. Oil management under varying load conditions.

9. Heat exchange method.

10. Secondary coolant selection.

11. Installed cost, operating costs, maintenance costs, system efficiency, and system simplicity.

12. Safe operation for building inhabitants.

13. Operating pressure and pressure ratios; single stage versus two stage versus multistaged.

14. Special electrical requirements.

15. Refrigerant system capacity estimate:
    a. Packaged systems: 2.0 lbs. refrigerant per ton.

    b. Split systems: 3.0 lbs. refrigerant per ton.

B. Refrigerant Pipe Design Criteria

1. Halocarbon refrigerants:
    a. Liquid lines (condensers to receivers)—100 FPM or less.

    b. Liquid lines (receivers to evaporator)—300 FPM or less.

    c. Compressor suction line—900 to 4,000 FPM.

    d. Compressor discharge line—2,000 to 3,500 FPM.

    e. Defrost gas supply lines—1,000 to 2,000 FPM.

    f. Condensate drop legs—150 FPM or less.

    g. Condensate mains—100 FPM or less.

h. Pressure loss due to refrigerant liquid risers is 0.5 psi per foot of lift.

i. Liquid lines should be sized to produce a pressure drop due to friction that corresponds to a 1°F to 2°F change in saturation temperature or less.

j. Discharge and suction lines should be sized to produce a pressure drop due to friction that corresponds to a 2°F change in saturation temperature or less.

k. Pump suction pipe sizing should be 2.5 fps maximum. Oversizing of pump suction piping should be limited to one pipe size.

2. Standard steel pipe sizes:1/2",3/4", 1",1-1/4",1-1/2", 2",2-1/2", 3", 4", 6", 8", 10", 12", 14", 16", 18", 20".

3. Standard copper pipe sizes:3/8",1/2",5/8",3/4",7/8", 1",1-1/8",1-1/4",1-3/8",1-1/2",1-5/8", 2",2-1/8",2-1/2",2-5/8", 3",3-1/8",3-5/8", 4",4-1/8", 6", 8", 10", 12".

4. Ammonia refrigerant:
   a. Liquid lines should be sized for 2.0 psi/100 ft. of equivalent pipe length or less. Liquid lines should be sized for a 3:1, 4:1, or 5:1 overfeed ratio (4:1 recommended).

   b. Suction lines should be sized for 0.25, 0.5, or 1.0°F/100 ft. of equivalent pipe length.

   c. Discharge lines should be sized for 1.0°F/100 ft. of equivalent pipe length.

   d. Pump suction pipe sizing should be 3.0 fps maximum. Oversizing of pump suction piping should be limited to one pipe size.

   e. Cooling water flow rate: 0.1 GPM/ton.

C. Halocarbon Refrigerant Pipe Materials

1. Pipe:	Type "L (ACR)" copper tubing, *ASTM B280,* hard drawn.
Fittings:	Wrought copper solder joint fittings, *ANSI/ASME B16.22.*
Joints:	Classification BAg-1 (silver) AWS A5.8 Brazed-Silver Alloy brazing. Brazing shall be conducted using a brazing flux. Do not use an acid flux.

D. Ammonia Refrigerant Pipe Materials

1. Liquid lines:

a. 1-1/2" and smaller:	Schedule 80 minimum.
b. 2" to 6":	Schedule 40 minimum.
c. 8" and larger:	Schedule 30 minimum.

2. Suction, discharge, and vapor lines:

a. 1-1/2" and smaller:	Schedule 80 minimum.
b. 2" to 6":	Schedule 40 minimum.
c. 8" and larger:	Schedule 30 minimum.

3. Fittings:
   a. Couplings, elbows, tees, and unions for threaded piping systems must be constructed of forged steel with a pressure rating of 300 psi.

   b. Welding fittings must match the weight of the pipe.

   c. Low-pressure side piping, vessels, and flanges should be designed for 150 psi.

   d. High-pressure side piping, vessels, and flanges should be designed for 250 psi if the system is water or evaporative cooled, and 300 psi if the system is air cooled.

4. Joints:
   a. 1-1/4" pipe and smaller may be threaded, although welded systems are superior.

b. 1-1/2" pipe and larger must be welded.

5. Recommended low pressure side piping requirements:

a. 1-1/4" and smaller:

Pipe:	Black steel pipe, *ASTM A53, Schedule 80*, Type E or S, Grade B or carbon steel pipe, *ASTM A106, Schedule 80*, Type S, Grade B.
Fittings:	Forged steel threaded fittings, 300 lbs.
Joints:	Pipe threads, general purpose (American) *ANSI/ASME B1.20.1.*

OR

Pipe:	Black steel pipe, *ASTM A53, Schedule 80*, Type E or S, Grade B or carbon steel pipe, *ASTM A106, Schedule 80*, Type S, Grade B.
Fittings:	Forged steel socket weld, 150 lbs. *ANSI B16.11*.
Joints:	Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9*.

b. 1-1/2":

Pipe:	Black steel pipe, *ASTM A53, Schedule 80*, Type E or S, Grade B or carbon steel pipe, *ASTM A106, Schedule 80*, Type S, Grade B.
Fittings:	Forged steel socket weld, 150 lbs. *ANSI B16.11*.
Joints:	Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9*.

c. 2" and larger:

Pipe:	Black steel pipe, *ASTM A53, Schedule 40*, Type E or S, Grade B or carbon steel pipe, *ASTM A106, Schedule 40*, Type S, Grade B.
Fittings:	Steel butt-welding fittings, 150 lbs., *ANSI/ASME B16.9*.
Joints:	Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9*.

6. Recommended high pressure side piping requirements:
   a. 1-1/4" and smaller:

Pipe:	Black steel pipe, *ASTM A53, Schedule 80*, Type E or S, Grade B or carbon steel pipe, *ASTM A106, Schedule 80*, Type S, Grade B.
Fittings:	Forged steel threaded fittings, 300 lbs.
Joints:	Pipe threads, general purpose (American) *ANSI/ASME B1.20.1.*

OR

Pipe:	Black steel pipe, *ASTM A53*, *Schedule 80*, Type E or S, Grade B or carbon steel pipe, *ASTM A106, Schedule 80*, Type S, Grade B.
Fittings:	Forged steel socket weld, 300 lbs. *ANSI B16.11*.
Joints:	Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*

   b. 1-1/2":

Pipe:	Black steel pipe, *ASTM A53, Schedule 80*, Type E or S, Grade B or carbon steel pipe, *ASTM A106, Schedule 80*, Type S, Grade B.
Fittings:	Forged steel socket weld, 300 lbs. *ANSI B16.11*.
Joints:	Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9*.

c. 2" and larger:

Pipe:	Black steel pipe, *ASTM A53, Schedule 40*, Type E or S, Grade B or carbon steel pipe, *ASTM A106, Schedule 40*, Type S, Grade B.
Fittings:	Steel butt-welding fittings, 300 lbs., *ANSI/ASME B16.9*.
Joints:	Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9*.

E. Refrigerant Piping Installation

1. Slope piping 1 percent in direction of oil return.
2. Install horizontal hot gas discharge piping with1/2" per 10 feet downward slope away from the compressor.
3. Install horizontal suction lines with1/2" per 10 feet downward slope to the compressor, with no long traps or dead ends that may cause oil to separate from the suction gas and return to the compressor in damaging slugs.
4. Liquid lines may be installed level.
5. Provide line size liquid indicators in the main liquid line leaving the condenser or receiver. Install moisture-liquid indicators in liquid lines between filter dryers and thermostatic expansion valves and in the liquid line to receiver.
6. Provide a line size strainer upstream of each automatic valve. Provide a shutoff valve on each side of the strainer.

7. Provide permanent filter dryers in low temperature systems and systems using hermetic compressors.

8. Provide replaceable cartridge filter dryers with three-valve bypass assembly for solenoid valves that are adjacent to receivers.

9. Provide refrigerant charging valve connections in the liquid line between the receiver shutoff valve and expansion valve.

10. Normally, only refrigerant suction lines are insulated, but liquid lines should be insulated where condensation will become a problem, and hot gas lines should be insulated where personal injury from contact may pose a problem.

11. Refrigerant lines should be installed a minimum of 7'6" above the floor.

F. Refrigerant Properties

1. Halocarbon refrigerants absorb 40-80 Btuh/lb., and ammonia absorbs 500–600 Btuh/lb.

2. Ammonia refrigeration systems require smaller piping than halocarbon refrigeration systems for the same pressure drop and capacity.

3. Human or living tissue contact with many refrigerants in their liquid state can cause instant freezing, frostbite, solvent defatting or dehydration, and/or caustic or acid burns.

4. Leak detectors are essential for all halocarbon refrigerants because they are generally heavier than air, are odorless, and can cause suffocation due to oxygen depravation. Ammonia is lighter than air and has a distinctive and unmistakable odor.

5. Ammonia properties:
   a. Refrigerant grade ammonia:
      1. 99.98 percent ammonia minimum.
      2. 0.015 percent water maximum.
      3. 3 ppm oil maximum.
      4. 0.2 mL/g noncondensable gases.

   b. Agricultural grade ammonia:
      1. 99.5 percent ammonia minimum.

2. 0.5 percent water maximum.

3. 0.2 percent water minimum.

4. 5 ppm oil maximum.

c. Ammonia limitations are shown in the following table.

Concentration of Ammonia in the Air	Limitations/Symptoms
4 ppm	Detectable by human sense of smell.
25 ppm	Maximum ACGIH Permissible Exposure Limit (PEL). Maximum European Government Limit.
30–35 ppm	Uncomfortable—breathing support desired or required. Common level around ammonia print machines. Maximum recommended exposure 15 minutes (ACGIH).
50 ppm	Maximum OSHA and NIOSH Permissible Exposure Limit (PEL).
100 ppm	Noticeable irritation to the eyes, throat, and mucous membranes.
400 ppm	Mucous membranes may be destroyed with prolonged contact with ammonia. No serious health threat with infrequent and less-than-one-hour exposures.
500 ppm	Immediate Danger to Life and Health (IDLH) Limit.
700 ppm	Significant eye irritation.
1,700 ppm	Convulsive coughing occurs. Fatal after short exposures of less than one half hour.
2,500 ppm	Exposure in as short a time as 30

Concentration of Ammonia in the Air	Limitations/Symptoms
2,500 ppm	Exposure in as short a time as 30 minutes is dangerous. Affects show up several days later—pulmonary edema (water in the lungs).
5,000 ppm and above	Immediate hazard to life due to suffocation. Full face respiratory protection is required, including eyes. Causes respiratory spasm, strangulation, and asphyxia—no exposure permissible.
15,000 ppm and above	Full body protection required. Ammonia reacts with body perspiration to form a caustic solution that attacks the skin causing burns and blisters.
160,000–270,000 ppm	Flammable in air at 68°F.
15.5% by volume	Lower Flammability Limit (LFL); also referred to Lower Explosive Limit (LEL)

6. Refrigerant physical properties are shown in the following table.

Refrigerant Physical Properties									
Refrigerant		ASHRAE Std. 15 Group No.	Molecular Mass	Boiling Point at 14.7 Psia °F	Freezing Point °F	Critical			
No.	Name					Temp. °F	Press. psia	Volume ft.³/lb.
R-11	—	A1	137.38	74.87	−168.0	388.4	639.5	0.0289
R-12	—	A1	120.93	−21.62	−252.0	233.6	596.9	0.0287
R-13	—	A1	104.47	−114.60	−294.0	83.9	561.0	0.0277
R-13B1	—	A1	148.93	−71.95	−270.0	152.6	575.0	0.0215
R-14	—	A1	88.01	−198.30	−299.0	−50.2	543.0	0.0256
R-22	—	A1	86.48	−41.36	−256.0	204.8	721.9	0.0305
R-40	—	B2	50.49	−11.60	−144.0	289.6	968.7	0.0454
R-113	—	A1	187.39	117.63	−31.0	417.4	498.9	0.0278
R-114	—	A1	170.94	38.80	−137.0	294.3	473.0	0.0275
R-115	—	A1	154.48	−38.40	−159.0	175.9	457.6	0.0261
R-123	—	B1	152.93	82.17	−160.9	362.8	532.9	—
R-134a	—	A1	102.03	−15.08	−141.9	214.0	589.8	0.0290
R-142b	—	A2	100.50	14.40	−204.0	278.8	598.0	0.0368
R-152a	—	A2	66.05	−13.00	−178.6	236.3	652.0	0.0439
R-170	Ethane	A3	30.07	−127.85	−297.0	90.0	709.8	0.0830
R-290	Propane	A3	44.10	−43.73	−305.8	206.3	617.4	0.0728
R-C318	—	A1	200.04	21.50	−42.5	239.6	403.6	0.0258
R-410A	—	A1	72.58	−60.84	—	161.83	714.50	0.0328
R-500	—	A1	99.31	−28.30	−254.0	221.9	641.9	0.0323
R-502	—	A1	111.63	−49.80	—	179.9	591.0	0.0286
R-503	—	A1	87.50	−127.60	—	67.1	607.0	0.0326
R-600	Butane	A3	58.13	31.10	−217.3	305.6	550.7	0.0702
R-600a	Isobutane	A3	58.13	10.89	−255.5	275.0	529.1	0.0725
R-611	—	B2	60.05	89.20	−146.0	417.2	870.0	0.0459
R-717	Ammonia	B2	17.03	−28.00	−107.9	271.4	1657.0	0.0680
R-744	Carbon dioxide	A1	44.01	−109.20	−69.9	87.9	1070.0	0.0342
R-764	Sulfur dioxide	B1	64.07	14.00	−103.9	315.5	1143.0	0.0306
R-1150	Ethylene	A3	28.05	−154.7	−272.0	48.8	742.2	0.0700
R-1270	Propylene	A3	42.09	−53.86	−301.0	197.2	670.3	0.0720

Refrigerant Type	**Energy Absorption Rate Btu/lb.**				
	40°F	**20°F**	**0°F**	**–20°F**	**–40°F**
R-11	80.863	82.507	84.126	85.732	87.335
R-12	64.649	66.953	69.098	71.116	73.038
R-22	86.503	90.344	93.891	97.193	100.296
R-123	76.787	78.078	79.167	80.162	81.340
R-134a	84.011	87.589	90.925	94.063	97.050
R-502	61.687	65.069	68.101	70.795	73.162
R-717 Ammonia	535.936	552.858	568.692	583.540	597.482

Citation

EXPORT

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. Part 24: Refrigerant Piping Systems, Chapter (McGraw-Hill Professional, 2016), AccessEngineering

Part 25: Air Handling Units

25. Part 25: Air Handling Units

Printed for University of California Berkeley Copyright McGraw-Hill Education Holdings

25.01. Air Handling Units, Air Conditioning Units, Heat Pumps

A. Definitions

1. *Air Handling Units (AHUs)*. AHUs contain fans, filters, coils, and other items but do not contain refrigeration compressors.
2. *Air Conditioning Units (ACUs)*. ACUs are AHUs that contain refrigeration compressors.
3. *Heat Pumps*. Heat pumps are ACUs with refrigeration systems capable of providing heat to the space as well as cooling.

B. Air Handling Unit Types

1. Packaged AHUs (central station AHUs):
   a. 800–50,000 CFM.
   b. 0–9" SP.
   c. 1/4–100 hp.
2. Factory-fabricated AHUs (custom AHUs):
   a. 1,000–125,000 CFM.
   b. 0–13" SP.
   c. 1/4–500 hp.
   d. Shipping limiting factor; two to three times more expensive than packaged

AHUs.

3. Field-fabricated AHUs:
    a. 10,000–804,000 CFM.
    b. 0–14" SP.
    c. 2–2500 hp.
    d. Fan size limiting factor.

C. Packaged Equipment, All Spaces

1. 300–500 CFM/ton @ 20°F ΔT.
2. 400 CFM/ton @ 20°F ΔT (typical).

D. Water Source Heat Pumps

1. Water heat rejection:
    a. 2.0–3.0 GPM/ton @ 15–10°F ΔT.
    b. 3.0 GPM/ton @ 10°F ΔT recommended.
2. 85–95°F Condenser water temperature.
3. 60–90°F Heat pump water loop temperatures:
    a. Winter design: 60°F.
    b. Summer design: 90°F.
4. Cooling tower, evap. cooler sizing:
    a. 1.4 × Block Cooling Load.
5. Supplemental heater sizing:
    b. 0.75 × Block Heating Load.

E. Geothermal Source Heat Pumps

1. Efficiencies:
    a. Average: 3.5–4.7 COP; 12–16 EER.
    b. High: 5.3–5.9 COP; 18–20 EER.
2. Vertical wells used for heat transfer are the most common system type in lieu of horizontal heat transfer sites.

3. Length of heat exchanger pipe required:
   a. Range: 130 ft./ton–175 ft./ton.

   b. Average: 150 ft./ton.

4. 50–110°F Heat pump water loop temperatures.

5. If the system is sized to meet cooling requirements, supplemental heat will not be required.

6. If the system is sized to meet heating requirements, a supplemental cooling tower will be required.

7. Pipe spacing:
   a. Commercial: 15 ft. × 15 ft. center to center grid.

   b. Residential: 10 ft. × 10 ft. center to center grid.

F. Air Handling Unit Fans

1. 1/2°F temperature rise for each 1" S.P. from fan heat.

2. See Part 26, Fans for more information.

3. A return air system with more than a1/2" pressure drop should have a return air fan. A return air fan is also required if you intend to use an economizer and still maintain the space under a neutral or negative pressure.

G. Economizers

1. Water side economizers take advantage of low condenser water temperature to either precool entering air, assist in mechanical cooling, or to provide total system cooling.

2. Air side economizers take advantage of cool outdoor air to either assist in mechanical cooling or to provide total system cooling.
   a. Dry bulb.

   b. Enthalpy—required by energy conservation codes.

H. System Types

1. VAV systems:
   a. Fans selected for 100 percent block airflow.

   b. Normal operation 60–80 percent block airflow.

c. Minimum airflow 30–50 percent block airflow.

2. Constant volume reheat systems:
   a. Fans selected and operated at a 100 percent sum of peak airflow.

   b. Constant volume systems are generally not permitted by energy conservation codes. If employed, a supply temperature reset must be employed.

3. Hybrid VAV/constant volume reheat systems:
   a. Fans selected for 100 percent block airflow for VAV spaces, plus 100 percent sum of peak airflow for constant volume spaces.

   b. Normal operation 60–80 percent of the system design airflow.

   c. Minimum airflow 30–50 percent of the system design airflow.

4. Dual duct systems:
   a. Cold deck designed for 100 percent of the sum of peak airflow.

   b. Hot deck designed for 75–90 percent of the sum of peak airflow.

   c. Fans selected and operated at 100 percent of the sum of peak airflow.

   d. Dual duct systems are generally not permitted by energy conservation codes. If employed, a cold deck and hot deck supply temperature reset must be employed.

5. Dual duct VAV systems:
   a. Cold deck designed for 100 percent of block airflow.

   b. Hot deck designed for 75–90 percent of block airflow.

   c. Fans selected for 100 percent block airflow.

   d. Normal operation 60–80 percent block airflow.

   e. Minimum airflow 30–50 percent block airflow.

6. Single zone and multizone systems:
   a. Cold deck designed for 100 percent of the sum of peak airflow.

   b. Hot deck designed for 75–90 percent of the sum of peak airflow.

   c. Fans selected and operated at 100 percent of the sum of peak airflow.

I. Clearance Requirements

1. Minimum recommended clearance around air handling units and similar equipment is 24 inches on the nonservice side and 36 inches on the service side. Maintain minimum clearance for coil pull as recommended by the equipment manufacturer; this is generally equal to the width of the air handling unit. Maintain minimum clearance as required to open access and control doors on air handling units for service, maintenance, and inspection.

2. Mechanical room locations and placement must take into account how large air handling units and similar equipment can be moved into and out of the building during the initial installation and after construction for maintenance and repair and/or replacement.

25.02. Coils

A. General

1. Field-erected and factory-assembled air handling unit coils should be arranged for removal from the upstream side without dismantling supports. Provide galvanized structural steel supports for all coils (except the lowest coil) in banks over two coils high to permit the independent removal of any coil.

2. When air handling units are used to supply makeup air (100 percent OA) for smoke control/smoke management systems, water coil freeze up must be considered. Some possible solutions are listed in the following:
   a. Provide preheat coil in AHU to heat the air from the outside design temperature to 45–50°F.

   b. Provide control of the system to open all water coil control valves serving smoke control/smoke management systems to full open and circulate water through the coils.

   c. Elect not to provide freeze protection with owner concurrence in the event a fire or other emergency occurs on a cold day. Also, many emergency situations are fairly short in duration. A follow-up letter should also be written.

3. Select water coils with tube velocities high enough at design flow so that tube velocities do not end up in the laminar flow region when the flow is reduced in response low-load conditions. Tube velocities become critical with units

designed for 100 percent outside air at low loads near 32°F. Higher tube velocity selection results in a higher water pressure drop for the water coil. Sometimes a trade-off between pressure drop and low load flows must be evaluated.

4. It is best to use water coils with same end connections to reduce flow imbalances caused by differences in velocity head.

5. In horizontal water coil headers, supply water flow should be downward, while return water flow should be upward for proper air venting.

6. Water coil flow patterns:
   a. Multiple path, parallel flow, grid type coil.

   b. Series flow, serpentine coil.

   c. Series and parallel flow.

B. Air Handling Unit Coil Designations

1. Preheat coils normally heat air to a desired setpoint level (quite often the setpoint is the cooling coil discharge temperature plus or minus 5°F). This setpoint temperature may or may not be adequate for maintaining space temperature for human comfort; however, it is generally adequate to prevent freezing and also for equipment room heating. Preheat coils may be hot water, steam, or electric type coils, or they may be direct-fired or indirect-fired gas heaters. Preheat coil (water or steam type) freeze protection methods are listed in the following:
   a. Preheat pumps (primary/secondary system).

   b. Internal face and bypass coils.

   c. Integral face and bypass dampers.

   d. Preheat coils are required whenever the design mixed air temperature is below 40°F or when 100 percent outside air units have an outside design temperature below 40°F.

2. Cooling coils provide both the sensible and latent cooling required to maintain temperature and humidity levels. Cooling coils are either chilled water or DX (refrigerant) type coils.

3. Heating coils are designed to maintain space temperatures acceptable for human comfort or process requirements. Heating coils should not operate

when cooling coils are operating. Automatic temperature control interlocks should be established to prevent simultaneous operation. Heating coils may be hot water, steam, or electric type coils, or they may be direct-fired or indirect-fired gas heaters.

4. Reheat coils will often operate in conjunction with cooling coils to maintain a temperature and/or relative humidity acceptable for human comfort or process requirements. Reheat coils may be hot water, steam, or electric type coils.

C. Water and Steam Coils

1. Preheat:
   a. Concurrent air/water or steam flow.

   b. Freeze protection:
      1. Preheat pumps (primary/secondary system). See Fig. 25.1.

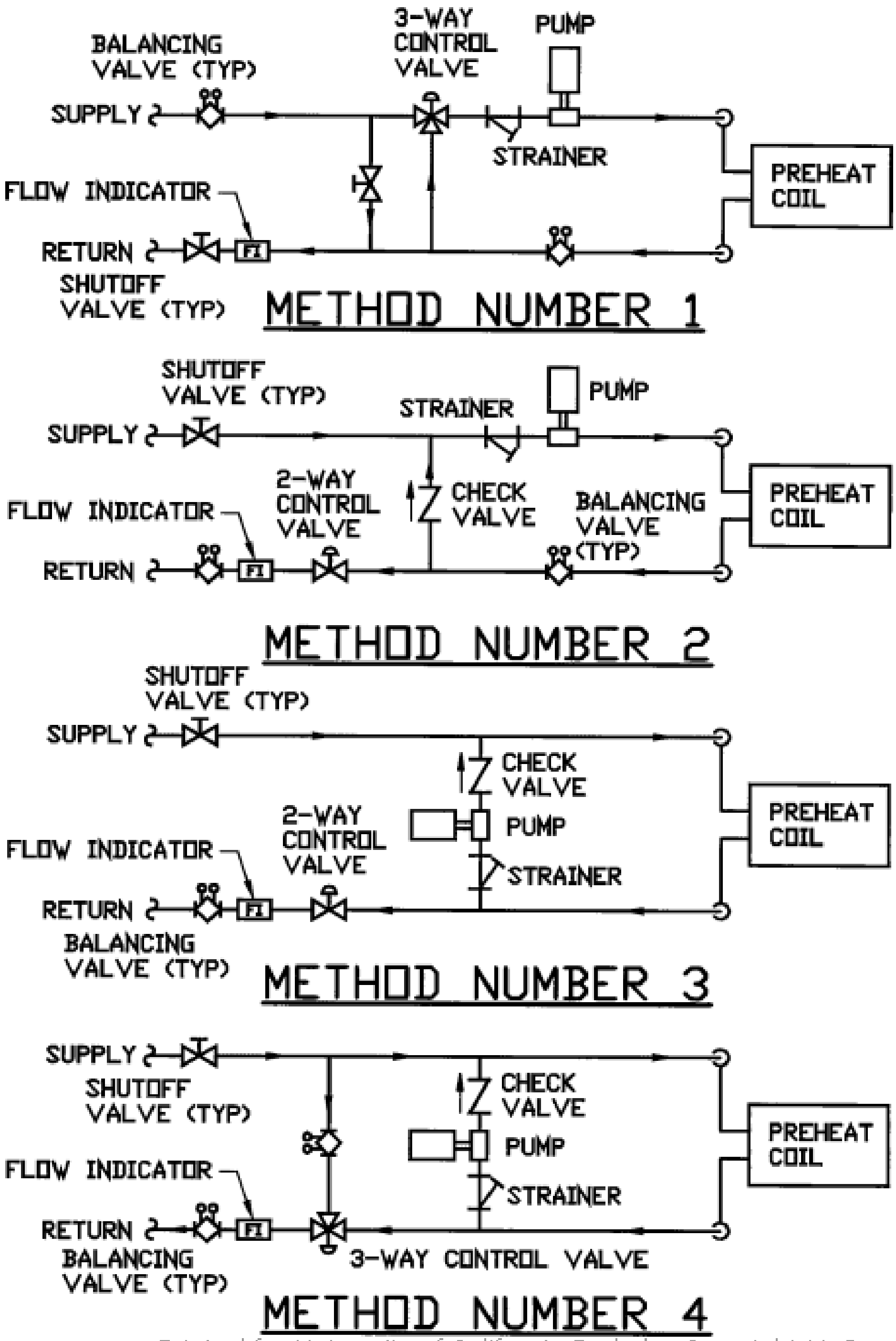


Figure 25.1. PREHEAT COIL PIPING DIAGRAMS.

2. Face and bypass dampers—internal. See Fig. 25.2.

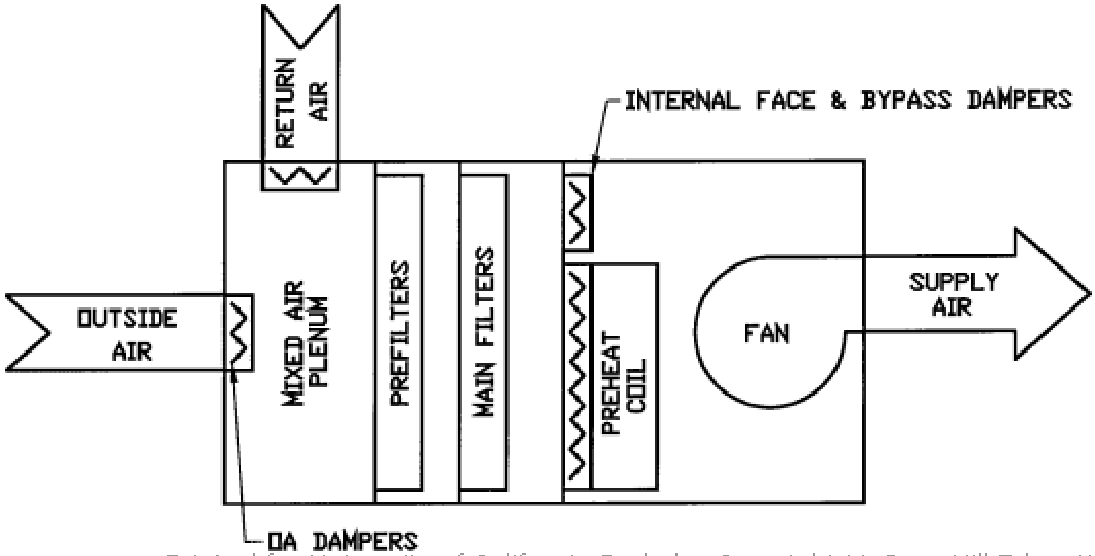


Figure 25.2. AIR HANDLING UNITS W/INTERNAL FACE AND BYPASS DAMPERS (PREHEAT COIL FREEZE PROTECTION).

3. Integral face and bypass (IFB) coils. See Fig. 25.3.

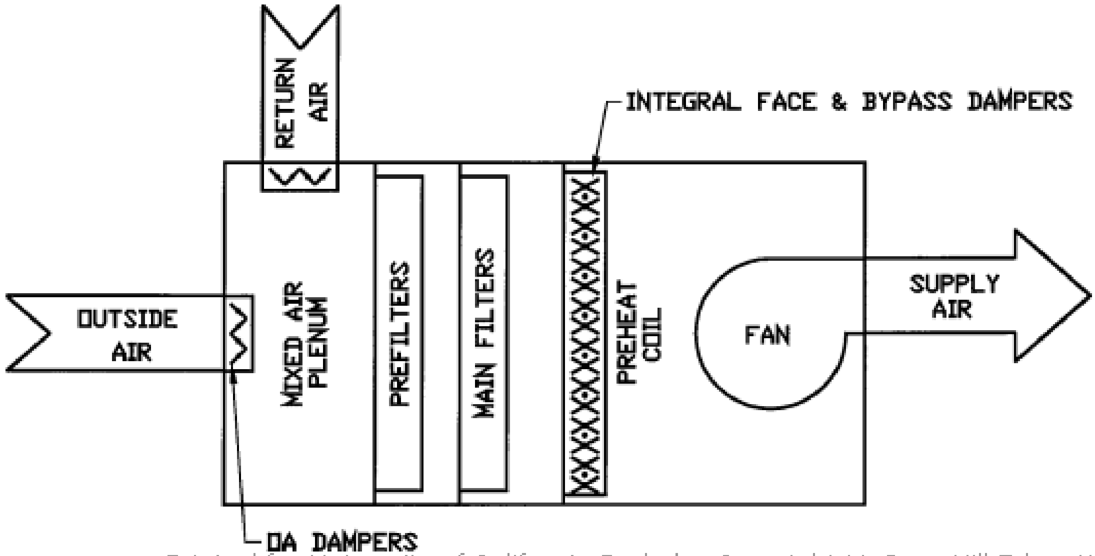


Figure 25.3. AIR HANDLING UNITS W/INTEGRAL FACE AND BYPASS DAMPERS (PREHEAT COIL FREEZE PROTECTION).

2. Cooling, heating, reheat:
   a. Counter air/water or steam flow.
3. Cooling coil face velocity:
   a. 450–550 fpm range.
   b. 500 fpm recommended.
   c. 450 fpm preferred.
4. Preheat, heating, and reheat coil face velocity:

a. 500–900 fpm range.

b. 600–700 fpm recommended.

c. 600 fpm preferred.

d. Use a preheat coil whenever the mixed air temperature (outside air and return air) is below 40°F.

D. Refrigerant Coils

1. Cooling:
   a. Counter air/refrigerant flow.

   b. Cooling coil face velocity:
      1. 450–550 fpm range.

      2. 500 fpm recommended.

      3. 450 fpm preferred.

E. Weight and Volume of Water in Standard Water Coils

1. Weight of water in the tubes:
   $W_{WT} = 0.966 \text{ lbs./row sq.ft.} \times \text{No. of Rows} \times \text{Face Area of Coil}$

2. Total weight of water in coil:
   $W_{WC} = W_{WT} + W_{WH}$

3. Total weight of water coils:
   $W_T = W_C + W_{WC}$

4. Volume of water in coil:
   $V = W_{WC} \times 0.12$

   where

   W_{WT} = water weight in the tubes (pounds)

   W_{WH} = water weight in the headers/U-bends, from table (pounds)

   W_{WC} = water weight in the coil (pounds)

   W_C = dry coil weight (pounds)

   W_T = total weight of the coil (pounds)

V = volume of the coil (gallons)

Weight of Water in Coil Headers and U-Bends

Finned Width	Number of Rows						
	1	2	3	4	5	6	8
6"	0.75	1.75	—	—	—	—	—
9"	1.00	2.75	—	—	—	—	—
12"	1.50	3.26	3.84	4.04	4.75	4.94	7.61
18"	2.75	3.94	4.82	5.07	6.21	8.70	13.10
24"	3.85	5.28	6.50	6.86	8.37	11.61	17.60
30"	4.72	8.66	10.12	10.50	12.48	16.52	24.00
33"	5.21	9.50	11.09	11.58	13.54	17.99	26.10
36"	—	16.34	19.58	22.82	26.06	29.30	32.55
42"	—	18.95	22.73	26.51	30.29	34.07	37.85
48"	—	21.55	25.88	30.20	34.52	38.84	43.16

F. Coil Pressure Drop

1. Air pressure drop (water, steam, refrigerant coils) is given in the following table:
   a. Cooling coils:
      1. Range: 0.5–1.0" WC.
      2. Recommended schedule value: 0.75" WC.
   b. Dehumidification/heat recovery coils:
      1. Range: 1.0–1.5" WC.
      2. Recommended schedule value: 1.25" WC.
   c. Heating coils:
      1. Range: 0.1–0.25" WC.
      2. Recommended schedule value: 0.15" WC.

Number of Rows	Face Velocity (fpm)						
	450	500	550	600	700	800	900
1	0.05–0.15	0.05–0.18	0.08–0.20	0.08–0.25	0.12–0.30	0.15–0.40	0.17–0.50
2	0.10–0.35	0.11–0.50	0.15–0.50	0.16–0.60	0.20–0.80	0.25–0.90	0.32–0.90
4	0.20–0.70	0.22–0.90	0.28–1.00	0.33–1.20	0.40–1.50	0.50–1.80	0.65–1.70
6	0.30–1.10	0.35–1.30	0.45–1.50	0.50–1.70	0.65–2.30	0.75–2.80	1.00–2.70
8	0.40–1.50	0.45–1.75	0.60–2.00	0.60–2.40	0.85–3.00	1.00–3.70	1.30–3.70
10	0.50–1.75	0.60–2.25	0.70–2.50	0.80–3.00	1.10–3.80	1.30–4.50	1.70–4.50

2. Water pressure drop is given in the following table:
   a. Cooling coils:
      1. Range: 10–20 ft. H_2O.

      2. Recommended schedule value: 15 ft. H_2O.

   b. Dehumidification/heat recovery coils:
      1. Range: 10–20 ft. H_2O.

      2. Recommended schedule value: 15 ft. H_2O.

   c. Heating coils:
      1. Range: 1–5 ft. H_2O.

      2. Recommended schedule value: 2.5 ft. H_2O.

Finned Width	Finned Length									
	12	24	36	48	60	72	84	96	108	120
12	0.11 8.77	0.13 10.1	0.14 11.6	0.15 13.1	0.16 14.6	0.17 16.2	0.18 17.7	0.19 19.2	0.20 20.7	0.21 22.2
18	0.07 6.31	0.09 7.65	0.10 9.16	0.11 10.7	0.12 12.2	0.13 13.7	0.14 15.2	0.15 16.7	0.16 18.2	0.17 19.7
24	0.09 8.21	0.11 9.55	0.12 11.1	0.13 12.6	0.14 14.1	0.15 15.6	0.16 17.1	0.17 18.6	0.18 20.1	0.19 21.7
30	0.12 10.3	0.14 11.6	0.15 13.2	0.16 14.7	0.17 16.2	0.18 17.7	0.19 19.2	0.20 20.7	0.21 22.2	0.22 23.7
33	0.15 11.4	0.17 12.7	0.18 14.2	0.19 15.7	0.20 17.2	0.21 18.7	0.22 20.2	0.23 21.8	0.24 23.3	0.25 24.8
36	0.17 13.2	0.19 14.5	0.20 16.1	0.21 17.5	0.22 19.0	0.23 20.5	0.24 22.1	0.25 23.6	0.26 25.1	0.27 26.6
42	0.20 14.7	0.22 16.1	0.23 17.5	0.24 19.1	0.25 20.6	0.26 22.1	0.27 23.6	0.28 25.1	0.29 26.6	0.30 28.1
48	0.22 16.4	0.24 17.8	0.25 19.3	0.26 20.8	0.27 22.3	0.28 23.8	0.29 25.3	0.30 26.8	0.31 28.3	0.32 29.8

Notes:

1. **Pressure drops in feet H_2O/row.**
2. **Top row is based on water velocity of 1.0 FPS.**
3. **Bottom row is based on water velocity of 8.0 FPS.**
4. **Water velocity (FPS) = (GPM × 1.66)/finned width.**
5. **Based on W type coil.**

G. Electric Coils

1. Open coils: Use when personnel contact is not a concern. It is the most common type of electric coil used in HVAC applications.
   a. Air pressure drops:

        1. 400–900 fpm 0.01–0.10 WG.

    b. Minimum velocity:
        1. 400 fpm   6 KW/sq.ft. of duct.
        2. 500 fpm   8 KW/sq.ft. of duct.
        3. 600 fpm   10 KW/sq.ft. of duct.
        4. 700 fpm   12 KW/sq.ft. of duct.
        5. 800 fpm   14 KW/sq.ft. of duct.
        6. 900 fpm   16 KW/sq.ft. of duct.
        7. The manufacturer's literature should be consulted.

2. Finned tubular coils: Use when personnel contact is a concern.
    a. Air pressure drops:
        1. 400–900 fpm 0.02–0.20 WG.
    b. Minimum velocity:
        1. 400 fpm   6 KW/sq.ft. of duct.
        2. 500 fpm   9 KW/sq.ft. of duct.
        3. 600 fpm   12 KW/sq.ft. of duct.
        4. 700 fpm   15 KW/sq.ft. of duct.
        5. 800 fpm   17 KW/sq.ft. of duct.
        6. 900 fpm   20 KW/sq.ft. of duct.
        7. Manufacturer's literature should be consulted.

H. Air Handling Units

1. Blow through versus draw through: The terminology of blow through and draw through air handling units is generally in reference to the cooling coil location. If the cooling coil is downstream of the fan, the unit is considered a blow through air handling unit. If the cooling coil is upstream of the fan, the unit is considered a draw through air handling unit. See Figs. 25.4 and 25.5.

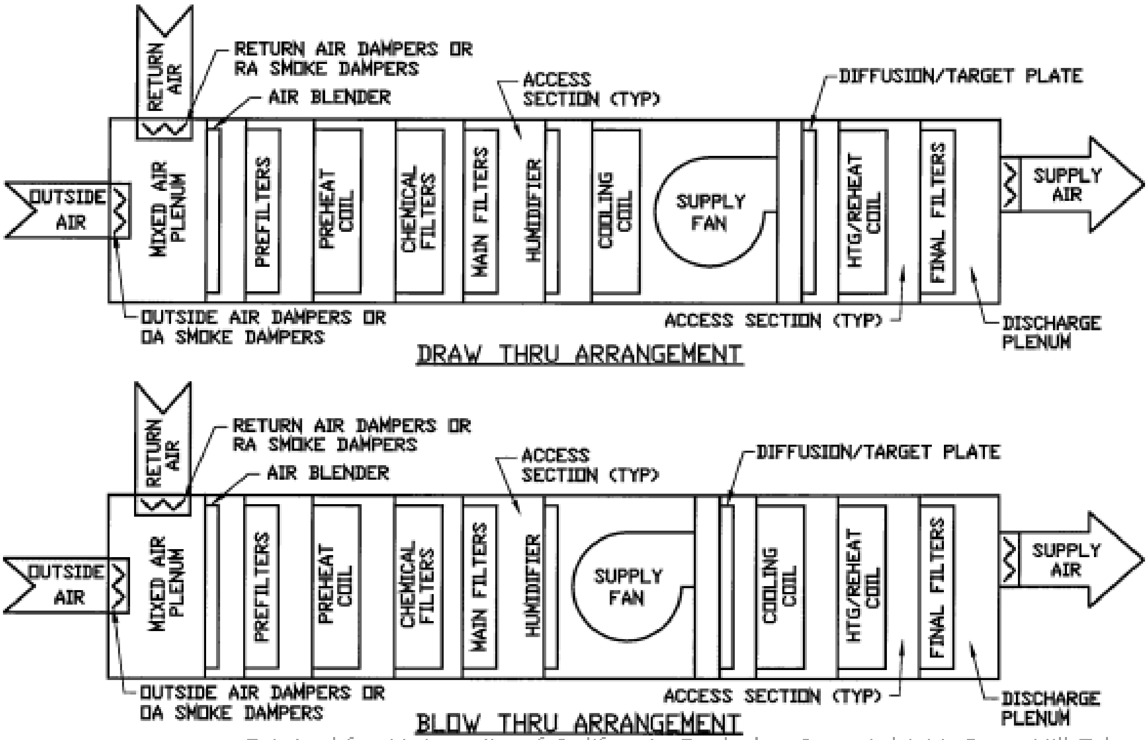


Figure 25.4. AIR HANDLING UNIT TERMINOLOGY.

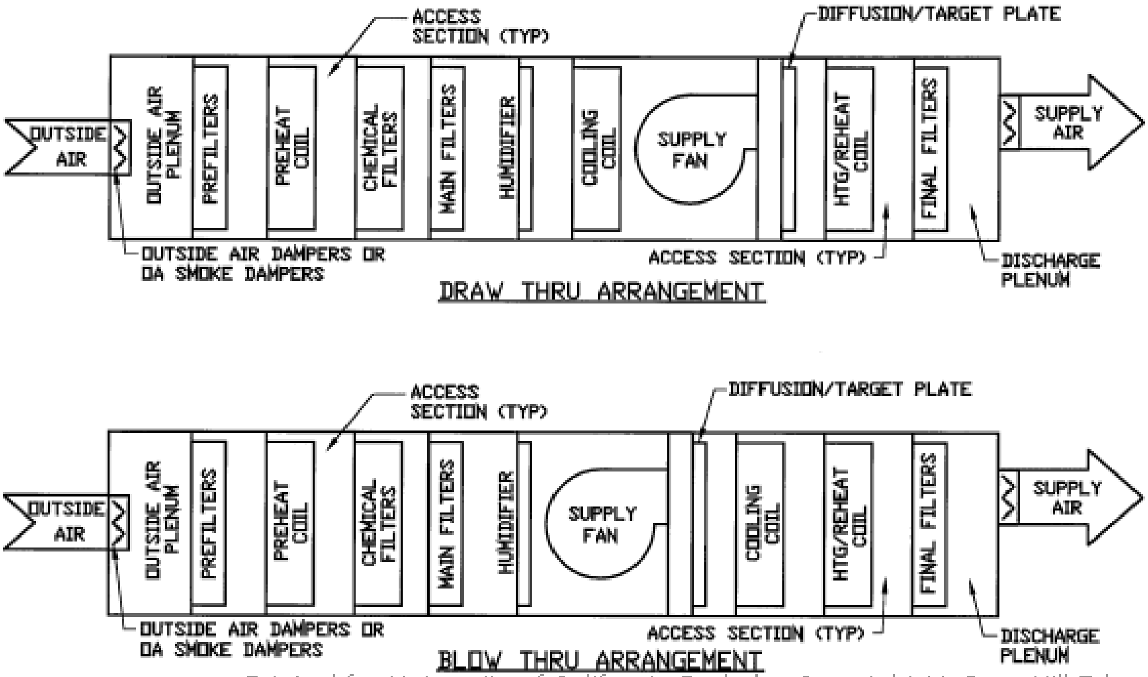


Figure 25.5. 100 PERCENT O.A. AIR HANDLING UNIT TERMINOLOGY.

2. Air handling unit terminology drawings show a number of different components. The design of air handling units may incorporate any number or combination of the components.

3. Coil arrangements:

a. Preheat/cooling: Preheat/cooling coil arrangements are used when mixed air or outside air design temperatures are below 40°F. The preheat coil heats the air to a desired setpoint level; quite often the setpoint is the cooling coil discharge temperature plus or minus 5°F. This setpoint temperature may or may not be adequate for maintaining space temperature for human comfort; however, it is generally adequate to prevent freezing and for equipment room heating.

b. Cooling/heating: Cooling/heating coil arrangements are used when the mixed air temperature will not fall below 40°F. Heating coils are designed to maintain space temperatures acceptable for human comfort or process requirements. Heating coils should not operate when cooling coils are operating. Automatic temperature control interlocks should be established to prevent simultaneous operation.

c. Heating/cooling: Heating/cooling coil arrangements are used when mixed air or outside air design temperatures are below 40°F. Heating coils are designed to maintain space temperatures acceptable for human comfort or process requirements. Heating coils should not operate when cooling coils are operating. Automatic temperature control interlocks should be established to prevent simultaneous operation.

d. Cooling/reheat: Cooling/reheat coil arrangements are used when air must be cooled to a temperature below that required to satisfy the space temperature to remove moisture and then heated to maintain space temperature.

4. Filter terminology:
   a. Prefilters (required):
      1. First stage of filtration.
      2. Filtration level guideline: 30–60 percent.
      3. Prefilters are required for air handling maintenance and operating requirements.
   b. Main filters (recommended):
      1. Second stage of filtration.
      2. Filtration level guideline: 60–90 percent.

3. Two stages of filtration are recommended in nearly all air handling systems because of current and future indoor air quality standards and requirements.

c. Final filters (optional):

1. Last stage of filtration.

2. Filtration level guideline: 90 percent to HEPA/ULPA filtration levels.

3. Use final filters whenever clean air is required at space (hospital operating rooms, nurseries, cleanrooms, laboratories).

5. Coils and filters located immediately downstream of fans will require a target/diffusion plate to distribute air evenly over the coil or filter and to prevent damage to that device, especially filters.

6. Access sections are recommended between each and every component in the air handling unit. However, the prefilters may be adjacent to the main filters without access between them, provided both sets of filters (prefilters and main filters) can be removed without having to remove the other (side access or upstream/downstream access).

7. Air blenders are used to promote proper mixing of the return air and the outside air flow streams and to prevent air stratification within the air handling unit. The use of air blenders will reduce the risk of localized freezing of water coils.

8. Smoke dampers and smoke detectors have not been shown on the air handling unit flow diagrams. Smoke dampers and smoke detectors may be required in the supply, return, or outside air ductwork depending on unit capacity, service, and code requirements. Verify smoke damper and smoke detector requirements with NFPA 90A, IBC, and local code requirements.

9. See Figs. 25.6 through 25.10 for examples of air handling units and a few of the many possible arrangements.

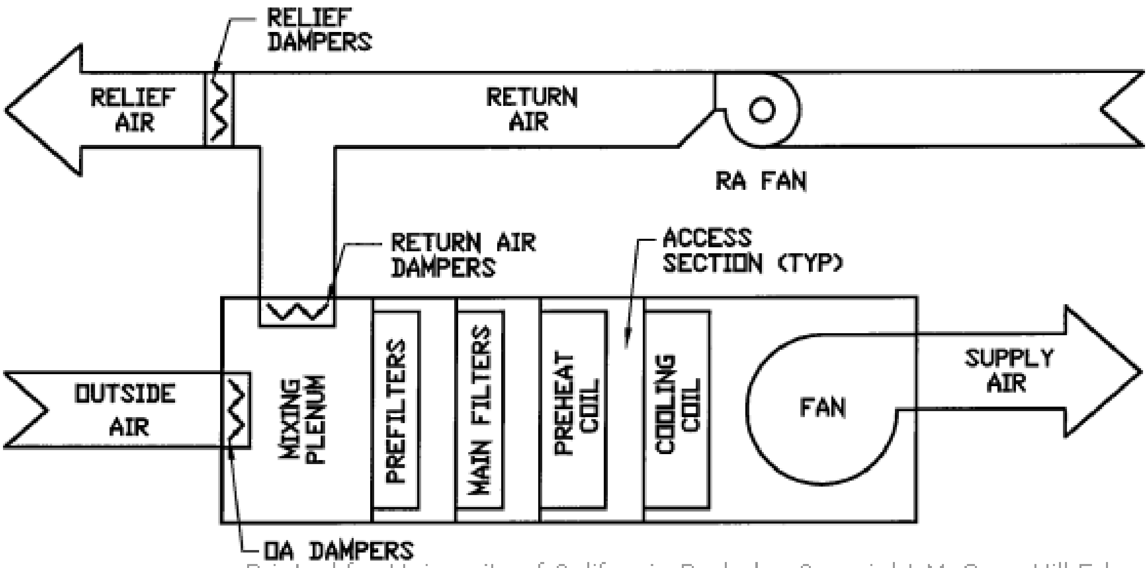


Figure 25.6. AHU EXAMPLE 1 AIR HANDLING UNITS—W/PREHEAT AND COOLING COILS W/RETURN AIR, RETURN FAN, AND POWERED RELIEF AIR.

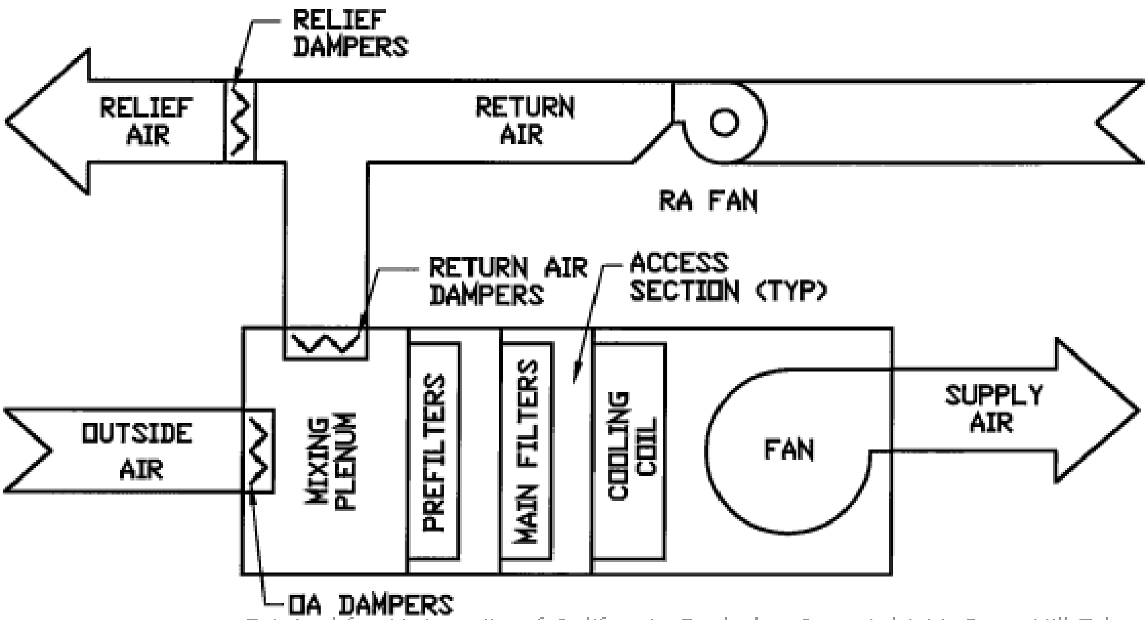


Figure 25.7. AHU EXAMPLE 2 AIR HANDLING UNITS—W/COOLING COIL ONLY W/RETURN AIR, RETURN FAN, AND POWERED RELIEF AIR.

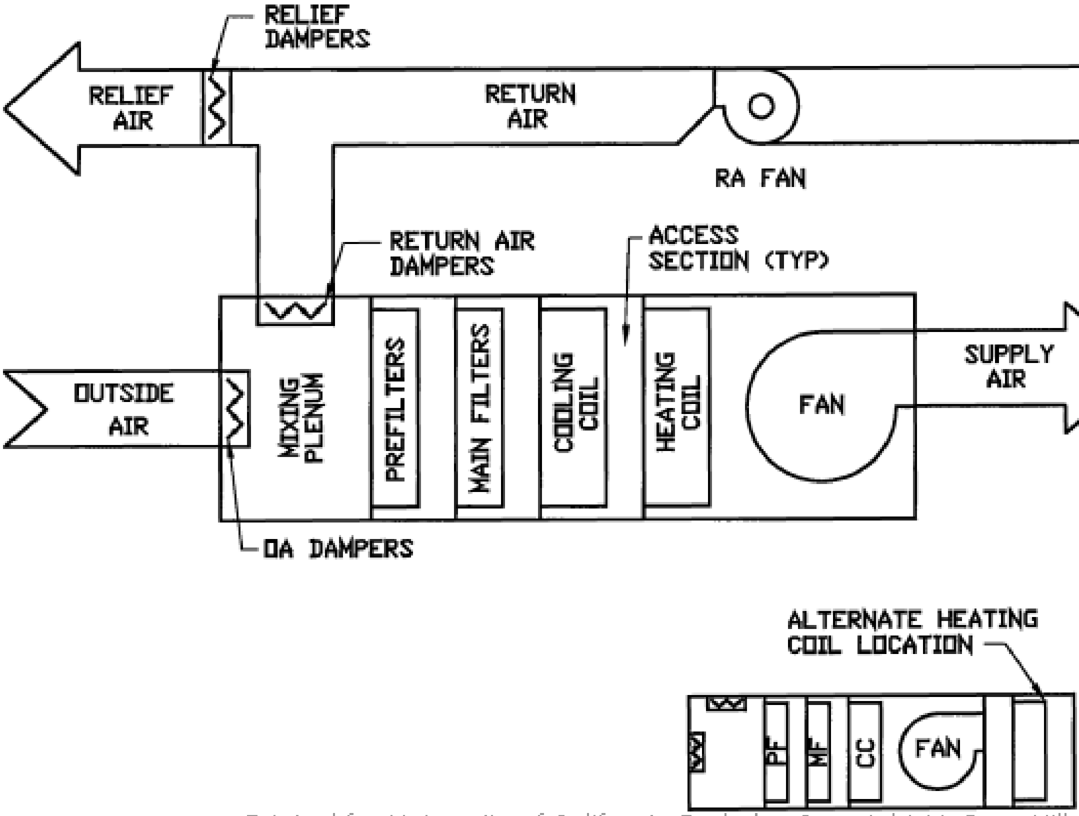


Figure 25.8. AHU EXAMPLE 3 AIR HANDLING UNITS—W/COOLING AND HEATING COILS W/RETURN AIR, RETURN FAN, AND POWERED RELIEF AIR.

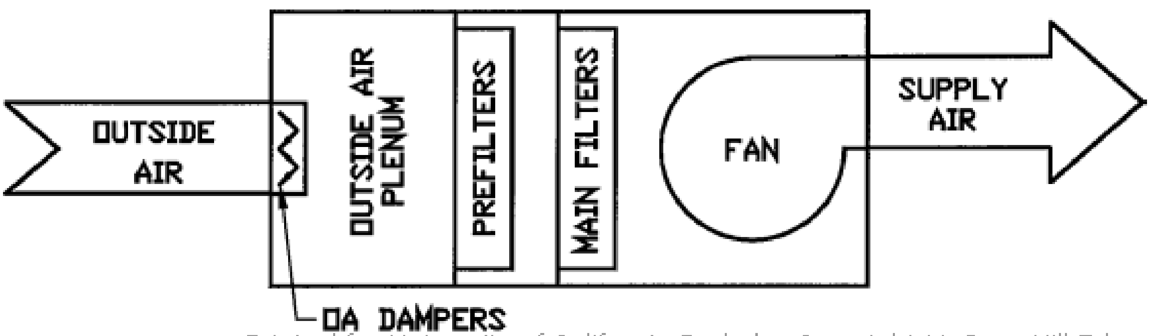


Figure 25.9. AHU EXAMPLE 4 AIR HANDLING UNITS—VENTILATING 100 PERCENT OUTSIDE AIR.

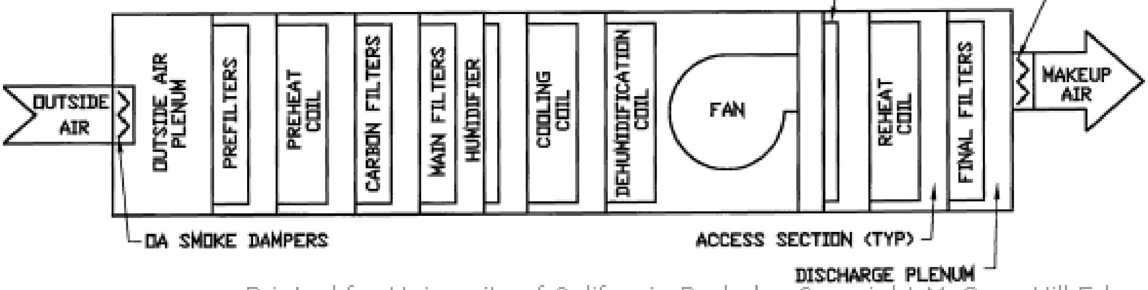


Figure 25.10. AHU EXAMPLE 5 CLEANROOM MAKEUP AIR HANDLING UNIT

W/CARBON FILTERS AND 100 PERCENT OUTSIDE AIR.

AccessEngineering
Authoritative content. Immediate solutions.

Part 26: Fans

26. Part 26: Fans

26.01. Fan Types and Size Ranges

A. Fan types and size ranges are shown in the following table.

FAN COMPARISON TABLE

Fan Type	Wheel\Drive Type	Sp in. W.G.	Wheel Dia. in.	CFM	hp
Utility Sets	FC/B BI/B FC/D	0–3 0–4 0–2.5	8–36 10–36 6–12	200–27,500 250–27,500 100–3,500	1/6–30 1/6–30 1/6–3
Centrifugal	SWSI-BI/B DWDI-BI/B SWSI-AF/B DWDI-AF/B	0–12 0–12 0–14 0–14	10–73 12–73 18–120 18–120	600–123,000 1,300–225,000 1,400–447,000 2,400–804,000	1/3–200 1/3–400 1/3–1500 3/4–2500
Tubular Centrifugal	BI/B BI/D	0–9	10–108	450–332,000	1/3–750
Vane Axial	–/B –/D	0–5 0–4	18–72 18–60	1,400–115,000	1/3–100 1/3–150

Notes:

FC—Forward Curved

FAN COMPARISON TABLE

Fan Type	Wheel\Drive Type	Sp in. W.G.	Wheel Dia. in.	CFM	hp
				1,200–148,000	
Tubeaxial	–/B –/D	0–1.5 0–1	12–60 18–48	900–76,000 2,600–48,000	1/3–25 1/4–15
Mixed Flow	–/B –/D	0–8.5 0–9.0	15–54 15–54	2,000–95,000 1,000–95,000	1/4–100 1/4–100
Propeller	–/B –/D	0–1 0–1	20–72 8–48	400–80,000 50–49,000	1/4–15 1/6–10
Roof Ventilator	BI/B BI/D	0–1.25 0–1	7–54 6–18	100–34,000 75–3,200	1/4–7.5 1/8–3/4
Roof Upblast	BI/B BI/D	0–1.25 0–1.25	9–48 9–14	200–26,000 300–3,100	1/4–5 1/8–1
Sidewall	BI/B BI/D	0–1.25 0–1	14–24 6–18	850–8,200 80–4,000	1/4–2 1/8–3/4
Inline Centrifugal	BI/B BI/D	0–2.25 0–1.75	7–36 6–16	60–22,600 60–5,100	1/4–10 1/8–2

Notes:

FC—Forward Curved

BI—Backward Inclined

AF—Backward Inclined Airfoil

B—Belt Drive

D—Direct Drive

DWDI—Double Width, Double Inlet

SWSI—Single Width, Single Inlet

B. Refer to Figure 26.1 for a photograph of a roof ventilator in its installed condition.

Figure 26.1. PHOTOGRAPH OF A ROOF VENTILATOR.

26.02. Fan Construction Classes

A. Fan construction classes are shown in the following table:

Fan Class	Maximum Total Pressure
I	3–3/4" W.G.
II	6–3/4" W.G.
III	12–3/4" W.G.
IV	Over 12–3/4" W.G.

26.03. Fan Selection Criteria

A. **Fan to be catalog rated for 15 percent greater static pressure (SP) than specified SP at specified volume.**

B. **Select the fan so that the specified volume is greater than at the apex of the fan curve.**

C. **Select the fan to provide a stable operation down to 85 percent of the design volume operating at a required speed for the specified conditions.**

D. **Specify SP at specified airflow.**

E. **Consider system effects. Fans are tested with open inlets and a length of straight duct on discharge. When field conditions differ from the test configuration, performance is reduced. Therefore, the fan must be selected at a slightly higher pressure to obtain the desired results.**

F. **Fan Design Arrangements (See Figure 26.2)**

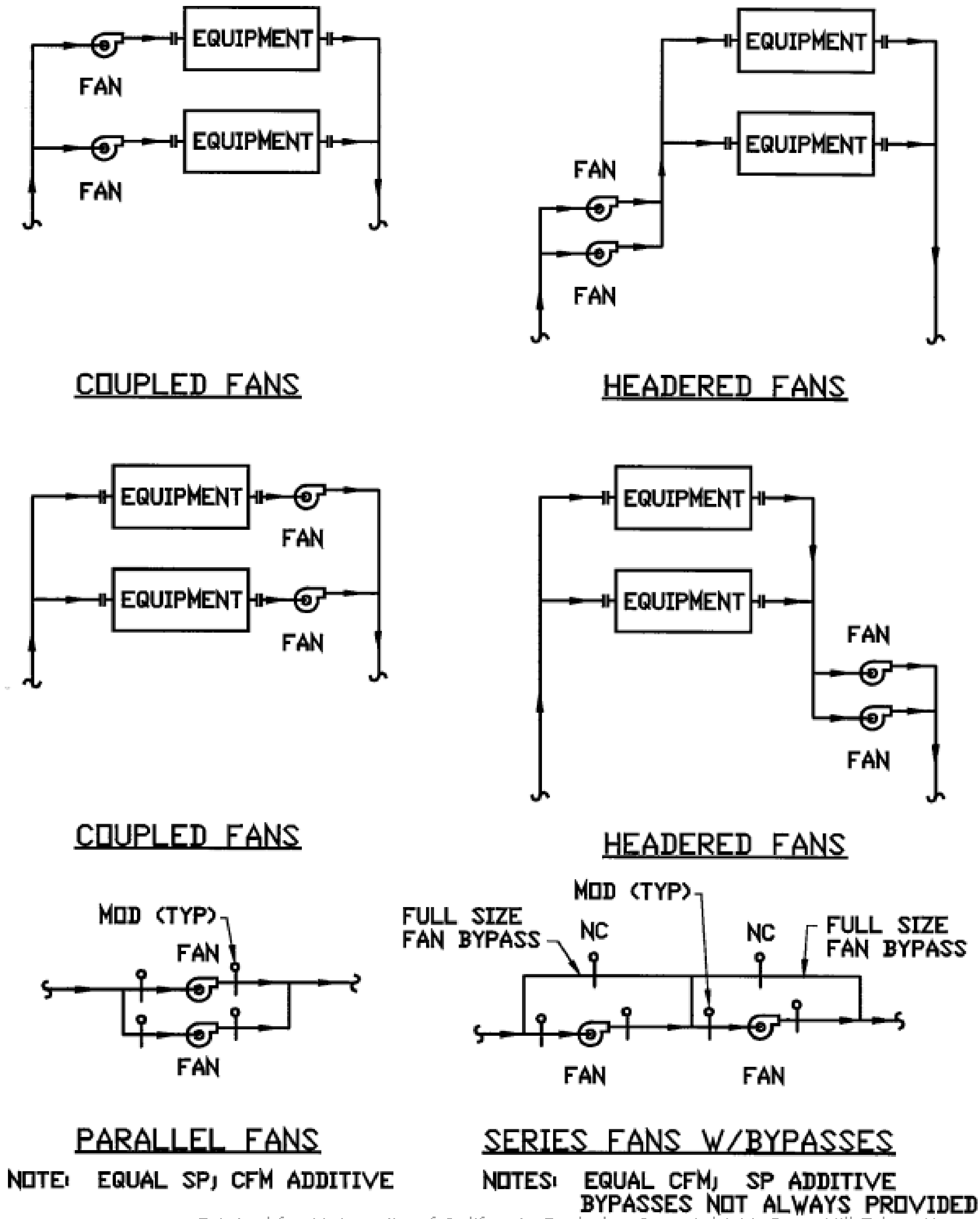


Figure 26.2. FAN SYSTEM ARRANGEMENTS.

1. Series Fan Operation: At equal CFM, static pressure is additive.
2. Parallel Fan Operation: At equal static pressure, CFM is additive.
3. Standby Fans: Standby fan arrangements are often used for reliability purposes in the event of fan failure. Standby fans may be provided with coupled or headered systems (see Figs. 26.3 and 26.4).

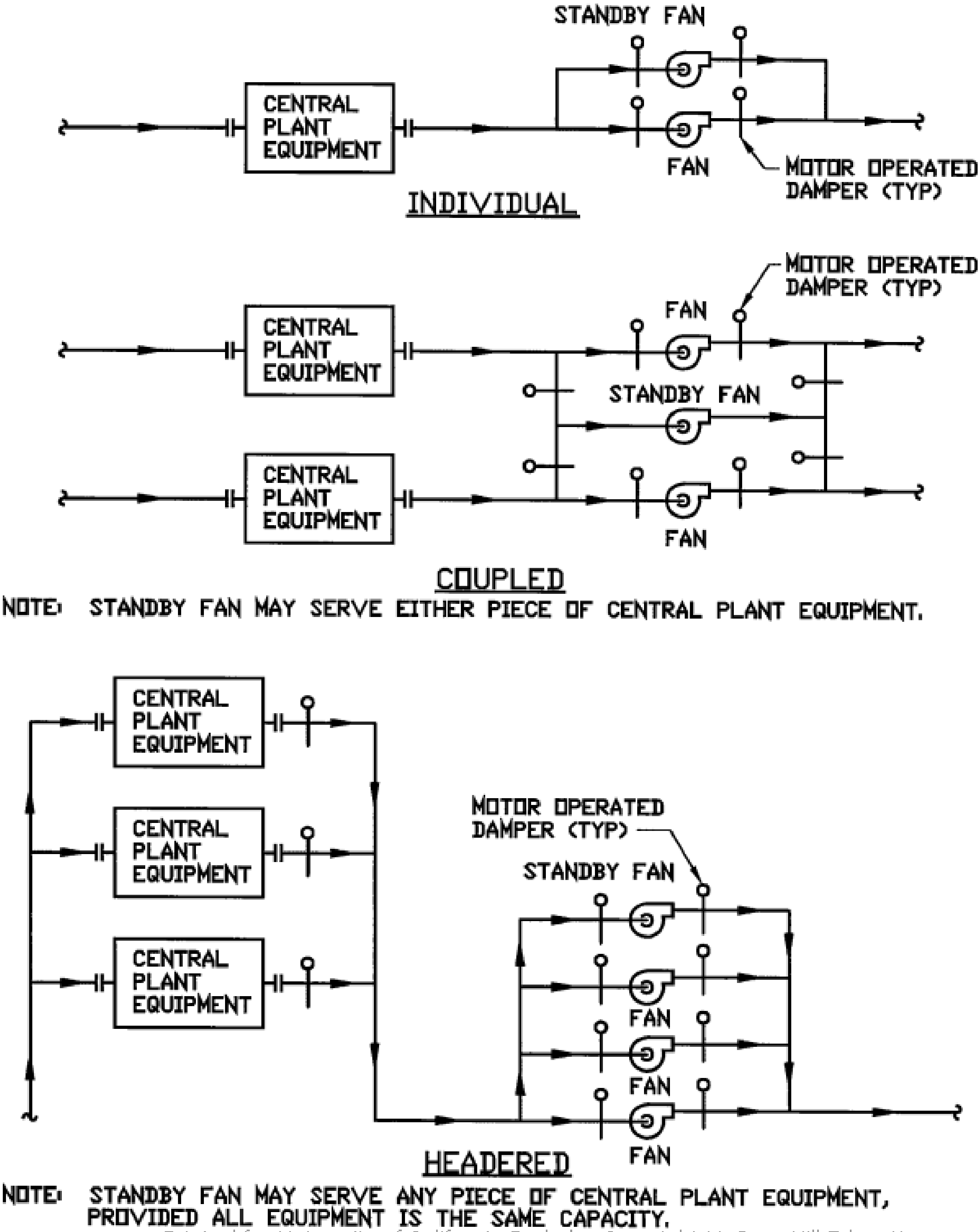


Figure 26.3. STANDBY FANS.

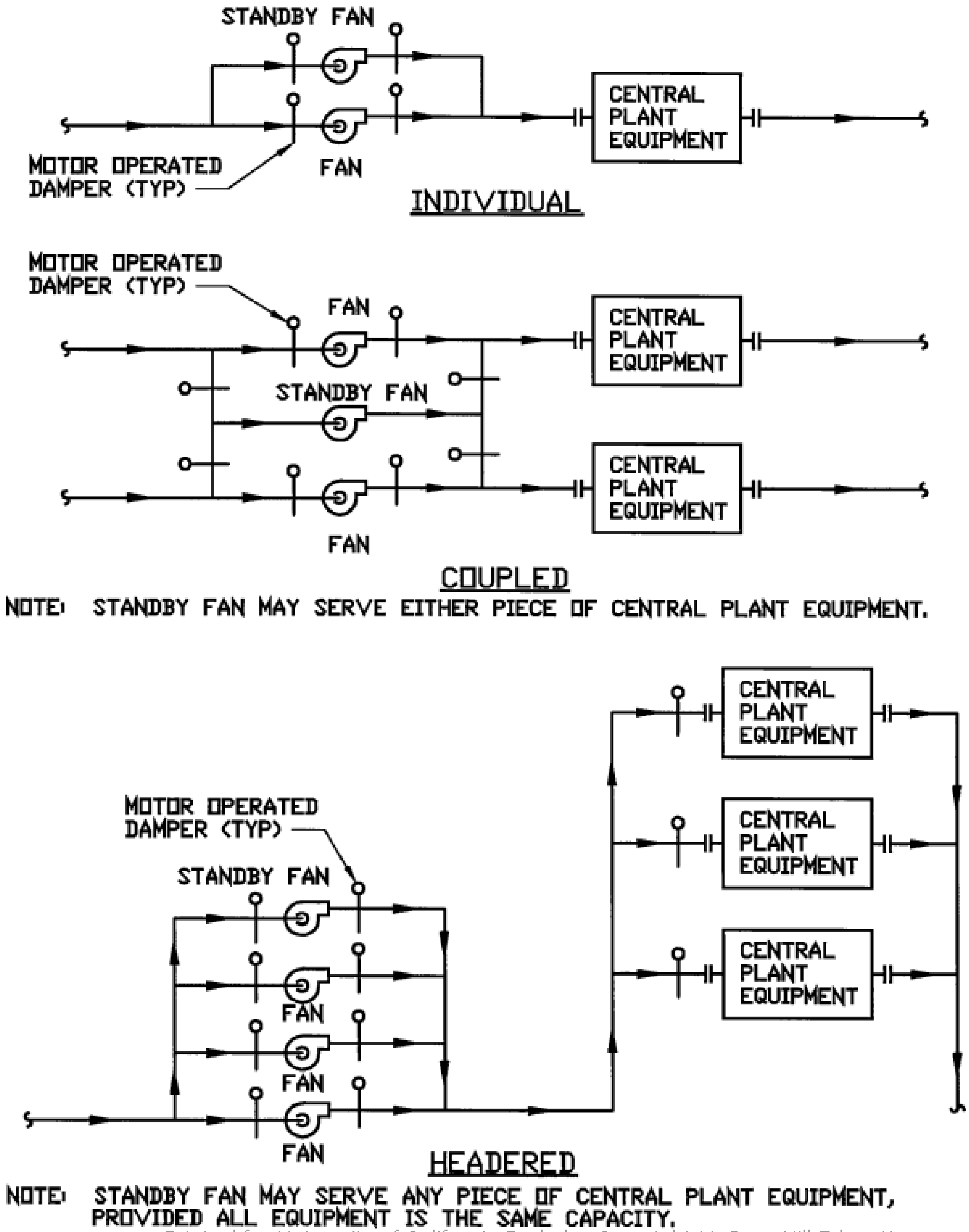


Figure 26.4. STANDBY FANS.

G. **Every attempt should be made to have 1.0–1.5 diameters of straight duct on the discharge of the fan as a minimum.**

H. **There should be a minimum of 1.0 diameter of straight duct between fan inlet and an elbow. In plenum installations, there should be a minimum of 0.75 of the wheel diameter between the fan inlet and the plenum wall.**

26.04. Fan Terms

A. ***Centrifugal*. Flow within the fan is substantially radial to the shaft.**

B. ***Axial*. Flow within the fan is substantially parallel to the shaft.**

C. ***Static Pressure*. Static pressure is the compressive pressure that exists in a confined airstream. Static pressure is a measure of potential energy available to produce flow and to maintain flow against resistance. Static pressure is exerted in all directions and can be positive or negative (vacuum).**

D. ***Velocity Pressure*. Velocity pressure is the measure of the kinetic energy resulting from the fluid flow. Velocity pressure is exerted in the direction of fluid flow. Velocity pressure is always positive.**

E. ***Total Pressure*. Total pressure is the measure of the total energy of the airstream. Total pressure is equal to static pressure plus velocity pressure. Total pressure can be either positive or negative.**

F. ***Quantity* of *Airflow*. Volume measurement expressed in Cubic Feet per Minute (CFM).**

G. ***Fan Outlet Velocity*. Fan airflow divided by the fan outlet area.**

H. ***Fan Velocity Pressure*. Fan velocity pressure is derived by converting fan velocity to velocity pressure.**

I. ***Fan Total Pressure*. Fan total pressure is equal to the fan's outlet total pressure minus the fan's inlet total pressure.**

J. ***Fan Static Pressure*. Fan static pressure is equal to the fan's total pressure minus the fan's velocity pressure. Numerically, it is equal to the fan's outlet static pressure minus the fan's inlet total pressure.**

K. ***Fan Horsepower*. Theoretical calculation of horsepower assuming there are no losses.**

L. ***Brake Horsepower (BHP)*. Brake horsepower is the actual power required to drive the fan.**

M. ***System Effect*. System effect is the reduced fan performance of the manufacturer's fan catalog data due to the difference between field**

installed conditions and laboratory test conditions (precisely defined inlet and outlet ductwork geometry assuring uniform entrance and exit velocities).

1. Maintain a minimum of three duct diameters of straight duct upstream and downstream of the fan inlet and outlet at 2,500 feet per minute (fpm) duct velocity or less. One additional duct diameter should be added for each 1,000 fpm above 2,500 fpm.

2. Recommend maintaining a minimum of five duct diameters of straight duct upstream and downstream of the fan inlet and outlet at 2,500 feet per minute (fpm) duct velocity or less. One additional duct diameter should be added for each 1,000 fpm above 2,500 fpm.

3. The system effect may require a range of 3–20 duct diameters of straight duct upstream and downstream of the fan inlet and outlet.

26.05. AMCA Spark Resistant Construction

A. **Type A. All parts of the fan in contact with the airstream must be made of nonferrous material.**

B. **Type B. The fan shall have a nonferrous impeller and nonferrous ring about the opening through which the shaft passes. Ferrous hubs, shafts, and hardware are allowed if construction is such that a shift of the impeller or shaft will not permit two ferrous parts of the fan to rub or strike.**

C. **Type C. The fan must be so constructed that a shift of the wheel will not permit two ferrous parts of the fan to rub or strike.**

26.06. Centrifugal Fans

A. Forward Curved (FC) Fan

1. FC fans have a peak static pressure curve corresponding to the region of maximum efficiency, slightly to the right. Best efficiency at low or medium pressure (0–5 in. W.G.).

2. BHP is minimum at no delivery and increases continuously with increasing flow, with maximum BHP occurring at free delivery.

3. They have a steep pressure volume performance curve; therefore, a slight change in pressure will not greatly affect CFM.

4. Fan blades curve toward the direction of rotation.

5. Advantages:
   a. Low cost. Less expensive than BC, BI, or AF fans.

   b. Low speed (400–1,200 RPM) minimizes the shaft and bearing sizes.

   c. Large operating range: 30–80 percent wide open CFM.

   d. Highest efficiency occurs: 40–50 percent wide open CFM.

6. Disadvantages:
   a. Possibility of paralleling in multiple fan applications.

   b. Possibility of overloading.

   c. Weak structurally: Not capable of high speeds necessary for developing high static pressures.

7. Used primarily in low- to medium-pressure HVAC applications: central station air handling units, rooftop units, packaged units, residential furnaces.

8. High CFM, low static pressure.

B. Backward Inclined (BI) and Backward Curved (BC) Fans

1. BC fans have a peak static pressure curve that occurs to the left of the maximum static efficiency. Best efficiency at medium pressure (3.5–5.0 in. W.G.).

2. BHP increases to a maximum, and then decreases. They are nonoverloading fans.

3. They have a steep pressure volume performance curve; therefore, a slight change in pressure will not greatly affect CFM.

4. Fan operates at high speeds—1,200–2,400 RPM—about double that of FC fans for similar air quantity.

5. Blades curve away from, or incline from, the direction of rotation.

6. BI fans are less expensive than BC fans but do not have as great a range of high efficiency operation.

7. Advantages:
   a. Higher efficiencies than FC fans.

   b. Highest efficiency occurs: 50–60 percent wide open CFM.

   c. Good pressure characteristics.

   d. Stronger structural design makes it suitable for higher static pressures.

   e. Nonoverloading power characteristics.

8. Disadvantages:
   a. Higher speeds require larger shaft and bearings.

   b. Has a larger surge area than a forward curved fan.

   c. Operating range 40–80 percent of wide open CFM.

   d. Can be noisier than FC fans.

   e. More expensive than FC fans.

9. Used primarily in large HVAC applications where power savings are significant. Can be used in low-, medium-, and high-pressure systems.

C. Airfoil Fans (AF)

1. AF fans have a peak static pressure curve that occurs to the left of the maximum static efficiency. Best efficiency at medium pressure (4.0–8.0 in. W.G.).

2. BHP increases to a maximum, and then decreases. They are nonoverloading fans.

3. They have a steep pressure volume performance curve; therefore, a slight change in pressure will not greatly affect CFM.

4. Fan operates at high speeds—1,200–2,800 RPM—about double that of FC fans for similar air quantity.

5. Blades have an aerodynamic shape similar to an airplane wing and are backwardly curved (away from direction of rotation).

6. Advantages:
   a. Higher efficiencies than FC fans.

b. Highest efficiency occurs: 50–60 percent wide open CFM.

c. Good pressure characteristics.

d. Stronger structural design makes it suitable for higher static pressures.

e. Nonoverloading power characteristics.

7. Disadvantages:
   a. Higher speeds require a larger shaft and bearings.

   b. Has a larger surge area than a forward curved fan.

   c. Operating range 40–80 percent of wide open CFM.

   d. Can be noisier than FC fans.

   e. Most expensive centrifugal fan.

8. Used primarily in large HVAC applications where power savings are significant. Can be used in low-, medium-, and high-pressure systems.

9. Airfoil blade fans have a slightly higher efficiency and the surge area is slightly larger than backward inclined or backward curved fans.

D. Radial (RA) Fans

1. Radial fans have self-cleaning blades.

2. Fan horsepower increases with an increase in air quantity (overloads), while static pressure decreases.

3. RA fans operate at high speed and pressure—2,000–3,000 RPM.

4. Blades radiate from the center along the radius of fan.

5. Used in industrial applications to transport dust, particles, or materials handling. Not commonly used in HVAC applications.

26.07. Axial Fans

A. Propeller Fans

1. Low pressure, high CFM fans.

2. Horsepower is lowest at maximum flow.

3. Maximum efficiency is approximately 50 percent and is reached near free delivery.

4. No ductwork.

5. Blade rotation is perpendicular to the direction of airflow.

6. Advantages:
    a. High volumes, low pressures.

    b. BHP is lowest at free delivery.

    c. Inexpensive.

    d. Operates at relatively low speeds—900–1,800 RPM.

7. Disadvantages:
    a. Cannot handle static pressure.

    b. BHP increases with static pressure; could overload and shut off.

    c. Air delivery decreases with increases in air resistance.

B. Tubeaxial Fans

1. Heavy duty propeller fans arranged for duct connection. Fan blades have aerodynamic configuration.

2. Slightly higher efficiency than propeller fans.

3. Discharge air pattern is circular in shape and swirls, producing higher static losses in the discharge duct.

4. Used primarily in low- and medium-pressure, high-volume, ducted HVAC applications where the discharge side is not critical. Also used in industrial applications: fume hoods, spray booths, drying ovens.

5. Fans operate at high speeds—2,000–3,000 RPM.

6. Fans are noisy.

7. Fans may be constructed to be overloading or nonoverloading. Nonoverloading type fans are more common.

8. Advantages:
   a. Straight through design.
   b. Space savings.
   c. Capable of higher static pressures than propeller fans.
9. Disadvantages:
   a. The discharge swirl creates higher pressure drops.
   b. High noise level.

C. Vaneaxial Fans

1. Vaneaxial fans are tubeaxial fans with additional vanes to increase efficiency by straightening out airflow.
2. Vaneaxial fans are more costly than tubeaxial fans.
3. High-pressure characteristics with medium flow rate capabilities.
4. Fans operate at high speeds—2,000–3,000 RPM.
5. Fans are noisy.
6. Fans may be constructed to be overloading or nonoverloading. Nonoverloading type fans are more common.
7. Typical selection: 65–95 percent wide open CFM.
8. Used in general HVAC applications—low-, medium-, and high-pressure—where straight through flow and compact installation are required. Also used in industrial applications: usually more compact than comparable centrifugal type fans for the same duty.
9. Advantages:
   a. Discharge vanes increase efficiency and reduce discharge losses.
   b. Reduced size and straight through design.
   c. Space savings.
   d. Capable of higher static pressures than propeller fans.
10. Disadvantages:
    a. Maximum efficiency only 65 percent.

b. Selection range: 65–90 percent wide open CFM.

c. High noise level.

D. Tubular Centrifugal Fans

1. Tubular centrifugal fans are similar to backward inclined centrifugal fans except that the fan capacity and pressure capabilities are lower.

2. Tubular centrifugal fans have a lower efficiency than backward inclined centrifugal fans.

3. Tubular centrifugal fans have a peak static pressure curve that occurs to the left of the maximum static efficiency.

4. BHP increases to a maximum, and then decreases. They are nonoverloading fans.

5. They have a steep pressure volume performance curve; therefore, a slight change in pressure will not greatly affect CFM.

6. The fan operates at high speeds—1,200–2,400.

7. Blades curve away from, or incline from, the direction of rotation.

8. Advantages:
   a. Good pressure characteristics.

   b. Nonoverloading power characteristics.

   c. The fan has straight through flow for inline duct applications.

9. Disadvantages:
   a. Higher speeds require a larger shaft and bearings.

   b. An operating range 40–80 percent of wide open CFM.

   c. Can be noisy.

10. Primarily used for low-pressure, return air HVAC systems.

E. Mixed Flow Fans

1. Mixed flow fans combine the best properties of tubeaxial, vaneaxial, and tubular centrifugal fans.

2. Mixed flow fans operate at a lower RPM than tubeaxial, vaneaxial, or centrifugal fans, resulting in less noise.

3. Used in general HVAC applications, low-, medium-, and high-pressure, where straight through flow and compact installation are required. Also used in industrial applications: usually more compact than comparable centrifugal type fans for the same duty.

4. Advantages:
   a. Less noisy than either the tubeaxial or vaneaxial fans.

   b. More efficient and therefore reduced horsepower requirements over tubeaxial, vaneaxial, or tubular centrifugal fans.

   c. Smaller physical size for equal airflow and static pressure requirements than tubeaxial, vaneaxial, or tubular centrifugal fans.

   d. Generally less expensive than comparable tubeaxial, vaneaxial, or tubular centrifugal fans.

26.08. Installation and Clearance Requirements

A. **The minimum recommended clearance around fans is 24 inches. Maintain minimum clearance as required to open access and control doors on fans for service, maintenance, and inspection.**

B. **Mechanical room locations and placement must take into account how fans can be moved into and out of the building during initial installation and after construction for maintenance and repair and/or replacement.**

26.09. Fan Rotation and Discharge Positions

See Fig. 26.5.

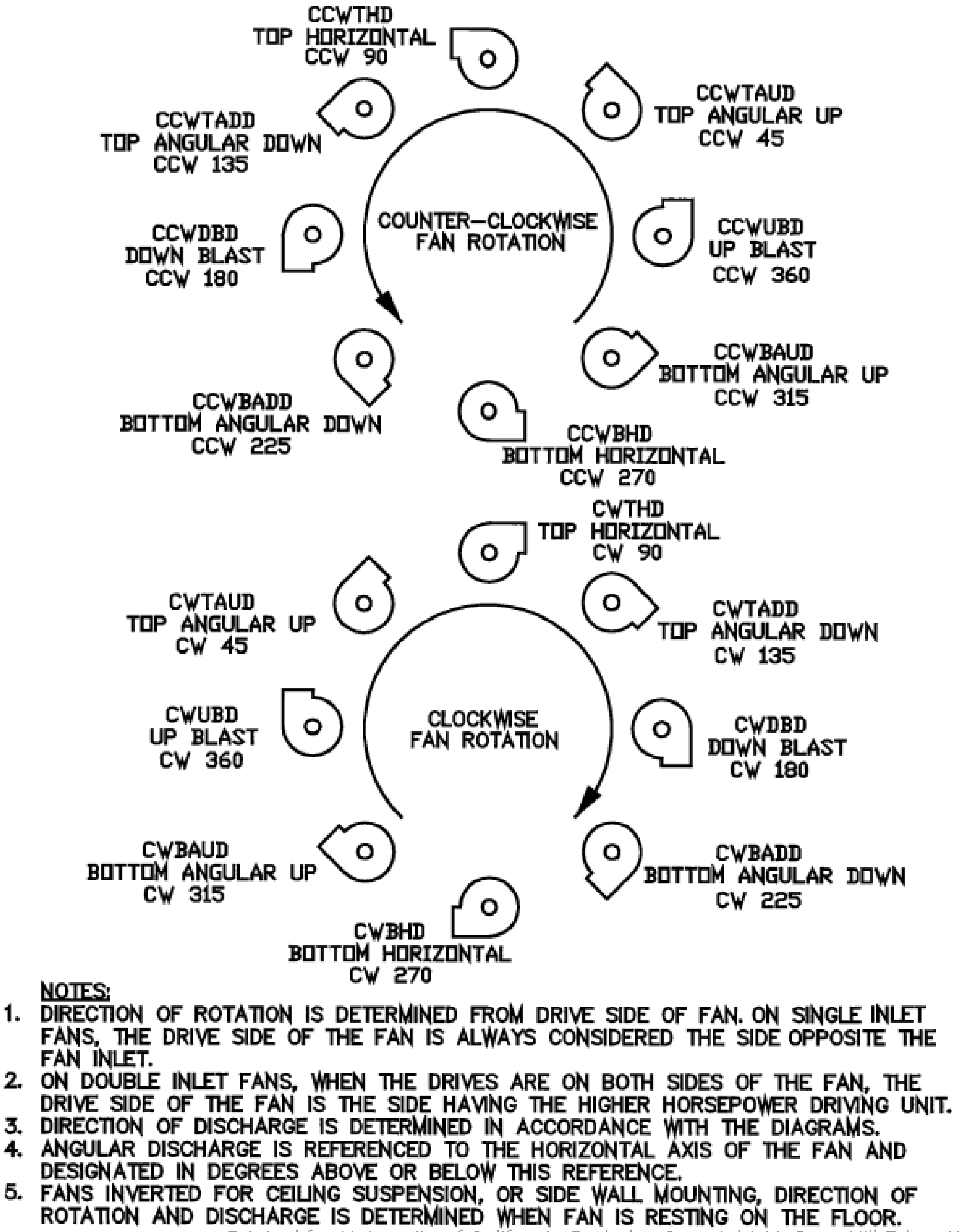


Figure 26.5. FAN ROTATION AND DISCHARGE POSITIONS.

26.10. Fan Motor Positions

See Figs. 26.6 and 26.7.

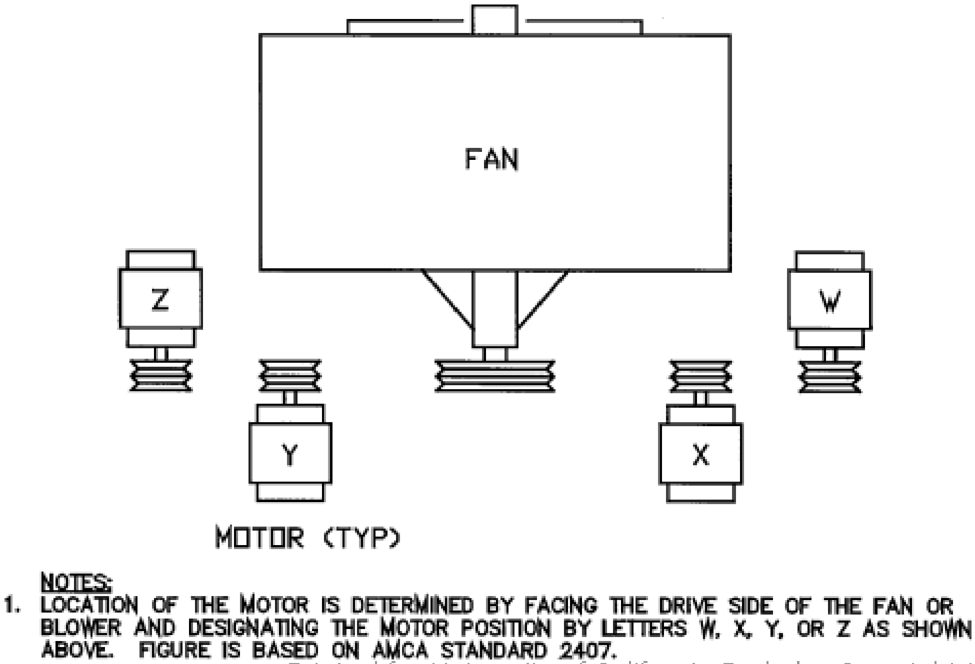


Figure 26.6. CENTRIFUGAL FAN MOTOR ARRANGEMENTS.

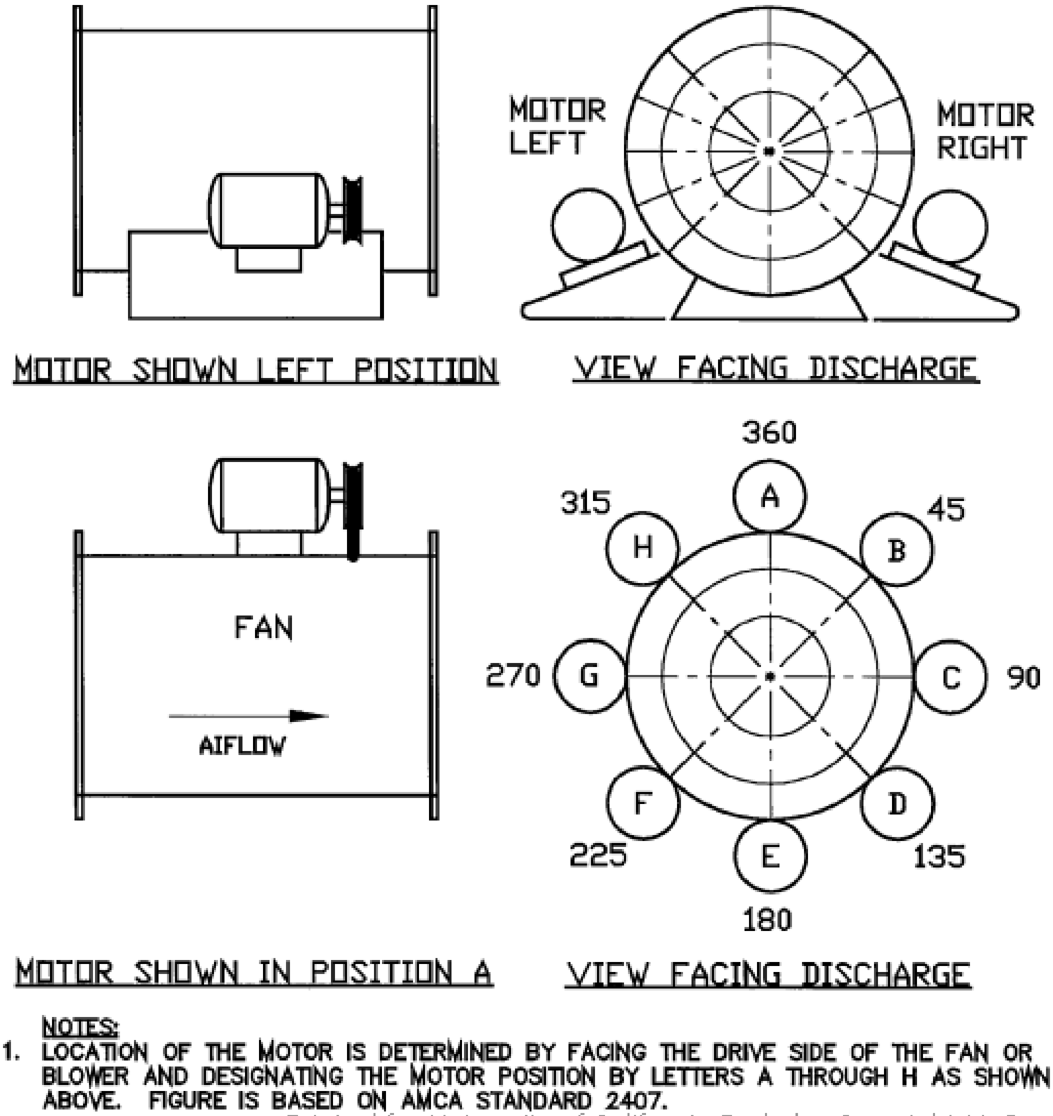


Figure 26.7. INLINE FAN MOTOR ARRANGEMENTS. Refer to the online resource for Sections 26.11 Fan Drive Arrangements, 26.12 Centrifugal Fan

Inlet Box Positions, and 26.13 Centrifugal Fan Damper Arrangements for Reversible Flow. www.mheducation.com/HVACequations

26.11. Fan Drive Arrangements

See Figs. 26.8 to 26.14.

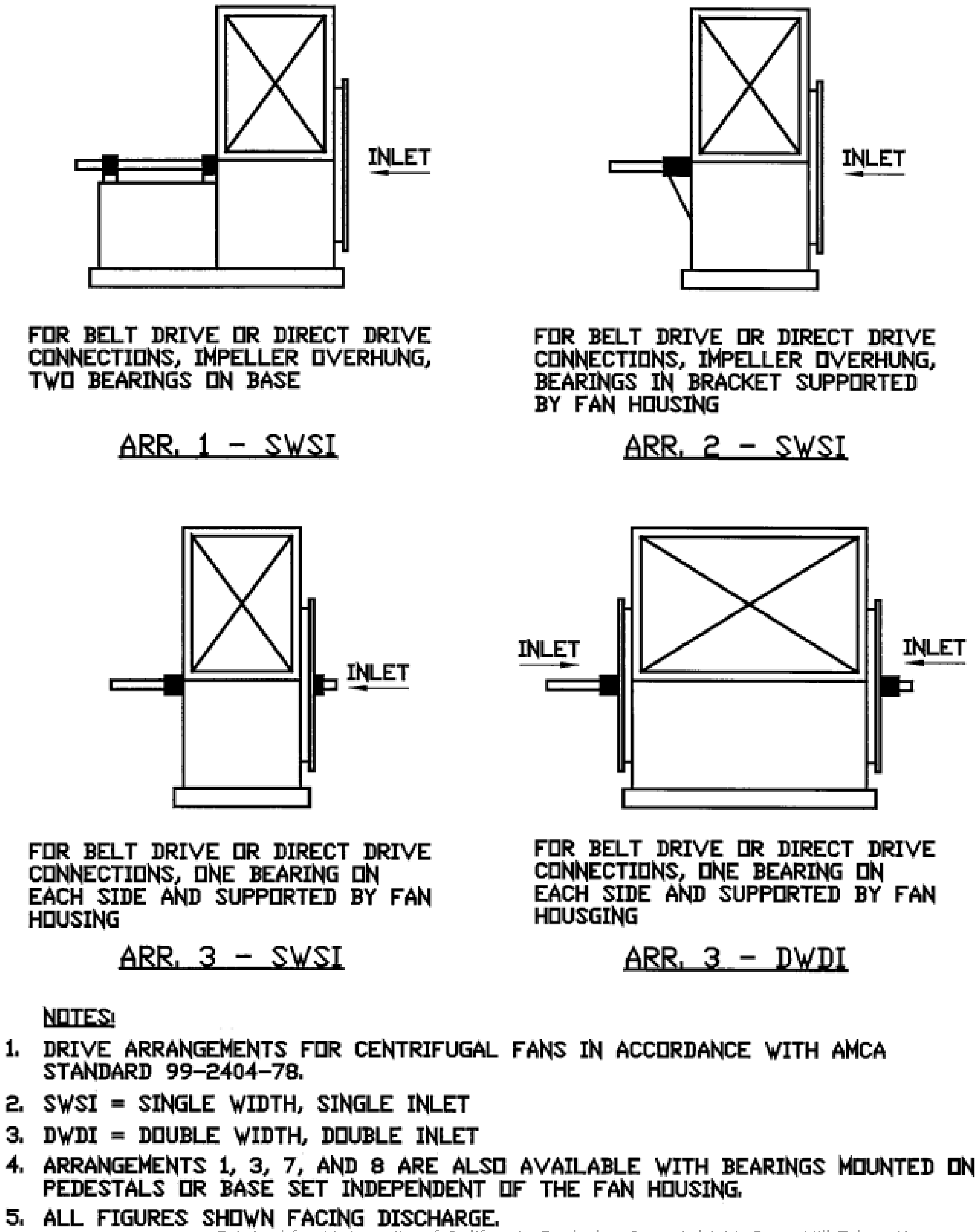


Figure 26.8. CENTRIFUGAL FAN DRIVE ARRANGEMENTS.

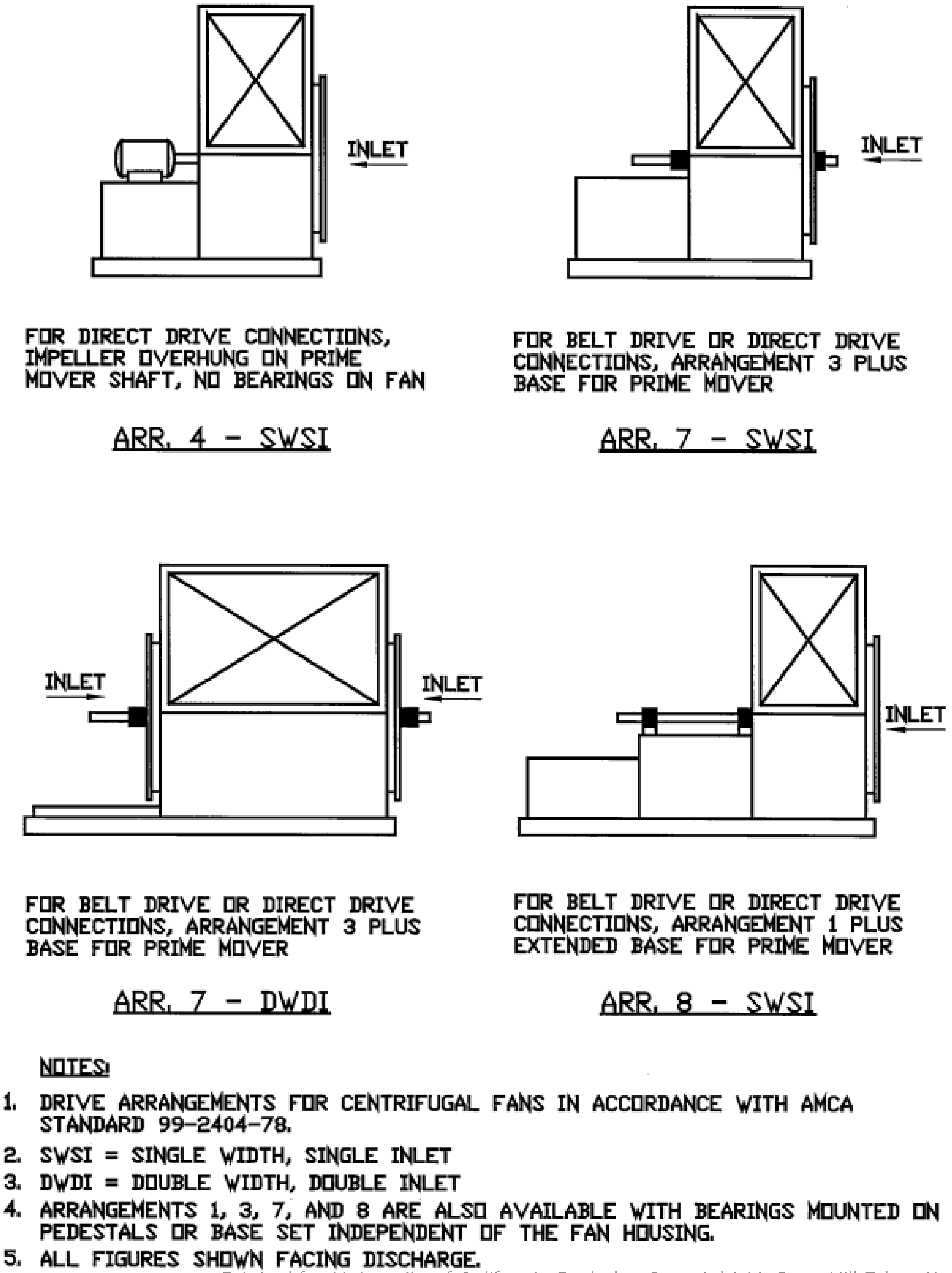
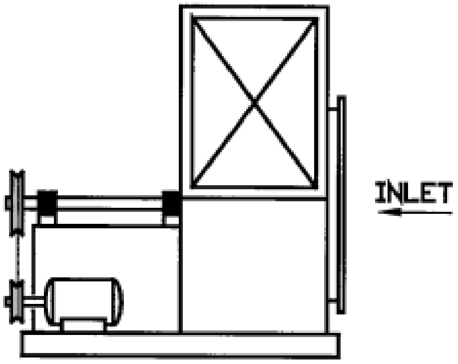
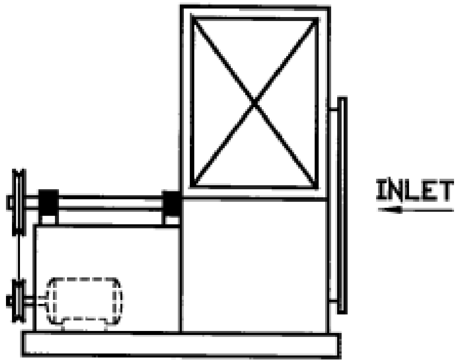


Figure 26.9. CENTRIFUGAL FAN DRIVE ARRANGEMENTS.



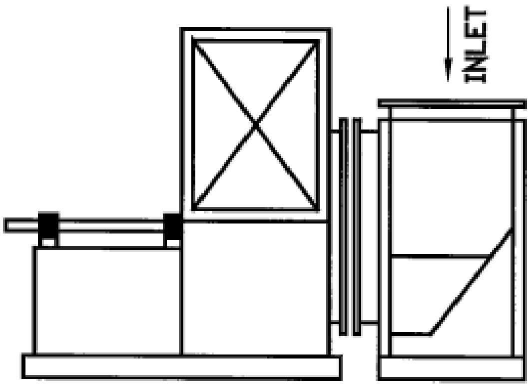
FOR BELT DRIVE CONNECTIONS, IMPELLER OVERHUNG, TWO BEARINGS WITH PRIME MOVER OUTSIDE BASE

ARR. 9 - SWSI



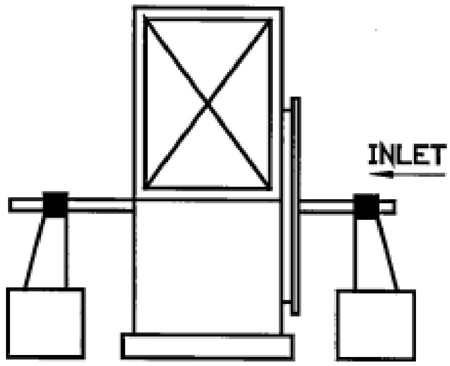
FOR BELT DRIVE CONNECTIONS, IMPELLER OVERHUNG, TWO BEARINGS WITH PRIME MOVER INSIDE BASE

ARR. 10 - SWSI



FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, IMPELLER OVERHUNG, TWO BEARINGS ON BASE

ARR. 1 - SWSI W/INLET BOX



FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, HOUSING IS SELF-SUPPORTING, ONE BEARING ON EACH SIDE SUPPORTED BY INDEPENDENT PEDESTALS

ARR. 3 - SWSI W/INDEPENDENT PEDESTAL BASE

NOTES:

1. DRIVE ARRANGEMENTS FOR CENTRIFUGAL FANS IN ACCORDANCE WITH AMCA STANDARD 99-2404-78.
2. SWSI = SINGLE WIDTH, SINGLE INLET
3. DWDI = DOUBLE WIDTH, DOUBLE INLET
4. ARRANGEMENTS 1, 3, 7, AND 8 ARE ALSO AVAILABLE WITH BEARINGS MOUNTED ON PEDESTALS OR BASE SET INDEPENDENT OF THE FAN HOUSING.
5. ALL FIGURES SHOWN FACING DISCHARGE.

Figure 26.10. CENTRIFUGAL FAN DRIVE ARRANGEMENTS.

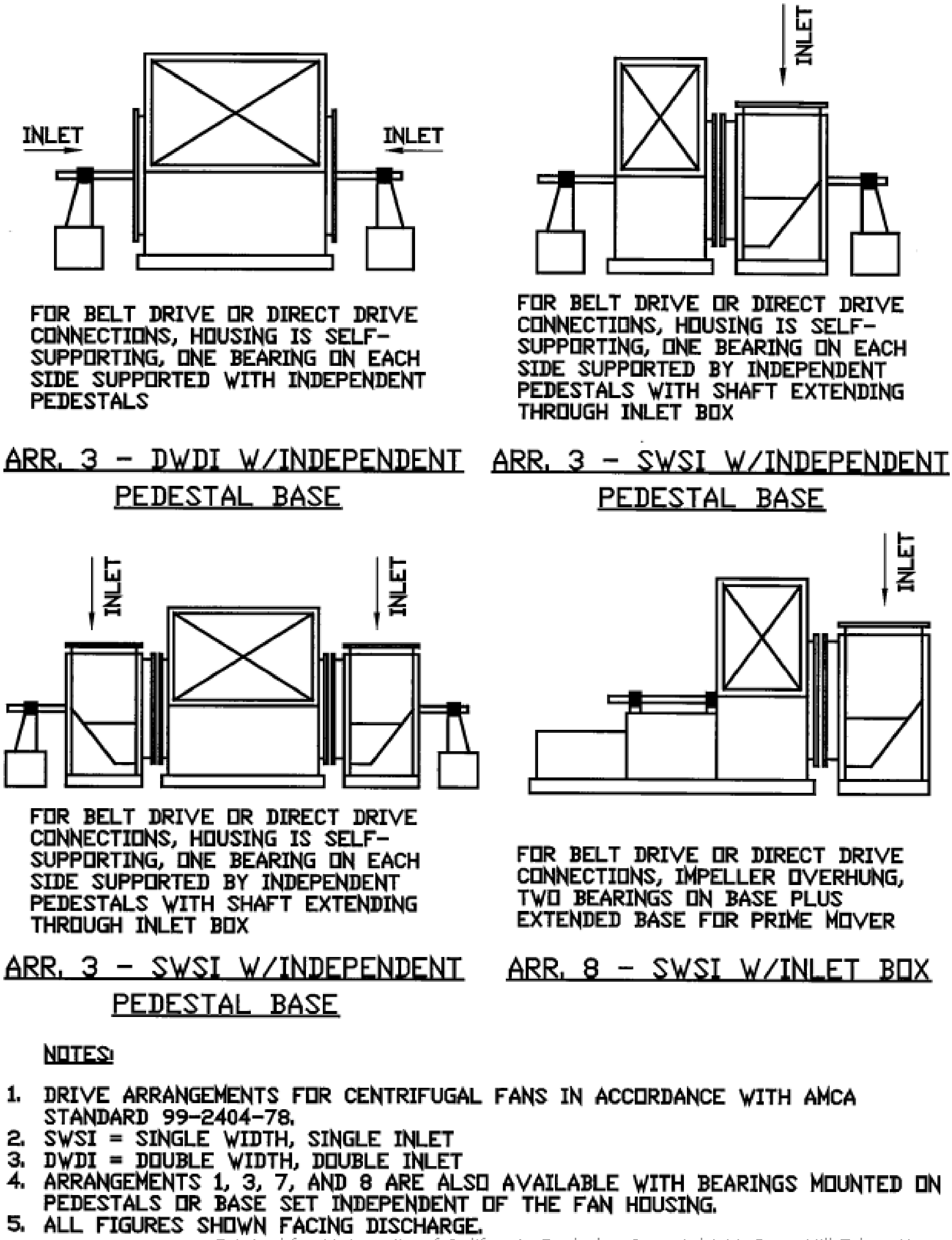


Figure 26.11. CENTRIFUGAL FAN DRIVE ARRANGEMENTS.

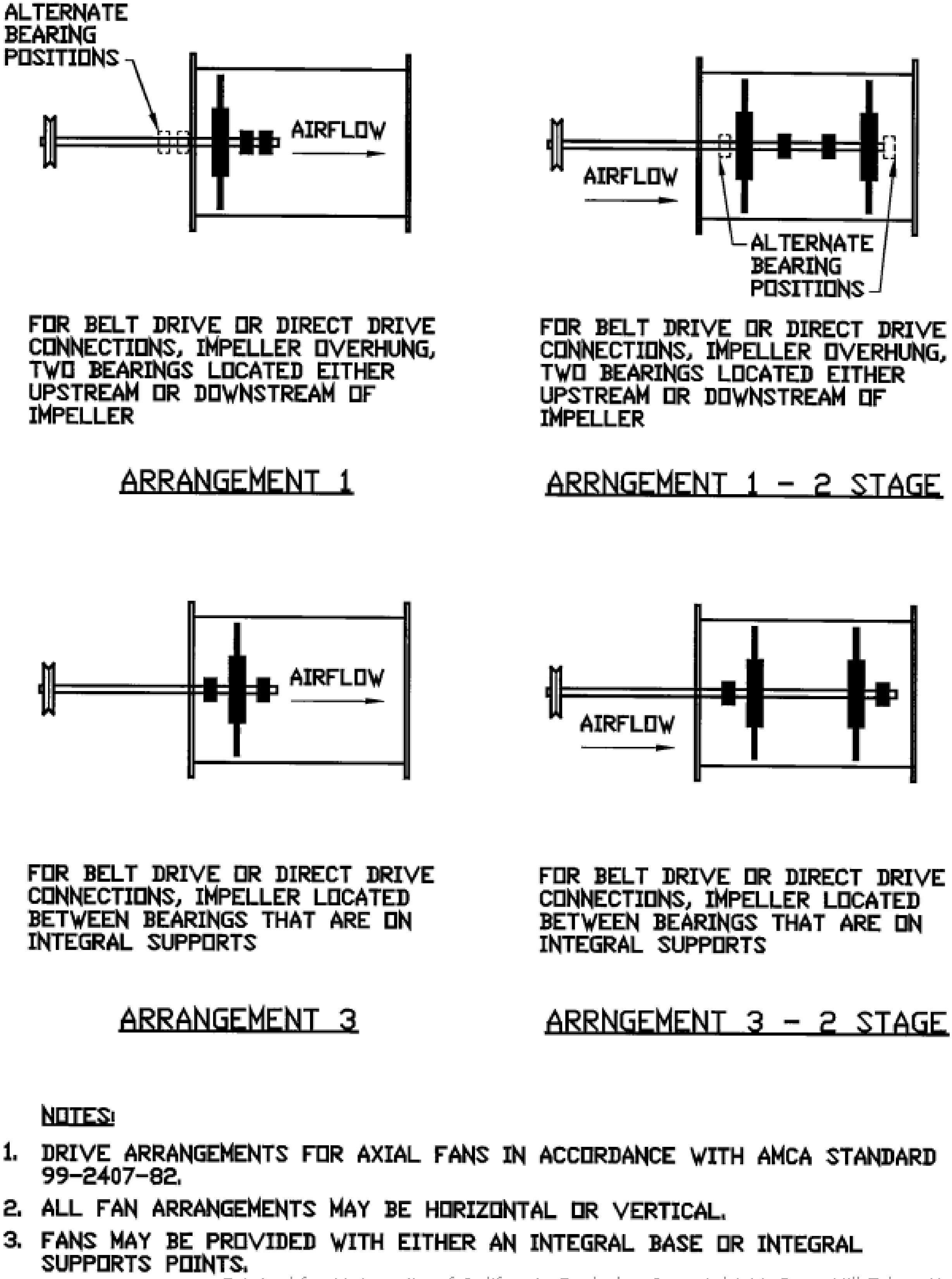
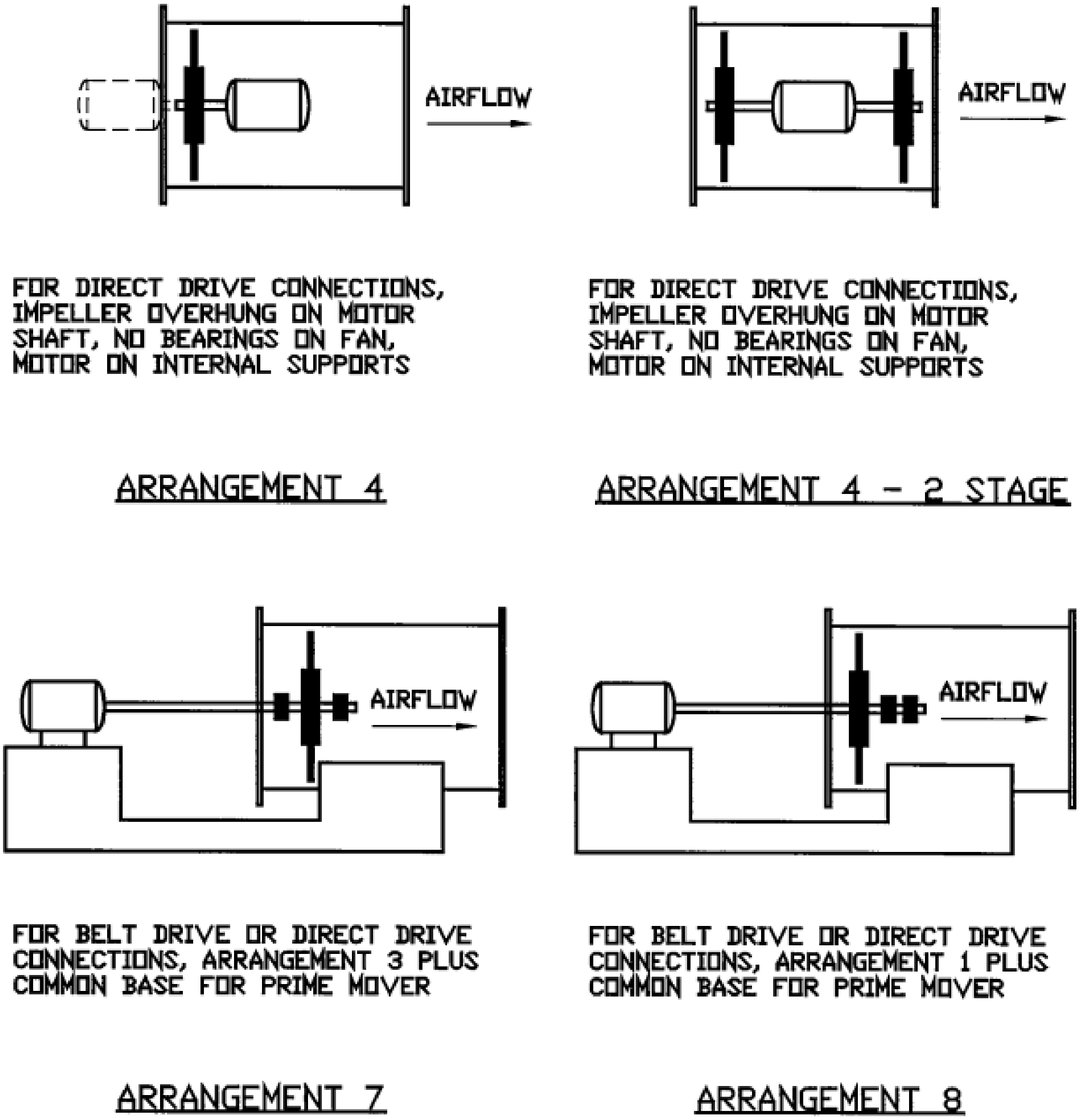


Figure 26.12. AXIAL FAN DRIVE ARRANGEMENTS.



NOTES:

1. DRIVE ARRANGEMENTS FOR AXIAL FANS IN ACCORDANCE WITH AMCA STANDARD 99-2407-82.
2. ALL FAN ARRANGEMENTS MAY BE HORIZONTAL OR VERTICAL.
3. FANS MAY BE PROVIDED WITH EITHER AN INTEGRAL BASE OR INTEGRAL SUPPORTS POINTS.

Figure 26.13. AXIAL FAN DRIVE ARRANGEMENTS.

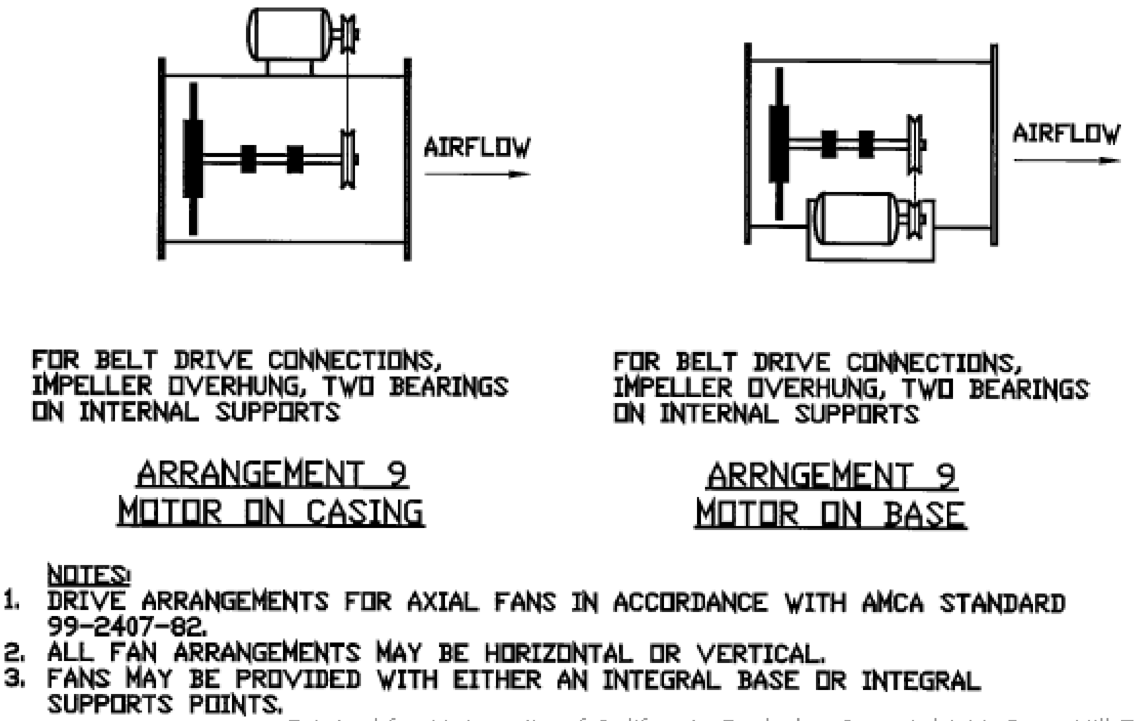


Figure 26.14. AXIAL FAN DRIVE ARRANGEMENTS.

26.12. Centrifugal Fan Inlet Box Positions

See Fig. 26.15.

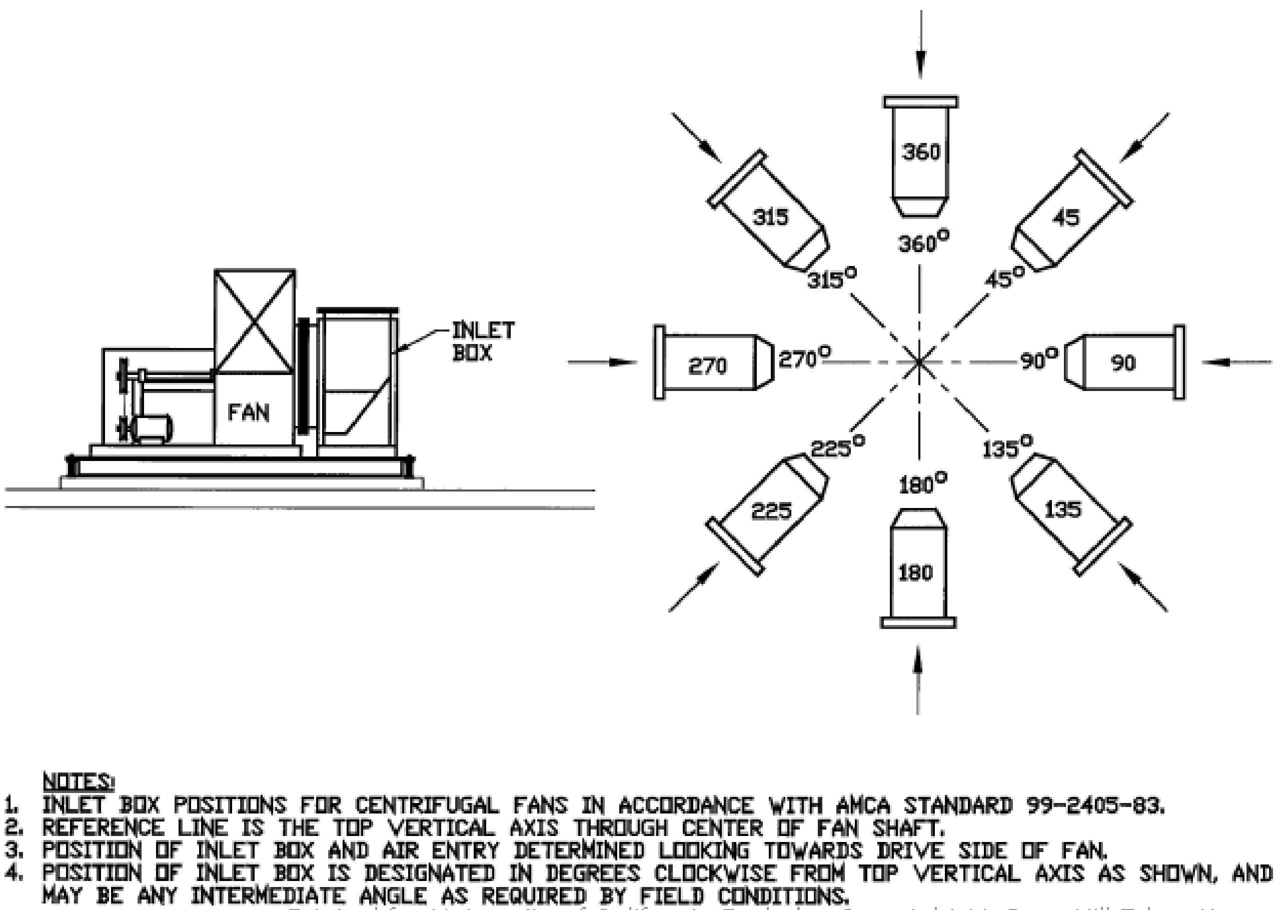


Figure 26.15. CENTRIFUGAL FAN INLET BOX POSITIONS.

26.13. Centrifugal Fan Damper Arrangements for Reversible Flow

See Figs. 26.16 and 26.17.

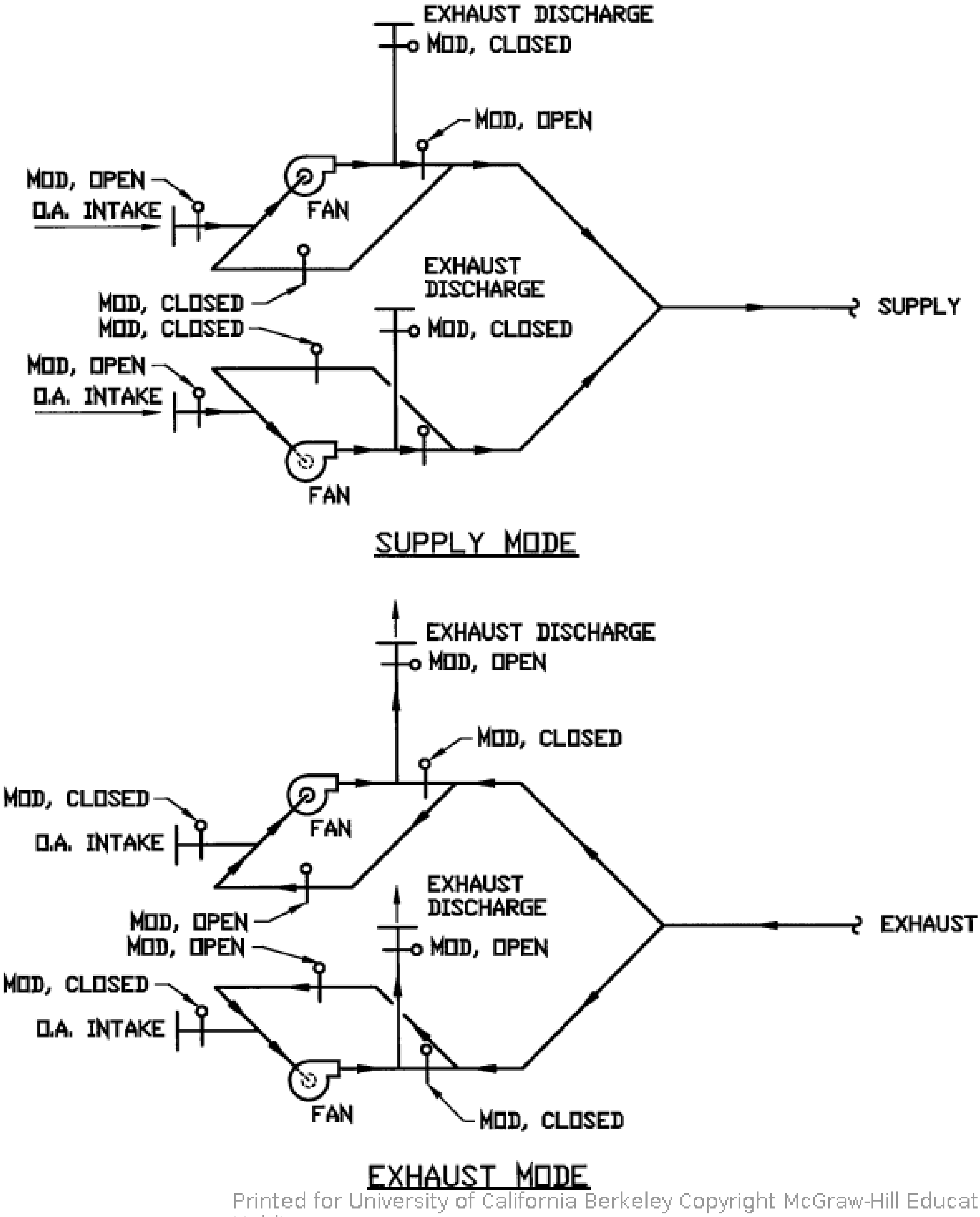


Figure 26.16. SWSI CENTRIFUGAL FANS (REVERSIBLE FLOW).

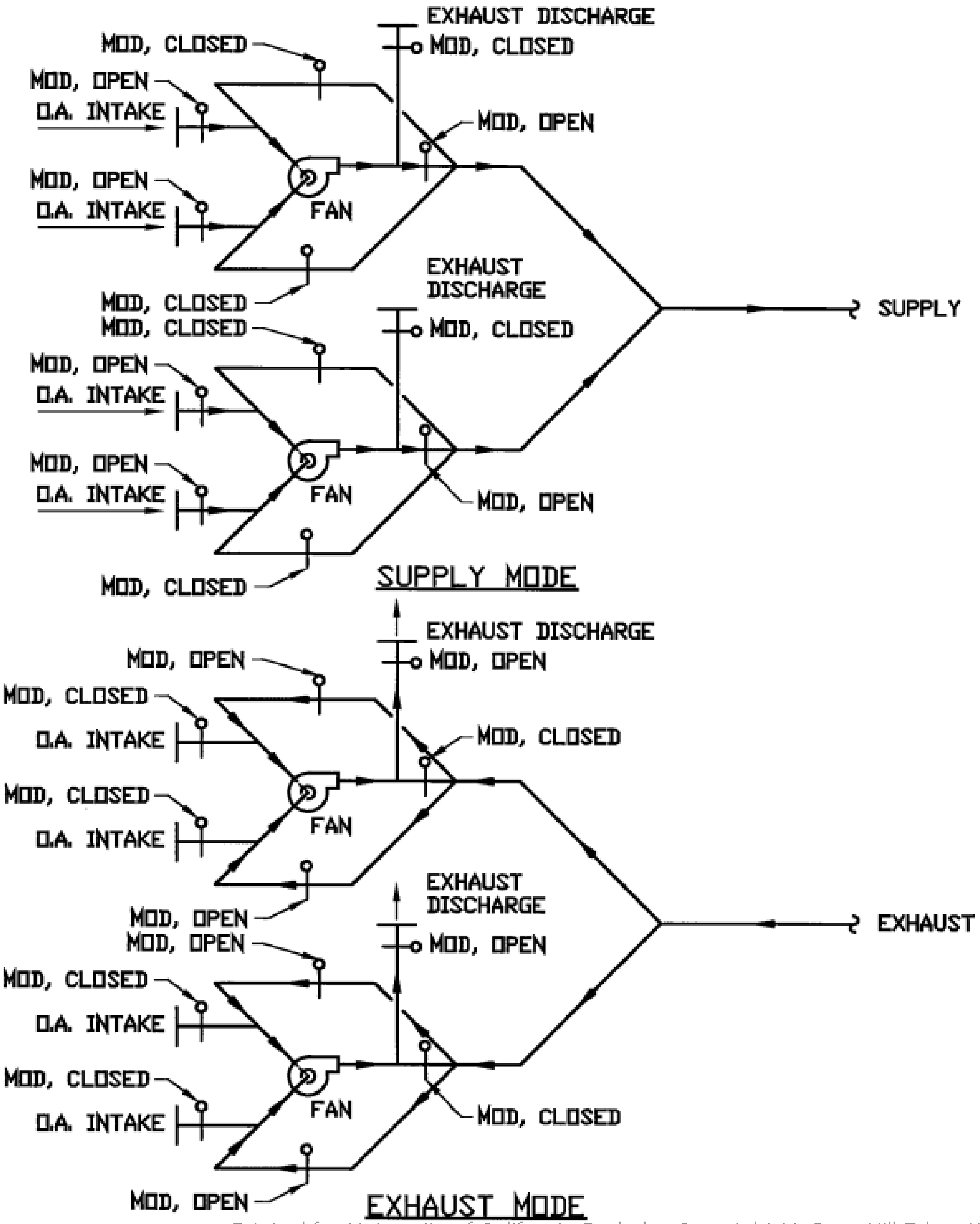


Figure 26.17. DWDI CENTRIFUGAL FANS (REVERSIBLE FLOW).

Citation

EXPORT

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. Part 26: Fans, Chapter (McGraw-Hill Professional, 2016), AccessEngineering

Part 27: Pumps

27. Part 27: Pumps

27.01. Pump Types and Size Ranges

A. **Available RPM**

1. 1,150 (1,200).
2. 1,750 (1,800).
3. 3,500 (3,600).

B. **Pump types are shown in the following table.**

Pump Type	GPM	Head Ft. H_2O	Horsepower
Circulators	0–150	0–60	1/4–5
Close coupled, end suction	0–2,000	0–400	1/4–150
Frame mounted, end suction	0–2,000	0–500	1/4–150
Horizontal split case	0–12,000	0–500	1–500
Vertical inline	0–2,000	0–400	1/4–75

C. **Refer to Fig. 27.1 for a photograph of frame mounted, end suction pumps in their installed condition.**

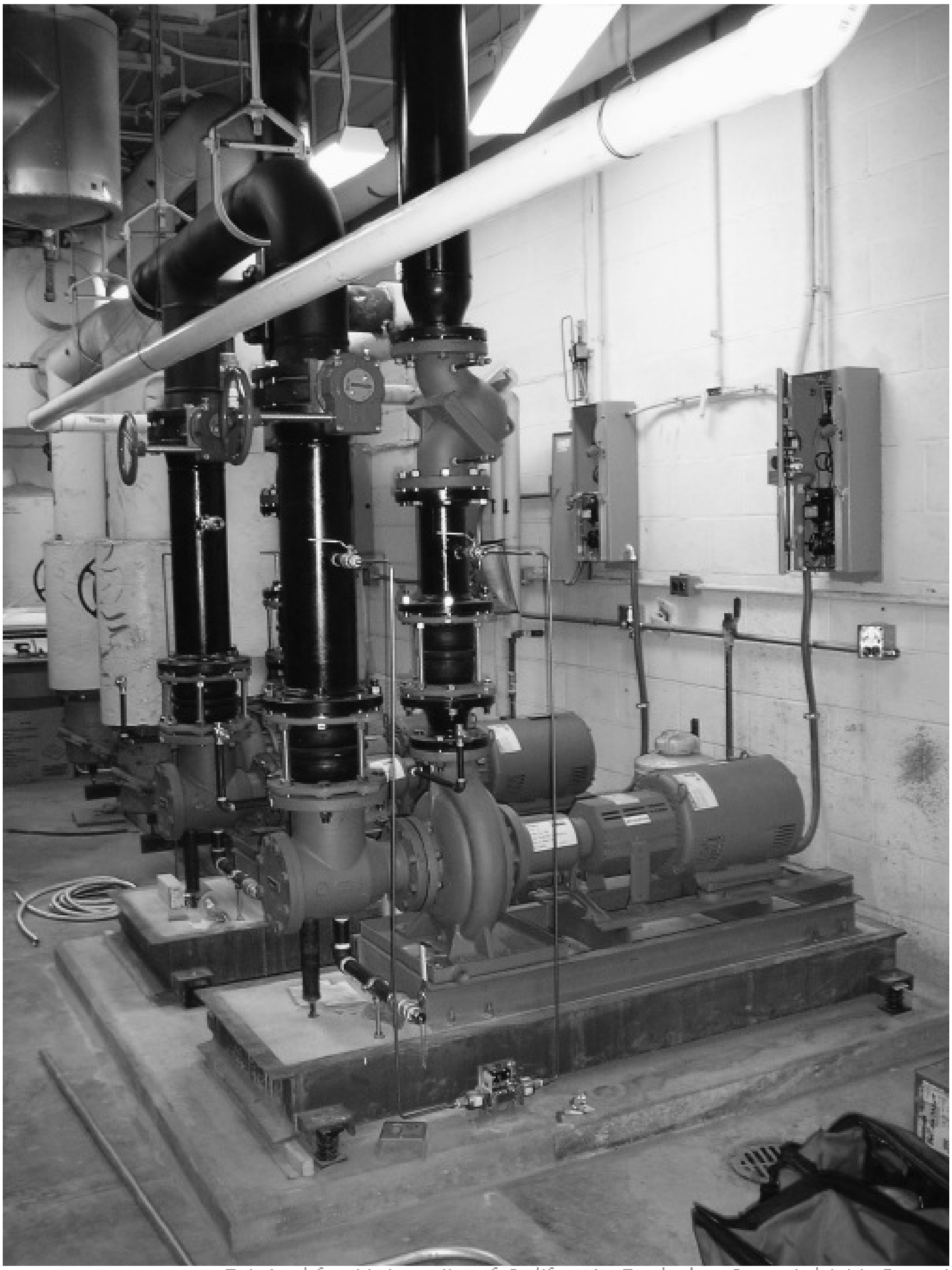


Figure 27.1. PHOTOGRAPH OF FRAME MOUNTED, END SUCTION PUMPS.

D. **Pump Location**

1. Heating water systems: Boilers to be on the suction side of pumps; pumps to draw through boilers.
2. Chilled water systems: Chillers to be on the discharge side of pumps; pumps to pump through chillers.

27.02. Pump Layout and Design Criteria

A. **Pump suction piping should be kept as short and direct as possible with a minimum length of straight pipe upstream of the pump suction as recommended by the pump manufacturer. Manufacturers recommend 5–12 pipe diameters.**

B. **Pump suction pipe size should be at least one pipe size larger than the pump inlet connection.**

C. **Use flat on top, eccentric reducer to reduce pump suction piping to the pump inlet connection size.**

D. **Pump suction should be kept free from air pockets.**

E. **Horizontal elbows should not be installed at the pump suction. If a horizontal elbow must be installed at the pump suction, the elbow should be installed at a lower elevation than the pump suction. A vertical elbow at the pump suction with the flow upward toward the pump is desirable.**

F. **Maintain a minimum of 5 pipe diameters of straight pipe immediately upstream of pump suction unless using suction diffuser.**

G. **Variable speed pumping cannot be used for pure lift applications, because reduced speeds will fail to provide the required lift.**

H. **Variable speed pumping is well suited for secondary and tertiary distribution loops of primary/secondary and secondary/tertiary hydronic distribution systems (chilled water and heating water systems).**

I. **Pump Design Arrangements (see Fig. 27.2)**

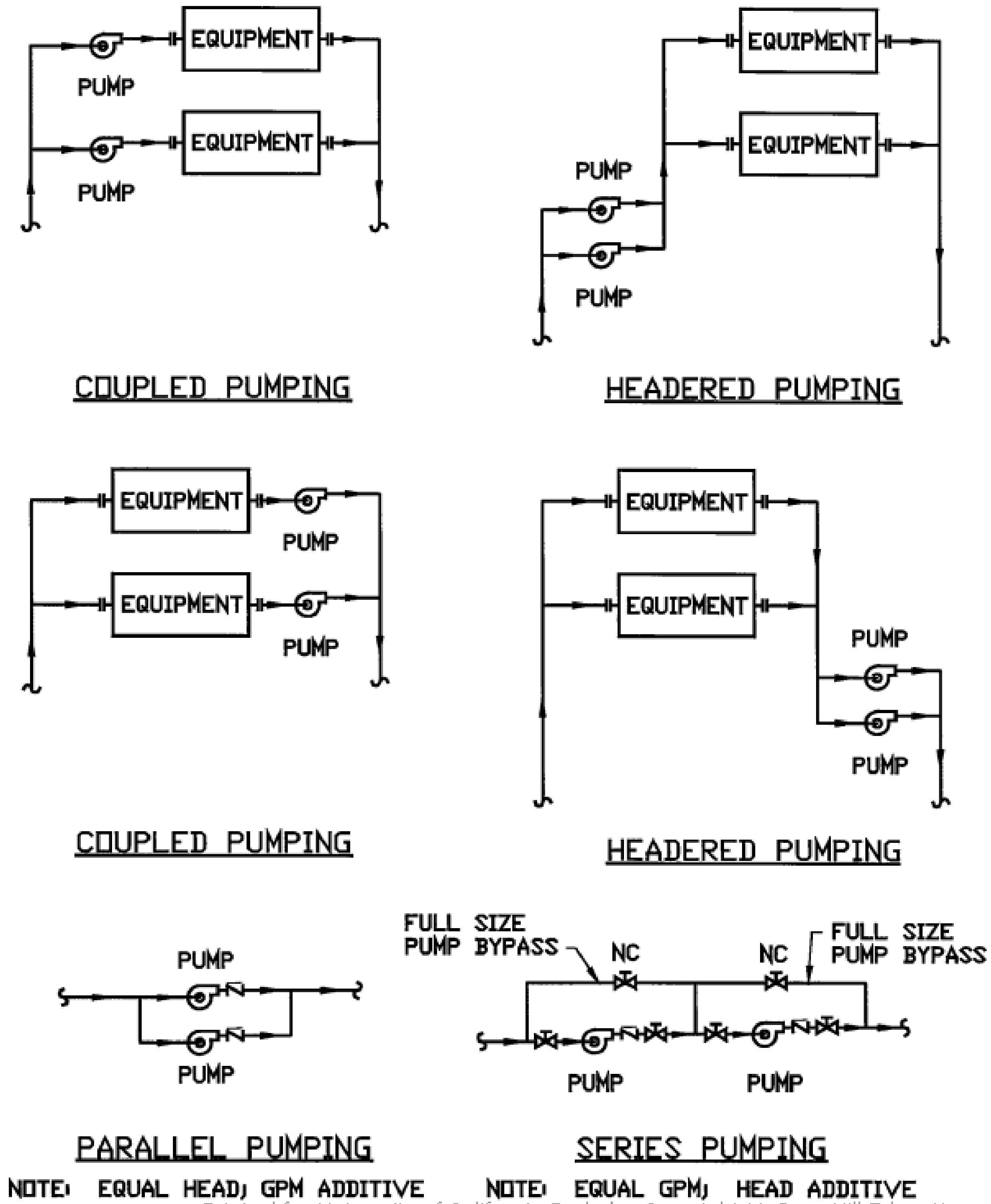


Figure 27.2. PUMPING ARRANGEMENTS.

1. Series pumps: equal flow, head additive.
2. Parallel pumps: equal head, flow additive.
3. Standby pumps: standby pumping arrangements are often used for reliability purposes in the event of pump failure. Standby pumps may be provided with coupled or headered systems (see Figs. 27.3 and 27.4).

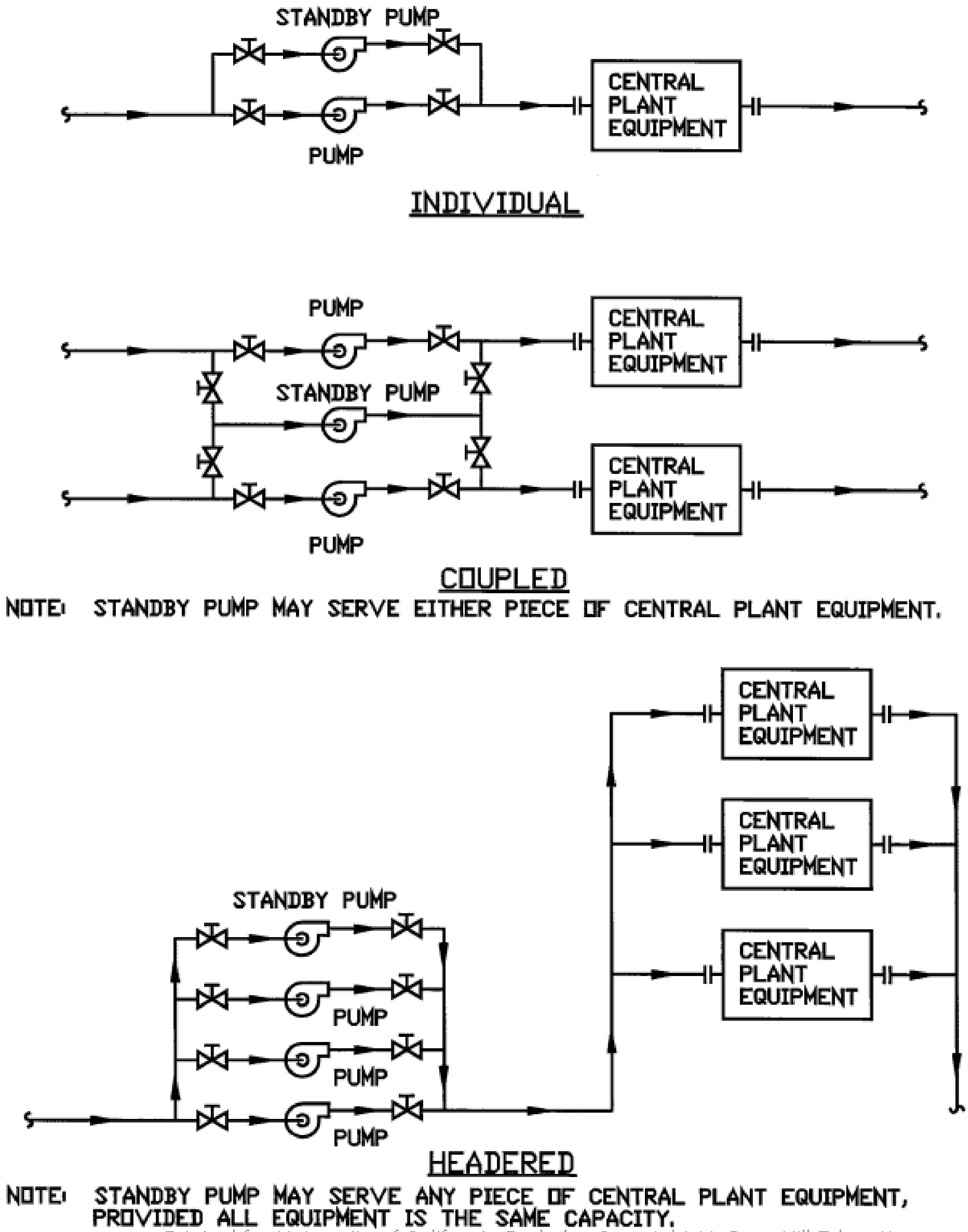


Figure 27.3. STANDBY PUMPS.

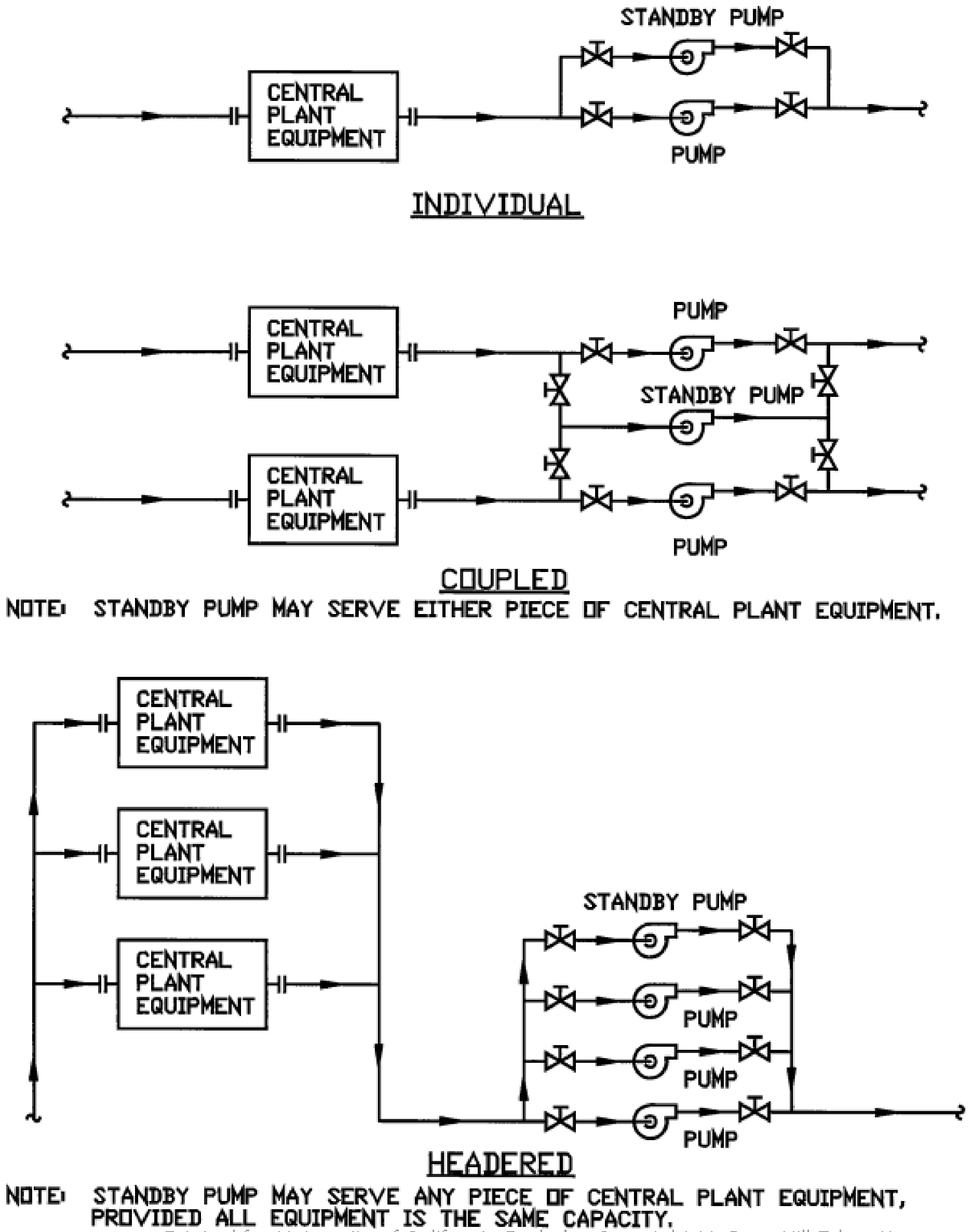


Figure 27.4. STANDBY PUMPS.

J. **Pump Discharge Check Valves**

1. Pump discharge check valves should be center-guided, spring-loaded, disc-type check valves.

2. Pump discharge check valves should be sized so the check valve is full open at the design flow rate. Generally, this will require the check valve to be one pipe size smaller than the connecting piping.

3. Condenser water system and other open piping system check valves should have globe-style bodies to prevent flow reversal and slamming.

4. Installing check valves 4–5 pipe diameters upstream of flow disturbances is recommended by most manufacturers.

K. **Differential pressure control of the system pumps should never be accomplished at the pump. The pressure bypass should be provided at the end of the system or at the end each of the subsystems, regardless of whether the system is a bypass flow system or a variable speed pumping system. Bypass flow need not exceed 20 percent of the pump design flow.**

27.03. Pump Selection Criteria

A. **The impeller size for specified duty should not exceed 85 percent of the volute cutwater diameter.**

B. **The maximum cataloged impeller size should be rated to produce not less than 110 percent of the specified head at the specified flow.**

C. **Parallel Pump Operation: At equal head, the GPM is additive.**

D. **Series Pump Operation: At equal GPM, the head is additive.**

E. **Selection Regions:**

1. Preferred selection—85–105 percent design flow.

2. Satisfactory selection—66–115 percent design flow.

F. **Pumps Curves**

1. Flat. A 12 percent rise from design point to the shutoff head (zero flow). Flat curves should be used for variable flow systems with single pumps. A flat pump curve is a pump curve where the head at shutoff is approximately 25 percent higher than the head at the best efficiency point.

2. Steep. A 40 percent rise from design point to shutoff head (zero flow). Steep curves should be used for variable speed and constant flow systems where two or more pumps are used.

3. Hump. The developed head rises to a maximum as flow decreases and then drops to a lower value at the point of shutoff. Hump curves should be used for constant flow systems with single pumps due to increased efficiency.

G. **Select pumps so the design point is as close as possible or to the left of the maximum efficiency point.**

H. **Boiler warming pumps should be selected for a flow rate of 0.1 GPM/BHP (range 0.05–0.1 GPM/BHP). See Part 31 for a more detailed description of boiler warming pumps and their operation.**

I. **Pump Seals**
1. Mechanical seal: closed systems.

2. Stuffing box seals: open systems.

J. **Cavitation. Net Positive Suction Head (NPSH)**
1. Cavitation: "If the pressure at any point inside the pump falls below the operating vapor pressure of the fluid, the fluid flashes into a vapor and forms bubbles. These bubbles are carried along in the fluid stream until they reach a region of higher pressure. Within this region, the bubbles collapse or implode with tremendous shock on the adjacent surfaces. Cavitation is accompanied by a low rumbling and/or a sharp rattling noise and even vibration causing mechanical destruction in the form of pitting and erosion."[1]

2. Causes:
   a. Discharge head is far below the pump's calibrated head at peak efficiency.

   b. The suction lift or suction head is lower than the pump rating.

   c. Speeds (RPM) are higher than the pump rating.

   d. Liquid temperatures are higher than that for which the system was designed.

3. Remedies:
   a. Increase the source fluid level height.

   b. Reduce the distance and/or friction losses (larger pipe) between the source and pump.

   c. Reduce the temperature of the fluid.

d. Pressurize the source.

e. Use a different pump.

f. Place the balancing valve in the pump discharge or trim the pump impeller.

4. Systems most susceptible to NPSH problems include:
   a. Boiler feedwater systems (steam systems).

   b. Cooling tower and other open systems.

   c. Medium- and high-temperature water systems.

5. Potential problems increase as:
   a. Elevation above sea level increases.

   b. Height of source above the pump decreases.

   c. Friction losses increase.

   d. Fluid temperature increases.

27.04. Pump Terms

A. ***Friction Head*. Friction head is the pressure expressed in psi or in the feet of liquid needed to overcome the resistance to the flow in the pipe and fittings.**

B. ***Suction Lift*. Suction lift exists when the source of the supply is below the centerline of the pump.**

C. ***Suction Head*. Suction head exists when the source of the supply is above the centerline of the pump.**

D. ***Static Suction Lift*. Static suction lift is the vertical distance from the centerline of the pump down to the free level of the liquid source.**

E. ***Static Suction Head*. Static suction head is the vertical distance from the centerline of the pump up to the free level of the liquid source.**

F. ***Static Discharge Head*. Static discharge head is the vertical elevation from the centerline of the pump to the point of free discharge.**

G. ***Dynamic Suction Lift*. Dynamic suction lift includes the sum of static suction lift, friction head loss, and velocity head.**

H. ***Dynamic Suction Head*. Dynamic suction head includes static suction head minus the sum of friction head loss and velocity head.**

I. ***Dynamic Discharge Head*. Dynamic discharge head includes the sum of static discharge head, friction head, and velocity head.**

J. ***Total Dynamic Head*. Total dynamic head includes the sum of the dynamic discharge head plus the dynamic suction lift or discharge head minus dynamic suction head.**

K. ***Velocity Head*. Velocity head is the head needed to accelerate the liquid. See the following table.**

Velocity (ft./sec.)	Velocity Head (feet)	Velocity (ft./sec.)	Velocity Head (feet)	Velocity (ft./sec.)	Velocity Head (feet)
0.5	0.004	7.5	0.875	14.5	3.269
1.0	0.016	8.0	0.995	15.0	3.498
1.5	0.035	8.5	1.123	15.5	3.735
2.0	0.062	9.0	1.259	16.0	3.980
2.5	0.097	9.5	1.403	16.5	4.232
3.0	0.140	10.0	1.555	17.0	4.493
3.5	0.190	10.5	1.714	17.5	4.761
4.0	0.248	11.0	1.881	18.0	5.037
4.5	0.314	11.5	2.056	18.5	5.321
5.0	0.389	12.0	2.239	19.0	5.613
5.5	0.470	12.5	2.429	19.5	5.912
6.0	0.560	13.0	2.627	20.0	6.219
6.5	0.657	13.5	2.833	21.0	6.856
7.0	0.762	14.0	3.047	22.0	7.525

L. ***Specific Gravity*. Specific gravity is the direct ratio of any liquid's weight to the weight of water at 62°F (62.4 lbs./cu.ft. or 8.33 lbs./gal.).**

M. ***Viscosity*. Viscosity is a property of a liquid that resists any force tending to produce flow. It is the evidence of cohesion between the particles of a fluid that causes a liquid to offer resistance analogous to friction. A change in the temperature may change the viscosity depending upon the liquid. Pipe friction loss increases as viscosity increases.**

N. ***Static Pressure*. Static pressure is the water pressure required to fill the system.**

O. ***Static System Pressure*. Static system pressure is the water pressure required to fill the system plus 5 psi.**

P. ***Flow Pressure*. Flow pressure is the pressure the pump must develop to overcome the resistance created by the flow through the system.**

27.05. Installation and Clearance Requirements

A. **The minimum recommended clearance around pumps is 24 inches. Maintain minimum clearance as required to open access and control doors on pumps for service, maintenance, and inspection.**

B. **Mechanical room locations and placement must take into account how pumps can be moved into and out of the building during initial installation and after construction for maintenance and repair and/or replacement.**

---

[1]Carrier Corporation, *Carrier System Design Manuals*, Part 8—Auxiliary Equipment (Syracuse: Carrier Corporation, 1971), pp. 8–11.

Citation

EXPORT

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. Part 27: Pumps, Chapter (McGraw-Hill Professional, 2016), AccessEngineering

Part 28: Chillers

28. Part 28: Chillers

28.01. Chiller Types and Manufacturer Offerings

Chiller Type	Capacity Range tons	kW/ton Range (1)	COP Range (1)	Turndown % Capacity	Refrigerant	Comme
Centrifugal—Water Cooled						
Carrier	200–3000	0.50–0.60	5.86–7.03	10	134a	2
Daikin	200–1250	0.60–0.62	5.86–5.67	10	134a	2, 6
	400–2500	0.61–0.64	5.49–5.76	10	134a	3, 6
Trane	200–2000	0.45–0.55	6.39–7.81	10	123	2
	1500–4000	0.45–0.55	6.39–7.81	10	123	4
York	200–3000	0.50–0.60	5.86–7.03	15	134a	2
	1800–6000	0.50–0.60	5.86–7.03	15 single, 10 dual compressor	134a	3
Centrifugal—Water Cooled with Unit-Mounted VFD						

Chiller Type	Capacity Range tons	kW/ton Range (1)	COP Range (1)	Turndown % Capacity	Refrigerant	Comme
Centrifugal—Water Cooled with Unit-Mounted VFD						
Carrier	200–3000	0.53–0.62	5.67–6.63	10	134a	2
Daikin	125–200	0.59–0.64	5.49–5.96	25	134a	2, 7
	145–400	0.62–0.67	5.25–5.67	12.5	134a	3, 7
	400–1500	0.55–0.58	6.06–6.39	10	134a	4, 7
Trane	200–4000	0.45–0.55	6.39–7.81	10	123	2, 4
York	200–1475	0.50–0.60	5.86–7.03	15 single, 10 dual compressor	134a	2
Reciprocating—Air Cooled						
Carrier	NA	NA	NA	NA	NA	
Daikin	NA	NA	NA	NA	NA	
Trane	NA	NA	NA	NA	NA	
York	NA	NA	NA	NA	NA	
Reciprocating—Water Cooled						
Carrier	NA	NA	NA	NA	NA	
Daikin	NA	NA	NA	NA	NA	
Trane	NA	NA	NA	NA	NA	
York	NA	NA	NA	NA	NA	

Notes:

Rotary Screw—Air Cooled (see Fig. 28.1)

1 ... and ... ues ... on

me

Figure 28.1. ROTARY SCREW AIR-COOLED CHILLER WITH UNIT-MOUNTED VARIABLE FREQUENCY DRIVE. (Material Courtesy of Trane.)

Carrier	80–500	1.01–1.21	2.91–3.48	6–15	134a	
Daikin	140–200	1.25–1.30	2.70–2.81	25	134a	
	170–550	1.20–1.30	2.70–2.93	25	134a	
Trane	140–500	1.05–1.16	3.03–3.35	15	134a	6
York	150–500	1.15–1.20	2.93–3.06	10	134a	

Notes:

Rotary Screw—Water Cooled (see Fig. 28.2)

1 **…ng characteristics and … and below the values …rers depending on … and capacities are …n the table based on …enser water …ines), outside air …f refrigerant.**

2

3

Figure 28.2. ROTARY SCREW WATER-COOLED CHILLER WITH UNIT-MOUNTED VARIABLE FREQUENCY DRIVE. (Material Courtesy of Trane.)

4. Centrifugal chillers with dual compressors and dual refrigerant circuit (see Fig. 28.4).

Chiller Type	Capacity Range tons	kW/ton Range (1)	COP Range (1)	Turndown % Capacity	Refrigerant	Comme
Carrier	175–550	0.53–	6.63–	10	134a	5
	75–265	0.69–0.72	4.88–5.10	10	134a	
	150–400	0.47–0.56	6.28–7.48	10	134a	
Daikin	130–190	0.72–0.74	4.75–4.88	10	134a	
Trane	140–450	0.58–0.70	5.02–6.06	15	134a	6
York	125–300	0.58–0.70	5.02–6.05	15	134a	

Scroll—Air Cooled (see Fig. 28.3)

Figure 28.3. SCROLL AIR-COOLED CHILLER. (Material Courtesy of Trane.)

Carrier	10–390	1.16–1.23	2.86–3.03	4–22	410a	
Notes:	10–150	0.76–0.91	3.86–4.63	5–20	410a	

1. KW/ton and COPs are based on full load operating characteristics and

Chiller Type	Capacity Range tons	kW/ton Range (1)	COP Range (1)	Turndown % Capacity	Refrigerant	Comme
Daikin	10–34	1.30–1.40	2.51–2.70	25	407c	
	30–70	1.10–1.20	2.93–3.20	25	410a	
Trane	20–130	1.05–1.20	2.93–3.34	25, 50	410a	
York	15–150	1.15–1.25	2.81–3.05	20	410a	
Scroll—Water Cooled						
Carrier	15–71	0.56–0.58	6.06–6.28	10	410a	
Daikin	30–200	0.76–0.80	4.39–4.63	10	410a	
York	60–200	0.77–0.85	4.13–4.56	12, 25 depending upon no. of compressors	410a	

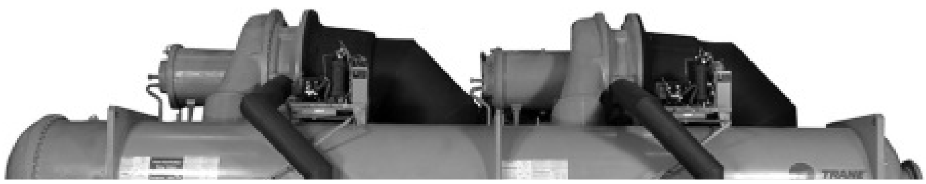
Notes:

1. **KW/ton and COPs are based on full load operating characteristics and are "ball park" figures. KW/ton and COPs above and below the values listed in the table are possible for all manufacturers depending on desired operating characteristics. KW/ton, COP, and capacities are driven by, and will vary from, the values listed in the table based on chilled water supply/return temperatures, condenser water supply/return temperatures (water-cooled machines), outside air temperatures (air-cooled machines), and type of refrigerant.**

2. **Centrifugal chillers with single compressor.**

3. **Centrifugal chillers with dual compressors.**

4. **Centrifugal chillers with dual compressors and dual refrigerant circuit (see Fig. 28.4).**



Ch efrigerant Comme
T

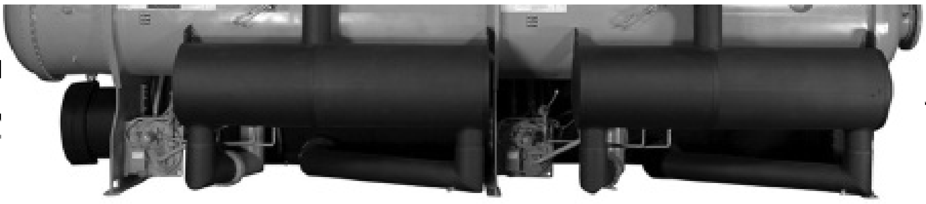


Figure 28.4. CENTRIFUGAL WATER-COOLED CHILLER WITH DUAL COMPRESSORS. (Material Courtesy of Trane.)

5. **Variable frequency drive screw chiller.**

6. **Variable frequency drive available.**

7. **Magnetic bearings.**

8. **COP, EER, and kW/ton relationships:**
 EER = COP × 3.413
 COP = 12,000 / (kW/ton × 3,413)
 kW/ton = 12,000 / (COP × 3,413)

28.02. Chiller Motor Types

A. **Hermetic Chillers/Motors**
 1. Motors are refrigerant cooled.
 2. Motor heat absorbed by the refrigerant must be removed by the condenser cooling medium (air or water).
 3. $TONS_{COND} = TONS_{EVAP} \times 1.25$
 = 12,000 Btu/h ton × 1.25 = 15,000 Btu/h ton.
 Therefore, motor heat gain is approximately 3,000 Btu/h ton.

B. **Open Chillers/Motors**
 1. Motors are air cooled.
 2. Motor heat is rejected directly to the space. Therefore, the space HVAC system must remove approximately 3,000 Btu/h ton of motor heat gain.

C. **In either case, the chillers must remove the 3,000 Btu/h ton of heat generated by the motors; the only difference is the method by which it is accomplished.**

28.03. Code Required Chiller Efficiencies

Equipment Type	Equipment Capacity Size Range	2015 IECC and ASHRAE Std. 90.1-2013	
		FL kW/ton	IPLV kW/ton
Air-Cooled Chillers with Condenser—Electric	< 150 tons	10.100 EER	13.700 EER
	≥ 150 tons	10.100 EER	14.000 EER
Air-Cooled Chillers without Condenser—Electric	All Capacities	Same as air-cooled chillers	
Water-Cooled Positive Displacement—Electric	< 75 tons	0.750	0.600
	≥ 75 tons and < 150 tons	0.720	0.560
	≥ 150 tons and < 300 tons	0.660	0.540
	≥ 300 tons and < 600 tons	0.610	0.520
	≥ 600 tons	0.560	0.500
Water-Cooled Centrifugal Chillers—Electric	< 150 tons	0.610	0.550
	≥ 150 tons and < 300 tons	0.610	0.550
	≥ 300 tons and < 400	0.560	0.520
Notes:	≥ 400 tons and <	0.560	0.500

Equipment Type	Equipment Capacity Size Range	2015 IECC and ASHRAE Std. 90.1-2013	
		FL kW/ton	IPLV kW/ton
	600		
	≥ 600 tons	0.560	0.500
Air-Cooled Absorption Chillers—Single Effect	All Capacities	0.600 COP	–
Water Cooled Absorption Chillers—Single Effect	All Capacities	0.700 COP	–
Absorption Chillers—Double Effect, Indirect Fired	All Capacities	1.000 COP	1.050 COP
Absorption Chillers—Double Effect, Direct Fired	All Capacities	1.000 COP	1.000 COP

Notes:

1. **Efficiency values apply to chillers with water temperatures above 40°F.**
2. **1 ton = 3.516 kW.**
3. **For centrifugal chillers operating at temperatures other than 44°F chilled water, 85°F condenser water, and 3.0 GPM/ton condenser water flow rate, maximum full-load kW/ton and part-load ratings shall be adjusted according to the equations given in ASHRAE Standard 90.1-2013, Section 6.4.1.2.1.**

28.04. Chiller Terms

A. ***Refrigeration Effect*. The refrigeration effect is the amount of heat absorbed by the refrigerant in the evaporator.**

B. ***Heat of Rejection*. The heat of rejection is the amount of heat rejected by the refrigerant in the condenser, which includes compressor heat.**

C. ***Subcooling*. Subcooling is the cooling of the refrigerant below the temperature at which it condenses. Subcooling the liquid refrigerant will increase the refrigeration effect of the system.**

D. ***Superheating*. Superheating is the heating of the refrigerant above the temperature at which it evaporates. Superheating the refrigerant by the evaporator is part of the system design to prevent a slug of liquid refrigerant from entering the compressor and causing damage.**

E. ***Coefficient of Performance (COP)*. The coefficient of performance is defined as the refrigeration effect (Btu/h) divided by the work of the compressor (Btu/h). Another way to define COP is Btu output divided by Btu input. COP is equal to EER divided by 3.413.**

F. ***Energy Efficiency Ratio (EER)*. The energy efficiency ratio is defined as the refrigeration effect (Btu/h) divided by the work of the compressor (watts). Another way to define EER is the Btu output divided by the watts input. The EER is equal to 3.413 times the COP.**

G. ***Pressure/Enthalpy Chart*. Pressure/Enthalpy chart is a graphic representation of the properties of a specific refrigerant with the pressure on the vertical axis and the enthalpy on the horizontal axis. The graph is used and is helpful in visualizing the changes that occur in a refrigeration cycle.**

H. ***Integrated Part Load Value (IPLV). ARI Specified Conditions* . Acceptable tolerances for specified conditions are 6.5 percent.**

I. ***Application Part Load Value (APLV). Engineer Specified Conditions (Real World Conditions)*. Acceptable tolerances for specified conditions are 6.5 percent.**

J. ***Rupture Disc*. A relief device on low-pressure machines.**

K. ***Relief Valve*. A relief device on high-pressure machines.**

L. ***Pumpdown*. Refrigerant pumped to the condenser for storage.**

M. ***Pumpout*. Refrigerant pumped to a separate storage vessel. Use pumpout type storage when a reasonable size and number of portable storage containers cannot be moved into the building.**

N. ***Purge Unit*. Removes air from the refrigeration machine; required on low-pressure machines only.**

O. ***Prevac*. Device that prevents air from entering the refrigeration machine. It is used to leak test the refrigeration machine. Required on low-pressure machines only.**

P. ***Factory Run Tests*. 1,500 tons and smaller; most manufacturers can provide them.**

1. *Certified Test*. Certifies performance—full load and/or part load—IPLV, and/or APLV.

2. Witnessed Tests:

   a. *Generic*. Any chiller the manufacturer produces of the same size and characteristics.

   b. *Specific*. The specific chiller required by the customer.

Q. ***Hot Gas Bypass*. Low limit to suction pressure of the compressor. Hot gas bypass is beneficial on DX systems and generally not beneficial on chilled-water systems, except when tight temperature tolerances are required for a manufacturing process. Chillers specified with both hot gas bypass and low ambient temperature control will result in the hot gas bypass increasing the low ambient temperature operating point of the chiller (decreases the ability for the chiller to operate at low ambient conditions).**

28.05. Basic Refrigeration Cycle Terminology

A. ***Compressor*. Mechanical device where the refrigerant is compressed from a lower pressure and lower temperature to a higher pressure and higher temperature.**

B. ***Hot Gas Piping*. Refrigerant piping from the compressor discharge to the compressor suction, to the evaporator outlet, or to the evaporator inlet, or from the compressor discharge and the condenser inlet to the compressor suction.**

C. ***Condenser*. Heat exchanger where the system heat is rejected and the refrigerant condenses into a liquid.**

D. ***Liquid Piping*. Refrigerant piping from the condenser outlet to the evaporator inlet.**

E. ***Evaporator*. Heat exchanger where the system heat is absorbed and the refrigerant evaporates into a gas.**

F. ***Suction Piping*. Refrigerant piping from the evaporator outlet to the compressor suction.**

G. ***Thermal Expansion Valve*. Pressure and temperature regulation valve, located in the liquid line, which is responsive to the superheat of the vapor leaving the evaporator coil.**

28.06. Chiller Energy Saving Techniques

A. ***Constant Speed Chillers*. For each 1°F increase in chilled-water temperature, the chiller efficiency increases 1.0–2.0 percent.**

B. ***Variable Speed Chillers*. For each 1°F increase in chilled-water temperature, the chiller efficiency increases 2.0–4.0 percent.**

C. **For each 1°F decrease in condenser water temperature, the chiller efficiency increases 1.0–2.0 percent.**

28.07. Cooler (Evaporator)/Chilled-Water System

A. **Leaving Water Temperature (LWT): 42–46°F**

B. **ΔT Range: 10–20°F**

C. **2.4 GPM/ton@10°F ΔT**

D. **2.0 GPM/ton@12°F ΔT**

E. **1.5 GPM/ton@16°F ΔT**

F. **1.2 GPM/ton@20°F ΔT**

G. **5,000 Btuh/GPM@10°F ΔT**

H. **6,000 Btuh/GPM@12°F ΔT**

I. **8,000 Btuh/GPM@16°F ΔT**

J. **10,000 Btuh/GPM@20°F ΔT**

K. **AHRI Evaporator Fouling Factor: 0.00010 h ft.^{2} °F/Btu**

L. **Chilled Water Flow Range: Chiller Design Flow ±10 percent**

M. **Chiller Tube Velocity for Variable Flow Chilled Water**

a. Minimum flow: 3.0 FPS.

b. Maximum flow: 12.0 FPS.

28.08. Condenser/Condenser Water Systems

A. **Entering Water Temperature (EWT): 85°F**

B. **ΔT Range: 10–20°F**

C. **Normal ΔT: 10°F**

D. **3.0 GPM/ton@10°F ΔT**

E. **2.5 GPM/ton@12°F ΔT**

F. **2.0 GPM/ton@15°F ΔT**

G. **1.5 GPM/ton@20°F ΔT**

H. **5,000 Btuh/GPM@10°F ΔT**

I. **6,000 Btuh/GPM@12°F ΔT**

J. **7,500 Btuh/GPM@15°F ΔT**

K. **10,000 Btuh/GPM@20°F ΔT**

L. **AHRI Condenser Fouling Factor: 0.00025 h ft.^{2} °F/Btu**

28.09. Chilled Water Storage Systems

A. **10°F ΔT**

1. 19.3 cu.ft./ton h

2. 623.1 Btu/cu.ft.; 83.3 Btu/gal.

B. **12°F ΔT**

1. 16.1 cu.ft./ton h
2. 747.7 Btu/cu.ft.; 100.0 Btu/gal.

C. **16°F ΔT**

1. 12.4 cu.ft./ton h
2. 996.9 Btu/cu.ft.; 133.3 Btu/gal.

D. **20°F ΔT**

1. 9.6 cu.ft./ton h
2. 1246.2 Btu/cu.ft.; 166.7 Btu/gal.

28.10. Ice Storage Systems

A. **144 Btu/lb.@32°F + 0.48 Btu/lb. for each 1°F below 32°F.**

B. **3.2 cu.ft./ton h**

C. **Only the latent heat capacity of ice should be used when designing ice storage systems.**

28.11. Water-Cooled Condensers

A. **Entering Water Temperature (EWT): 85°F**

B. **Leaving Water Temperature (LWT): 95°F**

C. **3.0 GPM/ton@10°F ΔT**

D. **For each 1°F decrease in condenser water temperature, chiller efficiency increases 1.0–2.0 percent.**

28.12. Refrigerant Estimate—Split Systems

A. **Total 3.0 lbs./ton**

B. **Equipment 2.0 lbs./ton**

C. **Piping 1.0 lbs./ton**

28.13. Chilled Water System Makeup Connection

Minimum connection size shall be 10 percent of the largest system pipe size or 1", whichever is greater. (A 20" system pipe size results in a 2" makeup water connection.)

28.14. Chemical Feed Systems for Chillers. Chemical Feed Systems are Designed to Control the Following

A. **System pH, normally between 8 and 9.**

B. **Corrosion.**

C. **Scale.**

28.15. Chiller Operating Sequence

A. **Start chilled water and condenser water pumps. Verify chilled water and condenser water flow.**

B. **Start chiller and cooling tower.**

C. **Runtime.**

D. **Stop chiller and cooling tower.**

E. **Stop chilled water and condenser water pumps after 0- to 30-second delay because some chiller manufacturers use chilled water or condenser water to cool the solid state starter circuitry.**

F. **Chiller Startup Piping (see Fig. 28.5)**

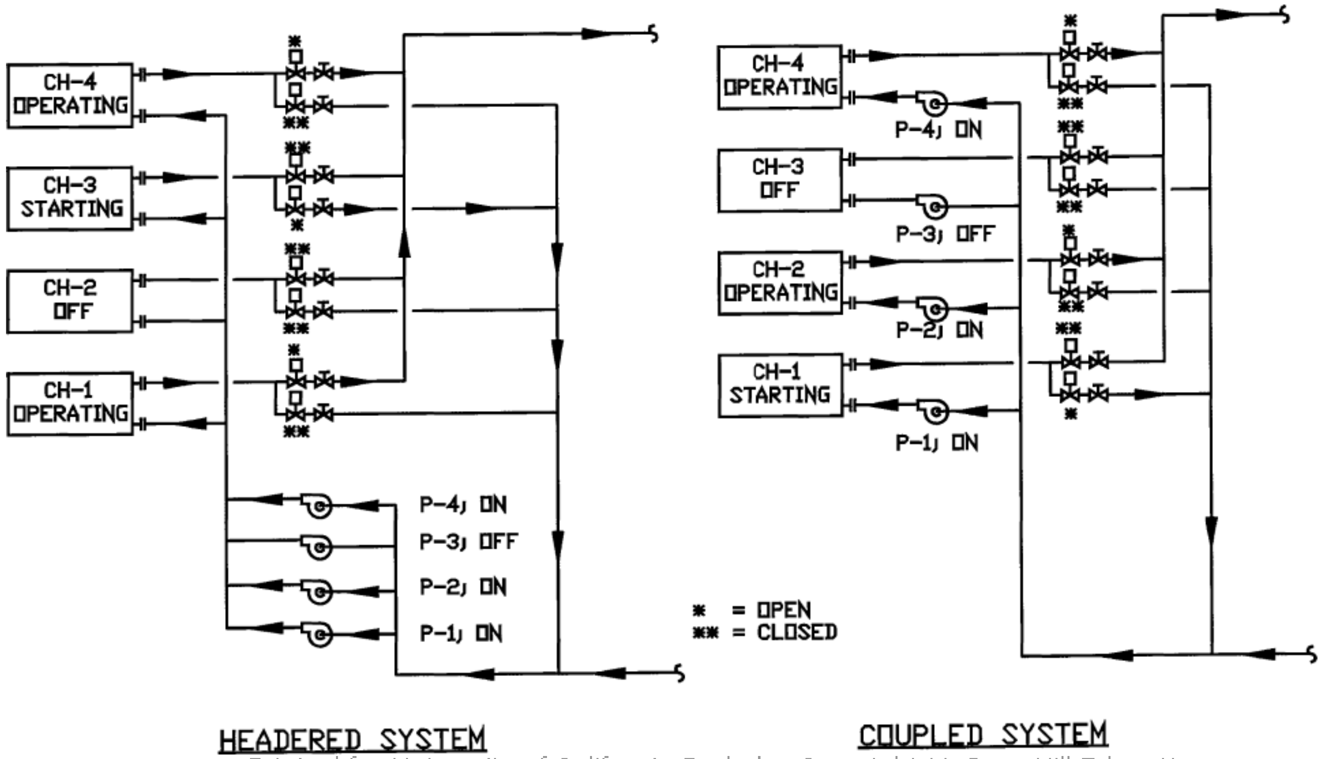


Figure 28.5. CHILLER STARTUP PIPING DIAGRAM.

1. Because it takes 5–15 minutes from the time the chiller start sequence is initiated until the time the chiller starts to provide chilled water at the design temperature, the chilled water supply temperature often rises above the desired control setpoint. If the chilled water supply temperature is critical, the method to correct this problem is to provide the chillers with startup piping which runs from the chiller discharge to the pump return main.

2. The designer should size startup piping for the flow of the largest chiller in the system. The common pipe size only needs to be sized for the flow of one chiller because it is unlikely that more than one chiller will be started at the same time.

3. Chilled-water system operation with startup piping should be as follows:
   a. On initiation of the chiller start sequence, the primary chilled water pump is started, the bypass valve is opened, and the supply header valve is closed. When the chilled water supply setpoint temperature is reached, as sensed in the bypass, the supply header valve is slowly opened, maintaining the setpoint temperature at all times. When the supply header valve is fully opened, the bypass valve is slowly closed.

   b. On initiation of the chiller stop sequence, the bypass valve is slowly opened. When the bypass valve is fully opened, the supply header valve is slowly closed. The chiller is stopped, and after a delay, the primary chilled water pump is stopped. When the primary chilled water pump stops, the bypass valve is left open to permit water to expand into, or contract from, the system. On headered systems, the chilled water return valve must be closed as well.

4. The chilled water diagram shows the chiller startup piping with motorized shutoff valves. Motorized valves are required for automatic or remote manual control. If the chilled-water system will be manually operated, these valves may be deleted. A separate manual shutoff valve has also been provided to allow for manual isolation of the system and to permit repair of the motorized valve without having to shut down the system. This manual shutoff valve may be deleted, provided the motorized shutoff valve has a manual means by which it can be opened and closed. Most motorized control valves do not have a manual means to open and close them.

28.16. Chiller Design, Layout, and Clearance Requirements/Considerations

A. **Design Conditions**

1. Chiller load. Tons, Btu/h, or MBH.
2. Chilled water temperatures. Entering and leaving or entering and ΔT.
3. Condenser water temperatures. Entering and leaving or entering and ΔT.
4. Chilled water flows and fluid type (correct all data for fluid type).
5. Condenser water flows and fluid type (correct all data for fluid type).
6. Evaporator and condenser pressure drops.
7. Fouling factor.
8. IPLV, desirable.
9. APLV, optional.
10. Chilled water or condenser water reset if applicable.
11. Ambient operating temperature, dry bulb and wet bulb.
12. Electrical data:
    a. Compressor or unit KW.

b. Full load, running load, and locked rotor amps.

c. Power factor.

d. Energy Efficiency Ratio (EER).

e. Voltage-phase-hertz.

B. **Multiple chillers should be used to prevent complete system or building shutdown upon failure of one chiller in all chilled-water systems over 200 tons (i.e., 2@50 percent, 2@67 percent, 2@70 percent, 3@34 percent, 3@40 percent).**

1. Series chiller design: Piping chillers in series can accomplish large temperature differentials without penalizing the chiller performance (see Figs. 28.6 and 28.7).

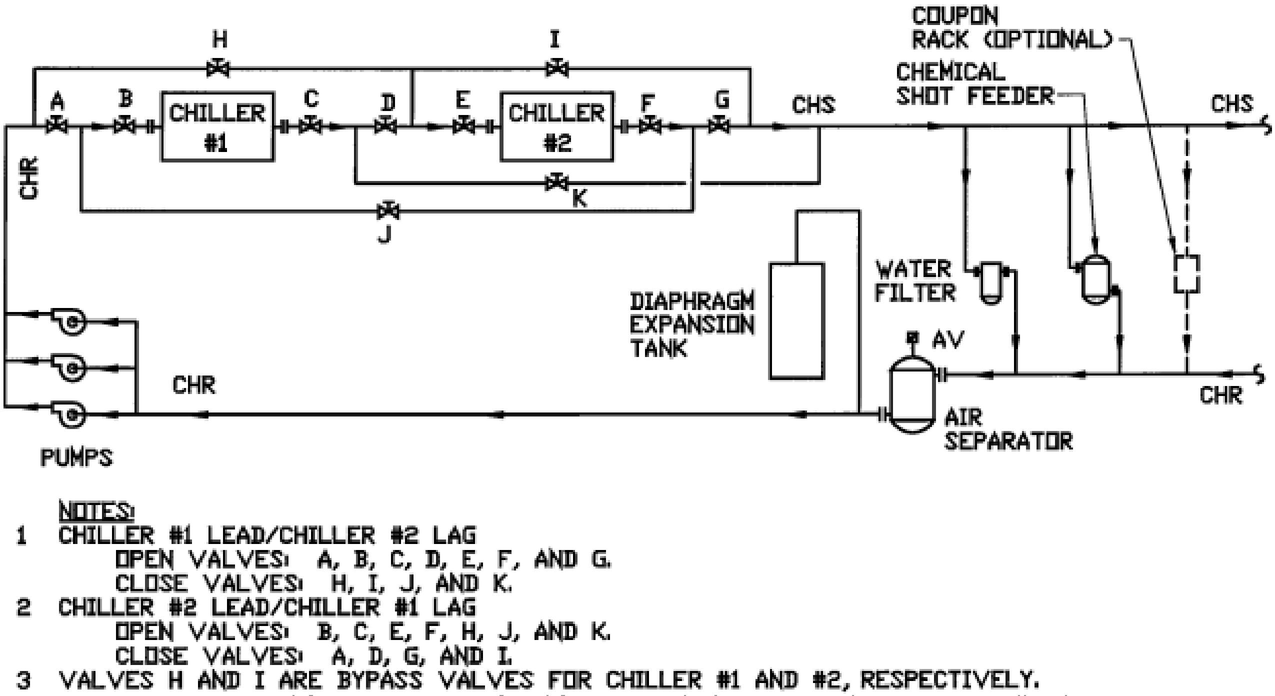


Figure 28.6. SERIES CHILLED-WATER SYSTEM.

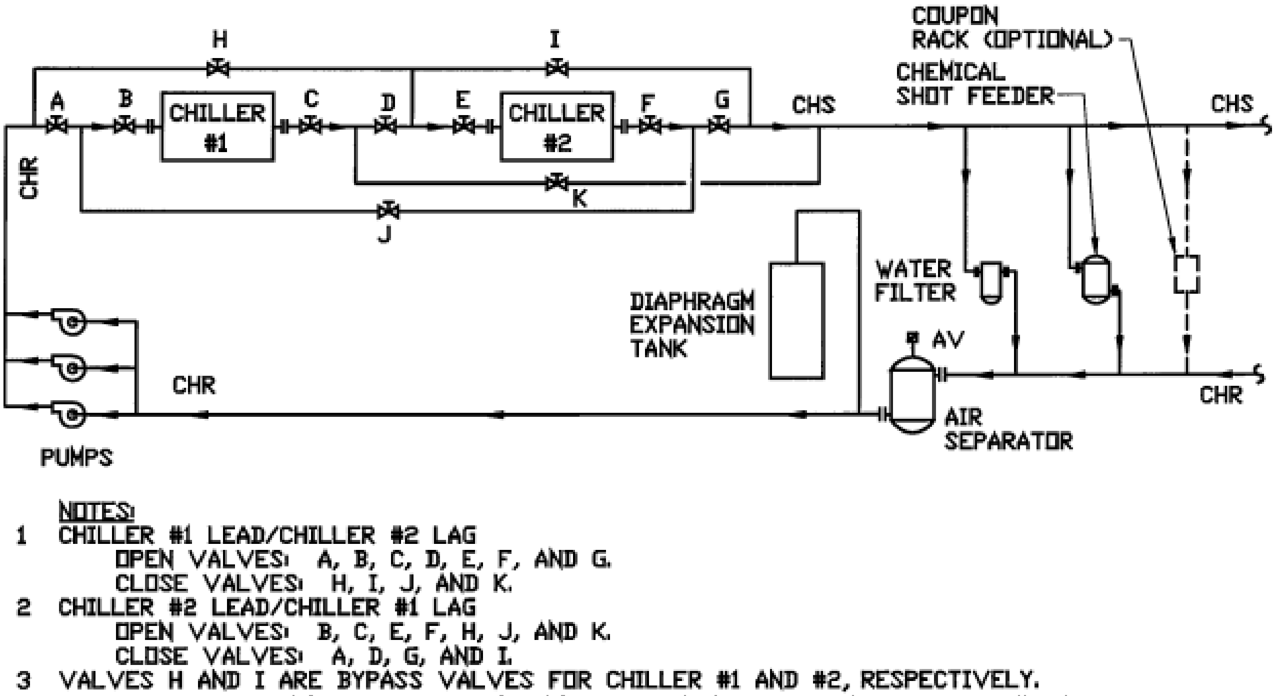


Figure 28.7. SERIES CHILLED-WATER SYSTEM WITH LEAD-LAG CHILLER CONTROL.

2. Parallel chiller design: Piping chillers in parallel provides a simpler installation and provides for multiple chiller arrangements with standby opportunities. Standby opportunities are also available with series chiller arrangements, but they become more complex and cumbersome (see Figs. 28.8 and 28.9).

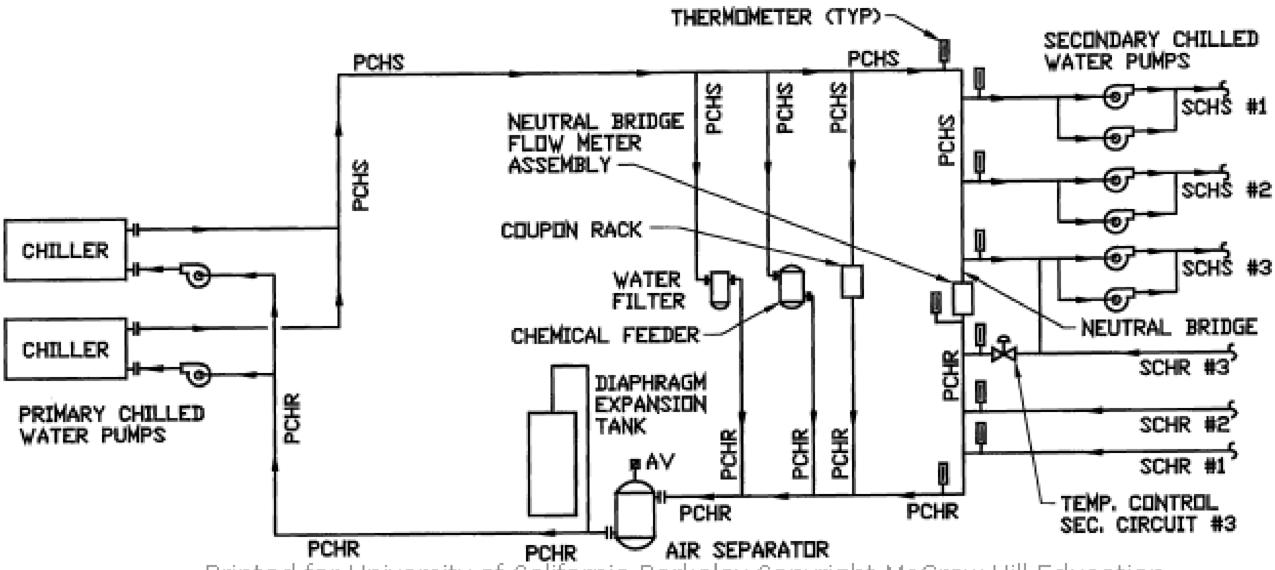


Figure 28.8. PARALLEL CHILLED-WATER SYSTEM—COUPLED PUMPS.

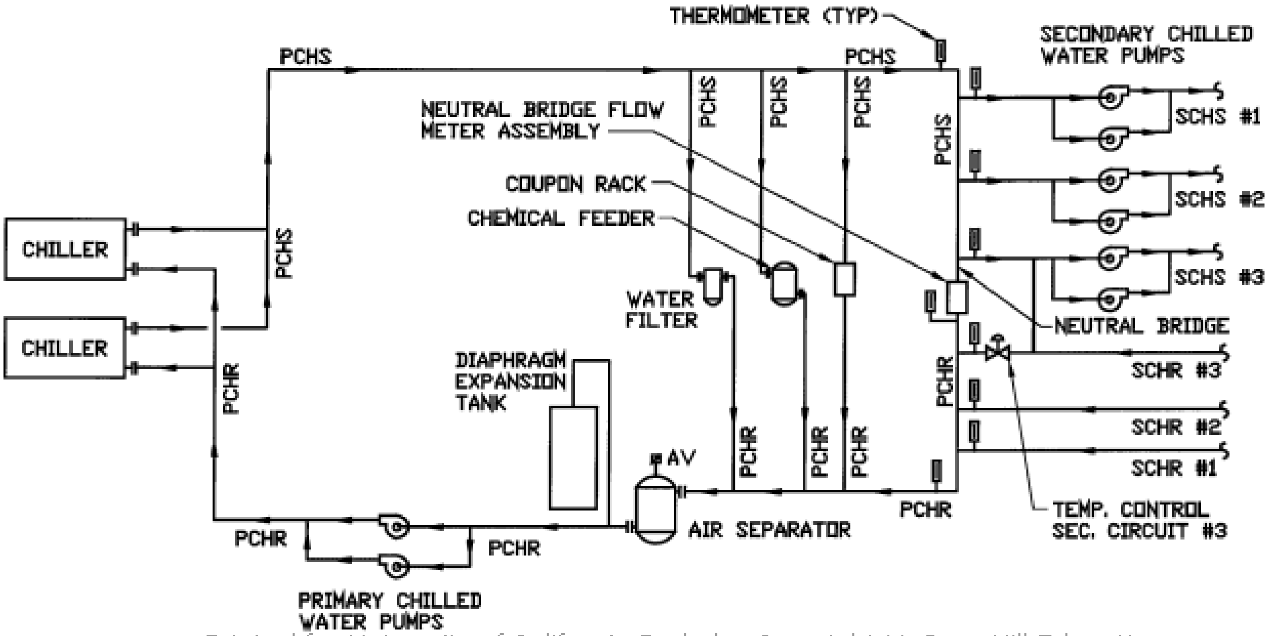


Figure 28.9. PARALLEL CHILLED-WATER SYSTEM—HEADERED PUMPS.

3. When designing chilled-water systems for computer centers, data centers, Internet host sites, and other mission-critical facilities where down time is not acceptable, consider utilizing a dual primary/secondary chilled-water system with primary/secondary chilled-water cross-connections and looped secondary system (see Figs. 28.10 and 28.11). This chilled-water system design permits isolating the piping segments as well as the equipment to permit service and repairs to both piping and equipment without shutdown of the system. The dual primary/secondary chilled-water system can be designed and sized to meet the Uptime Institute's Tier III classification (N+1 redundancy requirements; the arrangement actually provides N+2) and Tier IV classification (2[N+1] redundancy requirements). Chilled-water systems serving mission-critical facilities should always be designed for future expansion and growth. All future equipment and systems must provide for this growth. Space must be provided for future equipment, valved and capped connections must be provided for connections to piping mains so shutdowns are not required, piping mains must be sized for the ultimate growth of the facility, and electrical power systems must be designed and sized for the ultimate power utilized by the facility.

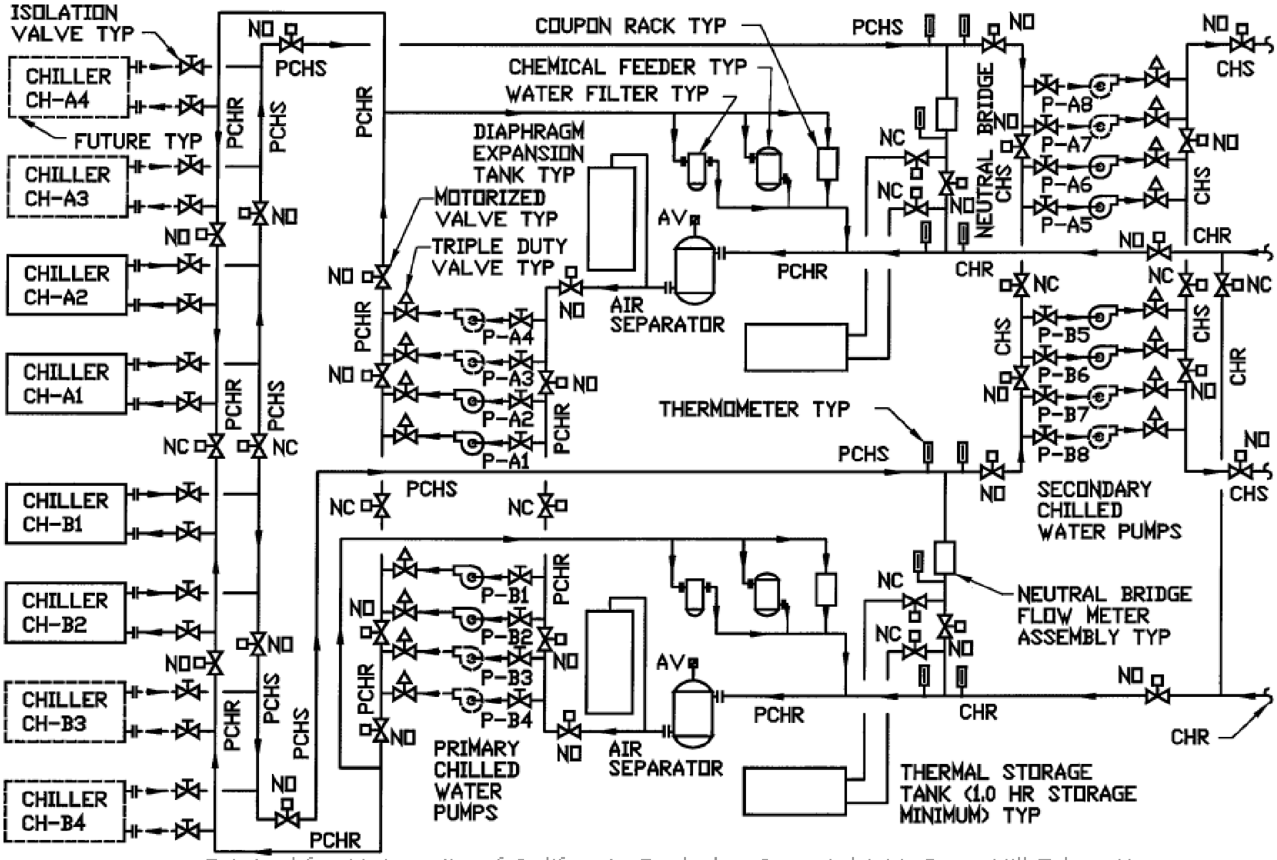


Figure 28.10. DUAL PRIMARY/SECONDARY CHILLED-WATER SYSTEM FLOW DIAGRAM.

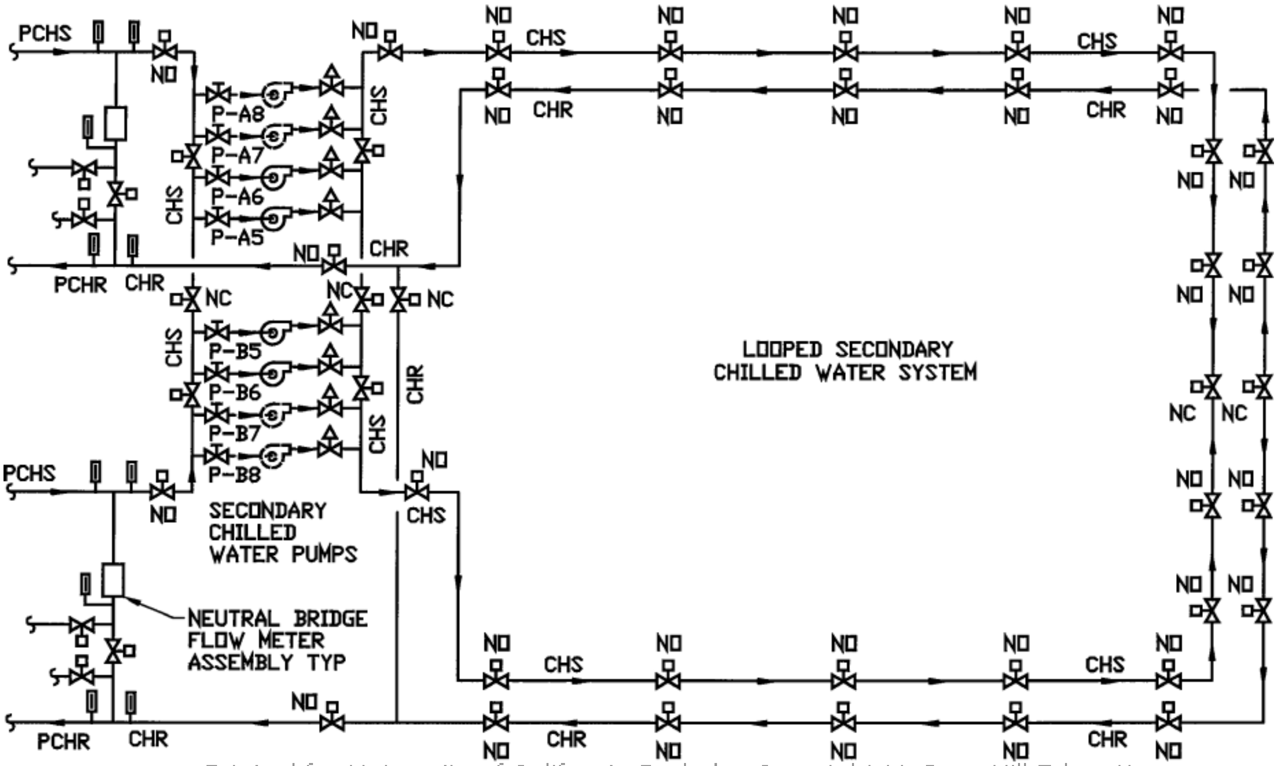


Figure 28.11. LOOPED SECONDARY CHILLED-WATER SYSTEM FLOW DIAGRAM.

C. **Water Boxes/Piping Connections**

1. Marine type. Marine water boxes enable piping to be connected to the side of the chiller so piping does not need to be disconnected in order to service machine. Recommend on large chillers, 500 tons and larger.

2. Nonmarine or standard type. Recommend on small chillers, less than 500 tons.

3. Provide victaulic or flanged connections for first three fittings at chiller with nonmarine or standard type connections.

4. Locate piping connections against the wall.

5. Locate all piping connections opposite the tube clean/pull side of the chiller.

6. Locate oil cooler connections.

D. **Show tube clean/pull clearances and location.**

E. **The minimum recommended clearance around chillers is 36 inches. Maintain minimum clearances for tube pull and cleaning of tubes as recommended by the equipment manufacturer. This is generally equal to the length of the chiller. Maintain minimum clearance as required to open access and control doors on chillers for service, maintenance, and inspection.**

F. **Maintain minimum electrical clearances as required by NEC.**

G. **Mechanical room locations and placement must take into account how chillers can be moved into and out of the building during initial installation and after construction for maintenance and repair and/or replacement.**

H. **If the chiller must be disassembled for installation (the chiller cannot be shipped disassembled), specify the manufacturer's representative for reassembly; do not specify insulation with chiller (field insulate), and specify the chiller to come with remote mounted starter.**

I. **Show the location of the chiller starter, disconnect switch, and control panel.**

J. **Show the chiller relief piping.**

K. **Show sanitary drain locations and chiller drain connections.**

L. **Locate refrigerant monitoring system refrigerant sensors and the refrigerant purge exhaust fan. The refrigerant exhaust system should be designed to remove refrigerant based on its specific gravity (lighter than air—high exhaust, heavier than air—low exhaust). Refrigerant detection devices are required by code, *ASHRAE Standard 15.* Detection devices sound an alarm at certain levels (low limit) and sound an alarm and activate ventilation system at a higher level (high limit), with levels dependent on refrigerant type.**

M. **Providing self-contained breathing apparatus within buildings for refrigerant emergencies is not recommended as in previous versions of ASHRAE Standard 15. Pre-positioning emergency response equipment should only be used by trained emergency responders and must be labeled for use by trained personnel only.**

N. **Coordinate the height of the chiller with overhead clearances and obstructions. Is a beam required above the chiller for lifting the compressor or other components?**

O. **Low ambient operation. Is the operation of the chiller required below 40°F, 0°F, etc., or will airside economizers provide cooling?**

P. **Wind direction and speed (air-cooled machines). Orient the short end of the chiller to the wind.**

Q. **If isolators are required for the chiller, has the isolator height been considered in clearance requirements? If isolators are required for the chiller, has piping isolation been addressed?**

R. **Locate flow switches in both the evaporator and condenser water piping systems serving each chiller and flow meters as required by system design.**

S. **Locate pumpdown, pumpout, and refrigerant storage devices if they are required.**

T. **When combining independent chilled-water systems into a central plant**

1. Create a central system concept, control scheme, and flow schematics.
2. The system shall only have a single expansion tank connection point sized to handle entire system expansion and contraction.

3. All systems must be altered, if necessary, to be compatible with central system concept (temperatures, pressures, flow concepts—variable or constant control concepts).

4. For constant flow and variable flow systems, the secondary chillers are tied into the main chiller plant return main. Chilled water is pumped from the return main through the chiller and back to the return main.

5. District chilled-water systems, due to their size, extensiveness, or both, may require that independent plants feed into the supply main at different points. If this is required, design and layout must enable isolating the plant; provide start-up and shutdown bypasses; and provide adequate flow, temperature, pressure, and other control parameter readings and indicators for proper plant operation and other design issues that affect plant operation and optimization.

U. **In large systems, it may be beneficial to install a steam-to-water or water-to-water heat exchanger to place an artificial load on the chilled-water system to test individual chillers or groups of chillers during plant startup, after repairs, or for troubleshooting chiller or system problems.**

V. **Large and campus chilled-water systems should be designed for large delta Ts and for variable flow secondary and tertiary systems.**

W. **Chilled-water pump energy must be accounted for in the chiller capacity because it adds heat load to the system.**

X. **It is best to design chilled-water and condenser-water systems to pump through the chiller.**

Part 29: Cooling Towers and Condensers

29. Part 29: Cooling Towers and Condensers

29.01. Cooling Tower Types (CTs)

A. **Induced Draft—Cross Flow**

1. 200–900 tons single cell.
2. 400–1,800 tons double cell.

B. **Forced Draft, Counter Flow**

1. 200–1,300 tons centrifugal fans.
2. 250–1,150 tons axial fans.
3. Figure 29.1 is a photograph of a forced draft, counter flow cooling tower in its installed condition.

Figure 29.1. PHOTOGRAPH OF A FORCED DRAFT, COUNTER FLOW COOLING TOWER.

C. **Ejector Parallel Flow**

1. 5–750 tons.

29.02. Definitions

A. ***Range*. Difference between entering and leaving water, system ΔT.**

B. ***Approach*. Difference between leaving water temperature and entering air wet bulb.**

C. ***Evaporation*. Method by which cooling towers cool the water.**

D. ***Drift*. Entrained water droplets carried off by the cooling tower. An undesirable side effect.**

E. ***Blowdown* or *Bleed*. Water intentionally discharged from the cooling tower to maintain water quality.**

F. ***Plume*. Hot moist air discharged from the cooling tower forming a dense fog.**

29.03. Condenser Water

A. **Most Common Entering Water Temperature (EWT): 95°F**

B. **Most Common Leaving Water Temperature (LWT): 85°F**

C. **Range: 10–40°F ΔT**

D. **3.0 GPM/ton@10°F ΔT**

E. **2.5 GPM/ton@12°F ΔT**

F. **2.0 GPM/ton@15°F ΔT**

G. **1.5 GPM/ton@20°F ΔT**

H. **0.75 GPM/ton@40°F ΔT**

29.04. Power

0.035–0.040 kW/ton

29.05. TONS_{COND}

= $TONS_{EVAP} \times 1.25$

= 12,000 Btu/h ton × 1.25

= 15,000 Btu/h ton

29.06. Condenser Water Makeup to Cooling Tower

A. Range:	**0.0306–0.0432 GPM/ton**
B. Range:	**0.0102–0.0144 GPM/Cond. GPM (1.0–1.4 percent Condenser GPM)**
C. Centrifugal:	**40 GPM/1,000 tons**
D. Reciprocating:	**40 GPM/1,000 tons**
E. Screw:	**40 GPM/1,000 tons**
F. Scroll:	**40 GPM/1,000 tons**
G. Absorption:	**80 GPM/1,000 tons**

29.07. Cooling Tower Drains

Use two times the makeup water rate for sizing cooling tower drains.

29.08. Cycles of Concentration

A. Range:	**2–10**
B. Recommend:	**3–5**

29.09. Evaporation

A. Range:	**0.024–0.03 GPM/ton**
B. Range:	**0.008–0.01 GPM/Cond. GPM (0.8–1.0 percent Condenser GPM)**
C. Recommend:	**0.01 GPM/Cond. GPM**

29.10. Drift

A. Range:	**0.0006–0.0012 GPM/ton**
B. Range:	**0.0002–0.0004 GPM/Cond. GPM (0.02–0.04 percent Condenser GPM)**
C. Recommend:	**0.0002 GPM/Cond. GPM**

29.11. Blowdown or Bleed (Based on 108F Range)

A. Range:	**0.006–0.012 GPM/ton**
B. Range:	**0.002–0.004 GPM/Cond. GPM (0.2–0.4 percent Condenser GPM)**
C. Recommend:	**0.002 GPM/Cond. GPM**
D. Centrifugal:	**10 GPM/1,000 tons**
E. Reciprocating:	**10 GPM/1,000 tons**
F. Screw:	**10 GPM/1,000 tons**
G. Scroll:	**10 GPM/1,000 tons**
H. Absorption:	**20 GPM/1,000 tons**

Blowdown GPM—% of Cond. GPM

Cooling Tower Range	**Cycles of Concentration**								
	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
10	0.80	0.40	0.30	0.20	0.10	0.10	0.10	0.10	0.10
15	1.20	0.60	0.40	0.30	0.20	0.20	0.15	0.15	0.15
20	1.60	0.80	0.50	0.40	0.30	0.30	0.20	0.20	0.20
25	2.00	1.00	0.65	0.50	0.40	0.35	0.25	0.25	0.23
30	2.40	1.20	0.80	0.60	0.50	0.40	0.30	0.30	0.25
35	2.75	1.40	0.95	0.70	0.55	0.45	0.35	0.35	0.30
40	3.10	1.60	1.10	0.80	0.60	0.50	0.40	0.40	0.35

29.12. Installation Location

Cooling towers should be located at least 100 feet from the building, when located on the ground, to reduce noise and prevent moisture from condensing on the building during the intermediate seasons (spring and fall). Cooling towers should also be located 100 feet from parking structures or parking lots to prevent staining of automobile finishes due to water treatment.

29.13. Air-Cooled Condensers and Condensing Units (ACCs and ACCUs)

A. Size Range:	**0.5–500 tons**
B. Air Flow:	**600–1,200 CFM/ton**
C. Power: 1. Condenser Fans: 0.1–0.2 HP/ton. 2. Compressors: 1.0–1.3 KW/ton.	

29.14. Evaporative Condensers and Condensing Units (ECs and ECUs)

A. Types and Sizes: 1. 10–1,600 tons centrifugal fans. 2. 10–1,500 tons axial fans.	
B. Drift:	**0.002 GPM/cond. GPM**
C. Evaporation:	**1.6–2.0 GPM/ton**
D. Bleed:	**0.8–1.0 GPM/ton**
E. Total:	**2.4–3.0 GPM/ton**

29.15. Installation of CTs, ACCs, ACCUs, ECs, and ECUs

A. **Allow ample space to provide the proper airflow to fans and units in accordance with the manufacturer's recommendations.**

B. **The top discharge of the unit should be at the same height or higher level than the adjoining building or wall to minimize recirculation caused by down drafts between the unit and wall. Raise the unit or provide a discharge hood to obtain the proper discharge height.**

C. **Elevating units may decrease the space required between units and between units and walls. Only decrease space in accordance with the manufacturer's recommendations.**

D. **Decking or metal plates over units between walls and other units may decrease the space required between units and between units and walls. Only decrease space in accordance with the manufacturer's recommendations.**

E. **Providing discharge hoods with units may decrease the space required between units and between units and walls. Only decrease space in accordance with the manufacturer's recommendations.**

F. **Chemical Feed Systems for CTs, ECs, and ECUs. Chemical feed systems are designed to control the following.**

1. System pH; normally between 8 and 9.
2. Corrosion.
3. Scale.
4. Biological and microbial growth.

G. **Clearance Requirements**

1. The minimum recommended clearance around CTs, ACCs, ACCUs, ECs, and ECUs is 36 inches. Maintain minimum clearances as recommended by the equipment manufacturer. Maintain the minimum clearance as required to open access and control doors on equipment for service, maintenance, and inspection.
2. Mechanical room locations and placement must take into account how CTs, ACCs, ACCUs, ECs, and ECUs can be moved into and out of the building during initial installation and after construction for maintenance and repair

and/or replacement.

Citation

EXPORT

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. Part 29: Cooling Towers and Condensers, Chapter (McGraw-Hill Professional, 2016), AccessEngineering

Part 30: Heat Exchangers

30. Part 30: Heat Exchangers

30.01. Shell and Tube Heat Exchangers

A. **Used Where the Approach of the System Is Greater than 15±°F**

B. **Straight Tube or U-Tube Design**

C. **Generally Used in Heating Systems**

D. **Water to Water**
   1. Maximum tube velocity: 6 ft./sec.
   2. Maximum shell velocity: 5 ft./sec.

E. **Steam to Water**
   1. Maximum water velocity: 6 ft./sec.
   2. If system steam capacity exceeds 2" control valve size, provide 2 control valves with 1/3 and 2/3 capacity split.

30.02. Plate and Frame Heat Exchangers

A. **Used Where the Approach of the System Is Less than 15±°F**

B. **Generally Used in Cooling Systems**

C. **Refer to Fig. 30.1 for a photograph of a plate and frame heat exchanger in its installed condition.**

Figure 30.1. PHOTOGRAPH OF A PLATE AND FRAME HEAT EXCHANGER.

30.03. Definitions

A. ***Range***: **Difference between entering and leaving water, system ΔT.**

B. ***Approach:*** **Difference between hot side entering water temperature and cold side leaving water temperature.**

30.04. Clearance and Design Requirements

A. **The minimum recommended clearance around heat exchangers is 36 inches. Maintain minimum clearances for tube pull and the cleaning of tubes as recommended by the equipment manufacturer. This is generally equal to the length of the heat exchanger.**

B. **Mechanical room locations and placement must take into account how heat exchangers can be moved into and out of the building during initial installation and after construction for maintenance and repair and/or replacement.**

C. **Multiple heat exchangers should be used to prevent complete system or building shutdown upon failure of one heat exchanger in all water systems over 200 tons or 2,400,000 Btu/h (e.g., 2@50 percent, 2@67 percent, 2@70 percent, 3@34 percent, 3@40 percent).**

D. **Heat Transfer Factors**

1. Change in enthalpy on the primary side (hydronic side).
2. Change in enthalpy on the secondary side.
3. Heat transfer through the heat exchanger is dependent on film coefficients and the heat transfer surface area.

E. **Methods of Heat Transfer**

1. Parallel flow. Both mediums flow in the same direction. The least effective method of heat transfer.
2. Counter-flow. Mediums flow in opposite directions. The most effective method of heat transfer.
3. Cross-flow. Mediums flow at right angles to each other. Heat transfer effectiveness between parallel and counter flow methods.
4. Combination. Cross-Flow/Counter-Flow or Cross-Flow/Parallel Flow. Typical in shell and tube heat exchangers.

at http://protege.stanford.edu//

Part 31: Boilers

31. Part 31: Boilers

31.01. Boilers, General

A. **Class I Boilers. ASME Boiler and Pressure Vessel Code, Section I**
   1. Steam boilers, greater than 15 psig
   2. Hot water boilers:
      a. Greater than 160 psig.
      b. Greater than 250°F.
   3. Common terminology:
      a. Process boilers.
      b. Power boilers.
      c. High-pressure boilers.

B. **Class IV Boilers. ASME Boiler and Pressure Vessel Code, Section IV**
   1. Steam boilers, 15 psig and less
   2. Hot water boilers:
      a. 160 psi and less.
      b. 250°F and less.
   3. Common terminology:
      a. Commercial boilers.
      b. Industrial boilers.

c. Heating boilers.

d. Low-pressure boilers.

C. **Common Boiler Design Pressures**

1. 15 psig.
2. 30 psig.
3. 60 psig.
4. 125 psig.
5. 150 psig.
6. 200 psig.
7. 250 psig.
8. 300 psig.
9. 350 psig.

D. **Boiler Sequence of Operation**

1. Prepurge.
2. Pilot ignition and verification.
3. Main flame ignition and verification.
4. Run time.
5. Post purge.
6. Boiler operational considerations:
    a. Hot water and steam boilers:
        1. Prevent hot or cold shock.
        2. Prevent frequent cycling.
        3. Provide proper water treatment.

    b. Hot water boilers only:
        1. Provide continuous circulation.
        2. Balance flow through boilers.

3. Provide proper overpressure.

c. Causes of increased stack temperature:

1. Soot buildup.

2. Scale buildup.

3. Combustion chamber and pass sealing problems.

E. **Boiler Types**

1. Fire tube boilers (Scotch Marine—see Fig. 31.1).

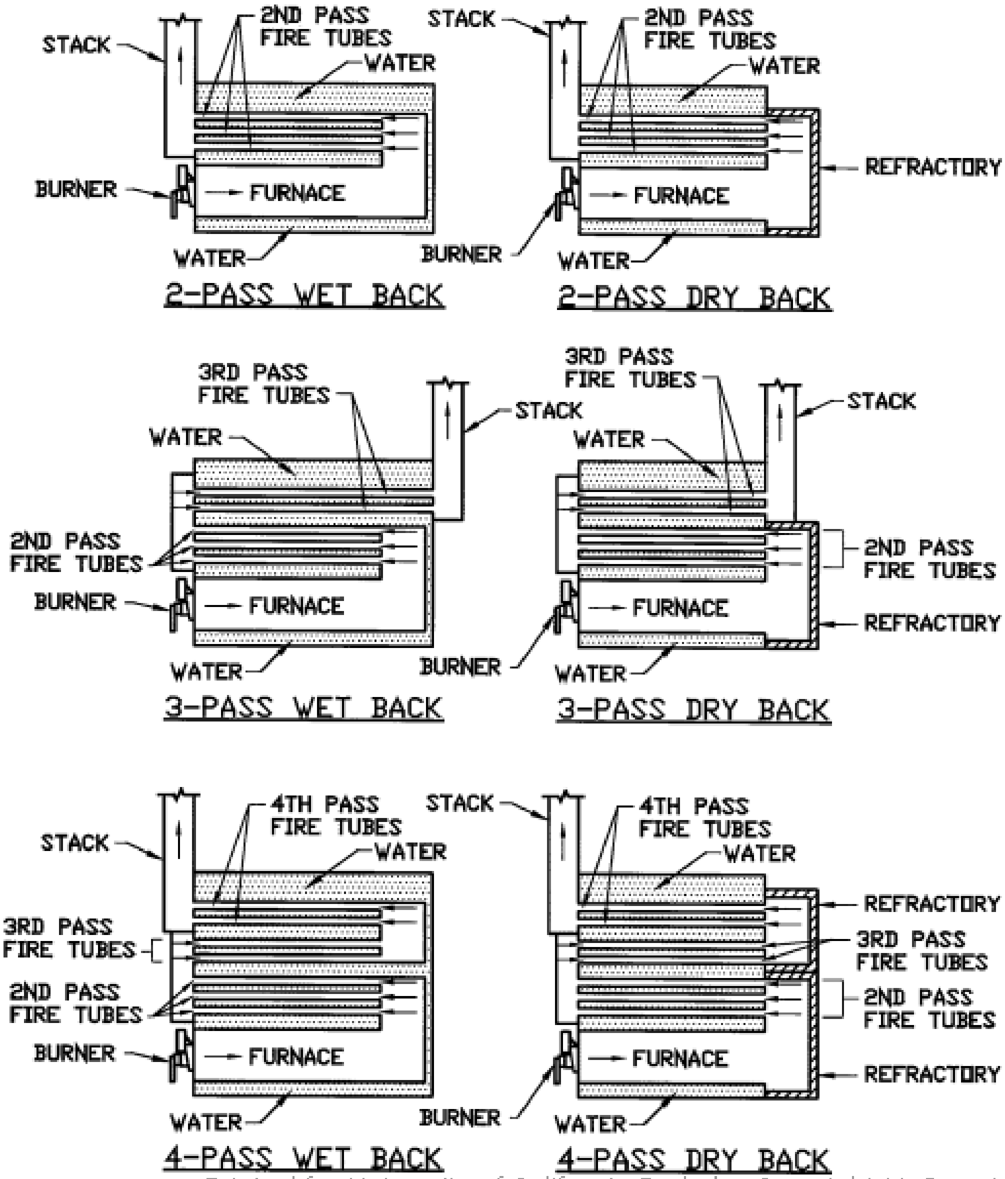


Figure 31.1. FIRE TUBE BOILER TYPES.

2. Water tube boilers (see Fig. 31.2).

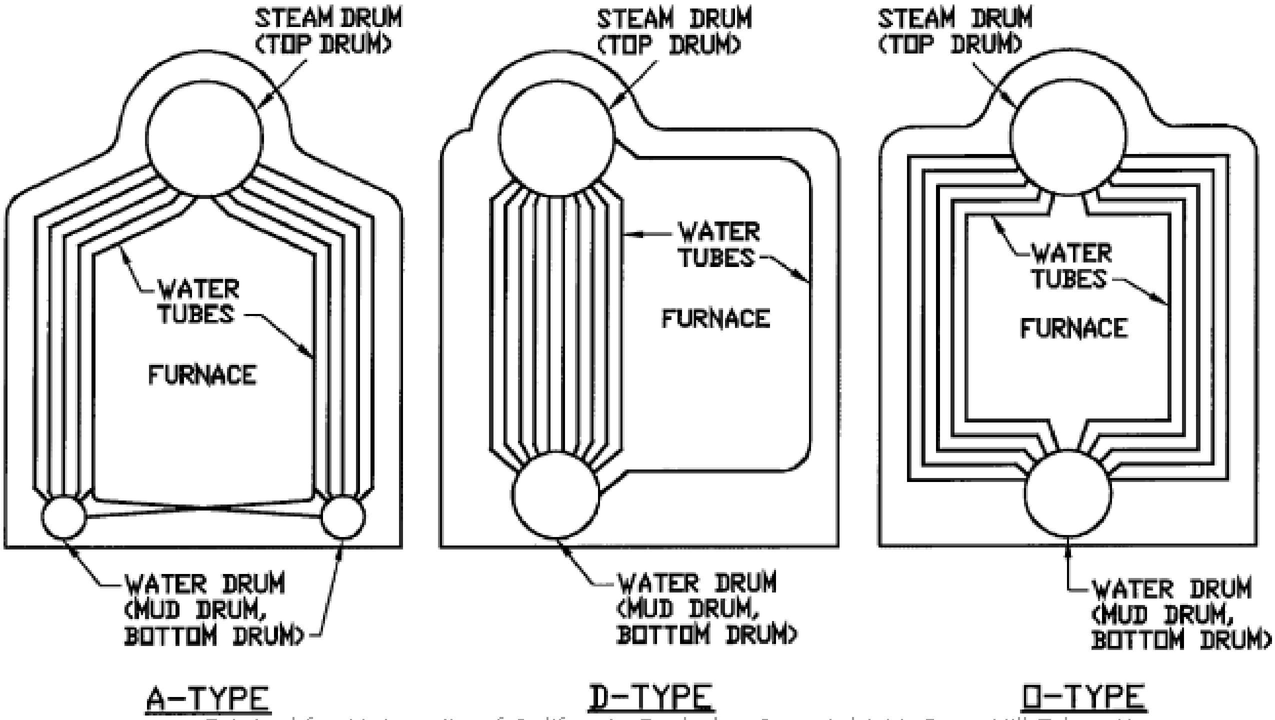


Figure 31.2. WATER TUBE BOILER TYPES.

3. Flexible tube boilers.

4. Cast iron boilers (see Figs. 31.3 through 31.5).

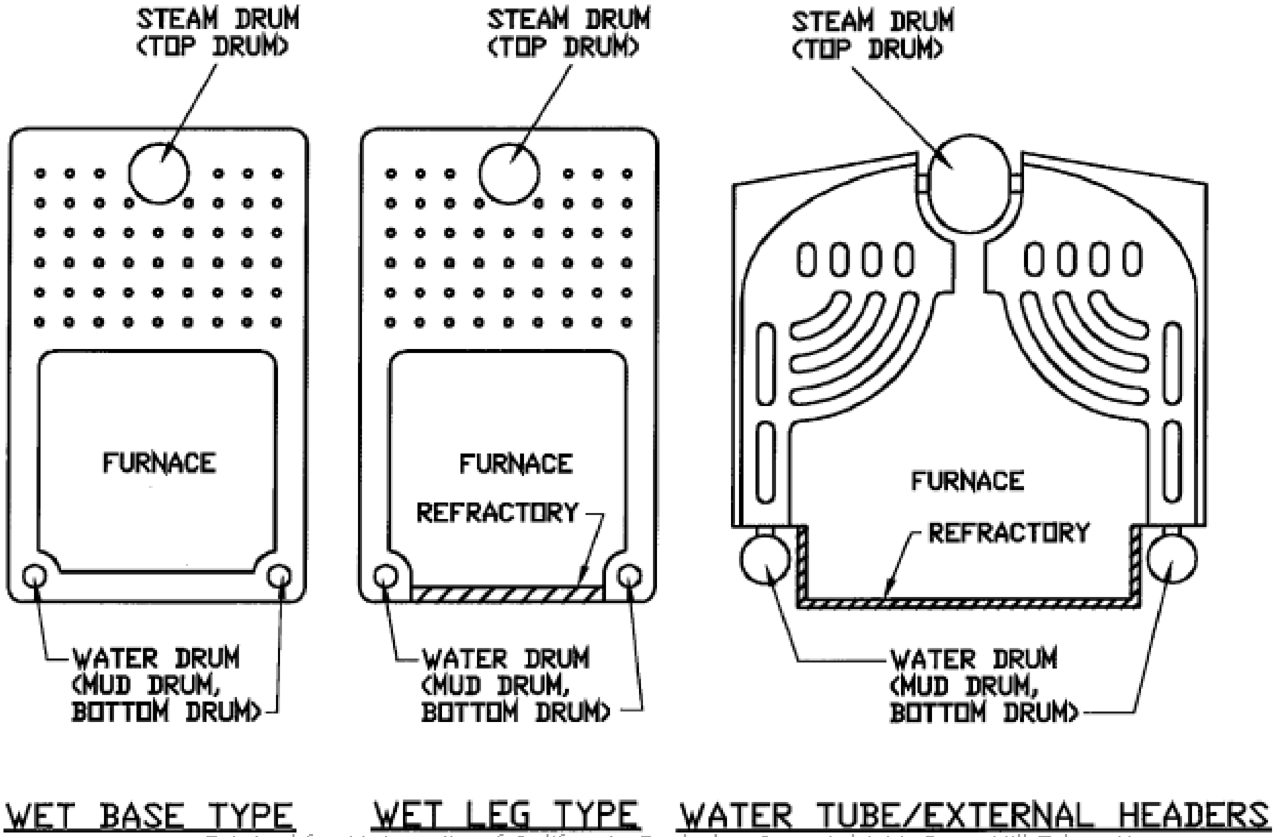


Figure 31.3. CAST IRON BOILER TYPES.

Figure 31.4. PHOTOGRAPH OF WET BASE CAST IRON BOILER.

Figure 31.5. PHOTOGRAPH OF WATER TUBE BOILER CAST IRON BOILER WITH EXTERNAL HEADERS.

5. Modular boilers.

6. Electric boilers.

7. Fire tube versus water tube boiler characteristics are shown in the following table:

FIRE TUBE VS. WATER TUBE BOILERS

Compared Item	Fire Tube Boilers	Water Tube Boilers
Steam Quality	98.5%	99.5%
Steam Purity	52.5 ppm	17.5 ppm can be modified to obtain 1 ppm
Efficiency	85% average	80% average
Design Pressure	300 psig	900 psig
Design Temperature	350°F	455°F
Super Heaters	None	Available to 750°F
Load Swings	Long recovery time	Short recovery time
Water Weight	Factor of 2.5	Factor of 1.0
Length	Longer	Shorter
Height	Shorter	Higher
Overfire	No	10–15% for short periods
Space	Door swing and tube pull	3'0" minimum all around
Electrical Load	Greater hp required	Lower hp required
Water Quality	Same	Same
Turn Down	10:1 gas; 8:1 fuel oil #2	10:1 gas; 8:1 fuel oil #2
U.L. Label	Standard entire package	Not available for entire package—components only
Soot Blowers	None	Standard option
Ultimate Decision	Customer preference	Customer preference

F. **Boiler Efficiency**

1. Combustion efficiency: Indication of the burner's ability to burn fuel measured by the unburned fuel and excess air in the exhaust.

2. Thermal efficiency: Indication of the heat exchanger's effectiveness to transfer heat from the combustion process to the water or steam in a boiler. Does not account for radiation and convection losses, however.

3. Fuel-to-steam efficiency: Indication of the overall efficiency of the boiler including effectiveness of the heat exchanger, radiation losses, and convection losses (output divided by input). The test to determine fuel-to-steam efficiency is defined by *ASME Power Test Code, PTC 4.1:*
    a. Input-output method.

    b. Heat loss method.

4. Boiler efficiency: Indication of either thermal efficiency or fuel-to-steam efficiency depending on context.

G. **Boiler Plant Efficiency Factors**
1. Boiler, 80–85% efficient:
    a. Radiation losses.

    b. Convection losses.

    c. Stack losses.

2. Boiler room, steam:
    a. Heating of combustion air.

    b. Heating of makeup water.

    c. Steam condensate not returned.

    d. Boiler blowdown.

    e. Radiation losses:
        1. Condensate tank.

        2. Condensate pump.

        3. Feedwater pump.

        4. Deaerator or feedwater tank.

3. Boiler room, hot water:
    a. Heating of combustion air.

    b. Radiation losses:

1. Expansion tank.

2. Air separator.

3. Pumps.

4. Plant, system:
   a. Steam leaks and bad steam traps.

   b. Piping, valves, and equipment radiation losses.

   c. Control valve operational problems.

   d. Flash steam losses.

   e. Water or condensate leaks/losses.

H. **Steam System Energy Saving Tips**

1. Insulate all hot surfaces to prevent heat loss.

2. Isolate all steam supply piping not being used.

3. Repair all steam piping leaks.

4. Repair all steam traps not operating properly which are bypassing steam.

5. Stop all internal steam leaks including venting of flash steam and open bypass valves around steam traps and control valves.

6. Produce clean, dry steam with the use of a steam separator and proper water treatment.

7. Properly control steam flow at equipment.

8. Use and properly select steam traps.

9. Use flash steam for preheating and other uses whenever possible.

I. **Packaged Boiler Fuel Types**

1. Natural gas.

2. Propane.

3. Light fuel oil #1 and #2.

4. Heavy fuel oil #4, #5, and #6.

5. Digester or landfill gas.

J. **Gas Trains**

1. Underwriter Laboratories, Standard (UL).

2. Industrial Risk Insurers (IRI).

3. Factory Mutual (FM).

4. Kemper.

5. ASME CSD-1 *Controls and Safety Devices for Automatically Fired Boilers*.

6. NFPA 8501 *Standard for Single Burner Boiler Operation*.

K. **Boiler Capacity Terminology**

1. Startup load. Capacity required to bring the boiler system up to temperature, pressure, or both.

2. Running load. Design capacity.

3. Maximum Instantaneous Demand (MID). A sudden peak load requirement of unusually short duration:
   a. MID loads are often hidden in process equipment loads.

   b. Cold startup or pickup loads that far exceed their normal operating demands.

   c. A full understanding of MID loads is required to properly select boiler system capacity.

   d. MID shortfall corrective actions:
      1. Change load reaction time to reduce impact; slow down valve operation, reduce number of items with simultaneous startup (staged startup).

      2. Add boiler capacity.

      3. Add back pressure regulator downstream of deaerator or feedwater tank steam supply connection.

      4. Add an accumulator.

L. **Combustion**

1. Improper combustion:

a. Oxygen rich-fuel lean: Wastes energy.

b. Oxygen lean-fuel rich: Produces CO, soot, and potentially hazardous conditions.

2. What affects combustion?
   a. Changes in barometric pressure.

   b. Changes in ambient air temperature:
      1. Oxygen trim systems compensate for ambient air temperature changes.

   c. Ventilation air:
      1. Total: 10 CFM/BHP

      2. Combustion air: 8 CFM/BHP

      3. Ventilation: 2 CFM/BHP

   d. Keep boiler room positive with respect to the stack and breeching (+0.10 in. W.G. maximum) to prevent the entrance of flue gases into the boiler room.

   e. Never exhaust boiler rooms; use supply air with relief air.

M. **Stacks and Breeching. Provide a manual damper (lock damper in the open position) or a motorized damper (two-position damper) at the boiler outlet. A motorized damper interlocked with boiler operation is preferred.**
   1. Multiple boilers with common stack and breeching. Damper will prevent products of combustion from entering the boiler room when repairing or inspecting boilers while system is still in operation.

   2. Multiple boilers with individual or common stack and breeching. Damper will prevent the natural draft through the boiler when not firing, thus reducing the energy lost up the stack.

N. **1990 Clean Air Act—Focused on the reduction of the following pollutants**
   1. Ozone (O_3).

   2. Carbon monoxide (CO).

   3. Nitrogen oxides (NO_x-NO/NO_2).

4. Sulfur oxides (SO_x-SO_2/SO_3).

5. Particulate matter, 10 ppm.

6. Lead.

O. **Standard Controls**

1. Steam boiler control and safeties:
   a. High limit pressure control. Provides a margin of safety.

   b. Operating limit pressure control. Starts/stops burner.

   c. Modulation pressure control. Varies burner firing rate.

   d. Low limit pressure control.

   e. Low water cutoff.

   f. Auxiliary low water cutoff.

   g. High water cutoff.

2. Hot water boiler controls and safeties:
   a. High limit pressure control. Provides a margin of safety.

   b. High limit temperature control. Provides a margin of safety.

   c. Operating limit temperature control. Starts/stops burner.

   d. Modulation temperature control. Varies burner firing rate.

   e. Low limit pressure control.

   f. Low limit temperature control.

   g. Low water cutoff.

   h. High water cutoff.

3. Fuel system controls and safeties:
   a. Low gas pressure switch.

   b. High gas pressure switch.

   c. Low oil pressure switch.

   d. High oil pressure switch.

e. Low oil temperature.

4. Combustion controls and safeties:
   a. Pilot failure switch.

   b. Flame failure switch.

   c. Combustion air proving switch.

   d. Oil atomization proving switch.

   e. Low fire hold control.

   f. Low fire switch.

   g. High fire switch.

P. **Safety, relief, and safety relief valve testing is dictated by the Insurance Underwriter.**

31.02. Hot Water Boilers

A. **Boiler Types**

1. Fire tube boilers:
   a. 15–800 BHP.

   b. 500–26,780 MBH.

   c. 30–300 psig.

2. Water tube boilers:
   a. 350–2,400 BHP.

   b. 13,000–82,800 MBH.

   c. 30–525 psig.

3. Flexible water tube boilers:
   a. 30–250 BHP.

   b. 1,000–8,370 MBH.

   c. 0–150 psig.

4. Cast-iron boilers:

a. 10–400 BHP.

b. 345–13,800 MBH.

c. 0–40 psig.

5. Modular boilers:
   a. 4–115 BHP.

   b. 136–4,000 MBH.

   c. 0–150 psig.

6. Electric boilers:
   a. 15–5,000 KW.

   b. 51–17,065 MBH.

   c. 0–300 psig.

B. **Hot Water Boiler Plant Equipment**

1. Boilers (see Fig. 31.6).

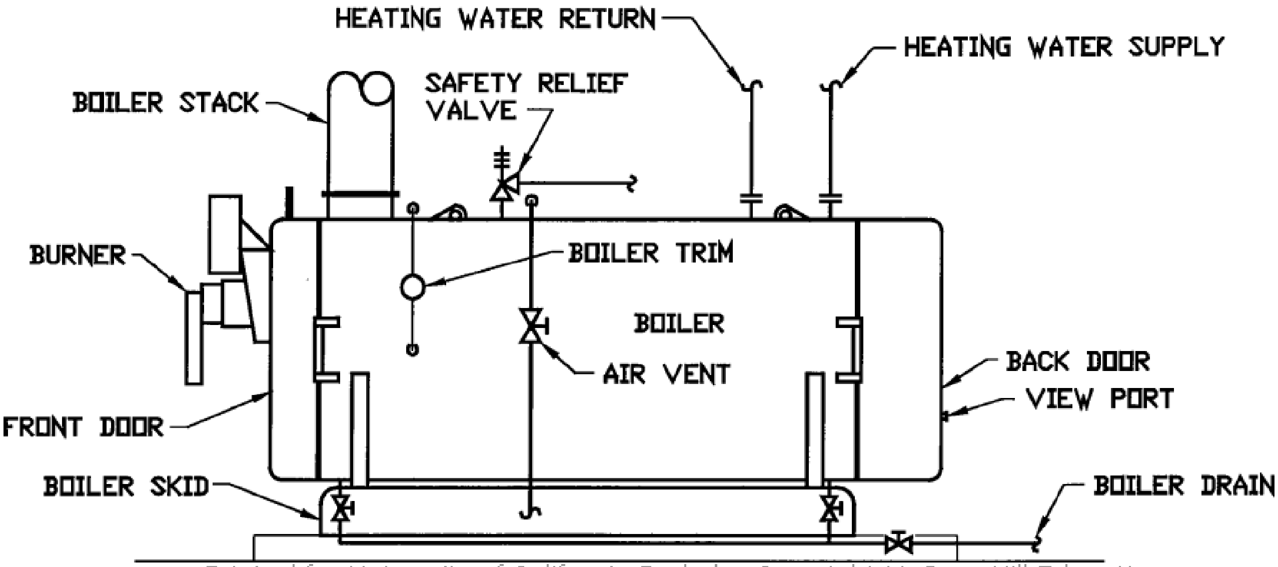


Figure 31.6. HEATING WATER SYSTEM AND BOILER TERMINOLOGY.

2. Pumps.

3. Air separators.

4. Expansion tanks.

C. **Heating Water**

1. Leaving water temperature (LWT): 180–200°F.

2. 20–40°F ΔT most common.

3. Boiler system design limits:
   a. Minimum flow through a boiler: 0.5–1.0 GPM/BHP.

   b. Maximum flow through a boiler: Boiler capacity divided by the temperature difference divided by 500.

   c. Pressure drop through a boiler: 3–5 feet H_2O.

   d. Minimum supply water temperature: 170°F. This temperature may vary with boiler design and with manufacturer; verify the exact temperature with the manufacturer.

   e. Minimum return water temperature: 150°F. This temperature may vary with boiler design and with manufacturer; verify the exact temperature with the manufacturer.

   f. Maximum supply water temperature: Based on the ASME Design Rating of the boiler.

4. Heating capacities:
   a. 3.45 GPM/BHP @20°F ΔT.

   b. 2.30 GPM/BHP @30°F ΔT.

   c. 1.73 GPM/BHP @40°F ΔT.

   d. 10.0 GPM/therm @20°F ΔT.

   e. 6.7 GPM/therm @30°F ΔT.

   f. 5.0 GPM/therm @40°F ΔT.

   g. 10,000 Btuh/GPM @20°F ΔT.

   h. 15,000 Btuh/GPM @30°F ΔT.

   i. 20,000 Btuh/GPM @40°F ΔT.

D. **System Types**

1. Low-temperature heating water systems:
   a. 250°F and less.

   b. 160 psig maximum.

2. Medium-temperature heating water systems:
   a. 251–350°F.

   b. 160 psig maximum.

3. High-temperature heating water systems:
   a. 351–450°F.

   b. 300 psig maximum.

E. **Heating Water Storage Systems**

1. 20°F ΔT:
   a. 0.80 cu.ft./MBtu

   b. 1246.2 Btu/cu.ft.

   c. 166.6 Btu/gal.

2. 30°F ΔT:
   a. 0.54 cu.ft./MBtu

   b. 1869.3 Btu/cu.ft.

   c. 249.9 Btu/gal.

3. 40°F ΔT:
   a. 0.40 cu.ft./MBtu

   b. 2492.3 Btu/cu.ft.

   c. 333.2 Btu/gal.

F. **Hot Water System Makeup Connection: Minimum connection size shall be 10 percent of largest system pipe size or 1", whichever is greater (20" system pipe size results in a 2" makeup water connection).**

G. **Chemical Feed Systems for Water Boilers. Chemical feed systems are designed to control the following:**

1. System pH, normally between 8 and 9.

2. Corrosion.

3. Scale.

H. **Design, Layout, and Clearance Requirements/Considerations**

1. Design conditions:

a. Boiler load, Btu/h, or MBH.

b. Heating water temperatures, entering and leaving, or entering and ΔT.

c. Heating water flows and fluid type (correct all data for fluid type).

d. Fuel input, gas, fuel oil, electric, etc.

e. Overall boiler efficiency.

f. Water pressure drops.

g. Fouling factor.

h. Heating water reset, if applicable. Verify with boiler manufacturer that temperature limits are not exceeded.

i. Electrical data:
   1. Unit kW, blower hp, compressor hp, and fuel oil pump hp.

   2. Full load, running load, and locked rotor amps.

   3. Voltage-phase-hertz.

2. Multiple hot water boilers should be used to prevent complete system or building shutdown upon failure of one hot water boiler in all heating water systems over 70 boiler horsepower or 2,400,000 Btu/h (i.e., 2 @ 50 percent, 2 @ 67 percent, 2 @ 70 percent, 3 @ 34 percent, 3 @ 40 percent).

3. Show tube clean/pull clearances and location.

4. The minimum recommended clearance around boilers is 36 in. Maintain minimum clearances for tube pull and the cleaning of tubes as recommended by the equipment manufacturer. This is generally equal to the length of the boiler. Maintain minimum clearance as required to open access and control doors on boilers for service, maintenance, and inspection.

5. Mechanical room locations and placement must take into account how boilers can be moved into and out of the building during initial installation and after construction for maintenance and repair and/or replacement.

6. Maintain the minimum electrical clearances as required by NEC.

7. Show the location of the boiler starter, disconnect switch, and control panel.

8. Show gas train and/or fuel oil train location.
9. Show boiler relief piping.
10. Show sanitary drain locations and boiler drain connections.
11. Design and locate combustion air louvers and motorized dampers, or engineered combustion air system. What happens if the engineered combustion air system malfunctions? Is a standby available? Verify that items that might freeze are not located in front of a combustion air intake.
12. Coordinate the height of the boiler with overhead clearances and obstructions. Is a beam required above the boiler for lifting components? Is a catwalk required to service the boiler?
13. Boiler stack and breeching. Coordinate routing in boiler room, through building, and discharge height above the building with the architect and structural engineer.
14. If isolators are required for the boiler, has the isolator height been considered in clearance requirements? If isolators are required for the boiler, has piping isolation been addressed?
15. Provide stop check valves (located closest to the boiler) and isolation valves with a drain between these valves on both the supply and return connections to all heating water boilers.
16. Boiler systems pumps should be located so the pump draws water out of the boiler, because it decreases the potential for entry of air into the system, and it does not impose the pump pressure on the boiler.
17. Interlock the boiler and the pump so the burner cannot operate without the pump operating.
18. Boiler warming pumps should be piped to both the system header and the boiler supply piping, allowing the boiler to be kept warm (in standby mode) from the system water flow or to warm the boiler when it has been out of service for repairs without the risk of shocking the boiler with the system water temperature (see Figs. 31.7 and 31.8).

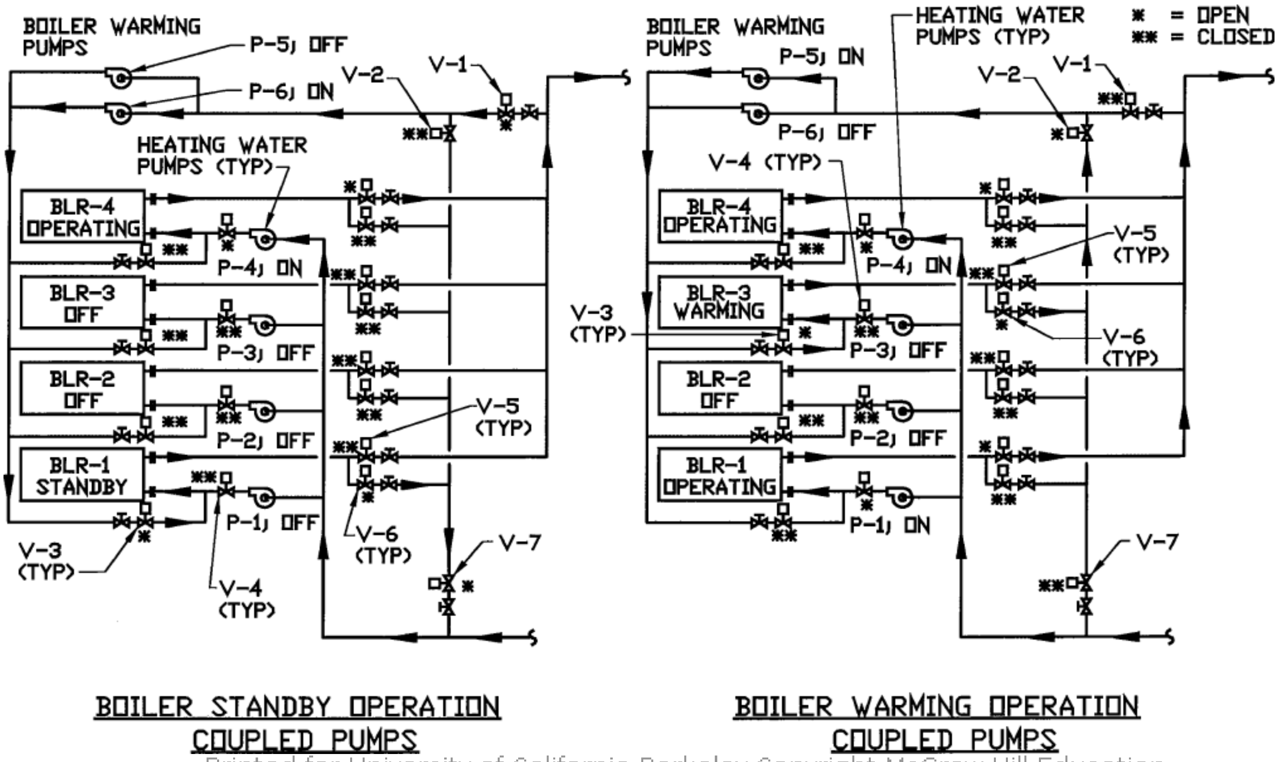


Figure 31.7. BOILER STANDBY AND WARMING DIAGRAM—COUPLED PUMPS.

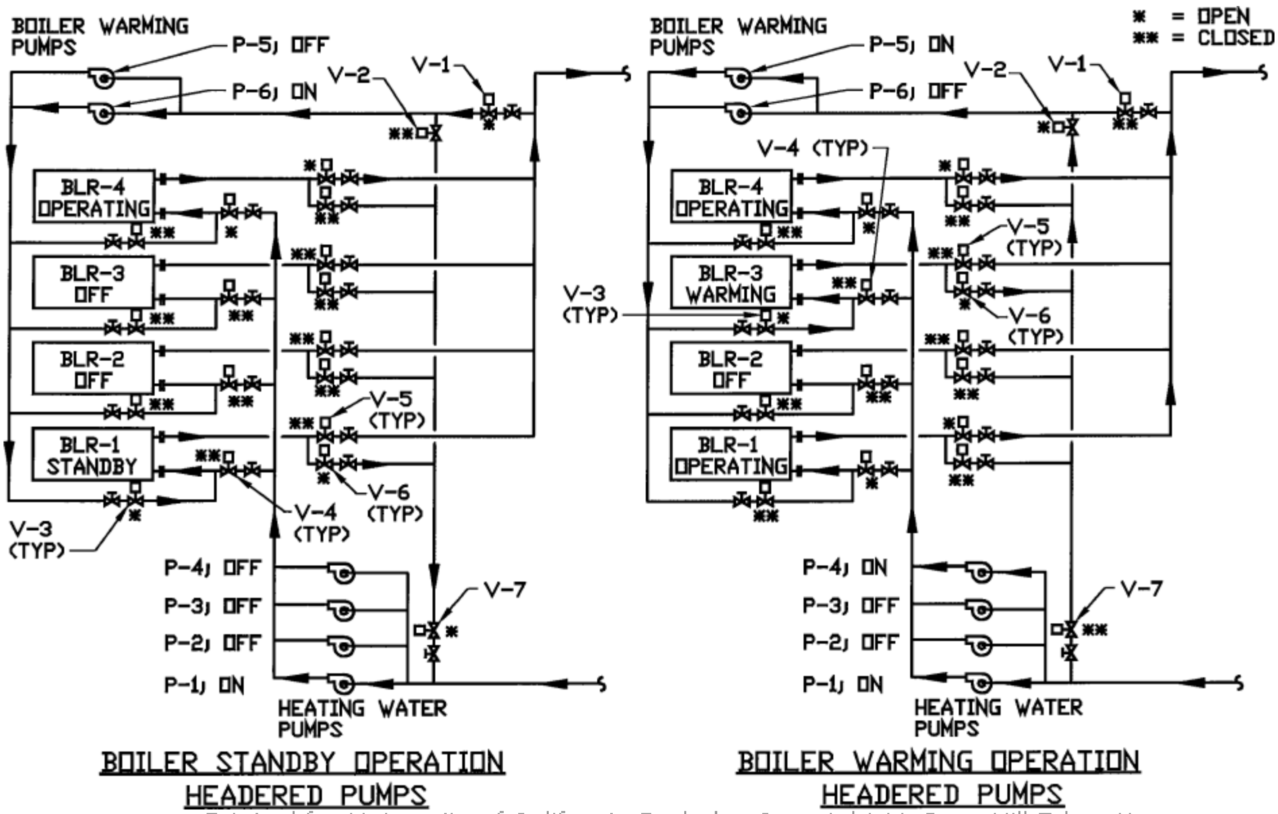


Figure 31.8. BOILER STANDBY AND WARMING DIAGRAM—HEADERED PUMPS.

19. Boiler warming pumps should be selected for 0.1 GPM/BHP (range 0.05–0.1 GPM/BHP). At 0.1 GPM/BHP, it takes 45–75 minutes to completely exchange the water in the boiler. This flow rate is sufficient to offset the heat loss by radiation and stack losses on boilers when in standby mode of operation. In addition, this flow rate allows the system to keep the boiler warm without firing the boiler, thus allowing for more efficient system operation. For example, it takes 8–16 hours to bring a boiler online from a cold start. Therefore, the standby boiler must be kept warm to enable immediate startup of the boiler upon failure of an operating boiler.

20. Circulating hot water through a boiler which is not operating, to keep it hot for standby purposes, creates a natural draft of heated air through the boiler and up the stack, especially in natural draft boilers. Forced draft or induced draft boilers have combustion dampers that close when not firing and therefore reduce, but don't eliminate, this heat loss. Although this heat loss is undesirable, for standby boilers, circulating hot water through the boiler is more energy efficient than firing the boiler. Operating (firing) a standby boiler may be in violation of air permit regulations in many jurisdictions today.

21. To provide fully automatic heating water system controls, the controls must look at and evaluate the boiler metal temperature (water temperature) and the refractory temperature prior to starting the primary pumps or enabling the boiler to fire. First, the boiler system design must circulate system water through the boilers to keep the boiler water temperature at system temperature when the boiler is in standby mode, as discussed for boiler warming pump arrangements. Second, the design must look at the water temperature prior to starting the primary pumps to verify the boiler is ready for service. And third, the design must look at refractory temperature to prevent boiler from going to high fire if the refractory is not at the appropriate temperature. However, the refractory temperature is usually handled by the boiler control package.

22. Outside air temperature reset of low temperature heating water systems is recommended for energy savings and controllability of terminal units at low load conditions. However, care must be taken with the boiler design to prevent thermal shock by low return water temperatures, or to prevent condensation in the boiler due to low supply water temperatures and, therefore, a lower combustion stack discharge temperature.

23. Combustion air dampers must be extra heavy duty and should be low

leakage (10 CFM/sq.ft. @ 4" WC differential) or ultralow leakage (6 CFM/sq.ft. @ 4" WC differential) type.

24. When the system design requires the use of dual fuel boilers (natural gas, fuel oil), provide a building automation control system I/O point to determine whether the boiler is on natural gas or fuel oil. Boiler control panels generally have a fuel type switch (Gas/Off/Fuel Oil Switch) which can be connected to create this I/O point. Switching from natural gas to fuel oil (or vice versa) cannot be a fully automatic operation because the boiler operator must first turn the boiler burner to the "Off" position, then turn the fuel type switch to fuel oil, then put combustion air linkage into the fuel oil position, then slide the fuel oil nozzle into position, then put the fuel oil pump into "Hand" or "Auto" position, and then turn the boiler burner to the "On" position. Remember to interlock the fuel oil pumps with operation of the boiler on fuel oil. Do not forget to include diesel generator interlocks with fuel oil pumps when the generators are fed from the same fuel oil system.

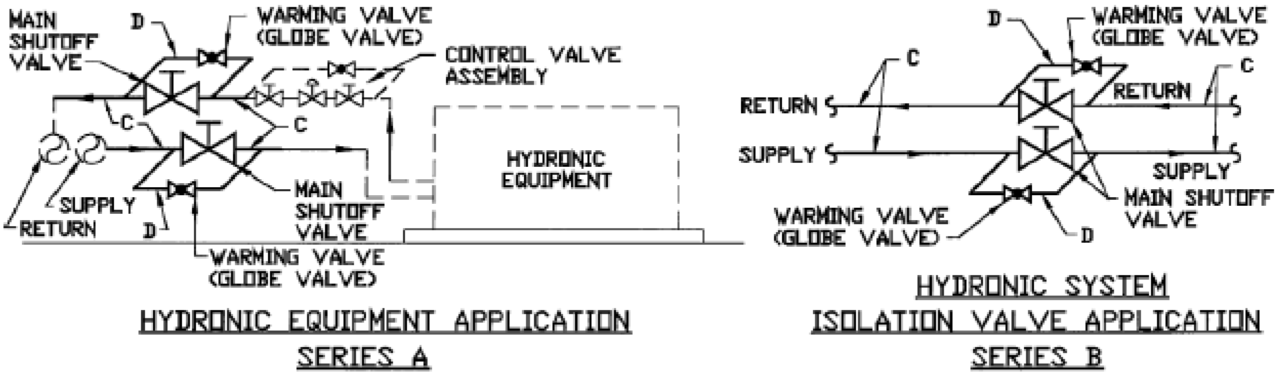
25. Heating water system warm-up procedure:
    a. Heating water system startup should not exceed a 100°F temperature rise per hour, but boiler or heat exchanger manufacture limitations should be consulted.

    b. It is recommended that no more than a 25°F temperature rise per hour be used when warming heating water systems. Slow warming of the heating water system allows for system piping, supports, hangers, and anchors to keep up with system expansion.

    c. Low temperature heating water systems (250°F and less) should be warmed slowly at a 25°F temperature rise per hour until the system design temperature is reached.

    d. Medium- and high-temperature heating water systems (above 250°F) should be warmed slowly at a 25°F temperature rise per hour until a 250°F system temperature is reached. At this temperature, the system should be permitted to settle for at least 8 hours or more (preferably overnight). The temperature and pressure maintenance time gives the system piping, hangers, supports, and anchors a chance to catch up with the system expansion. After allowing the system to settle, the system can be warmed up to 350°F or the system design temperature in 25°F temperature increments and 25 psig pressure increments, semi-alternating between temperature and pressure increases, and allowing the system to settle for an hour before increasing the temperature or pressure to the next increment. When the system reaches 350°F and the design temperature is above 350°F, the system should be allowed to settle for at least 8 hours or more (preferably overnight). The temperature and pressure maintenance time gives the system piping, hangers, supports, and anchors a chance to catch up with the system expansion. After allowing the system to settle, the system can be warmed up to 455°F or system design temperature in 25°F temperature increments and 25 psig pressure increments, semi-alternating between temperature and pressure increases, and allow the system to settle for an hour before increasing the temperature or pressure to the next increment.

26. Provide heating water systems with warm-up valves for in-service startup as follows (see Fig. 31.9). This will allow operators to warm these systems slowly and to prevent a sudden shock or catastrophic system failure when large system valves are opened. Providing warming valves also reduces wear on large system valves when only opened a small amount in an attempt to control the system warm-up speed.



NOTES:

1. SERIES A WARMING VALVES COVER STEAM OR MEDIUM/HIGH-TEMPERATURE HEATING WATER SERVICE FOR WARMING UP EQUIPMENT BEFORE THE MAIN SHUTOFF VALVES ARE OPENED, AND FOR BALANCING PRESSURES WHERE LINES ARE OF LIMITED VOLUME.
2. SERIES B WARMING VALVES COVER LINES CONVEYING GASES OR LIQUIDS WHERE BYPASSING MAY FACILITATE THE OPERATION OF THE MAIN VALVE BY BALANCING THE PRESSURES ON BOTH SIDES OF THE MAIN VALVE.

MAIN VALVE SIZE (C)	WARMING VALVE SIZE (D)	
	SERIES A WARMING VALVES	SERIES B WARMING VALVES
4″	1/2″	1″
5″, 6″	3/4″	1-1/4″
8″	3/4″	1-1/2″
10″	1″	1-1/2″
12″, 14″	1″	2″
16″, 18″, 20″	1″	3″
24″, 30″	1″	4″
36″, 42″	1″	6″
48″, 54″	1″	8″
60″, 72″	1″	10″
84″, 96″	1″	12″

Figure 31.9. HYDRONIC SYSTEM WARMING VALVES.

BYPASS AND WARMING VALVES

	Nominal Pipe Size	
Main Valve Nominal Pipe Size	**Series A Warming Valves**	**Series B Bypass Valves**
4	1/2	1
5	3/4	1-1/4
6	3/4	1-1/4
8	3/4	1-1/2
10	1	1-1/2
12	1	2
14	1	2
16	1	3
18	1	3
20	1	3
24	1	4
30	1	4
36	1	6
42	1	6
48	1	8
54	1	8
60	1	10
72	1	10
84	1	12
96	1	12

Notes:

1. **Series A comprehends steam service for warming up before the main line is opened, and for balancing pressures where lines are of limited volume.**

2. **Series B comprehends lines conveying gases or liquids where bypassing may facilitate the operation of the main valve through balancing the pressures on both sides of the disc or discs thereof. The valves in the larger sizes may be of the bolted on type.**

27. Heating water system warming valve procedure (see Fig. 31.9):
    a. Open the warming return valve slowly to pressurize the equipment without flow.
    b. Once the system pressure has stabilized, slowly open the warming supply valve to establish flow and to warm the system.
    c. Once the system pressure and temperature have stabilized, perform the following steps, one at a time:
        1. Slowly open the main return valve.
        2. Close the warming return valve.
        3. Slowly open the main supply valve.
        4. Close the warming supply valve.

31.03. Steam Boilers

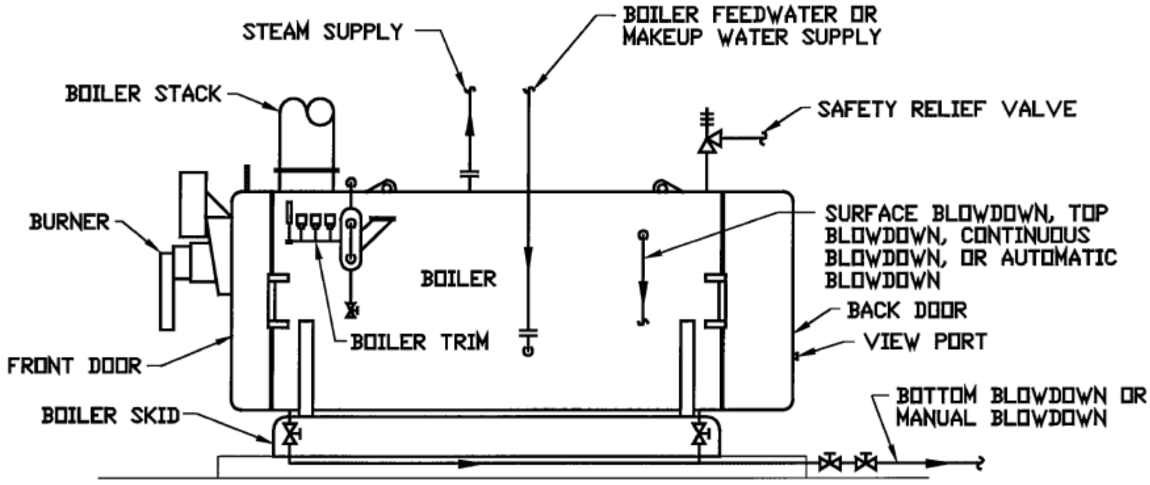
A. **Boiler Types**

1. Fire tube boilers:
    a. 15–800 BHP.
    b. 518–27,600 lbs./h
    c. 15–300 psig.
2. Water tube boilers:
    a. 350–2,400 BHP.
    b. 12,075–82,800 lbs./h
    c. 15–525 psig.
3. Flexible water tube boilers:
    a. 30–250 BHP.
    b. 10,000–82,000 lbs./h
    c. 15–525 psig.
4. Cast-iron boilers:
    a. 10–400 BHP.

    b. 1,035–8,625 lbs./h
    c. 0–150 psig.
5. Electric boilers:
    a. 15–5,000 KW.
    b. 51–17,065 MBH.
    c. 0–300 psig.

B. **Steam Boiler Plant Equipment**

1. Pretreatment systems:
    a. Filters.
    b. Softeners.
    c. Dealkalizers.
    d. RO units.
2. Feedwater systems:
    a. Deaerator:
        1. Spray type.
        2. Packed column type.
    b. Feedwater tank.
    c. Feedwater pumps.
3. Chemical feed systems:
    a. Chemical pumps.
    b. Chemical tanks.
    c. Agitators.
4. Sample coolers.
5. Blowdown coolers.
6. Surface blowdown/feedwater preheater.
7. Flue gas economizers.
8. Boilers (see <u>Fig. 31.10</u>).



NOTES:

1. BOILER BURNER MAY BE FORCED DRAFT, INDUCED DRAFT, OR NATURAL DRAFT TYPE DEPENDING ON BOILER TYPE AND CONSTRUCTION, FORCED DRAFT TYPE SHOWN.
2. BOILER TRIM IS COMPRISED OF THE LOW WATER LEVEL LIMIT AND ALARM, HIGH WATER LEVEL LIMIT AND ALARM, FEEDWATER CONTROLLER INCLUDING LEVEL CONTROLLER, SAFETIES, FUEL CUTOUTS, SAFETY RELIEF VALVES, PRESSURE GAUGES, THERMOMETERS, HIGH AND LOW LIMIT BURNER CONTROLS, AND OTHER APPURTENANCES.

Figure 31.10. STEAM SYSTEM AND BOILER TERMINOLOGY.

9. Condensate return units and pumps.
10. Condensate receiver tank.
11. Condensate pumps.
12. Accumulators:
    a. Type:
        1. Dry.
        2. Wet.
    b. Service:
        1. Total system.
        2. Dedicated lines to specific equipment.
13. Super heaters:
    a. Internal.
    b. External.

C. **Steam Capacities**

1. Approx. 1,000 Btuh/1 lb. steam.
2. lbs. steam/h = lb. water/h

STEAM CAPACITY PER BOILER HORSEPOWER

Feed Water Temp.	Pounds of Dry Saturated Ste @ System Pressure (psig) vs. Feedv									
	0	2	10	15	20	40	50	60	80	100
30	29.0	29.0	28.8	28.7	28.6	28.4	28.3	28.2	28.2	28.1
40	29.3	29.2	29.1	29.0	28.9	28.7	28.6	28.5	28.4	28.3
50	29.6	29.5	29.3	29.2	29.1	28.9	28.8	28.8	28.7	28.6
60	29.8	29.8	29.6	29.5	29.4	29.2	29.1	29.0	28.9	28.8
70	30.1	30.0	29.9	29.8	29.7	29.5	29.4	29.3	29.2	29.1
80	30.4	30.3	30.1	30.0	30.0	29.8	29.6	29.6	29.5	29.3
90	30.6	30.6	30.4	30.3	30.2	30.0	29.9	29.8	29.7	29.6
100	30.9	30.8	30.6	30.6	30.5	30.3	30.2	30.1	30.0	29.8
110	31.2	31.2	30.9	30.8	30.8	30.6	30.4	30.3	30.2	30.0
120	31.5	31.4	31.2	31.2	31.1	30.8	30.7	30.6	30.5	30.4
130	31.8	31.7	31.5	31.4	31.4	31.1	31.0	30.9	30.8	30.7
140	32.1	32.0	31.8	31.7	31.6	31.4	31.3	31.2	31.1	31.0
150	32.4	32.4	32.1	32.0	31.9	31.7	31.6	31.5	31.4	31.2
160	32.7	32.7	32.4	32.4	32.3	32.0	31.9	31.8	31.7	31.5
170	33.0	33.0	32.7	32.6	32.6	32.3	32.2	32.1	32.0	31.8
180	33.4	33.3	33.0	33.0	32.9	32.6	32.5	32.4	32.3	32.2
190	33.8	33.7	33.4	33.3	33.2	32.9	32.8	32.7	32.6	32.5
200	34.1	34.0	33.7	33.6	33.5	33.2	33.1	33.0	32.9	32.8
212	34.5	34.4	34.2	34.1	33.9	33.6	33.5	33.4	33.3	33.2
220	34.8	34.7	34.4	34.3	34.2	33.9	33.8	33.7	33.5	33.4
227	35.0	34.9	34.7	34.5	34.4	34.1	34.0	33.9	33.8	33.7
230	35.2	35.0	34.8	34.7	34.5	34.2	34.1	34.0	33.9	33.8

D. **Steam Boiler Drums**

1. Top drum: steam drum.
2. Bottom drum: mud or blowdown drum.

E. **System Types**

1. Low-pressure steam:	0–15 psig.
2. Medium-pressure steam:	16–100 psig.
3. High-pressure steam:	101 psig and greater.

F. **Steam Carryover**

1. Steam carryover is the entrainment of boiler water with the steam.
2. Causes of carryover:
   a. Mechanical:
      1. Poor boiler design.
      2. Burner misalignment.
      3. High water level.

   b. Chemical:
      1. High total dissolved solids (TDS).
      2. High total suspended solids (TSS).
      3. High alkalinity.
      4. High amine levels.
      5. Presence of oils or other organic materials.
3. Problems caused by carryover:
   a. Deposits minerals on valves, piping, heat transfer surfaces, and other steam-operated equipment.

   b. Causes thermal shock to the system.

   c. Contaminates process or products that have direct steam contact.

   d. If steam is used for humidification, a white dust is often left on the air handling unit components, ductwork surfaces, and furniture and other equipment within the space.

4. Carryover control:
   a. Install steam separation devices.

   b. Maintain the proper steam space in the steam drum and boiler.

   c. Maintain proper water chemistry—TDS, TSS, alkalinity, etc.

G. **Design, Layout, and Clearance Requirements/Considerations**

1. Design conditions:
   a. Boiler load: Btu/h, or MBH.

   b. Steam pressure and flow rate.

   c. Fuel input: gas, fuel oil, electric, etc.

   d. Overall boiler efficiency.

   e. Fouling factor.

   f. Electrical data:
      1. Unit kW, blower hp, compressor hp, and fuel oil pump hp.

      2. Full load, running load, and locked rotor amps.

      3. Voltage-phase-hertz.

2. Multiple steam boilers should be used to prevent complete system or building shutdown upon failure of 1 steam boiler in all steam systems over 70 boiler horsepower or 2,400,000 Btu/h (i.e., 2 @ 50 percent, 2 @ 67 percent, 2 @ 70 percent, 3 @ 34 percent, 3 @ 40 percent).

3. Show tube clean/pull clearances and location.

4. The minimum recommended clearance around boilers is 36 in. Maintain minimum clearances for tube pull and the cleaning of the tubes as recommended by the equipment manufacturer. This is generally equal to the length of the boiler. Maintain minimum clearance as required to open access and control doors on boilers for service, maintenance, and inspection.

5. Mechanical room locations and placement must take into account how boilers can be moved into and out of the building during initial installation and after construction for maintenance and repair and/or replacement.

6. Maintain minimum electrical clearances as required by the NEC.

7. Show the location of the boiler starter, disconnect switch, and the control panel.
8. Show gas train and/or fuel oil train location.
9. Show the boiler relief piping.
10. Show sanitary drain locations and boiler drain connections.
11. Design and locate combustion air louvers and motorized dampers or an engineered combustion air system. What happens if the engineered combustion air system malfunctions? Is a standby available? Verify that items that might freeze are not located in front of the combustion air intake.
12. Coordinate the height of the boiler with overhead clearances and obstructions. Is a beam required above the boiler for lifting components? Is a catwalk required to service the boiler.
13. Boiler stack and breeching. Coordinate routing in the boiler room, through the building, and the discharge height above building with architect and structural engineer.
14. Provide a stop check valve (located closest to the boiler) and an isolation valve with a drain between these valves on the steam supply connections to all steam boilers.
15. Combustion air dampers must be extra heavy duty and should be low leakage (10 CFM/sq.ft. @ 4" WC differential) or ultralow leakage (6 CFM/sq.ft. @ 4" WC differential) type.
16. When the system design requires the use of dual fuel boilers (natural gas, fuel oil), provide a building automation control system I/O point to determine whether the boiler is on natural gas or fuel oil. Boiler control panels generally have a fuel type switch (gas/off/fuel oil switch) that can be connected to create this I/O point. Switching from natural gas to fuel oil (or vice versa) cannot be a fully automatic operation because the boiler operator must first turn the boiler burner to the "Off" position, then turn the fuel type switch to fuel oil, then put the combustion air linkage into the fuel oil position, then slide the fuel oil nozzle into position, then put the fuel oil pump into the "Hand" or "Auto" position, and then turn the boiler burner to the "On"

position. Remember to interlock the fuel oil pumps with operation of the boiler on fuel oil. Do not forget to include diesel generator interlocks with fuel oil pumps when the generators are fed from the same fuel oil system.

17. Steam system warm-up procedure:
    a. Steam system startup should not exceed a 100°F temperature rise per hour (50 psig per hour); boiler or heat exchanger manufacture limitations should be consulted.

    b. It is recommended that no more than a 25°F temperature rise per hour (15 psig per hour) be used when warming steam systems. Slow warming of the steam system allows for system piping, supports, hangers, and anchors to keep up with system expansion.

    c. Low-pressure steam systems (15 psig and less) should be warmed slowly at a 25°F temperature rise per hour (15 psig per hour) until the system design pressure is reached.

    d. Medium- and high-pressure steam systems (above 15 psig) should be warmed slowly at a 25°F temperature rise per hour (15 psig per hour) until a 250°F-15 psig system temperature-pressure is reached. At this temperature-pressure, the system should be permitted to settle for at least 8 hours or more (preferably overnight). The temperature-pressure maintenance time gives the system piping, hangers, supports, and anchors a chance to catch up with the system expansion. After allowing the system to settle, the system can be warmed up to 120 psig or the system design pressure in 25 psig pressure increments, and allow the system to settle for an hour before increasing the pressure to the next increment. When the system reaches 120 psig and the design pressure is above 120 psig, the system should be allowed to settle for at least 8 hours or more (preferably overnight). The pressure maintenance time gives the system piping, hangers, supports, and anchors a chance to catch up with the system expansion. After allowing the system to settle, the system can be warmed up to 300 psig or the system design pressure in 25 psig pressure increments, and then must be permitted to settle for an hour before increasing the pressure to the next increment.

18. Provide steam systems with warm-up valves for in-service startup, as shown in the following table. This will allow operators to warm these systems slowly and prevent a sudden shock or catastrophic system failure when large

system valves are opened. Providing warming valves also reduces wear on large system valves when only opened a small amount in an attempt to control the system warm-up speed.

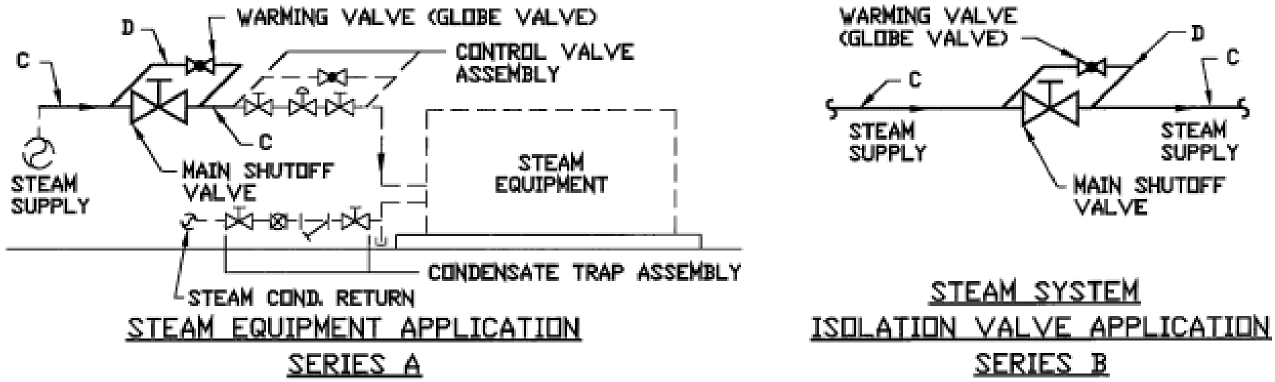
BYPASS AND WARMING VALVES

Main Valve Nominal Pipe Size	Nominal Pipe Size	
	Series A Warming Valves	Series B Bypass Valves
4 5 6	1/2 3/4 3/4	1 1-1/4 1-1/4
8 10 12	3/4 1 1	1-1/2 1-1/2 2
14 16 18	1 1 1	2 3 3
20 24 30	1 1 1	3 4 4
36 42 48	1 1 1	6 6 8
54 60 72	1 1 1	8 10 10
84 96	1 1	12 12

Notes:

1. **Series A comprehends steam service for warming up before the main line is opened, and for balancing pressures where lines are of limited volume.**
2. **Series B comprehends lines conveying gases or liquids where bypassing may facilitate the operation of the main valve through balancing the pressures on both sides of the disc or discs thereof. The valves in the larger sizes may be of the bolted on type.**

19. The steam system warming valve procedure (see Fig. 31.11):



NOTES:

1. SERIES A WARMING VALVES COVER STEAM OR MEDIUM/HIGH-TEMPERATURE HEATING WATER SERVICE FOR SYSTEM OR EQUIPMENT WARM-UP BEFORE THE MAIN SHUTOFF VALVE TO THE SYSTEM OR DEVICE IS OPENED. WARMING VALVES ARE ALSO USED FOR BALANCING PRESSURES WHERE LINES ARE OF LIMITED VOLUME.
2. SERIES B WARMING VALVES COVER LINES CONVEYING GASES OR LIQUIDS WHERE BYPASSING MAY FACILITATE THE OPERATION OF THE MAIN VALVE BY BALANCING THE PRESSURES ON BOTH SIDES OF THE MAIN VALVE.

MAIN VALVE SIZE (C)	WARMING VALVE SIZE (D)	
	SERIES A WARMING VALVES	SERIES B WARMING VALVES
4"	1/2"	1"
5", 6"	3/4"	1-1/4"
8"	3/4"	1-1/2"
10"	1"	1-1/2"
12", 14"	1"	2"
16", 18", 20"	1"	3"
24", 30"	1"	4"
36", 42"	1"	6"
48", 54"	1"	8"
60", 72"	1"	10"
84", 96"	1"	12"

Figure 31.11. STEAM SYSTEM WARMING VALVES.

a. Slowly open the warming supply valve to establish flow and to warm the system.

b. Once the system pressure and temperature have stabilized, perform the following items one at a time:
   1. Slowly open the main supply valve.
   2. Close the warming supply valve.

20. If isolators are required for the boiler, has isolator height been considered in clearance requirements? If isolators are required for the boiler, has piping isolation been addressed?

H. **Low Water Cutoffs**

1. Primary: Float type.
2. Auxiliary: Probe type.
3. Low water cutoffs should be tested by using an evaporation test:
   a. Take the boiler to low fire.
   b. Shut off the feedwater to the boiler.

c. Operate the boiler until the low water cutoff shuts down the boiler or the water level in the gauge glass falls below the low water cutoff activation point but still remains visible in glass.

d. Conduct an evaporation test at least every 30 days; once a week is recommended.

4. Class I boilers. Low water cutoff is 3" above the top row of tubes in fire tube boilers.

5. Class IV boilers. Low water cutoff is 0"–1/4" above the top row of tubes in fire tube boilers.

6. Water should always be visible in gauge glass. If water is not visible in gauge glass, immediately perform the following two steps one after another in any order:
   a. Shut off the boiler burner.

   b. Shut off the boiler feedwater.

   c. Then allow the boiler to cool and inspect it for damage.

I. **Deaerator or Feedwater Tank**

1. The deaerator or the feedwater tank purpose is to remove oxygen, carbon dioxide, hydrogen sulfide, and other noncondensable gases and to heat boiler feedwater.

2. They also preheat the feedwater prior to being pumped to the boiler. Cold feedwater temperatures may cause:
   a. Thermal shock.

   b. Oxygen-rich feedwater, which causes corrosion.

3. This equipment should remove oxygen in the water to levels measured in parts per billion (ppb).

4. Steam vent on the deaerator or feedwater tank. Steam should appear 12"–18" above the top of vent. If steam appears below 12", the deaerator or feedwater tank is not removing all the oxygen, carbon dioxide, hydrogen sulfide, and other noncondensable gases.

5. Deaerators should be used when:
   a. The system pressure is 75 psig and higher.

b. Steam systems are employed with little or no standby capacity.

c. The system depends on continuous operation.

d. The system requires 25 percent or more of makeup water.

J. **Sizing Boiler Feed Pumps, Condensate Return Pumps, and Condensate Receivers**

1. If the boiler is under 50 psi, the designer should size the boiler feed pumps or condensate return pumps so that they discharge at 5 psi above the working pressure of the boiler.

2. If the boiler is over 50 psi, the designer should size boiler feed pumps or condensate return pumps so that they discharge at 10 psi above the working pressure of the boiler.

3. The designer should size condensate receivers for 1 minute of net capacity based on the condensate return rate.

4. Size boiler feedwater system receivers for system capacity (normally estimated at 10 minutes):
    a. Deaerator systems: 10-minute supply.

    b. Feedwater tank systems: 15-minute supply.

5. Size condensate pumps at three times the condensate return rate.

6. Size boiler feedwater pumps and transfer pumps at:
    a. Turbine pumps, intermittent operation: Two times the boiler maximum evaporation rate or 0.14 GPM per boiler hp.

    b. Centrifugal pumps, continuous operation: 1.5 times the boiler maximum evaporation rate or 0.104 GPM per boiler hp.

    c. Boiler feedwater and transfer pump selection criteria:
        1. Continuous or intermittent operation.

        2. Temperature of feedwater or condensate.

        3. Flow capacity (GPM).

        4. Discharge pressure required: Boiler pressure plus piping friction loss.

        5. NPSH requirement.

7. Boiler feedwater control types:
    a. On/Off feedwater control is generally used with single boiler systems or in multiple boiler systems when one feedwater pump is dedicated to each boiler and is typically accomplished with a turbine pump.

    b. Level control is generally used with multiple boiler systems where feedwater pumps serve more than one boiler and is typically accomplished with a centrifugal pump.

8. Vacuum type steam condensate return units: 0.1 GPM/1,000 lbs./h of connected load.

9. Pumped steam condensate return units: 2.4 GPM/1,000 lbs./h.

K. **Boiler Blowdown Systems**

1. Bottom blowdown. Bottom blowdown, sometimes referred to as manual blowdown, functions to remove suspended solids and sediment that have settled out of the water and deposited on the bottom of the boiler. Bottom blowdown is most effective with several short discharges in lieu of one long discharge because the solids settle out between discharges; this results in the greatest removal of suspended solids with the least amount of water.

2. Surface blowdown. Surface blowdown, sometimes referred to as automatic blowdown, continuous blowdown, or periodic blowdown, depending on how the blowdown is controlled, functions to remove dissolved solids, surface water scum, and foam to maintain proper conductivity levels.
    a. Automatic:
        1. Conductivity probe.

        2. Timer.

    b. Continuous.

    c. Periodic (manual) by time.

L. **Boiler Blowdown Separator Makeup**

1. Noncontinuous blowdown (bottom blowdown): 5.0 GPM/1,000 lbs./h.

2. Continuous blowdown (surface blowdown): 0.5 GPM/1,000 lbs./h.

M. **Blowdown Separator Drains: 10 GPM/1000 lbs./h Boiler Output**

N. **Steam Boiler Water Makeup**

1. Boilers: 4.0 GPM/1,000 lbs./h each.

2. Deaerator/feedwater unit: 4.0 GPM/1,000 lbs./h each.

3. Makeup water for the steam system is only required at one of the boilers or one of the feedwater units at any given time for system sizing.

O. **Chemical Feed Systems for Steam Boilers. Chemical feed systems are designed to control the following.**

1. System pH, normally between 8 and 9.

2. Oxygen level, less than 0.007 PPM (7 ppb).

3. Water conditioning level.

4. Carbon dioxide level.

5. Scale.

6. Corrosion.

31.04. Fuel Systems and Types

A. **Fuel System Design Guidelines**

1. Natural gas pressure reducing valves (NGPRV):

   a. Use multiple NGPRVs when system natural gas capacity exceeds 2 NGPRV size, when normal operation calls for 10 percent of design load for sustained periods, or when there are two distinct load requirements (e.g., summer/winter) that are substantially different. Provide the number of NGPRVs to suit the project.

   b. If system capacity for a single NGPRV exceeds the 2 NGPRV size but is not larger than the 4 NGPRV size, use 2 NGPRVs with 33 percent and 67 percent or 50 percent and 50 percent capacity split.

   c. If system capacity for a single NGPRV exceeds 4 NGPRV size, use 3 NGPRVs with 25 percent, 25 percent, and 50 percent or 15 percent, 35 percent, and 50 percent capacity split to suit the project.

   d. Provide natural gas pressure regulating valves with positive shutoff ability to prevent the natural gas system from becoming equal to the gas utility system pressure when the building natural gas system is not using gas.

2. Natural gas meters should be provided as follows:

a. Coordinate equipment, building, or site meter requirements with the local utility company. If the project budget permits, these meter readings should be logged and recorded at the building facilities management and control system.

b. Meter for a campus or site of buildings. A site meter is generally provided by the utility company.

c. Meter for individual buildings on a campus. If fed from a site meter, design documents should provide a meter for each building. This meter will assist in tracking energy use at each building and for troubleshooting system problems.

d. Meter for individual buildings. A building meter will generally be provided by the utility company.

e. Meters for individual boilers. A meter should be provided by the design documents for each and every boiler; environmental air permit requirements insist natural gas be monitored at each boiler.

f. Meters for other major users. A meter should be provided by the design documents for each major user within the building (emergency generators, gas-fired AHUs, domestic water heaters, unit heaters, kitchens).

3. Boiler fuel oil pump flow rates and generator day tank pump flow rates are generally 2.5–3.0 times the boiler and generator consumption rates. Confirm with the manufacturer or the electrical engineer that the information received is the consumption rate of the boiler/generator or fuel oil pumping rate of the boiler/generator. When boilers are located above the fuel oil tanks, a method of preventing back siphoning through the return line must be provided. This may be accomplished by providing the return line with a pressure regulator or with an operated valve interlocked with the fuel oil pump. Also, the fuel oil pumps must be provided with a check valve in the discharge, or if large height differentials are required, a motorized discharge isolation valve interlocked with the pump may be required because check valves will leak.

4. Fuel oil meters should be provided as follows:
   a. If the fuel oil system is a circulating system with a fuel oil return line, meters must be provided in both the supply and return to determine the fuel oil consumed. Most manufacturers provide fuel oil meters with this

capability with controls and software to automatically calculate the fuel oil consumed. If the project budget permits, these meter readings should be logged and recorded at the building facilities management and control system. All fuel oil meters must be shown on the design documents. Environmental regulations require the fuel oil purchased versus fuel oil consumed be recorded and tracked for determining when leaks may be occurring in the system.

b. Meters for each group of site distribution pumps are located at the pumps.

c. Meters for individual buildings on a campus are located at each building. This meter will assist in tracking energy use at each building and for troubleshooting system problems.

d. Meters for individual boilers. A meter should be provided for each and every boiler; environmental air permit requirements require fuel oil to be monitored at each boiler.

e. Meters for other major users. A meter should be provided for each major user within the building (emergency generators, oil-fired AHUs, domestic water heaters, and unit heaters).

B. **Natural Gas**

1. 900–1200 Btu/cu.ft.

2. 1,000 Btu/cu.ft. average.

C. **Fuel Oil**

1. #2: 138,000 Btu/gal.

2. #4: 141,000 Btu/gal.

3. #5: 148,000 Btu/gal.

4. #6: 152,000 Btu/gal.

D. **LP Gas**

1. Butane:
   a. 21,180 Btu/lbs.

   b. 3,200 Btu/cu.ft.

2. Propane:
   a. 21,560 Btu/lbs.

b. 2,500 Btu/cu.ft.

E. **Electric**

1. 3,413 Btuh/KW.

2. 3,413 Btuh/watt.

F. **Coal**

1. Anthracite: 14,600–14,800 Btu/lb.

2. Bituminous: 13,500–15,300 Btu/lb.

G. **Wood**

1. 8,000–10,000 Btu/lb.

H. **Kerosene**

1. 135,000 Btu/gal.

Part 32: Motors and Motor Controllers

32. Part 32: Motors and Motor Controllers

32.01. Motors

A. **Motor Types. Items 1, 2, and 3 are the most common HVAC motor types.**

1. Open drip proof (ODP): Ventilation openings arranged to prevent liquid drops falling within an angle of 15 degrees from the vertical from affecting motor performance. Use indoors and in moderately clean environments.

2. Totally enclosed fan cooled (TEFC): A fan on the motor shaft, outside the stator housing and within the protective shroud, blows air over the motor. Use in damp, dirty, corrosive, or contaminated environments.

3. Explosion proof (EXPRF): Totally enclosed with enclosure designed to withstand internal explosion of a specific gas-air or dust-air mixture to prevent escape of ignition products. Motors are approved for a specific Hazard Classification as covered by the NEC. Class I Explosion Proof and Class II Dust Ignition Resistant are the two most common types of hazardous location motors.

4. Open drip proof air over (ADAO): Ventilation openings arranged to prevent liquid drops falling within an angle of 15 degrees from the vertical from affecting motor performance. Use indoors and in moderately clean environments. Rated for motor cooling by airflow from a driven device.

5. Totally enclosed non-ventilated (TENV): No ventilation openings in housing. Motor rated for cooling by airflow from a driven device. TENV motors are usually under 5 horsepower.

6. Totally enclosed air over (TEAO): No ventilation openings in housing. Motor rated for cooling by airflow from a driven device. TEAO motors frequently have dual horsepower ratings depending on speed and cooling air temperature.

B. **Motor Horsepowers, Voltage, Phase, and Operating Guidelines:**

1. Suggested horsepower and phase:
   a. Motors 1/2 horsepower and larger: 3 Phase.

   b. Motors less than 1/2 horsepower: Single Phase.

   c. Considering first cost economics only, it is less costly, on average, to have motors smaller than 1 hp to be single-phase. At 3/4 hp, single-phase and three-phase motors cost about the same, but branch circuits and control equipment for three-phase motors are usually more expensive.

   d. When life cycle owning and operating costs are considered, it is often more economical to provide motors as specified in lines a. and b. earlier.

2. Do not start and stop motors more than six times per hour.

3. Motors of 5 horsepower and larger should not be cycled; they should run continuously.

4. Specify energy-efficient motors—EPAct motors as a minimum; preferred premium efficiency motors. Premium efficiency motors are a higher efficiency motor than the EPAct motors.

5. Do not use energy-efficient motors with variable speed/frequency drives.

6. For best motor life and reliability, do not select motors to run within the service factors. Specify motors with a minimum 1.15 service factor.

7. For every 50°F (28°C) increase in motor operating temperature, the life of the motor is cut in half. Conversely, for every 50°F (28°C) decrease in motor operating temperature, the life of the motor is doubled.

8. Energy-efficient motors have a higher starting current than their standard efficiency counterparts.

9. The best sign of motor trouble is smoke and/or paint discoloration.

10. In general, motors can operate with voltages plus or minus 10 percent of their rated voltage.

11. Motors in storage should be turned by hand every 6 months to keep the bearings from drying out.

12. Available motor voltages are given in the following table:

Phase	Nominal Voltage	Nameplate Voltage
Single-Phase	120	115
	240	230
	277	265
Three-Phase	208	200
	240	230
	480	460
	600	575

C. **Standard motor sizes are given in the following table:**

Motor Sizes (hp)	Recommended Starter Type	Standard Service Factors
1/8; 1/10; 1/12; 1/15; 1/20; 1/25; 1/30; 1/60; 1/100	SPC or PSC	1.40
1/6	SPC or PSC	*
1/4; 1/3	CS	*
1/2; 3/4; 1	MS	*
1-1/2; 2	MS	*
3; 5; 7-1/2; 10; 15; 20; 25; 30; 40; 50; 60; 75; 100; 125; 150; 200; 250	MS	*
300; 350; 400; 450; 500; 600; 700; 750; 800; 900; 1000; 1250; 1500; 1750; 2000; 2250; 2500; 3000; 35[illegible]	MS	*

Notes:

SPC: Split phase capacitor start.

PSC: Permanent split capacitor start.

CS: Capacitor start.

Motor Sizes (hp)	Recommended Starter Type	Standard Service Factors
3500, 4000, 4500, 5000; 5500, 6000**		

Notes:

SPC: Split phase capacitor start.

PSC: Permanent split capacitor start.

CS: Capacitor start.

MS: Magnetic start; polyphase induction motors (squirrel cage).

1/2 hp through 50 hp across-the-line starter.

60 hp and larger reduced-voltage starter.

***See paragraph E below for motor service factors for these motors.**

****Motors generally not used in HVAC applications.**

D. **Standard Motor RPM: 3600, 1800, 1200, 900, 720, 600, and 514.**

E. **NEMA motor service factors are given in the following table:**

hp	3600 RPM	1800 RPM	1200 RPM	900 RPM
1/6–1/3	1.35	1.35	1.35	1.35
1/2	1.25	1.25	1.25	1.15
3/4	1.25	1.25	1.15	1.15
1	1.25	1.15	1.15	1.15
1-1/2–250	1.15	1.15	1.15	1.15
300–2500	1.15	1.15	1.15	1.15

F. **NEMA locked rotor indicating code letters are given in the following table:**

NEMA Locked Rotor Indicating Code Letters

Code Letter	KVA/hp	Code Letter	KVA/hp
A	0–3.14	L	9.00–9.99
B	3.15–3.54	M	10.00–11.19
C	3.55–3.99	N	11.20–12.49
D	4.00–4.49	O	Not used
E	4.50–4.99	P	12.50–13.99
F	5.00–5.59	Q	Not used
G	5.60–6.29	R	14.00–15.99
H	6.30–7.09	S	16.00–17.99
I	Not used	T	18.00–19.99
J	7.10–7.99	U	20.00–22.39
K	8.00–8.99	V	22.40 and up

1. Standard three-phase motors often have these NEMA starting locked rotor codes:

a. 1 horsepower and smaller:	Locked Rotor Code L.
b. 1-1/2–2 horsepower:	Locked Rotor Code K.
c. 3 horsepower:	Locked Rotor Code J.
d. 5 horsepower:	Locked Rotor Code H.
e. 7-1/2–10 horsepower:	Locked Rotor Code G.
f. 15 horsepower and larger:	Locked Rotor Code F.

2. Standard single-phase motors often have these locked rotor codes:

a. 1/2 horsepower and smaller:	Locked Rotor Code L.
b. 3/4–1 horsepower:	Locked Rotor Code K.
c. 1-1/2–2 horsepower:	Locked Rotor Code J.
d. 3 horsepower:	Locked Rotor Code H.
e. 5 horsepower:	Locked Rotor Code G.

3. Specify 15 horsepower and larger motors with NEMA Starting Code F or G.

4. Specify motors smaller than 15 horsepower with the manufacturer's standard starting characteristics.

G. **Motor Insulation Classes are given in the following table.**

1. Specify all motors with class F insulation and class B motor temperature rise.

2. Specify all motors with a minimum 1.15 service factor or NEMA standard service factor, whichever is higher.

Motor Insulation Class Temperature Rise

	A		**B**		**F**		**H**	
Motor Type	**°C**	**°F**	**°C**	**°F**	**°C**	**°F**	**°C**	**°F**
1. Motors with 1.0 Service Factor (except 3 and 4 below)	60	140	80	176	105	221	125	257
2. All Motors with 1.15 Service Factor or Higher	70	158	90	194	115	239	–	–
3. Totally Enclosed Nonventilated Motor with 1.0 Service Factor	65	149	85	185	110	230	135	275

Notes:

1. Abnormal deterioration of insulation may be expected if the ambient temperature of 40°C/104°F is exceeded in regular operation.

2. Temperature rise based on 40°C/104°F ambient. Temperature

Motor Type	Motor Insulation Class Temperature Rise							
	A		B		F		H	
	°C	°F	°C	°F	°C	°F	°C	°F
Factor								
4. Motors with Encapsulated Windings and with 1.0 Service, All Enclosures	65	149	85	185	110	230	–	–

Notes:

1. **Abnormal deterioration of insulation may be expected if the ambient temperature of 40°C/104°F is exceeded in regular operation.**

2. **Temperature rise based on 40°C/104°F ambient. Temperature rises are based on operation at altitudes of 3300 feet or less.**

3. **Class A Motors: Fractional hp motors, small appliances; maximum operating temperature 105°C/221°F.**

4. **Class B Motors: Motors for HVAC applications, high-quality fractional hp motors; maximum operating temperature 130°C/266°F.**

5. **Class F Motors: Inverter duty motors, industrial motors; maximum operating temperature 155°C/311°F.**

6. **Class H Motors: High temperature, high reliability, high ambient; maximum operating temperature 180°C/356°F.**

H. **NEMA Motor Design Designations**

1. Design A motors are built with high pullout torque and are used on injection molding machines.

2. Design B motors are built with high starting torque with reasonable starting current and are used with fans, pumps, air handling units, and other HVAC equipment. They are the most common HVAC motor.

3. Design C motors are built with high starting torque and used with hard-to-start loads and with conveyors.

4. Design D motors are built with high starting torque, low starting current, and

high slip and are used with cranes, hoists, and low-speed presses.

I. **Clearance Requirements**

1. The minimum recommended clearance around the motors is 24 inches.

2. Mechanical room locations and placement must take into account how motors can be moved into and out of the building during the initial installation and after construction for maintenance, repair, and/or replacement.

J. **Motor Efficiencies**

1. *ASHRAE Standard 90.1-2013:* NEMA Design A and B; Single Speed; 3600, 1800, or 1200 RPM; Open Drip Proof (ODP) or Totally Enclosed Fan-Cooled (TEFC) motors 1 hp and larger shall meet the following minimum nominal efficiencies:

	Minimum Nominal Efficiency (%)					
	Open Motors			**Enclosed Motors**		
	Number of Poles			**Number of Poles**		
	2	**4**	**6**	**2**	**4**	**6**
	Synchronous Speed (RPM)			**Synchronous Speed (RPM)**		
Motor Horsepower	**3600**	**1800**	**1200**	**3600**	**1800**	**1200**
1	–	82.5	80.0	75.5	82.5	80.0
1.5	82.5	84.0	84.0	82.5	84.0	85.5
2	84.0	84.0	85.5	84.0	84.0	86.5
3	84.0	86.5	86.5	85.5	87.5	87.5
5	85.5	87.5	87.5	87.5	87.5	87.5
7.5	87.5	88.5	88.5	88.5	89.5	89.5
10	88.5	89.5	90.2	89.5	89.5	89.5
15	89.5	91.0	90.2	90.2	91.0	90.2
20	90.2	91.0	91.0	90.2	91.0	90.2
25	91.0	91.7	91.7	91.0	92.4	91.7
30	91.0	92.4	92.4	91.0	92.4	91.7

Note:

Motor Horsepower	Minimum Nominal Efficiency (%) Open Motors			Minimum Nominal Efficiency (%) Enclosed Motors		
	Number of Poles			Number of Poles		
	2	4	6	2	4	6
	Synchronous Speed (RPM)			Synchronous Speed (RPM)		
	3600	1800	1200	3600	1800	1200
40	91.7	93.0	93.0	91.7	93.0	93.0
50	92.4	93.0	93.0	92.4	93.0	93.0
60	93.0	93.6	93.6	93.0	93.6	93.6
75	93.0	94.1	93.6	93.0	94.1	93.6
100	93.0	94.1	94.1	93.6	94.5	94.1
125	93.6	94.5	94.1	94.5	94.5	94.1
150	93.6	95.0	94.5	94.5	95.0	95.0
200	94.5	95.0	94.5	95.0	95.0	95.0

Note:

1. **Nominal efficiencies shall be established in accordance with NEMA MG1.**

MOTOR DIMENSIONS AND WEIGHTS—EPAct MOTORS

Motor Horsepower	Open Drip Proof— EPAct			Totally Enclosed Fan-Cooled—EPAct		
	Dia. Inches	Length Inches	Weight lbs.	Dia. Inches	Length Inches	Weight lbs.
1	9	11	67	9	13	70
1.5	11	13	88	11	15	90
2	11	14	97	11	16	101
3	12	16	132	12	18	139
5	12	18	158	12	20	165
7.5	14	21	211	14	24	257
10	14	23	260	14	25	295
15	15	23	343	15	26	414
20	15	25	392	15	28	473
25	16	27	529	16	33	626
30	16	28	573	16	34	763
40	18	29	726	18	35	932

Notes:

Motor Horsepower	Open Drip Proof—EPAct			Totally Enclosed Fan-Cooled—EPAct		
	Dia. Inches	Length Inches	Weight lbs.	Dia. Inches	Length Inches	Weight lbs.
40	18	29	[illegible]	18	[illegible]	[illegible]
50	18	30	803	18	35	933
60	20	33	970	20	34	1212
75	20	35	1105	20	35	1481
100	22	39	1166	22	47	1671
125	22	41	1276	22	48	1775
150	22	41	1364	22	48	1897
200	22	44	1810	22	54	2730
250	22	49	2160	22	59	3240

Notes:

1. **The motor dimensions and weights are based on 1,200-rpm motors. Motors above the 1,200 rpm rating are lighter and smaller in size.**
2. **Motor dimensions are rounded to the nearest inch.**

MOTOR DIMENSIONS AND WEIGHTS—PREMIUM EFFICIENCY MOTORS

Motor Horsepower	Open Drip Proof—Premium			Totally Enclosed Fan-Cooled—Premium		
	Dia. Inches	Length Inches	Weight lbs.	Dia. Inches	Length Inches	Weight lbs.
1	9	11	67	9	14	70
1.5	11	13	88	11	16	90
2	11	14	97	11	16	101
3	12	16	132	12	20	200
5	12	18	158	12	20	220
7.5	14	21	260	14	26	315
10	14	23	310	14	26	350
15	15	24	394	15	29	460
20	15	26	436	15	29	510

Motor Horsepower	Open Drip Proof—Premium			Totally Enclosed Fan-Cooled—Premium		
	Dia. Inches	Length Inches	Weight lbs.	Dia. Inches	Length Inches	Weight lbs.
25	16	27	580	18	33	700
30	16	28	639	18	34	765
40	18	29	770	19	35	1030
50	18	30	838	20	35	1070
60	20	33	1090	22	40	1480
75	20	35	1150	22	40	1540
100	22	39	1494	24	47	2060
125	22	41	1715	24	48	2130
150	22	44	2100	24	52	2860
200	22	50	2150	24	54	3070
250	22	54	2632	24	59	3440

Notes:

1. **The motor dimensions and weights are based on 1,200-rpm motors. Motors above the 1,200 rpm rating are lighter and smaller in size.**
2. **Motor dimensions are rounded to the nearest inch.**

32.02. Starters, Disconnect Switches, and Motor Control Centers

A. **Starter Types**

1. Manual starters (manual control):
   a. Reversing/nonreversing.

   b. Push button/toggle switch.

   c. Available for single-phase or three-phase electrical power.

2. Magnetic starters (automatic control):
   a. Full voltage/across the line.

   b. Reversing/nonreversing.

   c. Reduced voltage:

1. Reactor.
2. Resistance.
3. Auto transformer.
4. Wye-delta/star delta.
5. Full voltage part winding.
6. Reduced voltage part winding.
7. Solid state.

d. Two-speed starting:
   1. One winding. Full speed; half speed.
   2. Two winding. Full speed; 2/3 speed.
   3. Constant torque.
   4. Variable torque.
   5. Constant horsepower.

e. Available for single-phase or three-phase electrical power.

3. Combination starter disconnect switch: see "magnetic starters":
   a. Fused.
   b. Nonfused.
   c. Disconnect switches (locking/nonlocking—recommend locking switches).
   d. Available for three-phase electrical power only, but a three-phase starter can be used with a single-phase motor (although expensive).

B. **Starter Accessories**

1. Pilot lights: green, run; red, off.
2. Switches (locking/nonlocking—recommend locking switches).
   a. Hand-off-auto (HOA).
   b. Push button.
   c. Toggle switch.

3. Control transformer.

4. Overload protection:
    a. Fused.

    b. Nonfused.

    c. Motor circuit protector.

    d. Molded case circuit breaker.

    e. Circuit fuse protection: size based on circuit ampacity and wire size.

    f. Overload heaters: size based on motor overload capacity.

    g. Two levels of overload protection:
        1. Type 1: Considerable damage occurs to the contactor and overload relay when an overload happens but the enclosure remains externally undamaged. Parts of the starter or the entire starter may need to be replaced after an overload.

        2. Type 2: No damage occurs to the contactor or overload relay except light contact burning is permitted when an overload happens.

    h. The choice between circuit breakers and fuses is purely a matter of user preference.

5. Auxiliary contacts (NO-Normally Open/NC-Normally Closed).

6. Relays.

C. **Disconnect switch sizes and accepted fuse sizes are given in the following table:**

Safety Switch Size Amps	Acceptable Fuse Sizes Amps	Safety Switch Size Amps	Acceptable Fuse Sizes Amps
30	15, 20, 25, 30	1600	1600
60	35, 40, 45, 50, 60	2000	2000
100	70, 80, 90, 100	2500	2500
200	110, 125, 150, 175, 200	3000	3000
400	225, 250, 300, 350, 400	4000	4000
600	450, 500, 600	5000	5000
800	700, 800	6000	6000
1,200	1000, 1200	–	–

D. **Standard Fuse and Circuit Breaker Sizes (Amperes): 1, 3, 6, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 110, 125, 150, 175, 200, 225, 250, 300, 350, 400, 450, 500, 600, 700, 800, 1000, 1200, 1600, 2000, 2500, 3000, 4000, 5000, and 6000**

E. **Single-Phase Starter Types**

SINGLE-PHASE MOTOR CHARACTERISTIC TABLE

Characteristics	Motor Type Split Phase, Capacitor Start (SPC)	Permanent-Split Capacitor (PSC)	Capacitor Start, Induction Run (CSIR)	Capacitor Start, Capacitor Run (CSCR)	Sha P (S
Starting Control	Speed switch	None	Speed switch	Speed switch	Non
Ratings (Horsepower)	1/25–1/2	1/20–5	1/20–5	1/20–5	1/1 1/4
Full Load Speeds (RPM @ 60 Hz)	3450 1725	3450 1725	3450 1725	3500 1750	310 155 100
Locked Rotor Torque (Percent @ Full Load)	125–150%	250%	250–350%	250%	250
Breakdown Torque (Percent @ Full Load)	250–300%	250–300%	250–300%	250%	125
Speed Classification	Constant	Constant or variable	Constant	Constant	Con or vari
Full Load Power Factor	60%	95%	65%	95%	60%
Efficiency	Medium	High	Medium	High	Low

F. **Three-phase starter types by starting method are given in the following table:**
THREE-PHASE STARTERS

Starting Method	Inrush Current % LRA	Starting Torque % LRT
Across-the-Line	100	100
Auto-Transformer		
80% Tap	71	64
65% Tap	48	42
50% Tap	28	25
Primary Resistor or Reactor		
80% Applied Voltage	80	64
65% Applied Voltage	65	42
58% Applied Voltage	58	33
50% Applied Voltage	50	25
Star Delta	33	33
Part Winding	60	48
Part Winding w/Resistors	60–30	48–12
Wound Rotor (Approx.)	25	150
Solid State	3 × RLA	–

Notes:

1. **% LRA = Percent full voltage locked rotor current (amps).**
2. **% LRT = Percent full voltage locked rotor torque.**
3. **RLA = Rated load amps or running load amps.**

G. **Disconnect Switches**

1. Fused disconnect switches should be used whenever the equipment manufacturer requires fused disconnect switches or when more than one motor or piece of equipment is on a single electrical circuit. Fused disconnect switches are generally required with packaged air conditioning equipment, and some chillers. Fusing means it may be either a fuse or a

circuit breaker. Circuit breakers are preferred; however, some equipment will require fuses because they have not been tested or rated with circuit breakers.

a. Fuses shall be Class RK5 Time Delay, Dual Element Fuses.

b. Circuit breakers shall be Thermal Magnetic Circuit Breakers.

2. Nonfused disconnect switches should be used whenever fused disconnects are not required by the equipment manufacturer. Most fans, pumps, and air-handling units do not require fused disconnect switches.

H. **Motor Size, Starter and Disconnect Switch Size, and Fuse and Circuit Breaker Size are given in the following tables. The following notes are applicable to all schedules.**

1. Starters and/or disconnect switches. Fuses shall be Class RK5 Time Delay, Dual Element Fuses. Circuit breakers shall be Thermal Magnetic Circuit Breakers.

2. Motor data, starters, disconnect switches, and fuses based on *2014 NEC* and Square D Company.

115 Volt (120 Volt) Single-Phase Motor Starter Schedule

Motor hp	NEMA Starter Size	Full Load Amps Per Phase	Disc. Switch Size	Fuse Size Amperes	Circuit Breaker Size Amperes
1/8	1	3.0	30	4.5	15
1/6	1	4.4	30	7	15
1/4	1	5.8	30	9	15
1/3	1	7.2	30	12	15
1/2	1	9.8	30	15	20
3/4	1	13.8	30	20	25
1	1	16.0	30	25	30
1.5	1	20.0	30	30	40
2	1	24.0	30	30	50
3	2	34.0	60	50	70
5	3	56.0	100	80	90
7.5	4	80.0	100	100	110
10	–	–	–	–	–

230 Volt (240 Volt) Single-Phase Motor Starter Schedule

Motor hp	NEMA Starter Size	Full Load Amps Per Phase	Disc. Switch Size	Fuse Size Amperes	Circuit Breaker Size Amperes
1/8	1	1.7	30	2.5	15
1/6	1	2.2	30	3.5	15
1/4	1	2.9	30	4.5	15
1/3	1	3.6	30	5.6	15
1/2	1	4.9	30	8	15
3/4	1	6.9	30	10	15
1	1	8.0	30	12	15
1.5	1	10.0	30	15	20
2	1	12.0	30	17.5	25
3	1	17.0	30	25	35
5	2	28.0	60	40	60
7.5	2	40.0	60	60	80
10	3	50.0	60	60	90

200 Volt (208 Volt) Three-Phase Motor Starter Schedule

Motor hp	NEMA Starter Size	Full Load Amps per Phase	Disc. Switch Size	Fuse Size Amperes	Circuit Breaker Size Amperes
1/2	1	2.5	30	3.5	15
3/4	1	3.7	30	5	15
1	1	4.8	30	6.25	15
1.5	1	6.9	30	10	15
2	1	7.8	30	12	15
3	1	11.0	30	17.5	20
5	1	17.5	30	25	35
7.5	1	25.3	60	40	50
10	2	32.2	60	50	60
15	3	48.3	60	60	90
20	3	62.1	100	90	100
25	3	78.2	100	100	110
30	4	92.0	200	125	125
40	4	120.0	200	175	175
50	5	150.0	200	200	200
60	5	177.0	400	250	250
75	5	221.0	400	300	300
100	6	285.0	400	400	400
125	6	359.0	600	500	600
150	6	414.0	600	600	600
200	7	552.0	–	–	800

230 Volt (240 Volt) Three-Phase Motor Starter Schedule

Motor hp	NEMA Starter Size	Full Load Amps per Phase	Disc. Switch Size	Fuse Size Amperes	Circuit Breaker Size Amperes
1/2	1	2.2	30	3.2	15
3/4	1	3.2	30	4.5	15
1	1	4.2	30	5.6	15
1.5	1	6.0	30	8	15
2	1	6.8	30	10	15
3	1	9.6	30	15	20
5	1	15.2	30	25	30
7.5	1	22.0	30	30	45
10	2	28.0	60	40	60
15	2	42.0	60	60	80
20	3	54.0	100	80	90
25	3	68.0	100	100	100
30	3	80.0	100	100	110
40	4	104.0	200	150	150
50	4	130.0	200	200	200
60	5	154.0	200	200	225
75	5	192.0	400	300	250
100	5	248.0	400	350	350
125	6	312.0	400	400	450
150	6	360.0	600	500	600
200	6	480.0	600	600	800
250	7	600.0	800	800	800
300	7	720.0	1200	1000	1000
400	–	–	–	–	–

460 Volt (480 Volt) Three-Phase Motor Starter Schedule

Motor hp	NEMA Starter Size	Full Load Amps per Phase	Disc. Switch Size	Fuse Size Amperes	Circuit Breaker Size Amperes
1/2	1	1.1	30	1.6	15
3/4	1	1.6	30	2.25	15
1	1	2.1	30	2.8	15
1.5	1	3.0	30	4	15
2	1	3.4	30	5.6	15
3	1	4.8	30	8	15
5	1	7.6	30	12	15
7.5	1	11.0	30	17.5	20
10	1	14.0	30	20	25
15	1	21.0	30	30	40
20	1	27.0	60	40	60
25	2	34.0	60	50	70
30	2	40.0	60	60	80
40	3	52.0	100	80	90
50	3	65.0	100	100	100
60	3	77.0	100	100	110
75	4	96.0	200	150	125
100	4	124.0	200	175	200
125	5	156.0	200	200	225
150	5	180.0	400	250	250
200	5	240.0	400	350	350
250	6	302.0	600	500	500
300	6	361.0	600	600	600
400	6	477.0	800	700	700
500	7	590.0	1200	800	800

575 Volt (600 Volt) Three-Phase Motor Starter Schedule

Motor hp	NEMA Starter Size	Full Load Amps per Phase	Disc. Switch Size	Fuse Size Amperes	Circuit Breaker Size Amperes
1/2	1	0.9	30	1.25	15
3/4	1	1.3	30	1.6	15
1	1	1.7	30	2.25	15
1.5	1	2.4	30	3.5	15
2	1	2.7	30	4.5	15
3	1	3.9	30	6.25	15
5	1	6.1	30	10	15
7.5	1	9.0	30	15	15
10	1	11.0	30	17.5	20
15	2	17.0	30	25	35
20	2	22.0	30	30	45
25	2	27.0	60	40	60
30	3	32.0	60	50	60
40	3	41.0	60	60	80
50	3	52.0	100	80	90
60	4	62.0	100	90	100
75	4	77.0	100	110	110
100	4	99.0	200	150	150
125	5	125.0	200	175	200
150	5	144.0	200	200	200
200	5	192.0	400	300	250
250	6	242.0	600	350	350
300	6	289.0	600	400	400
400	6	382.0	600	500	500
500	7	472.0	800	800	700

I. **Motor Control Centers (MCCs)**

1. NEMA Class I, Type A:
    a. No terminal boards for load or control connections are provided.

   b. Numbered terminals for field-wired power and control connections are provided on the starter.

   c. Starter unit mounted pilot devices are internally wired to starter.

2. NEMA Class I, Type B:
   a. Terminal boards for load connections are provided for Size 3 and smaller controllers. For controllers larger than Size 3, numbered terminals for field-wired power connections are provided on starter.

   b. Unit control terminal boards for each combination motor controller are provided for field wiring.

   c. Both terminal boards are factory-wired and mounted on, or adjacent to, the unit.

   d. No load terminal boards for feeder tap units are provided.

   e. Starter unit mounted pilot devices are internally wired to the starter.

   f. NEMA Class I, Type B will be suitable for most HVAC applications.

3. NEMA Class I, Type C:
   a. Factory-wired master section terminal board, mounted on the stationary structure, is provided for each section.

   b. Terminal boards for load connections are provided for Size 3 and smaller controllers. For controllers larger than Size 3, numbered terminals for field-wired power connections are provided on the starter.

   c. Unit control terminal boards for each combination motor controller are provided for field wiring.

   d. Complete wiring between combination controllers or control assemblies and their master terminal boards is factory installed. No wiring between sections or between master terminals is provided. No interconnections between combination controllers and control assemblies.

   e. No load terminal boards for feeder tap units are provided.

4. NEMA Class II, Type B:
   a. Terminal boards for load connections are provided for Size 3 and smaller controllers. For controllers larger than Size 3, numbered terminals for field-wired power connections are provided on the starter.

b. Unit control terminal boards for each combination motor controller are provided for field wiring.

c. Both terminal boards are factory-wired and mounted on, or adjacent to, unit.

d. Complete wiring between combination controllers or control assemblies in the same and other sections is factory-wired.

e. No load terminal boards for feeder tap units are provided.

5. NEMA Class II, Type C:
   a. A factory-wired master section terminal board, mounted on the stationary structure, is provided for each section.

   b. Terminal boards for load connections are provided for Size 3 and smaller controllers. For controllers larger than Size 3, numbered terminals for field-wired power connections are provided on the starter.

   c. Unit control terminal boards for each combination motor controller are provided for field wiring.

   d. Complete wiring between combination controllers or control assemblies and their master terminal boards in the same section and other sections is factory-wired.

   e. No load terminal boards for feeder tap units are provided.

6. MCCs are available in NEMA enclosure types 1, 2, 3R, and 12.

32.03. Variable Frequency Drives

A. **Variable Frequency Drives have many names and acronyms.**

1. Variable frequency drives (VFDs)—Used within this text.

2. Adjustable frequency drives (AFDs).

3. Variable frequency controllers (VFCs).

4. Adjustable frequency controllers (AFCs).

B. **VFD Components (from power side to load side)**

1. Rectifier section: Silicon-controlled rectifiers (SCRs) or diodes change single- or three-phase AC power to DC power.

2. DC bus section: Capacitors and an inductor smooth the rippled DC power supplied by the rectifier.

3. Inverter section: An inverter converts the DC bus power to three-phase variable frequency power.

4. Controller section: The controller turns the inverter on and off to control the output frequency and voltage.

C. **VFD Types**

1. Variable voltage inverters (VVIs) use an SCR to convert incoming AC power to a varying DC power and then use an inverter to convert the DC power to three-phase variable voltage and variable frequency power. The disadvantages of VVIs are:
   a. Incoming line notching, which requires isolation transformers.

   b. The power factor is proportional to speed, which may require power factor correction capacitors.

   c. Torque pulsations are experienced at low speeds.

   d. Non-sinusoidal current waveforms produce additional heating in the motor.

2. Current source inverters (CSIs) use SCRs in the rectifier and inverter sections and only an inductor in the DC bus section. The disadvantages of CSIs are:
   a. Incoming line notching, which requires isolation transformers.

   b. The power factor is proportional to the speed, which may require power factor correction capacitors.

   c. Motor drive matching is critical to proper operation.

   d. Non-sinusoidal current waveforms produce additional heating in the motor.

3. Pulse width modulated (PWM) drives use a full wave diode bridge rectifier to convert the incoming AC power to DC power. Most PWM drives use a six-pulse converter, while some offer a 12-pulse converter in the rectifier section. The DC bus section consists of capacitors, and in some cases an inductor. The inverter section uses Insulated Gate Bipolar Transistors

(IGBTs), Bipolar Junction Transistors (BJTs), or Gate Turn off Thyristors (GTOs) to convert the DC bus power to a three-phase variable voltage and variable frequency power. PWM drives are the most common VFD in use in the HVAC industry today despite the fact it can punish motors electrically, especially 460 and 575 volt motors.

a. The advantages of PWM drives are:
   1. Minimal line notching.
   2. Better efficiency.
   3. Higher power factor.
   4. Larger speed ranges.
   5. Lower motor heating.

b. The disadvantages of the PWM drives are:
   1. Higher initial cost.
   2. Regenerative braking is caused because power is allowed to flow in both directions and can act as a drive or a brake.

D. **VFD Design Guidelines**

1. Provide VFDs with the following:
   a. VFDs serving motors:
      1. 10 hp and smaller: six-pulse VFD with a 3 percent impedance input line reactor.
      2. 15–40 hp: six-pulse VFD with a 5 percent impedance input line reactor.
      3. 50 hp and larger: 18-pulse VFD.
   b. NEMA-rated controller enclosure.
   c. Push-button stations, pilot lights, and selector switches: NEMA-ICS-2, heavy-duty type.
   d. Stop and lockout push-button station: Momentary-break, push-button station with a factory-applied hasp arranged so the padlock can be used to lock the push button in the depressed position with the control circuit open.
   e. Lockable disconnect switch.

f. Control relays: Auxiliary and adjustable time-delay relays.

g. Standard displays:
   1. Output frequency (Hz).
   2. Setpoint frequency (Hz).
   3. Motor current (amperes).
   4. DC-link voltage (VDC).
   5. Motor torque (percent).
   6. Motor speed (rpm).
   7. Motor output voltage (V).

h. Historical logging information and displays:
   1. Real-time clock with current time and date.
   2. Running log of total power versus time.
   3. Total runtime.
   4. Fault log, maintaining the last four faults with the time and date stamp for each.

i. Current-sensing, phase-failure relays for bypass controller: A solid-state sensing circuit with isolated output contacts for hard-wired connections; arranged to operate on phase failure, phase reversal, current unbalance of from 30 to 40 percent, or loss of supply voltage; with adjustable response delay.

2. For best motor life and reliability, do not operate motors run by VFDs into their service factor and do not select motors to run within the service factors.

3. Do not run motors below 25 percent of their rated speed or capacity.

4. Use inverter duty motors whenever possible. Inverter duty motors are built with winding thermostats that shut down the motor when elevated temperatures are sensed inside it. In addition, these motors are built with oversized frames and external blowers to cool the motor through the full range of speeds.

5. Motors that are operated with VFDs should be specified with phase insulation, should operate at a relatively low temperature rise (most high efficiency motors fit this category), and should use a high class of insulation (either insulation class F or H).

6. Generally, VFDs do not include disconnect switches; therefore, the engineer must include a disconnect switch in the project design. The disconnect switch should be fused with the fuse rated for the drive input current rating.

7. Multiple motors can be driven with one VFD.

8. All control wiring should be run separately from VFD wiring.

9. Most VFDs include the following features as standard:
    a. Overload protection devices.

    b. Short circuit protection.

    c. Ground fault protection.

10. Provide VFDs with a manual bypass in the event the drive fails.
    a. Manual bypasses may not be required when standby equipment is provided.

    b. Manual bypasses may not be required when multiple pieces of equipment are headered together, especially if three or more pieces of equipment are headered together.

11. Coordinate harmonic mitigation requirements with an electrical engineer.
    a. Line reactors.

    b. Active harmonic filters.

E. **VFDs produce nonlinear loads, which cause the following unwanted effects.**

1. AC system circuits containing excessive currents and unexpectedly higher or lower voltages.

2. Conductor, connector, and component heating, which is unsafe.

3. Loss of torque on motors.

4. Weaker contactor, relay, and solenoid action.

5. High heat production in transformers and motors can be destructive.

6. Poor power factor.

32.04. NEMA Enclosures

A. NEMA Type 1:	**Indoor General Purpose, Standard**
B. NEMA Type 2:	**Indoor Drip-Proof**
C. NEMA Type 3R:	**Outdoor, Rain Tight, Water Tight, Dust Tight**
D. NEMA Types 4, 4X, 5:	**Outdoor Rain Tight, Water Tight, Dust Tight, Corrosion Resistant**
E. NEMA Type 7X:	**Explosion-Proof**
F. NEMA Type 12:	**Indoor Oil and Dust Tight**

Part 33: Humidifiers

33. Part 33: Humidifiers

33.01. Humidifiers

A. The number of humidifier manifolds required is given in the following table:

Duct Height	Number of Manifolds
Less than 37"	1
37"–58"	2
59"–80"	3
81"–100"	4
101" and Over	5

A. **Humidifier Installation Requirements**
   1. Humidifiers shall be installed a minimum of 3'0" from any duct transformation, elbow, fitting, or outlet.
   2. Consideration must be given to the length of the vapor trail and air handling unit, and ductwork design must provide sufficient length to prevent the vapor trail from coming in contact with items downstream of the humidifier before the vapor has had time to completely evaporate.

B. **Humidifier Makeup Requirements**

1. Steam humidifiers:	5.6 GPM/1,000 kW input or 5.6 GPM/3413 MBH.
2. Electric humidifiers:	5.6 GPM/1,000 kW input or 5.6 GPM/3413 MBH.
3. Evaporative humidifiers:	5.0 GPM/1,000 lbs./h.
4. Spray coil humidifiers:	5.0 GPM/1,000 lbs./h.

C. **Humidifier Makeup Water Types**

1. Potable (untreated) water.
2. Softened water.
3. Deionized water (DI).
4. Reverse osmosis water.

D. **Residential Humidifier Types**

1. Pan humidifiers:
   a. Basic pan.
   b. Electrically heat pan.
   c. Pan with wicking plates.
2. Wetted element humidifiers:
   a. Fan type.
   b. Bypass type.
   c. Duct mounted type.
3. Atomizing humidifiers:
   a. Spinning disk.
   b. Spray nozzles—water pressure.
   c. Spray nozzles—compressed air.
   d. Ultrasonic.
4. Portable or non-ducted humidifiers.

E. **Industrial Humidifier Types**

1. Heated pan humidifiers:
   a. Steam.
   b. Hot water.
2. Direct steam injection humidifiers:
   a. Single or multiple steam jacketed humidifiers.
   b. Nonjacketed manifold or panel-type distribution humidifiers.
3. Electrically heated, self-contained steam humidifiers:
   a. Electrode type humidifier.
   b. Resistance type humidifiers.
4. Atomizing humidifiers:
   a. Ultrasonic humidifiers.
   b. Centrifugal humidifiers.
   c. Compressed air nozzle humidifiers.
5. Wetted media humidifiers:
   a. Rigid media humidifiers.
6. Evaporative cooling.

Part 34: Filters

34. Part 34: Filters

Printed for University of California Berkeley Copyright McGraw-Hill Education Holdings

34.01. Minimum Efficiency Reporting Value (MERV)

A. **MERV reports a filter's ability to capture particles between 0.3 and 10 microns.**

B. **MERV values are used in comparing the performance of different filters.**

C. **MERV ratings are derived from an ASHRAE test method.**

D. **The higher the MERV rating, the better the filter is at removing particulates from the air.**

E. **MERV Values.**

MERV RATINGS

MERV Rating	Average Particle Size in Microns	Efficiency	Filter Types
1–4	3.0–10.0	Less than 20%	Roll filters Flat or panel filters Electronic air cleaners Carbon filters (not designed to remove

MERV Rating	Average Particle Size in Microns	Efficiency	Filter Types (remove particulates)
5	3.0–10.0	20–34.9%	Flat or panel filters Pleated media filters Cartridge filters
6	3.0–10.0	35–49.9%	
7	3.0–10.0	50–69.9%	
8	3.0–10.0	70% or greater	
9	3.0–10.0 1.0–3.0	85% or greater Less than 50%	Bag filters Box filters
10	3.0–10.0 1.0–3.0	85% or greater 50–64.9%	
11	3.0–10.0 1.0–3.0	85% or greater 65–79.9%	
12	3.0–10.0 1.0–3.0	90% or greater 80% or greater	
13	3.0–10.0 1.0–3.0 0.30–1.0	90% or greater 90% or greater Less than 75%	Bag filters Box filters HEPA filters ULPA filters
14	3.0–10.0 1.0–3.0 0.30–1.0	90% or greater 90% or greater 75–84.9%	
15	3.0–10.0 1.0–3.0 0.30–1.0	90% or greater 90% or greater 85–94.9%	
16	3.0–10.0 1.0–3.0 0.30–1.0	95% or greater 95% or greater 95% or greater	

34.02. Flat or Panel Filters

A. **Efficiency: 20–35% (dust spot)**

B. **Face Velocity: 500 FPM**

C. **Initial Pressure Drop: 0.25" W.G.**

D. **Final Pressure Drop: 0.50" W.G.**

E. **Nominal Sizes**

1. 1" Thick: 24 × 24; 20 × 25; 20 × 24; 20 × 20; 16 × 25; 16 × 20
2. 2" Thick: 24 × 24; 20 × 25; 20 × 24; 20 × 20; 18 × 24; 16 × 25; 16 × 20; 12 × 24

F. **Test Method: *ASHRAE 52.2-2012*, Atmospheric**

34.03. Pleated Media Filters

A. **Efficiency (dust spot)**

1. 25–35%
2. 60–65%
3. 80–85%
4. 90–95%

B. **Face Velocity: 500 FPM**

C. **Initial Pressure Drop**

1. 25–35%:	0.25–0.45" W.G.
2. 60–65%:	0.50" W.G.
3. 80–85%:	0.60" W.G.
4. 90–95%:	0.70" W.G.

D. **Final Pressure Drop**

1. 25–35%:	1.20" W.G.
2. 60–65%:	1.20" W.G.
3. 80–85%:	1.20" W.G.
4. 90–95%:	1.20" W.G.

E. **Nominal Sizes**

1. Thicknesses (inches):

a. 25–35%:	1; 2; 4.
b. 60–65%:	4; 6; 12.
c. 80–85%:	4; 6; 12.
d. 90–95%:	4; 6; 12.

2. Face sizes:

a. 25–35%:	24 × 24; 20 × 25; 20 × 24; 20 × 20; 18 × 24; 16 × 25; 16 × 20; 12 × 24.
b. 60–65%:	24 × 24; 20 × 25; 20 × 24; 20 × 20; 18 × 24; 16 × 25; 16 × 20; 12 × 24.
c. 80–85%:	24 × 24; 20 × 25; 20 × 24; 20 × 20; 18 × 24; 16 × 25; 16 × 20; 12 × 24.
d. 90–95%:	24 × 24; 20 × 25; 20 × 24; 20 × 20; 18 × 24; 16 × 25; 16 × 20; 12 × 24.

F. **Test Method: *ASHRAE 52.2-2012*, Atmospheric**

34.04. Bag Filters

A. **Efficiency (dust spot)**

1. 40–45%

2. 50–55%

3. 60–65%

4. 80–85%

5. 90–95%

B. **Face Velocity: 500 FPM**

C. **Initial Pressure Drop**

1. 40–45%:	0.25" W.G.
2. 50–55%:	0.35" W.G.
3. 60–65%:	0.40" W.G.
4. 80–85%:	0.50" W.G.
5. 90–95%:	0.60" W.G.

D. **Final Pressure Drop**

1. 40–45%:	1.00" W.G.
2. 50–55%:	1.00" W.G.
3. 60–65%:	1.00" W.G.
4. 80–85%:	1.00" W.G.
5. 90–95%:	1.00" W.G.

E. **Nominal Sizes**

1. Thicknesses (inches):

a. 40–45%:	12; 15.
b. 50–55%:	21; 22; 30; 37.
c. 60–65%:	21; 22; 30; 37.
d. 80–85%:	21; 22; 30; 37.
e. 90–95%:	21; 22; 30; 37.

2. Face sizes:

a. 40–45%:	24 × 24; 24 × 20; 20 × 25; 20 × 24; 20 × 20; 16 × 25; 16 × 20; 12 × 24.
b. 50–55%:	24 × 24; 24 × 20; 20 × 24; 20 × 20; 12 × 24.
c. 60–65%:	24 × 24; 24 × 20; 20 × 24; 20 × 20; 12 × 24.
d. 80–85%:	24 × 24; 24 × 20; 20 × 24; 20 × 20; 12 × 24.
e. 90–95%:	24 × 24; 24 × 20; 20 × 24; 20 × 20; 12 × 24.

F. **Test Method: *ASHRAE 52.2-2012*, Atmospheric**

34.05. HEPA (High Efficiency Particulate Air) Filters

A. **Efficiency: 99.97% for 0.3 micron particles and larger**

B. **Face Velocity: 250 FPM maximum**

C. **Initial Pressure Drop**

1. 95%:	0.50" W.G.
2. 99.97–99.995%:	1.00" W.G.

D. **Final Pressure Drop**

1. 95%:	2.00" W.G.
2. 99.97–99.995%:	3.00" W.G.

E. **Nominal Sizes**

1. Thicknesses (inches):	3; 5; 6; 12.
2. Face sizes:	8 × 8; 12 × 12; 12 × 24; 16 × 20; 20 × 20; 24 × 12; 24 × 24; 24 × 30; 24 × 36; 24 × 48; 24 × 60; 24 × 72; 30 × 24; 30 × 30; 30 × 36; 30 × 48; 30 × 60; 30 × 72; 36 × 24; 36 × 30; 36 × 36; 36 × 48; 36 × 60; 36 × 72.

F. **Test Method: D.O.P. or Polystyrene Latex (PSL) Spheres (PSL preferred)**

34.06. ULPA (Ultra Low Penetrating Air) Filters

A. **Efficiency: 99.9997% for 0.12 micron particles and larger**

B. **Face Velocity: 250 FPM maximum**

C. **Initial Pressure Drop**

1. 99.997–99.9999%:	1.00" W.G.

D. **Final Pressure Drop**

1. 99.997–99.9999%:	3.00" W.G.

E. **Nominal Sizes**

1. Thicknesses (inches):	3; 5; 6; 12.
2. Face sizes:	8 × 8; 12 × 12; 12 × 24; 16 × 20; 20 × 20; 24 × 12; 24 × 24; 24 × 30; 24 × 36; 24 × 48; 24 × 60; 24 × 72; 30 × 24; 30 × 30; 30 × 36; 30 × 48; 30 × 60; 30 × 72; 36 × 24; 36 × 30; 36 × 36; 36 × 48; 36 × 60; 36 × 72.

F. **Test Method: D.O.P. or Polystyrene Latex (PSL) Spheres (PSL preferred)**

34.07. Roll Filters

A. **Efficiency: 20–25% (dust spot)**

B. **Face Velocity: 500 FPM**

C. **Initial Pressure Drop**

1. 20%:	0.20" W.G.

D. **Final Pressure Drop**

1. 20%:	0.45" W.G.

E. **Nominal Sizes**

1. Thicknesses:	2.
2. Face sizes:	
a. Height:	5'0–15'0" by increments of 4".
b. Width:	3'0–30'0" by increments of 1'0".

F. **Test Method: *ASHRAE 52.2-2012*, Atmospheric**

34.08. Carbon Filters

A. **Front/Back Access**

1. Face velocity:	500 FPM
a. Pressure drop:	0.35–0.45" W.G.
b. Nominal sizes:	24 × 24 × 24: 90 lbs. of carbon per 2,000 CFM. 24 × 12 × 24: 45 lbs. of carbon per 1,000 CFM.
c. Tray size:	24 × 24.
2. Face velocity:	250 FPM
a. Pressure drop:	0.30–0.40" W.G.
b. Nominal sizes:	24 × 24 × 8: 30 lbs. of carbon per 1,000 CFM. 24 × 24 × 8: 15 lbs. of carbon per 500 CFM.
c. Tray size:	24 × 8.

B. **Side Access**

1. Face velocity:	500 FPM
a. Pressure drop:	0.35–0.45" W.G.
b. Nominal sizes:	24 × 24 × 24: 108 lbs. of carbon per 2,000 CFM.
c. Tray size:	12 × 24.

C. **Test Method:** ***ASHRAE 52.2-2012*****, Atmospheric**

34.09. Electronic Air Cleaners

A. **Efficiency: 30–40% (dust spot)**

B. **Face Velocity: 625 FPM**

C. **Initial Pressure Drop**

1. 90%:	0.26" W.G.

D. **Final Pressure Drop**

1. 90%:	0.50" W.G.

E. **Nominal Sizes**

1. Thicknesses:	2'0–4'0".
2. Face sizes:	
a. Height:	2'4–15'8" by increments of 4".
b. Width:	2'8–18'8" by increments of 1'0".

F. **Test Method:** ***ASHRAE 52.2-2012*, Atmospheric**

34.10. Filter Characteristics

A. **Filter Removal Capabilities**

1. Fine mode	< 2.5 microns.
2. Coarse mode	2.5 microns.
3. Respirable	< 10.0 microns.
4. Nonrespirable	10.0 microns.

B. **Filter Design Factors**

1. Degree of air cleanliness required.
2. Particulate/contaminate size and form (solid or aerosols).
3. Concentration.
4. Cost (initial and maintenance).
5. Space requirements.
6. Pressure loss/energy use.

C. **Filter Characteristics**

1. *Efficiency*. Ability of the filter to remove particulates/contaminates.
2. *Airflow Resistance*. Static pressure drop of the filters.

3. *Dust Holding Capacity*. Amount of particulates/contaminates the filter will hold before efficiency drops drastically.

D. **Filter Classes**

1. Class 1 Filters: Filters that, when clean, do not contribute fuel when attacked by flame and emit only negligible amounts of smoke.

2. Class 2 Filters: Filters that, when clean, burn moderately when attacked by flame or emit moderate amounts of smoke, or both.

3. However, dust, trapped by filters, will support combustion and will produce smoke more than the filter itself.

4. 2015 IMC:
   a. Media-type air filters shall comply with UL-900.

   b. High-efficiency particulate air filters shall comply with UL-586.

   c. Electrostatic-type air filters shall comply with UL-867.

   d. Ducts and systems shall be designed to allow even distribution of air over the entire filter.

   e. Filters shall be either Class 1 or Class 2.

5. NFPA 90A-2015: Filters shall comply with UL-900.

E. **Filter Test Methods**

1. ASHRAE "test dust." ASHRAE test dust is composed of 72 percent standardized air cleaner test dust, fine; 23 percent powdered carbon; and 5 percent cotton linters.

2. Arrestance test:
   a. Uses ASHRAE test dust.

   b. Tests the ability of the filter to remove the larger atmospheric dust particles.

   c. Measures the concentration of the dust leaving the filter.

3. Atmospheric dust spot efficiency test:
   a. Measures the change in light transmitted by HEPA filter media targets.

   b. Intermittent flow method. Airflow upstream and downstream of the tested filter is drawn through separate target filters. Upstream airflow is intermittently drawn and the downstream airflow is continuously drawn. The test takes more time for higher efficiency filters.

c. Constant flow method. Airflow upstream and downstream of the tested filter is drawn through separate target filters at a constant flow. Test takes the same time for high- and low-efficiency filters.

4. Dust holding capacity test. The amount of dust held by the filter when the filter pressure drop reaches its maximum or final pressure drop, or when arrestance tests drop below 85 percent for two consecutive readings, or below 75 percent for one reading.

5. DOP (dioctyl phthalate) test:
   a. High-efficiency filter tests (HEPA and ULPA).

   b. DOP or BEP (Bis-[2-Ethylhexyl] Phthalate). Test aerosols are used.

   c. A cloud of DOP or BEP is passed through the test filter, and the amount passing through the filter is measured by a light-scattering photometer.

6. Polystyrene latex (PSL) spheres test:
   a. High-efficiency filter tests (HEPA and ULPA).

   b. Filter media thickness 20 mL.

   c. Media is tested at 10.5 feet per minute with PSL.

   d. Filters are tested at 70–100 feet per minute.

   e. PSL test material is selected to allow 90 percent of the mean size to be between 0.1 and 0.3 microns.

   f. The minimum number of PSL particles in the filter test challenge will be a minimum of 10 million particles per cubic foot.

   g. The particle test challenge is monitored in accordance with the Institute of Environmental Sciences (IES) standards *IES-RP-C001* for HEPA filters and *IES-RP-C007* for ULPA filters.

7. Leak scan tests:
   a. Used with HEPA and ULPA filters.

   b. The DOP Test is used while scanning the face of the filter for air leakage through or around the filters.

8. Particle size tests. No standard exists; depends heavily on the type of aerosol used.

Citation

EXPORT

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. Part 34: Filters, Chapter (McGraw-Hill Professional, 2016), AccessEngineering

Part 35: Insulation

35. Part 35: Insulation

35.01. Insulation Materials and Properties

A. **General**

1. Insulation, adhesives, mastics, sealants, and coverings shall have a flame spread rating of 25 or less and a smoke developed rating of 50 or less as determined by an independent testing laboratory in accordance with *NFPA 255* and *UL 728* as required by *ASHRAE 90A* and *90B.* Coatings and adhesives applied in the field shall be nonflammable in the wet state.

2. Hangers on chilled water and other cold piping systems should be installed on the outside of the insulation to prevent hangers from sweating.

3. Cold surfaces: Normal operating temperatures less than 75°F.

4. Hot surfaces: Normal operating temperatures of 100°F or higher.

5. Dual-temperature surfaces: Normal operating temperatures that vary from hot to cold.

6. Thermal conductivity:
   a. K-values.

   b. Thermal conductivity values express the rate of heat loss of a homogenous substance in Btu-in./h sq.ft.°F.

7. Thermal conductance:
   a. C-values.

b. Thermal conductance values express the rate of heat loss of a homogenous substance in Btu-in./h sq.ft.°F.

8. Thermal resistance:
   a. R-values.

   b. Thermal resistance values express the resistance of heat loss of a homogenous substance in °F sq.ft. h/Btu.

9. Overall heat transfer coefficients:
   a. U-values.

   b. Overall heat transfer coefficient values express the rate of heat loss of a nonhomogenous substance in Btu/h sq.ft.°F.

$$R=\frac{1}{C}=\frac{1}{K}\times Thickness$$

$$U=\frac{1}{\sum R}$$

B. **Materials**

1. Calcium silicate temperature range:	0 to +1200°F.
2. Fiberglass temperature range:	–20 to +1000°F.
3. Mineral wool temperature range:	+200 to +1900°F.
4. Urethane, styrene, beadboard temperature range:	–350 to +250°F.
5. Cellular glass temperature range:	–450 to +850°F.
6. Ceramic fiber temperature range:	0 to +3000°F.
7. Flexible tubing and sheets temperature range:	–40 to +250°F.

35.02. Pipe Insulation

A. **Insulation shall be sectional molded glass fiber, minimum 3.0 lbs. per cubic foot density, with a thermal conductivity not greater than 0.24 Btu-in./sq.ft./°F/h at a mean temperature difference of 75°F and a white factory-applied flame-retardant vapor barrier jacket of 0.001"**

aluminum foil laminated to Kraft paper reinforced with glass fibers, or all service jacket.

B. **Insulation shall be flexible foamed plastic, minimum 5.0 lbs. per cubic foot density, with a thermal conductivity not greater than 0.28 Btu-in./sq.ft./°F/h at a mean temperature difference of 75°F.**

C. **Insulation shall be cellular glass, with a thermal conductivity not greater than 0.40 Btu-in./sq.ft./°F/h at a mean temperature difference of 75°F.**

D. **Insulation shall be foamglass, minimum 8.5 lbs. per cubic foot density, with a thermal conductivity not greater than 0.35 Btu-in./sq.ft./°F/h at a mean temperature difference of 75°F.**

E. **Code Required Pipe Insulation Thickness.**
ASHRAE STANDARD 90.1-2013 AND 2015 IECC

Fluid Design Operating Temperature	Conductivity Btu-in./h ft.^{2} °F	Nominal Pipe or Tube Diameter				
		<1"	1–1-1/2"	>1-1/2–4"	>4–8"	≥8"
Heating Systems—Hot Water and Steam Condensate						
>350°F	0.32–0.34	4.5	5.0	5.0	5.0	5.0
251–350°F	0.29–0.32	3.0	4.0	4.5	4.5	4.5
201–250°F	0.27–0.30	2.5	2.5	2.5	3.0	3.0
141–200°F	0.25–0.29	1.5	1.5	2.0	2.0	2.0
105–140°F	0.22–0.28	1.0	1.0	1.5	1.5	1.5
Heating Systems—Steam						
>350°F >120 psig	0.32–0.34	4.5	5.0	5.0	5.0	5.0
251–350°F 16–120 psig	0.29–0.32	3.0	4.0	4.5	4.5	4.5
212–250°F 0–15 psig	0.27–0.30	2.5	2.5	2.5	3.0	3.0
Cooling Systems—Chilled Water, Glycol, Brine, and Refrigerant						
40–60°F	0.22–0.27	0.5	0.5	1.0	1.0	1.0
<40°F	0.20–0.26	0.5	1.0	1.0	1.0	1.5

F. Recommended pipe insulation thicknesses are provided in the following table:

Piping System (7)	Pipe Sizes	Insulation Thickness vs. Type (1, 8)			
		A	B	C	D
Chilled Water 40–60°F (3)	1-1/2" and smaller 2" and larger	1.0 1.5	1.5 2.0	2.0 2.5	1.5 2.5
Chilled Water	1" and smaller	1.0 1.5	1.5 2.0	2.0 2.5	1.5 2.5

Notes:

1. Type A: Fiberglass insulation

Piping System (7)	Pipe Sizes	Insulation Thickness vs. Type (1, 8)			
		A	B	C	D
Water 32–40°F (3)	smaller 1-1/4–6" 8" and larger	1.5 2.0	2.0 2.5	2.5 3.5	2.5 3.0
Chilled Water Below 32°F (3)	2" and smaller 2-1/2–6" 8" and larger	1.5 2.0 2.5	2.0 2.5 3.0	2.5 3.5 4.5	2.5 3.0 4.0
Condenser Water	All sizes	(2)	(2)	(2)	(2)
Condenser Water—Waterside Economizer	1-1/2" and smaller 2" and larger	1.0 1.5	1.5 2.0	2.0 2.5	1.5 2.5
Heating Water—Low Temperature 100–140°F (4)	1-1/2" and smaller 2" and larger	1.0 2.0	1.5 2.5	2.0 3.5	1.5 3.0
Heating Water—Low Temperature 141–200°F (4)	1-1/2" and smaller 2" and larger	1.5 2.0	1.5 2.5	2.0 3.5	1.5 3.0
Heating Water—Low Temperature 201–250°F (4)	1-1/4" and smaller 1-1/2" and larger	2.5 3.0	2.0 2.5	2.5 3.5	2.5 3.0
Heating Water—Medium Temperature 251–350°F (4)	3/4" and smaller 1–1-1/ 4" 1-1/2" and larger	3.0 4.0 4.5	(10)	2.5 4.5 5.0	2.5 4.0 4.5
Heating	3/4" and	4.5	(10)	4.5	4.0

Piping System (7)	Pipe Sizes	Insulation Thickness vs. Type (1, 8)			
		A	B	C	D
Heating Water—High Temperature 351–450°F (4)	3/4" and smaller 1–3" 4" and larger	4.5 5.0 5.0	(10)	4.5 5.0 6.5	4.0 4.5 6.0
Dual Temperature	All sizes	(9)	(9)	(9)	(9)
Heat Pump Loop	All sizes	(2)	(2)	(2)	(2)
Steam and Steam Condensate—Low Pressure (5) 15 psig and Lower 201–250°F	3" and smaller 4" and larger	2.5 3.0	2.0 4.0	2.5 5.0	2.5 4.5
Steam and Steam Condensate—Medium Pressure (5) 16–100 psig 251–350°F	3/4" and smaller 1–1-1/4" 1-1/2" and larger	3.0 4.0 4.5	(10)	2.5 4.5 5.0	2.5 4.0 4.5
Steam and Steam Condensate—High Pressure (5) 101–300 psig >350°F	3/4" and smaller 1" and larger	4.5 5.0	(10)	4.5 6.5	4.0 6.0
Refrigerant Suction and Liquid Lines (6)	1" and smaller 1-1/4–6" 8" and larger	1.0 1.5 2.0	1.5 2.0 2.5	2.0 2.5 3.5	1.5 2.5 3.0

Notes:

1. **Type A: Fiberglass insulation.**
   Type B: Flexible foamed plastic insulation.
   Type C: Cellular glass insulation.
   Type D: Foamglass insulation.

Piping System (7)	Pipe Sizes	Insulation Thickness vs. Type (1, 8)			
		A	B	C	D
Refrigerant Hot Gas (6)	All sizes	0.75	1.0	1.5	1.0
Air Conditioning Condensate	All sizes	0.5	0.5	1.0	0.75

Notes:

1. **Type A: Fiberglass insulation.**
   Type B: Flexible foamed plastic insulation.
   Type C: Cellular glass insulation.
   Type D: Foamglass insulation.

2. **Insulation is not required on systems with temperatures between 60°F and 105°F, unless insulating the pipe for freeze protection—in which case, use chilled water (40°F and above) thicknesses. Remember to include insulation on condenser water systems used for waterside economizer operation.**

3. **Chilled water system piping is often insulated with fiberglass insulation; although, cellular glass and flexible foamed plastic may be more appropriate for moisture condensation protection. Other types of insulation may be used.**

4. **Heating water system piping is generally insulated with fiberglass pipe insulation. Other types of insulation may be used.**

5. **Steam system piping and steam condensate system piping are generally insulated with fiberglass pipe insulation. Other types of insulation may be used.**

6. **Refrigerant system piping is generally insulated with flexible foamed plastic. Other types of insulation may be used. Normally, only refrigerant suction lines are insulated, but liquid lines should be insulated where condensation will become a problem, and hot gas lines should be insulated where personal injury from contact may pose a problem.**

7. **Table meets or exceeds ASHRAE Standard 90.1-2013 and the 2015 IECC.**

8. **For piping exposed to ambient temperatures, increase the insulation thickness by 1 in.**

9. For dual temperature systems, use insulation thickness for a more stringent system, usually the heating system.

Piping System (7)	Pipe Sizes	Insulation Thickness Type (1, 8)			
		A	B	C	D

10. The system temperature exceeds the temperature rating of the insulation.

35.03. Duct Insulation

A. **Internal Duct Liner**

1. 1-1/2 pounds per cubic foot density amber color glass fiber blanket with smooth coated matte facing to conform to *TIMA Standard AHC-101, NFPA 90A, NFPA 90B, NFPA 255, UL 181,* and *UL 723.* Duct lining shall have a thermal conductivity (k) not greater than 0.24 Btu/sq.ft./°F/h at a mean temperature difference of 75°F. Vinyl spray face shall not be permitted.

2. Thicknesses: 1", 1-1/2", 2".

B. **External Duct Insulation**

1. Duct wrap: Insulation shall be a flexible glass fiber blanket, minimum 3/4 lb. per cubic foot density, with a thermal conductivity (k) not greater than 0.29 Btu-in./sq.ft./°F/h at a mean temperature difference of 75°F and a factory-applied jacket of minimum 0.001" aluminum foil reinforced with glass fiber bonded to flame-resistant Kraft paper vapor barrier. Thicknesses: 1", 1-1/2", 2".

2. Duct board: Insulation shall be glass fiber, minimum 3.0 lbs. per cubic foot density, with a thermal conductivity (k) not greater than 0.23 Btu-in./sq.ft./°F/h at a mean temperature difference of 75°F and a white factory-applied flame-retardant vapor barrier jacket of 0.001" aluminum foil reinforced with glass fibers bonded to flame-resistant Kraft paper. Thicknesses: 1", 1-1/2", 2", 3", 4".

3. Duct board: Insulation shall be rigid glass fiber board, minimum 6.0 lbs. per cubic foot density, with a thermal conductivity (k) not greater than 0.22 Btu-in./sq.ft./°F/h at a mean temperature difference of 75°F and a white factory-applied flame-retardant vapor barrier jacket of 0.001" aluminum foil reinforced with glass fibers bonded to flame-resistant Kraft paper. Thicknesses: 1", 1-1/2", 2".

C. **Code Required Duct Insulation Thickness**

1. 2015 IECC:
   a. Supply and return air ducts and plenums located in unconditioned spaces: R-6 insulation minimum.

   b. Supply and return air ducts and plenums located outside: R-8 insulation minimum in Climate Zones 1 through 4, and R-12 insulation minimum in Climate Zones 5 through 8.

   c. Ducts or plenums shall be separated from the building exterior or unconditioned or exempt spaces by R-8 insulation minimum in Climate Zones 1 through 4, and R-12 insulation minimum in Climate Zones 5 through 8.

   d. Duct insulation is not required where located within equipment.

   e. Duct insulation is not required when the design temperature difference between the interior and exterior of the duct or plenum does not exceed 15°F. This exception will apply to most return air ducts except when located outside.

2. ASHRAE Standard 90.1-2013

			Duct Location		
Climate Zone	**Exterior**	**Ventilated Attic**	**Unvented Attic above Insul. Ceiling**	**Unvented Attic w/Roof Insulation**	**Unconditio Space**
Heating-Only Ducts					
1, 2	None	None	None	None	None
3	R-3.5	None	None	None	None
4	R-3.5	None	None	None	None
5	R-6	R-3.5	None	None	None
6	R-6	R-6	R-3.5	None	None
7	R-8	R-6	R-6	None	R-3.5
8	R-8	R-8	R-6	None	R-6
Cooling-Only Ducts					

Climate Zone	Exterior	Ventilated Attic	Unvented Attic above Insul. Ceiling	Unvented Attic w/Roof Insulation	Unconditio Space
	Duct Location				
1	R-6	R-6	R-8	R-3.5	R-3.5
2	R-6	R-6	R-6	R-3.5	R-3.5
3	R-6	R-6	R-6	R-3.5	R-1.9
4	R-3.5	R-3.5	R-6	R-1.9	R-1.9
5, 6	R-3.5	R-1.9	R-3.5	R-1.9	R-1.9
7, 8	R-1.9	R-1.9	R-1.9	R-1.9	R-1.9
Combined Heating and Cooling Ducts					
1	R-6	R-6	R-8	R-3.5	R-3.5
2	R-6	R-6	R-6	R-3.5	R-3.5
3	R-6	R-6	R-6	R-3.5	R-3.5
4	R-6	R-6	R-6	R-3.5	R-3.5
5	R-6	R-6	R-6	R-1.9	R-3.5
6	R-8	R-6	R-6	R-1.9	R-3.5
7	R-8	R-6	R-6	R-1.9	R-3.5
8	R-8	R-8	R-8	R-1.9	R-6
Return Ducts					
1–8	R-3.5	R-3.5	R-3.5	None	None

D. **Recommended duct insulation R-values and insulation thicknesses are provided in the following table:**

Climate Zone	Exterior	Ventilated Attic	Unvented Attic above Insul. Ceiling	Unvented Attic w/Roof Insulation	Unconditione Space
	Duct Location				
Heating Ducts Only					
All	R-8	R-8	R-8	R-5	R-6

Notes:

1. Climate

1. **The duct liner represented in the table has a K-value of 0.24 and a**

Climate Zone	Duct Location				
	Exterior	Ventilated Attic	Unvented Attic above Insul. Ceiling	Unvented Attic w/Roof Insulation	Unconditioned Space
Zones					
Duct Liner	2"	2"	2"	1.5"	1.5"
Duct Wrap	3"	3"	3"	2"	2"
Duct Board	2"	2"	2"	1.5"	1.5"
Cooling Ducts Only					
All Climate Zones	R-8	R-8	R-8	R-5	R-6
Duct Liner	2"	2"	2"	1.5"	1.5"
Duct Wrap	3"	3"	3"	2"	2"
Duct Board	2"	2"	2"	1.5"	1.5"
Cooling and Heating Ducts					
All Climate Zones	R-8	R-8	R-8	R-5	R-6
Duct Liner	2"	2"	2"	1.5"	1.5"
Duct Wrap	3"	3"	3"	2"	2"
Duct Board	2"	2"	2"	1.5"	1.5"
Return Ducts					
All Climate Zones	R-8	R-8	R-8	None	None
Duct	2"	2"	2"	None	None

Notes:

Climate Zone	Exterior	Ventilated Attic	Unvented Attic above Insul. Ceiling	Unvented Attic w/Roof Insulation	Unconditioned Space
				Duct Location	
Liner					
Duct Wrap	3"	3"	3"	None	None
Duct Board	2"	2"	2"	None	None

Notes:

1. **The duct liner represented in the table has a K-value of 0.24 and a**
2. **The duct wrap represented in the table has a K-value of 0.29 and a**
3. **The duct board represented in the table has a K-value of 0.22 and a**

35.04. Insulation Protection

A. **Aluminum roll jacketing and fitting covers produced from ASTM-B-209, 3003 Alloy, 0.016 in. thickness, H-14 temper with a smooth finish. Install in accordance with the manufacturer's recommendations.**

B. **Stainless steel roll jacketing and fitting covers produced from ASTM-A-167, Type 304 or 316, 0.10-in. thick, No. 2B finish, and factory cut and rolled to indicated sizes. Install in accordance with the manufacturer's recommendations.**

C. **Prefabricated PVC fitting covers and jacketing produced from 20-mil-thick, high-impact, ultra-violet-resistant PVC with the same insulation and thickness as specified. Install in accordance with the manufacturer's recommendations.**

D. **Bands: 3/4-in. wide, in one of the following materials compatible with jacket.**
   1. Aluminum: 0.007-in. thick.
   2. Stainless steel: Type 304, 0.020-in. thick.

Citation

EXPORT

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. Part 35: Insulation, Chapter (McGraw-Hill Professional,

2016), AccessEngineering

Part 36: Fire-Stopping and Through-Penetration Systems

36. Part 36: Fire-Stopping and Through-Penetration Systems

36.01. Fire-Stopping and Through-Penetration Protection Systems

A. **All openings in fire-rated and smoke-rated building construction must be protected from fire and smoke by systems that seal these openings to resist the passage of fire, heat, smoke, flames, and gases. These openings include passages for mechanical and electrical systems, expansion joints, seismic joints, construction joints, control joints, curtain wall gaps, the space between the edge of the floor slab and the exterior curtain wall and columns, and other openings or cracks.**

B. **Terms**

1. *Firestopping*. Firestopping is noncombustible building materials or a system of lumber pieces installed to prevent the movement of fire, heat, smoke, flames, and gases to other areas of the building through small concealed spaces. The term *firestopping* is used with all types of building construction, except for noncombustible and fire-resistive construction.

2. *Through-Penetration Protection Systems (TPPS)*. TPPS are building materials or assemblies of materials specifically designed and manufactured to form a system developed to prevent the movement of fire, heat, smoke, flames, and gases to other areas of the building through openings made in fire-rated

floors and walls to accommodate the passage of combustible and noncombustible items. The term *TPPS* is used with noncombustible and fire-resistive building construction.

3. *Combustible Penetrating Items*. Combustible penetrating items are materials such as plastic pipe and conduit, electrical cables, and combustible pipe insulation.

4. *Noncombustible Penetrating Items*. Noncombustible penetrating items are materials such as copper, iron, or steel pipe; steel conduit; EMT; electrical cable with steel jackets; and other noncombustible items.

5. *Annular Space Protection*. Annular space protection is the building materials or assembly of materials that protect the space between noncombustible penetrating items and the rated assembly. In concrete or masonry assemblies, the materials generally used for annular space protection are concrete, grout, or mortar. In all other assemblies, the materials must be tested and meet *ASTM E119* standard under positive pressure.

6. *Single-Membrane Protection*. Single-membrane protection is the building materials or assembly of materials that protect the opening through one side, or a single membrane, of a fire-resistive wall, roof/ceiling, or floor/ceiling to accommodate passage of combustible or noncombustible items. Materials protecting single membranes are annular space protection systems or TPPS.

7. *Shaft Alternatives*. A fire-rated shaft or enclosure is not required if a TPPS system with a flame rating (F-Rating) and a thermal rating (T-Rating) equal to the rating of the assembly is used to protect openings made in fire-rated floors and walls to accommodate the passage of combustible and noncombustible items.

C. **System Ratings**

1. F-Ratings define the period of time for which the fire-stopping or TPPS system prevents the passage of flames and hot gases to the unexposed side of the assembly, in accordance with *ASTM E814.* To receive an F-Rating, the system must also pass the hose stream test. F-Ratings are needed for all applications, and must be equal to the rating of the assembly.

2. T-Ratings define the period of time for which the fire-stopping or TPPS system prevents the passage of flames and hot gases to the unexposed side of the assembly (F-Rating), and must also restrict the temperature rise on

the unexposed surface to 325°F in accordance with *ASTM E814.* T-Ratings must be equal to the rating of the assembly and at least 1 hour. T-Ratings are rarely applied because most penetrations in commercial structures tend to be in noncombustible concealed spaces and are generally only applied where codes require open protectives.

D. **TPPS Materials**

1. Intumescent materials expand to form an insulating char.
2. Subliming materials pass from solid to vapor when heated without passing through the liquid phase.
3. Ablative materials char, melt, or vaporize when heated.
4. Endothermic materials, such as concrete and gypsum, absorb heat using chemically bounded water of the material.
5. Ceramic fibers are high-temperature refractory materials.

E. **Material Forms**

1. Caulks.
2. Putties.
3. Mixes.
4. Sheets, strips, or collars.
5. Kits.
6. Devices.

Part 37: Makeup Water

37. Part 37: Makeup Water

37.01. Makeup Water Requirements

A. **Hot Water System Makeup Connection: Minimum connection size shall be 10 percent of largest system pipe size or 1", whichever is greater (20" system pipe size results in a 2" makeup water connection).**

B. **Chilled Water System Makeup Connection: Minimum connection size shall be 10 percent of largest system pipe size or 1", whichever is greater (20" system pipe size results in a 2" makeup water connection).**

C. **Condenser Water Makeup to Cooling Tower**

1. Centrifugal:	40 GPM/1,000 tons.
2. Reciprocating:	40 GPM/1,000 tons.
3. Screw chillers:	40 GPM/1,000 tons.
4. Scroll chillers:	40 GPM/1,000 tons.
5. Absorption chillers:	80 GPM/1,000 tons.

D. **Cooling Tower Blowdown and Drains**

1. Drains: Use two times the makeup water rate for sizing cooling tower drains.
2. Blowdown:

a. Centrifugal:	10 GPM/1,000 tons.
b. Reciprocating:	10 GPM/1,000 tons.
c. Screw:	10 GPM/1,000 tons.
d. Scroll:	10 GPM/1,000 tons.
e. Absorption:	20 GPM/1,000 tons.

E. **Steam Boiler Water Makeup**

1. Boilers:	4.0 GPM/1,000 lbs./h each
2. Deaerator/feedwater unit:	4.0 GPM/1,000 lbs./h each
3. Makeup water for the steam system is only required at one of the boilers or one of the feedwater units at any given time, for system sizing.	

F. **Boiler Blowdown Separator Makeup**

1. Noncontinuous blowdown (bottom blowdown):	5.0 GPM/1,000 lbs./h.
2. Continuous blowdown (surface blowdown):	0.5 GPM/1,000 lbs./h.

G. **Blowdown Separator Drains: 10 GPM/1,000 lbs./h Boiler Output**

H. **Vacuum Type Steam Condensate Return Units: 0.1 GPM/1,000 lbs./h of Connected Load**

I. **Pumped Steam Condensate Return Units: 2.4 GPM/1,000 lbs./h**

J. **Humidifiers**

1. Steam humidifiers:	5.6 GPM/1,000 kW input or 5.6 GPM/3413 MBH.
2. Electric humidifiers:	5.6 GPM/1,000 kW input or 5.6 GPM/3413 MBH.
3. Evaporative humidifiers:	5.0 GPM/1,000 lbs./h.
4. Spray coil humidifiers:	5.0 GPM/1,000 lbs./h.

K. **Air Conditioning Condensate**

1. Unitary packaged AC equipment:	0.006 GPM/ton.
2. Air handling units (100% outdoor air):	0.100 GPM/1,000 CFM.
3. Air handling units (50% outdoor air):	0.065 GPM/1,000 CFM.
4. Air handling units (25% outdoor air):	0.048 GPM/1,000 CFM.
5. Air handling units (15% outdoor air):	0.041 GPM/1,000 CFM.
6. Air handling units (0% outdoor air):	0.030 GPM/1,000 CFM.

Part 38: Water Treatment and Chemical Feed Systems

38. Part 38: Water Treatment and Chemical Feed Systems

38.01. Water Treatment and Chemical Feed Systems

A. **General**

1. Water treatment objectives:
   a. Prevent hard scale and soft sludge deposits.

   b. Prevent corrosion and pitting.

   c. Protect boiler, piping, and equipment metal chemistry.

   d. Prevent steam carryover.

2. Corrosion and scale/deposit control factors:
   a. pH Level: As the pH of the system water increases (moves toward the alkaline side of the scale), the corrosiveness of the water decreases. However, as the pH of the system water increases, the formation of scale increases. Normal pH range is 6.5 to 9. A typical pH range is 7.8 to 8.8 (Acid pH = 1; Neutral pH = 7; Alkaline pH = 14).

   b. Hardness: As the hardness of the system water increases, the corrosiveness of the water decreases. However, as the hardness of the system water increases, the formation of scale increases.

   c. Temperature: As the temperature of the system water increases, the corrosiveness of the water increases. In addition, as the temperature of the system water increases, the formation of scale increases. Corrosion rates double for every 20°F increase in water temperature.

d. Foulants: The more scale-forming material and foulants in the system water, the greater the chances of scale and deposit formation. Foulants include calcium, magnesium, biological growth (algae, fungi, and bacteria), dirt, silt, clays, organic contaminants (oils), silica, iron, and corrosion by-products.

3. Water treatment limits:
    a. Oxygen: Less than 0.007 ppm (7 ppb).
    b. Hardness: Less than 5.0 ppm.
    c. Suspended matter: Less than 0.15 ppm.
    d. pH: 8 to 9.
    e. Silicas: Less than 150 ppm.
    f. Total alkalinity: Less than 700 ppm.
    g. Dissolved solids: Less than 7,000 mmho/cm.
4. Water source comparison:
    a. Surface water:
        1. High in suspended solids.
        2. High in dissolved gases.
        3. Low in dissolved solids.
    b. Well water:
        1. High in dissolved solids.
        2. Low in suspended solids.
        3. Low in dissolved gases.
5. Suspended solids:
    a. Dirt.
    b. Silt.
    c. Biological growth.
    d. Vegetation.

e. Insoluble organic matter.

f. Undissolved matter.

g. Iron.

6. Hardness measures the amount of calcium and magnesium in the water.

7. Alkalinity measures the water's ability to neutralize strong acid.

8. Scale is the result of precipitation of hardness salts on heat exchange surfaces.

9. Corrosion is the dissolving or wearing away of metals:
   a. *General Corrosion*. General corrosion is caused by acidic conditions.

   b. *Under-Deposit Corrosion*. Under-deposit corrosion is caused by foreign matter resting on a metal surface.

   c. *Erosion*. Erosion is caused by turbulent water flow.

   d. *Pitting Corrosion*. Pitting corrosion is caused by the presence of oxygen.

   e. *Galvanic Corrosion*. Galvanic corrosion is an electrochemical reaction between dissimilar metals.

10. Problems caused by poor water quality:
    a. Scale and deposits.

    b. Decreased efficiency/heat transfer.

    c. Equipment failure/unscheduled shutdowns.

    d. Corrosion.

    e. Tube burnout or fouling.

    f. Carryover in steam systems.

11. Chemical Types:
    a. Scale inhibitors. Scale inhibitors prevent scale formation:
       1. Phosphonate.

       2. Polyacrylate.

       3. Polymethacrylate.

4. Polyphosphate.

5. Polymaleic acid.

6. Sulfuric acid.

b. Biocides. Biocides prevent biological growth:
   1. Oxidizing:
      a. Chlorine. Most common.

      b. Chlorine dioxide.

      c. Bromine. Most common.

      d. Ozone.

   2. Non-Oxidizing:
      a. Carbamate. Most common.

      b. Organo-bromide.

      c. Methylenebis-thiocyanate.

      d. Isothiazoline.

      e. Quaternary ammonium salts.

      f. Organo-tin/quaternary ammonium salts.

      g. Glutaraldehyde.

      h. Dodecylguanidine.

      i. Triazine.

      j. Thiocyanates.

      k. Quaternary ammonium metallics.

   3. Biocide treatment program should include alternate use of oxidizing and non-oxidizing biocides for maximum effectiveness (see the following table):

	Effectiveness Against			Comments
Biocide	**Bacteria**	**Fungi**	**Algae**	
Oxidizing Biocides				

Biocide	Effectiveness Against			Comments
	Bacteria	Fungi	Algae	
Chlorine (Cl_2)	E	G	G	Usable pH range 5 to 8. Effective at neutral pH (pH = 7). Less effective at high pH. Reacts with–NH_2 groups.
Chlorine Dioxide (ClO_2)	E	G	G	Insensitive to pH levels. Insensitive to presence of–NH_2 groups.
Bromine	E	G	P	Usable pH range 5 to 10. Effective over broad pH range. Substitute for chlorine.
Ozone	E	G	G	pH range 7 to 9.
Non-Oxidizing Biocides				
Carbamate	E	E	G	pH range of 5 to 9. Good in high suspended solids systems. Incompatible with chromate treatment

Notes:

1. **Table Abbreviations:**

   E = Excellent Biocide Control

   G = Good Biocide Control

   P = Poor Biocide Control

   N = No Biocide Control

programs.

Biocide	Effectiveness Against			Comments
	Bacteria	Fungi	Algae	
Organo-Bromide (DBNPA)	E	P	P	pH range 6 to 8.5.
Methylenebis-Thiocyanate (MBT)	E	P	P	Decomposes above a pH of 8.
Isothiazoline	E	G	G	Insensitive to pH levels. Deactivated by HS and–NH_2 groups.
Quaternary Ammonium Salts	E	G	G	Tendency to foam. Surface active. Ineffective in organic-fouled systems.
Organo-Tin/Quaternary Ammonia Salts	E	G	E	Tendency to foam. Functions best in alkaline pH.
Glutaraldehyde	E	E	G	Effective over a broad pH range. Deactivated by–NH_2 groups.
Dodecylguanidine (DGH)	E	E	G	pH range of 6 to 9.
Triazine	N	N	E	pH range of 6 to 9. Specific for algae

Notes:

1. **Table Abbreviations:**

   E = Excellent Biocide Control

Biocide	Effectiveness Against			Comments
	Bacteria	Fungi	Algae	
				control Must be used with other biocides.

Notes:

1. Table Abbreviations:

E = Excellent Biocide Control

G = Good Biocide Control

P = Poor Biocide Control

N = No Biocide Control

c. Corrosion inhibitors. Corrosion inhibitors prevent corrosion:

1. Molybdate. Most common and most effective.
2. Nitrite. Most common.
3. Aromatic azoles.
4. Chromate.
5. Polyphosphate.
6. Zinc.
7. Orthophosphate.
8. Benzotriazole. Copper corrosion inhibitor.
9. Tolyltriazole. Copper corrosion inhibitor.
10. Silicate. Copper and steel corrosion inhibitor.

d. Dispersants. Dispersants prevent suspended and dissolved solids from settling out or forming scale in the system, remove existing deposits, and enhance biocide effectiveness:

1. Polyacrylate.
2. Polymethacrylate.

3. Polymaleic acid.

4. Surfactants.

12. Corrosion monitoring is recommended with the use of corrosion coupons for closed and open hydronic systems.

13. Side stream filtration is recommended to maintain system cleanliness. Filters should be sized to filter the entire volume of the system three to five times per day.

38.02. Closed System Chemical Treatment (Chilled-Water Systems, Heating Water Systems)

A. **The chemical treatment objective is to prevent and control the following:**
 1. Scale formation.
 2. Corrosion. Major concern.
 3. System pH (between 8 and 9).

B. **Chemical Types Used in Closed Systems:**
 1. Scale inhibitors.
 2. Corrosion inhibitors.
 3. Dispersants.

C. **Most Common Chemicals Used:**
 1. Molybdate.
 2. Nitrite-based inhibitors.

D. **Water analysis should be conducted at least once a year, preferably semiannually or quarterly, depending on system water losses.**

E. **See Figs. 38.1 and 38.2 regarding the chemical treatment components used in a closed piping system.**

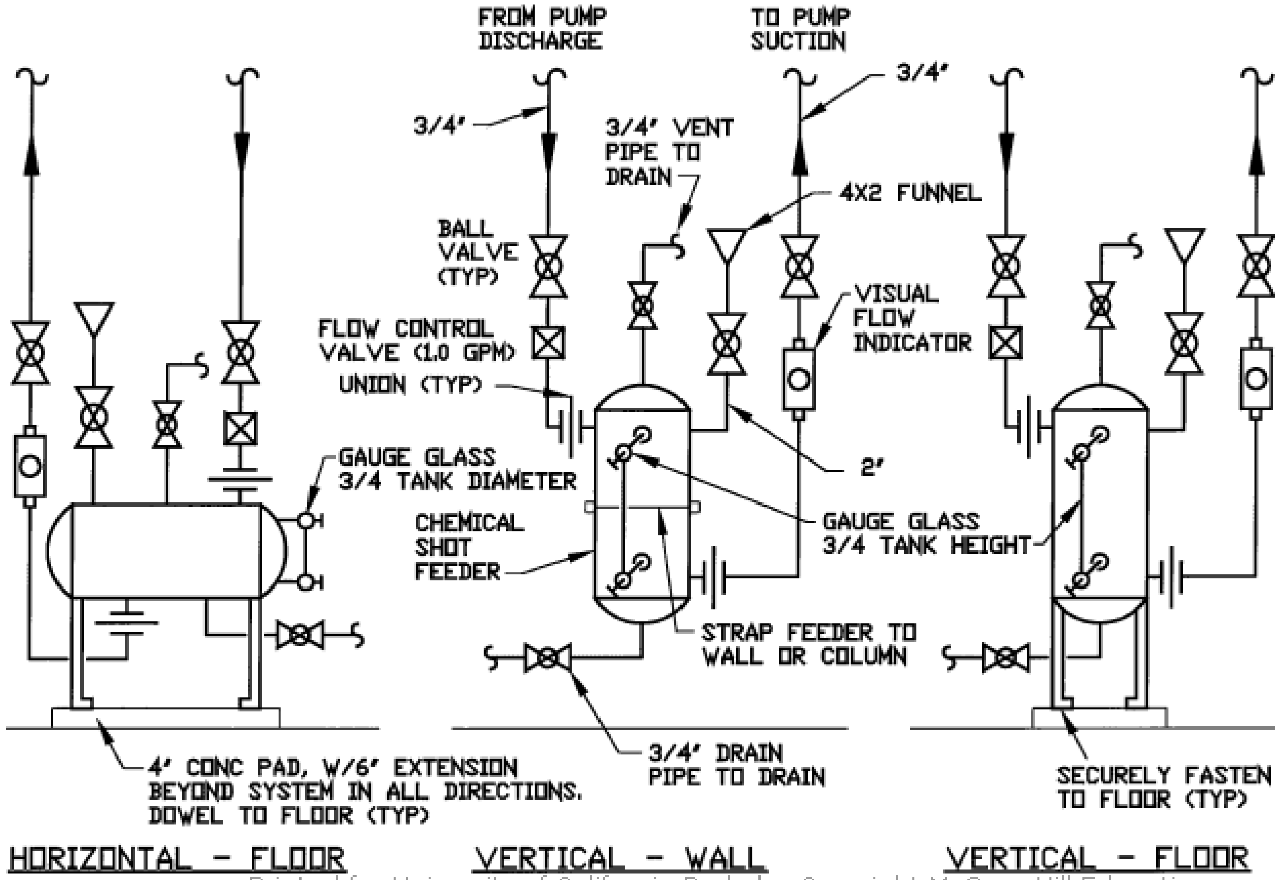


Figure 38.1. CLOSED SYSTEM CHEMICAL SHOT FEEDER.

Figure 38.2. PHOTOGRAPH OF A CLOSED SYSTEM CHEMICAL SHOT FEEDER.

38.03. Open System Chemical Treatment (Condenser Water Systems)

A. **The chemical treatment objective is to prevent and control the following:**
   1. Scale formation.
   2. Fouling:
      a. Particulate matter.

b. Biological growth.

3. Corrosion.

4. System pH. Between 8 and 9.

B. **Chemical Types Used in Open Systems:**

1. Scale inhibitors.

2. Biocides.

3. Corrosion inhibitors.

4. Dispersants.

C. **Makeup water analysis should be conducted at least twice a year, preferably quarterly.**

D. **System water analysis should be conducted at least once a week.**

E. **See Figs. 38.3 and 38.4 for chemical treatment components used in an open piping system.**

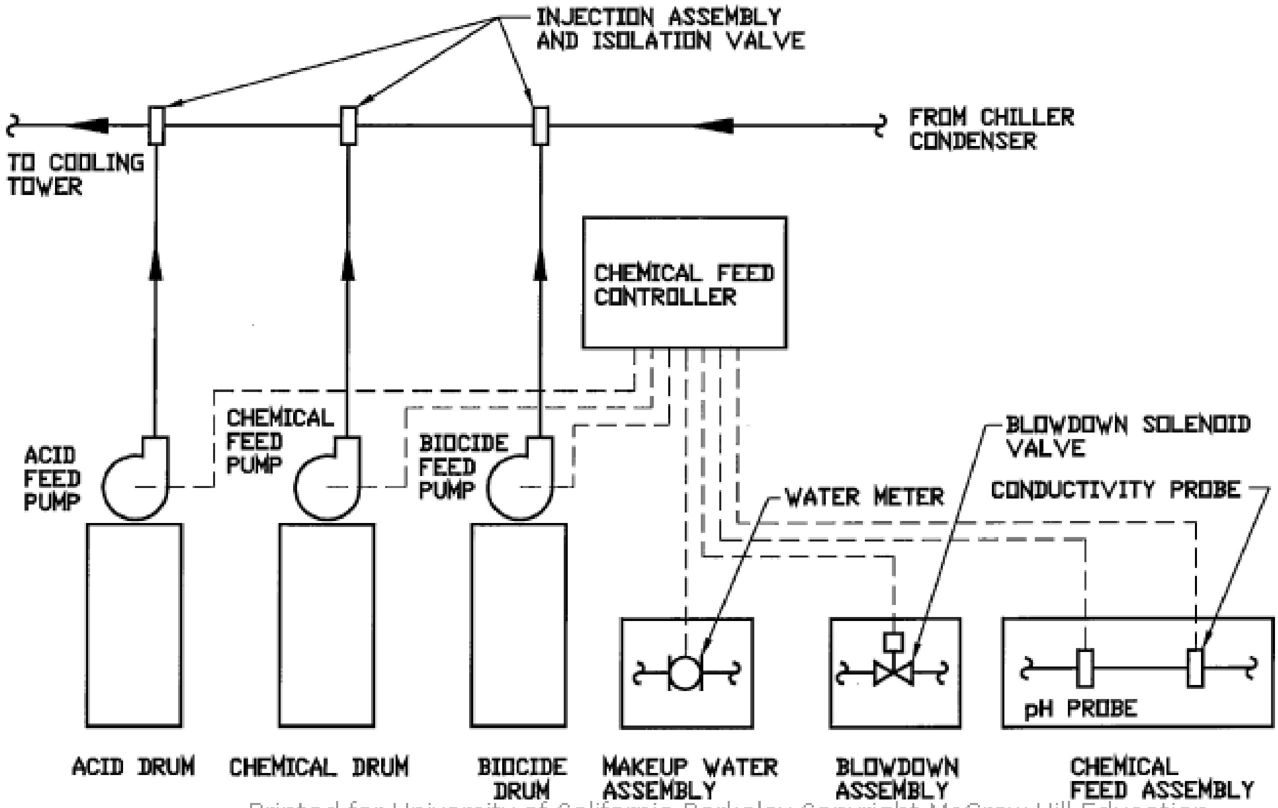


Figure 38.3. OPEN SYSTEM CHEMICAL TREATMENT.

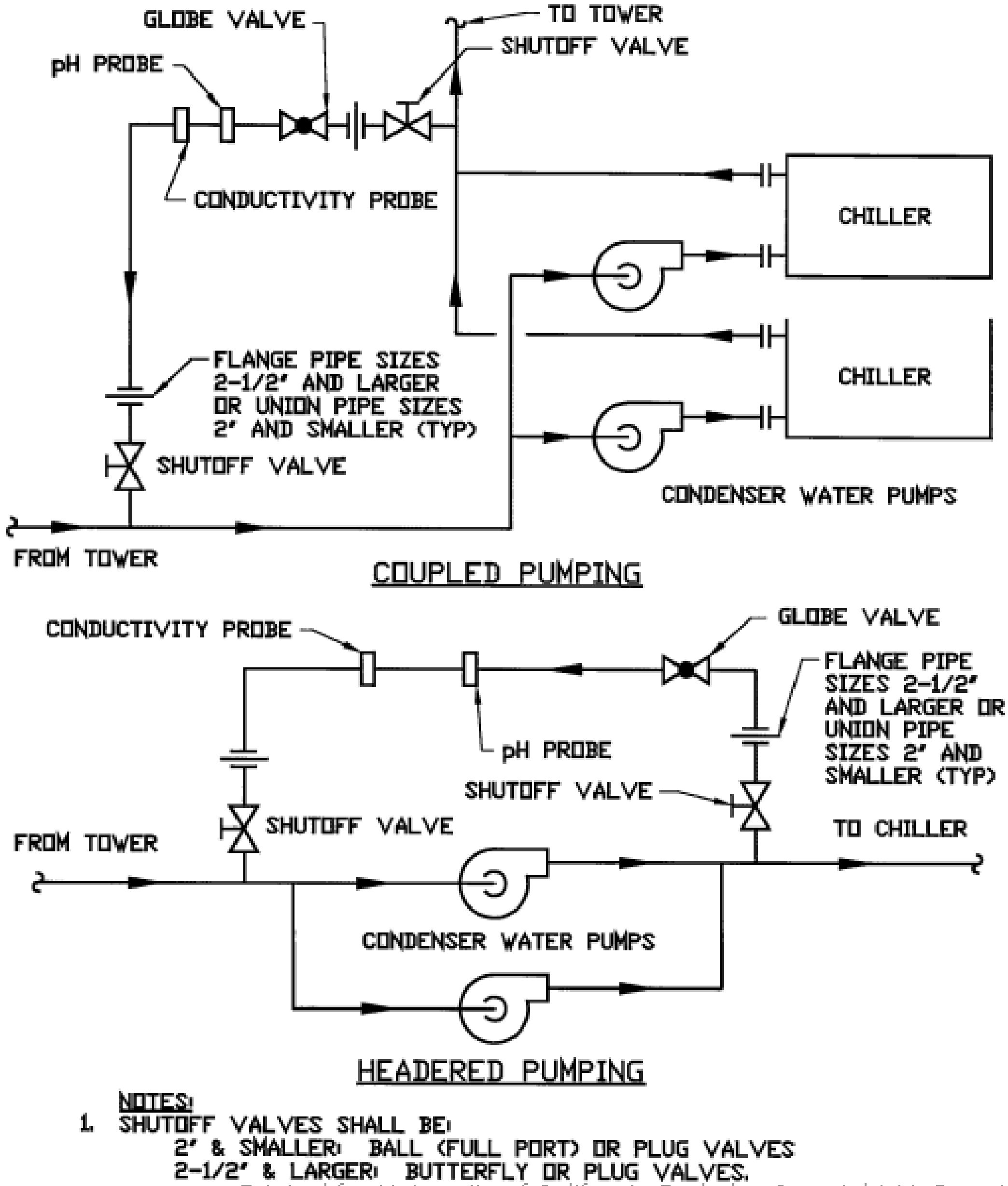


Figure 38.4. OPEN SYSTEM CHEMICAL FEED CONTROL ASSEMBLY.

38.04. Steam Systems

A. **The chemical treatment objective is to prevent and control the following:**

1. Scale formation.
2. Corrosion. Major concern.
3. System pH. Between 8 and 9.

B. **Chemical Types Used in Steam Systems:**

1. Scale inhibitors.
2. Corrosion inhibitors.

3. Dispersants.

C. **Steam Boiler System Water Treatment Equipment:**

1. Pre-treatment: Most effective way to control steam boiler chemical treatment issues:
   a. Softeners.

   b. Filters.

   c. Dealkalizers.

   d. RO units.

   e. See Figs. 38.5 and 38.6 for steam system chemical treatment. Figure 38.5 shows all the potential treatment equipment; however, many steam systems only require water softening.

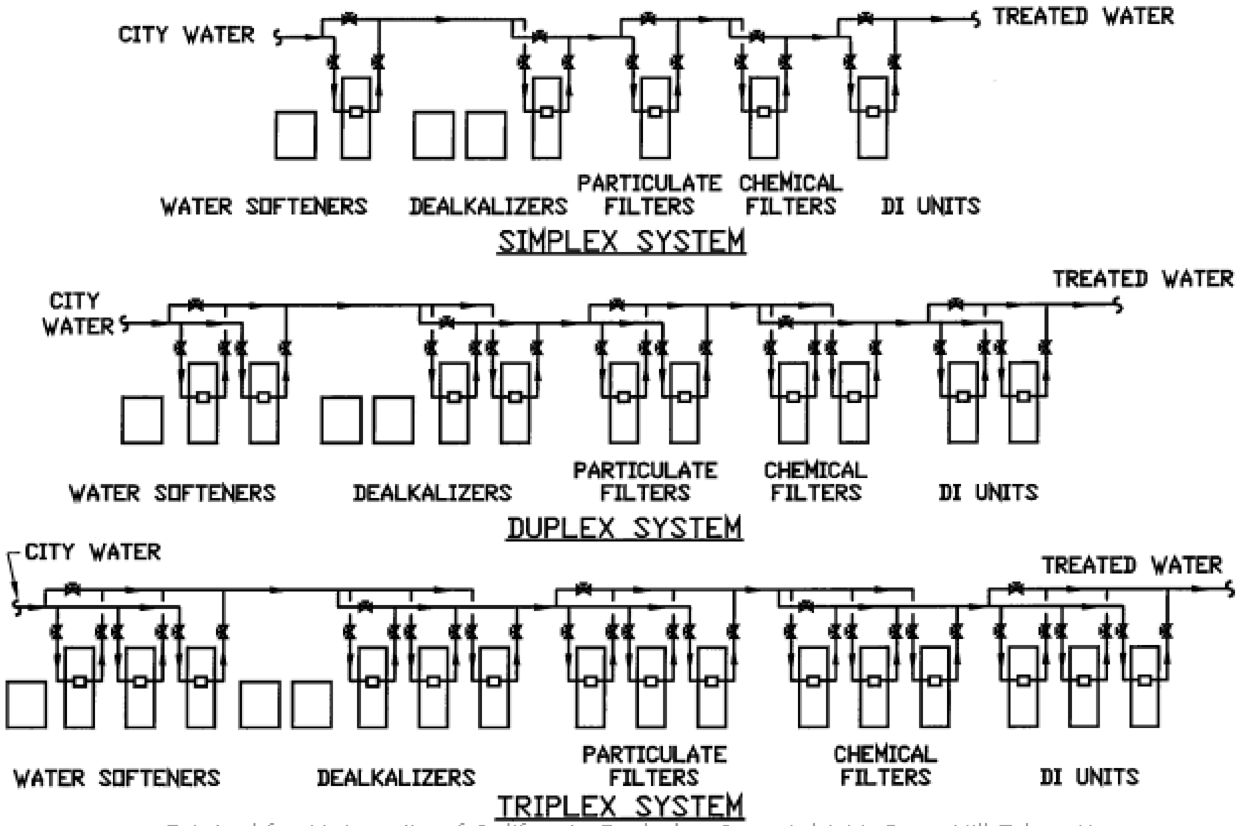


Figure 38.5. STEAM SYSTEM WATER TREATMENT.

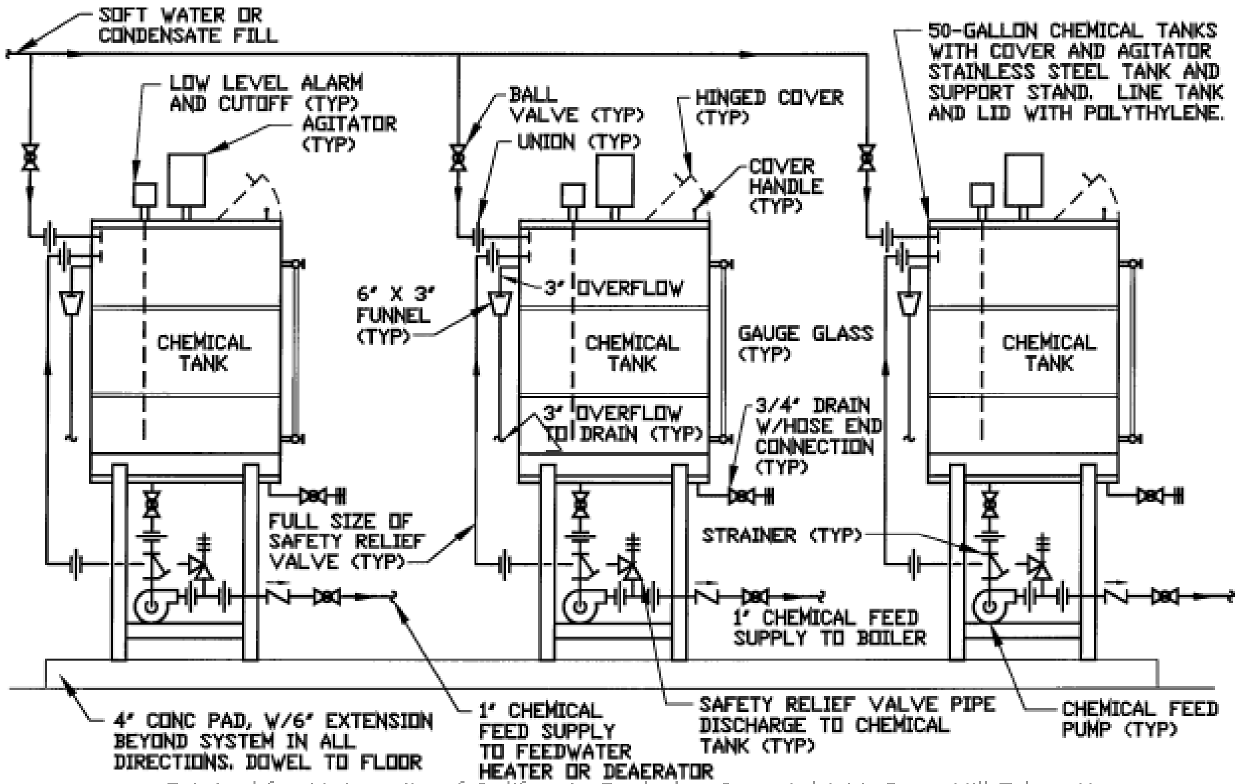


Figure 38.6. STEAM BOILER & FEEDWATER CHEMICAL TREATMENT SYSTEM.

2. Pre-boiler: Feedwater system treatment (deaerator, feedwater tank):
   a. An oxygen scavenger should be injected into the storage tank. Injection into the storage tank is the ideal location. It provides the maximum reaction time and protects the feedwater tank, pumps, and piping.

   b. An oxygen scavenger can be injected into the feedwater line, but is not recommended.

   c. Oxygen scavenger chemicals (see the following table):
      1. Sodium sulfite. Low- and medium-pressure systems.

      2. Hydrazine. Medium- and high-pressure systems.

Oxygen Scavenger	Feedwater Levels	Boiler Levels
Sodium Sulfite	10 to 15 ppm	30 to 60 ppm
Hydrazine	0.05 to 0.1 ppm	0.1 to 0.2 ppm

3. Boiler: Organic treatment program:
   a. Scale control chemicals should be injected directly into the boiler; however, they may be injected into the feedwater tank or feed water line as well.

b. Polymers. Most common.

c. Phosphonate.

4. After-boiler: Steam and Condensate Pipe Treatment:
   a. Amines:
      1. Neutralizing amines. Neutralize carbonic acid; may be injected into the boiler or steam header.

      2. Filming amines. Injected into the steam header.

   b. Injection location:
      1. Steam header. Best location.

      2. Boiler.

      3. Feedwater. Worst location; not recommended.

      4. These chemicals can be injected anywhere along the steam piping for better localized protection, especially in long piping runs.

D. **Chemical Feed Methods**
   1. Shot feed or batch process. Not recommended.

   2. Continuous:
      a. Manual control:
         1. Continuous.

         2. Clock timer.

         3. Percent timer.

      b. Automated control:
         1. Activated with feedwater pump.

         2. Activated with makeup water flow control.

         3. Activated with burner control.

E. **Makeup water analysis should be conducted at least twice a year, preferably quarterly.**

F. **System water analysis should be conducted at least once a week.**

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. Part 38: Water Treatment and Chemical Feed Systems, Chapter (McGraw-Hill Professional, 2016), AccessEngineering

Part 39: Automatic Controls Building Automation Systems

39. Part 39: Automatic Controls Building Automation Systems

39.01. Automatic Controls and Building Automation Systems

A. **Control Design Guidelines:**
1. Today's automatic control systems and building automation systems should be designed to meet the following:
   a. Open protocol design.
   b. Web-based system design.
   c. BACnet standards preferred.
   d. Security—passwords for different levels.
      1. View only.
      2. View and modify setpoints.
      3. View, modify setpoints, and program.
   e. BAS workstations.
      1. Computers:
         a. Web-based systems—any computer connected to the network can be a workstation. However, it is good practice to provide a work station for facilities use.
         b. Speed—the faster the better.

c. Provide laptop computers for facility maintenance staff to use on larger facilities or campus settings.

d. Items to specify:

    Processor.

    Memory.

    Storage.

    Media Drives.

    Communication.

    Modem.

    Monitor.

    Video.

    Backup.

    Ports.

    Accessories—keyboard, mouse, UPS.

    Operating system—industry standard, professional grade.

    Data base—industry standard, professional grade, enterprise class.

2. Report printers:
   a. LaserJet or Ink Jet

   b. Paper sizes:
      Letter—8.5" × 11".
      Legal—8.5" × 14".
      Tabloid—11" × 17" (for printing drawings).

3. Alarm printers:
   a. LaserJet or Ink Jet.

   b. Continuous paper feed is preferred; however, hard to find.

   c. Paper sizes:
      Letter—8.5" × 11".

f. Remote contact and alarm reporting:
   1. E-mail.
   2. Telephone.
   3. Smart phone.
   4. Other.

2. Two-way control valves should be installed upstream of equipment so that equipment is not subject to pump pressures.

3. *Proportional Band*. Throttling range over which the regulating device travels from fully closed to fully open.

4. *Drift or Offset*. Difference between the set point and the actual control point.

5. *Rangeability*. Ratio of maximum free area when fully open to the minimum free area.

6. Bypass valves should be plug valves, ball valves, or butterfly valves.

7. Control valves in HVAC systems should be the equal percentage type for output control, because equal percentage control valve flow characteristics are opposite of coil capacity characteristics.
   a. Do not oversize control valves; most control valves are at least one to two sizes smaller than the pipe size.
   b. The greater the resistance at design flow, the better the controllability.
   c. Control Valve Pressure Drop:
      1. Minimum control valve pressure drop: 5 percent of total system pressure drop.
      2. Preferred control valve pressure drop: 10 to 15 percent of total system pressure drop.
      3. Maximum control valve pressure drop: 25 percent of total system pressure drop.
   d. When specifying control valves include:
      1. Maximum design flow.
      2. Minimum design flow.

3. Internal pressure.

4. Pressure drop at design flow.

5. Pressure drop at minimum flow.

8. Two-way control valves:
   a. Two-way control valves should be selected for a resistance of 20 to 25 percent of the total system resistance at the valve location. This results in selecting the control valves for the available head at each location requiring a different pressure drop for each valve in direct return systems. In reverse return systems, control valves may be selected with equal pressure drop requirements. If control valves are selected for the pressure drop at each location, balancing valves are not required for external balancing of systems unless the pressure differential at the control valve location becomes excessive. Variable volume systems will be self-balancing.

9. Three-way control valves:
   a. Three-way control valves exhibit linear control characteristics that are not suited for output control at terminal units.

   b. If three-way control action is desired to maintain minimum flow requirements, use two opposed-acting, equal percentage, two-way valves. A balancing valve must be installed in the bypass adjusted to equal the coil pressure drop. Operate valves sequentially in lieu of simultaneously, because if both valves are operated simultaneously, significant flow variations may occur.

   c. The three-way valve pressure drop should be greater than the pressure drop (up to twice the pressure drop) of the coil it serves with a balancing valve in the bypass. The bypass valve pressure drop should be adjusted to equal to the coil pressure drop. A balancing valve or flow control device should be installed in the return downstream of the three-way valve.

10. Do not use on/off type control valves, except for small line sizes (1 inch and smaller).

11. Provide a fine mesh strainer ahead of each control valve to protect the control valve.

39.02. Control Definitions

The following control definitions were taken from the *Honeywell Control Manual* listed in Part 53:

A. *Algorithm*. A calculation method that produces a control output by operating on an error signal or a time series of error signals. Operational logic affected by a control system usually resident in controlled hardware or software.

B. *Amplifiers*. Amplifiers condition the control signal, including linearization, and raise it to a level adequate for transmission and use by controllers.

C. *Analog*. Continuously variable (e.g., mercury thermometer, clock, faucet controlling water from closed to open).

D. *Authority*. The effect of the secondary transmitter versus the effect of the primary transmitter.

E. *Automatic Control System*. A system that reacts to a change or imbalance in the variable it controls by adjusting other variables to restore the system to the desired balance.

F. *Binary*. A distinct variable; a noncontinuous variable (e.g., digital clock, digital thermometer, digital radio dial); also related to computer systems and the binary numbering system (base 2).

G. *Closed Loop Control System*. Sensor is directly affected by the action of the controlled device, system feedback.

H. *Contactors*. Similar to relays, but are made with much greater current carrying capacity. Used in devices with high power requirements.

I. *Controls*. As related to HVAC, three elements are necessary to govern the operation of HVAC systems:

1. *Sensor*. A device or component that measures the value of the variable (e.g., temperature, pressure, humidity).

2. *Controller*. A device that senses changes in the controlled variable, internally or remotely, and derives the proper corrective action and output to be taken (e.g., receiver/controller, DDC panel, thermostat).

3. *Controlled Device*. That portion of the HVAC system that affects the controlled variable (e.g., actuator, damper, valve).

J. C*ontrol Action*. Effect on a control device to create a response.

K. *Controlled Agent*. The medium in which the manipulated variable exists (e.g., steam, hot water, chilled water).

L. *Controlled Medium*. The medium in which the controlled variable exists (e.g., the air within the space).

M. *Controlled Variable*. The quantity or condition that is measured and controlled (e.g., temperature, flow, pressure, humidity, three states of matter).

N. *Control Point*. Actual value of the controlled variable (set point plus or minus set point).

O. *Corrective Action*. Control action that results in a change of the manipulated variable.

P. *Cycle*. One complete execution of a repeatable process.

Q. *Cycling*. A periodic change in the controlled variable from one value to another. Uncontrolled cycling is called "hunting."

R. *Cycling Rate*. The number of cycles completed per unit time, typically cycles per hour.

S. *Dampers*. Dampers are mechanical devices used to control airflow:

1. *Quick Opening*. Maximum flow is approached as the damper begins to open.

2. *Linear*. Opening and flow are related in direct proportion.

3. *Equal Percentage*. Each equal increment of opening increases flow by an equal percentage over the previous value.

4. *Opposed Blade*. Balancing, mixing, and modulating control applications. Half of the blades rotate in one direction, while the other half rotate in the other direction:
   a. At low pressure drops, opposed blade dampers tend to be equal percentage.

   b. At moderate pressure drops, opposed blade dampers tend to be linear.

c. At high pressure drops, opposed blade dampers tend to be quick opening.

5. *Parallel Blade*. Two-position control applications. All the blades rotate in a parallel, or in the same, direction:
   a. At low pressure drops, parallel blade dampers tend to be linear.

   b. At high pressure drops, parallel blade dampers tend to be quick opening.

T. *Deadband*. A range of the controlled variable in which no corrective action is taken by the controlled system and no energy is used.

U. *Discriminator*. A device that accepts a large number of inputs (up to 20) and selects the appropriate output signal (averaging relay, high relay, low relay).

V. *Deviation*. The difference between the set point and the value of the controlled variable at any moment. Also called *offset*.

W. *DDC*. Direct Digital Control.

X. *Differential*. The difference between the turn-on signal and the turn-off signal.

Y. *Digital*. Series of On and Off pulses arranged to carry messages (e.g., digital radio and TV dials, digital clock, computers).

Z. *Digital Control*. A control loop in which a microprocessor-based controller directly controls equipment based on sensor inputs and set point parameters. The programmed control sequence determines the output to the equipment.

AA. *Direct Acting*. Controller is direct acting when an increase in the level of the sensor signal results in an increase in the level of the controller output.

BB. *Droop*. A sustained deviation between the control point and the set point in a two-position control system caused by a change in the heating or cooling.

CC. *Dry Bulb Control*. Control of the HVAC system based on outside air dry bulb temperature (sensible heat).

DD. *Electric Control*. A control circuit that operates on line or low voltage and uses a mechanical means, such as temperature-sensitive bimetal or bellows, to perform control functions.

EE. *Electronic Control*. A control circuit that operates on low voltage and uses solid state components to amplify input signals and perform control functions.

FF. *Enthalpy Control*. Control of the HVAC system based on outside air enthalpy (total heat).

GG. *Fail Closed*. Position device will assume when system fails (e.g., fire dampers fail closed).

HH. *Fail Open*. Position device will assume when system fails (e.g., present coil valves fail open).

II. *Fail Last Position*. Position device will assume when system fails (e.g., process coding water valve fails in last position).

JJ. *Final Control Element*. A device such as a valve or damper that acts to change the value of the manipulated variable (e.g., controlled device).

KK. *Floating Action*. Dead spot or neutral zone in which the controller sends no signal but allows the device to float in a partly open position.

LL. *Gain*. Proportion of control signal to throttling range.

MM. *In Control*. Control point lies within the throttling range.

NN. *Interlocks*. Devices that connect HVAC equipment so operation is interrelated and systems function as a whole.

OO. *Lag*. A delay in the effect of a changed condition at one point in the system, or some other condition to which it is related. Also, the delay in response of the sensing element of a control due to the time required for the sensing element to sense a change in the sensed variable.

PP. *Lead/Lag*. A control method in which the selection of the primary and secondary piece of equipment is obtained and alternated to limit and equalize wear on the equipment.

QQ. *Manipulated Variable*. The quantity or condition regulated by the automatic control system to cause desired change in the controlled variable.

RR. *Measured Variable*. A variable that is measured and may be controlled.

SS. *Microprocessor-Based Control*. A control circuit that operates on low voltage and uses a microprocessor to perform logic and control functions. Electronic devices are primarily used as sensors. The controller often furnishes flexible DDC and energy management control routines.

TT. *Modulating Action*. The output of the controller can vary infinitely over the range of the controller.

UU. *Modulating Range*. Amount of change in the controlled variable required to run the actuator of the controlled device from one end of its stroke to the other.

VV. *Motor Starters*. Electromechanical device that utilizes the principle of electromagnetism to start and stop electric motors, often containing solenoid coil actuators, relays, and overload protective devices.

WW. *Normally Closed*. The device assumes the closed position when the control signal is removed (the device is in the closed position in the box prior to installation).

XX. *Normally Open*. The device assumes the open position when the control signal is removed (the device is in the open position in the box prior to installation).

YY. *Offset*. The difference between the control point and the set point.

ZZ. *On/Off Control*. A simple two-position control system in which the device being controlled is either full On or full Off with no intermediate operating positions available.

AAA. *Open Loop Control System*. The sensor is not directly affected by the action of the controlled device; no system feedback.

BBB. ***Out of Control*****. The control point lies outside of the throttling range.**

CCC. ***Pigtail*****. A loop put in a sensing device to prevent the element from experiencing temperature or pressure extremes.**

DDD. ***Pneumatic Control*****. A control circuit that operates on air pressure and uses a mechanical means, such as temperature-sensitive bimetal or bellows, to perform control functions.**

EEE. ***Proportional Control*****. A control algorithm or method in which the final control element moves to a position proportional to the deviation of the value of the controlled variable from the set point. Cyclical control (sine/cosine).**

FFF. ***Proportional-Integral (PI) Control*****. A control algorithm that combines the proportional (proportional response) and integral (reset response) control algorithms. Cyclical control, but automatically narrows the band between upper and lower points. Used most commonly in commercial building applications.**

GGG. ***Proportional-Integral-Derivative (PID) Control*****. A control algorithm that enhances the PI control algorithm by adding a component that is proportional to the rate of change (derivative) of the deviation of the controlled variable. Compensates for system dynamics and allows faster control response. Cyclical control, but automatically narrows the band between upper and lower points and also calculates the time between peak high and peak low and adjusts accordingly. Used most commonly in industrial applications.**

HHH. ***Relays*****. Electromagnetic devices for remote or automatic control actuated by variations in conditions of an electric circuit and operating, in turn, other devices (such as switches) in the same or different circuit. Carry low-level control voltages and currents.**

III. ***Reverse Acting*****. Controller is reverse acting when an increase in the level of the sensor signal results in a decrease in the level of the controller output.**

JJJ. ***Sensing Element*****. A device or component that measures the value of the variable.**

KKK. *Sensitivity*. Proportion of the control signal to throttling range.

LLL. *Set Point*. Desired value of the controlled variable (usually in the middle of the throttling range).

MMM. *Snubber*. A component installed with a sensing device that prevents sporadic fluctuations from reaching the sensing device. These sporadic fluctuations often make the sensing device inoperative.

NNN. *Step Control*. Control method in which a multiple-switch assembly sequentially switches equipment as the controller input varies through the proportional band.

OOO. *Time Delay Relays*. Relays that provide a delay between the time the coil is energized and the time the contactors open and/or close.

PPP. *Thermistor*. A solid state device in which resistance varies with temperature.

QQQ. *Throttling Action*. Amount of change in the controlled variable required to run the actuator of the controlled device from one end of its stroke to the other.

RRR. *Throttling Range*. Amount of change in the controlled variable required to run the actuator of the controlled device from one end of its stroke to the other. Also referred to as *proportional band*.

SSS. *Transducers*. Devices that change a pneumatic signal to an electric signal and vice versa. Pneumatic-Electric (PE) or Electric-Pneumatic (EP) switches (two-position transducer or analog to analog).

TTT. *Turndown Ratio*. The minimum flow or capacity of a piece of equipment expressed as a ratio of maximum flow/capacity to minimum flow/capacity. The higher the ratio, the better the control.

UUU. *Two-Position Control*. Control system in which the device being controlled is either full On or full Off with no intermediate operating positions available (On/Off; open/closed; also called *On/Off control*).

VVV. *Valves*. Valves are mechanical devices used to control the flow of steam, water, gas, and other fluids:

1. 2-Way: Temperature control, modulate flow to controlled device, variable flow system.

2. 3-Way mixing: Temperature control, modulate flow to controlled device, constant flow system; two inlets and one outlet.

3. 3-Way diverting: Used to divert flow; generally cannot modulate flow—two positions; one inlet and two outlets.

4. Quick opening control valves: Quick opening control valves produce wide free port area with relatively small percentage of total valve stem stroke. Maximum flow is approached as the valve begins to open.

5. Linear control valves: Linear control valves produce free port areas directly related to valve stem stroke. Opening and flow are related in direct proportion.

6. Equal percentage control valves: Equal percentage control valves produce an equal percentage increase in the free port area with each equal increment of valve stem stroke. Each equal increment of opening increases flow by an equal percentage over the previous value (most common HVAC control valve).

7. Control valves are normally smaller than line size unless used in two-position applications (open/closed).

8. Control valves should normally be sized to provide 20 to 60 percent of the total system pressure drop:
   a. Water system control valves should be selected with a pressure drop equal to two to three times the pressure drop of the controlled device.

      OR

      Water system control valves should be selected with a pressure drop equal to 10 ft. or the pressure drop of the controlled device, whichever is greater.

      OR

      Water system control valves for constant flow systems should be sized to provide 25 percent of the total system pressure drop.

OR

Water system control valves for variable flow systems should be sized to provide 10 percent of the total system pressure drop, or 50 percent of the total available system pressure.

b. Steam control valves should be selected with a pressure drop equal to 75 percent of the inlet steam pressure.

39.03. Types of Control Systems

A. **Pneumatic:**

1. Safe.
2. Reliable.
3. Proportional.
4. Inexpensive.
5. Fully modulating or two-position in nature.
6. Seasonal calibration required.
7. If there are more than a couple dozen control devices in a building, then pneumatic controls would be less expensive than electric or electronic controls.
8. Widely used in commercial, institutional, and industrial facilities.
9. Pneumatic control system pressure signals:
   a. Typical heating: 0–7 psi.
   b. Typical cooling: 8–15 psi.
   c. Max. system pressure: 30 psi.
10. Compressor runtime should be 1/3 to 1/2 the operating time.

B. **Electric:**

1. Simple control systems.
2. Used on small HVAC systems.
3. Mostly used for starting and stopping equipment.

4. Electric control system signals:
    a. 120 volts and less AC or DC.
    b. Typically 120 volts or 24 volts.

C. **Electronic:**

1. Used widely in prepackaged control systems.
2. Fully modulating in nature.
3. Reasonably inexpensive.
4. Electronic control system signals:
    a. 24 volts or less AC or DC.
    b. Typical voltage signal range of 0 to 10 volts.
    c. Typical amperage signal range of 4 to 20 milliamps.

D. **Direct Digital Control (DDC):**

1. Computerized control.
2. Fully modulating, start/stop and staged control.
3. Faster and more accurate than all other control systems.
4. Control systems can be adapted and changed to suit field conditions. Very flexible.
5. Able to communicate measured, control, input and output data over a network.
6. Fairly expensive.
7. Often DDC systems use DDC controllers and pneumatic actuators to operate valves, dampers, and other devices.
8. DDC system signals:
    a. Typical voltage signal range of 0 to 10 volts DC.
    b. Typical amperage signal range of 4 to 20 milliamps.
9. Most energy codes are forcing control system design to DDC.
10. Common names for DDC systems.

a. BAS—Building Automation System.

b. BMS—Building Management System.

c. EMS—Energy Management System.

d. FMS—Facility Management System.

39.04. Control System Objectives

A. **Define Control Functions:**

1. Start/Stop—All control systems should be provided with the following types of start/stop control.
   a. Manual—manual control at starter or variable frequency drive.

   b. Remote manual—manual control through the building automation system.

   c. Automatic control—automatic control through the building automation system.

2. Occupied/unoccupied/preparatory.

3. Fan capacity control:
   a. Variable Frequency Drives (VFDs)—energy codes are forcing the use of VFDs.

   b. Inlet Vanes.

   c. Two-speed motors.

   d. Discharge dampers—energy wasting; not typically permitted by energy codes.

   e. Scroll volume control.

   f. Supply air-, return air-, relief air-fan tracking.

4. Pump capacity control:
   a. Variable Frequency Drives (VFDs)—energy codes are forcing the use of VFDs.

   b. Two-speed motors.

   c. Variable flow pumping systems (two-way control valves).

5. Damper control (OA, RA, RFA, Inlet Vanes).
6. Valve control (two-way, three-way).
7. Temperature.
8. Humidity.
9. Pressure.
10. Flow.
11. Temperature Reset (SA, Water).
12. Terminal unit control (room, discharge, submaster).
13. Modulate, sequence, cycling.
14. Monitoring systems:
    a. HVAC systems.
    b. Plumbing systems.
    c. Medical gas, vacuum, and compressed air systems.
    d. Laboratory gas, vacuum, and compressed air systems.
    e. Fire protection systems.
    f. Electrical systems.
    g. Elevators.
    h. Other.
15. Alarms.
16. Energy/utility consumption—natural gas, fuel oil, electric, water.
17. Lighting—time of day schedule, daylighting.

B. **Define Interlock Functions:**

1. Fans/AHUs.
2. Pumps/boilers/chillers.
3. Smoke control system interlocks.

C. **Define Safety Functions:**

1. Fire.
2. Smoke.
3. Freeze protection.
4. Low/high pressure limit.
5. Low/high temperature limit.
6. Low/high water.
7. Low/high flow.
8. Over/under electrical current.
9. Vibration.

D. **Alarm Functions (most often safety alarms).**

E. **Typical Control Algorithms:**

1. Occupied/unoccupied/preparatory (time of day scheduling).
2. Night/weekend/holiday (time of day/week/year scheduling).
3. AHU dry-bulb economizer.
4. AHU enthalpy economizer.
5. Boiler/heat exchanger OA reset.
6. AHU discharge air control.
7. AHU discharge air control with room reset.
8. AHU VAV pressure independent.
9. AHU VAV pressure dependent.
10. Chiller discharge water reset.
11. Daylight savings time adjustments.
12. Electrical demand limiting.
13. Start/stop optimization.

14. Energy-performance optimization.

15. Duty cycle.

16. Enthalpy optimization.

17. Smoke control.

18. Trending.

19. Alarm instructions.

20. Maintenance work order.

21. Runtime totalizing.

F. **Types of Controls:**

1. *Operating Controls*. Operating controls are used to control a device, system, or entire facility in accordance with the needs of the device, system, or facility.

2. *Safety Controls*. Safety controls are used to protect the device, system, or facility from damage should some operating characteristic get out of control; to prevent catastrophic failure of the device or system; and to prevent harm to the occupants of the facility. Most safety controls come in the form of high or low limits:
   a. Automatic reset.

   b. Manual reset.

3. *Operator Interaction Controls*. Controls the building occupant would normally be provided with to activate various HVAC equipment devices or systems.

39.05. Building Automation and Control Networks (BACnet)

A. **BACnet is a communication protocol. A communication protocol is a set of rules governing the exchange of data between two computers. A protocol encompasses both hardware and software specifications, including the following:**

1. Physical medium.

2. Rules for controlling access to the medium.

3. Mechanics for addressing and routing messages.
4. Procedures for error recovery.
5. The specific formats for the data being exchanged.
6. The contents of the messages.

B. **The BACnet goal is to enable building automation and control devices from different manufacturers to communicate.**

C. **BACnet Data Structures:**

1. Analog input.
2. Analog output.
3. Analog value.
4. Binary input.
5. Binary output.
6. Binary value.
7. *Calendar*. Represents a list of dates that have special meaning when scheduling the operation of mechanical equipment.
8. Command.
9. *Device*. Contains general information about a particular piece of mechanical equipment (i.e., model, location).
10. *Device Table*. Shorthand reference to a list of devices.
11. *Directory*. Provides information on how to access other objects.
12. *Event Enrollment*. Provides a way to define alarms or other types of events.
13. File.
14. *Group*. Shorthand method to access a number of values in one request.
15. *Loop*. Represents a feedback control loop (PID).
16. Mailbox.
17. Multi-state input.

18. Multi-state output.
19. Program.
20. Schedule.

D. **BACnet Object Properties:**

1. Object identifier.
2. Object type.
3. Present value.
4. Description.
5. Status flags.
6. Reliability.
7. Override.
8. Out-of-service.
9. Polarity.
10. Inactive text.
11. Active text.
12. Change-of-state time.
13. Elapsed active time.
14. Change-of-state count.
15. Time of reset.

E. **BACnet Applications:**

1. Alarm and event services.
2. File access services (read, write).
3. Object access services (add, create, delete, read, remove, write).
4. Remove device management services.
5. Virtual terminal services (open, close, data).

F. **BACnet Conformance Classes:**

1. *Class 1*. Class 1 devices are the lowest level in BACnet system structure and consist of smart sensors.
2. *Class 2*. Class 2 devices consist of smart actuators.
3. *Class 3*. Class 3 devices consist of unitary controllers.
4. *Class 4*. Class 4 devices consist of general purpose local controllers.
5. *Class 5*. Class 5 devices consist of operator interface controllers.
6. *Class 6*. Class 6 devices are the highest level in the BACnet system structure and consist of head-end computers.

G. **BACnet Functional Groups:**

1. Clock.
2. Hand-held workstation.
3. Personal computer workstation.
4. Event initiation.
5. Event response.
6. Files.
7. Reinitialize.
8. Virtual operator interface.
9. Virtual terminal.
10. Router.
11. Device communications.
12. Time master.

39.06. Control Points List

A. **Inputs:**

1. Analog:
   a. Measured:

1. Temperature.
    a. Air
    b. Water
    c. Steam
2. Relative humidity.
3. Dewpoint.
4. Pressure.
    a. Air
    b. Water
    c. Steam
5. Differential pressure.
6. Airflow—CFM.
7. Water flow—GPM.
8. Steam flow—lbs./h.
9. Btu/hr.
10. Tons.
11. Gas flow—CFH.
12. Oil flow—GPH.
13. kW.
14. Current.
15. Voltage.
16. VFD speed.
17. CO_2 concentration.
18. CO sensor.
19. Refrigerant sensor.

20. Filter static.

21. Water or liquid level.

b. Calculated:

1. Relative humidity.

2. Dewpoint.

3. Specific humidity.

4. Wet bulb.

5. Enthalpy.

6. Steam consumption—lb.

7. Gas consumption—CF.

8. Oil consumption—gal.

9. Water consumption—gal.

10. Btu/h.

11. Tons.

12. kWh.

13. Runtime.

14. Efficiency.

15. Volume—gal.

2. Binary:

a. Run status—Flow Switch.

b. Run status—Differential Pressure Switch.

c. Run status—Current Switch.

d. Filter.

e. Smoke.

f. Freeze.

g. Airflow.

h. Water Flow.

i. Steam Flow.

j. Meter.

k. Interlocks.

l. Status.

m. Extinguishing agent flow.

B. **Outputs:**

1. Digital:

a. Off-on.

b. Off-auto-on.

c. Off-high-low.

d. Off-auto-on (VFD).

e. Damper open-closed.

f. Valve open-closed.

g. Heating stages.

2. Analog:

a. Damper position.

b. Damper control.

c. Valve position.

d. Valve control.

e. Setpoint adjustment.

f. Load reset.

g. Temperature reset.

h. Electric heat—SCR.

C. **System Features:**

1. Alarms:
    a. High analog.
    b. Low analog.
    c. High-high digital.
    d. High digital.
    e. Low digital.
    f. Low-low digital.
    g. Run status.
    h. Filter.
    i. Smoke.
    j. Freeze.
    k. Pressure.
    l. Fire.
    m. Vibration.
2. Programs:
    a. Time scheduling.
    b. Demand limiting.
    c. Duty cycle.
    d. Start/stop optimization.
    e. Energy/performance optimization.
    f. Enthalpy optimization.
    g. Smoke control.
    h. Trends.
    i. Alarm instruction.

j. Maintenance work order.

D. **General:**

1. Color graphics.
2. Summary report.
3. Alarm reports.
4. Trends reports.
5. X-Y graphic plots.
6. Statistical reports.
7. Historical reports.
8. Custom reports.
9. Expansion capacity: 10 to 25 percent spare capacity in controller, panels, and computer systems.
10. PC, monitor, keyboard.
11. Alarm printer.
12. Report printer.
13. Laptop computers.

39.07. DDC Control System Specification Outline

A. **Part 1—General**

1. Scope of work.
2. System description.
3. System performance.
   a. Graphic display.
   b. Graphic refresh.
   c. Object command.
   d. Object scan.

e. Alarm response time.

f. Program execution frequency.

g. Performance.

h. Multiple alarm annunciation.

i. Reporting accuracy.

j. Stability of control.

4. Codes and standards.

5. Products furnished and installed under this contract.
   a. Thermostats.

   b. Humidistats.

   c. Air distribution system temperature sensors.

   d. Air distribution system pressure and differential pressure sensors.

   e. Air distribution system flow switches.

   f. Refrigerant, CO_2, CO, and other gas detection systems.

   g. Current switches.

   h. All other devices not specifically mentioned in the following.

6. Products furnished but not installed under this contract.
   a. Piping temperature sensors, Wells, and Sockets.

   b. Piping pressure and differential Pressure Sensors.

   c. Piping flow switches.

   d. Control valves—may be furnished and installed under another division.

   e. Control dampers—may be furnished and installed under another division.

   f. Water flow meters—may be furnished and installed under another division.

   g. Airflow meters—may be furnished and installed under another division.

   h. Energy meters—may be furnished and installed under another division.

i. Terminal unit controls—may be furnished and installed under another division.

j. Air terminal unit controls—often furnished by the control contractor and manufacturer; installed under another division.

7. Products installed but not furnished under this contract.

8. Products not furnished or installed but integrated with under this contract.
   a. Chiller control package.
   b. Boiler control package.
   c. Cooling tower basin heater and water level control package.
   d. Packaged air handling system controllers.
   e. Variable frequency controllers.
   f. Motor controllers and disconnect switches.
   g. Fire, smoke, and fire/smoke dampers.
   h. Duct mounted smoke detectors.
   i. Control valves.
   j. Control dampers.
   k. Water flow meters.
   l. Airflow meters.
   m. Energy meters.
   n. Terminal unit controls.
   o. Air terminal unit controls.
   p. Electrical distribution systems—normal power, emergency power, and UPS systems.
   q. Emergency generator control package.
   r. Lighting control systems.

9. Quality assurance.
10. Submittals.
11. Warranty.
12. Ownership of proprietary material.

B. **Part 2—Products**
   1. Approved control system contractors/manufacturers.
   2. Materials.
   3. Communication.
      a. Network arrangement.
      b. Workstation communication.
      c. Controller communication.
      d. Secondary bus communication.
      e. System architecture.
      f. Communication performance.
      g. Communication protocols.
         1. Interoperability.
         2. Network communications.
   4. Integrating a proprietary system with an open protocol system.
   5. Operator interface.
      a. Number of work stations.
      b. System connection.
      c. System hardware.
         1. Fixed operator work stations:
            a. Computer terminal—computer, keyboard, monitor, mouse, modem, backup method.
            b. Report printer.
            c. Alarm printer.

2. Portable operator work stations—laptop computers.

d. System software:

1. Operating system.

2. System graphics.

3. System applications:

a. General.

b. Automatic and manual system database save and restore.

c. System configuration.

d. Online help.

e. Security.

f. System diagnostics.

4. Alarm processing.

5. Trend, alarm, and event logs.

6. Object and property status and control.

7. Clock synchronization.

8. Reports and logs.

9. Custom reports.

a. Tenant override reports.

b. Electrical, gas, water, utility, and weather reports.

c. ASHRAE Guideline 3 Report—large chillers.

10. Workstation application editors.

11. Controller.

12. Scheduling.

13. Custom application programming.

6. Controller software.

a. System security.

b. Scheduling.

c. Grouping.

d. Alarm processing.

e. Remote communications.

f. Standard application programs.

g. Demand limiting.

h. Maintenance management.

i. Sequencing.

j. PID control.

k. Staggered start.

l. Energy calculations.

m. Anti-short cycling.

n. On/off control with differential.

o. Runtime totalization.

7. Building controllers.
   a. General.

   b. Background.

   c. Internal software.

   d. Modularity.

   e. Operator software.

   f. Inputs and outputs.

   g. Power supplies, including UPS.

   h. Listings.

   i. Distribution of controllers—limits the number of systems on any one controller.

8. Custom application controllers.
    a. General.
    b. Internal software.
    c. Modularity.
    d. Operator software.
    e. Inputs and outputs.
    f. Power supplies, including UPS.
    g. Listings.
    h. Distribution of controllers—limits the number of systems on any one controller.
9. Application specific controllers.
    a. General.
    b. Background.
10. Input/output interface.
11. Power supplies and line filtering.
12. Auxiliary control devices.
    a. Motorized control dampers.
    b. Damper/valve actuators.
        1. Electric.
        2. Pneumatic.
    c. Control valves.
    d. Temperature devices.
    e. Humidity devices.
    f. Flow switches.
    g. Relays.
    h. Override timers.

i. Power monitoring.
   1. Current.
   2. Voltage.
   3. Power sensing.
j. Equipment status sensing.
k. Pressure devices.
l. Electro-pneumatic transducers.
m. Local control panels.

13. Wiring and raceways.
14. Fiber optic cable system.
15. Compressed air supply—pneumatic actuation.
    a. Air compressor.
    b. Air dryer.
    c. Air filters.
    d. Pressure reducing valves.
    e. Relief valves.
    f. Condensate drains.
    g. Pneumatic tubing.

C. **Part 3—Execution**

1. General installation.
2. Examination.
3. Protection.
4. Coordination.
5. General workmanship.
6. Field quality control.

7. Existing equipment.

8. Wiring.

9. Communication wiring.

10. Fiber optic cable.

11. Pneumatic systems installation.

12. Control air tubing installation.

13. Installation of sensors.

14. Flow switch installation.
    a. Airflow.

    b. Water flow.

15. Flow meter installation.

16. Control valve installation.

17. Control damper installation.

18. Valve and damper actuators.

19. Warning labels.

20. Identification of hardware and wiring.

21. Controllers—controller loading—spare capacity.

22. Programming.
    a. Project specific programming.
        1. Text-based programming.

        2. Graphic-based programming.

        3. Menu-driven programming.

    b. Point naming.

    c. Other programming and database setup.

23. Control system checkout and testing.

24. Control system demonstration and acceptance.
25. Commissioning.
26. Cleaning.
27. Training.
28. Sequences of operation—sequences of operation may be contained in a separate specification section.
29. I/O points lists—I/O points lists may be contained in a separate specification section or in a graphical matrix form.

Part 40: Sustainability Guidelines Relating to HVAC Systems

40. Part 40: Sustainability Guidelines Relating to HVAC Systems

40.01. Introduction

A. **Sustainability is a term used in the building industry to describe the focus on the design, construction, and operation of buildings in a manner that reduces their impact on the natural environment.**

B. **There are many aspects of sustainability in the building industry including site selection; water efficiency; use of recycled, renewable, and regional materials; energy efficiency; and indoor environmental quality. These aspects have been defined by the U.S. Green Building Council (USGBC) through its Leadership in Energy and Environmental Design (LEED) rating system.**

C. **The LEED rating system was started in 1993 to meet the need in the building industry for a system to define and measure "green buildings." Since that time, the LEED rating system has been expanded to cover all sectors of the building industry including new construction, existing buildings, commercial interiors, and others. The USGBC periodically updates the LEED rating system to refine its guidelines and incorporate emerging sustainability concepts.**

D. **Energy Star is an international standard for energy efficient consumer products that was created in 1992 by the U.S. Environmental Protection Agency. Products carrying the Energy Star service mark**

are generally 20 to 30 percent more energy efficient than what is required by federal standards. The program also includes labeling for residential HVAC equipment, such as air conditioning and heat pump units, furnaces, and boilers; lighting products; new homes; and commercial and industrial buildings.

40.02. Sustainable HVAC System Design

A. **This chapter presents sustainability guidelines relating to HVAC systems. These guidelines focus mainly on energy efficiency, commissioning, refrigerant management, and indoor environmental quality.**

B. **Energy Efficiency**

1. The minimum energy efficiency requirements for buildings and their associated energy systems are established by ANSI/ASHRAE/IESNA Standard 90.1-2013 *Energy Standard for Buildings Except Low-Rise Residential Buildings*. This standard prescribes the minimum energy efficiency requirements for all building envelope, electrical, and HVAC systems.

2. Increases in the energy efficiency of buildings can be achieved through improvements to the building envelope, reduction in lighting power densities, increases in motor efficiencies, and incorporation of energy-efficient HVAC systems.

3. Improvements in the energy efficiency of HVAC systems can be made in a number of ways, depending upon the system:
   a. Energy-efficient equipment.
      1. High-efficiency boilers and chillers.
         a. Select higher-efficient central heating and cooling equipment, such as boilers and chillers, in lieu of central HVAC equipment that meets the minimum energy efficiency requirements of ASHRAE Standard 90.1-2013. For example, condensing boilers which extract the latent heat of vaporization from hot flue gases are more energy-efficient than noncondensing boilers which must keep stack temperatures high in order to avoid condensation of moisture in the flue gases. Recent chiller technologies, such as variable speed compressors and magnetic bearings, have greatly increased the energy efficiency of this equipment.

2. High-efficiency air conditioning equipment.
   a. Select air conditioning and heat pump equipment that exceeds the minimum energy efficiency requirements of ASHRAE Standard 90.1-2013.

3. NEMA premium efficiency motors.
   a. For motors 1 horsepower and larger, specify NEMA premium efficiency motors as defined by NEMA Standards Publication MG 1-2014 Table 52 in lieu of motors classified as energy efficient by NEMA Standards Publication MG 1-2014 Table 51.

b. HVAC system configuration.
   1. Variable flow systems.
      a. Variable flow water and air systems are inherently more energy-efficient than constant flow water and air systems. Variable frequency drives for pumps and fans can reduce energy use considerably when there are fluctuations in the loads this equipment serves.

   2. Heat reclaim systems.
      a. Systems which reclaim heat that would otherwise be rejected to the outdoors improve the energy efficiency of HVAC systems. Heat is most often reclaimed from building exhaust airstreams and mechanical refrigeration equipment. Heat reclaimed from exhaust airstreams can be used to preheat/precool outdoor air, and heat reclaimed from mechanical refrigeration equipment is often used to preheat domestic hot water. Heat reclaim can also be used to provide dehumidification in some cases where humidity control is required by the space usage.

   3. Thermal storage systems.
      a. Thermal storage systems can reduce energy costs by operating central cooling systems during off-peak hours when energy is less expensive. (The downside to thermal storage systems is that the central cooling equipment actually uses more, albeit less expensive, energy than the same central cooling equipment in nonthermal storage systems.)

c. HVAC system control strategies.
   1. Water and air temperature reset.

a. Reset of water and air temperatures based on outdoor air temperature improves energy efficiency by more closely matching the HVAC systems' capacities to the building HVAC loads.

2. Demand-control ventilation.
   a. Adjusting the outdoor air ventilation delivered by the HVAC systems to meet the ventilation requirements of the building occupants (referred to as demand-control ventilation, or DCV) is an energy-efficient strategy that only delivers the outdoor air ventilation that is necessary for acceptable indoor air quality. DCV is usually applied to HVAC systems which serve densely occupied spaces (those with a design occupant density greater than or equal to 25 people per 1,000 sq.ft.), such as conference rooms and auditoriums. Space CO_2 sensors located within the breathing zone (between 3 in. and 72 in. above the floor) of these spaces are used to control the amount of outdoor air ventilation delivered by the HVAC system. A CO_2 concentration that is about 700 ppm above outdoor air levels will satisfy a substantial majority of visitors entering a space with respect to human bioeffluents (body odor) according to ASHRAE Standard 62.1-2013, Appendix C. CO_2 concentrations in acceptable outdoor air range from 300 to 500 ppm. Therefore, the CO_2 setpoint for the space CO_2 sensors for DCV systems should be between 1,000 and 1,200 ppm.

3. Night setback.
   a. Night setback control of the space temperature setpoint reduces energy use during unoccupied periods.

4. Economizers.
   a. Airside and waterside economizers reduce energy use by utilizing outdoor air for cooling instead of mechanical refrigeration when the outdoor air conditions are suitable for this use. Airside economizers compare the enthalpy or dry bulb temperature of the outdoor air and return air and increase the outdoor airflow beyond the minimum value when the outdoor air has a lower enthalpy or dry bulb temperature and cooling is required by the HVAC system. Dry bulb economizers are often disabled above an outdoor air temperature of approximately 60°F in order to prevent the possibility of increasing the indoor space relative humidity above an acceptable limit. Waterside economizers can only be incorporated into central chilled

water systems which utilizes water-cooled chillers. When the outdoor air wet bulb temperature is low enough for the cooling tower(s) to cool the returning chilled water, the returning chilled water is diverted to a plate and frame heat exchanger where it is cooled by the cooling tower water. Thus, the outdoor air is used to cool (or precool) the chilled water loop through the cooling tower(s) instead of (or in addition to) using mechanical refrigeration to cool the chilled water loop through the chiller(s).

d. Architectural components.

1. Close coordination with the architectural design can improve energy efficiency by increasing the insulating quality of walls (above and below grade), roofs, partitions, and the edges of slabs on grade or below grade. Other areas of consideration include building orientation, window-to-wall ratio, glazing properties, and both internal and external shading of windows.

C. **Commissioning**

1. The commissioning process is defined by ASHRAE Guideline 0-2013 *The Commissioning Process* as "a quality-oriented process for achieving, verifying, and documenting that the performance of facilities, systems, and assemblies meets the defined objectives and criteria."

2. Commissioning of HVAC systems ensures that the energy-efficient features of the project that are desired by the owner and intended by the design are actually implemented by the completed facilities, systems, and assemblies.

3. Commissioning begins in the predesign phase with stated goals called the Owner's Project Requirements (OPRs), continues during the design phase by meeting the OPRs with the Basis of Design (BOD) and the construction documents, moves into the construction phase with submittal review, installation checklists, issues log, startup checklists, prefunctional checklists, functional testing, and training in the operation and maintenance of the commissioned systems. Commissioning should continue at least through the warranty period with ongoing monitoring of the commissioned systems. Ideally, commissioning should continue throughout the life of the building.

4. When implemented properly throughout the course of design, construction, and operation, commissioning plays a key role in ensuring that the intended sustainability initiatives are fully implemented.

5. The commissioning process is defined in detail by ASHRAE Guideline 0-2013 *The Commissioning Process* and ASHRAE Guideline 1.1-2007 *HVAC&R Technical Requirements for the Commissioning Process*.

D. **Refrigerant Management**

1. From a sustainability standpoint, the two characteristics of a refrigerant that are of the greatest concern are the refrigerant's ozone-depletion potential (ODP) and its global warming potential (GWP). The types of refrigerants most commonly used in HVAC equipment are hydrochlorofluorocarbon (HCFC)-based refrigerants and hydrofluorocarbon (HFC)-based refrigerants. Chlorofluorocarbon (CFC)-based refrigerants, such as R-11 and R-12, are no longer produced because of their ODP.

2. The LEED rating system requires zero use of chlorofluorocarbon (CFC)-based refrigerants, such as R-11 and R-12, in new base building heating, ventilating, air conditioning, and refrigeration (HVAC&R) systems.

3. The LEED rating system discourages the use of hydrochlorofluorocarbon (HCFC)-based refrigerants, such as R-22 and R-123, because of their ODP. Although these refrigerants have a lesser ODP than CFC-based refrigerants, they are scheduled to cease production in the year 2030 due to their ODP.

4. Hydrofluorocarbon (HFC)-based refrigerants, such as R-134a and R-410A, do not have any ODP and are therefore not scheduled to cease production. However, both HCFC- and HFC-based refrigerants have GWPs that need to be considered in sustainable HVAC system design. The LEED rating system is concerned with the lifecycle direct global warming potential (LCGWP) of refrigerants used in HVAC&R systems. The LCGWP of a piece of HVAC&R equipment is a function of the refrigerant's GWP, the equipment's life and refrigerant leakage rate, the end-of-life refrigerant loss, and the equipment's refrigerant charge.

5. Small HVAC units (defined as containing less than 0.5 pounds of refrigerant) are not considered part of the base building system and are not subject to the requirements of the LEED rating system.

E. **Indoor Environmental Quality**

1. Many factors contribute to the quality of the indoor environment. From an HVAC standpoint, indoor air quality, thermal comfort, and acoustic quality need to be considered. Other factors, such as interior lighting, daylight, and

quality views of the outdoors also contribute to the quality of the indoor environment but are not HVAC-related.

2. Indoor air quality.
    a. Some indoor air contaminants which must be controlled in order to ensure acceptable indoor air quality are airborne particulates, formaldehyde and volatile organic compounds (VOCs) from building materials, and ozone which is generated by copying and printing equipment. Airborne particulates are suspended in the air and can be removed through air filtration. Formaldehyde, VOCs, and ozone, on the other hand, cannot be removed through air filtration, but must be controlled through dilution ventilation and exhaust at their source.
        1. Air filtration.
            a. The minimum level of air filtration efficiency recommended for commercial HVAC systems is a minimum efficiency reporting value (MERV) of 8, as determined by ASHRAE Standard 55.2-2012 *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size*.

            b. For superior air filtration, MERV 13 air filters may be used, but at the expense of higher installed and maintenance costs and increased energy use of the air handling equipment.

            c. All inlets for air handling equipment used during construction should be protected with air filters having a minimum efficiency of MERV 8 to keep the air handling equipment and ductwork free from airborne particulates generated by the construction activities.

            d. Ductwork should also be kept clean during construction in accordance with the recommended control measures of the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) *IAQ Guidelines for Occupied Buildings under Construction*, 2nd edition, 2007, ANSI/SMACNA 008-2008, Chap. 3. These measures include covering all openings of air handling equipment and ductwork with plastic until the systems are operational.

        2. Dilution ventilation.
            a. The concentration of indoor air contaminants can be reduced to acceptable levels for human occupancy by introducing outdoor air to the building through the air handling equipment. The Ventilation Rate Procedure in Section 6.2 of ASHRAE Standard 62.1-2013 *Ventilation*

for Acceptable Indoor Air Quality describes the procedure for determining the minimum rates of outdoor ventilation for various types of occupancy.

3. Source control of contaminants through exhaust.
   a. Where indoor air contaminants are generated within a building, these contaminants should be captured at their source and exhausted to the outdoors. Areas such as toilet rooms, copying and printing rooms, janitor's closets, garages, and storage closets where hazardous chemicals are stored should be exhausted at the rate required by the applicable mechanical code (minimum of 0.50 cfm per sq.ft.). These rooms should also be kept at under negative air pressurization with respect to adjacent spaces when the doors are closed.

4. Testing airborne pollutant levels.
   a. The best way to demonstrate that indoor pollutants have been reduced to acceptable levels after construction has been completed is to test for pollutants in accordance with the California Department of Public Health (CDPH) Standard Method v1.1. Air testing includes measurements of the concentrations of formaldehyde; particulate matter (PM) up to 10 microns in diameter (PM10); PM up to 2.5 microns in diameter (PM2.5); ozone; total VOCs, target chemicals listed in CDPH Standard Method v1.1, Table 4-1, except formaldehyde; and carbon monoxide (CO).

5. Building flush-out.
   a. Another acceptable means of reducing indoor pollutants after construction has been completed is to flush the building (or project area) with a minimum of 14,000 cu.ft. of outdoor air per sq.ft. of gross floor area. This amounts to operating a typical HVAC system at 100 percent outdoor air for approximately 2 weeks. For optimum results, the space temperature should be maintained at a minimum of 60°F and a maximum of 80°F. Space relative humidity during the flush-out process should be no higher than 60 percent.

6. Thermal comfort.
   a. Comfort conditions for humans are subject to six primary variables: surface temperature, air temperature, relative humidity, air movement, metabolic rate, and clothing. Comfort conditions are also a matter of personal preference and a certain percentage of

dissatisfied building occupants can be expected for any indoor environmental condition. Minimizing this percentage of building occupants is the goal of sustainable HVAC design as it relates to thermal comfort. Providing occupants with the ability to control air temperature, relative humidity, air speed, and radiant temperature for their individual spaces or shared group spaces can reduce the percentage of dissatisfied building occupants. Since it is not possible to achieve an indoor environmental condition that is acceptable for all building occupants, *ASHRAE Standard 55-2013 Thermal Comfort Conditions for Human Occupancy* has defined an acceptable indoor environment as one in which 80 percent of occupants are satisfied. Achieving acceptable thermal comfort conditions in buildings is a part of sustainable HVAC system design because workers' satisfaction and productivity increase with improved thermal comfort in buildings.

7. Acoustic performance.
   a. Background noise of HVAC systems is the only acoustic performance consideration of the LEED rating system that is related to building HVAC systems.

   b. Building HVAC systems are to be designed to meet the background noise levels specified in 2011 *ASHRAE Handbook—HVAC Applications*, Chapter 48, Table 1; *AHRI Standard 885-2008*, Table 15; or a local equivalent. Noise levels are to be calculated or measured.

Part 41: New Technologies for HVAC Systems

41. Part 41: New Technologies for HVAC Systems

41.01. Variable Refrigerant Flow Systems

A. **Introduction**

1. Variable refrigerant flow (or VRF) systems utilize refrigerant as the working fluid to provide heating and cooling in the same way that conventional refrigeration systems do, with the exception that the refrigerant flow within the system can be modulated through a variable speed drive on the compressor motor. This modulation of refrigerant flow enables VRF systems to closely match the refrigeration system capacity to the heating or cooling load on the system. Variable speed condenser fan motors also improve the load matching capabilities of these systems. VRF systems also utilize circuiting manifolds which enable multiple indoor fan-coil units to be connected to a single outdoor unit. For some manufacturers, one outdoor unit can serve up to 50 indoor fan-coil units.

B. **VRF Heat Pump and Energy Recovery Systems**

1. VRF heat pump systems.
   a. VRF heat pump systems can provide either heating or cooling to all of the indoor fan-coil units served by a single outdoor unit.

2. VRF energy recovery systems.
   a. VRF energy recovery systems can simultaneously provide heating to some indoor fan-coil units and cooling to other indoor fan-coil units, all of which are served by the same outdoor unit. This exchange of energy from spaces requiring heating to spaces requiring cooling, and vice versa, reduces the use of purchased energy for the system.

C. **Equipment Configurations**

1. Indoor fan-coil units.

   a. Indoor fan-coil unit configurations include: ceiling-recessed cassettes, wall-mounted, ceiling-suspended, ceiling-concealed ducted, and vertical ducted units. Figures 41.1 through 41.6 illustrate these fan-coil unit configurations.

Figure 41.1. CEILING-RECESSED CASSETTE, FOUR-WAY BLOW. ((c) 2015 Mitsubishi Electric US. All Rights Reserved.)

Figure 41.2. CEILING-RECESSED CASSETTE, ONE-WAY BLOW. ((c) 2015 Mitsubishi Electric US. All Rights Reserved.)

Figure 41.3. WALL-MOUNTED FAN-COIL UNIT. ((c) 2015 Mitsubishi Electric US. All Rights Reserved.)

Figure 41.4. CEILING-SUSPENDED FAN-COIL UNIT. ((c) 2015 Mitsubishi Electric US. All Rights Reserved.)

Figure 41.5. CEILING-CONCEALED DUCTED FAN-COIL UNIT. ((c) 2015 Mitsubishi Electric US. All Rights Reserved.)

Figure 41.6. VERTICAL DUCTED FAN-COIL UNIT. ((c) 2015 Mitsubishi Electric US. All Rights Reserved.)

2. Outdoor units.
    a. The capacity of a single outdoor module is limited to about 25 tons; however, two or three modules can be combined through the use of a twinning kit in order to increase the capacity of the outdoor unit. Figure 41.7 illustrates a typical outdoor unit.

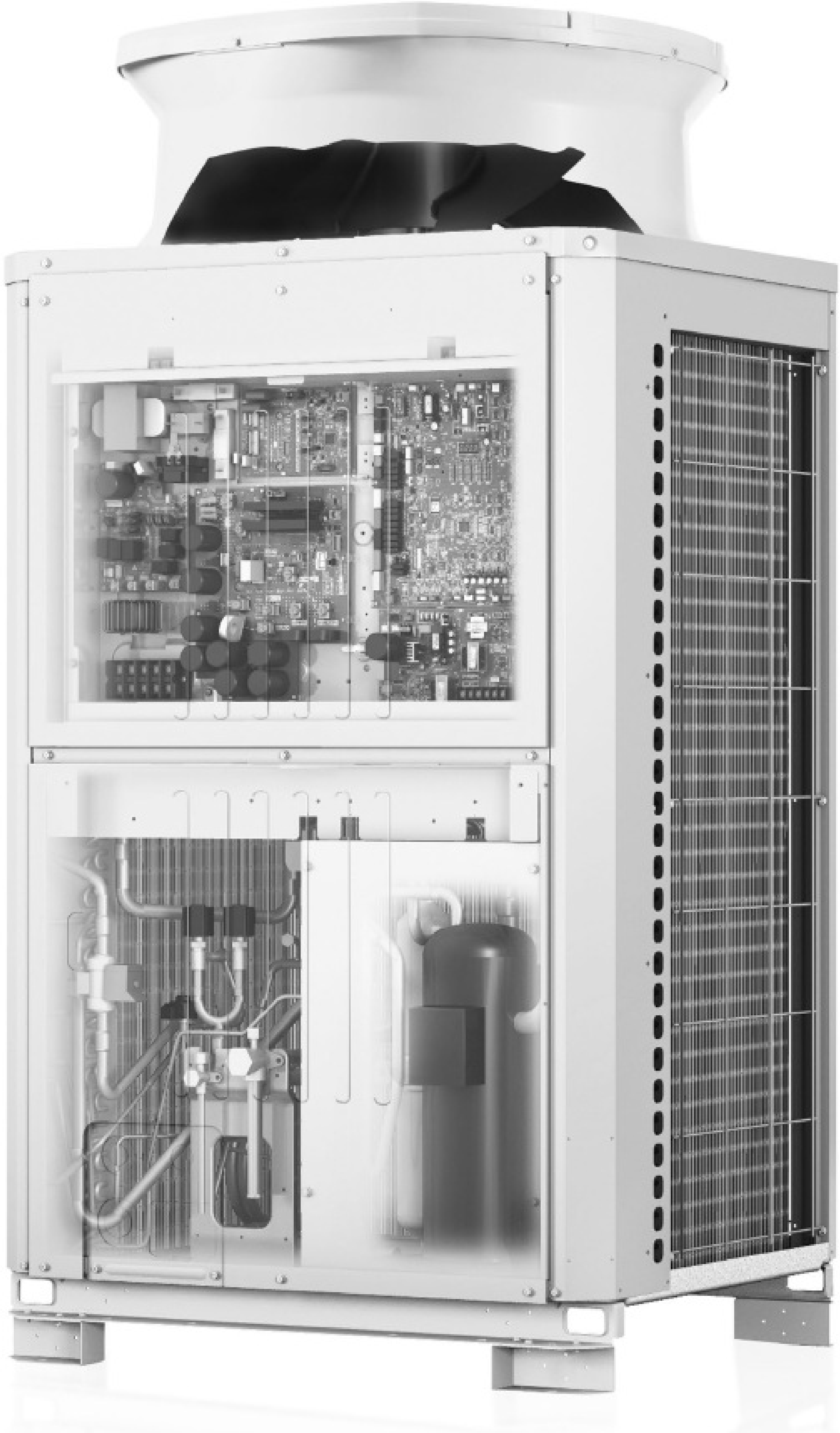


Figure 41.7. TYPICAL VRF OUTDOOR UNIT. ((c) 2015 Mitsubishi Electric US. All Rights Reserved.)

3. Refrigerant piping.

a. Some manufacturers utilize three pipes between the refrigerant piping manifold and the outdoor unit, while other manufacturers utilize two pipes. Figure 41.8 illustrates the two-pipe and three-pipe configurations.

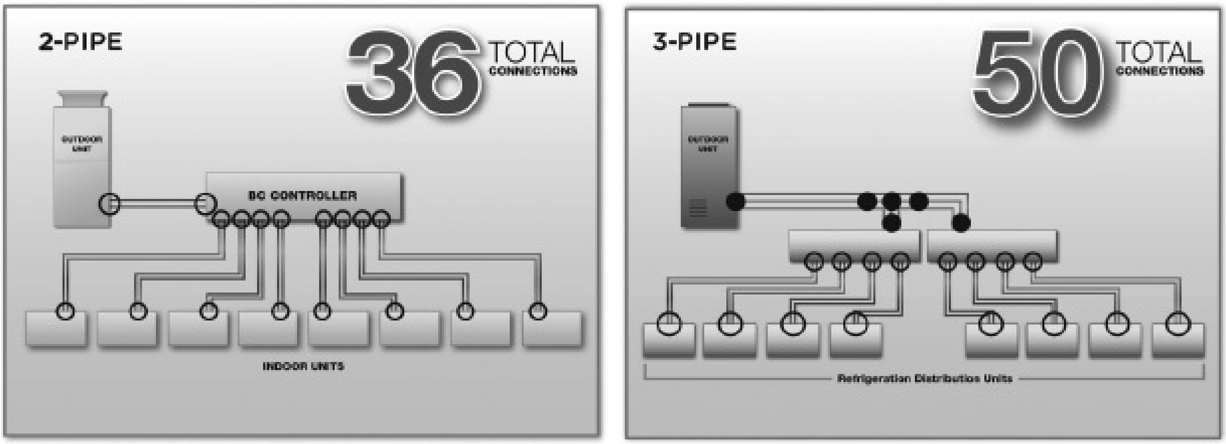


Figure 41.8. TWO-PIPE AND THREE-PIPE CONFIGURATIONS. ((c) 2015 Mitsubishi Electric US. All Rights Reserved.)

4. Air-source and water-source heat rejection/absorption
   a. Heat rejection/absorption can be accomplished through air-source equipment located outdoors, or through water-source equipment located indoors that receives cooling/heating water from an external heat rejection/absorption system. Figure 41.9 illustrates a water-source heat exchanger.

Figure 41.9. WATER-SOURCE HEAT EXCHANGER. ((c) 2015 Mitsubishi Electric US. All Rights Reserved.)

b. Manufacturers have improved the heating capabilities of the outdoor air-source heat pump units so that approximately 85 percent of the heating capacity at 47°F is available at –13°F. High heating capacity heat pump units are also available which provide 100 percent of the heating capacity at –4°F.

5. Air conditioning condensate.

a. Condensate that is formed on the cooling coil of the indoor fan-coil units and in the circuiting manifolds must be drained to the outdoors or to the building storm water system. Indoor fan-coil units are equipped with condensate pumps which are capable of between 20 and 33 inches of lift.

6. Controls.
    a. Wireless or hardwired room temperature sensors are available to control the indoor fan-coil units. (One temperature sensor is required for each fan-coil unit.) These controls can be networked to a central, stand-alone, proprietary, web-interface control system. The VRF control system can also be connected to a building automation system through a LonWorks or BACnet gateway.

7. System efficiency.
    a. VRF energy recovery systems are capable of obtaining an integrated energy efficiency ratio (IEER) rating as high as 22.1 (based on AHRI 1230 test method). Actual system efficiency will depend upon the level of energy recovery that can be achieved. Care must be taken during the design of VRF energy recovery systems to ensure that simultaneous heating and cooling is required by the zones served by the VRF system in order to maximize the system efficiency.

41.02. Variable Frequency Drives for Chillers

A. **Variable frequency drives (VFDs), also called variable speed drives (VSDs), adjustable frequency drives (AFDs), or adjustable speed drives (ASDs) have been used for many years in the HVAC industry to control the speed of fans and pumps because of the energy savings that can be achieved during part-load operation.**

B. **VFDs are now being used by HVAC equipment manufacturers to control the speed of compressors in both water- and air-cooled chillers to achieve part-load energy savings as well.**

C. **VFDs can be used on scroll, helical rotary (or screw), and centrifugal compressors.**

D. **Application**
    1. For both scroll and screw compressors, refrigeration capacity is proportional to compressor speed. Therefore, VFDs can be the sole means of capacity control for these types of compressors. Other means of capacity control are

available for scroll and screw compressor, such as compressor cycling, digital on/off, and hot gas bypass. Slide valve control is available for capacity control of screw compressors. However, VFDs provide the greatest energy savings at part-load operation for both scroll and screw compressors.

2. For centrifugal compressors, refrigeration capacity can be varied not only by compressor speed, but also by guide vanes on the inlet of the impeller. The inlet guide vanes control the flow rate of refrigerant through the compressor, while the compressor speed determines the differential pressure across the compressor. Since both refrigerant flow and differential pressure affect a chiller's capacity, VFDs are commonly used in conjunction with inlet guide vanes on centrifugal compressors. Compressor cycling and hot gas bypass can also be used for capacity control of centrifugal compressors, but the use of VFDs coupled with inlet guide vanes provides the greatest energy savings at part-load operation.

3. Because only refrigerant lift (temperature difference between the condenser and evaporator conditions) is affected by the speed of a centrifugal compressor, variable-speed centrifugal chillers should be used in conjunction with a reduction in the temperature of entering condenser water in water-cooled chillers in order to maximize the energy-efficiency associated with their capacity control capabilities.

4. Using a fixed entering condenser water temperature, such as 85°F, can negate the savings that can be achieved by using VFDs on the compressors for water-cooled chillers.

5. For multiple-chiller plants, it is common to utilize one (or more) constant-speed chiller(s) and one variable-speed chiller. In this design, the constant-speed chiller(s) are staged while the capacity of the variable-speed chiller is controlled to meet the cooling load.

E. **Other Considerations**

1. It is important to note that the full-load efficiency of a variable-speed chiller is actually lower than the full-load efficiency of the same constant-speed chiller because the VFD introduces an additional electric efficiency loss. Care must be taken during the chiller plant design to ensure that the variable-speed chiller operates predominantly at part-load in order to maximize its energy efficiency.

2. The full-load energy efficiency rating of a chiller (either energy efficiency ratio [EER] or coefficient of performance [COP]) should not be the sole criterion for comparing the energy-efficiency of variable-speed and constant-speed chillers. Integrated part load value (IPLV) or nonstandard part load value (NPLV) should be used instead because these performance characteristics also take into consideration the energy-efficiency of the chillers at part-load operation. IPLV and NPLV will provide a better relative measure of a chiller's annual energy use. For example, a chiller with an IPLV of 20 Btuh/W will use approximately 5 percent less energy on an annual basis than a chiller with an IPLV of 19 Btuh/W.

3. Chillers utilizing VFDs on the compressors are able to achieve lower sound levels at part-load conditions than constant-speed chillers.

4. VFDs are capable of handling voltage dips, surges, and other imbalances in the electrical distribution system.

5. As with all VFDs, harmonic distortion must be addressed by the VFD manufacturer to meet the IEEE 519 requirement for less than 5 percent total demand distortion.

41.03. Magnetic Bearings for Centrifugal Compressors

A. **Description**

1. Magnetic bearings levitate the centrifugal compressor shaft in a magnetic electric field instead of utilizing oil-lubricated bearings.

2. When coupled with a direct drive motor, the use of magnetic bearings results in a totally oil-free compressor.

3. Sensors are required at each magnetic bearing to provide real-time feedback to the bearing control system.

4. In the event of a power failure, the compressor motor acts as a generator and provides power to the bearing control system during coast down.

5. A system is required to gently de-levitate the compressor shaft.

6. Figures 41.10 through 41.12 illustrate the magnetic bearing technology.

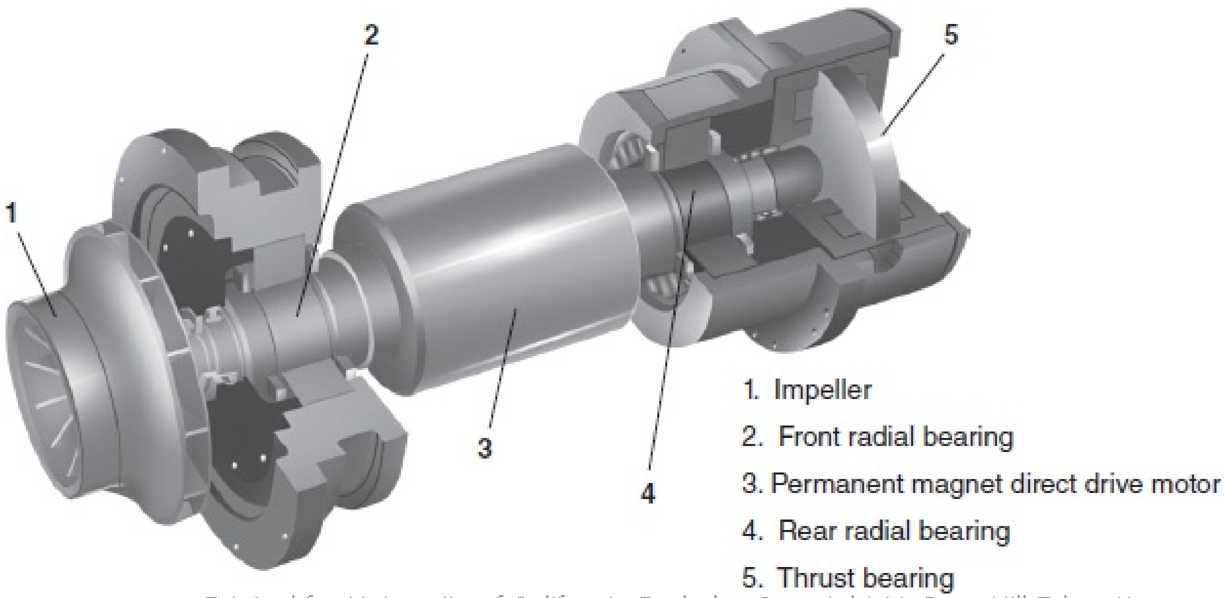


Figure 41.10. CUT-AWAY VIEW OF COMPRESSOR SHAFT. (Daikin Applied Americas Inc.)

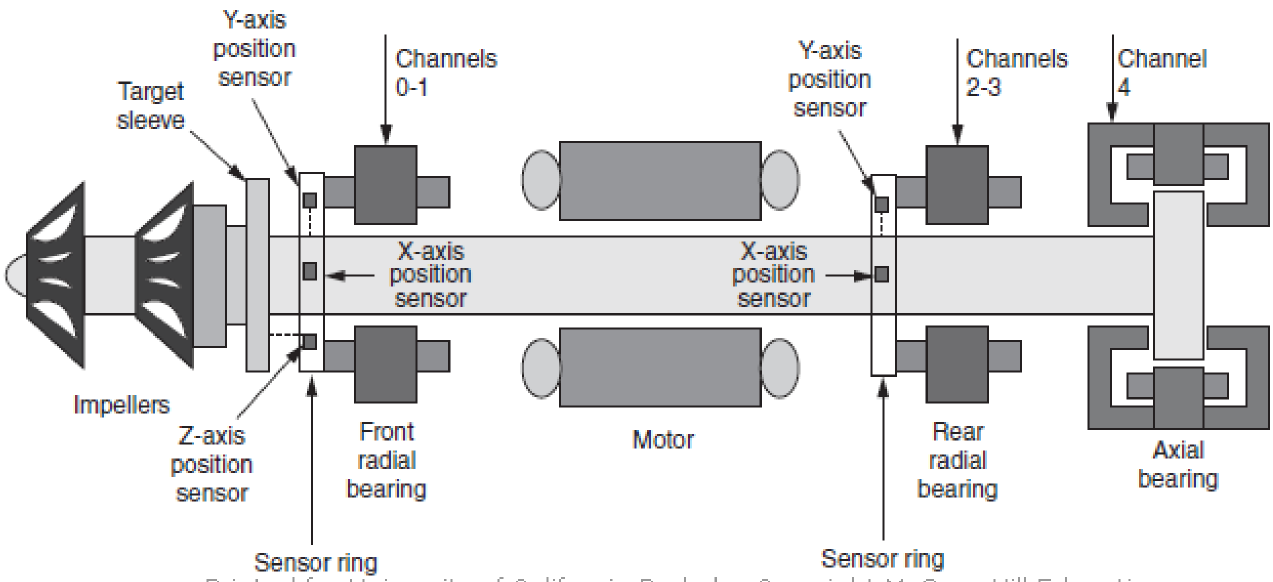


Figure 41.11. SCHEMATIC DIAGRAM OF COMPRESSOR SHAFT. (Daikin Applied Americas Inc.)

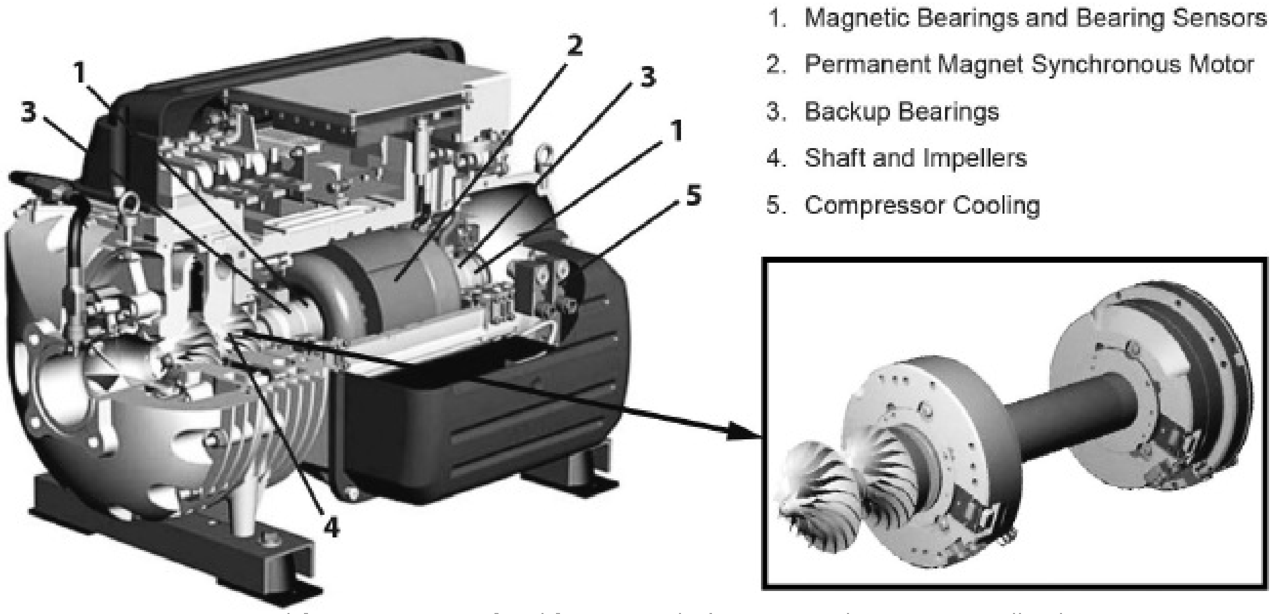


Figure 41.12. CUT-AWAY VIEW OF COMPRESSOR. (Daikin Applied Americas Inc.)

B. **Benefits**

1. Reduced frictional losses within the bearing system.
2. Improved reliability and reduced maintenance cost due to oil-free operation.
    a. No need for oil-handling equipment, such as oil pumps, oil reservoirs, oil coolers, oil filters, water regulating valves, oil relief valves, oil system controls, starter, piping, heaters, etc.
    b. No possibility of oil loss at light loads.
    c. No need for oil system maintenance such as oil sampling, oil and filter changes, and oil leak repairs.
    d. No need for oil storage and disposal.
3. Consistent efficiency over the life of the equipment since there is no oil to coat heat transfer surfaces.
4. Lower compressor vibration that could be transmitted to the structure.
5. Lower compressor sound level compared to traditional centrifugal chillers.

41.04. Electronically-Commutated Motors (ECMs) for Fans and Pumps

A. **Description**

1. Electronically-commutated, or brushless DC permanent-magnet, motors use the same principle as AC motors—interaction of rotating magnetic fields in the rotor (rotating member in the motor) and stator (stationary members in the motor).

2. Electronically-commutated motors (ECMs) are more energy efficient than the traditional shaded pole and permanent-split capacitor (PSC) AC motors commonly used in the fractional horsepower (less than 1 hp) size range. Fractional horsepower ECMs are approximately 70 percent efficient; whereas, fractional horsepower PSC motors are approximately 50 percent efficient.

3. ECMs are not only more efficient at full-load, the efficiency difference is even greater at part-load. This gives ECMs a decided advantage over traditional AC motors in variable speed applications.

4. In addition to greater energy efficiency, ECMs have the advantages of quieter operation, greater output power, higher operating speeds, and longer service life.

5. The disadvantages of ECMs are that they have a higher first cost than traditional AC motors and also create disruptive harmonic currents in the electrical power distribution system which can overheat conductors and connectors and can also interfere with the operation of sensitive electronic equipment.

B. **Applications**

1. ECMs are now a commonly available option for fan-powered VAV terminal units and small fan-coil units (up to about 800 CFM). Thermostats which enable variable speed operation of the fan motors take advantage of the higher efficiencies of ECMs at part load than traditional AC motors.

2. ECMs are also available for fractional horsepower pumps for heating, cooling, and domestic hot water applications. One pump manufacturer incorporates a variable speed drive into the pump motor to provide constant speed, constant differential pressure, or proportional differential pressure operation. Pump control is accomplished without the use of external sensors, but rather by the pump control system which continuously monitors the electric current draw of the motor and adjusts the motor speed accordingly based on the pump's hydraulic performance which is mapped into memory. Figures 41.13 and 41.14 illustrate this type of pump.

Figure 41.13. INTEGRAL VARIABLE SPEED DRIVE FOR FRACTIONAL HORSEPOWER PUMP. (Xylem AWS)

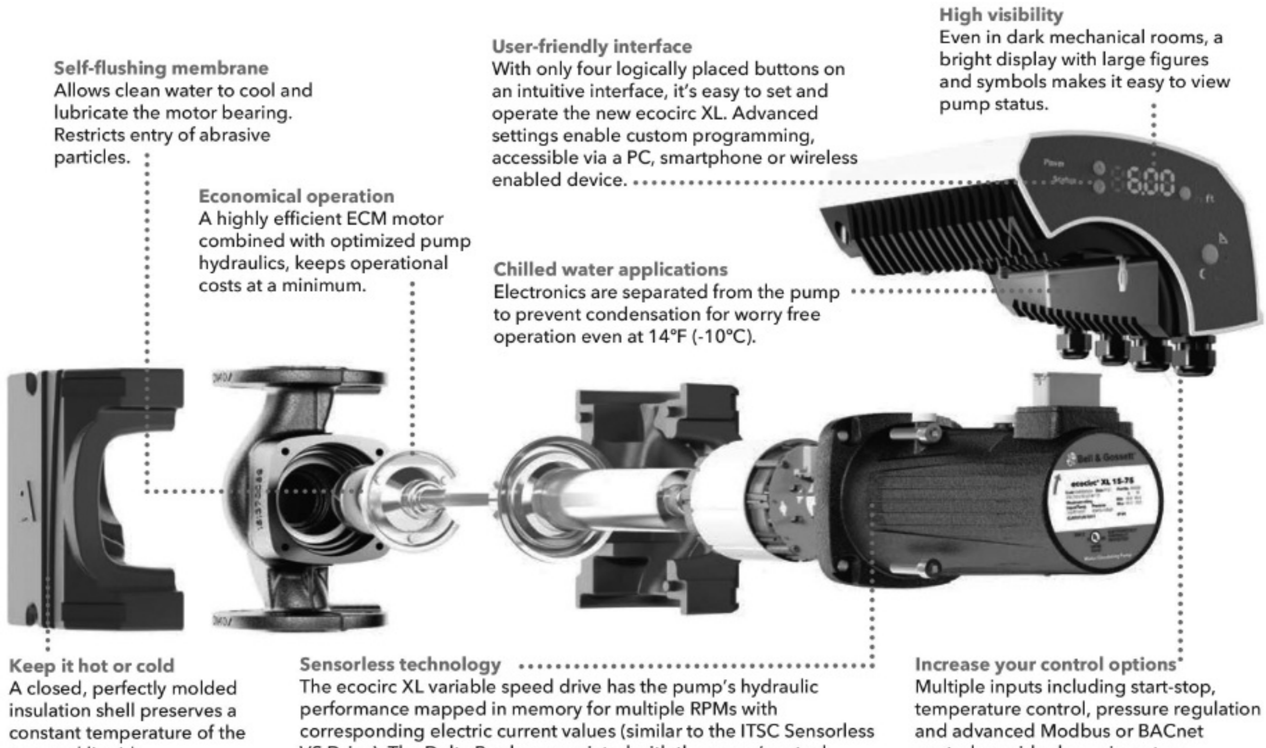


Figure 41.14. EXPLODED VIEW OF PUMP, MOTOR, AND DRIVE. (Xylem AWS)

41.05. New Technologies for Small Packaged Rooftop Units

A. **New Energy-Efficient Options**

1. Many of the options previously available only for large packaged, and custom rooftop units (20 tons and larger) are now available for small packaged rooftop units in the 3 to 15 ton range. These options include: variable speed supply and exhaust fans (through the use of electronically-commutated motors), single-zone and multiple-zone variable air volume operation, variable speed condenser fans (through the use of electronically-commutated motors), electronic expansion valve, outdoor airflow monitoring and control, variable speed drives for the compressors, and an energy recovery wheel. These options significantly increase the energy efficiency of these units, particularly at part-load operation.

B. **Other New Options**

1. Other options that are now available in this size range include a modulating hot gas reheat coil for humidity control, and 2-inch and 4-inch filter racks for a filtration efficiency as high as MERV 14.

C. **Standard Options**

1. Other options that are not new for this size range include integrated airside economizer; communication to a building automation system through BACnet, LonWorks, or a manufacturer-specific communications protocol; natural gas, electric, or hot water heating coil; single-point electrical connection; unit-powered ground fault circuit interrupter-type receptacle; nonfused safety switch; and a field-erected roof curb.

Citation

EXPORT

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. Part 41: New Technologies for HVAC Systems, Chapter (McGraw-Hill Professional, 2016), AccessEngineering

Part 42: Plastic Piping Systems

42. Part 42: Plastic Piping Systems

42.01. Cross-Linked Polyethylene (PEX or XLPE)

A. **Description**

1. High density polyethylene plastic pipe cross-linked during or after extrusion of the piping. Cross-linking improves the temperature limitations of the material.

B. **Uses**

1. Domestic hot and cold water systems.
2. Radiant heating systems.
   a. PEX-AL-PEX—Aluminum tube laminated between interior and exterior layers of plastic.
3. Available in sizes from 1/4 in. to 4 in.
4. Red and blue piping used for domestic hot and cold water, respectively.

C. **Advantages**

1. Flexible.
2. Scale, chlorine, and corrosion resistant.
3. Fewer joints. PEX piping can be run continuously from source to outlet.
4. Less costly material than copper tubing.
5. Less costly installation than copper tubing.

6. Won't develop "pinhole" leaks.

7. Approved for use in domestic water piping systems in all 50 states of the United States as well as Canada.

D. **Disadvantages**

1. Costly crimping tools required for fittings.

2. Degradation from ultraviolet radiation.

3. Dezincification in yellow brass fittings having 30 percent zinc content. Red brass fittings are recommended which have 5 to 10 percent zinc content.

E. **Temperature Limitations**

1. Maximum operating temperature of 180°F.

F. **Pressure Limitations**

1. 100 psi maximum nonshock operating pressure at 180°F.

42.02. Polypropylene (PP)

A. **Description**

1. Chemically inert thermoplastic polymer.

B. **Uses**

1. Domestic hot and cold water systems.

2. High purity water systems.

3. Clean chemical processes.

4. Pharmaceutical operations.

5. Food processing.

6. Available in sizes from 1/2 in. to 6 in.

C. **Advantages**

1. Corrosion and chemical resistant.

2. Impact resistant.

3. Joined by heat fusion rather than gluing.

D. **Disadvantages**

1. Degradation from ultraviolet radiation.

E. **Temperature Limitations**
   1. Maximum operating temperature of 180°F.

F. **Pressure Limitations**
   1. 4" Schedule 80 PP pipe with thermo-seal joints:
      a. 160 psi maximum nonshock operating pressure at 73°F.
      b. 104 psi maximum nonshock operating pressure at 140°F.
   2. Smaller pipe sizes have higher pressure ratings and larger pipe sizes have lower pressure ratings.

42.03. Polyvinyl Chloride (PVC)

A. **Description**
   1. Thermoplastic polymer.

B. **Uses**
   1. Sanitary (sewage) systems.
   2. Intake and exhaust piping for high efficiency condensing water heaters.
   3. Schedule 80 piping—chilled water systems.
   4. Available in sizes from 1/4 in. to 12 in.

C. **Advantages**
   1. Light weight.
   2. Low cost.
   3. Corrosion and chemical resistant.
   4. Ease of joining.

D. **Disadvantages**
   1. Brittle.

E. **Temperature Limitations**
   1. Maximum operating temperature of 140°F.

F. **Pressure Limitations**

1. 12" Schedule 40 PVC pipe with solvent cemented joints:
    a. 130 psi maximum nonshock operating pressure at 73°F.

2. Smaller pipe sizes have higher pressure ratings and larger pipe sizes have lower pressure ratings.

42.04. Chlorinated Polyvinylchloride (CPVC)

A. **Description**
1. Thermoplastic produced by chlorination of polyvinyl chloride.

B. **Uses**
1. Domestic hot and cold water systems.
2. Sprinkler systems.
3. Available in sizes from 1/4 in. to 12 in.

C. **Advantages**
1. Higher temperature limitation than PVC.
2. Low cost.
3. Corrosion and chemical resistant.
4. Ease of joining.
5. More ductile than PVC.

D. **Disadvantages**
1. Degradation from ultraviolet radiation.
2. Brittle.

E. **Temperature Limitations**
1. Maximum operating temperature of 210°F.

F. **Pressure Limitations**
1. 6" Schedule 40 CPVC pipe with solvent cemented joints:
    a. 180 psi maximum nonshock operating pressure at 73°F
    b. 99 psi maximum nonshock operating pressure at 140°F.

2. Smaller pipe sizes have higher pressure ratings and larger pipe sizes have lower pressure ratings.

42.05. High-Density Polyethylene (HDPE)

A. **Description**
   1. Linear polymer prepared from ethylene by a catalytic process.

B. **Uses**
   1. Geothermal systems.
   2. Irrigation systems.
   3. Sprinkler systems.
   4. Industrial systems.
   5. Available in sizes from 3/4 in. to 24 in. Available in coils through 6".

C. **Advantages**
   1. Nontoxic.
   2. Corrosion, abrasion, and chemical resistant.
   3. Durable and light weight.
   4. Carbon black is added to provide ultraviolet protection.
   5. Joined by heat fusion rather than gluing.

D. **Disadvantages**
   1. Non-UV stabilized pipe degrades from ultraviolet radiation.

E. **Temperature Limitations**
   1. Maximum operating temperature of 122°F.

F. **Pressure Limitations**
   1. 4" Type IV HDPE pipe with butt fused joints:
      a. 232 psi maximum nonshock operating pressure at 68°F.
      b. 93 psi maximum nonshock operating pressure at 122°F.
   2. Larger pipe sizes have lower pressure ratings.

Citation

Part 43: Noise and Vibration Control

43. Part 43: Noise and Vibration Control

43.01. Noise Control

A. **Indoor Noise Control**

1. Mechanical equipment rooms.
   a. Locate mechanical equipment rooms away from noise-sensitive areas.
   b. Design spaces such as corridors and storage rooms around mechanical equipment rooms that can be used as buffer zones for noise control.
   c. Design walls of mechanical equipment rooms to be constructed of concrete masonry units.
   d. Design mechanical chases terminating in mechanical equipment rooms to be closed at the mechanical equipment room.
   e. Specify sleeves for all duct and pipe penetrations of mechanical equipment room walls, floors, ceilings, and mechanical chase enclosures. The gap between the pipe or duct and the sleeve should be packed with an appropriate material and caulked.
   f. Specify rubber flexible pipe connectors for piping connections to pumps and chillers.
   g. Specify noise suppressors for steam pressure reducing valves where recommended by the manufacturer.
2. Fans and air handling units.

a. Design flexible duct connectors for all duct connections to fans and air handling units.

b. Design duct silencers (sound attenuators) for supply and return air duct connections to air handling units.

c. Consider the use of round or oval ductwork for the first 20 feet of ductwork. This will reduce low frequency breakout noise from the equipment.

d. Keep the aspect ratio of the ductwork near the equipment as low as possible.

e. Select fans at their point of maximum efficiency.

f. Minimize the system effect of ductwork connected to fans and air handling units.

g. For VAV systems, select fans for maximum efficiency at 70 to 80 percent of maximum airflow, which is the airflow at which the system will operate most of the time.

h. Locate equipment away from noise-sensitive areas inside the building.

i. Where rooftop units need to be located over noise-sensitive areas, design concrete pads under the units and/or design acoustical material in the areas directly beneath the condensing sections. Only the supply and return air ducts for each rooftop unit should penetrate the acoustical material and roof deck within the curb perimeter. Openings around the supply and return air duct penetrations should be sealed once the ducts are installed.

3. Ductwork.

a. Do not exceed airflow velocities of: 950 fpm for ducts within occupied spaces, 1,200 fpm for ducts above suspended ceilings, 1,700 fpm for ducts in shafts, and 2,000 fpm for supply air ducts upstream of VAV terminal units.

b. Maintain at least four to five duct diameters of straight duct between duct fittings, such as elbows and branch takeoffs.

c. Specify turning vanes for all duct elbows.

d. Design open-end ductwork for a maximum of 500 fpm airflow velocity through the opening.

e. Design open-end return air ductwork to have at least one elbow or tee between the opening and the air handling unit.

f. Design transfer air ducts to be sound-lined and have a Z-configuration.

4. VAV terminal units.
   a. Locate fan-powered VAV terminal units over areas that are not noise-sensitive, such as corridors and storage rooms.

   b. For most applications, select VAV terminal units for a maximum noise criterion of NC 30 (incorporating sound attenuating effects from the room).

   c. Design 5 feet of sound-lined ductwork or specify duct silencers downstream of VAV terminal units.

5. Diffusers, registers, and grilles.
   a. For most applications, select diffusers, registers, and grilles for a maximum noise criterion of NC 30 (incorporating sound attenuating effects from the room).

   b. Do not exceed airflow velocities at the neck of supply and return air diffusers, registers, and grilles of: 425 fpm for supply air outlets, and 500 fpm for return and exhaust air inlets.

   c. Design insulated flexible ducts for final connections to diffusers, registers, and grilles installed above suspended ceilings. Maximum length of flexible ducts should be 8 feet. Keep flexible ducts straight with long radius bends. Avoid abrupt bend at connection to diffusers, registers, and grilles.

   d. Design branch takeoffs from duct mains that are at least 5 feet long for final connections to diffusers, registers, and grilles. Avoid direct connections of diffusers, registers, and grilles to duct mains.

   e. Locate balancing dampers at least 5 feet away from diffusers, registers, and grilles.

   f. Do not use dampers at the neck of diffusers and registers for significant throttling of airflow.

B. **Outdoor Noise Control**

1. Outdoor equipment.

a. Locate equipment away from noise-sensitive areas outside of the building.

b. Specify manufacturer-furnished sound attenuating devices, such as compressor enclosures and oversized condenser fans, when available.

c. Design sound barriers around equipment, maintaining all required clearances between equipment and barrier.

d. Ensure that noise at the property lines generated by mechanical equipment (usually expressed in terms of A-weighted sound pressure [dBA]) is below the daytime and nighttime limits of the local noise ordinance.

43.02. Vibration Control

A. **Mechanical Equipment**

1. Specify vibration isolation for all reciprocating and rotating equipment connected to the structure.

   a. Specify vibration isolation hangers for all equipment that is suspended from the building structure.

   b. Specify vibration isolators and bases for all floor-mounted equipment. Refer to the 2011 *ASHRAE Handbook—HVAC Applications*, Chap. 48, Table 47, for complete information on recommended vibration isolation for floor-mounted equipment.

   c. For roofs and floors constructed with open web joists or any unusually light construction, ensure that the isolator deflection is at least 15 times the deflection of the structure that is attributed to the mechanical equipment.

   d. Avoid both internal and external vibration isolation of air handling units.

2. Specify vibration isolation pipe hangers for all piping in mechanical equipment rooms and for piping within 50 feet of vibration-isolated equipment.

3. Specify vibration isolation roof curbs for rooftop units located above noise-sensitive areas.

B. **Piping Risers**

1. Locate pipe risers away from noise sensitive areas so that pipe anchors and

guides rigidly attached to the building structure to accommodate pipe expansion do not need to be vibration isolated.

2. Completely spring-isolated piping riser systems must be carefully designed to avoid overstressing the piping due to movements in the riser and branch takeoffs.

43.03. Sound Information

VELOCITY OF SOUND IN VARIOUS MEDIA

	Velocity	
Medium	**Feet per Second**	**Miles per Hour**
Rubber	310	211
Air	1,130	770
Water Vapor	1,328	905
Cork	1,640	1,118
Lead	4,026	2,745
Water	4,625	3,153
Wood	10,825	7,380
Brass	11,480	7,827
Copper	11,670	7,957
Brick	11,800	8,045
Concrete	12,100	8,250
Wood	12,500	8,523
Steel and Iron	16,000	10,909
Glass	16,400	11,181
Aluminum	19,000	12,955

VOICE LEVEL COMPARISON AT VARIOUS DISTANCES

Distance Feet	Normal Voice Level dB	Raised Voice Level dB	Very Loud Voice dB	Shouting Voice dB
1	70	76	82	88
3	60	66	72	78
6	54	60	66	72
12	48	54	60	66
24	42	48	54	60

DIRECTIONAL EFFECT ON SOUND

Direction of Sound Source with Respect to Listener	Decrease in Speech Energy
Face to Face	0 dB
30 Degree Rotation Away	1.5
60 Degree Rotation Away	3.0
90 Degree Rotation Away	4.5
120 Degree Rotation Away	6.0
150 Degree Rotation Away	7.5
180 Degree Rotation Away Source Turned Away from Listener	9.0

TYPICAL SOUND LEVELS

Pressure Level dB	Typical Sound	Subjective Impression
150	Jet plane take-off Military jet take-off at 100 ft.	Short exposure can cause hearing loss.
140		
130	Artillery fire at 10 ft. Machine gun	Deafening (threshold of pain)
120	Siren at 100 ft.	

Pressure Level dB	Typical Sound	Subjective Impression
	Jet plane (passenger ramp) Thunder Sonic boom	
110	Wood working shop Accelerating motorcycle Hard rock band 75-piece orchestra	Threshold of discomfort
100	Subway (steel wheels) Propeller plane, outboard motor Loud street noise Power lawn mower	Very loud
90	Truck unmuffled Train whistle Kitchen blender Pneumatic jackhammer Shouting at 5 ft.	
80	Printing press Subway (rubber wheels) Noisy office Computer printout room Average factory	Loud Intolerable for phone use
70	Average street noise Quiet typewriter Freight train at 100 ft. Average radio Speech at 3 ft.	Loud
60	Noisy home Average office Normal conversation at 3 ft.	Loud Unusual background
50	General office Quiet office Quiet radio, window AC unit Average home	Moderate

Pressure Level dB	Typical Sound	Subjective Impression
	Average home Quiet street	
40	Private office Quiet home/residential area	Moderate
30	Quiet conversation Broadcast studio	Noticeably quiet
20	Empty auditorium Whisper Watch ticking Buzzing inset at 3 ft. Rural ambient	Very quiet
10	Rustling leaves Soundproof room Human breathing	Very faint Threshold of good hearing
0		Intolerably quiet Threshold of audibility (youthful hearing)

TYPICAL NOISE LEVELS

Equipment	dBA
Saturn rocket	200
Turbo jet engine	170
Jet plane/aircraft at take-off, inside jet engine test cell	150
Turbo propeller plane at take-off, military jet take-off at 100 ft.	140
Large pipe organ, artillery fire at 10 ft., machine gun	130
Jolt squeeze hammer	122
Small aircraft engine, siren at 100 ft., jet plane (passenger ramp), thunder, sonic boom, threshold of feeling (pain)	120

Equipment	dBA
(pain)	
Blaring radio, wood working shop, accelerating motorcycle, hard rock band, 75-piece orchestra, chain saw	110
Vacuum pump, large air compressor	108
Positive displacement blower, air hammer	107
Magnetic drill press, air chisel, high-pressure gas leak	106
Banging of steel plate, wood planer	104
Air compressor, automobile at highway speed, subway (steel wheels), propeller plane, outboard motor, loud street noise, power lawn mower, helicopter	100
Turbine condenser, welder, punch press, riveter, power saws, plastic chipper	98
Small air compressor, airplane cabin normal flight	94
Heavy duty grinder	93
Heavy diesel powered vehicle, spinning machines-looms, noisy street	92
Voice, shouting, truck unmuffled, train whistle, kitchen blender, pneumatic jackhammer, shouting at 5 ft., noisy factory, blender	90
Printing press, inside average rail road car, toilet flushing	86
Garbage disposal, printing press, subway (rubber wheels), noisy office, computer printout room, average factory, lathe, police whistle, telephone ring, clothes washer, dish	80

Equipment	dBA
washer, TV–loud	
Voice—conversational level, average street noise, quiet typewriter, freight train at 100 ft., average radio, speech at 3 ft., inside average automobile, clothes dryer, vacuum cleaner, TV–soft	70
Electronic equipment ventilation fan, noisy home, average office, normal conversation at 3 ft., hair dryer	60
Office air diffuser, general office, quiet office, quiet radio, window AC unit, average home, quiet street	50
Small electric clock, private office, quiet home/residential area, refrigerator, bird singing, wilderness ambient, agricultural land	40
Voice, soft whisper, quiet conversation, broadcast studio	30
Rustling leaves, empty auditorium, whisper, watch ticking, buzzing inset at 3 ft., rural ambient	20
Human breath, sound proof room, rustling leaves	10
Threshold of hearing	0

SUBJECTIVE EFFECT OF CHANGES IN SOUND CHARACTERISTICS

Change in Sound Pressure Level	Change in Apparent Loudness
1 dB	Insignificant
3 dB	Just perceptible
5 dB	Clearly noticeable
10 dB	Twice or half as loud
15 dB	Significant change
20 dB	Much louder or quieter

DECIBEL ADDITION

Difference between Two Levels dB	Add to Higher Level dB
0	3
1	2.5
2	2
3	2
4	1.5
5	1
6	1
7	1
8	0.5
9	0.5
10	0.5
More than 10	0

ACCEPTABLE HVAC NOISE LEVELS

Space Type	Recommended NC Level	Recommended RC Level	Equivalent Sound Level Meter Readings (A

Space Type	Recommended NC Level	Recommended RC Level	Equivalent Sound Level Meter Readings (A Scale) dB
Apartments	NC 25–35	RC 25–35	35–45
Assembly Halls	NC 25–30	RC 25–30	35–40
Churches	NC 30–35	RC 30–35	40–45
Concert and Recital Halls	NC 15–20	RC 15–20	25–30
Courtrooms	NC 30–40	RC 30–40	40–50
Factories	NC 40–65	RC 40–65	50–75
Hospitals and Clinics			
Private Rooms	NC 25–30	RC 25–30	35–40
Wards	NC 30–35	RC 30–35	40–45
Operating Rooms	NC 25–30	RC 25–30	35–40
Laboratories	NC 35–40	RC 35–40	45–50
Corridors	NC 30–35	RC 30–35	40–45
Public Areas	NC 35–40	RC 35–40	45–50
Hotels/Motels			
Individual Rooms/Suites	NC 25–35	RC 25–35	35–45
Meeting/Banquet Rooms	NC 25–35	RC 25–35	35–45
Halls/Corridors/Lobbies	NC 35–40	RC 35–40	45–50
Service/Support Areas	NC 40–45	RC 40–45	50–55
Legitimate Theaters	NC 20–25	RC 20–25	30–35
Libraries	NC 30–40	RC 30–40	40–50
Music Rooms	NC 20–25	RC 20–25	30–35
Movie/Motion Picture Theaters	NC 30–35	RC 30–35	40–45
Offices			
Executive	NC 25–30	RC 25–30	35–40

Space Type	Recommended NC Level	Recommended RC Level	Equivalent Sound Level Meter Readings (A Scale) dB
Conference Rooms	NC 25–30	RC 25–30	35–40
Private	NC 30–35	RC 30–35	40–45
Open-Plan Offices/Areas	NC 35–40	RC 35–40	45–50
Business Mach/Computers	NC 40–45	RC 40–45	50–55
Public Circulation	NC 40–45	RC 40–45	50–55
Private Residences	NC 25–35	RC 25–35	35–45
Recording Studios	NC 15–20	RC 15–20	25–30
Restaurants	NC 40–45	RC 40–45	50–55
Retail Stores	NC 40–45	RC 40–45	50–55
Schools			
Lecture and Classrooms	NC 25–30	RC 25–30	35–40
Open-Plan Classrooms	NC 35–40	RC 35–40	45–50
Sports Coliseums	NC 45–55	RC 45–55	55–65
TV/Broadcast Studios	NC 15–25	RC 15–25	25–35

Part 44: Building Construction Business Fundamentals

44. Part 44: Building Construction Business Fundamentals

44.01. Engineering/Construction Contracts

A. **Methods of Obtaining Contracts**

1. *Competitive Bidding Contracts*. Contracts in which engineers/contractors are selected on the basis of their competitive bids.

2. *Negotiated Contracts*. Contracts in which engineers/contractors are selected on the basis of ability, reputation, past experience with the owner, or type of project, etc., and fees are then negotiated.

B. **Contract Types**

1. *Lump Sum Contract*. A contract in which the engineer/contractor agrees to carry out the stipulated project for a fixed sum of money.

2. *Unit Price Contract*. A contract based on estimated quantities of adequately specified items of work, and the costs for these items of work are expressed in dollars per unit of work. For example, the unit of work may be dollars per foot of caisson drilled, dollars per cubic yard of rock excavated, or dollars per cubic yard of soil removed.
   a. This contract is generally only applicable to construction contracts.

   b. Unit price contracts are usually used when quantities of work cannot be accurately defined by the construction documents (driving piles, foundation excavation, rock excavation, contaminated soil removal, etc.).

Unit prices may be included in part of a lump sum or other type of contract.

3. *Cost Plus Contracts*. A contract in which the owner reimburses the engineer/contractor for all costs incurred and compensates them for services rendered. Cost plus contracts are always negotiated. Compensation may be based on the following:
   a. Fixed percentage of the cost of the work (cost plus fixed percentage contract). Compensation is based on an agreed percentage of the cost.

   b. Sliding-scale percentage of the cost of the work (cost plus sliding-scale percentage contract). Compensation is based on an agreed sliding-scale percentage of the cost (federal income taxes are paid on an increasing sliding scale).

   c. Fixed fee (cost plus fixed fee contract). Compensation is based on an agreed fixed sum of money.

   d. Fixed fee with guaranteed maximum price (cost plus fixed fee with guaranteed maximum price contract). Compensation is based on an agreed fixed sum of money and the total cost will not exceed an agreed upon total project cost.

   e. Fixed fee with bonus (cost plus fixed fee with bonus contract). Compensation is based on an agreed fixed sum of money and an agreed upon bonus is established for completing the project ahead of schedule, under budget, for superior performance, etc.

   f. Fixed fee with guaranteed maximum price and bonus (cost plus fixed fee with guaranteed maximum price and bonus contract). Compensation is based on an agreed fixed sum of money, a guaranteed maximum price, and an agreed upon bonus is established for completing the project ahead of schedule, under budget, for superior performance, etc.

   g. Fixed fee with agreement for sharing any cost savings (cost plus fixed fee with agreement for sharing any cost savings contract). Compensation is based on an agreed upon fixed sum of money and an agreed upon method of sharing any cost savings.

   h. Other fixed fee contracts can be generated using variations on those listed earlier or by negotiating certain aspects particular to the project into a cost plus fixed fee contract with the owner.

4. *Incentive Contracts*. A contract in which the owner awards or penalizes the engineer/contractor for performance of work in accordance with an agreed upon target. The target is often project cost or project schedule.

5. *Liquidated Damages Contracts*. A contract in which the engineer/contractor is required to pay the owner an agreed upon sum of money in accordance with an agreed upon target. The target is often for each calendar day of delay in completion of the project.
   a. Liquidated damages, when included in the contract, must be a reasonable measure of the damages suffered by the owner due to delay in the completion of the project to be enforceable in a court of law. The owner must also be able to demonstrate and prove the damages suffered due to delay in the completion of the project. Weather, strikes, contract changes, natural disasters, and other events beyond the control of the contractor can void the claim for liquidated damages.

6. *Percentage of Construction Fee Contracts*. A contract in which the engineer's fee is based on an agreed upon the percentage of the project's construction cost.

7. *Scope of Work*. The scope of work is part of the engineer's contract defining the engineer's responsibilities and work required to produce the contract documents required by the owner to get the project built. The engineer's scope of work can be compared to the Contract Documents defining a construction contract.

44.02. Building Construction Business Players

A. ***Owner.*** **The individual (or individuals) who initiates the building design process (may be a business, corporation, developer, hospital, local government, municipality, state government, or federal government).**

B. ***Architect.*** **Design team member responsible for internal and external space planning, space sizes, relative location and interconnection of spaces, emergency egress, internal and external circulation, aesthetics, life safety, etc. Generally, the architect is the lead and the driving force behind the project.**

C. ***Civil Engineers*. The design team members responsible for site drainage, roadways, parking, site grading, site circulation, retaining walls, site utilities (sometimes done by the mechanical and electrical engineers), etc.**

D. ***Structural Engineers*. The design team members responsible for building structure (design of beams, columns, foundations, floors, roof). Responsible for making the building stand.**

E. ***Interior Designers*. The design team members responsible for building finishes (wall coverings, floor coverings, ceilings); often assist with, or are responsible for, space planning. Frequently, this is also done by the architect.**

F. ***Landscape Architect*. The design team member responsible for interior as well as external plantings (grass, shrubs, trees, flowers), etc.**

G. ***Surveyors*. Design team members responsible for establishing contours and site boundaries and locating existing benchmarks, trees, roads, water lines, sanitary and storm sewers, electric and telephone utilities, etc.**

H. ***Geologists/Soils Analysts*. Design team members responsible for establishing soil characteristics for foundation analysis, potential ground water problems, rock formations, etc.**

I. ***Transportation Engineer*. The design team member responsible for elevators, escalators, dumbwaiters, and other modes of vertical and/or horizontal transportation.**

J. ***Electrical Engineer*. The design team member responsible for the design of electrical distribution systems, lighting, powering mechanical and other equipment, receptacles, communication systems (telephone, intercom, paging), fire alarm and detection systems, site lighting, site electrical (or civil engineer), emergency power systems, uninterruptible power systems, security systems, etc.**

K. **Mechanical Engineers**

1. *Plumbing Engineer*. The design team member responsible for water supply and distribution systems; sanitary, vent, and storm water systems; natural gas systems; medical and laboratory gas and drainage systems;

underground storage tanks; plumbing fixtures; etc.

2. *Fire Protection Engineer*. The design team member responsible for sprinkler and other fire protection systems, standpipe and hose systems, fire pumps, site fire mains, fire extinguishers (sometimes fire extinguishers are designated by the architect), etc.

3. *HVAC Engineer*. The design team member responsible for the design of the heating, ventilating, and air conditioning systems; ductwork and piping systems; automatic temperature control systems; industrial ventilation systems; environmental control; indoor air quality; heat loss and heat gain within the building; human comfort; etc.

L. **Contractors**

1. *General Contractor*. Also referred to as prime contractor in single-contract construction projects. The general contractor is the construction team member responsible for construction of the building structure and foundations, building envelope, interior partitions, building finishes, roofing, site work, elevators, project schedule, project coordination, project management, etc. The general contractor may subcontract some or all of the work to other contractors. In single-contract projects, the general contractor is also responsible for mechanical and electrical work as well, but this work is most often done by subcontractors.

2. *Mechanical Contractor*. Also referred to as a subcontractor in single-contract construction projects. The mechanical contractor is the construction team member responsible for construction of the building HVAC, plumbing, and fire protection systems. The mechanical contractor may be broken into one, two, or three subcontracts for HVAC and plumbing and/or fire protection. The mechanical contractor may subcontract some or all of the work to other contractors (plumbing, sheet metal, fire protection, automatic temperature controls, etc.).

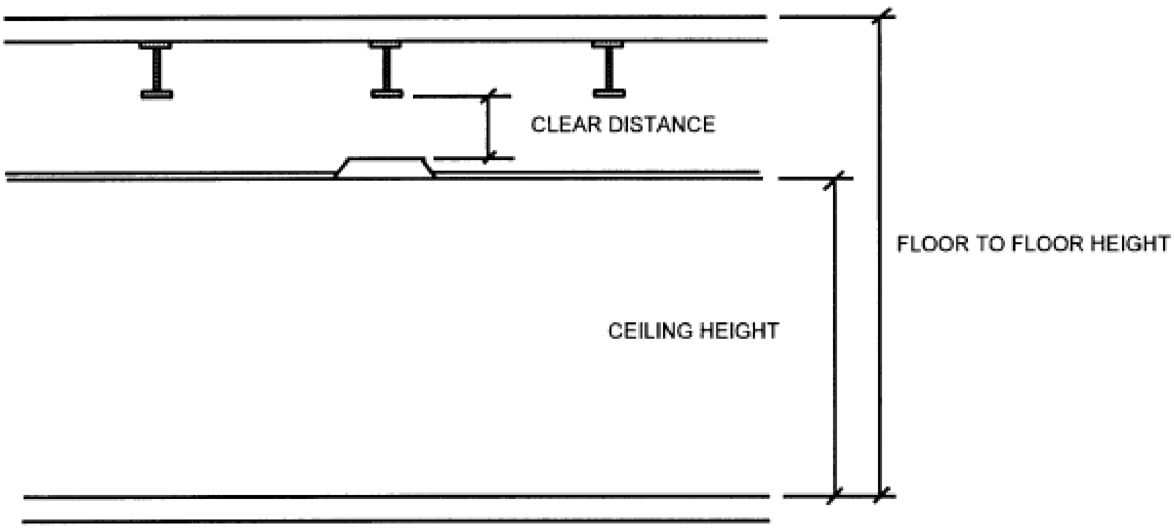
3. *Electrical Contractor*. Also referred to as a subcontractor in single-contract construction projects. The electrical contractor is the construction team member responsible for construction of the building electrical systems, fire alarm systems, communication systems, security systems, lighting systems, etc. The electrical contractor may subcontract some or all of the work to other contractors (communication, security fire alarm, etc.).

4. *Prime Contractor*. The contractor who signs a contract with the owner to perform the work.
5. *Multiple Prime Contractors*. When more than one contractor signs a contract with the owner to perform the work. Often this is accomplished with four prime contracts as follows, but may be done with any number of contracts:
   a. General contract.
   b. Mechanical (HVAC) contract.
   c. Plumbing/fire protection contract.
   d. Electrical contract.
6. *Subcontractor*. The contractor or contractors who sign a contract with the general or prime contractor to perform a particular portion of the prime contractor's work.
7. *Sub-Subcontractor*. The contractor or contractors who sign a contract with a subcontractor to perform a particular portion of the subcontractor's work.

Part 45: Architectural, Structural, and Electrical Information

45. Part 45: Architectural, Structural, and Electrical Information

45.01. Ceiling Plenum Space Requirements



CEILING PLENUM SPACE

Clear Distance—Light to Beam in Inches

Floor to Floor	Ceiling Height	Beam Depth								
		12"	14"	16"	18"	21"	24"	27"	30"	33"
9'0"	7'0"	*	*	*	*	*	*	*	*	*
	7'6"	*	*	*	*	*	*	*	*	*
	8'0"	*	*	*	*	*	*	*	*	*
	8'6"	*	*	*	*	*	*	*	*	*

Notes:

1. Assumptions: 2" fire proofing on beam, 6" fluorescent light depth, 5-1 floor slab thickness, 2" suspended ceiling thickness.

Clear Distance—Light to Beam in Inches

Floor to Floor	Ceiling Height	Beam Depth 12"	14"	16"	18"	21"	24"	27"	30"	33"
	9'0"	*	*	*	*	*	*	*	*	*
10'0"	7'0"	10.5	8.5	6.5	4.5	1.5	*	*	*	*
	7'6"	4.5	2.5	*	*	*	*	*	*	*
	8'0"	*	*	*	*	*	*	*	*	*
	8'6"	*	*	*	*	*	*	*	*	*
	9'0"	*	*	*	*	*	*	*	*	*
11'0"	8'0"	10.5	8.5	6.5	4.5	1.5	*	*	*	*
	8'6"	4.5	2.5	*	*	*	*	*	*	*
	9'0"	*	*	*	*	*	*	*	*	*
	9'6"	*	*	*	*	*	*	*	*	*
	10'0"	*	*	*	*	*	*	*	*	*
	10'6"	*	*	*	*	*	*	*	*	*
12'0"	8'0"	22.5	20.5	18.5	16.5	13.5	10.5	7.5	4.5	1.5
	8'6"	16.5	14.5	12.5	10.5	7.5	4.5	1.5	*	*
	9'0"	10.5	8.5	6.5	4.5	1.5	*	*	*	*
	9'6"	4.5	2.5	0.5	*	*	*	*	*	*
	10'0"	*	*	*	*	*	*	*	*	*
	10'6"	*	*	*	*	*	*	*	*	*
13'0"	8'0"	34.5	32.5	30.5	28.5	25.5	22.5	19.5	16.5	13.5
	8'6"	28.5	26.5	24.5	22.5	19.5	16.5	13.5	10.5	7.5
	9'0"	22.5	20.5	18.5	16.5	13.5	10.5	7.5	4.5	1.5
	9'6"	16.5	14.5	12.5	10.5	7.5	4.5	1.5	*	*
	10'0"	10.5	8.5	6.5	4.5	1.5	*	*	*	*
	10'6"	4.5	2.5	0.5	*	*	*	*	*	*
14'0"	8'0"	46.5	44.5	42.5	40.5	37.5	34.5	31.5	28.5	25.5
	8'6"	40.5	38.5	36.5	34.5	31.5	28.5	25.5	22.5	19.5
	9'0"	34.5	32.5	30.5	28.5	25.5	22.5	19.5	16.5	13.5
	9'6"	28.5	26.5	24.5	22.5	19.5	16.5	13.5	10.5	7.5
	10'0"	22.5	20.5	18.5	16.5	13.5	10.5	7.5	4.5	1.5
	10'6"	16.5	14.5	12.5	10.5	7.5	4.5	1.5	*	*
	11'0"	10.5	8.5	6.5	4.5	1.5	*	*	*	*
	11'6"	4.5	2.5	0.5	*	*	*	*	*	*
15'0"	8'0"	58.5	56.5	54.5	52.5	49.5	46.5	43.5	40.5	37.5
	8'6"	52.5	50.5	48.5	46.5	43.5	40.5	37.5	34.5	31.5
	9'0"	46.5	44.5	42.5	40.5	37.5	34.5	31.5	28.5	25.5
	9'6"	40.5	38.5	36.5	34.5	31.5	28.5	25.5	22.5	19.5
	10'0"	34.5	32.5	30.5	28.5	25.5	22.5	19.5	16.5	13.5

Notes:

1. **Assumptions: 2" fire proofing on beam, 6" fluorescent light depth, 5-1 floor slab thickness, 2" suspended ceiling thickness.**
2. **For depth from beam to finished ceiling add 6" to the [illegible]**

Floor to Floor	Ceiling Height	Clear Distance—Light to Beam in Inches								
		Beam Depth								
		12"	14"	16"	18"	21"	24"	27"	30"	33"
	10'0"	34.5	32.5	30.5	28.5	25.5	22.5	19.5	16.5	13.5
	10'6"	28.5	26.5	24.5	22.5	19.5	16.5	13.5	10.5	7.5
	11'0"	22.5	20.5	18.5	16.5	13.5	10.5	7.5	4.5	1.5
	11'6"	16.5	14.5	12.5	10.5	7.5	4.5	1.5	*	*
	12'0"	10.5	8.5	6.5	4.5	1.5	*	*	*	*
20'0"	9'0"	106	104	102	100	97.5	94.5	91.5	88.5	85.5
	9'6"	100	98.5	96.5	94.5	91.5	88.5	85.5	82.5	79.5
	10'0"	94.5	92.5	90.5	88.5	85.5	62.5	79.5	76.5	73.5
	10'6"	88.5	86.5	84.5	82.5	79.5	76.5	73.5	70.5	67.5
	11'0"	82.5	80.5	78.5	76.5	73.5	70.5	67.5	64.5	61.5
	11'6"	76.5	74.5	72.5	70.5	67.5	64.5	61.5	58.5	55.5
	12'0"	70.5	68.5	66.5	64.5	61.5	58.5	55.5	52.5	49.5

Notes:

1. **Assumptions: 2" fire proofing on beam, 6" fluorescent light depth, 5-1**
   floor slab thickness, 2" suspended ceiling thickness.
2. **For depth from beam to finished ceiling, add 6" to the preceding figu**
3. **For depth from underside of the slab to light, add depth of beam plus**
4. *** Indicates a beam protruding through the ceiling.**

45.02. Building Structural Systems

A. **Standard Nominal Structural Steel Depths**
   1. W-Shapes (Wide Flange Beams): 4, 5, 6, 8, 10, 12, 14, 16, 18, 21, 24, 27, 30, 33, 36, 40, 44.
   2. S-Shapes (I beams): 3, 4, 5, 6, 7, 8, 10, 12, 15, 18, 20, 24.
   3. C-Shapes (Channels): 3, 4, 5, 6, 7, 8, 9, 10, 12, 15.

B. **Standard Nominal Joist Depths as Manufactured by Vulcraft**
   1. K-Series: 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30.
   2. LH-Series and DLH-Series: 18, 20, 24, 28, 32, 36, 40, 44, 48, 52, 56, 60, 64, 68, 72, 84.

C. **Building mechanical equipment support points should not deflect**

more than 0.33 in. for cooling towers and no more than 0.25 in. for all other mechanical equipment.

D. **Maximum duct and pipe sizes that may pass through steel joists are given in the following table:**

Joist Depth	**Round Duct or Pipe Size**	**Square Duct Size**	**Rectangle Duct Size**
8"	5"	4 × 4	3 × 8
10"	6"	5 × 5	3 × 8
12"	7"	6 × 6	4 × 9
14"	8"	6 × 6	5 × 9
16"	9"	7 × 7	6 × 10
18"	11"	8 × 8	7 × 11
20"	11"	9 × 9	7 × 12
22"	12"	9 × 9	8 × 12
24"	13"	10 × 10	8 × 13
26"	15"	12 × 12	9 × 18
28"	16"	13 × 13	9 × 18
30"	17"	14 × 14	10 × 18

Notes:

1. **Table based on Vulcraft K Series joists. For LH or DLH Series joists, consult with Vulcraft.**

2. **The preceding values are maximum sizes. The designer must consider duct insulation or duct liner thickness.**

3. **Do not recommend running ductwork through joists or between joists because it generally becomes a problem in the field. If you must run ductwork through joists or between joists, notify the structural engineer and verify the locations of joist bridging.**

E. **Floor Span vs. Structural Member Depths is given in the following table:**

Floor—Structural Member Depth (1)

Structural Member Span	Structural Steel Shapes				Structural Steel Joist			
	Beams		Girders		Joists (9)		Joists Girder	
	Min. (2,4)	Max. (3,4,8)	Min. (2,5,7)	Max. (3,5,8)	Min. (2,4,6)	Max. (3,6)	Min. (2,5)	M (:
20 ft.	10"	14"	16"	24"	12"	14"	18"	2
30 ft.	16"	18"	21"	33"	16"	24"	20"	4
40 ft.	21"	24"	24"	36"	20"	24"	24"	5
50 ft.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N
60 ft.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N

Notes:

1. **Floor spans generally do not exceed 40 ft.**
2. **Assumed Floor Dead Load (DL) = 50 psf; Live Load (LL) = 50 psf.**
3. **Assumed Floor Dead Load (DL) = 50 psf; Live Load (LL) = 150 psf.**
4. **Assumed Spacing = ± 5'0".**
5. **Assumed Spacing = ± 30'0".**
6. **Assumed Spacing = ± 2'0".**
7. **Assumed Steel Grade 50 ksi.**
8. **Assumed Steel Grade 36 ksi.**
9. **K Series Joists for 20' and 30' spans; LH Series for 40' spans.**
10. **Rule of Thumb: Beam and joist depths (in inches) are approximatel 1/2 the length of the span (in feet).**
11. **Rule of Thumb: Girder and joist girder depths (in inches) are approximately 3/4 the length of the span (in feet).**

F. **Roof Span vs. Structural Member Depths is given in the following table:**

Roof—Structural Member Depth

Structural Member Span	Structural Steel Shapes				Structural Steel Joists			
	Beams		Girders		Joists (7)		Joists Girders	
	Min. (1,3)	Max. (2,3)	Min. (1,4,5)	Max. (2,4,6)	Min. (1,3)	Max. (2,3)	Min. (1,4)	Max. (2,4)
20 ft.	8"	10"	10"	18"	12"	14"	18"	28"
30 ft.	14"	16"	16"	24"	16"	20"	20"	40"
40 ft.	18"	21"	21"	30"	20"	24"	24"	52"
50 ft.	N/A	N/A	27"	36"	28"	32"	32"	64"
60 ft.	N/A	N/A	30"	36"	32"	36"	44"	84"

Notes:

1. **Assumed Roof Dead Load (DL) = 20 psf; Live Load (LL) = 20 psf.**
2. **Assumed Roof Dead Load (DL) = 35 psf; Live Load (LL) = 50 psf.**
3. **Assumed Spacing = ± 5'0".**
4. **Assumed Spacing = ± 30'0".**
5. **Assumed Steel Grade 50 ksi.**
6. **Assumed Steel Grade 36 ksi.**
7. **K Series Joists for 20' and 30' spans; LH Series for 40', 50', and 60' spans.**

45.03. Architectural and Structural Information

A. **Equipment Weights. Provide equipment weights, sizes, and locations to the architect and structural engineer. The architect does not normally need the weights of equipment, but this information is needed by the structural engineer. Obtain weights and sizes from the**

manufacturers' catalogs or the manufacturers' representatives. Equipment weights should include the following information at minimum.

1. Item designation.
2. Location.
3. Size—length, width, height—include curb height if required.
4. Weight. Operating weight if substantially different from the installed weight.
5. Floor/roof openings. Wall openings if load bearing or shear walls are used.
6. Special remarks.

B. **Ductwork Weight. Coordinate all ductwork with the structural engineer, especially when ductwork weight is 20 lbs./lf. or more. Provide ductwork weight and drawings showing the location of ductwork and sizes. See Part 17 for ductwork weight information.**

C. **Piping Weight. Coordinate all piping with the structural engineer, especially pipe sizes 6 in. and larger. Provide piping weight, location of anchors and forces, and drawings showing the location of piping and pipe sizes.**

Structural List

PROJECT STRUCTURAL LIST

PROJECT NAME: ____ **SUBMI**

PRELIMI
FIRS
SECO
THIR
FINA

SHEET NO. ____________ OF____________ PROJECT NO.____________

ITEM NO.	**ITEM DESIGNATION**	**LOCATION**	**SIZE**			**WEIGHT**
			LENGTH	**WIDTH**	**HEIGHT**	

PROJECT STRUCTURAL LIST

PROJECT NAME: ____ **SUBMI**

PRELIMI
FIRS
SECO
THIR
FINA

SHEET NO. ____________ OF____________ PROJECT NO.____________

ITEM NO.	ITEM DESIGNATION	LOCATION	SIZE			WEIGHT
			LENGTH	WIDTH	HEIGHT	

45.04. Electrical Information

A. **Provide electrical information for all mechanical equipment requiring electrical power to the electrical engineer. Electrical information should include the following information at minimum.**

1. Item designation.
2. Location.
3. Voltage-phase-hertz.
4. Horsepower, full load amps, locked rotor amps, kW, minimum circuit amps: provide 1 or more.

5. Is equipment to be on emergency power?

6. Who provides the starter? Who provides the disconnect switch?

7. Control type, hand-off-automatic (HOA), manual, two-speed, etc.

8. Special requirements?

Electrical List

PROJECT ELECTRICAL LIST

PROJECT NAME: ____

F

SHEET NO. _____________ OF_____________ PROJECT NO.______________

ITEM NO.	ITEM DESIGNATION	LOCATION	VOLTAGE/PHASE	HP OR FLA	EMERG. POWER	ST

			PROJECT ELECTRICAL LIST			
PROJECT NAME: ____						
						F
SHEET NO. ____________ OF____________ PROJECT NO.____________						

45.05. Mechanical/Electrical Equipment Space Requirements

A. **Commercial Buildings**

1. 18–20% of gross floor area. Most of the mechanical equipment is located indoors (i.e., no rooftop AHUs).
2. 1/4–1/3 of total building volume. This includes the ceiling plenum as mechanical/electrical space.

B. **Hospital and Laboratory Buildings**

1. 15–50% of gross floor area. Most of the mechanical equipment is located indoors (i.e., no rooftop AHUs).
2. 1/3–1/2 of total building volume. This includes the ceiling plenum as mechanical/electrical space.

C. **The original building design should allow from 10 to 15 percent additional shaft space for future expansion and modification of the facility. This additional shaft space will also reduce the initial installation cost.**

D. **Minimum recommended clearance around the boilers and chillers is 36 in. The minimum recommended clearance around all other mechanical equipment is 24 in. Maintain minimum clearances for coil pull, tube pull, and the cleaning of tubes as recommended by the equipment manufacturer. This is generally equal to the length of the tubes and width of the piece of equipment. Maintain minimum clearance as required to open access and control doors on equipment for service, maintenance, and inspection.**

E. **Minimum recommended clearance between the top of the lights and the deepest structural member is 24 in.**

F. **Mechanical and electrical rooms should be centrally located to minimize ductwork, pipe, and conduit runs (size and length). Centrally locating mechanical and electrical spaces will minimize construction, maintenance, and operating costs. Additional space is quite often required when mechanical and electrical equipment rooms cannot be centrally located or when space requirements are fragmented throughout the building. In addition, centrally located equipment rooms will simplify distribution systems and will in some cases decrease above ceiling space requirements.**

G. **Mechanical rooms with fans and air handling equipment should have at least 10–15 sq. ft. of floor area for each 1,000 CFM of equipment air flow.**

H. **Mechanical rooms with refrigeration equipment must have an exit door that opens directly to the outside or through a vestibule type exit equipped with self-closing, tight-fitting doors.**

I. **Mechanical rooms must be clear of electrical rooms, elevators, and stairs on at least two sides, preferably on three sides.**

J. **Electrical rooms must be clear of elevators and stairs on at least two sides, preferably on three sides.**

K. **In general, mechanical equipment rooms require from 12–20 ft. clearance from the floor to the underside of the structure.**

L. **Mechanical and electrical shafts must be clear of elevators and stairs on at least two sides. Rectangular shafts with aspect ratios of 2:1 to 4:1 are easier to work mechanical and electrical distribution systems in and out of the shafts than square shafts.**

M. **The main electrical switchgear room should be located as close as possible to the incoming electrical service. If an emergency generator is required, the emergency generator room should be located adjacent to the main switchgear room to minimize electrical costs and interconnection problems. The emergency generator room should be located on an outside wall, preferably a corner location to enable proper ventilation, combustion air, and venting of engine exhaust.**

N. **A mechanical equipment room should be located on the first floor or basement floor to accommodate the incoming domestic water service main, the fire protection service mains, and the gas service. These service mains may include meter and regulator assemblies if these assemblies are not installed in meter vaults or outside the building. Consult your local utility company for service and meter/regulator assembly requirements.**

O. **The locations and placement of mechanical and electrical rooms must take into account how large pieces of equipment (chillers, boilers, cooling towers, transformers, and others) can be moved into and out of the building during initial installation and after construction for maintenance and repair and/or replacement.**

45.06. Americans with Disabilities Act (ADA)

A. **ADA Titles**

1. Title I—Equal Employment Opportunity.
2. Title II—State and Local Governments.
3. Title III—Public Accommodations and Commercial Facilities.

B. **Drinking Fountains**

1. Where only one drinking fountain is provided on a floor, a drinking fountain with two bowls, one high bowl and one low bowl, is required.
2. Where more than one drinking fountain is provided on a floor, 50% shall be handicapped accessible and shall be on an accessible route.
3. Spouts shall be no higher than 36 in. above the finished floor or grade.
4. Spouts shall be located at the front of the unit and shall direct the water flow parallel or nearly parallel to the front of the unit.
5. Controls shall be mounted on the front or side of the unit.
6. Clearances:
   a. Knee space below the unit should be 27 in. high, 30 in. wide, and 17–19 in. deep, with a minimum front clear floor space of 30 in. × 48 in.

    b. Units without clear space below: 30-in. × 48-in. clearance is suitable for parallel approach.

C. **Water Closets**

1. The height of the water closet shall be 17–19 in. to the top of the toilet seat.

2. Flush controls shall be hand-operated or automatic. Controls shall be mounted on the wide side of toilet areas, and no more than 44 in. above the floor.

3. At least one toilet shall be handicapped accessible.

D. **Urinals**

1. Urinals shall be stall-type or wall hung with an elongated rim at a maximum of 17 in. above the floor.

2. Flush controls shall be hand-operated or automatic. Controls shall be mounted no more than 44 in. above the floor.

3. If urinals are provided, at least one shall be handicapped accessible.

E. **Lavatories**

1. Lavatories shall be mounted with the rim or counter surface no higher than 34 in. above the finished floor with a clearance of at least 29 in. to the bottom of the apron.

2. Hot water and drain pipe under lavatories shall be insulated or otherwise configured to protect against contact.

3. Faucets shall be lever-operated, push-type, or electronically controlled. Self-closing valves are acceptable, provided they remain open a minimum of 10 seconds.

F. **Bathtubs**

1. Bathtub controls shall be located toward the front half of the bathtub.

2. Shower units shall be provided with a hose at least 60 in. long that can be used both as a fixed shower head and a handheld shower head.

G. **Shower Stalls**

1. The shower controls shall be opposite the seat in a 36 in. × 36 in. shower stall and adjacent to the seat in a 30 in. × 60 in. shower stall.

2. Shower units shall be provided with a hose at least 60 in. long that can be used both as a fixed shower head and a handheld shower head.

H. **Forward Reach**

1. Maximum high forward reach: 48 in.

2. Minimum low forward reach: 15 in.

I. **Side Reach**

1. Maximum high side reach: 54 in.

2. Minimum low side reach: 9 in.

J. **Areas of Rescue Assistance**

1. A portion of a stairway landing within a smokeproof enclosure.

2. A portion of an exterior exit balcony located immediately adjacent to an exit stairway.

3. A portion of a 1-hour fire-resistive corridor located immediately adjacent to an exit enclosure.

4. A portion of a stairway landing within an exit enclosure that is vented to the exterior and is separated from the interior of the building with not less than 1-hour fire-resistive doors.

5. A vestibule located immediately adjacent to an exit enclosure and constructed to the same fire-resistive standards as required for corridors.

6. When approved by the authorities having jurisdiction, an area or room that is separated from other portions of the building by a smoke barrier.

7. An elevator lobby when elevator shafts and adjacent lobbies are pressurized as required for smokeproof enclosures by local regulations and when complying with the requirements herein for size, communication, and signage.

8. Size:
   a. Each area of rescue assistance shall have at least two accessible areas 30 × 48 minimum.

   b. Area shall not encroach on the exit width.

c. The total number of areas per floor shall be one for every 200 persons. If the occupancy per floor is less than 200, the authorities having jurisdiction may reduce the number of areas to one.

9. A method of two-way communication, with both visible and audible signals, is required between the primary fire entry and the areas of rescue assistance.

10. Each area must be identified.

K. **Stairway Width, 48 in. Between Handrails Minimum**

L. **Protruding Objects**

1. Objects protruding from the wall with their leading edges between 27 and 80 in. above the finished floor shall protrude no more than 4 in. into walks, halls, corridors, passageways, or aisles.

2. Objects mounted with their leading edges at or below 27 in. above the finished floor may protrude any amount.

3. Protruding objects shall not reduce the clear width of an accessible route or maneuvering space.

4. Walks, halls, corridors, passageways, aisles, or other circulation spaces shall have 80 in. minimum clear head room.

M. **Controls and Operating Mechanisms**

1. The highest operable part of controls, dispensers, receptacles, and other operable equipment shall be placed within at least one of the reach ranges.

2. Electrical and communication system receptacles on walls shall be mounted no less than 15 in. above the floor.

3. Controls and operating mechanisms shall be operable with one hand and shall not require tight grasping, pinching, or twisting of the wrist. The force required to activate shall be no greater than 5 lbf.

Citation

EXPORT

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. Part 45: Architectural, Structural, and Electrical Information, Chapter (McGraw-Hill Professional, 2016), AccessEngineering

Access Engineering
Authoritative content. Immediate solutions.

Part 46: Properties of Air

46. Part 46: Properties of Air

46.01. Thermodynamic Properties of Air/Water Vapor Mixtures

A. **Psychrometric Definitions**

1. Dry bulb temperature: The temperature of air read on a standard thermometer. Units: °F.DB. Symbol: T_{DB} or DB.

2. Wet bulb temperature: The wet bulb temperature is the temperature indicated by a thermometer whose bulb is covered by a wet wick and exposed to air moving at a velocity of 1,000 ft./min. Units: °F.WB. Symbol: T_{WB} or WB.

3. Humidity ratio: The weight of water vapor in each pound of dry air; also known as specific humidity. Units: lbs.H_2O/lbs.DA or Gr.H_2O/lbs.DA. Symbol: W.

4. Enthalpy: A thermodynamic property that serves as a measure of the heat content above some datum temperature (air 0°F.DB and water 32°F). Units: Btu/lbs.DA or Btu/lbs.H_2O. Symbol: h.

5. Specific volume: The cubic feet of air/water mixture per pound of dry air. Units: cu.ft./lbs.DA. Symbol: SpV.

6. Dewpoint temperature. The temperature at which moisture will start to condense from the air. Units: °F.DP. Symbol: T_{DP} or DP.

7. Relative humidity: The ratio of water vapor in the air/water mixture to the water vapor in saturated air/water mixture. Units: %RH. Symbol: RH.

8. Sensible heat: Heat that causes a rise in temperature. Units: Btu/h. Symbol: H_S.

9. Latent heat: Heat that causes a change in state (e.g., liquid water to gaseous water). Units: Btu/h. Symbol: H_L.

10. Total heat: Sum of sensible heat and latent heat. Units: Btu/h. Symbol: H_T.

11. Sensible heat ratio: The ratio of the sensible heat to the total heat. Units: None. Symbol: SHR.

12. Vapor pressure: Pressure exerted by water vapor in the air. Units: in. Hg. Symbol: P_W.

13. Standard barometric pressure: Pressure at sea level (29.921 in. Hg. = 14.7 psi).

B. **Thermodynamic properties of air/water mixtures are given in the following table:**

Temperature Range °F	Specific Heat Btu/lb. °F
–80–129	0.240
130–215	0.241
216–280	0.242
281–330	0.243
331–370	0.244
371–400	0.245
401–440	0.246
441–460	0.247
461–470	0.248
471–500	0.249

Refer to the online resource for thermodynamic and barometric properties of moist air, and physical properties of gases. www.mheducation.com/HVACequations

THERMODYNAMIC PROPERTIES OF MOIST AIR @14.696 psia

	Humidity Ratio	Specific Volume ft.³/lbs. DA	Enthalpy Btu/lb. DA

Temp °F	Grains/ lb. DA	Pounds/ lb. DA	N_a	N_{as}	N_s	h_a	h_{as}	h_s
−80	0.0343	0.0000049	9.553	0.000	9.553	−19.221	0.005	−19.215
−79	0.0371	0.0000053	9.579	0.000	9.579	−18.980	0.005	−18.975
−78	0.0399	0.0000057	9.604	0.000	9.604	−18.740	0.006	−18.734
−77	0.0434	0.0000062	9.629	0.000	9.629	−18.500	0.007	−18.493
−76	0.0469	0.0000067	9.655	0.000	9.655	−18.259	0.007	−18.252
−75	0.0504	0.0000072	9.680	0.000	9.680	−18.019	0.007	−18.011
−74	0.0546	0.0000078	9.705	0.000	9.705	−17.778	0.008	−17.770
−73	0.0588	0.0000084	9.731	0.000	9.731	−17.538	0.009	−17.529
−72	0.0630	0.0000090	9.756	0.000	9.756	−17.298	0.010	−17.288
−71	0.0679	0.0000097	9.781	0.000	9.781	−17.057	0.010	−17.047
−70	0.0728	0.0000104	9.807	0.000	9.807	−16.806	0.011	−16.817
−69	0.0784	0.0000112	9.832	0.000	9.832	−16.577	0.012	−16.565
−68	0.0840	0.0000120	9.858	0.000	9.858	−16.336	0.013	−16.324
−67	0.0903	0.0000129	9.883	0.000	9.883	−16.096	0.013	−16.083
−66	0.0973	0.0000139	9.908	0.000	9.908	−15.856	0.015	−15.841
−65	0.1043	0.0000149	9.934	0.000	9.934	−15.616	0.015	−15.600
−64	0.1120	0.0000160	9.959	0.000	9.959	−15.375	0.017	−15.359
−63	0.12 04	0.0000172	9.984	0.000	9.984	−15.117	0.018	−15.135
−62	0.1288	0.0000184	10.010	0.000	10.010	−14.895	0.019	−14.876
−61	0.1386	0.0000198	10.035	0.000	10.035	−14.654	0.021	−14.634
−60	0.1484	0.0000212	10.060	0.000	10.060	−14.414	0.022	−14.392
−59	0.1590	0.0000227	10.085	0.000	10.085	−14.174	0.024	−14.150
−58	0.1701	0.0000243	10.111	0.000	10.111	−13.933	0.025	−13.908
−57	0.1820	0.0000260	10.136	0.000	10.136	−13.693	0.027	−13.666
−56	0.1953	0.0000279	10.161	0.000	10.161	−13.453	0.029	−13.424
−55	0.2086	0.0000298	10.187	0.000	10.187	−13.213	0.031	−13.182
−54	0.2233	0.0000319	10.212	0.001	10.213	−12.972	0.033	−12.939
−53	0.2387	0.0000341	10.237	0.001	10.238	−12.732	0.035	−12.697
−52	0.2555	0.0000365	10.263	0.001	10.263	−12.492	0.038	−12.454
−51	0.2730	0.0000390	10.288	0.001	10.289	−12.251	0.041	−12.211
−50	0.2912	0.0000416	10.313	0.001	10.314	−12.011	0.043	−11.968
−49	0.3115	0.0000445	10.339	0.001	10.340	−11.771	0.046	−11.725
−48	0.3325	0.0000475	10.364	0.001	10.365	−11.531	0.050	−11.481
−47	0.3549	0.0000507	10.389	0.001	10.390	−11.290	0.053	−11.237
−46	0.3787	0.0000541	10.415	0.001	10.416	−11.050	0.056	−10.994
−45	0.4039	0.0000577	10.440	0.001	10.441	−10.810	0.060	−10.750
−44	0.4305	0.0000615	10.465	0.001	10.466	−10.570	0.064	−10.505
−43	0.4592	0.0000656	10.491	0.001	10.492	−10.329	0.068	−10.261
−42	0.4893	0.0000699	10.516	0.001	10.517	−10.089	0.073	−10.016
−41	0.5208	0.0000744	10.541	0.001	10.543	−9.849	0.078	−9.771
−40	0.5551	0.0000793	10.567	0.001	10.568	−9.609	0.083	−9.526
−39	0.5908	0.0000844	10.592	0.001	10.593	−9.368	0.088	−9.280
−38	0.6286	0.0000898	10.617	0.002	10.619	−9.128	0.094	−9.034
−37	0.6692	0.0000956	10.643	0.002	10.644	−8.888	0.100	−8.788
−36	0.7119	0.0001017	10.668	0.002	10.670	−8.648	0.106	−8.541
−35	0.7567	0.0001081	10.693	0.002	10.695	−8.407	0.113	−8.294
−34	0.8050	0.0001150	10.719	0.002	10.721	−8.167	0.120	−8.047
−33	0.8554	0.0001222	10.744	0.002	10.746	−7.927	0.128	−7.799
−32	0.9086	0.0001298	10.769	0.002	10.772	−7.687	0.136	−7.551
−31	0.9653	0.0001379	10.795	0.002	10.797	−7.447	0.145	−7.302
−30	1.0255	0.0001465	10.820	0.003	10.822	−7.206	0.154	−7.053
−29	1.0885	0.0001555	10.845	0.003	10.848	−6.966	0.163	−6.803
−28	1.1550	0.0001650	10.871	0.003	10.873	−6.726	0.173	−6.553
−27	1.2257	0.0001751	10.896	0.003	10.899	−6.486	0.184	−6.302
−26	1.3006	0.0001858	10.921	0.003	10.924	−6.245	0.195	−6.051
−25	1.3790	0.0001970	10.947	0.003	10.950	−6.005	0.207	−5.798
−24	1.4616	0.0002088	10.972	0.004	10.976	−5.765	0.220	−5.545
−23	1.5498	0.0002214	10.997	0.004	11.001	−5.525	0.233	−5.292
−22	1.6422	0.0002346	11.022	0.004	11.027	−5.284	0.247	−5.038
−21	1.7395	0.0002485	11.048	0.004	11.052	−5.044	0.261	−4.783
−20	1.8424	0.0002632	11.073	0.005	11.078	−4.804	0.277	−4.527

−19	1.9502	0.0002786	11.098	0.005	11.103	−4.564	0.293	−4.271
−18	2.0650	0.0002950	11.124	0.005	11.129	−4.324	0.311	−4.013
−17	2.1847	0.0003121	11.149	0.006	11.155	−4.084	0.329	−3.754
−16	2.3121	0.0003303	11.174	0.006	11.180	−3.843	0.348	−3.495
−15	2.4451	0.0003493	11.200	0.006	11.206	−3.603	0.368	−3.235
−14	2.5858	0.0003694	11.225	0.007	11.232	−3.363	0.390	−2.973
−13	2.7335	0.0003905	11.250	0.007	11.257	−3.123	0.412	−2.710
−12	2.8896	0.0004128	11.276	0.007	11.283	−2.882	0.436	−2.447
−11	3.0534	0.0004362	11.301	0.008	11.309	−2.642	0.460	−2.182
−10	3.2256	0.0004608	11.326	0.008	11.335	−2.402	0.487	−1.915
−9	3.4069	0.0004867	11.351	0.009	11.360	−2.162	0.514	−1.647
−8	3.5973	0.0005139	11.377	0.009	11.386	−1.922	0.543	−1.378
−7	3.7975	0.0005425	11.402	0.010	11.412	−1.681	0.574	−1.108
−6	4.0082	0.0005726	11.427	0.010	11.438	−1.441	0.606	−0.835
−5	4.2287	0.0006041	11.453	0.011	11.464	−1.201	0.640	−0.561
−4	4.4611	0.0006373	11.478	0.012	11.490	−0.961	0.675	−0.286
−3	4.7054	0.0006722	11.503	0.012	11.516	−0.721	0.712	−0.008
−2	4.9616	0.0007088	11.529	0.013	11.542	−0.480	0.751	0.271
−1	5.2304	0.0007472	11.554	0.014	11.568	−0.240	0.792	0.552
0	5.5125	0.0007875	11.579	0.015	11.594	0.000	0.835	0.835
1	5.8086	0.0008298	11.604	0.015	11.620	0.240	0.880	1.121
2	6.1194	0.0008742	11.630	0.016	11.646	0.480	0.928	1.408
3	6.4449	0.0009207	11.655	0.017	11.672	0.721	0.978	1.699
4	6.7865	0.0009695	11.680	0.018	11.699	0.961	1.030	1.991
5	7.1449	0.0010207	11.706	0.019	11.725	1.201	1.085	2.286
6	7.5201	0.0010743	11.731	0.020	11.751	1.441	1.143	2.584
7	7.9142	0.0011306	11.756	0.021	11.778	1.681	1.203	2.884
8	8.3265	0.0011895	11.782	0.022	11.804	1.922	1.266	3.188
9	8.7584	0.0012512	11.807	0.024	11.831	2.162	1.332	3.494
10	9.2106	0.0013158	11.832	0.025	11.857	2.402	1.402	3.804
11	9.6845	0.0013835	11.857	0.026	11.884	2.642	1.474	4.117
12	10.1808	0.0014544	11.883	0.028	11.910	2.882	1.550	4.433
13	10.7002	0.0015286	11.908	0.029	11.937	3.123	1.630	4.753
14	11.2434	0.0016062	11.933	0.031	11.964	3.363	1.714	5.077
15	11.8118	0.0016874	11.959	0.032	11.991	3.603	1.801	5.404
16	12.4068	0.0017724	11.984	0.034	12.018	3.843	1.892	5.736
17	13.0291	0.0018613	12.009	0.036	12.045	4.084	1.988	6.072
18	13.6801	0.0019543	12.035	0.038	12.072	4.324	2.088	6.412
19	14.3605	0.0020515	12.060	0.040	12.099	4.564	2.193	6.757
20	15.0717	0.0021531	12.085	0.042	12.127	4.804	2.303	7.107
21	15.8144	0.0022592	12.110	0.044	12.154	5.044	2.417	7.462
22	16.5921	0.0023703	12.136	0.046	12.182	5.285	2.537	7.822
23	17.4041	0.0024863	12.161	0.048	12.209	5.525	2.662	8.187
24	18.2511	0.0026073	12.186	0.051	12.237	5.765	2.793	8.558
25	19.1373	0.0027339	12.212	0.054	12.265	6.005	2.930	8.935
26	20.0620	0.0028660	12.237	0.056	12.293	6.246	3.073	9.318
27	21.0273	0.0030039	12.262	0.059	12.321	6.486	3.222	9.708
28	22.0360	0.0031480	12.287	0.062	12.349	6.726	3.378	10.104
29	23.0888	0.0032984	12.313	0.065	12.378	6.966	3.541	10.507
30	24.1864	0.0034552	12.338	0.068	12.406	7.206	3.711	10.917
31	25.3330	0.0036190	12.363	0.072	12.435	7.447	3.888	11.335
32	26.5265	0.0037895	12.389	0.075	12.464	7.687	4.073	11.760
33	27.6290	0.0039470	12.414	0.079	12.492	7.927	4.243	12.170
34	28.7630	0.0041090	12.439	0.082	12.521	8.167	4.420	12.587
35	29.939	0.004277	12.464	0.085	12.550	8.408	4.603	13.010
36	31.164	0.004452	12.490	0.089	12.579	8.648	4.793	13.441
37	32.431	0.004633	12.515	0.093	12.608	8.888	4.990	13.878
38	33.740	0.004820	12.540	0.097	12.637	9.128	5.194	14.322
39	35.098	0.005014	12.566	0.101	12.667	9.369	5.405	14.773
40	36.512	0.005216	12.591	0.105	12.696	9.609	5.624	15.233
41	37.968	0.005424	12.616	0.110	12.726	9.849	5.851	15.700
42	39.480	0.005640	12.641	0.114	12.756	10.089	6.086	16.175
43	41.041	0.005863	12.667	0.119	12.786	10.330	6.330	16.660
44	42.658	0.006094	12.692	0.124	12.816	10.570	6.582	17.152

45	44.338	0.006334	12.717	0.129	12.846	10.810	6.843	17.653
46	46.067	0.006581	12.743	0.134	12.877	11.050	7.114	18.164
47	47.866	0.006838	12.768	0.140	12.908	11.291	7.394	18.685
48	49.721	0.007103	12.793	0.146	12.939	11.531	7.684	19.215
49	51.646	0.007378	12.818	0.152	12.970	11.771	7.984	19.756
50	53.627	0.007661	12.844	0.158	13.001	12.012	8.295	20.306
51	55.685	0.007955	12.869	0.164	13.033	12.252	8.616	20.868
52	57.813	0.008259	12.894	0.171	13.065	12.492	8.949	21.441
53	60.011	0.008573	12.920	0.178	13.097	12.732	9.293	22.025
54	62.279	0.008897	12.945	0.185	13.129	12.973	9.648	22.621
55	64.631	0.009233	12.970	0.192	13.162	13.213	10.016	23.229
56	67.060	0.009580	12.995	0.200	13.195	13.453	10.397	23.850
57	69.566	0.009938	13.021	0.207	13.228	13.694	10.790	24.484
58	72.163	0.010309	13.046	0.216	13.262	13.934	11.197	25.131
59	74.844	0.010692	13.071	0.224	13.295	14.174	11.618	25.792
60	77.609	0.011087	13.096	0.233	13.329	14.415	12.052	26.467
61	80.472	0.011496	13.122	0.242	13.364	14.655	12.502	27.157
62	83.433	0.011919	13.147	0.251	13.398	14.895	12.966	27.862
63	86.485	0.012355	13.172	0.261	13.433	15.135	13.446	28.582
64	89.635	0.012805	13.198	0.271	13.468	15.376	13.942	29.318
65	92.890	0.013270	13.223	0.281	13.504	15.616	14.454	30.071
66	96.250	0.013750	13.248	0.292	13.540	15.856	14.983	30.840
67	99.722	0.014246	13.273	0.303	13.577	16.097	15.530	31.626
68	103.306	0.014758	13.299	0.315	13.613	16.337	16.094	32.431
69	107.002	0.015286	13.324	0.326	13.650	16.577	16.677	33.254
70	110.824	0.015832	13.349	0.339	13.688	16.818	17.279	34.097
71	114.765	0.016395	13.375	0.351	13.726	17.058	17.901	34.959
72	118.832	0.016976	13.400	0.365	13.764	17.299	18.543	35.841
73	123.025	0.017575	13.425	0.378	13.803	17.539	19.204	36.743
74	127.358	0.018194	13.450	0.392	13.843	17.779	19.889	37.668
75	131.831	0.018833	13.476	0.407	13.882	18.020	20.595	38.615
76	136.437	0.019491	13.501	0.422	13.923	18.260	21.323	39.583
77	141.190	0.020170	13.526	0.437	13.963	18.500	22.075	40.576
78	146.097	0.020871	13.551	0.453	14.005	18.741	22.851	41.592
79	151.158	0.021594	13.577	0.470	14.046	18.981	23.652	42.633
80	156.380	0.022340	13.602	0.487	14.089	19.222	24.479	43.701
81	162.330	0.023109	13.627	0.505	14.132	19.462	25.332	44.794
82	167.314	0.023902	13.653	0.523	14.175	19.702	26.211	45.913
83	173.040	0.024720	13.678	0.542	14.220	19.943	27.120	47.062
84	178.941	0.025563	13.703	0.561	14.264	20.183	28.055	48.238
85	185.031	0.026433	13.728	0.581	14.310	20.424	29.021	49.445
86	191.303	0.027329	13.754	0.602	14.356	20.664	30.017	50.681
87	197.778	0.028254	13.779	0.624	14.403	20.905	31.045	51.949
88	204.456	0.029208	13.804	0.646	14.450	21.145	32.105	53.250
89	211.323	0.030189	13.829	0.669	14.498	21.385	33.197	54.582
90	218.421	0.031203	13.855	0.692	14.547	21.626	34.325	55.951
91	225.729	0.032247	13.880	0.717	14.597	21.866	35.489	57.355
92	233.261	0.033323	13.905	0.742	14.647	22.107	36.687	58.794
93	241.031	0.034433	13.930	0.768	14.699	22.347	37.924	60.271
94	249.039	0.035577	13.956	0.795	14.751	22.588	39.199	61.787
95	257.299	0.036757	13.981	0.823	14.804	22.828	40.515	63.343
96	265.804	0.037972	14.006	0.852	14.858	23.069	41.871	64.940
97	274.575	0.039225	14.032	0.881	14.913	23.309	43.269	66.578
98	283.612	0.040516	14.057	0.912	14.969	23.550	44.711	68.260
99	292.936	0.041848	14.082	0.944	15.026	23.790	46.198	69.988
100	302.533	0.043219	14.107	0.976	15.084	24.031	47.730	71.761
101	312.438	0.044634	14.133	1.010	15.143	24.271	49.312	73.583
102	322.630	0.046090	14.158	1.045	15.203	24.512	50.940	75.452
103	333.144	0.047592	14.183	1.081	15.264	24.752	52.621	77.373
104	343.980	0.049140	14.208	1.118	15.326	24.993	54.354	79.346
105	355.159	0.050737	14.234	1.156	15.390	25.233	56.142	81.375
106	366.681	0.052383	14.259	1.196	15.455	25.474	57.986	83.460
107	378.539	0.054077	14.284	1.236	15.521	25.714	59.884	85.599

108	390.782	0.055826	14.309	1.279	15.588	25.955	61.844	87.799
109	403.396	0.057628	14.335	1.322	15.657	26.195	63.866	90.061
110	416.402	0.059486	14.360	1.367	15.727	26.436	65.950	92.386
111	429.807	0.061401	14.385	1.414	15.799	26.677	68.099	94.776
112	443.646	0.063378	14.411	1.462	15.872	26.917	70.319	97.237
113	457.877	0.065411	14.436	1.511	15.947	27.158	72.603	99.760
114	472.584	0.067512	14.461	1.562	16.023	27.398	74.964	102.362
115	487.732	0.069676	14.486	1.615	16.101	27.639	77.396	105.035
116	503.356	0.071908	14.512	1.670	16.181	27.879	79.906	107.786
117	519.477	0.074211	14.537	1.726	16.263	28.120	82.497	110.617
118	536.102	0.076586	14.562	1.784	16.346	28.361	85.169	113.530
119	553.252	0.079036	14.587	1.844	16.432	28.601	87.927	116.528
120	570.920	0.081560	14.613	1.906	16.519	28.842	90.770	119.612
121	589.183	0.084169	14.638	1.971	16.609	29.083	93.709	122.792
122	608.020	0.086860	14.663	2.037	16.700	29.323	96.742	126.065
123	627.431	0.089633	14.688	2.106	16.794	29.564	99.868	129.432
124	647.500	0.092500	14.714	2.176	16.890	29.805	103.102	132.907
125	668.192	0.095456	14.739	2.250	16.989	30.045	106.437	136.482
126	689.528	0.098504	14.764	2.325	17.090	30.286	109.877	140.163
127	711.599	0.101657	14.789	2.404	17.193	30.527	113.438	143.965
128	734.370	0.104910	14.815	2.485	17.299	30.767	117.111	147.878
129	757.890	0.108270	14.840	2.569	17.409	31.008	120.908	151.916
130	782.166	0.111738	14.865	2.655	17.520	31.249	124.828	156.076
131	807.254	0.115322	14.891	2.745	17.635	31.489	128.880	160.370
132	833.161	0.119023	14.916	2.837	17.753	31.730	133.066	164.796
133	859.985	0.122855	14.941	2.934	17.875	31.971	137.403	169.374
134	887.628	0.126804	14.966	3.033	17.999	32.212	141.873	174.084
135	916.265	0.130895	14.992	3.136	18.127	32.452	146.504	178.957
136	945.868	0.135124	15.017	3.242	18.259	32.693	151.294	183.987
137	976.458	0.139494	15.042	3.352	18.394	32.934	156.245	189.179
138	1008.133	0.144019	15.067	3.467	18.534	33.175	161.374	194.548
139	1040.872	0.148696	15.093	3.585	18.678	33.415	166.677	200.092
140	1074.766	0.153538	15.118	3.708	18.825	33.656	172.168	205.824
141	1110.501	0.158643	15.143	3.835	18.978	33.897	177.857	211.754
142	1146.236	0.163748	15.168	3.967	19.135	34.138	183.754	217.892
143	1173.854	0.169122	15.194	4.103	19.297	34.379	189.855	244.233
144	1222.858	0.174694	15.219	4.245	19.464	34.620	196.183	230.802
145	1263.269	0.180467	15.244	4.392	19.637	34.860	202.740	237.600
146	1305.220	0.186460	15.269	4.545	19.815	35.101	209.550	244.651
147	1348.676	0.192668	15.295	4.704	19.999	35.342	216.607	251.949
148	1393.770	0.199110	15.320	4.869	20.189	35.583	223.932	259.514
149	1440.544	0.205792	15.345	5.040	20.385	35.824	231.533	267.356
150	1489.110	0.212730	15.370	5.218	20.585	36.064	239.426	275.490
151	1539.615	0.219945	15.396	5.404	20.799	36.305	247.638	283.943
152	1592.003	0.227429	15.421	5.596	21.017	36.546	256.158	292.705
153	1646.526	0.235218	15.446	5.797	21.243	36.787	265.028	301.816
154	1703.163	0.243309	15.471	6.005	21.477	37.028	274.245	311.273
155	1762.166	0.251738	15.497	6.223	21.720	37.269	283.849	321.118
156	1823.584	0.260512	15.522	6.450	21.972	37.510	293.849	331.359
157	1887.508	0.269644	15.547	6.686	22.233	37.751	304.261	342.012
158	1954.162	0.279166	15.572	6.933	22.505	37.992	315.120	353.112
159	2023.707	0.289101	15.598	7.190	22.788	38.233	326.452	364.685
160	2096.15	0.29945	15.623	7.459	23.082	38.474	338.263	376.737
161	2171.89	0.31027	15.648	7.740	23.388	38.715	350.610	389.325
162	2250.92	0.32156	15.673	8.034	23.707	38.956	363.501	402.457
163	2333.52	0.33336	15.699	8.341	24.040	39.197	376.979	416.175
164	2420.04	0.34572	15.724	8.664	24.388	39.438	391.095	430.533
165	2510.55	0.35865	15.749	9.001	24.750	39.679	405.865	445.544
166	2605.40	0.37220	15.774	9.355	25.129	39.920	421.352	461.271
167	2685.83	0.38639	15.800	9.726	25.526	40.161	437.578	477.739
168	2809.17	0.40131	15.825	10.117	25.942	40.402	454.630	495.032
169	2918.86	0.41698	15.850	10.527	26.377	40.643	472.554	513.197
170	3034.01	0.43343	15.875	10.959	26.834	40.884	491.372	532.256
171	3155.53	0.45079	15.901	11.414	27.315	41.125	511.231	552.356

172	3283.35	0.46905	15.926	11.894	27.820	41.366	532.138	573.504
173	3418.03	0.48829	15.951	12.400	28.352	41.607	554.160	595.767
174	3560.69	0.50867	15.976	12.937	28.913	41.848	577.489	619.337
175	3711.33	0.53019	16.002	13.504	29.505	42.089	602.139	644.229
176	3870.58	0.55294	16.027	14.103	30.130	42.331	628.197	670.528
177	4039.70	0.57710	16.052	14.741	30.793	42.572	655.876	698.448
178	4219.18	0.60274	16.078	15.418	31.496	42.813	685.260	728.073
179	4410.14	0.63002	16.103	16.138	32.242	43.054	716.524	759.579
180	4613.77	0.65911	16.128	16.909	33.037	43.295	749.871	793.166
181	4830.84	0.69012	16.153	17.730	33.883	43.536	785.426	828.962
182	5063.17	0.72331	16.178	18.609	34.787	43.778	823.487	867.265
183	5311.95	0.75885	16.204	19.551	35.755	44.019	864.259	908.278
184	5579.21	0.79703	16.229	20.564	36.793	44.260	908.061	952.321
185	5867.19	0.83817	16.254	21.656	37.910	44.501	955.261	999.763
186	6177.57	0.88251	16.280	22.834	39.113	44.742	1006.149	1050.892
187	6513.99	0.93057	16.305	24.111	40.416	44.984	1061.314	1106.298
188	6879.04	0.98272	16.330	25.498	41.828	45.225	1121.174	1166.399
189	7276.57	1.03951	16.355	27.010	43.365	45.466	1186.382	1231.848
190	7710.78	1.10154	16.381	28.661	45.042	45.707	1257.614	1303.321
191	8187.55	1.16965	16.406	30.476	46.882	45.949	1335.834	1381.783
192	8712.97	1.24471	16.431	32.477	48.908	46.190	1422.047	1468.238
193	9295.16	1.32788	16.456	34.695	51.151	46.431	1517.581	1564.013
194	9942.03	1.42029	16.481	37.161	53.642	46.673	1623.758	1670.430
195	10667.72	1.52396	16.507	39.928	56.435	46.914	1742.879	1789.793
196	11484.90	1.64070	16.532	43.046	59.578	47.155	1877.032	1924.188
197	12410.93	1.77299	16.557	46.580	63.137	47.397	2029.069	2076.466
198	13473.04	1.92472	16.583	50.636	67.218	47.638	2203.464	2251.102
199	14698.25	2.09975	16.608	55.316	71.923	47.879	2404.668	2452.547
200	16131.78	2.30454	16.663	60.793	77.426	48.121	2640.084	2688.205

46.02. Barometric Properties of Air

BAROMETRIC PRESSURES AT VARIOUS ALTITUDES AT 70°F

Altitude Feet	Barometer (Absolute Pressure)				Relative Density
	in.Hg.	psi	ft.H_2O	in. W.G.	
60,000	2.14	1.05	2.43	29.1	0.07
50,000	3.44	1.69	3.90	46.8	0.11
40,000	5.56	2.73	6.31	75.7	0.18
30,000	8.90	4.37	10.10	121.1	0.30
20,000	13.76	6.76	15.61	187.2	0.46
15,000	16.88	8.29	19.15	229.7	0.56
10,000	20.57	10.11	23.34	280.0	0.69
9,000	21.34	10.49	24.22	290.5	0.71
8,000	22.12	10.87	25.10	301.0	0.74
7,000	23.09	11.34	26.20	314.2	0.77
6,000	23.98	11.78	27.21	326.4	0.80
5,000	24.89	12.23	28.24	338.8	0.83
4,000	25.84	12.70	29.32	351.7	0.86
3,500	26.33	12.94	29.88	358.3	0.88
3,000	26.81	13.17	30.42	364.8	0.90
2,500	27.31	13.42	30.99	371.7	0.91
2,000	27.82	13.67	31.57	378.6	0.93
1,500	28.33	13.92	32.15	385.6	0.95
1,000	28.85	14.17	32.74	392.6	0.96
500	29.38	14.43	33.33	399.9	0.98
Sea Level	29.92	14.70	33.95	407.2	1.00
–500	30.47	14.97	34.57	414.7	1.02
–1,000	31.02	15.24	35.20	422.2	1.04
–2,000	32.15	15.80	36.48	437.5	1.07
–3,000	33.31	32.16	37.80	453.3	1.11
–4,000	34.51	16.96	39.16	469.7	1.15
–5,000	35.74	17.56	40.55	486.4	1.19

46.03. Properties of Air—Effects on Standard HVAC Air Equations

AIR EQUATION CONSTANTS FOR ALTITUDE

		Latent Heat		
Altitude Feet	Sensible Heat	Gr.H_2O (2)	lbs.H_2O (3)	Total Heat (4)
60,000	0.08	0.048	339	0.315
50,000	0.12	0.075	532	0.495
40,000	0.19	0.123	871	0.810
30,000	0.32	0.204	1452	1.350
20,000	0.49	0.306	2178	2.025
15,000	0.56	0.382	2710	2.520
10,000	0.69	0.470	3,340	3.105
9,000	0.77	0.483	3436	3.195
8,000	0.74	0.504	3582	3.330
7,000	0.77	0.525	3727	3.465
6,000	0.80	0.545	3872	3.600
5,000	0.83	0.566	4017	3.735
4,000	0.86	0.586	4162	3.870
3,500	0.88	0.600	4259	3.960
3,000	0.90	0.613	4356	4.050
2,500	0.91	0.620	4404	4.095
2,000	0.93	0.634	4501	4.185
1,500	0.95	0.647	4598	4.275
1,000	0.96	0.654	4646	4.320
500	0.98	0.668	4743	4.410
Sea Level	1.08	0.681	4840	4.500
–500	1.19	0.695	4937	4.590
–1,000	1.12	0.708	5034	4.680
–2,000	1.16	0.729	5179	4.815
–3,000	1.20	0.756	5372	4.995
–4,000	1.24	0.783	5566	5.175
–5,000	1.29	0.810	5760	5.335

Notes:

1. Equation Constants Units: Btu/h. CFM °F.

Altitude Feet	Sensible Heat	Latent Heat Gr.H_2O (2)	Latent Heat lbs.H_2O (3)	Total Heat (4)

2. Equation Constants Units: Btu lbs. DA/h. Gr.H_2O CFM.

3. Equation Constants Units: Btu lbs. DA/h. lbs.H_2O CFM.

4. Equation Constants Units: lbs.DA/h. CFM.

5. Use table values in lieu of constants in equations in Part 3.

AIR EQUATION CONSTANTS FOR TEMPERATURE

Temperature °F	Sensible Heat	Latent Heat Gr.H_2O (2)	Latent Heat lbs.H_2O (3)	Total Heat (4)
0	1.204	0.759	5397	5.018
50	1.102	0.695	4937	4.590
60	**1.080**	**0.681**	**4840**	**4.500**
100	1.015	0.640	4550	4.230
150	0.950	0.599	4259	3.960
200	0.896	0.565	4017	3.735
250	0.842	0.531	3775	3.510
300	0.799	0.504	3582	3.330
350	0.756	0.477	3388	3.150
400	0.724	0.456	3243	3.015
450	0.691	0.436	3098	2.880
500	0.659	0.415	2952	2.745
550	0.626	0.395	2807	2.610
600	0.610	0.385	2735	2.543
650	0.583	0.368	2614	2.430
700	0.567	0.358	2541	2.363
750	0.551	0.347	2468	2.295
800	0.529	0.334	2372	2.205
850	0.513	0.323	2299	2.138
900	0.497	0.313	2226	2.070
950	0.486	0.306	2178	2.025
1000	0.470	0.296	2105	1.958

Notes:

1. **Equation Constants Units: Btu/h. CFM °F.**
2. **Equation Constants Units: Btu lbs.DA/h. Gr.H_2O CFM.**
3. **Equation Constants Units: Btu lbs.DA/h. lbs.H_2O CFM.**
4. **Equation Constants Units: lbs.DA/h. CFM.**
5. **Use table values in lieu of constants in equations in Part 3.**

AIR EQUATION FACTORS FOR DENSITY

Altitude Feet	Temperature °F						
	–40	**0**	**40**	**70**	**100**	**150**	**200**
60,000	0.90	0.08	0.08	0.07	0.07	0.06	0.06
50,000	0.14	0.13	0.12	0.11	0.11	0.10	0.09
40,000	0.23	0.21	0.20	0.19	0.18	0.16	0.15
30,000	0.37	0.34	0.32	0.30	0.28	0.26	0.24
20,000	0.58	0.53	0.49	0.46	0.44	0.40	0.37
15,000	0.71	0.65	0.60	0.56	0.54	0.49	0.45
10,000	0.87	0.79	0.73	0.69	0.65	0.60	0.55
9,000	0.90	0.82	0.76	0.71	0.68	0.62	0.57
8,000	0.93	0.85	0.79	0.74	0.70	0.65	0.60
7,000	0.97	0.89	0.82	0.77	0.73	0.67	0.62
6,000	1.01	0.91	0.85	0.80	0.75	0.69	0.64
5,000	1.05	0.95	0.88	0.83	0.78	0.72	0.66
4,000	1.09	0.99	0.92	0.86	0.81	0.75	0.69
3,500	1.11	1.01	0.94	0.87	0.83	0.77	0.70
3,000	1.13	1.03	0.95	0.89	0.85	0.78	0.71
2,500	1.15	1.05	0.97	0.91	0.87	0.80	0.73
2,000	1.17	1.07	0.99	0.93	0.88	0.81	0.74
1,500	1.20	1.09	1.01	0.95	0.90	0.83	0.76
1,000	1.22	1.11	1.02	0.96	0.92	0.84	0.77
500	1.24	1.13	1.04	0.98	0.94	0.86	0.79
Sea Level	1.26	1.15	1.06	1.00	0.95	0.87	0.80
–500	1.28	1.17	1.08	1.02	0.97	0.89	0.81
–1,000	1.31	1.19	1.10	1.04	0.98	0.90	0.83
–2,000	1.35	1.24	1.14	1.07	1.02	0.93	0.86
–3,000	1.40	1.28	1.18	1.11	1.06	0.97	0.89
–4,000	1.45	1.33	1.22	1.15	1.10	1.00	0.92
–5,000	1.51	1.37	1.27	1.19	1.13	1.04	0.96

Note:

1. Multiply constants in equations in Part 3 by values in the table.

AIR EQUATION FACTORS FOR DENSITY

Altitude Feet	Temperature °F 250	300	350	400	450	500	550
60,000	0.05	0.05	0.05	0.04	0.04	0.04	0.04
50,000	0.09	0.08	0.07	0.07	0.07	0.06	0.06
40,000	0.14	0.13	0.12	0.12	0.11	0.10	0.10
30,000	0.22	0.21	0.19	0.18	0.17	0.16	0.16
20,000	0.34	0.32	0.30	0.29	0.27	0.26	0.24
15,000	0.42	0.39	0.37	0.35	0.33	0.31	0.30
10,000	0.51	0.48	0.45	0.42	0.40	0.38	0.36
9,000	0.53	0.50	0.47	0.44	0.42	0.39	0.38
8,000	0.56	0.52	0.49	0.46	0.43	0.41	0.39
7,000	0.58	0.54	0.51	0.48	0.45	0.43	0.41
6,000	0.60	0.56	0.52	0.49	0.46	0.44	0.42
5,000	0.62	0.58	0.54	0.51	0.48	0.45	0.44
4,000	0.64	0.60	0.56	0.53	0.50	0.47	0.45
3,500	0.66	0.61	0.57	0.54	0.51	0.48	0.46
3,000	0.67	0.62	0.58	0.55	0.52	0.49	0.47
2,500	0.69	0.64	0.59	0.56	0.53	0.50	0.48
2,000	0.70	0.65	0.60	0.57	0.54	0.51	0.49
1,500	0.71	0.66	0.61	0.59	0.55	0.52	0.50
1,000	0.72	0.67	0.62	0.60	0.56	0.53	0.51
500	0.74	0.69	0.64	0.61	0.57	0.54	0.52
Sea Level	0.75	0.70	0.65	0.62	0.58	0.55	0.53
–500	0.76	0.71	0.66	0.63	0.59	0.56	0.54
–1,000	0.78	0.73	0.67	0.64	0.60	0.57	0.55
–2,000	0.81	0.75	0.70	0.67	0.62	0.59	0.57
–3,000	0.83	0.78	0.72	0.69	0.65	0.61	0.59
–4,000	0.87	0.81	0.75	0.72	0.67	0.63	0.61
–5,000	0.90	0.84	0.78	0.74	0.69	0.66	0.63

Note:

1. Multiply constants in equations in Part 3 by values in the table.

AIR EQUATION FACTORS FOR DENSITY

	Temperature °F						
Altitude Feet	**600**	**650**	**700**	**750**	**800**	**900**	**1000**
60,000	0.04	0.03	0.03	0.03	0.03	0.03	0.03
50,000	0.06	0.06	0.05	0.05	0.05	0.04	0.04
40,000	0.09	0.09	0.09	0.08	0.08	0.07	0.07
30,000	0.15	0.14	0.14	0.13	0.12	0.12	0.11
20,000	0.23	0.22	0.21	0.20	0.19	0.18	0.17
15,000	0.28	0.27	0.26	0.25	0.24	0.22	0.20
10,000	0.34	0.33	0.32	0.31	0.29	0.27	0.25
9,000	0.35	0.34	0.33	0.32	0.30	0.28	0.26
8,000	0.37	0.36	0.34	0.33	0.31	0.29	0.27
7,000	0.39	0.37	0.35	0.33	0.32	0.30	0.28
6,000	0.40	0.38	0.37	0.35	0.33	0.31	0.29
5,000	0.41	0.40	0.38	0.37	0.35	0.32	0.30
4,000	0.43	0.41	0.39	0.38	0.36	0.33	0.31
3,500	0.44	0.42	0.40	0.39	0.37	0.34	0.32
3,000	0.45	0.43	0.41	0.39	0.37	0.35	0.32
2,500	0.46	0.44	0.42	0.40	0.38	0.36	0.33
2,000	0.46	0.45	0.43	0.41	0.39	0.36	0.33
1,500	0.47	0.46	0.44	0.42	0.40	0.37	0.34
1,000	0.48	0.46	0.44	0.42	0.40	0.37	0.35
500	0.49	0.47	0.45	0.43	0.41	0.38	0.36
Sea Level	0.50	0.48	0.46	0.44	0.42	0.39	0.36
–500	0.51	0.49	0.47	0.45	0.43	0.40	0.37
–1,000	0.52	0.50	0.48	0.46	0.44	0.41	0.38
–2,000	0.54	0.52	0.49	0.47	0.45	0.42	0.39
–3,000	0.56	0.53	0.51	0.49	0.47	0.43	0.40
–4,000	0.58	0.55	0.53	0.51	0.48	0.45	0.42
–5,000	0.60	0.57	0.55	0.55	0.50	0.47	0.43

Note:

1. Multiply constants in equations in Part 3 by values in the table.

Altitude Feet	Temperature °F 600	650	700	750	800	900	1000

46.04. Physical Properties of Gases—Comparison with Air

PHYSICAL PROPERTIES OF GASES

Substance	Formula	Molecular Weight	Phase	Specific Volume cu.ft./lb.m	Density lbs.m/cu.ft.	Sp Gr
Gases						
Air	–	28.996	Gas	13.333	0.075	1.0
Carbon	C	12.01	Solid	–	–	–
Hydrogen	H_2	2.016	Gas	187.723	0.005	0.0
Ammonia	NH_3	17.031	Gas	21.914	0.046	0.6
Sulfur	S	32.06	Gas	7.407	0.135	1.8
Hydrogen Sulfide	H_2S	34.076	Gas	10.979	0.091	1.2
Nitrous Oxide	N_2O	44.013	Gas	8.772	0.114	1.5
Ozone	O_3	48.0	Gas	8.032	0.125	1.6
Argon	Ar	39.948	Gas	9.662	0.104	1.3
Chlorine	Cl_2	70.906	Gas	5.442	0.184	2.4
Helium	He	4.002	Gas	96.618	0.010	0.1
Neon	Ne	20.179	Gas	19.130	0.052	0.6
Products of Combustion—Complete						
Carbon Dioxide	CO_2	44.01	Gas	8.548	0.117	1.5
Water Vapor	H_2O	18.016	Gas	21.017	0.048	0.6
Oxygen	O_2	32.000	Gas	11.819	0.085	1.1

Substance	Formula	Molecular Weight	Phase	Specific Volume cu.ft./lb.m	Density lbs.m/cu.ft.	Sp Gr
Nitrogen	N_2	28.016	Gas	13.443	0.074	0.9
Products of Combustion—Incomplete						
Carbon Monoxide	CO	28.01	Gas	13.699	0.073	0.9
Nitric Oxide	NO	30.006	Gas	12.821	0.078	1.0
Nitrogen Dioxide	NO_2	46.006	Gas	–	–	–
Nitrous Trioxide	NO_3	62.005	Gas	–	–	–
NOx	NO_x	–	Gas	–	–	–
Sulfuric Oxide	SO	48.063	Gas	–	–	–
Sulfur Dioxide	SO_2	64.06	Gas	5.770	0.173	2.3
Sulfur Trioxide	SO_3	80.062	Gas	–	–	–
SOx	SO_x	–	Gas	–	–	–

Citation

EXPORT

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. Part 46: Properties of Air, Chapter (McGraw-Hill Professional, 2016), AccessEngineering

Part 47: Properties of Water

47. Part 47: Properties of Water

47.01. Properties of Water—Effects on Standard HVAC Water Equations

WATER EQUATION FACTORS

System Type	System Temperature Range °F	Equation Factor
Low Temperature (Glycol) Chilled Water	0–40	See Note 2
Chilled Water	40–60	500
Condenser Water Heat Pump Loop	60–110	500
Low Temperature Heating Water	110–150	490
	151–200	485
	201–250	480
Medium Temperature Heating Water	251–300	475
	301–350	470
High Temperature Heating Water	351–400	470
	401–450	470

Notes:

1. **Water equation corrections for temperature, density, and specific heat.**
2. **For glycol system equation factors, see Part 20.**

A. **Water Equation Factor Derivations**

1. Standard water conditions:
   a. Temperature: 60°F.

   b. Pressure: 14.7 psia (sea level)

   c. Density: 62.4 lbs./ft.^{3}

2. Water equation examples:
   $H = m \times c_w \times \Delta T$
   Water @ 250°F

c_w = 1.02 Btu/~~Lb H_2O~~ °F × 62.4 ~~Lbs.H_2O/ft.^{3}~~ × 1.0 ~~ft.^{3}~~ / 7.48052 gal. × 60 min./h × 0.94 (SG)
= 480 Btu min./h °F gal.
H_{250F} = 480 Btu min./h °F Gal. × GPM (gal./min.) × ΔT (°F)
H_{250F} = 480 × GPM × ΔT (°F)
Water @ 450°F
c_w = 1.13 Btu/~~Lb H_2O~~ °F × 62.4 ~~Lbs.H_2O/ft.^{3}~~ × 1.0 ~~ft.^{3}~~/7.48052 gal. × 60 min./h × 0.83 (SG)
= 470 Btu min./h °F gal.
H_{450F} = 470 Btu min./h °F gal. × GPM (gal./min.) × ΔT (°F)
H_{450F} = 470 × GPM × ΔT (°F)

Refer to the online resource for Section 47.02 Thermodynamic Properties of Water.

47.02. Thermodynamic Properties of Water

BOILING POINTS OF WATER

Psia	Boiling Point °F	Psia	Boiling Point °F	Psia	Boiling Point °F
0.5	79.6	44	273.1	150	358.5
1	101.7	46	275.8	175	371.8
2	126.0	48	278.5	200	381.9
3	141.4	50	281.0	225	391.9
4	152.9	52	283.5	250	401.0
5	162.2	54	285.9	275	409.5
6	170.0	56	288.3	300	417.4
7	176.8	58	290.5	325	424.8
8	182.8	60	292.7	350	431.8
9	188.3	62	294.9	375	438.4
10	193.2	64	297.0	400	444.7
11	197.7	66	299.0	425	450.7
12	201.9	68	301.0	450	456.4
13	205.9	70	303.0	475	461.9
14	209.6	72	304.9	500	467.1
14.69	**212.0**	74	306.7	525	472.2
15	213.0	76	308.5	550	477.1
16	216.3	78	310.3	575	481.8

Psia	Boiling Point °F	Psia	Boiling Point °F	Psia	Boiling Point °F
17	219.4	80	312.1	600	486.3
18	222.4	82	313.8	625	490.7
19	225.2	84	315.5	650	495.0
20	228.0	86	317.1	675	499.2
22	233.0	88	318.7	700	503.2
24	237.8	90	320.3	725	507.2
26	242.3	92	321.9	750	511.0
28	246.4	94	323.4	775	514.7
30	250.3	96	324.9	800	518.4
32	254.1	98	326.4	825	521.9
34	257.6	100	327.9	850	525.4
36	261.0	105	331.4	875	528.8
38	264.2	110	334.8	900	532.1
40	267.3	115	338.1	950	538.6
42	270.2	120	341.3	1000	544.8

THERMODYNAMIC PROPERTIES OF WATER

		Specific Volume ft.^{3}/lb.			Enthalpy Btu/lb.		
Temp °F	Press Psia	v_l	v_{lg}	v_g	h_l	h_{lg}	h_g
–80	0.000116	0.01732	1953234	1953234	–193.50	1219.19	1025.[illegible]
–79	0.000125	0.01732	1814052	1814052	–193.11	1219.24	1026.[illegible]
–78	0.000135	0.01732	1685445	1685445	–192.71	1219.28	1026.[illegible]
–77	0.000145	0.01732	1566663	1566663	–192.31	1219.33	1027.[illegible]
–76	0.000157	0.01732	1456752	1456752	–191.92	1219.38	1027.[illegible]
–75	0.000169	0.01733	1355059	1355059	–191.52	1219.42	1027.[illegible]
–74	0.000182	0.01733	1260977	1260977	–191.12	1219.47	1028.[illegible]
–73	0.000196	0.01733	1173848	1173848	–	1219.51	1028.[illegible]
–72	0.000211	0.01733	1093149	1093149		1219.55	1029.[illegible]
–71	0.000227	0.01733	1018381	1018381		1219.59	1029.[illegible]

Temp °F	Press Psia	Specific Volume ft. /lb. v	v	v	190.72 – 190.32 – 189.92 h	Enthalpy Btu/lb. h	h
–70	0.000245	0.01733	949067	949067	–189.52	1219.63	1030.
–69	0.000263	0.01733	884803	884803	–189.11	1219.67	1030.
–68	0.000283	0.01733	825187	825187	–188.71	1219.71	1031.
–67	0.000304	0.01734	769864	769864	–188.30	1219.74	1031.
–66	0.000326	0.01734	718508	718508	–187.90	1219.78	1031.
–65	0.000350	0.01734	670800	670800	–187.49	1219.82	1032.
–64	0.000376	0.01734	626503	626503	–187.08	1219.85	1032.
–63	0.000404	0.01734	585316	585316	–186.67	1219.88	1033.
–62	0.000433	0.01734	548041	548041	–186.26	1219.91	1033.
–61	0.000464	0.01734	511446	511446	–185.85	1219.95	1034.
–60	0.000498	0.01734	478317	478317	–185.44	1219.98	1034.
–59	0.000533	0.01735	447495	447495	–185.03	1220.01	1034.
–58	0.000571	0.01735	418803	418803	–184.61	1220.03	1035.
–57	0.000612	0.01735	392068	392068	–184.20	1220.06	1035.
–56	0.000655	0.01735	367172	367172	–183.78	1220.09	1036.
–55	0.000701	0.01735	343970	343970	–183.37	1220.11	1036.
–54	0.000750	0.01735	322336	322336		1220.14	1037.

Temp °F	Press Psia	Specific Volume ft. /lb. v	v	v	Enthalpy Btu/lb. h	h	h
–53 –52 –51	0.000802 0.000857 0.000916	0.01735 0.01735 0.01736	302157 283335 265773	302157 283335 265773	– 182.95 – 182.53 – 182.11 – 181.69	1220.16 1220.18 1220.21	1037. 1038. 1038.
–50 –49 –48 –47 –46	0.000979 0.001045 0.001116 0.001191 0.001271	0.01736 0.01736 0.01736 0.01736 0.01736	249381 234067 219766 206398 193909	249381 234067 219766 206398 193909	– 181.27 – 180.85 – 180.42 – 181.00 – 179.57	1220.23 1220.25 1220.26 1220.28 1220.30	1038. 1039. 1039. 1040. 1040.
–45 –44 –43 –42 –41	0.001355 0.001445 0.001541 0.001642 0.001749	0.01736 0.01736 0.01737 0.01737 0.01737	182231 171304 161084 151518 142566	182231 171304 161084 151518 142566	– 179.14 – 178.72 – 178.29 – 177.86 – 177.43	1220.31 1220.33 1220.34 1220.36 1220.37	1041. 1041. 1042. 1042. 1042.
–40 –39 –38 –37 –36	0.001863 0.001984 0.002111 0.002247 0.002390	0.01737 0.01737 0.01737 0.01737 0.01738	134176 126322 118959 112058 105592	134176 126322 118959 112058 105592	– 177.00 – 176.57 – 176.13 – 175.70 – 175.26	1220.38 1220.39 1220.40 1220.40 1220.41	1043. 1043. 1044. 1044. 1045.

Temp °F	Press Psia	Specific Volume ft.³/lb.			Enthalpy Btu/lb.		
		v	v	v	h	h	h
–35	0.002542	0.01738	99522	99522	–174.83	1220.42	1045.5
–34	0.002702	0.01738	93828	93828	–174.39	1220.42	1046.0
–33	0.002872	0.01738	88489	88489	–173.95	1220.43	1046.4
–32	0.003052	0.01738	83474	83474	–173.51	1220.43	1046.9
–31	0.003242	0.01738	78763	78763	–173.07	1220.43	1047.3
–30	0.003443	0.01738	74341	74341	–172.63	1220.43	1047.8
–29	0.003655	0.01738	70187	70187	–172.19	1220.43	1048.2
–28	0.003879	0.01739	66282	66282	–171.74	1220.43	1048.6
–27	0.004116	0.01739	62613	62613	–171.30	1220.43	1049.1
–26	0.004366	0.01739	59161	59161	–170.86	1220.43	1049.5
–25	0.004630	0.01739	55915	55915	–170.41	1220.42	1050.0
–24	0.004909	0.01739	52861	52861	–169.96	1220.42	1050.4
–23	0.005203	0.01739	49986	49986	–169.51	1220.41	1050.9
–22	0.005514	0.01739	47281	47281	–169.07	1220.41	1051.3
–21	0.005841	0.01740	44733	44733	–168.62	1220.40	1051.7
–20	0.006186	0.01740	42333	42333	–168.16	1220.39	1052.2
–19	0.006550	0.01740	40073	40073	–167.71	1220.38	1052.6
–18	0.006933	0.01740	37943	37943	–167.26	1220.37	1053.1
–17	0.007337	0.01740	35934	35934	–166.81	1220.36	1053.5
–16	0.007763	0.01740	34041	34041		1220.34	1053.9

Temp °F	Press Psia	Specific Volume ft. /lb. v	v	v	Enthalpy Btu/lb. h	h	h
					–166.35		
–15 –14 –13 –12 –11	0.008211 0.008683 0.009179 0.009702 0.010252	0.01740 0.01741 0.01741 0.01741 0.01741	32256 30572 28983 27483 26067	32256 30572 28983 27483 26067	–165.90 –165.44 –164.98 –164.52 –164.06	1220.33 1220.31 1220.30 1220.28 1220.26	1054. 1054. 1055. 1055. 1056.
–10 –9 –8 –7 –6	0.010830 0.011438 0.012077 0.012749 0.013456	0.01741 0.01741 0.01741 0.01742 0.01742	24730 23467 22274 21147 20081	24730 23467 22274 21147 20081	–163.60 –163.14 –162.68 –162.21 –162.75	1220.24 1220.22 1220.20 1220.18 1220.16	1056. 1057. 1057. 1057. 1058.
–5 –4 –3 –2 –1	0.014197 0.014977 0.015795 0.016654 0.017556	0.01742 0.01742 0.01742 0.01742 0.01742	19074 18121 17220 16367 15561	19074 18121 17220 16367 15561	–161.28 –160.82 –160.35 –159.88 –159.41	1220.13 1220.11 1220.08 1220.05 1220.02	1058. 1059. 1059. 1060. 1060.
0 1 2 3 4	0.018502 0.019495 0.020537 0.021629 0.022774	0.01743 0.01743 0.01743 0.01743 0.01743	14797 14073 13388 12740 12125	14797 14073 13388 12740 12125	–158.94 –158.47 –157.99	1220.00 1219.96 1219.93 1219.90 1219.87	1061. 1061. 1061. 1062. 1062.

Temp °F	Press Psia	Specific Volume ft. /lb. v	v	v	157.99 –157.52 –157.05 h	Enthalpy Btu/lb. h	h
5	0.023975	0.01743	11543	11543	–156.57	1219.83	1063.
6	0.025233	0.01743	10991	10991	–156.09	1219.80	1063.
7	0.026552	0.01744	10468	10468	–155.62	1219.76	1064.
8	0.027933	0.01744	9971	9971	–155.14	1219.72	1064.
9	0.029379	0.01744	9500	9500	–154.66	1219.68	1065.
10	0.030894	0.01744	9054	9054	–154.18	1219.64	1065.
11	0.032480	0.01744	8630	8630	–153.70	1219.60	1065.
12	0.034140	0.01744	8228	8228	–153.21	1219.56	1066.
13	0.035878	0.01745	7846	7846	–152.73	1219.52	1066.
14	0.037696	0.01745	7483	7483	–152.24	1219.47	1067.
15	0.039597	0.01745	7139	7139	–151.76	1219.43	1067.
16	0.041586	0.01745	6811	6811	–151.27	1219.38	1068.
17	0.043666	0.01745	6501	6501	–150.78	1219.33	1068.
18	0.045841	0.01745	6205	6205	–150.30	1219.28	1068.
19	0.048113	0.01745	5924	5924	–149.81	1219.23	1069.
20	0.050489	0.01746	5657	5657	–149.32	1219.18	1069.
21	0.052970	0.01746	5404	5404	–	1219.13	1070.
22	0.055563	0.01746	5162	5162		1219.08	1070.

Temp °F	Press Psia	Specific Volume ft. /lb. v	v	v	Enthalpy Btu/lb. h	h	h
23 24	0.058271 0.061099	0.01746 0.01746	4932 4714	4932 4714	148.82 – 148.33 – 147.84 – 147.34	1219.02 1218.97	1071. 1071.
25 26 27 28 29	0.064051 0.067133 0.070349 0.073706 0.077207	0.01746 0.01747 0.01747 0.01747 0.01747	4506 4308 4119 3940 3769	4506 4308 4119 3940 3769	– 146.85 – 146.35 – 145.85 – 145.35 – 144.85	1218.91 1218.85 1218.80 1218.74 1218.68	1072. 1072. 1072. 1073. 1073.
30 31 32 33 34	0.080860 0.084669 0.08865 0.09229 0.09607	0.01747 0.01747 0.01602 0.01602 0.01602	3606 3450 3302.07 3178.15 3059.47	3606 3450 3302.09 3178.16 3059.49	– 144.35 – 143.85 –0.02 0.99 2.00	1218.61 1218.55 1075.15 1074.59 1074.02	1074. 1074. 1075. 1075. 1076.
35 36 37 38 39	0.09998 0.10403 0.10822 0.11257 0.11707	0.01602 0.01602 0.01602 0.01602 0.01602	2945.66 2836.60 2732.13 2631.88 2535.86	2945.68 2836.61 2732.15 2631.89 2535.88	3.00 4.01 5.02 6.02 7.03	1073.45 1072.88 1072.32 1071.75 1071.18	1076. 1076. 1077. 1077. 1078.
40 41 42 43 44	0.12172 0.12654 0.13153 0.13669 0.14203	0.01602 0.01602 0.01602 0.01602 0.01602	2443.67 2355.22 2270.42 2189.02 2110.92	2443.69 2355.24 2270.43 2189.04 2110.94	8.03 9.04 10.04 11.04 12.05	1070.62 1070.05 1069.48 1068.92 1068.35	1078. 1079. 1079. 1079. 1080.
45 46 47 48	0.14755 0.15326 0.15917 0.16527	0.01602 0.01602 0.01602 0.01602	2035.91 1963.85 1894.71 1828.28	2035.92 1963.87 1894.73 1828.30	13.05 14.05 15.06 16.06	1067.79 1067.22 1066.66 [illegible]	1080. 1081. 1081. [illegible]

Temp °F	Press Psia	Specific Volume ft³/lb.			Enthalpy Btu/lb.		
		v	v	v	h	h	h
48	0.16527	0.01602	1828.28	1828.30	16.06	1066.09	1082.1
49	0.17158	0.01602	1764.44	1764.46	17.06	1065.53	1082.5
50	0.17811	0.01602	1703.18	1703.20	18.06	1064.96	1083.0
51	0.18484	0.01602	1644.25	1644.26	19.06	1064.40	1083.4
52	0.19181	0.01603	1587.64	1587.65	20.07	1063.83	1083.9
53	0.19900	0.01603	1533.22	1533.24	21.07	1063.27	1084.3
54	0.20643	0.01603	1480.89	1480.91	22.07	1062.71	1084.7
55	0.21410	0.01603	1430.61	1430.62	23.07	1062.14	1085.2
56	0.22202	0.01603	1382.19	1382.21	24.07	1061.58	1085.6
57	0.23020	0.01603	1335.65	1335.67	25.07	1061.01	1086.0
58	0.23864	0.01603	1290.85	1290.87	26.07	1060.45	1086.5
59	0.24735	0.01603	1247.76	1247.78	27.07	1059.89	1086.9
60	0.25635	0.01604	1206.30	1206.32	28.07	1059.32	1087.3
61	0.26562	0.01604	1166.38	1166.40	29.07	1058.76	1087.8
62	0.27519	0.01604	1127.93	1127.95	30.07	1058.19	1088.2
63	0.28506	0.01604	1090.94	1090.96	31.07	1057.63	1088.7
64	0.29524	0.01604	1055.32	1055.33	32.07	1057.07	1089.1
65	0.30574	0.01604	1020.98	1021.00	33.07	1056.50	1089.5
66	0.31656	0.01604	987.95	987.97	34.07	1055.94	1090.0
67	0.32772	0.01605	956.11	956.12	35.07	1055.37	1090.4
68	0.33921	0.01605	925.44	925.45	36.07	1054.81	1090.8
69	0.35107	0.01605	895.86	895.87	37.07	1054.24	1091.3
70	0.36328	0.01605	867.34	867.36	38.07	1053.68	1091.7
71	0.37586	0.01605	839.87	839.88	39.07	1053.11	1092.1
72	0.38882	0.01606	813.37	813.39	40.07	1052.55	1092.6
73	0.40217	0.01606	787.85	787.87	41.07	1051.98	1093.0
74	0.41592	0.01606	763.19	763.21	42.06	1051.42	1093.4
75	0.43008	0.01606	739.42	739.44	43.06	1050.85	1093.9
76	0.44465	0.01606	716.51	716.53	44.06	1050.29	1094.3
77	0.45966	0.01607	694.38	694.40	45.06	1049.72	1094.7
78	0.47510	0.01607	673.05	673.06	46.06	1049.16	1095.2
79	0.49100	0.01607	652.44	652.46	47.06	1048.59	1095.6
80	0.50736	0.01607	632.54	632.56	48.06	1048.03	1096.0
81	0.52419	0.01608	613.35	613.37	49.06	1047.46	1096.5
82	0.54150	0.01608	594.82	594.84	50.05	1046.89	1096.9
83	0.55931	0.01608	576.90	576.92	51.05	1046.33	1097.3
84	0.57763	0.01608	559.63	559.65	52.05	1045.76	1097.8

Temp °F	Press Psia	Specific Volume ft. /lb. v	v	v	Enthalpy Btu/lb. h	h	h
85	0.59647	0.01609	542.93	542.94	53.05	1045.19	1098.
86	0.61984	0.01609	526.80	526.81	54.05	1044.63	1098.
87	0.63975	0.01609	511.21	511.22	55.05	1044.06	1099.
88	0.65622	0.01609	496.14	496.15	56.05	1043.49	1099.
89	0.67726	0.01610	481.60	481.61	57.04	1042.92	1099.
90	0.69889	0.01610	467.52	467.53	58.04	1042.36	1100.
91	0.72111	0.01610	453.91	453.93	59.04	1041.79	1100.
92	0.74394	0.01611	440.76	440.78	60.04	1041.22	1101.
93	0.76740	0.01611	428.04	428.06	61.04	1040.65	1101.
94	0.79150	0.01611	415.74	415.76	62.04	1040.08	1102.
95	0.81625	0.01612	403.84	403.86	63.03	1039.51	1102.
96	0.84166	0.01612	392.33	392.34	64.03	1038.95	1102.
97	0.86776	0.01612	381.20	381.21	65.03	1038.38	1103.
98	0.89456	0.01612	370.42	370.44	66.03	1037.81	1103.
99	0.92207	0.01613	359.99	360.01	67.03	1037.24	1104.
100	0.95031	0.01613	349.91	349.92	68.03	1036.67	1104.
101	0.97930	0.01613	340.14	340.15	69.03	1036.10	1105.
102	1.00904	0.01614	330.69	330.71	70.02	1035.53	1105.
103	1.03956	0.01614	321.53	321.55	71.02	1034.95	1105.
104	1.07088	0.01614	312.67	312.69	72.02	1034.38	1106.
105	1.10301	0.01615	304.08	304.10	73.02	1033.81	1106.
106	1.13597	0.01615	295.76	295.77	74.02	1033.24	1107.
107	1.16977	0.01616	287.71	287.73	75.01	1032.67	1107.
108	1.20444	0.01616	279.91	279.92	76.01	1032.10	1108.
109	1.23999	0.01616	272.34	272.36	77.01	1031.52	1108.
110	1.27644	0.01617	265.02	265.03	78.01	1030.95	1108.
111	1.31381	0.01617	257.91	257.93	79.01	1030.38	1109.
112	1.35212	0.01617	251.02	251.04	80.01	1029.80	1109.
113	1.39138	0.01618	244.36	244.38	81.01	1029.23	1110.
114	1.43162	0.01618	237.89	237.90	82.00	1028.66	1110.
115	1.47286	0.01619	231.62	231.63	83.00	1028.08	1111.
116	1.51512	0.01619	225.53	225.55	84.00	1027.51	1111.
117	1.55842	0.01619	219.63	219.65	85.00	1026.93	1111.
118	1.60277	0.01620	213.91	213.93	86.00	1026.36	1112.
119	1.64820	0.01620	208.36	208.37	87.00	1025.78	1112.
120	1.69474	0.01620	202.98	202.99	88.00	1025.20	1113.

Temp °F	Press Psia	Specific Volume ft.³/lb. v	v	v	Enthalpy Btu/lb. h	h	h
120	1.69474	0.01620	[illegible]	[illegible]	88.00	1025.20	1113.
121	1.74240	0.01621	197.76	197.76	89.00	1023.62	1113.
122	1.79117	0.01621	192.69	192.69	90.00	1024.05	1114.
123	1.84117	0.01622	187.78	187.78	90.99	1024.47	1114.
124	1.89233	0.01622	182.98	182.99	91.99	1022.90	1114.
125	1.94470	0.01623	178.34	178.36	92.99	1022.32	1115.
126	1.99831	0.01623	173.85	173.86	93.99	1021.74	1115.7
127	2.05318	0.01623	169.47	169.49	94.99	1021.16	1116.
128	2.10934	0.01624	165.23	165.25	95.99	1020.58	1116.5
129	2.16680	0.01624	161.11	161.12	96.99	1020.00	1116.9
130	2.22560	0.01625	157.11	157.12	97.99	1019.42	1117.4
131	2.28576	0.01625	153.22	153.23	98.99	1018.84	1117.8
132	2.34730	0.01626	149.44	149.46	99.99	1018.26	1118.
133	2.41025	0.01626	145.77	145.78	100.99	1017.68	1118.
134	2.47463	0.01627	142.21	142.23	101.99	1017.10	1119.
135	2.54048	0.01627	138.74	138.76	102.99	1016.52	1119.5
136	2.60782	0.01627	135.37	135.39	103.98	1015.93	1119.9
137	2.67667	0.01628	132.10	132.12	104.98	1015.35	1120.
138	2.74707	0.01628	128.92	128.94	105.98	1014.77	1120.7
139	2.81903	0.01629	125.83	125.85	106.98	1014.18	1121.
140	2.89260	0.01629	122.82	122.84	107.98	1013.60	1121.5
141	2.96780	0.01630	119.90	119.92	108.98	1013.01	1122.
142	3.04465	0.01630	117.05	117.07	109.98	1012.43	1122.4
143	3.12320	0.01631	114.29	114.31	110.98	1011.84	1122.8
144	3.20345	0.01631	111.60	111.62	111.98	1011.26	1123.
145	3.28546	0.01632	108.99	109.00	112.98	1010.67	1123.
146	3.36924	0.01632	106.44	106.45	113.98	1010.09	1124.
147	3.45483	0.01633	103.96	103.98	114.98	1009.50	1124.4
148	3.54226	0.01633	101.55	101.57	115.98	1008.91	1124.8
149	3.63156	0.01634	99.21	99.22	116.98	1008.32	1125.
150	3.72277	0.01634	96.93	96.94	117.98	1007.73	1125.7
151	3.81591	0.01635	94.70	94.72	118.99	1007.14	1126.
152	3.91101	0.01635	92.54	92.56	119.99	1006.55	1126.5
153	4.00812	0.01636	90.44	90.46	120.99	1005.96	1126.9
154	4.10727	0.01636	88.39	88.41	121.99	1005.37	1127.
155	4.20848	0.01637	86.40	86.41	122.99	1004.78	1127.7
156	4.31180	0.01637	84.45	84.47	123.99	1004.19	1128.

Temp °F	Press Psia	Specific Volume ft.³/lb.			Enthalpy Btu/lb.		
		v	v	v	h	h	h
157	4.41725	0.01638	82.56	82.58	124.99	1003.60	1128.
158	4.52488	0.01638	80.72	80.73	125.99	1003.00	1128.
159	4.63472	0.01639	78.92	78.94	126.99	1002.41	1129.
160	4.7468	0.01639	77.175	77.192	127.99	1001.82	1129.
161	4.8612	0.01640	75.471	75.488	128.99	1001.22	1130.
162	4.9778	0.01640	73.812	73.829	130.00	1000.63	1130.
163	5.0969	0.01641	72.196	72.213	131.00	1000.03	1131.
164	5.2183	0.01642	70.619	70.636	132.00	999.43	1131.
165	5.3422	0.01642	69.084	69.101	133.00	998.84	1131.
166	5.4685	0.01643	67.587	67.604	134.00	998.24	1132.
167	5.5974	0.01643	66.130	66.146	135.00	997.64	1132.
168	5.7287	0.01644	64.707	64.723	136.01	997.04	1133.
169	5.8627	0.01644	63.320	63.336	137.01	996.44	1133.
170	5.9993	0.01645	61.969	61.989	138.01	995.84	1133.
171	6.1386	0.01646	60.649	60.666	139.01	995.24	1134.
172	6.2806	0.01646	59.363	59.380	140.01	994.64	1134.
173	6.4253	0.01647	58.112	58.128	141.02	994.04	1135.
174	6.5729	0.01647	56.887	56.904	142.02	993.44	1135.
175	6.7232	0.01648	55.694	55.711	143.02	992.83	1135.
176	6.8765	0.01648	54.532	54.549	144.03	992.23	1136.
177	7.0327	0.01649	53.397	53.414	145.03	991.63	1136.
178	7.1918	0.01650	52.290	52.307	146.03	991.02	1137.
179	7.3539	0.01650	51.210	51.226	147.03	990.42	1137.
180	7.5191	0.01651	50.155	50.171	148.04	989.81	1137.
181	7.6874	0.01651	49.126	49.143	149.04	989.20	1138.
182	7.8589	0.01652	48.122	48.138	150.04	988.60	1138.
183	8.0335	0.01653	47.142	47.158	151.05	987.99	1139.
184	8.2114	0.01653	46.185	46.202	152.05	987.38	1139.
185	8.3926	0.01654	45.251	45.267	153.05	986.77	1139.
186	8.5770	0.01654	44.339	44.356	154.06	986.16	1140.
187	8.7649	0.01655	43.448	43.465	155.06	985.55	1140.
188	8.9562	0.01656	42.579	42.595	156.07	984.94	1141.
189	9.1510	0.01656	41.730	41.746	157.07	984.32	1141.
190	9.3493	0.01657	40.901	40.918	158.07	983.71	1141.
191	9.5512	0.01658	40.092	40.108	159.08	983.10	1142.
192	9.7567	0.01658	39.301	39.317	160.08	982.48	1142.

Temp °F	Press Psia	Specific Volume ft³/lb. v	v	v	Enthalpy Btu/lb. h	h	h
193	9.9659	0.01659	38.528	38.544	161.09	981.87	1142.
194	10.1788	0.01659	37.774	37.790	162.09	981.25	1143.
195	10.3955	0.01660	37.035	37.052	163.10	980.63	1143.
196	10.6160	0.01661	36.314	36.331	164.10	980.02	1144.
197	10.8404	0.01661	35.611	35.628	165.11	979.40	1144.
198	11.0687	0.01662	34.923	34.940	166.11	978.78	1144.
199	11.3010	0.01663	34.251	34.268	167.12	978.16	1145.
200	11.5374	0.01663	33.594	33.610	168.13	977.54	1145.
201	11.7779	0.01664	32.951	32.968	169.13	976.92	1146.
202	12.0225	0.01665	32.324	32.340	170.14	976.29	1146.
203	12.2713	0.01665	31.710	31.726	171.14	975.67	1146.
204	12.5244	0.01666	31.110	31.127	172.15	975.05	1147.
205	12.7819	0.01667	30.523	30.540	173.16	974.42	1147.
206	13.0436	0.01667	29.949	29.965	174.16	973.80	1147.
207	13.3099	0.01668	29.388	29.404	175.17	973.17	1148.
208	13.5806	0.01669	28.839	28.856	176.18	972.54	1148.
209	13.8558	0.01669	28.303	28.319	177.18	971.92	1149.
210	14.1357	0.01670	27.778	27.795	178.19	971.29	1149.
212	14.7096	0.01671	26.763	26.780	180.20	970.03	1150.
214	15.3025	0.01673	25.790	25.807	182.22	968.76	1150.
216	15.9152	0.01674	24.861	24.878	184.24	967.50	1151.
218	16.5479	0.01676	23.970	23.987	186.25	966.23	1152.
220	17.2013	0.01677	23.118	23.134	188.27	964.95	1153.
222	17.8759	0.01679	22.299	22.316	190.29	963.67	1153.
224	18.5721	0.01680	21.516	21.533	192.31	962.39	1154.
226	19.2905	0.01682	20.765	20.782	194.33	961.11	1155.
228	20.0316	0.01683	20.045	20.062	196.35	959.82	1156.
230	20.7961	0.01684	19.355	19.372	198.37	958.52	1156.
232	21.5843	0.01686	18.692	18.709	200.39	957.22	1157.
234	22.3970	0.01688	18.056	18.073	202.41	955.92	1158.
236	23.2345	0.01689	17.466	17.463	204.44	954.62	1159.
238	24.0977	0.01691	16.860	16.877	206.46	953.31	1159.
240	24.9869	0.01692	16.298	16.314	208.49	952.00	1160.
242	25.9028	0.01694	15.757	15.774	210.51	950.68	1161.
244	26.8461	0.01695	15.238	15.255	212.54	948.35	1161.
246	27.8172	0.01697	14.739	14.756	214.57	948.03	1162.
248	28.8169	0.01698	14.259	14.276	216.60	946.70	1163.

Temp °F	Press Psia	Specific Volume ft. /lb.			Enthalpy Btu/lb.		
		v	v	v	h	h	h
250	29.8457	0.01700	13.798	13.815	218.63	945.36	1163.9
252	30.9043	0.01702	13.355	13.372	220.66	944.02	1164.6
254	31.9934	0.01703	12.928	12.945	222.69	942.68	1165.3
256	33.1135	0.01705	12.526	12.147	224.73	939.99	1166.7
258	34.2653	0.01707	12.123	12.140	226.76	939.97	1166.7
260	35.4496	0.01708	11.742	11.759	228.79	938.61	1167.4
262	36.6669	0.01710	11.376	11.393	230.83	937.25	1168.0
264	37.9180	0.01712	11.024	11.041	232.87	935.88	1168.7
266	39.2035	0.01714	10.684	10.701	234.90	934.50	1169.4
268	40.5241	0.01715	10.357	10.374	236.94	933.12	1170.0
270	41.8806	0.01717	10.042	10.059	238.98	931.74	1170.7
272	43.2736	0.01719	9.737	9.755	241.03	930.35	1171.3
274	44.7040	0.01721	9.445	9.462	243.07	928.95	1172.0
276	46.1723	0.01722	9.162	9.179	245.11	927.55	1172.6
278	47.6794	0.01724	8.890	8.907	247.16	926.15	1173.3
280	49.2260	0.01726	8.627	8.644	249.20	924.74	1173.9
282	50.8128	0.01728	8.373	8.390	251.25	923.32	1174.5
284	52.4406	0.01730	8.128	8.146	253.30	921.90	1175.2
286	54.1103	0.01731	7.892	7.910	255.35	920.47	1175.8
288	55.8225	0.01733	7.664	7.681	257.40	919.03	1176.4
290	57.5780	0.01735	7.444	7.461	259.45	917.59	1177.0
292	59.3777	0.01737	7.231	7.248	261.51	916.15	1177.6
294	61.2224	0.01739	7.026	7.043	263.56	914.69	1178.2
296	63.1128	0.01741	6.827	6.844	265.62	913.24	1178.8
298	65.0498	0.01743	6.635	6.652	267.68	911.77	1179.4
300	67.03	0.01745	6.450	6.467	269.74	910.3	1180.0
302	69.01	0.01747	6.275	6.292	271.79	909.0	1180.7
304	71.09	0.01749	6.102	6.119	273.86	907.5	1181.3
306	73.22	0.01751	5.933	5.951	275.93	906.0	1181.9
308	75.40	0.01753	5.771	5.789	278.00	904.5	1182.5
310	77.64	0.01755	5.614	5.632	280.06	903.0	1183.0
312	79.92	0.01757	5.462	5.480	282.13	901.5	1183.6
314	82.26	0.01759	5.315	5.333	284.21	899.9	1184.1
316	84.65	0.01761	5.172	5.190	286.28	898.4	1184.6
318	87.10	0.01763	5.034	5.052	288.36	896.9	1185.2
320	89.60	0.01765	4.901	4.919	290.43	895.3	1185.7

Temp °F	Press Psia	Specific Volume ft. /lb.			Enthalpy Btu/lb.		
		v	v	v	h	h	h
322	92.16	0.01767	4.772	4.790	292.51	893.8	1186.3
324	94.78	0.01770	4.647	4.665	294.59	892.2	1186.7
326	97.46	0.01772	4.525	4.543	296.67	890.7	1187.3
328	100.20	0.01774	4.408	4.426	298.76	889.1	1187.8
330	103.00	0.01776	4.294	4.312	300.84	887.5	1188.3
332	105.86	0.01778	4.183	4.201	302.93	885.9	1188.8
334	108.78	0.01780	4.076	4.094	305.02	884.3	1189.3
336	111.76	0.01783	3.973	3.991	307.11	882.7	1189.8
338	114.82	0.01785	3.872	3.890	309.21	881.1	1190.3
340	117.93	0.01787	3.774	3.792	311.30	879.5	1190.8
342	121.11	0.01789	3.680	3.698	313.39	877.9	1191.2
344	124.36	0.01792	3.588	3.606	315.49	876.3	1191.7
346	127.68	0.01794	3.499	3.517	317.59	874.6	1192.1
348	131.07	0.01796	3.412	3.430	319.70	873.0	1192.7
350	134.53	0.01799	3.328	3.346	321.80	871.3	1193.1
352	138.06	0.01801	3.247	3.265	323.91	869.6	1193.5
354	141.66	0.01804	3.167	3.185	326.02	868.0	1194.0
356	145.34	0.01806	3.091	3.109	328.13	866.3	1194.4
358	149.09	0.01808	3.286	3.304	330.24	864.6	1194.8
360	152.92	0.01811	2.943	2.961	332.35	862.9	1195.2
362	156.82	0.01813	2.873	2.891	334.47	861.2	1195.6
364	160.80	0.01816	2.804	2.822	336.59	859.5	1196.0
366	164.87	0.01818	2.738	2.756	338.71	857.7	1196.4
368	169.01	0.01821	2.673	2.691	340.83	856.0	1196.8
370	173.23	0.01823	5.283	2.628	342.96	854.2	1197.1
372	177.53	0.01826	2.549	2.567	345.08	852.5	1197.5
374	181.92	0.01828	2.325	2.508	347.21	850.7	1197.9
376	186.39	0.01831	2.432	2.450	349.35	848.9	1198.2
378	190.95	0.01834	2.376	2.394	351.48	847.2	1198.6
380	195.60	0.01836	2.321	2.339	353.62	845.4	1199.0
382	200.33	0.01839	2.268	2.286	355.76	843.6	1199.3
384	205.15	0.01842	2.216	2.234	357.90	841.7	1199.6
386	210.06	0.01844	2.165	2.183	360.04	839.9	1199.9
388	215.06	0.01847	2.116	2.134	362.19	838.1	1200.2
390	220.2	0.01850	2.069	2.087	364.34	836.2	1200.5
392	225.3	0.01853	2.021	2.040	366.49	834.4	1200.8

Temp °F	Press Psia	Specific Volume ft.^{3}/lb. v	v	v	Enthalpy Btu/lb. h	h	h
394	230.6	0.01855	1.976	1.995	368.64	832.5	1201.
396	236.0	0.01858	1.932	1.951	370.80	830.6	1204.
398	241.5	0.01861	1.889	1.908	372.96	828.7	1201.
400	247.1	0.01864	1.847	1.866	375.12	826.8	1201.
405	261.4	0.01871	1.747	1.766	380.53	822.0	1202.
410	276.5	0.01878	1.654	1.673	385.97	817.2	1203.
415	292.1	0.01886	1.566	1.585	391.42	812.2	1203.
420	308.5	0.01894	1.483	1.502	396.89	807.2	1204.
425	325.6	0.01901	1.406	1.425	402.38	802.1	1204.
430	343.3	0.01909	1.333	1.352	407.89	796.9	1204.
435	361.9	0.01918	1.265	1.284	413.42	791.7	1205.
440	381.2	0.01926	1.200	1.219	418.98	786.3	1205.
445	401.2	0.01935	1.139	1.158	424.55	780.9	1205.
450	422.1	0.01943	1.082	1.101	430.20	775.4	1205.
455	443.8	0.01952	1.027	1.047	435.80	769.8	1205.
460	466.3	0.01961	0.976	0.996	441.40	764.1	1205.
465	489.8	0.01971	0.928	0.948	447.10	758.3	1205.
470	514.1	0.01980	0.883	0.903	452.80	752.4	1205.
475	539.3	0.01990	0.840	0.8594	458.5	746.4	1204.
480	565.5	0.02000	0.799	0.8187	464.3	740.3	1204.
485	592.6	0.02011	0.760	0.7801	470.1	734.1	1204.
490	620.7	0.02021	0.723	0.7436	475.9	727.8	1203.
495	649.8	0.02032	0.689	0.7090	481.8	721.3	1203.
500	680.0	0.02043	0.656	0.6761	487.7	714.8	1202.
525	847.1	0.02104	0.514	0.5350	517.8	680.0	1197.
550	1044.0	0.02175	0.406	0.4249	549.1	641.6	1190.
575	1274.0	0.02259	0.315	0.3378	581.9	598.6	1180.
600	1541.0	0.02363	0.244	0.2677	616.7	549.7	1166.

PROPERTIES OF WATER

Temp °F	Specific Heat Btu/lb. °F	Density lbs./ft.^{3}	Specific Gravity
32–100	1.00	62.40	1.000
101–150	1.00	61.15	0.980
151–200	1.01	59.90	0.960
201–250	1.02	58.66	0.940
251–300	1.03	57.41	0.920
301–350	1.05	55.85	0.895
351–400	1.08	53.98	0.865
401–450	1.13	51.79	0.830

Part 48: Cleanroom Criteria

48. Part 48: Cleanroom Criteria

48.01. Airborne Contaminants

A. **Particle Classifications**

1. Fine	<2.5 microns
2. Course	2.5 microns
3. Respirable	<10.0 microns
4. Nonrespirable	10.0 microns

B. **Relative Sizes**

1. Micron = 1 millionth of a meter (0.000001 meter) = 39 millionths of an in. (0.000039 in.)	
2. Visible to the naked eye:	25 microns
3. Human hair:	100 microns
4. Dust:	25 microns
5. Optical microscope:	0.25 microns
6. Scanning electron microscope:	0.002 microns
7. Macro particle range	25 microns and larger
8. Micro particle range	1.0–25 microns
9. Molecular macro range	0.085–1.0 microns
10. Molecular range	0.002–0.085 microns
11. Ionic range	0.002 microns and smaller

C. **Airborne particle sizes are given in the following table:**

AIRBORNE PARTICLE SIZE TABLE

Particle	Particle Size Microns	Particle	Particle Size Microns
Plant			
Pollen Spanish moss pollen Mold	10–100 150–750 3–12	Tea dust Grain dusts Sawdust	8–300 5–1,000+ 30–600
Spores Starches Milled flour	3–40 3–100 1–100	Corn starch Pudding mix Cayenne pepper	0.09–0.75 3–160 15–1,000
Milled corn Mustard Ginger	1–100 6–10 25–40	Snuff Textile fibers Corn cob chaff	3–30 8–1,000+ 30–100
Coffee Coffee roast soot	5–400 0.6–3.5	Carbon black Channel black	0.2–10 0.2–100
Animal			
Bacteria	0.3–60	Human hair	60–600

Particle	Particle Size Microns	Particle	Particle Size Microns
Bacteria Viruses Dust mites	0.3–60 0.005–0.1 100–300	Human hair Hair Red blood cells	60–600 5–200 5–10
Spider web Disintegrated feces Feces	2.5 0.8–1.5 10–45	Liquid droplets: sneezed Bone dust	– 0.5–5 3–350
Combustion			
Combustion Tobacco smoke Burning wood	0.01–0.1 0.01–4.5 0.2–3	Smoke particles: natural materials synthetic materials	– 0.01–0.1 1–50
Rosin smoke Coal flue gas Oil smoke	0.01–1 0.08–0.2 0.03–1	Smoldering cooking oil Flaming cooking oil Auto emissions	– 0.3–0.9 0.3–0.9 1–150
Fly ash	0.9–1000		
Mineral			
Asbestos Cement dust Coal dust	0.7–90 3–100 1–100	Carbon dust Carbon dust-graphite Fertilizer	0.25–5 0.02–2 10–1,000
Sea salt Textiles Clay	0.035–0.5 6–20 0.1–50	Ground limestone Lead Bromine	10–1,000 0.1–0.7 0.1–0.7
Calcium, zinc Iron Lead dust	0.7–20 4–20 2	Glass wool Fiberglass Insulation	1,000 8 1–1,000
Talc NH_3Cl fumes	0.5–50 0.1–3	Metallurgical dust Metallurgical fumes	0.1–1,000 0.1–1,000
Other			

Particle	Particle Size Microns	Particle	Particle Size Microns
Atmospheric dust Lung damaging dust Mist	0.001–40 0.6–7 70–350	Yeast cells Sugars Gelatin	2–75 0.0008–0.005 5–90
Oxygen Carbon dioxide Atomic radii	0.00050 0.00065 0.0001–0.001	Beach sand Copier toner Fabric protector	100–10,000 0.5–15 2.5–5
Air freshener Hairspray Spray paint	0.2–2 3–7 8–10	Face powder Lint Humidifier	0.1–30 10–90 0.9–3
Antiperspirant Dusting aid Paint pigments	6–10 6–15 0.1–5	Artificial textile fibers Insecticide dusts	– 10–30 0.5–10

D. **Cleanroom Definitions**

1. A *clean zone* is a defined space in which the concentration of airborne particles is controlled to meet a specified airborne particulate cleanliness class.

2. A *cleanroom* is a room in which the concentration of airborne particles is controlled and which contains one or more clean zones.
   a. An as-built cleanroom is a cleanroom complete and ready for operation, certifiable, with all services connected and functional, but without equipment or operating personnel in the facility.

   b. An at-rest cleanroom is a cleanroom that is complete, with all services functioning and with equipment installed and operable or operating, as specified, but without operating personnel in the facility.

   c. An operational cleanroom is a cleanroom in normal operation, with all services functioning and with equipment and personnel, if applicable, present and performing their normal work functions in the facility.

48.02. Cleanroom Class Designations: FED-STD-209E

CLEANROOM CLASS DESIGNATIONS

Cleanroom Class Name		0.1 µm Volume Units		0.2 µm Volume Units		0.3 µm Volume Units		0.! Volun
		Class Limits						
SI	English	M^3	$Ft.^3$	M^3	$Ft.^3$	M^3	$Ft.^3$	M^3
M1		350	9.91	75.7	2.14	30.9	0.875	10.0
M1.5	1	1,240	35.0	265	7.50	106	3.00	35.3
M2		3,500	99.1	757	21.4	309	8.75	100
M2.5	10	12,400	350	2,650	75.0	1,060	30.0	353
M3		35,000	991	7,570	214	3,090	87.5	1,000
M3.5	100	–	–	26,500	750	10,600	300	3,530
M4		–	–	75,700	2,140	30,900	875	10,000
M4.5	1,000	–	–	–	–	–	–	35,300
M5		–	–	–	–	–	–	100,000
M5.5	10,000	–	–	–	–	–	–	353,000
M6		–	–	–	–	–	–	1,000,000
M6.5	100,000	–	–	–	–	–	–	3,530,000
M7		–	–	–	–	–	–	10,000,00

Notes:

1. **Federal Standard 209E is obsolete and superseded by the Internation ISO 14644.**
2. **Federal Standard 209E information provided for comparison purposes**

48.03. Cleanroom Class Designations: ISO Standard 14644-1

CLEANROOM CLASS DESIGNATIONS

Maximum Number of Particles in the Air (Particles in Each Cubic Meter Equal to or Greater than the Specified Particle

ISO Class	Maximum Number of Particles in the Air (Particles in Each Cubic Meter Equal to or Greater than the Specified Particle Size)					
	Particle Size					
	>0.1 µm	>0.2 µm	>0.3 µm	>0.5 µm	>1.0 µm	>5.0 µm
ISO Class 1	10	2	0	0	0	0
ISO Class 2	100	24	10	4	0	0
ISO Class 3	1,000	237	102	35	8	0
ISO Class 4	10,000	2,370	1,020	352	83	0
ISO Class 5	100,000	23,700	10,200	3,520	832	29
ISO Class 6	1,000,000	237,000	102,000	35,200	8,320	293
ISO Class 7				352,000	83,200	2,930
ISO Class 8				3,520,000	832,000	29,300
ISO Class 9				35,200,000	8,320,000	293,000

Notes:

1. **Cleanrooms are maintained virtually free of contaminants, such as**

dust or bacteria, are used in laboratory work, and in the production of precision parts for electronic or aerospace equipment.

ISO Class	Maximum Number of Particles in the Air (Particles in Each Cubic Meter Equal to or Greater than the Specified Particle Size)					
	Particle Size					
	>0.1 µm	>0.2 µm	>0.3 µm	>0.5 µm	>1.0 µm	>5.0 µm

2. In the cleanroom standard ISO 14644-1 *Classification of Air Cleanliness*, the classes are based on the formula:

   $C_n = 10^N (0.1/D)^{2.08}$

   where

   C_n = the maximum permitted number of particles per cubic meter equal to or greater than the specified particle size, rounded to a whole number

   N = the ISO Class number, which must be a multiple of 1 and be 9 or less

   D = the particle size in micrometers

3. ISO Cleanroom Standards

   ISO 14644-1 Classification of Air Cleanliness
   ISO 14644-2 Cleanroom Testing for Compliance
   ISO 14644-3 Methods for Evaluating and Measuring Cleanroom and Associated Controlled Environment
   ISO 14644-4 Cleanroom Design and Construction
   ISO 14644-5 Cleanroom Operations
   ISO 14644-6 Terms, Definitions, and Units
   ISO 14644-7 Enhanced Clean Devices
   ISO 14644-8 Molecular Contamination
   ISO 14698-1 Bio-contamination: Control General Principles
   ISO 14698-2 Bio-contamination: Evaluation and Interpretation of Data
   ISO 14698-3 Bio-contamination: Methodology for Measuring Efficiency of Cleaning Inert Surfaces

48.04. Cleanroom Design Criteria

CLEANROOM DESIGN CRITERIA

Cleanroom Design Criteria	Federal Standard 209e Classifications English/Metric					
	1	10	100	1,000	10,000	100,(
	M1.5	M2.5	M3.5	M4.5	M5.5	M6.
Notes / Ventilation	360	360	210–540	120	30–120	12–60

Federal Standard 209e Classifications English/Metric

Cleanroom Design Criteria	1 M1.5	10 M2.5	100 M3.5	1,000 M4.5	10,000 M5.5	100,0 M6.
Circulation Rate AC/h (8)	360–540	360–540	210–540	120–300	30–120	12–6
Room Air Velocity ft./min.	60–90	60–90	35–90 (1)	20–50	5–20	2–10
% Filter Coverage	100	100	50–100 (1)	25–60	10–40	5–20
Room Characteristics	Laminar	Laminar	Laminar/non-laminar	Non-laminar	Non-laminar	Non-lamin
Unidirectional Flow	Yes	Yes	Yes/No	No	No	No
Parallelism Degrees (2)	10–35	10–35	10–35 N/A	N/A	N/A	N/A

Notes:

1. **Velocity and filter coverage could be reduced possibly as low as 35 fp and 50 percent coverage if parallelism requirements are relaxed by th client.**

2. **Parallelism requirements are often driven by a client's standard facili criteria.**

3. **Makeup air: 1–6 CFM/sq.ft.**

4. **Pressurization requirement: 1/4–1/2 CFM/sq.ft.**

5. **Temperature**
   a. **Range: 68–74°F**

   b. **Tolerance: ±0.1–±2.0°F**

   c. **Change rate: 0.75–2.0°F/h**

   d. **Example: 72°F, ±2.0°F**

6. **Relative humidity**
   a. **Range: 30–50 percent RH**

   b. **Tolerance: ±1.0–± 5.0 percent RH**

   c. **Change rate: 1.0–5.0 percent RH/h**

c. Change rate: 1.0–5.0 percent RH/h

d. Example: 45 percent RH, ±5.0 percent RH

Cleanroom Design Criteria	Federal Standard 209e Classifications English/Metric					
	1	10	100	1,000	10,000	100,0
	M1.5	M2.5	M3.5	M4.5	M5.5	M6.

7. Fire protection/smoke purge exhaust: 3–5 CFM/sq ft.

8. The air change rate is based on a 10'0" ceiling height.

Refer to the online resource for Sections 48.05 Areas and Circumferences of Circles, 48.06 Fraction/Decimal Equivalents, 48.07 Physical Properties of Fuels and Oils, and 48.08 U.S. Postal Service Abbreviations. www.mheducation.com/HVACequations

48.05. Areas and Circumferences of Circles

AREAS AND CIRCUMFERENCES OF CIRCLES

Diameter in Inches	Area		Circumference	
	Square Inches	Square Feet	Inches	Feet
0.5	0.20	0.0014	1.57	0.1309
0.75	0.44	0.0031	2.36	0.1963
1	0.79	0.0055	3.14	0.2618
1.25	1.23	0.0085	3.93	0.3272
1.5	1.77	0.0123	4.17	0.3927
2	3.14	0.0218	6.28	0.5236
2.5	4.91	0.0341	7.85	0.6545
3	7.07	0.0491	9.42	0.7854
3.5	9.62	0.0668	11.00	0.9163
4	12.57	0.0873	12.57	1.0472
4.5	15.90	0.1104	14.14	1.1781
5.0	19.63	0.1364	15.71	1.3090
5.5	23.76	0.1650	17.28	1.4399
6	28.27	0.1963	18.85	1.5708
6.5	33.18	0.2304	20.42	1.7017
7	38.48	0.2673	21.99	1.8326

Diameter in Inches	Area		Circumference	
	Square Inches	Square Feet	Inches	Feet
7.5	44.18	0.3068	23.56	1.9635
8	50.27	0.3491	25.13	2.0944
8.5	56.75	0.3941	26.70	2.2253
9	63.62	0.4418	28.27	2.3562
9.5	70.88	0.4922	29.85	2.4871
10	78.54	0.5454	31.42	2.6180
10.5	86.59	0.6013	32.99	2.7489
11	95.03	0.6600	34.56	2.8798
11.5	103.87	0.7213	36.13	3.0107
12	113.10	0.7854	37.70	3.1416
13	132.73	0.9218	40.84	3.4034
14	153.94	1.0690	43.98	3.6652
15	176.71	1.2272	47.12	3.9270
16	201.06	1.3963	50.27	4.1888
17	226.98	1.5763	53.41	4.4506
18	254.47	1.7671	56.55	4.7124
19	283.53	1.9689	59.69	4.9742
20	314.16	2.1817	62.83	5.2360
21	346.36	2.4053	65.97	5.4978
22	380.13	2.6398	69.12	5.7596
23	415.48	2.8852	72.26	6.0214
24	452.39	3.1416	75.40	6.2832
25	490.87	3.4088	78.54	6.5450
26	530.93	3.6870	81.68	6.8068
27	572.56	3.9761	84.82	7.0686
28	615.75	4.2761	87.96	7.3304
29	660.52	4.5869	91.11	7.5922
30	706.86	4.9087	94.25	7.8540
31	754.77	5.2414	97.39	8.1158
32	804.25	5.5851	100.53	8.3776
33	855.30	5.9396	103.67	8.6394
34	907.92	6.3050	106.81	8.9012
35	962.11	6.6813	109.96	9.1630
36	1017.88	7.0686	113.10	9.4248
37	1075.21	7.4667	116.24	9.6866

Diameter in Inches	Area		Circumference	
	Square Inches	Square Feet	Inches	Feet
38	1134.11	7.8758	119.38	9.9484
39	1194.59	8.2958	122.52	10.2102
40	1256.64	8.7266	125.66	10.4720
41	1320.25	9.1684	128.81	10.7338
42	1385.44	9.6211	131.95	10.9956
43	1452.20	10.0847	135.09	11.2574
44	1520.53	10.5592	138.23	11.5192
45	1590.43	11.0447	141.37	11.7810
46	1661.90	11.5410	144.51	12.0428
47	1734.94	12.0482	147.65	12.3046
48	1809.55	12.5663	150.80	12.5663
49	1885.74	13.0954	153.94	12.8282
50	1963.50	13.6354	157.08	13.0900
52	2123.72	14.7480	163.36	13.6136
54	2290.22	15.9043	169.65	14.1372
56	2463.01	17.1042	175.93	14.6608
58	2642.08	18.3478	182.21	15.1844
60	2827.43	19.6350	188.50	15.7080
62	3019.07	20.9658	194.78	16.2316
64	3216.99	22.3402	201.06	16.7552
66	3421.19	23.7583	207.35	17.2788
68	3631.68	25.2200	213.63	17.8024
70	3848.45	26.7254	219.91	18.3260
72	4071.50	28.2743	226.19	18.8496
74	4300.84	29.8669	232.48	19.3732
76	4536.46	31.5032	238.76	19.8968
78	4778.36	33.1831	245.04	20.4204
80	5026.55	34.9066	251.33	20.9440
82	5281.02	36.6737	257.61	21.4675
84	5541.77	38.4845	263.89	21.9911
86	5808.80	40.3389	270.18	22.5147
88	6082.12	42.2370	276.46	23.0383
90	6361.73	44.1786	282.74	23.5619

48.06. Fraction/Decimal Equivalents

FRACTION/DECIMAL EQUIVALENTS

64THS	32NDS	16THS	8THS	4THS	Half	Whole	Decimal
1/64	–	–	–	–	–	–	0.0156
2/64	1/32	–	–	–	–	–	0.0313
3/64	–	–	–	–	–	–	0.0469
4/64	2/32	1/16	–	–	–	–	0.0625
5/64	–	–	–	–	–	–	0.0781
6/64	3/32	–	–	–	–	–	0.0938
7/64	–	–	–	–	–	–	0.1094
8/64	4/32	2/16	1/8	–	–	–	0.1250
9/64	–	–	–	–	–	–	0.1406
10/64	5/32	–	–	–	–	–	0.1563
11/64	–	–	–	–	–	–	0.1719
12/64	6/32	3/16	–	–	–	–	0.1875
13/64	–	–	–	–	–	–	0.2031
14/64	7/32	–	–	–	–	–	0.2188
15/64	–	–	–	–	–	–	0.2344
16/64	8/32	4/16	2/8	1/4	–	–	0.2500
17/64	–	–	–	–	–	–	0.2656
18/64	9/32	–	–	–	–	–	0.2813
19/64	–	–	–	–	–	–	0.2969
20/64	10/32	5/16	–	–	–	–	0.3125
21/64	–	–	–	–	–	–	0.3281
22/64	11/32	–	–	–	–	–	0.3438
23/64	–	–	–	–	–	–	0.3594
24/64	12/32	6/16	3/8	–	–	–	0.3750
25/64	–	–	–	–	–	–	0.3906
26/64	13/32	–	–	–	–	–	0.4063
27/64	–	–	–	–	–	–	0.4219
28/64	14/32	7/16	–	–	–	–	0.4375
29/64	–	–	–	–	–	–	0.4531
30/64	15/32	–	–	–	–	–	0.4688

64	32	16	8	4	Half	Whole	Decimal
31/64	–	–	–	–	–	–	0.4844
32/64	16/32	8/16	4/8	2/4	1/2	–	0.5000
33/64	–	–	–	–	–	–	0.5156
34/64	17/32	–	–	–	–	–	0.5312
35/64	–	–	–	–	–	–	0.5469
36/64	18/32	9/16	–	–	–	–	0.5625
37/64	–	–	–	–	–	–	0.5781
38/64	19/32	–	–	–	–	–	0.5938
39/64	–	–	–	–	–	–	0.6094
40/64	20/32	10/16	5/8	–	–	–	0.6250
41/64	–	–	–	–	–	–	0.6406
42/64	21/32	–	–	–	–	–	0.6563
43/64	–	–	–	–	–	–	0.6719
44/64	22/32	11/16	–	–	–	–	0.6875
45/64	–	–	–	–	–	–	0.7031
46/64	23/32	–	–	–	–	–	0.7188
47/64	–	–	–	–	–	–	0.7343
48/64	24/32	12/16	6/8	3/4	–	–	0.7500
49/64	–	–	–	–	–	–	0.7656
50/64	25/32	–	–	–	–	–	0.7813
51/64	–	–	–	–	–	–	0.7969
52/64	26/32	13/16	–	–	–	–	0.8125
53/64	–	–	–	–	–	–	0.8281
54/64	27/32	–	–	–	–	–	0.8438
55/64	–	–	–	–	–	–	0.8594
56/64	28/32	14/16	7/8	–	–	–	0.8750
57/64	–	–	–	–	–	–	0.8906
58/64	29/32	–	–	–	–	–	0.9063
59/64	–	–	–	–	–	–	0.9219
60/64	30/32	15/16	–	–	–	–	0.9375
61/64	–	–	–	–	–	–	0.9531
62/64	31/32	–	–	–	–	–	0.9688
63/64	–	–	–	–	–	–	0.9844
64/64	32/32	16/16	8/8	4/4	2/2	1	1.0000

48.07. Physical Properties of Fuels and Oils

PHYSICAL PROPERTIES OF FUELS AND OILS

Substance	Formula	Molecular Weight	Phase	Specific Volume cu.ft./lb.m	Density lbs.m/cu.ft.	S G
Fuels						
Gasoline	–	113.0	Liq.	0.0223	44.9	0.
Kerosene	–	154.0	Liq.	0.0200	49.9	0.
Diesel Fuel (1-D)	–	170.0	Liq.	0.0183	54.6	0.
Diesel Fuel (2-D)	–	184.0	Liq.	0.0174	57.4	0.
Diesel Fuel (4-D)	–	198.0	Liq.	0.0167	59.9	0.
Fuel Oil No. 1	–	–	Liq.	0.0183	54.6	0.
Fuel Oil No. 2	–	–	Liq.	0.0174	57.4	0.
Fuel Oil No. 4	–	198.0	Liq.	0.0167	59.8	0.
Fuel Oil No. 5 Lt	–	–	Liq.	0.0167	59.9	0.
Fuel Oil No. 5 Hv	–	–	Liq.	0.0167	59.9	0.
Fuel Oil No. 6	–	–	Liq.	0.0167	59.9	0.
Paraffin or Alkane Series						
Methane (Nat. Gas)	CH_4	16.041	Gas	24.0963	0.0415	0.
Ethane	C_2H_6	30.067	Gas	12.9032	0.0775	1.

Substance	Formula	Molecular Weight	Phase	Specific Volume cu.ft./lb.m	Density lbs.m/cu.ft.	S G
Propane	C_3H_8	44.092	Gas	8.7719	0.114	1.
N-Butane	C_4H_{10}	58.118	Gas	0.0276	36.14	4
Isobutane	C_4H_{10}	58.118	Gas	0.0288	34.77	4
N-Pentane	C_5H_{12}	72.144	Liq.	0.0256	39.08	0.
Isopentane	C_5H_{12}	72.144	Liq.	0.0258	38.77	0.
Neopentane	C_5H_{12}	72.144	Gas	0.0261	38.27	5
N-Hexane	C_6H_{14}	86.178	Liq.	0.0243	41.14	0.
Neohexane	C_6H_{14}	86.178	Liq.	0.0247	40.51	0.
N-Heptane	C_7H_{16}	100.206	Liq.	0.0239	41.70	0.
Triptane	C_7H_{16}	100.206	Liq.	0.0232	43.07	0.
N-Octane	C_8H_{18}	114.223	Liq.	0.0227	44.14	0.
Iso-Octane	C_8H_{18}	114.223	Liq.	0.0228	43.82	0.
Olefin or Alkene Series						
Ethylene	C_2H_4	28.054	Gas	13.6426	0.0733	0.
Propylene	C_3H_6	42.081	Gas	7.5187	0.113	1.
Butylene	C_4H_8	56.108	Gas	0.0269	37.12	4
Isobutene	C_4H_8	56.108	Gas	0.0272	36.83	4
N-Pentene	C_5H_{10}	70.135	Liq.	0.0250	40.02	0.
Aromatic Series						
Benzene	C_6H_6	78.114	Liq.	0.0172	58.18	0.
Toluene	C_7H_8	92.141	Liq.	0.0181	55.31	0.
Xylene	C_8H_{10}	106.169	Liq.	0.0186	53.75	0.
Other Hydrocarbons						
Acetylene	C_2H_2	26.038	Gas	14.8148	0.0675	0.
Naphthalene	$C_{10}H_8$	128.175	Solid	–	71.48	–
Methyl Alcohol	CH_3OH	32.041	Liq.	0.0204	49.10	0.
Ethyl Alcohol	C_2H_5OH	46.067	Liq.	0.0204	49.01	0.

Substance	Formula	Molecular Weight	Phase	Specific Volume cu.ft./lb.m	Density lbs.m/cu.ft.	S G
Motor Oils						
5W	–	–	Liq.	0.0176	54.9–58.7	0. 0.
10W	–	–	Liq.	0.0176	54.9–58.7	0. 0.
20W	–	–	Liq.	0.0176	54.9–58.7	0. 0.
30W	–	–	Liq.	0.0176	54.9–58.7	0. 0.
40W	–	–	Liq.	0.0176	54.9–58.7	0. 0.
50W	–	–	Liq.	0.0176	54.9–58.7	0. 0.
Gear Oils						
75W	–	–	Liq.	0.0176	54.9–58.7	0. 0.
80W	–	–	Liq.	0.0176	54.9–58.7	0. 0.
85W	–	–	Liq.	0.0176	54.9–58.7	0. 0.
90	–	–	Liq.	0.0176	54.9–58.7	0. 0.
120	–	–	Liq.	0.0176	54.9–58.7	0. 0.
140	–	–	Liq.	0.0176	54.9–58.7	0. 0.
150	–	–	Liq.	0.0176	54.9–58.7	0. 0.

PHYSICAL PROPERTIES OF FUELS AND OILS

Flammability

Boiling Pt **Ignition** **Limits (in**

Substance	Boiling Pt. °F	Ignition Temp. °F	Flash Point	Flammability Limits (in Air) % by Volume
Fuels				
Gasoline	100–400	536	–45	1.4–7.6
Kerosene	304–574	410	100–162	0.7–5.0
Diesel Fuel (1-D)	–	–	100	–
Diesel Fuel (2-D)	–	–	125	–
Diesel Fuel (4-D)	–	–	130	–
Fuel Oils No. 1	304–574	410	100–162	0.7–5.0
Fuel Oils No. 2	–	494	126–204	–
Fuel Oils No. 4	–	505	142–240	–
Fuel Oils No. 5 Lt	–	–	156–336	–
Fuel Oils No. 5 Hv	–	–	160–250	–
Fuel Oils No. 6	–	–	150	–
Paraffin or Alkane Series				
Methane (Nat. Gas)	–258.7	900–1170	Gas	5.0–15.0
Ethane	–127.5	959	Gas	3.0–12.5
Propane	–43.8	842	Gas	2.1–10.1
N-Butane	31.1	761	–76	1.86–8.41
Isobutane	10.9	864	–117	1.80–8.44
N-Pentane	97.0	500	<–40	1.40–7.80

Substance	Boiling Pt. °F	Ignition Temp. °F	Flash Point	Flammability Limits (in Air) % by Volume
Isopentane	82.2	788	<–60	1.32–9.16
Neopentane	49.1	842	Gas	1.38–7.22
N-Hexane	155.7	437	–7	1.25–7.0
Neohexane	121.5	797	–54	1.19–7.58
N-Heptane	209.1	419	25	1.00–6.00
Triptane	177.6	849	–	1.08–6.69
N-Octane	258.3	428	56	0.95–3.20
Iso-Octane	243.9	837	10	0.79–5.94
Olefin or Alkene Series				
Ethylene	–154.7	914	Gas	2.75–28.6
Propylene	–53.9	856	Gas	2.00–11.1
Butylene	21.2	829	Gas	1.98–9.65
N-Butene	–	–	–	–
Isobutene	19.6	869	Gas	1.8–9.0
N-Pentene	86.0	569	–	1.65–7.70
Aromatic Series				
Benzene	176.2	1040	12	1.35–6.65
Toluene	321.1	992	40	1.27–6.75
Xylene	281.1	867	63	1.00–6.00
Other Hydrocarbons				
Acetylene	–119.2	581	Gas	2.50–100
Naphthalene	424.4	959	174	0.90–5.90
Methyl Alcohol	151	725	–	6.7–36.0
Ethyl Alcohol	172	689	–	3.3–19.0
Motor Oils				
5W	–	–	420	–
10W	–	–	425	–

Substance	Boiling Pt. °F	Ignition Temp. °F	Flash Point	Flammability Limits (in Air) % by Volume
10W			425	
20W	–	–	465	–
30W	–	–	450	–
40W	–	–	475	–
50W	–	–	485	–
Gear Oils				
75W	–	–	375	–
80W	–	–	425	–
85W	–	–	435	–
90	–	–	425	–
120	–	–	425	–
140	–	–	580	–
150	–	–	580	–

48.08. U.S. Postal Service Abbreviations

U.S. POSTAL SERVICE ABBREVIATIONS

United States Postal Service Standard Abbreviations

State	Abbrev.	State	Abbrev.
Alabama	AL	Montana	MT
Alaska	AK	Nebraska	NE
Arizona	AZ	Nevada	NV
Arkansas	AR	New Hampshire	NH
California	CA	New Jersey	NJ
Colorado	CO	New Mexico	NM
Connecticut	CT	New York	NY
Delaware	DE	North Carolina	NC
District of Columbia	DC	North Dakota	ND

United States Postal Service Standard Abbreviations

State	Abbrev.	State	Abbrev.
Columbia			
Florida	FL	Ohio	OH
Georgia	GA	Oklahoma	OK
Hawaii	HI	Oregon	OR
Idaho	ID	Pennsylvania	PA
Illinois	IL	Puerto Rico	PR
Indiana	IN	Rhode Island	RI
Iowa	IA	South Carolina	SC
Kansas	KS	South Dakota	SD
Kentucky	KY	Tennessee	TN
Louisiana	LA	Texas	TX
Maine	ME	Utah	UT
Maryland	MD	Vermont	VT
Massachusetts	MA	Virginia	VA
Michigan	MI	Washington	WA
Minnesota	MN	West Virginia	WV
Mississippi	MS	Wisconsin	WI
Missouri	MO	Wyoming	WY

Part 49: Wind Chill and Heat Index

49. Part 49: Wind Chill and Heat Index

49.01. Wind Chill Index

WIND CHILL INDEX

°F Dry Bulb	Wind Velocity (mph) 0 Calm	5	10	15	20	25	30	35	40	45	50
35	35	33	21	16	12	7	5	3	1	1	0
30	30	27	16	11	3	0	–2	–4	–5	–6	–7
25	25	21	9	1	–4	–7	–11	–13	–15	–17	–17
20	20	16	2	–6	–9	–15	–18	–20	–22	–24	–24
15	15	12	–2	–11	–17	–22	–26	–27	–29	–31	–31
10	10	7	–9	–18	–24	–29	–33	–35	–37	–38	–39
5	5	0	–15	–25	–32	–37	–41	–43	–45	–46	–47
0	0	–6	–22	–33	–40	–45	–49	–52	–53	–54	–56
–5	–5	–11	–27	–40	–46	–52	–56	–60	–62	–63	–63
–10	–10	–15	–31	–45	–52	–58	–63	–67	–69	–70	–70
–15	–15	–20	–38	–51	–60	–67	–70	–72	–76	–78	–79
–20	–20	–25	–45	–60	–68	–75	–78	–83	–87	–87	–88
–25	–25	–31	–52	–65	–76	–83	–87	–90	–94	–94	–96

Notes:

°F Dry Bulb	Wind Velocity (mph)										
	0 Calm	5	10	15	20	25	30	35	40	45	50
–30	–30	–35	–58	–70	–81	–89	–94	–98	–101	–101	–103
–35	–35	–41	–64	–78	–88	–96	–101	–105	–107	–108	–110
–40	–40	–47	–70	–85	–96	–104	–109	–113	–116	–118	–120
–45	–45	–54	–77	–90	–103	–112	–117	–123	–128	–129	–130

Notes:

1. **The table provides equivalent wind chill temperatures at various outside dry bulb temperatures and corresponding wind velocities.**
2. **Wind speeds greater than 40 mph have little additional chilling effect.**
3. **$WCF \cong T_{DB} - (1.5 \times W_S)$**
   WCF = Wind Chill Factor
   T_{DB} = Dry Bulb Air Temperature
   W_S = Wind Speed

49.02. Heat Index

HEAT INDEX

%RH	Apparent Temperature, °F Temperature, °F											
	70	75	80	85	90	95	100	105	110	115	120	125
0	64	69	73	78	83	87	91	95	99	103	107	111
5	64	69	74	79	84	88	83	97	102	107	111	115
10	65	70	75	80	85	90	95	100	105	111	116	123
15	65	71	76	81	85	91	97	102	106	115	123	131
20	66	72	77	82	87	93	99	105	112	120	130	141
[illegible]	66	72	77	83	88	94	101	109	117	127	139	

Notes:

%RH	Apparent Temperature, °F Temperature, °F											
	70	**75**	**80**	**85**	**90**	**95**	**100**	**105**	**110**	**115**	**120**	**125**
25	66	72	77	83	88	94	101	109	117	127	139	
30	67	73	78	84	90	96	104	113	123	135	148	
35	67	73	79	85	91	98	107	118	130	143		
40	68	74	79	86	93	101	110	123	137	151		
45	68	74	80	87	95	104	115	129	143			
50	69	75	81	88	96	107	120	135	150			
55	69	75	81	89	96	110	126	142				
60	70	76	82	90	100	114	132	149				
65	70	76	83	91	102	119	138					
70	70	77	85	93	106	124	144					
75	70	77	86	95	109	130						
80	71	77	86	97	113	136						
85	71	78	87	99	117							
90	71	79	88	102	122							
95	71	79	89	105								
100	72	80	91	106								

Notes:

1. **The table provides equivalent heat index temperatures at various ten corresponding relative humidities.**

2. **The heat index is a measure of how the average person perceives ten humidity and how it affects the body's ability to cool itself.**

3. **Sunstroke and heat exhaustion are likely when the heat index is 105 (**

Citation

EXPORT

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. Part 49: Wind Chill and Heat Index, Chapter (McGraw-Hill Professional, 2016), AccessEngineering

Part 50: General Notes

50. Part 50: General Notes

50.01. General

A. Provide all materials and equipment and perform all labor required to install complete and operable mechanical systems as indicated on the drawings, as specified, and as required by code.

B. Contract document drawings for mechanical work (HVAC, plumbing, and fire protection) are diagrammatic and are intended to convey scope and general arrangement only.

C. Install all mechanical equipment and appurtenances in accordance with manufacturers' recommendations, contract documents, and applicable codes and regulations.

D. Provide vibration isolation for all mechanical equipment to prevent transmission of vibration to building structure.

E. Provide vibration isolators for all piping supports connected to, and within 50 ft. of, isolated equipment (except at base elbow supports and anchor points) throughout mechanical equipment rooms. Do the same for supports of steam mains within 50 ft. of boiler or pressure-reducing valves.

F. Provide vibration isolators for all piping supports of steam mains within 50 ft. of boilers and pressure-reducing valves.

G. The location of existing underground utilities is shown in an approximate way only. The contractor shall determine the exact location

of all existing utilities before commencing work. The contractor shall pay for and repair all damages caused by failure to exactly locate and preserve any and all underground utilities unless otherwise indicated.

H. Coordinate construction of all mechanical work with architectural, structural, civil, electrical work, etc., shown on other contract document drawings.

I. Maintain a minimum 6'8" clearance to the underside of pipes, ducts, conduits, suspended equipment, etc., throughout access routes in mechanical rooms.

J. All tests shall be completed before any mechanical equipment or piping insulation is applied.

K. Locate all temperature, pressure, and flow measuring devices in accessible locations with the straight section of pipe or duct up- and downstream as recommended by the manufacturer for good accuracy.

L. Testing, adjusting, and balancing agency shall be a member of the Associated Air Balance Council (AABC) or the National Environmental Balancing Bureau (NEBB). Testing, adjusting, and balancing shall be performed in accordance with the AABC standards.

M. Where two or more items of the same type of equipment are required, the product of one manufacturer shall be used.

N. Reinforcement, detailing, and placement of concrete shall conform to *ASTM 315* and *ACI 318*. Concrete shall conform to *ASTM C94*. Concrete work shall conform to *ACI 318*, part entitled "Construction Requirements." Compressive strength in 28 days shall be 3,000 psi. Total air content of exterior concrete shall be between 5 and 7 percent by volume. Slump shall be between 3 and 4 in. Concrete shall be cured for 7 days after placement.

O. Coordinate all equipment connections with manufacturers' certified drawings. Coordinate and provide all duct and piping transitions required for final equipment connections to furnished equipment. Field verify and coordinate all duct and piping dimensions before fabrication.

P. All control wire and conduit shall comply with the National Electric Code and Division 16 of the specification.

Q. Concrete housekeeping pads to suit mechanical equipment shall be sized and located by the mechanical contractor. Minimum concrete pad thickness shall be 6 in. Pad shall extend beyond the equipment a minimum of 6 in. on each side. Concrete housekeeping pads shall be provided by the general contractor. It shall be the responsibility of the mechanical contractor to coordinate the size and location of concrete housekeeping pads with the general contractor.

R. All mechanical room doors shall be a minimum of 4'0" wide.

S. Where beams are indicated to be penetrated with ductwork or piping, coordinate ductwork and piping layout with beam opening size and opening locations. Coordination shall be done prior to the fabrication of ductwork, cutting of piping, or fabrication of beams.

T. When mechanical work (HVAC, plumbing, sheet metal, fire protection, etc.) is subcontracted, it shall be the mechanical contractor's responsibility to coordinate subcontractors and the associated contracts. When discrepancies arise pertaining to which contractor provides a particular item of the mechanical contract or which contractor provides final connections for a particular item of the mechanical contract, it shall be brought to the attention of the mechanical contractor, whose decision shall be final.

U. The locations of all items shown on the drawings or called for in the specifications that are not definitely fixed by dimensions are approximate only. The exact locations necessary to secure the best conditions and results must be determined by the project site conditions and shall have the approval of the engineer before being installed. Do not scale drawings.

V. All miscellaneous steel required to ensure proper installation and as shown in details for piping, ductwork, and equipment (unless otherwise noted) shall be furnished and installed by the mechanical contractor.

W. Provide access panels for installation in walls and ceilings, where required, to service dampers, valves, smoke detectors, and other concealed mechanical equipment. Access panels shall be turned over to the general contractor for installation.

X. All equipment, piping, ductwork, etc., shall be supported as detailed, specified, and required to provide a vibration-free installation.

Y. All ductwork, piping, and equipment supported from structural steel shall be coordinated with the general contractor. All attachments to steel bar joists, trusses, or joist girders shall be at panel points. Provide beam clamps meeting MSS standards. Welding to structural members shall not be permitted. The use of C-clamps shall not be permitted.

Z. Mechanical equipment, ductwork, and piping shall not be supported from a metal deck.

AA. All roof-mounted equipment curbs for equipment provided by the mechanical contractor shall be furnished by the mechanical contractor and installed by the general contractor.

BB. Locations and sizes of all floor, wall, and roof openings shall be coordinated with all other trades involved.

CC. All openings in fire walls due to ductwork, piping, conduit, etc., shall be fire stopped with a product similar to 3M or an approved equal.

DD. All air conditioning condensate drain lines from each air handling unit and rooftop unit shall be piped full size of the unit drain outlet, with "P" trap, and piped to the nearest drain. See the details shown in the drawings or the contract specifications for the depth of the air conditioning condensate trap.

EE. Refer to typical details for ductwork, piping, and equipment installation.

50.02. Piping

A. Provide all materials and equipment and perform all labor required to install complete and operable piping systems as indicated on the drawings, as specified, and as required by code.

B. Elevations shown on the drawings are to the bottom of all pressure piping and to the invert of all gravity piping unless otherwise noted.

C. Maintain a minimum of 36" of ground cover over all underground HVAC piping (edit the depth of the ground cover to suit frost line depth and project requirements).

D. Unless otherwise noted, all chilled water and heating water piping shall be 3/4 in. size (edit system type or pipe size to suit project requirements).

E. Provide an air vent at the high point of each drop in the heating-water, chilled-water, and other closed-water piping systems (edit system types to suit the project requirements). All piping shall grade to low points. Provide hose end drain valves at the bottom of all risers and low points.

F. Unless otherwise noted, all piping is overhead, tight to the underside of the structure or slab, with space for insulation if required.

G. Install piping so all valves, strainers, unions, traps, flanges, and other appurtenances requiring access are accessible.

H. All valves shall be installed so that the valve remains in service when equipment or piping on the equipment side of the valve is removed.

I. All balancing valves and butterfly valves shall be provided with position indicators and maximum adjustable stops (memory stops).

J. Provide chainwheel operators for all valves in equipment rooms mounted greater than 7'0" above floor level; chain shall extend to 7'0" above floor level.

K. All valves (except control valves) and strainers shall be the full size of the pipe before reducing in size to make connections to equipment and controls.

L. Unions and/or flanges shall be installed at each piece of equipment, in bypasses, and in long piping runs (100 ft. or more) to permit disassembly for alteration and repairs.

M. Pitch steam piping downward in the direction of flow 1/4 in. per 10 ft. (1 in. in 40 ft.) minimum. Pitch all steam return lines downward in the direction of condensate flow 1/2 in. per 10 ft. (1 in. in 20 ft.) minimum. Where the length of branch lines is less than 8 ft., pitch branch lines toward mains 1/2 in. per ft. minimum.

N. Pitch up all steam and condensate runouts to risers and equipment 1/2 in./ft. Where this pitch cannot be obtained, runouts over 8 ft. in length shall be one size larger than noted.

O. Tap all branch lines from the top of steam mains (45 degrees preferred; 90 degrees acceptable).

P. Provide an end of main drip at each rise in the steam main. Provide condensate drips at the bottom of all steam risers, downfed runouts to equipment, radiators, etc., at the end of mains and low points, and ahead of all pressure regulators, control valves, isolation valves, and expansion joints.

Q. On straight steam piping runs with no natural drainage points, install drip legs at intervals not exceeding 200 ft. where the pipe is pitched downward in the direction of steam flow and a maximum of 100 ft. where the pipe is pitched up so that condensate flow is opposite of steam flow.

R. Steam traps shall be minimum 3/4" size.

S. Install all piping without forcing or springing.

T. All piping shall clear doors and windows.

U. All valves shall be adjusted for smooth and easy operation.

V. All piping work shall be coordinated with all trades involved. Offsets in piping around obstructions shall be provided at no additional cost to the owner.

W. Provide flexible connections in all piping systems connected to pumps, chillers, cooling towers, and other equipment which require vibration isolation except water coils. Flexible connections shall be provided as close to the equipment as possible or as indicated on the drawings.

X. Slope refrigerant piping one percent in the direction of oil return. Liquid lines may be installed level.

Y. Install horizontal refrigerant hot gas discharge piping with 1/2" per 10 ft. downward slope away from the compressor.

Z. Install horizontal refrigerant suction lines with 1/2" per 10 ft.

downward slope to the compressor, with no long traps or dead ends that may cause oil to separate from the suction gas and return to the compressor in damaging slugs.

AA. Provide line size liquid indicators in the main liquid line leaving the condenser or receiver. Install moisture-liquid indicators in liquid lines between filter dryers and thermostatic expansion valves, and in liquid line to receiver.

BB. Provide a line size strainer upstream of each automatic valve. Provide a shutoff valve on each side of the strainer.

CC. Provide permanent filter dryers in low-temperature systems and systems using hermetic compressors.

DD. Provide replaceable cartridge filter dryers with a three-valve bypass assembly for solenoid valves, adjacent to receivers.

EE. Provide refrigerant charging valve connections in the liquid line between the receiver shutoff valve and the expansion valve.

50.03. Plumbing

A. Provide all materials and equipment and perform all labor required to install complete and operable plumbing systems as indicated on the drawings, as specified, and as required by code.

B. Run all soil waste and vent piping with 2 percent minimum grade unless otherwise noted (edit the slope to suit project requirements). Horizontal vent piping shall be graded to drip back to the soil or waste pipe by gravity.

C. Elevations shown on the drawings are to the bottom of all pressure piping and to the invert of all gravity piping.

D. Adjust sewer inverts to keep the tops of pipes in line where the pipe's size changes.

E. Maintain a minimum of 3'6" of ground cover over all underground water mains and a minimum of 3'0" of ground cover over all underground sewers and drains (edit the depth of the ground cover to suit frost line depth and project requirements).

F. Provide shutoff valves in all domestic water piping system branches in which branch piping serves two or more fixtures.

G. Unless otherwise noted, all domestic cold and hot water piping shall be 1/2" size (edit the system type or pipe size to suit project requirements).

H. Unless otherwise noted, all piping is overhead, tight to the underside of the slab, with space for insulation if required.

I. Install piping so all valves, strainers, unions, traps, flanges, and other appurtenances requiring access are accessible.

J. Where domestic cold and hot water piping drops into a pipe chase, the size shown for the pipe drops shall be used to the last fixture.

K. Install all piping without forcing or springing.

L. All piping shall clear doors and windows.

M. All piping shall grade to low points. Provide hose end drain valves at the bottom of all risers and low points.

N. Unions and/or flanges shall be installed at each piece of equipment, in bypasses, and in long piping runs (100 ft. or more) to permit disassembly for alteration and repairs.

O. All valves shall be adjusted for smooth and easy operation.

P. All valves (except control valves) and strainers shall be the full size of the pipe before reducing the size to make connections to the equipment and controls.

Q. Provide chainwheel operators for all valves in equipment rooms mounted greater than 7'0" above floor level; chain shall extend to 7'0" above floor level.

R. Provide all plumbing fixtures and equipment with accessible stops.

S. Unless otherwise noted, drains shall be installed at the low point of roofs, areaways, floors, etc.

T. Provide cleanouts in sanitary and storm drainage systems at ends of runs, at changes in direction, near the base of stacks, every 50 ft. in horizontal runs, and elsewhere as indicated (edit horizontal cleanout spacing to suit code and project requirements).

U. All cleanouts shall be the full size of the pipe for pipe sizes 6 in. and smaller, and shall be 6 in. for pipe sizes larger than 6 in.

V. All balancing valves and butterfly valves shall be provided with position indicators and maximum adjustable stops (memory stops).

W. All valves shall be installed so the valve remains in service when the equipment or piping on the equipment side of the valve is removed.

X. All piping work shall be coordinated with all trades involved. Offsets in piping around obstructions shall be provided at no additional cost to the owner.

Y. Provide flexible connections in all piping systems connected to pumps and other equipment that require vibration isolation. Flexible connections shall be provided as close to the equipment as possible or as indicated on the drawings.

50.04. HVAC/Sheet Metal

A. Provide all materials and equipment and perform all labor required to install complete and operable HVAC systems as indicated on the drawings, as specified, and as required by code.

B. Certain items such as rises and drops in ductwork, access doors, volume dampers, etc., are indicated on the contract document drawings for clarity for a specific location requirement and shall not be interpreted as the extent of the requirements for these items.

C. In corridors where ceiling speakers and air diffusers are indicated between the same light fixtures, install both devices at the quarter points between the same fixture.

D. Unless otherwise shown, locate all room thermostats and humidistats 4'-0" (centerline) above the finished floor. Notify the engineer of any rooms where the preceding location cannot be maintained or where there is a question on location.

E. All ductwork shall clear doors and windows.

F. All ductwork dimensions, as shown on the drawings, are internal clear dimensions. Duct size shall be increased to compensate for duct lining thickness.

G. Provide all 90-degree square elbows with double radius turning vanes unless otherwise indicated. Elbows in dishwasher, kitchen, and laundry exhausts shall be of unvaned smooth radius construction with a centerline radius equal to 1-1/2 times the width of the duct. Provide access doors upstream of all elbows with turning vanes.

H. Coordinate diffuser, register, and grille locations with architectural reflected ceiling plans, lighting, and other ceiling items and make minor duct modifications to suit.

I. Field-erected and factory-assembled air handling unit coils shall be arranged for removal from the upstream side without dismantling supports. Provide galvanized structural steel supports for all coils (except the lowest coil) in banks over two coils high to permit the independent removal of any coil.

J. All air handling units shall operate without moisture carryover.

K. Locate all mechanical equipment (single duct, dual duct, variable volume, constant volume and fan-powered boxes, fan coil units, cabinet heaters, unit heaters, unit ventilators, coils, steam humidifiers, etc.) for unobstructed access to unit access panels, controls, and valving.

L. Finned tube radiation enclosures shall be wall-to-wall unless otherwise indicated.

M. Provide flexible connections in all ductwork systems (supply, return, and exhaust) connected to air handling units, fans, and other equipment that require vibration isolation. Flexible connections shall be provided at the point of connection to the equipment unless otherwise indicated.

N. Unless otherwise noted, all ductwork is overhead, tight to the underside of the structure, with space for insulation if required.

O. Runs of flexible duct shall not exceed 5 ft. (edit the maximum length of the flexible duct to suit the project; 5 ft. maximum recommended length, 8 ft. maximum length).

P. All ductwork shall be coordinated with all trades involved. Offsets in ducts, including divided ducts and transitions around obstructions, shall be provided at no additional cost to the owner.

Q. Provide access doors in ductwork to provide access for all smoke detectors, fire dampers, smoke dampers, volume dampers, humidifiers, coils, and other items located in the ductwork that require service and/or inspection.

R. Provide access doors in ductwork for the operation, adjustment, and maintenance of all fans, valves, and mechanical equipment.

S. All ducts shall be grounded across flexible connections with flexible copper grounding straps. Grounding straps shall be bolted or soldered to both the equipment and the duct.

T. Smoke detectors shall be furnished and wired by the electrical contractor. The mechanical contractor shall be responsible for mounting the smoke detector in ductwork as shown on the drawings and in accordance with the manufacturer's printed instructions.

U. Terminate gas vents for unit heaters, water heaters, high-pressure parts washers, high-pressure cleaners, and other gas appliances a minimum of 30" above the roof with rain cap (edit any appliances and the height above the roof to meet the code and suit project requirements).

V. See specifications for ductwork gauges, bracing, hangers, and other requirements.

W. Exterior louvers are indicated for information only. Detailed descriptions are provided in the architectural specifications.

X. Exterior louvers are indicated for information only. Louver sizes, locations, and details shall be coordinated with the general contractor.

Y. Exterior louvers are indicated for information only. Louver sizes, locations, mounting, and details shall be coordinated with other trades involved.

50.05. Fire Protection

A. Provide all materials and equipment and perform all labor required to install complete and operate fire protection systems as indicated on the drawings, as specified, and in compliance with the standards of the National Fire Protection Association, Industrial Risk Insurers, Factory Mutual, and all state and local regulations.

B. The entire building sprinkler system shall be hydraulically designed unless otherwise noted on the drawings. Head spacing in general and water quantity shall be based on Light Hazard Occupancy (edit occupancy classification to suit project requirements; see NFPA 13—Light Hazard Occupancy, Ordinary Hazard Group I Occupancy, Ordinary Hazard Group II Occupancy, Extra Hazard Group I Occupancy, Extra Hazard Group II Occupancy).

C. The entire building sprinkler system shall be pipe schedule designed unless otherwise noted on the drawings. Head spacing in general and water quantity shall be based on Light Hazard Occupancy (edit the occupancy classification to suit project requirements; see NFPA 13—Light Hazard Occupancy, Ordinary Hazard Group I Occupancy, Ordinary Hazard Group II Occupancy, Extra Hazard Group I Occupancy, Extra Hazard Group II Occupancy).

D. Provide an automatic wet pipe sprinkler system throughout the entire building, complete in all respects and ready for operation including all test and drain lines, pressure gauges, hangers and supports, signs, and other standard appurtenances. Wiring shall be provided under the electrical division.

E. Provide an automatic dry pipe sprinkler system throughout the entire building, complete in all respects and ready for operation, including all test and drain lines, pressure gauges, dry pipe valves, air compressors, hangers and supports, signs, and other standard appurtenances. Wiring shall be provided under the electrical division.

F. See the architectural drawings for the exact location of fire extinguisher cabinets, fire hose cabinets, and Siamese connections.

G. All shutoff valves in the sprinkler, standpipe, and combined systems shall be approved, indicating type.

H. Coordinate sprinkler head locations with the architectural reflected ceiling plans, lighting, and other ceiling items, and make minor modifications for suitability purposes.

I. Sprinklers installed in the ceilings of finished areas shall be symmetrical in relation to ceiling system components and centered in the ceiling tile.

Part 51: Designer's Checklist

51. Part 51: Designer's Checklist

51.01. Boilers, Chillers, Cooling Towers, Heat Exchangers, and Other Central Plant Equipment

A. Have owner redundancy requirements been met? Has future equipment space been clearly indicated on the drawings? Has move-in route and replacement access been determined?

B. Have multiple pieces of central plant equipment been provided to prevent system shutdown in the event of equipment failure? Has low load been evaluated and is equipment selected capable of operating at this low-load condition?

C. Has proper service access been provided? Has tube pull or cleaning space been provided?

D. Have final loads been calculated and the final equipment selection been made? Has equipment been specified and capacity scheduled?

E. Has chemical treatment of hydronic and steam systems been properly addressed? Have flushing and passivation of the hydronic and steam systems been adequately covered in particular waste treatment handling of spent flushing water and chemicals?

F. Does central plant equipment need to be on emergency power?

G. When multiple pieces of equipment are headered together, have adequate provisions for expansion and contraction been provided, especially regarding boiler systems? Recommendation: Multiple boiler

connections to header, from boiler nozzles to header main, should be U-shaped (first traveling away from the header, then traveling parallel to the header, and finally traveling back toward the header) to accommodate expansion and contraction of piping to prevent excess stress on the boiler nozzles.

H. When specifying boiler control and oxygen trim systems, chillers with remote starters and remote control panels, cooling tower basin heaters, and other electrical or control systems associated with central plant equipment, has field wiring required for these systems been coordinated with the electrical and instrumentation and control (I&C) engineers? This includes panel installation, interconnecting power and control wiring, instrument air, and the mounting of devices.

I. Have starter, disconnect switch, variable frequency drive, and/or motor control center spaces been coordinated and/or located?

J. When specifying dual fuel boilers, does the owner want a dual fuel pilot (natural gas and fuel oil) or is a tee connection preferred for connection to a portable propane bottle?

51.02. Air Handling Equipment—Makeup, Recirculation, and General Air Handling Equipment

A. Have owner redundancy requirements been met? Has future equipment space been clearly indicated on the drawings? Has move-in route and replacement access been determined?

B. Have multiple pieces of air handling equipment been provided to prevent system shutdown in the event of equipment failure?

C. Has adequate coil pull space and service space been provided? Recommendation: The service access space should be a minimum of the unit width plus 2 ft. on at least one side and a minimum of 2 ft. on the other side.

D. Have unit components and capacities been properly specified, detailed, and scheduled—coils, filters, fans, motors, humidifiers, outside air and return air dampers, smoke detectors, smoke dampers, access section, service vestibules, access doors, interior lighting (incandescent, fluorescent), etc.? Have coil and filter air pressure drops been

scheduled? Have coil water pressure drops been scheduled?

E. Have outside air and return air been mixed prior to entering any air handling unit filters or coils?

F. Has proper length downstream of humidifiers been provided to absorb humidification vapor trail? The first air handling unit section downstream of the humidifier should be stainless steel, including coil frames, especially with deionized (DI), reverse osmosis (RO), or ultra pure water (UPW).

G. Have cooling coils been locked out during the air handling unit preheat and humidification operation?

H. Has piping in service vestibules been checked for adequate space? Recommendation: A minimum of 6'0" wide and a minimum of 9'0" high clearance should be maintained to allow for pipe installation for the full length of the unit.

I. Are access doors of adequate size to remove fans, motors, filters, dampers, actuators, inlet guide vanes or other variable flow device, and other devices requiring service and/or replacement?

J. Do all air handling unit preheat coils with a design mixed air temperature below 40°F have preheat pumps? To reduce the risk of freezing, preheat pumps are recommended for all preheat coils with a design mixed air temperature below 40°F.

K. Have coil selections been made so that low water flows, in direct response to low loads, do not fall into laminar flow region?

L. Have air conditioning condensate drains been piped to an appropriate drainage system? Have drains been provided for storm water and sanitary?

M. Have receptacles been provided for roof-mounted equipment in accordance with the NEC?

N. Have the starter, disconnect switch, adjustable frequency drive, and/or motor control center spaces been coordinated and/or located?

O. Does air handling equipment need to be on emergency power?

51.03. Piping Systems—General

A. Expansion tank: Has size, location, adequate space, support, makeup water pressure, and makeup water location been coordinated with the plumbing engineer?

B. Are there provisions for piping expansion and contraction, anchors, guides, loops vs. joints? Have anchor locations and forces been coordinated with the structural engineer? Locate anchors at steel beams and avoid joists if possible. Is piping coordinated with building expansion joints?

C. Do the drawings clearly indicate where ASME code piping and valves are required at the boilers in accordance with ASME code requirements for high temperature (over 250°F) and high-pressure boilers (over 15 psig)?

D. Does the boiler layout and design have enough expansion and flexibility in the boiler connection piping to prevent overstressing the boiler nozzle? It is best to use a U-shaped layout to the header.

E. Have flexible connections been clearly shown on the drawings and have they been properly detailed? Have the appropriate flexible connections been specified for the application?

F. Is there structural support for large water risers?

G. Are there drains and air vents on water systems and adequate space for service?

H. Are balancing valves required on parallel piping loops?

I. Is adequate space available for the pitching of pipes?

J. Is there space for coil and tube removal or cleaning (e.g., AHUs, chillers, boilers, etc.) and is it clearly shown on the drawings where it is required?

K. Is coil piped for counterflow or parallel flow as indicated by detail (parallel flow for preheat coils only; all others counter flow)?

L. Condensate drains from room terminals with chilled, dual

temperature water and packaged cooling units: Do local authorities require condensate drains to be piped to sanitary or to storm? Can condensate drains be discharged onto roof? Onto grade?

M. Are relief valve settings noted on drawings or schedules?

N. Is there adequate straight pipe up- and downstream of flow meter orifices?

O. Have all required equipment valves not covered by standard details been indicated? Avoid duplications.

P. Do not run horizontal piping in solid masonry walls or in narrow stud partitions.

Q. Has all piping been eliminated from electrical switchgear, transformer, motor control center, and emergency generator rooms? If not, have drain troughs or enclosures been provided?

R. Are shutoff valves provided at the base of all risers?

S. Are all systems compatible with flow requirements established by control diagrams?

T. Is cathodic protection required for buried piping?

U. Has required heat tracing been included, coordinated, and insulated?

V. Will large mains or risers transmit noise to occupied spaces? Are isolators required in supply and return at the pump?

W. Is the present and future duty for pumps, boilers, chillers, cooling towers, heat exchangers, terminal units, coils, AHUs, etc., specified? Scheduled?

X. Are air conditioning and steam condensate (when wasted) piped to storm water or sanitary? Is steam condensate cooled?

51.04. Steam and Condensate Piping

A. See the "Piping Systems—General" section earlier for additional requirements.

B. Are the ends of main drips shown, detailed, and specified?

C. Will condensate drain? Are pipes oversized for opposing flow?

D. Will humidifier arms add excessive sensible heat to the air stream (likely on small flat ducts and some AHUs)? Insulate where needed. Provide motor-operated shutoff valves if steam is live during the mechanical cooling season.

E. Are riser drips shown, detailed, and specified?

F. Flash tanks for medium- and high-pressure condensate. Vent flash tanks either to low pressure steam or outdoors.

G. Are relief valves piped to outside? Have they been sized?

H. Has steam consumption for humidification been considered in establishing the water makeup quantity for the boiler?

I. Has adequate space been allowed for pressure reducing stations? Have standard details been edited?

J. Are water sampling connections provided?

K. Are steam injectors piped to the floor drains?

L. Avoid cross-connections between gravity condensate returns and pumped condensate return lines.

M. Is there adequate height between the condensate receiver and/or feedwater heater and the pump to prevent flashing at the pump, particularly with condensate above 200°F?

N. Has bypass around the boiler feedwater heater been provided for maintenance?

O. Are there drip runouts to equipment such as sterilizers and glassware washers?

P. Are the ends of main drips piped?

Q. Are condensate return systems compatible?

R. Have noise suppressors been provided on the reduced pressure side of PRVs? Will radiated noise be a problem? Are there adequate numbers of stages of pressure reduction for quiet operation and an adequate number of valves for capacity control?

S. Are steam and/or condensate flow meters and recorders required?

T. Is there adequate access to components requiring service on the boilers? Is a catwalk required?

U. Are boilers piped in accordance with the ASME code? Is there a nonreturn plus a shutoff valve on the HP boiler?

V. Is the condensate tank vented to the outside?

W. Are chemicals used in the treatment system suitable for humidification? Are chemical feed systems shown, detailed, and specified?

X. Is a feedwater heater or deaerator required?

Y. Are water softeners required on makeup? Are they shown, detailed, and specified?

Z. Are bottom blowdown and continuous blowdown shown, detailed, and specified?

AA. Avoid lifting steam condensate, if possible.

BB. Are proper traps being used? Have they been specified and scheduled?

CC. Are air conditioning and steam condensate (when wasted) piped to storm water or to sanitary? Is steam condensate cooled?

DD. Are large system isolation valves provided with the bypass warming valve?

51.05. Low Temperature Hot Water and Dual Temperature Systems

A. See the "Piping Systems—General" section earlier for additional requirements.

B. Are balancing valves indicated? Are flow measuring stations needed and indicated?

C. Is pressure regulation needed?

D. Is a bypass filter required? Is GPM included in pump capacity?

E. Is a standby pump needed?

F. Converter support: Are details needed? Is elevation indicated?

G. Are service valves shown?

H. Will branch piping and ducts fit in the allotted space or enclosure?

I. Are riser shutoff valves shown?

J. Are riser drains and vents shown?

K. Is there adequate space for the installation and use of riser valves?

L. Will the minimum allowable circulation be maintained through the hot water boiler?

M. Is the distribution system reverse return? If not, will balancing problems result?

51.06. Chilled Water and Condenser Water Systems

A. See the "Piping Systems—General" earlier for additional requirements.

B. Are balancing valves indicated? Are flow measuring stations needed? Have they been indicated?

C. Is pressure regulation needed?

D. Is a bypass filter required? Is the GPM included in the pump capacity?

E. Is a standby pump needed?

F. Are service valves shown?

G. Will branch piping and ducts fit in the allotted space or enclosure?

H. Are riser shutoff valves shown?

I. Are riser drains and vents shown?

J. Is there adequate space for the installation and use of riser valves?

K. Will the minimum allowable circulation be maintained through the chiller?

L. Is the distribution system reverse return? If not, will balancing problems result?

M. Condenser water piping: loop traps to avoid excessive drainage, submerged impeller. Has the available NPSH been calculated? Is the NPSH indicated in the pump schedule?

N. For cooling tower makeup, overflow, and drain splash blocks, are there balancing valves in branch lines to tower cells? Coordinate the makeup with the plumbing engineer.

51.07. Air Systems

A. Are adequate balancing dampers provided to prevent noise at outlets due to excessive pressure, or to avoid complicated balancing procedures on extensive low-pressure systems or exhaust systems (e.g., each zone of a multizone system; to limit flow variation due to stack effect in vertical low pressure and exhaust systems)?

B. Are fire damper locations, type, and flow restrictions indicated? Is there adequate height for a damper recess pocket at the shaft wall? Is breakaway ductwork at the fire damper wall sleeve detailed or specified?

C. Are smoke damper locations, type, and flow restrictions indicated? Is there adequate height for a damper at the shaft wall? Is breakaway ductwork at the smoke damper wall sleeve detailed or specified? Is the smoke damper operator located on the supported duct and not on a breakaway duct?

D. Are access doors at fire dampers, smoke dampers, turning vanes, humidifiers, coils, etc., properly specified and included in the general notes?

E. Are proper relief air provisions provided?

F. Is a return air fan needed? Is an outside air fan needed?

G. Are condensate drains provided? Are outside air intake drains provided?

H. Are flexible connections shown and specified?

I. Is sound lining required? Is it properly located and specified?

J. Will the duct arrangement permit the transfer of excessive noise between offices, toilet rooms, and rooms of a different function?

K. Is there objectionable fan noise from intakes or exhaust points to nearby buildings?

L. Are outlets located in supply mains? Are there noisy conditions?

M. Do trunk ducts pass above quiet rooms? Will noise be a problem?

N. Have fan class, bearing arrangement, motor location, etc., been shown, scheduled, or specified?

O. Are air intakes on party walls?

P. Will outlets blow at lights, beams, sprinkler heads, or smoke detectors? Sprinkler head and smoke detector locations must meet code requirements. Locate them in accordance with code.

Q. Have outlet and return grille elevations been coordinated with the architect and indicated?

R. Adjust outlet air quantities for duct heat gain and duct leakage.

S. Are isotope and chemical exhaust ducts accessible?

T. Is there interference between sill grille discharge and drapes or blinds? Beware of the annoying movement of vertical blinds or light drapes caused by sill air discharge nearby.

U. Are the present and future duties for air terminal units, AHUs, fans, etc., specified and scheduled?

V. Is the exhaust or relief discharge or plumbing stack effluent near intakes? Maintain a minimum of 10 ft. of clearance.

W. Is there an anti-stratification provision at intakes, large mixing box outlets, and downstream of steam coils or water coils? Are air blenders indicated on all AHUs?

X. Are there aluminum grilles on the shower, sterilizer, etc., exhaust? Is stainless steel ductwork or aluminum ductwork required? Is it clearly indicated on drawings as to extent? Has it been specified?

Y. Are there sealing and sloping of shower, cage washer, etc., exhaust ducts? When more than one type of duct material is used, is the extent and location clearly defined?

Z. Has adequate relief from rooms been provided? Are there door louvers, undercut doors, transfer grilles, and direct exhaust? Have they been coordinated?

AA. Will door louvers defeat the needed acoustical privacy (e.g., conference rooms, private offices, VP office)? Will door louvers defeat the needed door fire rating? Are door louvers located in accordance with code?

BB. Are the types of branch takeoffs and duct splits shown? Are details included on drawings?

CC. Are there intermediate drip pans on cooling coil banks? Are they piped to the floor drain? Include detail.

DD. Are there drains for kitchen exhaust duct risers?

EE. Is there excessive duct heat gain from nearby steam pipes and other heat sources?

FF. Are there combustion air intakes for boilers, water heaters, etc.? Are vents, stacks, breeching, and chimneys shown, specified, and detailed? Are termination heights clearly indicated?

GG. Locate exhaust grilles near the floor in operating rooms, flammable storage rooms, chlorine storage rooms, battery rooms (high and low), etc.

HH. Do not use corridors as return air plenums in hospitals, nursing homes, offices, and other facilities.

II. Have insulated louver blank-off panels or sheets been included where required?

JJ. Are filters provided in makeup air to elevator equipment rooms? Are filters provided for air-cooled condensers and condensing units located indoors?

KK. Are there motor-operated dampers in wall louvers? Do not use operable louvers. Use stationary louvers with motor-operated dampers behind when required.

LL. Are casings adequately described as prefabricated or field-fabricated? Is the extent of the sound paneling clear? Has an adequate pressure rating been specified?

MM. Has the architect provided adequate framing for the linear diffuser in the metal lath and plaster or dry wall bulkheads? Do not dimension diffuser lengths for wall-to-wall installations—note the dimension as "wall to wall."

NN. Have fan systems been checked for excessive sound transmission?

OO. Is there adequate space for servicing fans, motors, belts, etc.?

PP. Has sufficient space been provided between coils of AHUs to accommodate temperature sensors?

QQ. Are adequate service space or equipment size access panels noted on drawings for equipment installed above ceilings? Coordinate with the architect who furnishes, installs, provides.

RR. Are there adequate straight duct branch length or straightening vanes between the main duct and diffuser?

SS. Do ducts pierce partitions at 90-degree angles wherever possible?

TT. Are wash down systems or fire protection systems required for fume hoods or kitchen hoods?

UU. Are fume hood exhaust systems balanceable? Are orifice plates required?

VV. Are correct outside air quantities and pressurization included?

WW. Is a smoke control system required?

XX. Avoid contamination of air intake from exhaust air, contaminated vents, vehicle exhaust, etc. Are locations in accordance with code?

YY. Are static pressure sensors indicated or specified?

ZZ. Are fire and smoke dampers coordinated with fire and smoke walls? Are fire rated floor/ceiling assemblies used? Will diffusers, registers, and grilles require fire dampers? Are smoke dampers required for air handling units or fans?

AAA. Is the floor suitable for "built-up" air handling units?

BBB. Have ventilation systems been provided for equipment rooms and other non-air-conditioned spaces?

CCC. Are flow measuring devices located? Is there adequate straight run?

DDD. Is there adequate straight duct upstream of terminal units? VAV, constant volume reheat, dual duct, fan-powered, and other air terminal unit runouts should be sized based on the ductwork criteria established for sizing the ductwork upstream of the air terminal unit, and not on the terminal unit connection size. The transition from the runout size to the air terminal unit connection size should be made at the terminal unit. A minimum of 3 ft. of straight duct should be provided upstream of all air terminal units.

EEE. Is the system compatible with architectural floor/ceiling assemblies?

FFF. Do toilet rooms have the code-required minimum exhaust?

GGG. Locate exterior wall louvers, especially intake louvers, a minimum of 2'0" above the roof, finished grade, etc.

HHH. Locate gravity roof ventilators, especially intake ventilators, a minimum of 1'0" from the finished roof to the top of the roof curb.

III. Are air-conditioning condensate drains piped to storm water or sanitary as required by the local authority?

51.08. Process Exhaust Systems

A. Branches and laterals should be connected above the duct centerline. If branches and laterals are connected below the duct centerline, drains will be required at the low point.

B. Provide blast gates or butterfly dampers at each branch, at each submain, and at each equipment or tool connection. Wind loading on blast gates needs to be considered when installed on the roof or outside the building, especially those blast gates that are normally open.

C. Blast gate blades for process exhaust systems should be specified with an EPDM wiper gasket to provide a tight seal. For blast gates installed for future use, it is recommended that the blade be removed and a gasketed blind flange be provided where the blade goes in the duct to reduce leakage.

D. Does duct pitch to low points and drains? Are drains provided at all low points?

E. Has correct duct material been specified? Is it Stainless Steel, Halar Coated Stainless Steel, FRP, or PVC? PVC is not recommended and the maximum size is 8" round.

F. Has the proper pressure class been specified upstream and downstream of scrubbers and other abatement equipment?

G. Is ductwork installed outside or in unconditioned spaces and will condensation occur on the outside or inside of this duct? Is duct insulation or heat tracing required?

H. Are adequate butterfly balancing dampers shown for system balancing?

I. Are bubble tight dampers specified and shown when and where required?

J. Are process exhaust fans on emergency power as required by code?

K. Process exhaust ductwork cannot penetrate fire-rated construction. Fire dampers are generally not desirable. If penetrating fire-rated construction cannot be avoided, process exhaust ductwork must be

enclosed in a fire-rated enclosure until it exits the building, or sprinkler protection inside the duct may be used if approved by the authority having jurisdiction.

L. Are pressure ports provided at the ends of all laterals, submains, and mains?

M. Are drains required in fan scroll, scrubber, or other abatement equipment?

N. Are flexible connections provided at fans and are flexible connections specified suitable for application?

O. Are stacks properly located and is the discharge height adequate to prevent contamination of outside air intakes, CT intakes, and combustion air intakes? Are termination heights clearly indicated?

P. Have redundancy requirements been met?

Q. Are variable frequency drives required, located, and coordinated with the electrical engineer?

51.09. Refrigeration

A. See the "Piping Systems—General" section earlier for additional requirements.

B. Is future machine space indicated on the drawings?

C. Is the space for servicing indicated on the drawings?

D. Are there rigging supports for large water boxes and compressor shells?

E. Is noise transmission likely to occupied spaces?

F. Is there adequate control of chilled water temperature?

G. Are sprinklers required for wood fill towers? *NFPA 214.*

H. Is refrigerant relief piping shown on the drawings? Is it piped to the outside?

I. Is noise from the cooling towers likely to be a problem?

J. Will cooling tower discharge air pocket or recirculate?

K. Should the cooling tower be winterized?

L. Have the cooling tower support locations been cleared with the structural engineer. When determining the cooling tower enclosure height, has the height of vibration isolators been considered (8–12 in. high) and has the height of the safety rail been considered?

M. Are cooling tower discharge duct connections necessary?

N. Are flow diagrams required? Have they been coordinated?

O. Are present and ultimate duties noted where applicable and coordinated with pumps and coils, etc.?

P. Is ethylene or propylene glycol required? Has it been specified and equipment capacities derated?

Q. Has additional insulation been included for low temperature systems?

R. Has single-phase protection been included for packaged (single and/or split systems) air conditioning and heat pump compressor motors?

51.10. Controls

A. Are all panels located? Have they been coordinated with the Electrical Engineer? Are they local or central?

B. Are flow meter locations an adequate distance up- and downstream of the orifice?

C. Are thermostat and humidistat locations indicated? Do not mount stats on glass panels or door frames. Avoid middle-of-the-wall locations.

D. Are control settings, schedules, and diagrams indicated or specified?

E. Are temperature tolerances in lab areas clearly specified?

F. Are power and control wiring diagrams shown? Is interlocking wiring included?

G. Have reheat coils requiring full capacity in summer been supplied from a constant temperature hot water supply?

H. Are low-leak dampers specified on intakes and elsewhere as required?

I. Have compressor location and motor size been coordinated with the Electrical Engineer?

J. Are all AHUs and systems accounted for on control design?

K. Coordinate the purchase and installation of duct smoke detectors and duct fire stat locations with the Electrical Department for connection to the building fire detection system.

L. Are direct digital controls appropriate?

M. Are valve positions (normally open or normally closed) indicated where applicable?

N. Is the compressor sized for ultimate duty?

51.11. Sanitary and Storm Water Systems

A. See the "Piping Systems—General" section earlier for additional requirements.

B. Adjust sewer inverts to keep the tops of pipes in line where the pipe's size changes (note this on the drawings).

C. Maintain at least a minimum cover on sewers for the entire run.

D. Has the sewer authority been contacted for the following:

1. Are sewer authority mains capable of handling additional discharge?
2. The location, size, and depth of sanitary and storm sewer mains.
3. Connection requirements.
4. Requirements for grease traps, sand interceptors, oil/water separators, etc.

5. Has the DER or EPA been contacted?

6. Have storm water management requirements been determined?

E. Sewer profiles are usually required where contours vary extensively or where possible interference with other lines exists. Indicate contours where required.

F. Indicate sewer inverts at points of connection to public sewers, at building walls, at crossover points, and at points of possible interference. Are all underground utilities coordinated with foundations and grade beams?

G. Indicate foundation drain tile inverts. Provide back water valves (BWVs) at connections to the storm water system. Check accessibility. Is a manhole required?

H. Is there a dry manhole for BWVs outside the building or deep BWVs inside the building?

I. Provide headwall and rip rap for storm water discharge to a drainage ditch, storm water retention pond/tank, or stream.

J. Size site storm sewers large enough to prevent stoppage by leaves, paper, silt, etc. Except for light duty sewers, use an 8" or 10" pipe minimum.

K. Are all plumbing fixtures designated and scheduled?

L. Coordinate fixture locations with final architectural plans. Check ADA requirements. Are handicapped fixtures identified?

M. Provide BWVs for drains and groups of drains connected to the storm water below grade or where backflow is possible above grade.

N. Vent sumps for sanitary and storm water drainage.

O. Is the elevation of mains selected to be above the footings? Advise the Structural Engineer if mains must run below footings or through footings.

P. Is there adequate ceiling space for AHU floor drain traps on upper floors? Are deep seal traps required? Are they indicated?

Q. Are drains for overflows piped?

R. Are there separate vapor vents for sterilizer and bed pan washers?

S. Are grease traps required for commercial kitchens? Are sand interceptors and/or oil/water separators required for garages and parking areas? Is oil and/or water collected by the oil/water separator to be treated as hazardous waste?

T. If an oil-filled transformer is located inside the building, provide the transformer room with a drain and pipe to an accessible storage tank.

U. Provide floor drains for air handling units, boilers, chemical feed equipment, air compressors, pumps, generators, etc., especially for relief valve discharge and pump stuffing box discharge.

V. Are disposals directly connected to heavy flow mains? Do not connect to a grease interceptor.

W. Provide a floor drain to create an indirect waste connection for commercial dishwashers, kitchen sinks, and kitchen equipment processing food.

X. Is the plumbing fixture connection schedule included?

Y. Does the general piping or equipment interfere with the overhead door's travel?

Z. Do not run horizontal piping in solid masonry walls.

AA. Is there adequate AHU pad height to allow condensate drain from the pan to be properly trapped? Are condensate drains piped to the storm or sanitary made with indirect connections? Do local authorities require condensate drains to be piped to sanitary or to storm? Can condensate drains be discharged onto the roof or grade?

BB. Are floor drains, roof drains, and trench drains coordinated with the structural system? Are drains coordinated with building expansion joints?

CC. Are air conditioning and steam condensate (when wasted) piped to storm water or sanitary? Is steam condensate cooled?

DD. Are automatic trap priming systems required?

EE. Are floor drain, roof drain, and trench drain types suitable for duty and traffic rating?

FF. Are flow or riser diagrams required by plumbing authorities? Are fixture units clearly indicated on riser diagrams when required?

GG. Is the minimum size of the vent through the roof indicated (e.g., recommend 3")? Has the minimum size pipe below floor been coordinated with local codes (e.g., Allegheny Co. 4" minimum pipe size below floor)?

HH. Are fixtures and drains trapped and vented in accordance with applicable code?

II. Will drainage to grade freeze and create a slippery condition?

JJ. Is tub overflow assembly accessible? Use a solid connection, if not.

KK. Are cooling tower and evaporative cooler overflows, bleeds, and drains piped to sanitary?

LL. Do not use cleanouts on Washington, D.C., projects. Verify requirements.

MM. Are acid waste and vent systems clearly indicated on the drawings and specified?

NN. Site drainage: Are adequate manholes, catch basins, and other items shown on the drawings and specified?

OO. Are future connections and/or expansions considered in the slope of piping, size of piping, and sewer connection sizing?

PP. Provide manways for septic and sewage holding tanks. Manholes and covers should be waterproof/watertight.

51.12. Domestic Water Systems

A. See the "Piping Systems—General" section earlier for additional requirements.

B. Has the water authority been contacted to obtain the following:

1. Water static and residual pressures and flows at the water main. Are these pressures and flows adequate?

2. The location and size of water mains.

3. Water hardness and the corrosiveness of the water.

4. Backflow prevention requirements.

5. Water meter location requirements and meter pit requirements if necessary.

C. Are pressure regulating valves required? Do pressures exceed 60 psi? If so, pressure reducing valves should be provided.

D. Are there submain section valves?

E. Are there provisions for piping and building expansion?

F. Have all wall, box, and yard hydrants been provided and specified?

G. Are water softeners for laundry and boiler makeup required?

H. Is makeup water connected to the boiler, heating, chilled, condenser, and other HVAC water systems? Is freeze protection required? Is sufficient pressure available to overcome static head?

I. Provide hose bibbs at cooling towers and in boiler rooms, mechanical rooms, large toilet rooms, dormitory toilet rooms, and kitchens.

J. In boiler and chiller rooms, provide service sink and water sampling connections.

K. Are flow or riser diagrams required by plumbing authorities? Are fixture units clearly indicated on riser diagrams when required?

L. Is a hot water recirculating pump required, located, scheduled, and specified?

M. Are all hospital, laboratory, kitchen, and other special equipment connections shown on the drawings? Are hospital, laboratory, kitchen, and other special equipment connection schedules required and included?

N. Are backflow preventers provided at the service entrance, at the fire protection service, and at the connection to the HVAC water systems fill connections? Use reduced pressure backflow preventers on all HVAC systems and double-check backflow preventers on domestic water and fire protection service.

O. Is a pressure boosting system required?

P. Is a main shutoff valve provided? Are shutoff valves shown at each toilet room and groups of two or more plumbing fixtures?

Q. Are all plumbing fixtures shown on the drawings and specified?

R. Is a water meter required? Is submetering required?

S. Are balancing valves on the hot water recirculation system shown?

T. Use a 3/4" cold water connection to eye wash units.

U. Are water heater connections shown (gas, water, vents, etc.)?

V. Is a dishwasher booster heater connected?

W. Are future connections and/or expansions considered in the size of the piping and service entrance?

X. Are all underground utilities coordinated with foundations?

51.13. Fire Protection

A. See the "Piping Systems—General" section earlier for additional requirements.

B. Are Siamese connections shown and coordinated with the architect?

C. Are check valves and shutoff valves shown on the drawings?

D. Have fire extinguishers and/or cabinets been specified by the architect or engineer? Have fire hoses and/or cabinets been specified by the architect or engineer?

E. Is fire protection for kitchen hoods required?

F. Is there adequate space for sprinkler mains?

G. Are dry systems provided for areas subject to freezing?

H. Is there a sprinkler for trash and linen chutes?

I. Are there drains for ball drips of Siamese connections?

J. Are pressures noted for hydraulically calculated systems?

K. Is the extent of the sprinklered area indicated? If more than one type of sprinkler system is required (wet, dry, pre-action, deluge, etc.), are they clearly indicated on the drawings?

L. Are fire department valves clearly indicated on the drawings?

M. Are special fire protection systems included?

N. Are standpipes and fire department valves shown?

O. Is sprinkler zoning compatible with the fire alarm zoning?

P. Are all test connections shown and locations coordinated with the Architect? Are drains for test connections provided?

Q. Has the water authority been contacted to obtain the following:

1. Water static and residual pressures and flows at the water main. Are these pressures and flows adequate or is a fire pump required?

2. The location and size of water mains.

3. The water hardness and the corrosiveness of the water.

4. Backflow prevention requirements.

5. Water meter location requirements and meter pit requirements if necessary.

6. Street or onsite fire hydrant requirements.

7. The fire hydrant and fire department connection size, thread type, etc.

R. Have electrical requirements for the fire pump, tamper switches, flow switches, etc., been coordinated with the electrical department?

S. Have fire pump requirements been coordinated between the spec and the drawings?

T. Have the fire hose and fire extinguisher locations been coordinated

with the Electrical Department for the wiring of the blue indicator light?

U. Who paints fire protection piping and what color (red)?

51.14. Natural Gas Systems

A. See the "Piping Systems—General" section earlier for additional requirements.

B. Determine the minimum gas pressure required. Is the gas company pressure available at the street adequate for the equipment? Has the gas company been contacted to obtain the following:

1. Pressures and flows at the gas main. Are these pressures and flows adequate?
2. The location and size of the gas mains.
3. Gas meter location requirements and meter pit requirements if necessary.

C. Has the gas meter size been coordinated with the gas company? Has the capacity requirement and site location been given to the gas company? Is the meter required to be located inside or outside? Who provides gas meter and regulator assembly? The gas company? Who provides gas piping from the main to the curb box, from the curb box to the meter assembly, from the meter assembly to the building, and inside the building?

D. Have gas pressure regulators been evaluated for low-load conditions and during startup? It is recommended that multiple gas pressure regulators be used, especially on large central utility plant natural gas systems, not only for low-load conditions but for the replacement of regulators without a shutdown of the entire plant. For instance, the natural gas system design may use two regulators sized at 50–50, 33–67, or 40–60 percent, or it may use three regulators sized at 15–35–50 or 25–25–50 percent.

E. Is there gas meter access and room ventilation (when required)?

F. Are there drip pockets if gas lines cannot drain back to the meter, and adequate space for the pitch?

G. Are there submain section gas cocks?

H. Are gas vent valves and vents from pressure regulating valves piped to the outside?

I. Do not locate natural draft burners in the room under "negative" pressure.

J. Coordinate the gas train with gas pressure available and with the Owner's insurance carrier.

K. Are stacks, vents, and breeching shown on the drawings and are they properly sized and specified? Coordinate with the design team other equipment requiring gas vents (e.g., water heaters, shop equipment, kitchen equipment, lab equipment, hospital equipment).

L. Is combustion air for fuel-fired equipment properly designed in accordance with code? Watch for water heaters in janitor closets.

M. What pressures are permitted to be run inside the building?

N. Is piping run in plenum? If so, valves cannot be located in plenum, including walls.

O. Check with the local gas company for welded and screwed pipe requirements (concealed, exposed, etc.). Screwed pipes and fittings may only be used if gas service is less than 1 psig and vertical runs are less than four stories. Otherwise, use welded pipe.

P. Plastic pipe can only be used for underground service. Require the contractor to install #14 insulated tracer wire 4 to 6 in. above all underground plastic lines.

51.15. Fuel Oil Systems

A. See the "Piping Systems—General" section earlier for additional requirements.

B. Do not locate natural draft burners in rooms under "negative" pressure.

C. Is the suction lift within allowable limits of the fuel oil pump?

D. Is the underground fuel oil tank location coordinated with the site plan? Does it have adequate cover? Has truck traffic been considered?

Are leak detection systems and double wall piping systems shown on the drawings and specified?

E. Are the tank vent and fill indicated and away from air intakes? Are vents properly sized?

F. Are fuel oil heaters required (#4, #5, #6 fuel oils)?

G. Is a tank heater required? (They are not permitted with fiberglass tanks.)

H. Is compressed air for the tank gauge provided?

I. Is a specified tank suitable for installation? Has it been coordinated with the owner? Is future conversion to heavy oil a consideration?

J. Are leak detection, double wall piping, spill containment, double wall tanks, etc., properly specified and shown on the drawings?

K. Are stacks, vents, and breeching shown on the drawings and properly sized and specified? Coordinate with the design team other equipment requiring vents (e.g., water heaters, shop equipment, lab equipment, hospital equipment).

L. Is combustion air for fuel-fired equipment properly designed in accordance with code? Watch for water heaters in janitor closets.

M. Are EPA tank requirements met? Have state police requirements been met?

N. Are emergency vents properly sized for indoor tanks?

O. Are manholes and covers for fill and access openings specified and/or detailed to be waterproof/watertight?

51.16. Laboratory and Medical Gas Systems

A. Is a separate zone valve required?

B. Are medical gas alarm panels required?

C. Is the air intake for the hospital compressor indicated? Is it outside? Does it provide clean air?

D. Vacuum pump discharge should not be at rubber membrane roofs, due to the adverse reaction of oil with membrane materials.

E. Are *NFPA 99* requirements met?

51.17. General

A. Are all mechanical items specified and coordinated with other disciplines as to who provides, furnishes, and/or installs? Have all items on the specification coordination list been coordinated? Do all disciplines have the most current drawings showing mechanical equipment?

B. Is there a north arrow, title block, and engineer's stamp with signature?

C. Are scales noted on the plans? Does the project or client require graphic scales?

D. Are there client and project numbers on all projects, and the company name, logo, address, etc., on all drawings?

E. Check for completeness of general notes, legend, abbreviations, and title blocks.

F. Check column numbers and grids.

G. Check room names and numbers.

H. Is the extent of the demolition clearly defined? Is what is to remain clearly defined? Are points of connection between the new and old clearly defined?

I. Check the coordination and contrast of new and existing work.

J. Coordinate the following with architectural, structural, and electrical departments:

1. Clearances between lighting fixtures, structure, and ducts and pipes.

2. Clearances between conduits out of electrical panels and pull boxes, structure, and ducts and pipes.

3. Wiring of filters (roll filters and air purification systems).

K. Does the electrical department have the final motor list and heater list?

L. Have existing mechanical/electrical services and available space for new work been adequately field checked?

M. Advise the electrical department of any relocated mechanical equipment having electrical components.

N. Has the division of work between the architectural, structural, mechanical, and electrical disciplines been coordinated (as to who furnishes, installs, and/or provides) on such items as:

1. Starters and disconnect switches.
2. Line and low voltage control wiring and power wiring to control panels.
3. Access panels.
4. Fire extinguishers, fire hoses, and/or cabinets.
5. Catwalks and ladders.
6. Under-window unit discharge grilles on built-in cabinets.
7. Louvers.
8. Door grilles, undercut doors.
9. Generators, mufflers, fuel oil piping, engine exhausts, engine cooling air ductwork, and accessories.
10. Painting and priming.
11. Mechanical equipment screens.
12. Equipment supports and concrete housekeeping pads.
13. Roof curbs (equipment, ductwork, and piping), flashing, and counter flashing.
14. Site work/building utility design termination (5'0" outside of the foundation wall).
15. Foundation drains.

16. Excavation.

17. Kitchenette units.

18. Bus washer, vehicle lifts, hydraulic piping and accessories, and paint booths and accessories.

19. Countertop plumbing fixtures; built-in showers.

20. Kitchen hoods.

21. Laboratory fume hoods.

O. Where the ceiling height and door or window head heights provide no leeway to lower ceiling, have mechanical and electrical work space above the ceiling been closely checked?

P. Check the framing of holes in existing structures.

Q. Is the structure adequate for new mechanical equipment in existing buildings?

R. Is there adequate clearance for the removal of ceiling systems for access to equipment? A tee bar system requires 3" minimum from the underside of the ceiling to the equipment.

S. Have the heating and ventilation of bathrooms and toilet rooms been provided?

T. Is there equipment room, PRV room, electrical room, and electrical closet ventilation?

U. Has insulation or ventilation been provided to overcome radiant heat from boiler or incinerator stacks?

V. Has specified equipment been properly described by current model designation?

W. Have all items specified "As indicated on the drawings" been coordinated? Coordinate references between drawings, details, sections, risers, and specifications.

X. Is there any material or equipment for which there is no catalog data in the office library?

Y. Have details been coordinated?

Z. Has space for future ducts, pipes, fans, pumps, chillers, boilers, cooling towers, water heaters, and other equipment been clearly indicated?

AA. Are "floating floors" required for noise control? Have they been specified and detailed?

BB. Has the existing area been adequately field checked?

CC. Are elevator machine rooms free of piping, ductwork, and equipment except elevator machine equipment? Is the elevator machine room ventilated? Does the elevator machine room need to be air conditioned?

DD. Have chemical treatment systems been included?

EE. Have handwash sinks been included in mechanical equipment rooms?

FF. Have chain operators for valves more than 7'0" above the finished floor been specified?

GG. Are general notes, drawing notes, and keyed notes included?

HH. Is a key plan needed?

II. Are applicable standard details included and coordinated?

JJ. Have applicable codes been researched?

KK. Should smoke and fire walls be indicated?

LL. Are present and ultimate duties included in schedules where applicable and coordinated with the Electrical Engineer? Are future flows accounted for in duct and pipe sizing and appropriate provisions made?

MM. Have authorities having jurisdiction been consulted regarding fire detection and protection systems, applicable codes, etc.?

NN. Is the minimum head room (6'8") maintained in equipment rooms?

OO. Is verification that the building meets *ASHRAE Standard 90.1* or other Energy Conservation Codes required?

PP. Is access to equipment with electrical connections (such as ceiling-mounted heat pumps) adequate to satisfy the NEC?

QQ. Have all equipment housekeeping pads been indicated, specified, and coordinated?

RR. Is asbestos present in the existing building? Is preparation of the removal documents part of the contract?

51.18. Architect and/or Owner Coordination

A. Have all shafts/chases been coordinated? Are they large enough?

B. Do shafts/chases line up floor to floor? Are structural members located in the shaft space?

C. Have pipe or duct chases been provided where required?

D. Will partitions accommodate piping and plumbing fixtures?

E. Has a suitable type stationary louver been specified?

F. Are bird screens (not insect screens) specified? Are bird screens located on the inside or outside of louver? The outside of louver is easier to clean but its appearance is undesirable.

G. Have louver locations and sizes been coordinated? Who provides, furnishes, and/or installs louvers?

H. Have plumbing fixtures, as required, been specified under the architectural section?

I. Have all plumbing fixtures been coordinated?

J. Has all special equipment been coordinated?

K. Have not in contract (NIC) or future items requiring "stub-up" services been identified?

L. Have masonry air shafts been avoided? If not, are they specified to be airtight?

M. Has proper access to roof mounted equipment been provided?

N. Have provisions for equipment replacement been made?

O. Have supply air ceiling plenums been coordinated? Are partitions floor-to-floor where required? Is the supply air plenum area sealed where required?

P. Have return air ceiling plenums been coordinated? Are partitions floor-to-floor? If so, have provisions been provided to return air from these spaces?

Q. Have trenches, sumps, and covers been coordinated?

R. Have under-window units been coordinated?

S. Have air outlet types been coordinated?

T. Have thermostat types been selected and approved by the owner?

U. Have plumbing fixtures and types been approved? Have countertop fixtures been coordinated? Who provides, furnishes, and/or installs countertop fixtures?

V. Include vibration isolators, grillage, and cooling tower safety rails when dimensioning the height of the cooling tower for the architectural screen.

W. Have all skylights, roof hatches, bulkheads, and multiple height ceilings been coordinated with ductwork, piping, and other mechanical equipment?

X. Who provides, furnishes, and/or installs roof curbs for mechanical equipment?

Y. Who provides, furnishes, and/or installs flashing and counterflashing?

Z. Who provides cutting and patching?

51.19. Structural Engineer Coordination

A. Have equipment locations, sizes, and weights been given to the Structural Engineer? Have equipment housekeeping pad locations and sizes been coordinated? Has the final and complete structural list been given to the Structural Engineer?

B. Have all floor, roof, and wall openings been coordinated?

C. Have pipes 6 in. and larger been located and coordinated with the Structural Engineer?

D. Have all sleeved beams, grade beams, and foundations been coordinated? Have pipes and ducts been coordinated?

E. Has structural framing in the shafts been considered?

F. Has the mechanical layout been coordinated with the structural system, especially in post-tensioned concrete structural systems? (Penetrations at columns and column lines are not normally possible.)

G. Is the structural system adequate for future equipment?

H. Where equipment must be "rolled" into place, is the structure over which equipment will be rolled adequate?

I. Have catwalks been coordinated?

J. Have pipe risers been coordinated?

K. Do structural openings allow for insulation and ductwork reinforcing?

L. Have anchor locations and associated forces been given to the Structural Engineer? Avoid locating anchors at joist or joist girder locations.

M. Have louver openings, sizes, and framing been coordinated with the Structural Engineer?

51.20. Electrical Engineer Coordination

A. Has the final and complete motor list been given to the Electrical Engineer?

B. Have all electrical and telecommunication rooms and closets been ventilated? Do they need to be air conditioned?

C. Have duct smoke detectors, duct fire stats, and/or smoke dampers been coordinated?

D. Have valve position indicators/tamper switches been coordinated?

E. Have sprinkler flow switches and alarms been coordinated?

F. Have fuel tank level alarms and gauges been coordinated?

G. Have cooling tower electric basin heaters and vibration switches for propeller fans been coordinated?

H. Have medical gas alarms been coordinated?

I. Have the automatic trap priming systems for the kitchen and other areas been coordinated?

J. Has the automatic trap priming system for the AHUs been coordinated?

K. Has lighting inside the AHUs been coordinated?

L. Has power at the pneumatic tube stations been coordinated?

M. Has power for the ATC compressors and refrigerated air dryers been coordinated?

N. Who provides starters and disconnect switches? Who provides line voltage and low-voltage control wiring? Who provides power wiring to the control panels? Have starters, wall switches, remote starter pushbuttons, and disconnect switches been located on the mechanical drawings?

O. Have two disconnects been provided at duplex pumps?

P. Are there automatic fire suppression systems for fume hoods and kitchen hoods?

Q. Are there alarms on sump pumps, condensate pumps, sewage pumps, hot water generators, and similar items?

R. Are there chiller oil heaters and control circuits (winterize air-cooled chillers)?

S. Are there diesel generator fuel oil pumps on emergency power? Who provides the engine exhaust, fuel-oil piping, day tank, muffler, cooling air, fuel storage tank, etc.?

T. Steam or water flow on the BTU meter recorders?

U. Have shower controls been coordinated?

V. Are there automatic fire suppression systems for the computer rooms? Are AHUs interlocked with the computer room shutdown system?

W. Are there smoke or thermal detectors for AHUs and RA fans? Who furnishes, installs, and/or provides them?

X. Has heat tracing for piping systems been coordinated?

Y. Are there electric fuel tank heating systems?

Z. Is there auxiliary equipment on the water chillers?

AA. Has the motor list been coordinated with equipment schedules?

BB. Has the motor list been coordinated with control diagrams?

CC. Have electric humidifiers been coordinated?

DD. Have hot water generator or boiler circulating pumps been coordinated?

EE. Has relocated equipment been coordinated?

FF. Have allowances been made for lighting fixture access? Have the heights of lighting fixtures been coordinated, especially high hat fixtures?

GG. No ductwork, piping, or other mechanical equipment should be in electrical rooms or closets.

HH. Are motor control centers (MCCs) shown and specified? Are starters shown and specified?

II. Is there adequate space for MCCs?

JJ. Is there enough space for electric water level detectors?

KK. Are electric motor-operated dampers wired?

LL. Are there air handling light fixtures, supply, return, and heat transfer?

MM. Has the extent of return air ceilings been coordinated with the Electrical Engineer?

NN. Is the equipment on emergency power clearly defined and coordinated? Include the control air compressor and dryer.

OO. Are explosion proof motors, starters, disconnect switches, etc., required?

Part 52: Professional Societies and Trade Organizations

52. Part 52: Professional Societies and Trade Organizations

Printed for University of California Berkeley Copyright McGraw-Hill Education Holdings

52.01. Professional Societies and Trade Organizations

AABC	Associated Air Balance Council
AACC	American Automatic Control Council
AAHC	American Association of Health Care Consultants
ABMA	American Boiler Manufacturers' Association
ACCA	Air Conditioning Contractors of America
ACGIH	American Conference of Governmental and Industrial Hygienists
ACI	American Concrete Institute
ACS	American Ceramic Society
ACS	American Chemical Society
ACSM	American Congress on Surveying and Mapping
ADA	Americans with Disabilities Act

ADA	Americans with Disabilities Act
ADAAG	ADA Accessibility Guidelines for Buildings and Facilities
ADC	Air Diffusion Council
AEE	Association of Energy Engineers
AEI	Architectural Engineering Institute
AFBMA	American Fan and Bearing Manufacturers' Association
AFS	American Foundrymen's Society
AGA	American Gas Association
AGMA	American Gear Manufacturers Association
AHA	American Hospital Association
AHCA	American Health Care Association
AHRI	Air-Conditioning, Heating, and Refrigeration Institute
AIA	American Institute of Architects
AIA	American Insurance Association
AICE	American Institute of Consulting Engineers
AIChE	American Institute of Chemical Engineers
AIHA	American Industrial Hygiene Association
AIIE	American Institute of Industrial Engineers, Inc.
AIPE	American Institute of Plant Engineers
AISC	American Institute of Steel Construction
AISE	Association of Iron and Steel Engineers

AISI	American Iron and Steel Institute
AMCA	Air Movement and Control Association International, Inc.
ANSI	American National Standards Institute
APCA	Air Pollution Control Association
APFA	American Pipe and Fittings Association
APHA	American Public Health Association
API	American Petroleum Institute
APWA	American Public Works Association
ASA	Acoustical Society of America
ASCE	American Society of Civil Engineers
ASCET	American Society of Certified Engineering Technicians
ASEE	American Society for Engineering Education
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
ASLE	American Society of Lubricating Engineers
ASME	American Society of Mechanical Engineers International
ASNT	American Society for Nondestructive Testing
ASPE	American Society of Plumbing Engineers
ASQC	American Society of Quality Control, Inc.
ASSE	American Society of Safety Engineers
ASSE	American Society of Sanitary

	Engineers
ASTM	American Society for Testing and Materials
ATBCB	Architectural and Transportation Barrier Compliance Board
AWS	American Welding Society
AWWA	American Water Works Association, Inc.
BCMC	Board for the Coordination of Model Codes (a Board of CABO)
BDC	Building Design and Construction
BEPS	Building Energy Performance Standards
BICSI	Building Industries Consulting Services International
BOCA	Building Officials and Code Administrators
BOMA	Building Owners' and Managers' Association
BRI	Building Research Institute
BSI	British Standards Institute
CABO	Council of American Building Officials
CAGI	Compressed Air and Gas Institute
CANENA	North American Electro/Technical Standards Harmonization Council
CEC	Consulting Engineers Council of the United States
CEN	European Standards Organization
CENELEC	European Committee for Electro/Technical Standardization
CGA	Compressed Gas Association, Inc.

CISPI	Cast Iron Soil Pipe Institute
CSA	Canadian Standards Association
CSI	Construction Specifications Institute
CTI	Cooling Tower Institute
DER	Department of Environmental Resources
DOE	Department of Energy
DOH	Department of Health
ECPD	Engineers' Council for Professional Development
EF	Engineering Foundation
EJC	Engineers' Joint Council
EJMA	Expansion Joint Manufacturers' Association
EPA	Environmental Protection Agency
ETL	ETL Testing Laboratories
FM	Factory Mutual System
FPS	Fluid Power Society
HAP	Hospital & Healthsystem Association of Pennsylvania
HEI	Heat Exchange Institute
HI	Hydraulic Institute
HTFMI	Heat Transfer and Fluid Mechanics Institute
HYDI	Hydronics Institute
IAHHS	International Association for Healthcare Security and Safety
IAPMO	International Association of Plumbing and Mechanical Officials
IBR	Institute of Boiler and Radiator

	Manufacturers
ICBO	International Conference of Building Officials
ICC	International Code Council (BOCA, CABO, ICBO, and SBCCI combined)
ICET	Institute for the Certification of Engineering Technicians
IEC	International Electro/Technical Commission
IEEE	Institute of Electrical and Electronics Engineers
IES	Illuminating Engineering Society
IESNA	Illuminating Engineering Society of North America
IFCI	International Fire Code Institute
IFI	Industrial Fasteners Institute
IFMA	International Facility Managers' Association
IHCA	Integrated Health Care Association
IIAR	International Institute of Ammonia Refrigeration
IRI	HSB Industrial Risk Insurers
IRI	Industrial Research Institute, Inc.
ISA	Instrument Society of America
ISO	International Organization for Standardization
JCAHO	Joint Commission on Accreditation of Healthcare Organizations
MCAA	Mechanical Contractors Association of America
MSS	Manufacturers' Standardization

	Society of the Valve and Fittings Industry
NACE	National Association of Corrosion Engineers
NAE	National Academy of Engineering
NAHC	National Association of Health Consultants
NAHSE	National Association of Health Services Executives
NAIMA	North American Insulation Manufacturers Association
NAPE	National Association of Power Engineers, Inc.
NAPHCC	National Association of Plumbing-Heating-Cooling Contractors
NAS	National Academy of Sciences
NBFU	National Board of Fire Underwriters
NBS	National Bureau of Standards
NCEE	National Council of Engineering Examiners
NCPWB	National Certified Pipe Welding Bureau
NCSBCS	National Conference of States on Building Codes and Standards
NEBB	National Environmental Balancing Bureau
NEC	National Electric Code
NEMA	National Electrical Manufacturers' Association
NEMI	National Energy Management Institute
NFPA	National Fire Protection Association
NFRC	National Fenestration Rating Council

NFRC	National Fenestration Rating Council
NFSA	National Fire Sprinkler Association
NIAOP	National Association of Industrial and Office Properties
NICE	National Institute of Ceramic Engineers
NICET	National Institute of Certified Engineering Technicians
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
NRC	National Research Council
NRCA	National Roofing Contractors' Association
NRCC	National Research Council of Canada
NSAE	National Society of Architectural Engineers
NSF	National Sanitation Foundation International
NSPE	National Society of Professional Engineers
NUSIG	National Uniform Seismic Installation Guidelines
OSHA	Occupational Safety and Health Administration
PDI	Plumbing and Drainage Institute
PFI	Pipe Fabrication Institute
RESA	Scientific Research Society of America
SAE	Society of Automotive Engineers
SAME	Society of American Military Engineers
SAVE	Society of American Value Engineers

SAVE	Society of American Value Engineers
SBCCI	Southern Building Code Congress International
SES	Solar Energy Society
SFPE	Society of Fire Protection Engineers
SMACNA	Sheet Metal and Air Conditioning Contractors' National Association
SPE	Society of Plastics Engineers, Inc.
SSPC	Structural Steel Painting Council
SSPMA	Sump and Sewage Pump Manufacturers' Association
SWE	Society of Women Engineers
TEMA	Tubular Exchanger Manufacturers Association
TIMA	Thermal Insulation Manufacturers' Association
UL	Underwriters' Laboratories, Inc.
WPCF	Water Pollution Control Federation

Part 53: References and Design Manuals

53. Part 53: References and Design Manuals

Printed for University of California Berkeley Copyright McGraw-Hill Education Holdings

53.01. References and Design Manuals

A. **The references listed in the paragraphs to follow form the basis for most of the information contained in this manual. In addition, these references are excellent HVAC design manuals and will provide expanded explanations of the information contained within this text. These references are recommended for all HVAC engineers' libraries.**

B. **American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Handbooks**

ASHRAE. *ASHRAE Handbook, 2015 HVAC Applications Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 2015.

ASHRAE. *ASHRAE Handbook, 2014 Refrigeration Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 2014.

ASHRAE. *ASHRAE Handbook, 2013 Fundamentals Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 2013.

ASHRAE. *ASHRAE Handbook, 2012 HVAC Systems and Equipment Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 2012.

ASHRAE. *ASHRAE Handbook, 2011 HVAC Applications Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 2011.

ASHRAE. *ASHRAE Handbook, 2010 Refrigeration Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 2010.

ASHRAE. *ASHRAE Handbook, 2009 Fundamentals Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 2009.

ASHRAE. *ASHRAE Handbook, 2008 HVAC Systems and Equipment Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 2008.

ASHRAE. *ASHRAE Handbook, 2007 HVAC Applications Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 2007.

ASHRAE. *ASHRAE Handbook, 2006 Refrigeration Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 2006.

ASHRAE. *ASHRAE Handbook, 2005 Fundamentals Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 2005.

ASHRAE. *ASHRAE Handbook, 2004 HVAC Systems and Equipment Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 2004.

ASHRAE. *ASHRAE Handbook, 2003 HVAC Applications Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 2003.

ASHRAE. *ASHRAE Handbook, 2002 Refrigeration Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 2002.

ASHRAE. *ASHRAE Handbook, 2001 Fundamentals Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 2001.

ASHRAE. *ASHRAE Handbook, 2000 HVAC Systems and Equipment Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 2000.

ASHRAE. *ASHRAE Handbook, 1999 HVAC Applications Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 1999.

ASHRAE. *ASHRAE Handbook, 1998 Refrigeration Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 1998.

ASHRAE. *ASHRAE Handbook, 1997 Fundamentals Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 1997.

ASHRAE. *ASHRAE Handbook, 1996 HVAC Systems and Equipment Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 1996.

ASHRAE. *ASHRAE Handbook, 1995 HVAC Applications Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 1995.

ASHRAE. *ASHRAE Handbook, 1994 Refrigeration Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 1994.

ASHRAE. *ASHRAE Handbook, 1993 Fundamentals Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 1993.

ASHRAE. *ASHRAE Handbook, 1992 HVAC Systems and Equipment Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 1992.

ASHRAE. *ASHRAE Handbook, 1991 HVAC Applications Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 1991.

ASHRAE. *ASHRAE Handbook, 1990 Refrigeration Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 1990.

ASHRAE. *ASHRAE Handbook, 1989 Fundamentals Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 1989.

ASHRAE. *ASHRAE Handbook, 1988 Equipment Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 1988.

ASHRAE. *ASHRAE Handbook, 1987 HVAC Systems and Applications Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 1987.

ASHRAE. *ASHRAE Handbook, 1986 Refrigeration Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 1986.

ASHRAE. *ASHRAE Handbook, 1985 Fundamentals Volume, Inch-Pound Edition*. Atlanta, GA: ASHRAE, 1985.

ASHRAE. *ASHRAE Handbook, 1984 Systems Volume*. Atlanta, GA: ASHRAE, 1984.

ASHRAE. *ASHRAE Handbook, 1983 Equipment Volume*. Atlanta, GA: ASHRAE, 1983.

ASHRAE. *ASHRAE Handbook, 1982 Applications Volume*. Atlanta, GA: ASHRAE, 1982.

ASHRAE. *ASHRAE Handbook, 1981 Fundamentals Volume*. Atlanta, GA: ASHRAE, 1981.

ASHRAE. *ASHRAE Handbook, 1980 Systems Volume*. Atlanta, GA: ASHRAE, 1980.

C. **American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standards, and Manuals**

1. Standards:

ASHRAE. *ASHRAE Standard 15-2013, Safety Standard for Refrigeration Systems*. Atlanta, GA: ASHRAE, 2013.

ASHRAE. *ASHRAE Standard 34-2013, Design and Safety Classification of Refrigerants*. Atlanta, GA: ASHRAE, 2013.

ASHRAE. *ASHRAE Standard 52.1-2007, Gravimetric and Dust-Spot Procedures for Testing Air-Cleaning Devices Used in General Ventilation for Removing Particulate Matter*. Atlanta, GA: ASHRAE, 2007.

ASHRAE. *ASHRAE Standard 52.2-2012, Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size*. Atlanta, GA: ASHRAE, 2012.

ASHRAE. *ASHRAE Standard 55-2013, Thermal Environmental Conditions for Human Occupancy*. Atlanta, GA: ASHRAE, 2013.

ASHRAE. *ASHRAE Standard 62.1-2013, Ventilation for Acceptable Indoor Air Quality*. Atlanta, GA: ASHRAE, 2013.

ASHRAE. *ASHRAE Standard 62.2-2013, Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings*. Atlanta, GA: ASHRAE, 2013.

ASHRAE. *ASHRAE Standard 90.1-2013, Energy Standard for Buildings Except Low-Rise Residential Buildings*. Atlanta, GA: ASHRAE, 2013.

ASHRAE. *ASHRAE Standard 90.2-2007, Energy Efficient Design of Low-Rise Residential Buildings*. Atlanta, GA: ASHRAE, 2007.

ASHRAE. *ASHRAE Standard 100-2006, Energy Conservation in Existing Buildings*. Atlanta, GA: ASHRAE, 2006.

ASHRAE. *ASHRAE Standard 110-1995, Method of Testing Performance of Laboratory Fume Hoods*. Atlanta, GA: ASHRAE, 1995.

ASHRAE. *ASHRAE Standard 111-2008, Practices for Measurement, Testing, Adjusting, and Balancing of Building Heating, Ventilation, Air-Conditioning, and Refrigeration Systems*. Atlanta, GA: ASHRAE, 2008.

ASHRAE. *ASHRAE Standard 135-2012, BACnet: A Data Communication Protocol for Building Automation Control Networks*. Atlanta, GA: ASHRAE, 2012.

ASHRAE. *ASHRAE Standard 135.1-2013, Method of Test for Conformance to BACnet*. Atlanta, GA: ASHRAE, 2013.

ASHRAE. *ASHRAE Standard 154-2011, Ventilation for Commercial Cooking Operations*. Atlanta, GA: ASHRAE, 2011.

ASHRAE. *ASHRAE Standard 170-2013, Ventilation of Health Care Facilities*. Atlanta, GA: ASHRAE, 2013.

2. Guidelines:

ASHRAE. *ASHRAE Guideline 1.1-2007, HVAC&R Technical Requirements for the Commissioning Process*. Atlanta, GA: ASHRAE, 2007.

ASHRAE. *ASHRAE Guideline 1.5-2012, Commissioning Process for Smoke Control Systems*. Atlanta, GA: ASHRAE, 2012.

ASHRAE. *ASHRAE Guideline 4-2008, Preparation of Operating and Maintenance Documentation for Building Systems*. Atlanta, GA: ASHRAE, 2008.

ASHRAE. *ASHRAE Guideline 12-2000, Minimizing the Risk of Legionellosis Associated with Building Water Systems*. Atlanta, GA: ASHRAE, 2000.

ASHRAE. *ASHRAE Guideline 13-2014, Specifying Direct Digital Control Systems*. Atlanta, GA: ASHRAE, 2014.

3. Manuals:

ASHRAE. *Design of Smoke Control Systems for Buildings*. 1st Ed., Atlanta, GA: ASHRAE, 1983.

ASHRAE. *Pocket Handbook for Air Conditioning, Heating, Ventilation, Refrigeration*. Atlanta, GA: ASHRAE, 1987.

McIntosh, Ian B.D., Dorgan, Chad B., and Dorgan, Charles E. *ASHRAE Laboratory Design Guide.* Atlanta, GA: ASHRAE, 2001.

ASHRAE. *ASHRAE HVAC Design Manual for Hospitals and Clinics*. Atlanta, GA: ASHRAE, 2003.

Klote, John H. and Milke, James A. *Principles of Smoke Management*. Atlanta, GA: ASHRAE, 2002.

Grumman, David L., Editor. *ASHRAE Green Guide*. Atlanta, GA: ASHRAE, 2003.

Ross, Donald E. HVAC *Design Guide for Tall Commercial Buildings*. Atlanta, GA: ASHRAE, 2004.

D. **American National Standards Institute (ANSI) and American Society of Mechanical Engineers (ASME)**

ANSI/ASME. *ANSI/ASME A13.1 Scheme for the Identification of Piping Systems, 2007*. New York, NY: ANSI/ASME, 2007.

ANSI/ASME. *ANSI/ASME B31.1 Power Piping, 2014.* New York, NY: ANSI/ASME, 2014.

ANSI/ASME. *ANSI/ASME B31.3 Process Piping, 2014.* New York, NY: ANSI/ASME, 2014.

ANSI/ASME. *ANSI/ASME B31.5 Refrigeration Piping and Heat Transfer Components, 2013.* New York, NY: ANSI/ASME, 2013.

ANSI/ASME. *ANSI/ASME B31.9 Building Services Piping, 2014*. New York, NY: ANSI/ASME, 2014.

ANSI/ASME. *ANSI/ASME Boiler and Pressure Vessel Code, 2015*. New York, NY: ANSI/ASME, 2015.

E. **Bell and Gossett Manuals**

ITT Corporation. *Pump and System Curve Data for Centrifugal Pump Selection and Application.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1967.

ITT Corporation. *Pump Data Book.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1970.

ITT Corporation. *Parallel and Series Pump Application.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1965.

ITT Corporation. *Principles of Centrifugal Pump Construction and Maintenance.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1965.

ITT Corporation. *Cooling Tower Pumping and Piping.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1968.

ITT Corporation. *Variable Speed/Variable Volume Pumping Fundamentals.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1985.

ITT Corporation. *Heat Exchangers, Application and Installation.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1965.

ITT Corporation. *Primary Secondary Pumping Application Manual.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1968.

ITT Corporation. *One Pipe Primary Systems, Flow Rate and Water Temperature Determination.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1966.

ITT Corporation. *Primary Secondary Pumping Adaptations to Existing Systems.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1966.

ITT Corporation. *Dual Temperature Change Over Single Zone.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1967.

ITT Corporation. *Single Coil Instantaneous Room by Room Heating-Cooling Systems.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1965.

ITT Corporation. *Equipment Room Piping Practice.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1965.

ITT Corporation. *Pressurized Expansion Tank Sizing/Installation Instructions for Hydronic Heating/Cooling Systems.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1988.

ITT Corporation. *Snow Melting System Design and Problems.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1966.

ITT Corporation. *Hydronic Systems Anti-Freeze Design.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1965.

ITT Corporation. *Air Control for Hydronic Systems.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1966.

ITT Corporation. *Basic System Control and Valve Sizing Procedures.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1970.

ITT Corporation. *Hydronic Systems: Analysis and Evaluation.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1969.

ITT Corporation. *Circuit Setter Valve Balance Procedure Manual.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1971.

ITT Corporation. *Domestic Water Service.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1970.

F. **Carrier Manuals**

Carrier Corporation. *Carrier System Design Manuals, Part 1—Load Estimating.* Syracuse, NY: Carrier Corporation, 1972.

Carrier Corporation. *Carrier System Design Manuals, Part 2—Air Distribution.* Syracuse, NY: Carrier Corporation, 1974.

Carrier Corporation. *Carrier System Design Manuals, Part 3—Piping Design.* Syracuse, NY: Carrier Corporation, 1973.

Carrier Corporation. *Carrier System Design Manuals, Part 4—Refrigerants, Brines, Oils.* Syracuse, NY: Carrier Corporation, 1969.

Carrier Corporation. *Carrier System Design Manuals, Part 5—Water Conditioning.* Syracuse, NY: Carrier Corporation, 1972.

Carrier Corporation. *Carrier System Design Manuals, Part 6—Air Handling Equipment.* Syracuse, NY: Carrier Corporation, 1968.

Carrier Corporation. *Carrier System Design Manuals, Part 7—Refrigeration Equipment.* Syracuse, NY: Carrier Corporation, 1969.

Carrier Corporation. *Carrier System Design Manuals, Part 8—Auxiliary Equipment.* Syracuse, NY: Carrier Corporation, 1966.

Carrier Corporation. *Carrier System Design Manuals, Part 9—Systems and Applications.* Syracuse, NY: Carrier Corporation, 1971.

Carrier Corporation. *Carrier System Design Manuals, Part 10—Air-Air Systems.* Syracuse, NY: Carrier Corporation, 1975.

Carrier Corporation. *Carrier System Design Manuals, Part 11—Air-Water Systems.* Syracuse, NY: Carrier Corporation, 1966.

Carrier Corporation. *Carrier System Design Manuals, Part 12—Water and DX Systems.* Syracuse, NY: Carrier Corporation, 1975.

G. **Cleaver Brooks Manuals**

Cleaver Brooks. *The Boiler Book: A Complete Guide to Advanced Boiler Technology for the Specifying Engineer*. 1st Ed., Milwaukee, WI: Cleaver Brooks, 1993.

Cleaver Brooks. *Hot Water Systems, Components, Controls, and Layouts.* Milwaukee, WI: Cleaver Brooks, 1972.

Cleaver Brooks. *Application … and Misapplication of Hot Water Boilers*. Milwaukee, WI: Cleaver Brooks, 1976.

H. **Johnson Controls Manuals**

Johnson Controls. *Fundamentals of Pneumatic Control.* Milwaukee, WI: Johnson Controls.

Johnson Controls. *Johnson Field Training Handbook, Fundamentals of Electronic Control Equipment*. Milwaukee, WI: Johnson Controls.

Johnson Controls. *Johnson Field Training Handbook, Fundamentals of Systems*. Milwaukee, WI: Johnson Controls.

I. **Honeywell Manual**

Honeywell. Engineering Manual of Automatic Control for Commercial Buildings, Heating, Ventilating, and Air Conditioning. Inch-Pound Edition, Minneapolis, MN: Honeywell, 1991.

J. **Industrial Ventilation Manual**

American Conference of Governmental and Industrial Hygienists. *Industrial Ventilation, A Manual of Recommended Practice.* 28th Ed., Cincinnati, OH: American Conference of Governmental and Industrial Hygienists, 2013.

K. **SMACNA (Sheet Metal and Air-Conditioning Contractors' National Association, Inc.) Manuals**

SMACNA. *Fibrous Glass Duct Construction Standards.* 7th Ed., Vienna, VA: SMACNA, 2003.

SMACNA. *Fire, Smoke, and Radiation Damper Installation Guide for HVAC*. 5th Ed., Vienna, VA: SMACNA, 2002.

SMACNA. *HVAC Air Duct Leakage Test Manual.* 2nd Ed., Vienna, VA: SMACNA, 2012.

SMACNA. *HVAC Duct Construction Standards—Metal and Flexible*. 3rd Ed., Vienna, VA: SMACNA, 2005.

SMACNA. *HVAC Systems Duct Design.* 4th Ed., Vienna, VA: SMACNA, 2006.

SMACNA. *HVAC Systems Testing, Adjusting, and Balancing*. 3rd Ed., Vienna, VA: SMACNA, 2002.

SMACNA. *Rectangular Industrial Duct Construction Standards*. 2nd Ed., Vienna, VA: SMACNA, 2004.

SMACNA. *Round Industrial Duct Construction Standards*. 2nd Ed., Vienna, VA: SMACNA, 1999.

SMACNA. *Seismic Restraint Manual Guidelines for Mechanical Systems*. 3rd Ed., Vienna, VA: SMACNA, 2008.

SMACNA. *Thermoplastic Duct (PVC) Construction Manual*. 2nd Ed., Vienna, VA: SMACNA, 1995.

L. **Trane Manuals**

The Trane Company. *Trane Air-Conditioning Manual.* LaCross, WI: The Trane Company, 1988.

The Trane Company. *Psychrometry.* LaCross, WI: The Trane Company, 1988.

M. **United McGill Corporation**

United McGill Corporation. *Engineering Design Reference Manual for Supply Air Handling Systems.* Westerville, OH: United McGill Corporation, 1989.

United McGill Corporation. *Underground Duct Installation (No. 95).* Westerville, OH: United McGill Corporation, 1992.

United McGill Corporation. *Flat Oval vs. Rectangular Duct (No. 150).* Westerville, OH: United McGill Corporation, 1989.

United McGill Corporation. *Flat Oval Duct—The Alternative to Rectangular (No. 151).* Westerville, OH: United McGill Corporation, 1989.

United McGill Corporation. *Underground Duct Design (No. 155).* Westerville, OH: United McGill Corporation, 1992.

N. **Manufacturers Standardization Society of the Valve and Fitting Industry**

Manufacturers Standardization Society of the Valve and Fitting Industry. *Standard Marking System for Valves, Fittings, Flanges and Unions (Standard SP-25-1988).* Vienna, VA: Manufacturers Standardization Society of the Valve and Fitting Industry, 1988.

Manufacturers Standardization Society of the Valve and Fitting Industry. *Pipe Hangers and Supports—Materials, Design, and Manufacturers (Standard SP-58-1988).* Vienna, VA: Manufacturers Standardization Society of the Valve and Fitting Industry, 1988.

Manufacturers Standardization Society of the Valve and Fitting Industry. *Pipe Hangers and Supports—Selection and Application (Standard SP-69-1983).* Vienna, VA: Manufacturers Standardization Society of the Valve and Fitting Industry, 1983.

Manufacturers Standardization Society of the Valve and Fitting Industry. *Pipe Hangers and Supports—Fabrication and Installation Practices (Standard SP-89-1985).* Vienna, VA: Manufacturers Standardization Society of the Valve and Fitting Industry, 1985.

Manufacturers Standardization Society of the Valve and Fitting Industry. *Guidelines on Terminology for Pipe Hangers and Supports (Standard SP-90-1986).* Vienna, VA: Manufacturers Standardization Society of the Valve and Fitting Industry, 1986.

Manufacturers Standardization Society of the Valve and Fitting Industry. *Guidelines for Manual Operation of Valves (Standard SP-91-1984).* Vienna, VA: Manufacturers Standardization Society of the Valve and Fitting Industry, 1984.

Manufacturers Standardization Society of the Valve and Fitting Industry. *MSS Valve User Guide (Standard SP-92-1987).* Vienna, VA: Manufacturers Standardization Society of the Valve and Fitting Industry, 1987.

Manufacturers Standardization Society of the Valve and Fitting Industry. *Guidelines on Terminology for Valves and Fittings (Standard SP-96-1986).* Vienna, VA: Manufacturers Standardization Society of the Valve and Fitting Industry, 1986.

O. **Miscellaneous**

Angel, W. Larsen. *HVAC Design Sourcebook.* New York, NY: The McGraw-Hill Companies, Inc., 2012.

Armstrong. *Steam Conservation Guidelines for Condensate Drainage.* Three Rivers, MI: Armstrong Machine Works, 1976.

Avallone, Eugene A. and Baumeister, III Theodore. *Mark's Standard Handbook for Mechanical Engineers.* 9th Ed., New York, NY: McGraw-Hill Book Co., 1986.

Bolz, D. and Tuve, George L. *CRC Handbook of Tables for Applied Engineering Science.* 2nd. Ed., Boca Raton, FL: CRC Press, Inc., 1980.

Clough, Richard H. *Construction Contracting.* 4th Ed., New York, NY: John Wiley and Sons, Inc., 1981.

Dryomatic, Div. Airflow, Co. *Dehumidification Engineering Manual.* Frederick, MD: Dryomatic, Div. Airflow, Co., 1965.

Haines, Roger W. *Control Systems for Heating, Ventilating, and Air Conditioning.* 4th Ed., New York, NY: Van Nostrand Reinhold Company, 1987.

Hansen, Erwin G. *Hydronic System Design and Operation, A Guide to Heating and Cooling with Water.* New York, NY: The McGraw-Hill Companies, Inc., College Customs Series, 1996.

Harris, Norman C. *Modern Air Conditioning Practice.* 3rd Ed., New York, NY: Glencoe Div. of Macmillan/McGraw-Hill, 1992.

Hauf, Harold D. *Architectural Graphic Standards.* 6th Ed., New York, NY: John Wiley and Sons, Inc., 1970.

Heald, C. C. *Cameron Hydraulic Data.* 17th Ed., Woodcliff Lake, NJ: Ingersoll Rand, 1988.

Leslie Control, Inc. *Steam Pressure Control Systems.* Tampa, FL: Leslie Controls, Inc.

The Marley Cooling Tower Co. *Cooling Tower Fundamentals.* 2nd Ed., Kansas City, MO: The Marley Cooling Tower Co., 1985.

McGuinness, William J. *Mechanical and Electrical Equipment for Buildings.* 6th Ed., New York, NY: John Wiley and Sons, Inc., 1980.

Nayyar, Mohinder L. *Piping Handbook.* 6th Ed., New York, NY: McGraw Hill, Inc. 1992.

The Singer Company. *Designing the Installation of the Electro-Hydronic Energy Conservation System.* Auburn, NY: The Singer Company, Climate Control Div., 1978.

Spence Engineering Co. *Steam Pressure Reducing Station Noise Treatment.* Walden, NY: Spence Engineering Co.

Spirax/Sarco. *Design of Fluid Systems, Steam Utilization.* Allentown, PA: Spirax/Sarco, 1991.

Spirax/Sarco. *Design of Fluid Systems, Hook-ups.* Allentown, PA: Spirax/Sarco, 1992.

Strock, Clifford. *Handbook of Air Conditioning, Heating, and Ventilating.* 1st Ed., New York, NY: The Industrial Press, 1959.

Systecon, Inc. Distributed Pumping (Pressure Gradient Control) for Chilled Water and Hot Water Systems. Cincinnati, OH: Systecon, Inc., 1992.

53.02. Building Codes

A. **2015 International Code Council Series of Codes (ICC)**

1. ICC. *2015 International Building Code*. 2015 Ed., Country Club Hills, IL: ICC, 2015.
2. ICC. *2015 International Mechanical Code*. 2015 Ed., Country Club Hills, IL: ICC, 2015.
3. ICC. *2015 International Energy Conservation Code*. 2015 Ed., Country Club Hills, IL: ICC, 2015.
4. ICC. 2015 *International Plumbing Code*. 2015 Ed., Country Club Hills, IL: ICC, 2015.
5. ICC. *2015 International Fire Code*. 2015 Ed., Country Club Hills, IL: ICC, 2015.
6. ICC. *2015 International Fuel Gas Code*. 2015 Ed., Country Club Hills, IL: ICC, 2015.
7. ICC. *2015 International Residential Code*. 2015 Ed., Country Club Hills, IL: ICC, 2015.
8. ICC. *2015 International Existing Building Code*. 2015 Ed., Country Club Hills, IL: ICC, 2015.
9. ICC. *2015 International Performance Code for Buildings and Facilities*. 2015 Ed., Country Club Hills, IL: ICC, 2015.
10. ICC. *2015 International Private Sewage Disposal Code*. 2015 Ed., Country Club Hills, IL: ICC, 2015.
11. ICC. *2015 International Property Maintenance Code*. 2015 Ed., Country Club Hills, IL: ICC, 2015.
12. ICC. *2015 International Zoning Code*. 2015 Ed., Country Club Hills, IL: ICC, 2015.
13. ICC. *2015 International Wildland-Urban Interface Code*. 2015 Ed., Country Club Hills, IL: ICC, 2015.

B. **National Fire Protection Association (NFPA)**

NFPA. *NFPA 1 Fire Code.* Quincy, MA: NFPA, 2015.

NFPA. *NFPA 10 Standard for Portable Fire Extinguishers*. Quincy, MA: NFPA, 2013.

NFPA. *NFPA 13 Standard for the Installation of Sprinkler Systems*. Quincy, MA: NFPA, 2013.

NFPA. *NFPA 13 Standard for the Installation of Sprinkler Systems Handbook*. Quincy, MA: NFPA, 2013.

NFPA. *NFPA 14 Standard for the Installation of Standpipe and Hose Systems*. Quincy, MA: NFPA, 2013.

NFPA. *NFPA 16 Standard for the Deluge Foam-Water Sprinkler and Foam-Water Spray Systems*. Quincy, MA: NFPA, 2015.

NFPA. *NFPA 17 Standard for Dry Chemical Extinguishing Systems*. Quincy, MA: NFPA, 2013.

NFPA. *NFPA 17A Standard for Wet Chemical Extinguishing Systems*. Quincy, MA: NFPA, 2013.

NFPA. *NFPA 20 Standard for the Installation of Stationary Pumps for Fire Protection*. Quincy, MA: NFPA, 2013.

NFPA. *NFPA 24 Standard for the Installation of Private Fire Service Mains and Their Appurtenances*. Quincy, MA: NFPA, 2013.

NFPA. *NFPA 30 Flammable and Combustible Liquids Code*. Quincy, MA: NFPA, 2015.

NFPA. *NFPA 31 Standard for the Installation of Oil-Burning Equipment*. Quincy, MA: NFPA, 2011.

NFPA. *NFPA 45 Standard on Fire Protection for Laboratories Using Chemicals*. Quincy, MA: NFPA, 2015.

NFPA. *NFPA 52 Vehicular Gaseous Fuel Systems Code.* Quincy, MA: NFPA, 2013.

NFPA. *NFPA 54 National Fuel Gas Code.* Quincy, MA: NFPA, 2015.

NFPA. *NFPA 54 National Fuel Gas Code Handbook*. Quincy, MA: NFPA, 2015.

NFPA. *NFPA 55 Compressed Gases and Cryogenic Fluids Code*. Quincy, MA: NFPA, 2013.

NFPA. *NFPA 58 Liquefied Petroleum Gas Code*. Quincy, MA: NFPA, 2014.

NFPA. *NFPA 70 National Electrical Code*. Quincy, MA: NFPA, 2014.

NFPA. *NFPA 70 National Electrical Code Handbook*. Quincy, MA: NFPA, 2014.

NFPA. *NFPA 72 National Fire Alarm and Signaling Code*. Quincy, MA: NFPA, 2013.

NFPA. *NFPA 75 Standard for the Protection of Information Technology Equipment*. Quincy, MA: NFPA, 2013.

NFPA. *NFPA 76 Standard for the Protection of Telecommunications Facilities*. Quincy, MA: NFPA, 2012.

NFPA. *NFPA 88A Standard for Parking Structures.* Quincy, MA: NFPA, 2015.

NFPA. *NFPA 90A Standard for the Installation of Air-Conditioning and Ventilating Systems*. Quincy, MA: NFPA, 2015.

NFPA. *NFPA 90B Standard for the Installation of Warm Air Heating and Air-Conditioning Systems*. Quincy, MA: NFPA, 2015.

NFPA. *NFPA 91 Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Particulate Solids*. Quincy, MA: NFPA, 2015.

NFPA. *NFPA 92A Standard for Smoke Control Systems.* Quincy, MA: NFPA, 2015.

NFPA. *NFPA 92B Standard for Smoke Management Systems in Malls, Atria, and Large Spaces*. Quincy, MA: NFPA, 2009.

NFPA. *NFPA 96 Standard for Ventilation Control and Fire Protection of Commercial Cooking Operations*. Quincy, MA: NFPA, 2014.

NFPA. *NFPA 99 Health Care Facilities Code.* Quincy, MA: NFPA, 2015.

NFPA. *NFPA 101 Life Safety Code.* Quincy, MA: NFPA, 2015.

NFPA. *NFPA 110 Standard for Emergency and Standby Power Systems*. Quincy, MA: NFPA, 2013.

NFPA. *NFPA 204 Standard for Smoke and Heat Venting*. Quincy, MA: NFPA, 2015.

NFPA. *NFPA 211 Standard for Chimneys, Fireplaces, Vents, and Solid Fuel-Burning Appliances*. Quincy, MA: NFPA, 2013.

NFPA. *NFPA 214 Standard on Water-Cooling Towers.* Quincy, MA: NFPA, 2011.

NFPA. *NFPA 318 Standard for the Protection of Semiconductor Fabrication Facilities*. Quincy, MA: NFPA, 2015.

NFPA. *NFPA 418 Standard for Heliports.* Quincy, MA: NFPA, 2011.

NFPA. *NFPA 750 Water Mist Fire Protection Systems*. Quincy, MA: NFPA, 2015.

NFPA. *NFPA 900 Building Energy Code.* Quincy, MA: NFPA, 2013.

NFPA. *NFPA 909 Code for the Protection of Cultural Resource Properties—Museums, Libraries, and Places of Worship*. Quincy, MA: NFPA, 2013.

NFPA. *NFPA 914 Code for Fire Protection of Historic Structures*. Quincy, MA: NFPA, 2015.

NFPA. NFPA 5000 Building Construction and Safety Code. Quincy, MA: NFPA, 2015.

C. **Miscellaneous**

The Facility Guidelines Institute. *Guidelines for Design and Construction of Hospitals and Outpatient Facilities.* Washington, D.C.: American Hospital Association, 2014.

The Facility Guidelines Institute. *Guidelines for Design and Construction of Residential Health, Care, and Support Facilities.* Chicago, IL: American Society for Healthcare Engineering, 2014.

The American Institute of Architects Center for Advanced Technology Facilities Design. *Guidelines and Planning and Design of Biomedical Research Laboratory Facilities*. Washington, D.C: The American Institute of Architects' Press, 1999.

American Industrial Hygiene Association and The American National Standards Institute. *American National Standard—Laboratory Ventilation*. Fairfax, VA: American Industrial Hygiene Association, 2003.

Air Conditioning Contractors' Association. *Manual J Residential Load Calculations*. Version 2.10, Arlington, VA: Air Conditioning Contractors' Association, 2011.

Mower, Joe. *Updating Your Old Steam Heating System Using Modern Components*. Shippensburg, PA: Burd Street Press, 2003.

Associated Air Balance Council. AABC *Commissioning Guideline for Building Owners, Design Professionals, and Commissioning Service Providers*. Washington, D.C.: Associated Air Balance Council, 2002.

The Pennsylvania Housing Research/Resource Center (PHRC). *Pennsylvania's Alternative Residential Energy Provisions*. University Park, PA: PHRC, 2003.

Part 54: Equipment Schedules

54. Part 54: Equipment Schedules

54.01. General

A. **The equipment requirements listed in this section are general in nature and should be edited to suit the project. The items listed for a particular piece of equipment are generally not all required. For example, a variable volume terminal unit will have either a hot water coil or a steam coil, but not both. Also some Clients and Authorities Having Jurisdiction may not permit some of this information to be included on the drawings (i.e., Manufacturer's Name and Model No.).**

B. **Abbreviations**

1. CFM	= Air Flow Rate (Cubic Feet per Minute)
2. GPM	= Water Flow Rate (Gallons per Minute)
3. MBH	= 1,000 Btu/h
4. hp	= Horsepower
5. DB	= Dry Bulb Temperature (°F)
6. WB	= Wet Bulb Temperature (°F)
7. RH	= Relative Humidity (%)
8. EAT	= Entering Air Temperature (°F)
9. LAT	= Leaving Air Temperature (°F)

10. EWT	= Entering Water Temperature (°F)
11. LWT	= Leaving Water Temperature (°F)
12. SP	= Static Pressure (in. W.G.)
13. ESP	= External Static Pressure (in. W.G.)
14. TSP	= Total Static Pressure (in. W.G.)
15. FLA	= Full Load Amps
16. LRA	= Locked Rotor Amps
17. MCA	= Minimum Circuit Amps
18. MOCP	= Maximum Overcurrent Protection
19. FPM	= Feet per Minute
20. RPM	= Revolutions per Minute
21. APD	= Air Pressure Drop (in. W.G.)
22. WPD	= Water Pressure Drop (ft. H_2O)
23. PRV	= Pressure Reducing Valve (psig)
24. RV	= Relief Valve (psig)
25. psig	= Pounds per Square Inch
26. SA	= Supply Air CFM
27. RA	= Return Air CFM
28. OA	= Outside Air CFM
29. EXH	= Exhaust Air CFM
30. RFA	= Relief Air CFM
31. CC	= Cooling Coil
32. HC	= Heating Coil
33. PHC	= Preheat Coil
34. RHC	= Reheat Coil
35. ΔT	= Delta T, Temperature Difference, °F
36. CHWS	= Chilled Water Supply Temperature, °F

	Temperature, °F
37. CHWR	= Chilled Water Return Temperature, °F
38. CWS	= Condenser Water Supply Temperature, °F
39. CWR	= Condenser Water Return Temperature, °F
40. HWS	= Heating Water Supply Temperature, °F
41. HWR	= Heating Water Return Temperature, °F
42. LPS	= Low Pressure Steam, psig
43. MPS	= Medium Pressure Steam, psig
44. HPS	= High Pressure Steam, psig

54.02. Air Balance Schedule

Room Number

Room Name

Room Area

Source

Number of Occupants

Code Requirements:

OA CFM

SA CFM

Supply CFM

Return CFM

Relief CFM

Exhaust CFM

Outdoor CFM

Transfer Air:

- CFM
- To Room
- From Room

Remarks

54.03. Air Compressors

Designation

Location

Service

Type (Reciprocating, Rotary Screw, Duplex, Simplex)

CFM

Pressure psig

Receiver Size:

- Gallons
- Diameter
- Length

Motor:

- hp
- RPM
- Volts-phase-hertz

Operating Weight lbs.

Manufacturer's Name and Model No.

Remarks

54.04. Air-Cooled Condensers

Designation

Location

Service

Type

Tons or MBH

Refrigerant Type

Saturated Condenser Temperature

Condenser EAT °F DB/°F WB

Minimum OA Temperature

Fans:

- Number
- hp
- Volts-phase-hertz

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.05. Air-Cooled Condensing Units

Designation

Location

Service

Type

Tons or MBH

Refrigerant Type

Saturated Condenser Temperature

Condenser EAT °F DB/°F WB

Minimum OA Temperature

Compressor:

- Number
- kW or hp
- FLA
- LRA
- MCA
- MOCP
- Volts-phase-hertz

Fans:

- Number
- hp
- Volts-phase-hertz

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.06. Air Conditioning Units

Designation

Location

Service

Min. OA CFM

Fan:

- CFM
- ESP
- TSP
- Number of Wheels
- Wheel Diameter In.
- Motor hp

Filters:

- Type
- Efficiency

Cooling Coil:

- Refrigerant Type
- Sensible MBH
- Total MBH
- EAT °F DB/°F WB
- LAT °F DB/°F WB

Compressor:

- Number
- FLA
- LRA
- kW or hp

Condenser:

EAT

Number of Fans

Motor hp

Exhaust Fan Motor hp

Electric Heat:

kW

No. of Control Steps

EAT

LAT

Gas Heater:

Output MBH

Input MBH

EAT

LAT

Hot Water Coil:

MBH

EAT

LAT

EWT

LWT

GPM

WPD

Steam Coil:

MBH

EAT

LAT

Steam/h

Steam Pressure psig

Electric:

MCA

MOCP

Volts-phase-hertz

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.07. Air Filters (Pre-Filters, Filters, Final-Filters)

Designation

Location

Equipment Served

Service (Pre-Filters, Filters, Final-Filters)

Number

Type

Width

Height

Depth

Efficiency %

Initial APD

Final APD

Remarks

54.08. Air Handling Units—Custom, Factory Assembled, Factory Packaged, or Field Fabricated

Designation

Location

Service

Min. OA CFM

Fan:

CFM

Type (AF, BI, FC, DWDI, SWSI)

Class (I, II, III, IV)

Number of Wheels

Wheel Diameter

ESP

TSP

Motor hp

Volts-phase-hertz

Starter Type (Combination Starter/Disc. Switch, VFD, etc.)

Filters (see Air Filters)

Coils (see Coils—DX, Electric, Steam, Water)

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.09. Air Handling Units—Packaged, Central Station

Designation

Location

Service

Min. OA CFM

Fan:

CFM

Type (AF, BI, FC, DWDI, SWSI)

No. of Wheels

Wheel Diameter In.

ESP

TSP

Motor hp

Volts-phase-hertz

Starter Type (Combination Starter/Disc. Switch, VFD, etc.)

Filters (see Air Filters)

Coils (see Coils—DX, Electric, Steam, Water)

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.10. Boilers, Hot Water

Designation

Location

Service

Output MBH

Water:

GPM

EWT

LWT

WPD

Heater:

Gas Input MBH

Oil Input GPH

Electric:

kW

No. of Control Steps

Volts-phase-hertz

RV Setting

Accessories:

hp

kW

MCA

MOCP

Volts-phase-hertz

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.11. Boilers, Steam

Designation

Location

Service

Output # Steam/h

Steam Pressure psig

Feedwater Temperature

Heating Surface sq.ft.

Steam Drum Diameter

Lower Drum Diameter

Gas Input MBH

Oil Input GPH

Electric:

- kW
- No. of Control Steps
- Volts-phase-hertz

RV Setting

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.12. Cabinet Unit Heaters

Designation

Location

Type (Recessed, Semi-recessed, Exposed, Concealed, Ceiling, Floor, Up Discharge, Down Discharge, Hot Water, Steam, Electric, etc.)

Fan:

- CFM
- RPM
- Motor hp
- Volts-phase-hertz

Hot Water Coil:

- Capacity MBH
- EAT
- GPM
- EWT
- WPD

Steam Coil:

- Capacity MBH
- EAT
- # Steam/h
- Steam Pressure psig

Electric Coil:

- kW
- No. of Control Steps
- Volts-phase-hertz

Runouts:

- Supply
- Return

Manufacturers' Name and Model No.

Remarks

54.13. Chemical Feed Systems

Designation

Location

Service

Pump:

Type (Positive Displacement)

GPH

psi

hp

Volts-phase-hertz

Tank Gallons

Agitator:

hp

RPM

Volts-phase-hertz

Remarks

54.14. Chillers, Absorption

Designation

Location

Service

Type

Refrigerant Type

Capacity:

Tons Cooling

MBH Heating

Evaporator:

EWT

LWT

GPM

WPD

Condenser:

EWT

LWT

GPM

WPD

Absorber:

Steam Pressure psig

Steam/h

Gas Pressure in. W.G.

Gas Input MBH

Oil Input GPH

Heating Water GPM

EWT

LWT

WPD

Heating:

EWT

LWT

GPM

WPD

Electrical:

hp

kW

Volts-phase-hertz

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.15. Chillers, Air Cooled

Designation

Location

Service

Type

Refrigerant Type

Capacity Tons

Evaporator:

EWT

LWT

GPM

WPD

Condenser Temperature

Condenser:

EAT

Fans:

Number

hp

Compressor:

Compressor

kW

FLA

LRA

MCA

MOCP

Volts-phase-hertz

Starter Type (Wye-Delta, Solid State, Reduced Voltage, Auto Transformer, VFD, etc.)

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.16. Chillers, Water Cooled

Designation

Location

Service

Type

Refrigerant Type

Capacity Tons

Evaporator:

- EWT
- LWT
- GPM
- WPD

Condenser:

- EWT
- LWT
- GPM
- WPD

Heating (Heat Recovery Type):

- EWT
- LWT
- GPM
- WPD

Compressor:

- Number
- kW
- FLA
- LRA
- MCA

MOCP

Volts-phase-hertz

Starter Type (Wye-Delta, Solid State, Reduced Voltage, Auto Transformer, VFD, etc.)

Evaporator Temperature

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.17. Coils, Direct Expansion (DX)

Designation

Location

Equipment Served

Service (CC, Heat Recovery)

Refrigerant Type

MBH

CFM

EAT °F DB/°F WB

LAT °F DB/°F WB

Maximum Face Velocity FPM

APD

Remarks

54.18. Coils, Electric

Designation

Location

Equipment Served

Service (PHC, HC, RHC)

MBH

CFM

EAT

LAT

Maximum Face Velocity FPM

APD

kW

Volts-phase-hertz

Number of Control Steps

Manufacturers' Name and Model No.

Remarks

54.19. Coils, Steam

Designation

Location

Equipment Served

Service (HC, PHC, RHC)

MBH

CFM

EAT

LAT

Maximum Face Velocity FPM

APD

Steam/h

Steam Pressure psig

Runout Sizes:

Supply

Return

Remarks

54.20. Coils, Water

Designation

Location

Equipment Served

Service (PHC, CC, HC, RHC)

MBH

CFM

Cooling:

EAT °F DB/°F WB

LAT °F DB/°F WB

Max. Face Velocity FPM

GPM

EWT

LWT

APD

WPD

Heading:

Heating:

- EAT
- LAT
- Max. Face Velocity FPM
- GPM
- EWT
- LWT
- APD
- WPD

Runout Size:

- Supply
- Return

Remarks

54.21. Condensate Pump and Receiver Sets

Designation

Location

Service

Type (Simplex, Duplex)

GPM

Head ft. H_2O

Motor hp

Volts-phase-hertz

Tank Capacity Gallons

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.22. Convectors

Designation

Location

Type (Recessed, Semi-recessed, Exposed, Concealed, Ceiling, Floor, etc.)

Capacity MBH

EAT

GPM

EWT

WPD

Steam/h

Steam Pressure psig

kW

No. of Control Steps

Volts-phase-hertz

Runout Size:

- Supply
- Return

Manufacturers' Name and Model No.

Remarks

54.23. Cooling Towers

Designation

Location

Service

Type (Induced Draft, Forced Draft, etc.)

GPM

EWT

LWT

Ambient Air °F WB

Fans:

- Number of Fans
- CFM
- No. of Motors
- hp
- ESP
- Volts-phase-hertz
- Starter Type (Combination Starter/Disc. Switch, VFD, etc.)

Nozzle PD

Height Difference (Static Lift)

Basin Heaters:

- kW
- Volts-phase-hertz

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.24. Deaerators

Designation

Location

Service

Type

Number of Stages

Outlet Capacity lbs./h

Storage Capacity:

Pounds

Minutes

Steam:

lbs./h

psig

Size (Length × Diameter)

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.25. Design Conditions—Airside

Summer:

Outside: °F DB/°F WB

Inside: °F DB/%RH

Winter:

Outside: °F DB/°F WB

Inside: °F DB/%RH

Remarks

54.26. Design Conditions—Waterside

Chilled Water System:

CHWS

CHWR

ΔT

Condenser Water System:

CWS

CWR

ΔT

Heating Water System:

HWS

HWR

ΔT

Steam System:

LPS

MPS

HPS

54.27. Electric Baseboard Radiation

Designation

Type (see Specification for Type Designation)

Style (Wall Mounted, Floor Mounted, Flat Top, Sloped Top, Extruded Aluminum Grille, etc.)

Number of Elements

Electric:

kW

Volts-phase-hertz

Manufacturers' Name and Model No.

Remarks

54.28. Electric Radiant Heaters

Designation

Type (see Specification for Type Designation)

Style

Number of Elements

Length of Unit

Electric:

kW

Volts-phase-hertz

Manufacturers' Name and Model No.

Remarks

54.29. Evaporative Condensers

Designation

Location

Service

Type

Tons or MBH

Refrigerant Type

Saturated Condenser Temperature

Condenser EAT °F DB/°F WB

Minimum OA Temperature

Fans:

Number

ESP

hp

Volts-phase-hertz

Pump:

Number

hp

Head ft H_2O

Volts-phase-hertz

Basin Heaters:

kW

Volts-phase-hertz

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.30. Expansion Tanks

Designation

Location

Service (Hot Water, Chilled Water, Condenser Water, etc.)

Type (Closed, Open, Diaphragm)

Capacity Gallons

Size Diameter × Length

PRV Setting psig

RV Setting psig

Connection Size:

Fill

System

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.31. Fans (Supply, Return, Exhaust, Relief)

Designation

Location

Service (SA, RA, EA)

CFM

RPM

Drive (Belt, Direct)

Type (BI, AF, FC, Roof, Propeller, etc.)

Class (I, II, III, IV)

Wheel Diameter Inches

SP

Motor hp

Volts-phase-hertz

Starter Type (Combination Starter/Disc. Switch, VFD, etc.)

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.32. Fan Coil Units

Designation

Nominal CFM

Type (2-Pipe, 4-Pipe, 2-Pipe with Electric Heat)

Style (Recessed, Semi-recessed, Exposed, Concealed, Cabinet, Vertical Hi-Rise, Ceiling, Floor, etc.)

Fan:

- CFM
- Motor hp
- ESP
- Volts-phase-hertz

Cooling:

- Sensible MBH
- Total MBH
- GPM
- EWT
- LWT

EAT °F DB/°F WB

WPD

Runout Size:

Supply

Return

Drain Size

Heating:

MBH

GPM

WPD

EWT

LWT

EAT °F DB/°F WB

Runout Size:

Supply

Return

kW

No. of Control Steps

Volts-phase-hertz

Number of Control Steps

Manufacturers' Name and Model No.

Remarks

54.33. Finned Tube Radiation

Designation

Type (see Specification for Type Designation)

Style (Wall Mounted, Floor Mounted, Flat Top, Sloped Top, Extruded Aluminum Grille, etc.)

Number of Elements

Element Size:

Fins

Tube

Water:

Capacity MBH

EWT

LWT

EAT

GPM

WPD

Steam:

Capacity MBH

EAT

Steam/h

Steam Pressure

Manufacturers' Name and Model No.

Remarks

54.34. Flash Tanks

Designation

Location

Service

Type

Discharge Steam Pressure psig

Tanks Size (Diameter × Height)

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.35. Fluid Coolers/Closed Circuit Evaporative Coolers

Designation

Location

Service

Type

Fluid Type

GPM

EWT

LWT

Ambient Air °F WB

Fans:

- CFM
- Number of Motors
- hp
- ESP
- Volts-phase-hertz

Starter Type (Combination Starter/Disc. Switch, VFD, etc.)

Pumps:

Number

hp

Head ft H_2O

Volts-phase-hertz

Starter Type (Combination Starter/Disc. Switch, VFD, etc.)

Basin Heaters:

kW

Volts-phase-hertz

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.36. Fuel Oil Tanks

Designation

Location

Fuel Type

Tank Type (Double Wall, Steel, Fiberglass, Below Ground, Above Ground)

Capacity Gallons

Size:

Length

Diameter

Approximate Weight

Connection Sizes:

Supply

Return

Fill

Vent

Gauge

Heating Supply and Return

Sounding Drop (Tank, Storage)

Pad Size (L × W × Th)

Manhole Size

Manufacturers' Name and Model No.

Remarks

54.37. Gas Pressure Regulators

Designation

Location

Capacity cu.ft./h

Inlet:

psig

Pipe Size

Outlet:

psig

Pipe Size

Manufacturers' Name and Model No.

Remarks

54.38. Gravity Ventilators

Designation

Location

Service

Type (Dome, Louvered, Filters, No Filters)

Throat Size (L × W)

Physical Size (L × W × H)

Manufacturers' Name and Model No.

Remarks

54.39. Heat Exchangers, Plate and Frame, Steam to Water

Designation

Location

Service

Capacity MBH

Cold Side:

- GPM
- EWT
- LWT
- WPD

Hot Side:

- # Steam/h
- Steam Pressure psig

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.40. Heat Exchangers, Plate and Frame, Water to Water

Designation

Location

Service

Capacity MBH

Cold Side:

- GPM
- EWT
- LWT
- WPD

Hot Side:

- GPM
- EWT
- LWT
- WPD

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.41. Heat Exchangers, Shell and Tube, Steam to Water (Converter)

Designation

Location

Service

Capacity MBH

Shell:

Steam/h

Steam Pressure psig

Tubes:

GPM

EWT

LWT

WPD

Minimum Surface Area sq. ft.

Number of Passes

Approximate Length ft.

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.42. Heat Exchangers, Shell and Tube, Water to Water

Designation

Location

Service

Capacity MBH

Shell:

GPM

EWT

LWT

WPD

Tubes:

GPM

EWT

LWT

WPD

Minimum Surface Area sq. ft.

Number of Passes

Approximate Length ft.

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.43. Heat Pumps, Air Source

Designation

Location

Service

Type (Recessed, Semi-recessed, Exposed, Concealed, Ceiling, Floor, etc.)

Fan:

Total CFM

OA CFM

ESP

Cooling:

Sensible MBH

Total MBH

EAT °F DB/°F WB

LAT °F DB/°F WB

Sink Air Temperature

Heating Capacity:

Compressor MBH

Total MBH

Source Air Temperature

Electrical:

Evaporator Fan hp

Condenser Fan hp

Compressor kW

Heater kW

No. of Control Steps

MCA

MOCP

Volts-phase-hertz

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.44. Heat Pumps, Water Source

Designation

Location

Service

Type (Recessed, Semi-recessed, Exposed, Concealed, Ceiling, Floor, etc.)

Fan:

- Total CFM
- OA CFM
- ESP

Cooling:

- Sensible MBH
- Total MBH
- EAT °F DB/°F WB
- LAT °F DB/°F WB
- EWT

Heating Capacity:

- Compressor MBH
- Total MBH
- EWT

Source Water:

- GPM
- WPD

Runout Size:

- Supply
- Return

Electrical:

Fan hp

Compressor kW

Heater kW

No. of Control Steps

MCA

MOCP

Volts-phase-hertz

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.45. Humidifiers

Designation

Location

Service

Capacity:

Steam/h

Steam Pressure psig

Electric:

kW

Volts-phase-hertz

Duct/Air Handling Unit Size

Number of Manifolds

Runout Size:

Supply

Return

Drain

Manufacturers' Name and Model No.

Remarks

54.46. Motor Control Centers

Item Number

hp/kW

FLA

Starter Size

Starter Type (Combination Starter/Disc. Switch, VFD, etc.)

Circuit Breaker Size

Auxiliary Equipment (Specifications)

Nameplate Designation

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.47. Packaged Terminal AC Systems

Designation

Location

Service

Minimum OA CFM

Fan:

CFM

ESP

Number of Wheels

Motor hp

Filters:

Type

Efficiency %

DX Cooling:

Sensible MBH

Total MBH

EAT °F DB/°F WB

LAT °F DB/°F WB

Compressors:

Number

kW

Condenser:

EAT

Motor hp

Electric Heat:

kW

No. of Control Steps

EAT

LAT

Hot Water:

MBH

EAT

LAT

EWT

LWT

GPM

WPD

Steam Heat:

MBH

EAT

LAT

Steam/h

Steam Pressure psig

Electric:

MCA

MOCP

Volts-phase-hertz

Operating Weight lbs.

Remarks

54.48. Pumps

Designation

Location

Service (Chilled, Heating, Condenser Water, etc.)

Type (End Suction, Horizontal Split Case, In-Line, etc.)

GPM

Head ft.

NPSH

RPM

Motor hp

Volts-phase-hertz

Starter Type (Combination Starter/Disc. Switch, VFD, etc.)

Operating Weight lbs.

Manufacturers: Name and Model No.

Remarks

54.49. Radiant Heaters

Designation

Output Capacity MBH

Gas Input MBH

Burner:

- FLA
- LRA
- Volts-phase-hertz

Vacuum Pump:

- FLA
- LRA
- Motor hp

Volts-phase-hertz

Length of Reflector

Manufacturers' Name and Model No.

Remarks

54.50. Radiant Ceiling Panels

Designation

Type

Width

Average Water Temperature

Capacity Btu/h

WPD

Manufacturers' Name and Model No.

Remarks

54.51. Steam Pressure Reducing Valves

Designation

Location

Capacity # Steam/h

Inlet:

Pressure psig

Pipe Size

Outlet:

Pressure psig

Pipe Size

Manufacturers' Name and Model No.

Remarks

54.52. Steam Pressure Relief Valve

Designation

Location

Capacity # Steam/h

Relief Valve Setting psig

Discharge Pipe Size

Manufacturers' Name and Model No.

Remarks

54.53. Sound Attenuators (Duct Silencers, Sound Traps)

Designation

Location

Service

Type

CFM

Noise Reduction:

- 63 Hz
- 125 Hz
- 250 Hz
- 500 Hz
- 1,000 Hz
- 2,000 Hz

4,000 Hz

8,000 Hz

Face Velocity FPM

Maximum APD

Length ft.

Manufacturers' Name and Model No.

Remarks

54.54. Terminal Units, Constant Volume Reheat

Designation

CFM Range

Inlet Duct Size

Hot Water Coil:

Capacity MBH

EAT

Number of Rows

GPM

EWT

WPD

Steam Coil:

Capacity MBH

EAT

Number of Rows

#Steam/h

Steam Pressure psig

Runout Size:

Supply

Return

Electric Coil:

kW

Volts-phase-hertz

No. of Control Steps

Type of Control (DDC, Electric, Pneumatic)

Control Power Volts-phase-hertz

Manufacturers' Name and Model No.

Remarks

54.55. Terminal Units, Dual Duct Mixing Box

Designation

CFM Range

Minimum/Maximum CFM:

Cold Deck

Hot Deck

Inlet Duct Size:

Cold

Hot

Type of Control (DDC, Electric, Pneumatic)

Control Power Volts-phase-hertz

Manufacturers' Name and Model No.

Remarks

54.56. Terminal Units, Fan Powered

Designation

CFM Range

Minimum CFM Setting

Inlet Duct Size

Fan:

Type (Series, Parallel)

CFM

ESP

Motor hp

Volts-phase-hertz

Hot Water Coil:

Capacity MBH

EAT

Number of Rows

GPM

EWT

WPD

Steam Coil:

Capacity MBH

EAT

Number of Rows

Steam/h

Steam Pressure psig

Runout Size:

Supply

Return

Electric Coil:

kW

Volts-phase-hertz

Number of Control Steps

Type of Control (DDC, Electric, Pneumatic)

Control Power Volts-phase-hertz

Manufacturers' Name and Model No.

Remarks

54.57. Terminal Units, Variable Air Volume (VAV)

Designation

CFM Range

Minimum CFM Setting

Inlet Duct Size

Hot Water Coil:

Capacity MBH

EAT

Number of Rows

GPM

EWT

WPD

Steam Coil:

Capacity MBH

EAT

Number of Rows

Steam/h

Steam Pressure psig

Runout Size:

Supply

Return

Electric Coil:

kW

Volts-phase-hertz

Number of Control Steps

Type of Control (DDC, Electric, Pneumatic)

Control Power Volts-phase-hertz

Manufacturers' Name and Model No.

Remarks

54.58. Unit Heaters

Designation

Location

Type (Horizontal Discharge, Vertical Discharge, Hot Water, Steam, Electric, Gas Fired, Oil Fired, etc.)

Fan:

CFM

RPM

Motor hp

Volts-phase-hertz

Hot Water Coil:

Capacity MBH

EAT

GPM

EWT

WPD

Steam Coil:

Capacity MBH

EAT

Steam/h

Steam Pressure psig

Gas Heater:

Output Capacity MBH

Input MBH

EAT

Oil Heater:

Output Capacity MBH

Input GPH

EAT

Electric Coil:

kW

Volts-phase-hertz

No. of Control Steps

Runouts:

Supply

Return

Manufacturers' Name and Model No.

Remarks

54.59. Water Softeners

Designation

Location

Service

Number of Tanks

Capacity:

Minimum Grains

Maximum Grains

GPM

Tank Size (Diameter × Height)

Brine Tank (Diameter × Height)

Electrical Volts-phase-hertz

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

ACCESS Engineering
Authoritative content. Immediate solutions.

Part 55: Equipment Manufacturers

55. Part 55: Equipment Manufacturers

55.01. General

A. **The manufacturers listed in the following are organized using the new six-digit AIA Masterspec specifications sections.**

B. **The manufacturers listed in the following are not all inclusive of the manufacturers that may produce the particular product.**

55.02. Section 230500—Common Work Results for HVAC

A. **Plastic-to-Metal Transition Fittings**

1. Charlotte Pipe and Foundry Company.
2. Eslon Thermoplastic.
3. IPEX Inc.
4. Kbi.

B. **Plastic-to-Metal Transition Adaptors**

1. Thompson Plastics, Inc.

C. **Plastic-to-Metal Transition Unions**

1. Charlotte Pipe and Foundry Company.
2. IPEX Inc.
3. Kbi.

4. NIBCO, Inc.

5. NIBCO, Inc., Chemtrol Div.

D. **Dielectric Unions**

1. Capitol Manufacturing Co.

2. Central Plastics Company.

3. Eclipse, Inc.

4. Epco Sales, Inc.

5. Hart Industries International, Inc.

6. Watts Industries, Inc., Water Products Div.

7. Zurn Industries, Inc., Wilkins Div.

E. **Dielectric Flanges**

1. Capitol Manufacturing Co.

2. Central Plastics Company.

3. Epco Sales, Inc.

4. Watts Industries, Inc., Water Products Div.

5. Wilkins; Zurn Plumbing Products Group.

F. **Dielectric-Flange Kits**

1. Advance Products & Systems, Inc.

2. Calpico, Inc.

3. Central Plastics Company.

4. Pipeline Seal and Insulator, Inc.

G. **Dielectric Couplings**

1. Calpico, Inc.

2. Lochinvar Corp.

H. **Dielectric Nipples**

1. Perfection Corp.

2. Precision Plumbing Products, Inc.
3. Sioux Chief Manufacturing Co., Inc.
4. Victaulic Co. of America.

I. **Mechanical Sleeve Seals**
1. Advance Products & Systems, Inc.
2. Calpico, Inc.
3. Metraflex Co.
4. Pipeline Seal and Insulator, Inc.

55.03. Section 230513—Common Motor Requirements for HVAC Equipment

A. **Baldor.**

B. **Century.**

C. **Dayton.**

D. **General Electric Company.**

E. **Leeson Electric.**

F. **Lincoln Electric.**

G. **Louis Allis.**

H. **Magnetek.**

I. **Maraton Electric.**

J. **Reliance Motors.**

K. **Toshiba.**

L. **US Motors.**

55.04. Section 230516—Expansion Fittings and Loops for HVAC Piping

A. **Metal-Bellows Expansion Joints**

1. Badger Industries.
2. Expansion Joint Systems, Inc.
3. Flex-Hose Co., Inc.
4. Hyspan Precision Products, Inc.
5. Metraflex, Inc.
6. Proco Products, Inc.
7. Senior Flexonics, Inc., Pathway Division.
8. Unaflex Inc.

B. **Expansion Compensators**

1. Flexicraft Industries.
2. Flex-Weld, Inc.
3. Hyspan Precision Products, Inc.
4. Metraflex, Inc.
5. Senior Flexonics, Inc., Pathway Division.
6. Unaflex Inc.

C. **Rubber Expansion Joints**

1. Flex-Hose Co., Inc.
2. General Rubber Corp.
3. Mason Industries, Inc.; Mercer Rubber Co.
4. Metraflex, Inc.
5. Proco Products, Inc.
6. Senior Flexonics, Inc., Pathway Division.
7. Unaflex Inc.
8. Vibration Mountings & Controls, Inc.

D. **Flexible-Hose Expansion Joints**

1. Flex-Hose Co., Inc.
2. Flexicraft Industries.
3. Flex-Pression Ltd.
4. Mason Industries, Inc.; Mercer Rubber Co.
5. Metraflex, Inc.

E. **Packed Slip Expansion Joints**

1. Adsco Manufacturing, LLC.
2. Advanced Thermal Systems, Inc.
3. Senior Flexonics, Inc., Pathway Division.
4. Hyspan Precision Products, Inc.

F. **Flexible Ball Joints**

1. Advanced Thermal Systems, Inc.
2. Hyspan Precision Products, Inc.

G. **Alignment Guides**

1. Adsco Manufacturing, LLC.
2. Advanced Thermal Systems, Inc.
3. Flex-Hose Co., Inc.
4. Hyspan Precision Products, Inc.
5. Metraflex, Inc.
6. Piping Technology & Products, Inc.
7. Senior Flexonics, Inc., Pathway Division.

55.05. Section 230519—Meters and Gages for HVAC Piping

A. **Metal-Case, Liquid-In-Glass Thermometers**

1. Palmer—Wahl Instruments Inc.

2. Trerice, H. O. Co.

3. Weiss Instruments, Inc.

4. Weksler Instruments Operating Unit, Dresser Industries, Instrument Div.

B. **Plastic-Case, Liquid-In-Glass Thermometers**

1. Marsh Bellofram.

2. Miljoco Corp.

3. Trerice, H. O. Co.

4. Weksler Instruments Operating Unit, Dresser Industries, Instrument Div.

5. Winters Instruments.

C. **Duct-Type, Liquid-In-Glass Thermometers**

1. Miljoco Corp.

2. Palmer—Wahl Instruments Inc.

3. Trerice, H. O. Co.

4. Weiss Instruments, Inc.

D. **Direct-Mounting, Vapor-Actuated Dial Thermometers**

1. Ashcroft Commercial Instrument Operations, Dresser Industries, Instrument Div.

2. Marsh Bellofram.

3. Trerice, H. O. Co.

4. Weiss Instruments, Inc.

5. Weksler Instruments Operating Unit, Dresser Industries, Instrument Div.

E. **Remote-Mounting, Vapor-Actuated Dial Thermometers**

1. AMETEK, Inc.; U.S. Gauge Div.

2. Ashcroft Commercial Instrument Operations, Dresser Industries, Instrument Div.

3. Marsh Bellofram.

4. Miljoco Corp.

5. Palmer—Wahl Instruments Inc.
6. REO TEMP Instrument Corporation.
7. Tel-Tru Manufacturing Company.
8. Trerice, H. O. Co.; Weiss Instruments, Inc.
9. Weksler Instruments Operating Unit, Dresser Industries, Instrument Div.
10. Winters Instruments.

F. **Bimetallic-Actuated Dial Thermometers**

1. Ashcroft Commercial Instrument Operations, Dresser Industries, Instrument Div.
2. Marsh Bellofram.
3. Miljoco Corp.
4. Palmer—Wahl Instruments Inc.
5. Tel-Tru Manufacturing Company.
6. Trerice, H. O. Co.
7. Weiss Instruments, Inc.
8. Weksler Instruments Operating Unit, Dresser Industries, Instrument Div.
9. WIKA Instrument Corporation.
10. Winters Instruments.

G. **Thermowells**

1. AMETEK, Inc.; U.S. Gauge Div.
2. Ashcroft Commercial Instrument Operations, Dresser Industries, Instrument Div.
3. Marsh Bellofram.
4. Palmer—Wahl Instruments Inc.
5. Tel-Tru Manufacturing Company.
6. Trerice, H. O. Co.

7. Weiss Instruments, Inc.
8. Weksler Instruments Operating Unit, Dresser Industries, Instrument Div.
9. WIKA Instrument Corporation.
10. Winters Instruments.

H. **Pressure Gauges**

1. AMETEK, Inc., U.S. Gauge Div.
2. Ashcroft Commercial Instrument Operations, Dresser Industries, Instrument Div.
3. Marsh Bellofram.
4. Miljoco Corp.
5. Palmer—Wahl Instruments Inc.
6. Trerice, H. O. Co.
7. Weiss Instruments, Inc.
8. Weksler Instruments Operating Unit, Dresser Industries, Instrument Div.
9. WIKA Instrument Corporation.
10. Winters Instruments.

I. **Test Plugs**

1. Flow Design, Inc.
2. MG Piping Products Co.
3. National Meter, Inc.
4. Peterson Equipment Co., Inc.
5. Sisco Manufacturing Co.
6. Trerice, H. O. Co.
7. Watts Industries, Inc., Water Products Div.

J. **Wafer-Orifice Flow Meters**

1. ABB, Inc.; ABB Instrumentation.

2. Armstrong Pumps, Inc.
3. Badger Meter, Inc., Industrial Div.
4. Bell & Gossett; ITT Industries.
5. Meriam Instruments Div., Scott Fetzer Co.

K. **Venturi Flow Meters**

1. Armstrong Pumps, Inc.
2. Badger Meter, Inc., Industrial Div.
3. Bailey-Fischer & Porter Co.
4. Flow Design, Inc.
5. Gerand Engineering Co.
6. Hyspan Precision Products, Inc.
7. Preso Meters Corporation.
8. Victaulic Co. of America.

L. **Turbine Flow Meters**

1. Badger Meter, Inc., Industrial Div.
2. Bailey-Fischer & Porter Co.
3. Data Industrial Corp.
4. Engineering Measurements Company.
5. Fischer, George Inc.
6. ISTEC Corporation.
7. ONICON Incorporated.
8. Thermo Measurement Ltd.
9. Venture Measurement.

M. **Vortex-Shedding Flow Meters**

1. Bailey-Fischer & Porter Co.

2. Engineering Measurements Company.

3. ISTEC Corporation.

4. MCO/Eastech, Inc.

5. Schlumberger Limited, Measurement Div.

6. Venture Measurement.

N. **Pitot-Tube Flow Meters**

1. Dieterich Standard, Inc.

2. Meriam Instruments Div., Scott Fetzer Co.

3. Preso Meters Corporation.

4. Taco, Inc.

5. Veris Industries.

O. **Flow Indicators**

1. Brooks Instrument Div., Emerson Electric Co.

2. Dwyer Instruments, Inc.

3. Ernst Gage Co.

4. Eugene Ernst Products Co.

5. OPW Engineered Systems; Dover Corp.

6. Penberthy, Inc.

P. **Insertion-Turbine, Thermal-Energy Meter Systems**

1. Data Industrial Corp.

2. ONICON Incorporated.

3. Thermo Measurement Ltd.

Q. **Inline-Turbine, Thermal-Energy Meter Systems**

1. Engineering Measurements Company.

2. Hoffer Flow Controls, Inc.

3. ISTEC Corporation.

4. Thermo Measurement Ltd.
5. Venture Measurement.

R. **Ultrasonic, Thermal-Energy Meter Systems**
   1. Controlotron Corporation.
   2. Engineering Measurements Company.
   3. Mesa Laboratories, Inc., Nusonics Div.

55.06. Section 230523—General-Duty Valves for HVAC Piping

A. **Hydronic System Valve Schedule**
   1. Shutoff/isolation valves:
      a. 2" and smaller:
         1. Full port, bronze ball valves—copper piping systems.
         2. Full port, iron ball valves—steel piping systems.

      b. 2-1/2" and larger:
         1. Standard performance, butterfly valves.
         2. Medium performance, butterfly valves—mains and risers, hospitals, laboratories, and other critical facilities.
         3. High performance, butterfly valves—critical equipment and piping mains, central plants, hospitals, laboratories, and other critical facilities.

   2. Balancing valves:
      a. 2" and smaller:
         1. Reduced port, bronze ball valves—copper piping systems.
         2. Reduced port, iron ball valves—steel piping systems.
         3. Calibrated balancing valves: see "section 23211—hydronic piping."

      b. 2-1/2" and larger:
         1. Standard performance, butterfly valves.
         2. Medium performance, butterfly valves—mains and risers, hospitals, laboratories, and other critical facilities.

3. High performance, butterfly valves—critical equipment and piping mains, central plants, hospitals, laboratories, and other critical facilities.

4. Calibrated balancing valves: see "section 23211—hydronic piping."

3. Control valves:
   a. 2" and smaller:
      1. Reduced port, bronze ball valves.

      2. Reduced port, iron ball valves—steel piping systems.

      3. Bronze globe valves—copper piping systems.

      4. Iron globe valves—steel piping systems.

   b. 2-1/2" and larger:
      1. Standard performance, butterfly valves.

      2. Medium performance butterfly valves—mains and risers, hospitals, laboratories, and other critical facilities.

      3. High performance, butterfly valves—critical equipment and piping mains, central plants, hospitals, laboratories, and other critical facilities.

      4. Globe valves.

4. Check valves:
   a. Pumps:
      1. 2" and smaller:
         a. Bronze swing check valves—copper piping systems.

         b. Iron swing check valves—steel piping systems.

      2. 2-1/2" and larger: ductile iron center guided check valve, spring loaded, metal seat.

   b. All other locations:
      1. Bronze swing or lift check valves—copper piping systems.

      2. Iron swing or lift check valves—steel piping systems.

B. **Steam System Valve Schedule**
1. Shutoff/isolation valves:
   a. 2" and smaller:
      1. Full port, bronze ball valves—copper piping systems.

2. Full port, iron ball valves—steel piping systems.

3. Bronze gate valves—copper piping systems.

4. Iron gate valves—steel piping systems.

b. 2-1/2" and larger:

1. Gate valves.

2. High performance, butterfly valves—rated for steam service

2. Control valves:

a. 2" and smaller:

1. Bronze globe valves—copper piping systems.

2. Iron globe valves—steel piping systems.

b. 2-1/2" and larger:

1. Iron globe valves—steel piping systems.

3. Check valves:

a. Pumps:

1. 2" and smaller:

a. Bronze swing check valves—copper piping systems.

b. Iron swing check valves—steel piping systems.

2. 2-1/2" and larger: ductile iron center guided check valve, spring loaded, metal seat.

b. All other locations:

1. Bronze swing or lift check valves—copper piping systems.

2. Iron swing or lift check valves—steel piping systems.

C. **Bronze Angle Valves—Class 150, with Nonmetallic Disc**

1. Crane Co., Crane Valve Group, Crane Valves.

2. Crane Co., Crane Valve Group, Jenkins Valves.

3. Crane Co., Crane Valve Group, Stockham Division.

4. Hammond Valve.

5. Milwaukee Valve Company.

6. NIBCO, Inc.

7. Powell Valves.

D. **Bronze Ball Valves**

1. Bronze ball valves—two-piece, full-port, or regular (reduced) port, with bronze trim:

   a. Conbraco Industries, Inc.; Apollo Valves.

   b. Crane Co., Crane Valve Group, Crane Valves.

   c. Hammond Valve.

   d. Milwaukee Valve Company.

   e. Watts Regulator Co., a division of Watts Water Technologies, Inc.

2. Bronze ball valves—two-piece, full-port, or regular (reduced)-port, with stainless-steel trim:

   a. Conbraco Industries, Inc.; Apollo Valves.

   b. Crane Co., Crane Valve Group, Crane Valves.

   c. Hammond Valve.

   d. Milwaukee Valve Company.

   e. Watts Regulator Co., a division of Watts Water Technologies, Inc.

E. **Iron Ball Valves—Class 125**

1. American Valve, Inc.

2. Conbraco Industries, Inc.; Apollo Valves.

3. Kitz Corporation.

4. Sure Flow Equipment, Inc.

5. Watts Regulator Co., a division of Watts Water Technologies, Inc.

F. **Standard Performance, Butterfly Valves—150 CWP, Iron, Single-Flange (Lug Type), with EPDM Seat and Aluminum-Bronze or Stainless Steel Disc**

1. Bray Controls; a division of Bray International.

2. Centerline.

3. Conbraco Industries, Inc.; Apollo Valves.
4. Cooper Cameron Valves, a division of Cooper Cameron Corp.
5. DeZurik Water Controls.
6. Keystone.
7. Norriseal, a Dover Corporation Company.
8. W-K-M.
9. Iron, Grooved-End Butterfly Valves—175 CWP:
   a. Anvil International, Inc.
   b. Tyco Fire Products LP; Grinnell Mechanical Products.
   c. Victaulic Company.

G. **Medium Performance, Butterfly Valves—200 CWP, Iron, Single-Flange (Lug Type), with EPDM Seat and Aluminum-Bronze or Stainless Steel Disc**
1. Centerline.
2. Cooper Cameron Valves; a division of Cooper Cameron Corp.
3. Demco.
4. DeZurik Water Controls.
5. Keystone.
6. Norriseal, a Dover Corporation Company.
7. Iron, Grooved-End Butterfly Valves—300 CWP:
   a. Anvil International, Inc.
   b. Tyco Fire Products LP; Grinnell Mechanical Products.
   c. Victaulic Company.

H. **High Performance Butterfly Valves—Class 150 or 300, Iron, Single-Flange (Lug Type), with TFE or RTFE Seat and Stainless Steel Disc**
1. Bray Controls, a division of Bray International.
2. Cooper Cameron Valves, a division of Cooper Cameron Corp.

3. DeZurik Water Controls.

4. Flowseal.

5. Jamesbury, a subsidiary of Metso Automation.

6. Norriseal, a Dover Corporation company.

7. Posiseal

8. W-K-M.

9. Iron, Grooved-End Butterfly Valves—300 CWP:
   a. Anvil International, Inc.

   b. Tyco Fire Products LP; Grinnell Mechanical Products.

   c. Victaulic Company.

I. **Iron, Grooved-End Butterfly Valves—Class 175 or 300, Iron, Grooved, with EPDM Seat and Stainless Steel Disc**
   1. Anvil International, Inc.

   2. Tyco Fire Products LP; Grinnell Mechanical Products.

   3. Victaulic Company.

J. **Bronze Lift Check Valves—Class 125 with Bronze Disc**
   1. Crane Co., Crane Valve Group, Crane Valves.

   2. Crane Co., Crane Valve Group, Jenkins Valves.

   3. Crane Co., Crane Valve Group, Stockham Division.

K. **Bronze Swing Check Valves—Class 150 with Bronze Disc**
   1. American Valve, Inc.

   2. Crane Co., Crane Valve Group, Crane Valves.

   3. Crane Co., Crane Valve Group, Jenkins Valves.

   4. Crane Co., Crane Valve Group, Stockham Division.

   5. Milwaukee Valve Company.

L. **Iron Swing Check Valves**
   1. Iron Swing Check Valves—Class 125 with Metal Seats:

a. Crane Co., Crane Valve Group, Crane Valves.

b. Crane Co., Crane Valve Group, Jenkins Valves.

c. Crane Co., Crane Valve Group, Stockham Division.

d. Hammond Valve.

e. Milwaukee Valve Company.

f. Powell Valves.

g. Watts Regulator Co., a division of Watts Water Technologies, Inc.

2. Iron Swing Check Valves—Class 250 with Metal Seats:
   a. Crane Co., Crane Valve Group, Crane Valves.

   b. Crane Co., Crane Valve Group, Jenkins Valves.

   c. Crane Co., Crane Valve Group, Stockham Division.

   d. Hammond Valve.

   e. Milwaukee Valve Company.

   f. Watts Regulator Co., a division of Watts Water Technologies, Inc.

M. **Iron, Grooved-End Swing Check Valves—300 CWP, Grooved-End Swing Check Valves**
1. Anvil International, Inc.

2. Tyco Fire Products LP; Grinnell Mechanical Products.

3. Victaulic Company.

N. **Center-Guided Check Valves—Metal Seat**
1. Ductile iron, Class 150, globe, spring loaded:
   a. APCO Willamette Valve and Primer Corporation.

   b. Crispin Valve.

   c. Miller Manufacturing Company.

   d. Val-Matic Valve & Manufacturing Corp.

2. Ductile iron, Class 300, compact-wafer, spring loaded:
   a. APCO Willamette Valve and Primer Corporation.

b. Crispin Valve.

c. Miller Manufacturing Company.

d. Val-Matic Valve & Manufacturing Corp.

3. Ductile iron, Class 300, globe, spring loaded:
   a. APCO Willamette Valve and Primer Corporation.

   b. Crispin Valve.

   c. Miller Manufacturing Company.

   d. Val-Matic Valve & Manufacturing Corp.

O. **Center-Guided Check Valves—EPDM Resilient Seat**

1. Ductile Iron, Class 150, globe, spring loaded:
   a. APCO Willamette Valve and Primer Corporation.

   b. Crispin Valve.

   c. DFT Inc.

   d. Val-Matic Valve & Manufacturing Corp.

2. Ductile Iron, Class 300, compact-wafer, spring loaded:
   a. APCO Willamette Valve and Primer Corporation.

   b. Crispin Valve.

   c. Val-Matic Valve & Manufacturing Corp.

3. Ductile Iron, Class 300, globe, spring loaded:
   a. APCO Willamette Valve and Primer Corporation.

   b. Crispin Valve.

   c. Val-Matic Valve & Manufacturing Corp.

P. **Bronze Gate Valves**

1. Bronze Gate Valves—Class 125, NRS and RS:
   a. Crane Co., Crane Valve Group, Crane Valves.

   b. Crane Co., Crane Valve Group, Jenkins Valves.

   c. Crane Co., Crane Valve Group, Stockham Division.

d. Hammond Valve.

e. Milwaukee Valve Company.

f. Powell Valves.

g. Watts Regulator Co., a division of Watts Water Technologies, Inc.

2. Bronze Gate Valves—Class 150, NRS and RS:

a. Crane Co., Crane Valve Group, Crane Valves.

b. Crane Co., Crane Valve Group, Stockham Division.

c. Hammond Valve.

d. Milwaukee Valve Company.

e. Powell Valves.

f. Watts Regulator Co., a division of Watts Water Technologies, Inc.

Q. **Iron Gate Valves**

1. Iron Gate Valves—Class 125, NRS:

a. Crane Co., Crane Valve Group, Crane Valves.

b. Crane Co., Crane Valve Group, Jenkins Valves.

c. Crane Co., Crane Valve Group, Stockham Division.

d. Hammond Valve.

e. Milwaukee Valve Company.

f. Powell Valves.

g. Watts Regulator Co., a division of Watts Water Technologies, Inc.

2. Iron Gate Valves—Class 125, OS&Y:

a. Crane Co., Crane Valve Group, Crane Valves.

b. Crane Co., Crane Valve Group, Jenkins Valves.

c. Crane Co., Crane Valve Group, Stockham Division.

d. Hammond Valve.

e. Milwaukee Valve Company.

f. Powell Valves.

g. Watts Regulator Co., a division of Watts Water Technologies, Inc.

3. Iron Gate Valves—Class 250, NRS:
   a. Crane Co., Crane Valve Group, Crane Valves.

   b. Crane Co., Crane Valve Group, Stockham Division.

4. Iron Gate Valves—Class 250, OS&Y:
   a. Crane Co., Crane Valve Group, Crane Valves.

   b. Crane Co., Crane Valve Group, Stockham Division.

   c. Hammond Valve.

   d. Milwaukee Valve Company.

   e. Powell Valves.

   f. Watts Regulator Co., a division of Watts Water Technologies, Inc.

R. **Bronze Globe Valves—Class 150 with Nonmetallic Disc**

1. Crane Co., Crane Valve Group, Crane Valves.

2. Crane Co., Crane Valve Group, Stockham Division.

3. Hammond Valve.

4. Milwaukee Valve Company.

5. Powell Valves.

6. Watts Regulator Co., a division of Watts Water Technologies, Inc.

S. **Iron Globe Valves**

1. Iron Globe Valves—Class 125:
   a. Crane Co., Crane Valve Group, Crane Valves.

   b. Crane Co., Crane Valve Group, Jenkins Valves.

   c. Crane Co., Crane Valve Group, Stockham Division.

   d. Hammond Valve.

   e. Milwaukee Valve Company.

f. Powell Valves.

g. Watts Regulator Co., a division of Watts Water Technologies, Inc.

2. Iron Globe Valves—Class 250:
   a. Crane Co., Crane Valve Group, Crane Valves.

   b. Crane Co., Crane Valve Group, Jenkins Valves.

   c. Crane Co., Crane Valve Group, Stockham Division.

   d. Hammond Valve.

   e. Milwaukee Valve Company.

   f. NIBCO Inc.

   g. Watts Regulator Co., a division of Watts Water Technologies, Inc.

T. **Lubricated Plug Valves—Class 125 or 250, Cylindrical with Threaded or Flanged Ends**
   1. Homestead Valve, a division of Olson Technologies, Inc.

   2. Milliken Valve Company.

   3. R & M Energy Systems, a unit of Robbins & Myers, Inc.

U. **Eccentric Plug Valves—175 CWP with Resilient Seating**
   1. DeZurik Water Controls.

   2. Homestead Valve, a division of Olson Technologies, Inc.

   3. M&H Valve Company, a division of McWane, Inc.

   4. Milliken Valve Company.

V. **Chainwheels**
   1. Babbitt Steam Specialty Co.

   2. Roto Hammer Industries.

   3. Trumbull Industries.

W. **Backflow Preventers and Pressure Reducing Valves**
   1. Conbraco Industries, Inc.; Apollo Valves.

   2. Watts Regulator Co., a division of Watts Water Technologies, Inc.

55.07. Section 230529—Hangers and Supports for HVAC Piping and Equipment

A. **Steel Pipe Hangers and Supports**

1. Basic Engineering.
2. Bergen-Power Pipe Supports.
3. B-Line Systems, Inc., a division of Cooper Industries.
4. Carpenter & Paterson, Inc.
5. Empire Industries, Inc.
6. ERICO/Michigan Hanger Co.
7. Grinnell Corp.
8. PHS Industries, Inc.
9. Unistrut.
10. Superstrut.

B. **Fiberglass Pipe Hangers**

1. B-Line Systems, Inc., a division of Cooper Industries.
2. Champion Fiberglass, Inc.
3. Cope, T. J., Inc.; Tyco International Ltd.
4. Seasafe, Inc.

C. **Thermal-Hanger Shield Inserts**

1. Bergen Pre-Insulated Pipe Supports, Inc.
2. Carpenter & Paterson, Inc.
3. ERICO/Michigan Hanger Co.
4. Insul-Shield.
5. PHS Industries, Inc.
6. Pipe Shields, Inc.

7. Rilco Manufacturing Company, Inc.

8. Value Engineered Products, Inc.

D. **Fastener Systems—Powder-Actuated Fasteners**

1. Hilti, Inc.

2. ITW Ramset/Red Head.

3. Masterset Fastening Systems, Inc.

4. MKT Fastening, LLC.

5. Powers Fasteners.

E. **Fastener Systems—Mechanical-Expansion Anchors**

1. B-Line Systems, Inc., a division of Cooper Industries.

2. Empire Industries, Inc.

3. Hilti, Inc.

4. ITW Ramset/Red Head.

5. MKT Fastening, LLC.

6. Powers Fasteners.

F. **Pipe Stand Fabrication**

1. ERICO/Michigan Hanger Co.

2. MIRO Industries.

3. Portable Pipe Hangers.

G. **Equipment Curbs and Rails**

1. Roof Product Systems Corp. (RPS).

2. The Pate Co.

3. Thycurb.

H. **Pipe Portals**

1. Roof Product Systems Corp. (RPS).

2. The Pate Co.

3. Thycurb.

I. **Pipe Mounting Pedestals**

1. Roof Product Systems Corp. (RPS).
2. The Pate Co.
3. Thycurb.

J. **Duct Mounting Pedestals**

1. Roof Product Systems Corp. (RPS).
2. The Pate Co.
3. Thycurb.

K. **Non-Penetrating Support Systems**

1. MIRO Industries, Inc.
2. Portable Pipe Hangers, Inc.

55.08. Section 230533—Heat Tracing for HVAC Piping

A. **Plastic-Insulated, Series-Resistance Heating Cables**

1. Delta-Therm Corporation.
2. Easy Heat Inc.
3. Pyrotenax, a division of Tyco Thermal Controls.
4. Raychem, a division of Tyco Thermal Controls.
5. Watts Radiant Inc.

B. **Self-Regulating, Parallel-Resistance Heating Cables**

1. Chromalox, Inc., Wiegard Industrial Division, Emerson Electric Company.
2. Delta-Therm Corporation.
3. Easy Heat Inc.
4. Pyrotenax, a division of Tyco Thermal Controls.
5. Raychem, a division of Tyco Thermal Controls.

6. Thermon Manufacturing Co.

55.09. Section 230548—Vibration and Seismic Controls for HVAC Piping and Equipment

A. **Vibration Isolators**

1. Amber/Booth Company, Inc.
2. Kinetics Noise Control.
3. Korfund Dynamics Corp.
4. Mason Industries.
5. Peabody Noise Control.
6. Vibration Eliminator Co., Inc.
7. Vibration Isolation.
8. Vibration Mountings & Controls, Inc.

B. **Air-Mounting Systems**

1. Kinetics Noise Control.
2. Mason Industries.
3. Vibration Eliminator Co., Inc.

C. **Restrained Vibration Isolation Roof-Curb Rails**

1. Amber/Booth Company, Inc.
2. Kinetics Noise Control.
3. Korfund Dynamics Corp.
4. Mason Industries.
5. Peabody Noise Control.
6. Vibration Eliminator Co., Inc.
7. Vibration Isolation.
8. Vibration Mountings & Controls, Inc.

D. **Vibration Isolation Equipment Bases**

1. Amber/Booth Company, Inc.
2. Kinetics Noise Control.
3. Korfund Dynamics Corp.
4. Mason Industries.
5. Peabody Noise Control.
6. Vibration Eliminator Co., Inc.
7. Vibration Isolation.
8. Vibration Mountings & Controls, Inc.

E. **Seismic-Restraint Devices**

1. Amber/Booth Company, Inc.
2. Cooper B-Line, Inc., a division of Cooper Industries.
3. Hilti, Inc.
4. Kinetics Noise Control.
5. Mason Industries.
6. Unistrut; Tyco International Ltd.

55.10. Section 230553—Identification for HVAC Piping and Equipment

A. **Bunting.**

B. **Brady USA, Inc.**

C. **Carlton Industries, Inc.**

D. **Industrial Safety Supply Co., Inc.**

E. **MSI.**

F. **Seton Name Plate Corp.**

G. **W.H. Brady Co.**

55.11. Section 230700—HVAC Insulation

A. **Thermal Insulation**

1. Calcium Silicate: Industrial Insulation Group.
2. Cellular glass:
    a. Cell-U-Foam Corporation.
    b. Pittsburgh Corning Corporation.
3. Flexible elastomeric (Armaflex):
    a. Aeroflex USA Inc.
    b. Armacell LLC (Armstrong).
    c. RBX Corporation (Rubatex).
4. Mineral-fiber blanket insulation:
    a. CertainTeed Corp.
    b. Johns Manville.
    c. Knauf Insulation.
    d. Owens Corning.
5. High-temperature, mineral-fiber blanket insulation:
    a. Johns Manville.
    b. Owens Corning.
6. Mineral-fiber board insulation:
    a. CertainTeed Corp.
    b. Fibrex Insulations Inc.
    c. Johns Manville.
    d. Knauf Insulation.
    e. Owens Corning.
7. High-temperature, mineral-fiber board insulation:
    a. Fibrex Insulations, Inc.

    b. Johns Manville.

    c. Owens Corning.

    d. Rock Wool Manufacturing Company.

    e. Thermafiber.

8. Mineral-fiber, preformed pipe insulation:
    a. Fibrex Insulations, Inc.

    b. Johns Manville.

    c. Knauf Insulation.

    d. Owens Corning.

9. Mineral-fiber, pipe insulation wicking system:
    a. Knauf Insulation; Permawick Pipe Insulation.

    b. Owens Corning; VaporWick Pipe Insulation.

10. Mineral-fiber, pipe and tank insulation:
    a. CertainTeed Corp.

    b. Johns Manville.

    c. Knauf Insulation.

    d. Owens Corning.

11. Phenolic: Kingspan Corp.

12. Polyisocyanurate:
    a. Apache Products Company.

    b. Dow Chemical Company.

    c. Duna USA Inc.

    d. Elliott Company.

13. Polyolefin:
    a. Armacell LLC.

    b. Nomaco Inc.

c. RBX Corporation.

14. Polystyrene:
    a. Dow Chemical Company.

    b. Knauf Insulation.

15. Fire-rated insulation systems:
    a. Fire-rated board: Johns Manville.

    b. Fire-rated blanket:
        1. CertainTeed Corp.

        2. Johns Manville.

        3. Nelson Firestop Products.

        4. Thermal Ceramics.

        5. 3M.

        6. Vesuvius.

16. Insulating cements:
    a. Insulco, Division of MFS, Inc.

    b. P. K. Insulation Mfg. Co., Inc.

    c. Rock Wool Manufacturing Company.

B. **Adhesives**
1. Childers Products, a division of ITW.

2. Foster Products Corporation, H. B. Fuller Company.

3. ITW TACC, a division of Illinois Tool Works.

4. Marathon Industries, Inc.

5. Mon-Eco Industries, Inc.

6. Vimasco Corporation.

C. **Flexible Elastomeric and Polyolefin Adhesives**
1. Aeroflex USA, Inc.

2. Armacell LCC.

3. Foster Products Corporation, H. B. Fuller Company.

4. RBX Corporation.

D. **PVC Jacket Adhesives**

1. Dow Chemical Company.

2. Johns-Manville.

3. P.I.C. Plastics, Inc.

4. Speedline Corporation.

E. **Mastics**

1. Childers Products, a division of ITW.

2. Foster Products Corporation, H. B. Fuller Company.

3. ITW TACC, Division of Illinois Tool Works.

4. Marathon Industries, Inc.

5. Mon-Eco Industries, Inc.

6. Vimasco Corporation.

F. **Sealants**

1. Childers Products, a division of ITW.

2. Foster Products Corporation, H. B. Fuller Company.

3. Marathon Industries, Inc.

4. Mon-Eco Industries, Inc.

5. Pittsburgh Corning Corporation.

6. Vimasco Corporation.

G. **Factory-Applied Jackets: Dow Chemical Company**

H. **Field-Applied Fabric-Reinforcing Mesh**

1. Vimasco Corporation.

2. Childers Products, a division of ITW.

3. Foster Products Corporation, H. B. Fuller Company.

4. Vimasco Corporation.

I. **Field-Applied Cloths: Alpha Associates, Inc.**

J. **PVC Jacket**

1. Johns Manville.
2. P.I.C. Plastics, Inc.
3. Proto PVC Corporation.
4. Speedline Corporation.

K. **Metal Jacket**

1. Childers Products, a division of ITW.
2. PABCO Metals Corporation.
3. RPR Products, Inc.

L. **Underground Direct-Buried Jacket**

1. Pittsburgh Corning Corporation.
2. Polyguard.

M. **Tapes**

1. Avery Dennison Corporation, Specialty Tapes Division.
2. Compac Corp.
3. Ideal Tape Co., Inc., an American Biltrite Company.
4. Venture Tape.
5. Dow Chemical Company.

N. **Bands**

1. Childers Products.
2. PABCO Metals Corporation.
3. RPR Products, Inc.

O. **Insulation Pins, Hangers, and Weld Pins**

1. AGM Industries, Inc.
2. GEMCO.

3. Midwest Fasteners, Inc.

4. Nelson Stud Welding.

P. **Wire**

1. C & F Wire.

2. Childers Products.

3. PABCO Metals Corporation.

4. RPR Products, Inc.

55.12. Section 230900—Instrumentation and Control for HVAC

A. **HVAC Control Systems—Commercial**

1. Alerton Inc.

2. American Auto-Matrix.

3. Andover Controls Corporation.

4. Automated Logic Corporation.

5. Carrier Corporation, a member of the United Technologies Family.

6. Combustion Service & Equipment Co. (CS&E).

7. Delta Controls Inc.

8. Honeywell International Inc.; Home & Building Control.

9. Invensys Building Systems.

10. Johnson Controls, Inc.; Controls Group.

11. KMC Controls/Kreuter Manufacturing Company.

12. McQuay International.

13. Siemens Building Technologies, Inc.

14. TAC Americas, Inc.

15. Trane.

16. Voltec, Inc.

B. **HVAC Control Systems—Hospital**

1. American Auto-Matrix.
2. Automated Logic Corporation.
3. Johnson Controls, Inc.; Controls Group.
4. Siemens Building Technologies, Inc.

C. **HVAC Control Systems—Laboratory**

1. American Auto-matrix.
2. Auto Flow.
3. CMR Controls, a division of C.M. Richter Ltd.
4. Phoenix Controls Incorporated.
5. TSI Incorporated.
6. Siemens Building Technologies, Inc.

D. **Time Clocks**

1. ATC-Diversified Electronics.
2. Grasslin Controls Corporation.
3. Paragon Electric Co., Inc.
4. Precision Multiple Controls, Inc.
5. SSAC Inc.; ABB USA.
6. TCS/Basys Controls.
7. Time Mark Corporation.

E. **Thermistor Temperature Sensors and Transmitters**

1. BEC Controls Corporation.
2. Ebtron, Inc.
3. Heat-Timer Corporation.
4. I.T.M. Instruments Inc.

5. MAMAC Systems, Inc.

6. RDF Corporation.

F. **RTDs and Transmitters**

1. BEC Controls Corporation.

2. MAMAC Systems, Inc.

3. RDF Corporation.

G. **Humidity Sensors**

1. BEC Controls Corporation.

2. General Eastern Instruments.

3. MAMAC Systems, Inc.

4. ROTRONIC Instrument Corp.

5. TCS/Basys Controls.

6. Vaisala.

H. **Pressure Transmitters/Transducers**

1. BEC Controls Corporation.

2. General Eastern Instruments.

3. MAMAC Systems, Inc.

4. ROTRONIC Instrument Corp.

5. TCS/Basys Controls.

6. Vaisala.

I. **Digital-to-Pneumatic Transducers**

1. BEC Controls Corporation.

2. MAMAC Systems, Inc.

J. **Water-Flow Switches**

1. BEC Controls Corporation.

2. ITM Instruments, Inc.

K. **Gas Detection Equipment**

1. ACME Engineering Products, Inc.
2. Ebtron, Inc.
3. MSA Canada Inc.
4. Rel-Tek Corporation.
5. Sauter Controls Corporation.
6. TSI Incorporated.
7. Vaisala.
8. Vulcain, Inc.

L. **Duct Airflow Station**

1. Air Monitor Corporation.
2. Cambridge Air Sentinel.
3. Wetmaster Co., Ltd.

M. **Water Flow Measuring Systems, Portable and Permanent**

1. Barco.
2. Barton.
3. Bell and Gossett.
4. Dietrich Standard.
5. Fisher and Porter.
6. Girand.
7. Rockwell International, Inc.
8. Taco.

N. **Thermostats**

1. Erie Controls.
2. Danfoss, Inc., Air-Conditioning and Refrigeration Div.
3. Heat-Timer Corporation.

4. Sauter Controls Corporation.

5. Tekmar Control Systems, Inc.

6. Theben AG—Lumilite Control Technology, Inc.

O. **Humidistats**

1. MAMAC Systems, Inc.

2. ROTRONIC Instrument Corp.

P. **Control Valves (see also "Section 230523—General-Duty Valves for HVAC Piping")**

1. Danfoss, Inc., Air Conditioning & Refrigeration Div.

2. Erie Controls.

3. Hayward Industrial Products, Inc.

4. Magnatrol Valve Corporation.

5. Neles-Jamesbury.

6. Parker Hannifin Corporation, Skinner Valve Division.

7. Pneuline Controls.

8. Sauter Controls Corporation.

Q. **Control Dampers**

1. Air Balance Inc., a division of Mestek, Inc.

2. American Warming and Ventilating, a division of Mestek, Inc.

3. Arrow United Industries, a division of Mestek, Inc.

4. Duro Dyne, Inc.

5. Greenheck Fan Corporation.

6. McGill AirFlow LLC.

7. Nailor Industries, Inc.

8. Pottorff, a division of PCI Industries, Inc.

9. Ruskin Company.

10. SEMCO Incorporated.

11. United Air/Safe Air.

12. Vent Products Company, Inc.

13. Young Regulator Company.

55.13. Section 231113—Facility Fuel-Oil Piping

A. **Double-Containment Pipe and Fittings**

1. Flexible, double-containment piping:
   a. Environ Products, Inc.

   b. OPW.

2. Rigid, double-containment piping:
   a. Ameron International; Fiberglass Pipe Group.

   b. Conley Corporation.

   c. Perma-Pipe, Inc.

   d. Smith Fibercast.

B. **Piping specialties**

1. Metallic Flexible Connectors:
   a. American Flexible Hose Co., Inc.

   b. Metraflex Company (The).

   c. Proco Products, Inc.

   d. Tru-Flex Metal Hose Corp.

   e. Unaflex.

2. Nonmetallic flexible connectors:
   a. American Flexible Hose Co., Inc.

   b. Hose Master, Inc.; Metraflex Company (The); Tru-Flex Metal Hose Corp.

3. Strainers:
   a. Boylston.

b. Metraflex.

c. McAlear.

d. Mueller.

e. Nicholson.

f. Sarco.

g. Spence.

h. Tate Tempco.

C. **Manual Fuel-Oil Shutoff Valves—Two-Piece, Full-Port, or Regular Port, Bronze Ball Valves with Bronze Trim**

1. BrassCraft Manufacturing Company, a Masco company.

2. Conbraco Industries, Inc., Apollo Div.

3. McDonald, A. Y. Mfg. Co.

4. Perfection Corporation, a subsidiary of American Meter Company.

D. **Specialty Valves**

1. Pressure relief valves:

   a. Anderson Greenwood, a division of Tyco Flow Control.

   b. Fulflo Specialties, Inc.

   c. Webster Fuel Pumps & Valves, a division of Capital City Tool, Inc.

2. Oil safety valves:

   a. Anderson Greenwood, a division of Tyco Flow Control.

   b. Suntec Industries Incorporated.

   c. Webster Fuel Pumps & Valves, a division of Capital City Tool, Inc.

3. Emergency shutoff valves:

   a. Ameron International; Fiberglass Pipe Group.

   b. Conley Corporation.

   c. EMCO Wheaton, a Gardner Denver Company.

   d. Environ Products, Inc.

e. OPW.

4. Mechanical leak detector:
   a. FE Petro, Inc.

   b. Red Jacket Pumps, a division of Veeder-Root.

E. **Fuel Oil Storage Tank—Above-Ground, Vertical, Horizontal, Steel**

1. Ace Tank & Equipment Company.

2. Adamson Global Technology Corporation.

3. Buffalo Tank Company, Inc.

4. Containment Solutions, Inc.

5. Highland Tank & Manufacturing Company, Inc.

6. Palmer Manufacturing & Tank, Inc.

7. Safe-T-Tank Corp.

8. Steel Tank & Fabricating Co., Inc.

9. Watco Tanks, Inc.

F. **Fuel Oil Storage Tank—Above-Ground, Containment-Dike, Steel**

1. Buffalo Tank Company, Inc.

2. Containment Solutions, Inc.

3. Highland Tank & Manufacturing Company, Inc.

4. Palmer Manufacturing & Tank, Inc.

5. Safe-T-Tank Corp.

6. Watco Tanks, Inc.

G. **Fuel Oil Storage Tank—Above-Ground, Insulated, Steel**

1. Ace Tank & Equipment Company.

2. Adamson Global Technology Corporation.

3. Containment Solutions, Inc.

4. Highland Tank & Manufacturing Company, Inc.

5. Palmer Manufacturing & Tank, Inc.

6. Steel Tank & Fabricating Co., Inc.

H. **Fuel Oil Storage Tank—Above-Ground, Concrete-Vaulted, Steel**

1. Cardinal Tank Corp.

2. ConVault, Inc.

3. Earthsafe Systems, Inc.

4. EcoVault, Inc.

I. **Fuel Oil Storage Tank—Under-Ground, Steel, STI-P3**

1. Ace Tank & Equipment Company.

2. Adamson Global Technology Corporation.

3. Containment Solutions, Inc.

4. Highland Tank & Manufacturing Company, Inc.

5. Palmer Manufacturing & Tank, Inc.

6. Steel Tank & Fabricating Co., Inc.

7. Watco Tanks, Inc.

J. **Fuel Oil Storage Tank—Under-Ground, Composite, Steel**

1. Ace Tank & Equipment Company.

2. Adamson Global Technology Corporation.

3. Containment Solutions, Inc.

4. Palmer Manufacturing & Tank, Inc.

5. Watco Tanks, Inc.

K. **Fuel Oil Storage Tank—Under-Ground, Jacketed, Steel**

1. Ace Tank & Equipment Company.

2. Highland Tank & Manufacturing Company, Inc.

3. Palmer Manufacturing & Tank, Inc.

L. **Fuel Oil Storage Tank—Under-Ground, FRP**

1. Containment Solutions, Inc.

2. Xerxes Corporation.

M. **Fuel Oil Storage Tank Piping Specialties**

1. EBW, Inc.

2. Environ Products, Inc.

3. Morrison Bros. Co.

4. OPW.

5. Preferred Utilities Manufacturing Corporation.

6. Universal Valve Company.

N. **Submersible Fuel-Oil Pumps**

1. FE Petro, Inc.

2. Red Jacket Pumps; a division of Veeder-Root.

O. **Simplex Fuel-Oil Transfer Pumps**

1. DESMI Inc./Rotan Pumps.

2. Haight Pumps, a division of Baker Mfg.

3. Preferred Utilities Manufacturing Corporation.

4. Suntec Industries Incorporated.

5. Tuthill Corporation; Tuthill Pump Div.

6. Viking Pump Inc., a unit of IDEX Corporation.

7. Webster Fuel Pumps & Valves, a division of Capital City Tool, Inc.

P. **Duplex or Triplex Fuel-Oil Transfer Pump Sets**

1. Alyan Pump Company.

2. Hydronic Modules Corporation.

3. Preferred Utilities Manufacturing Corporation.

4. Smith-Koch, Inc.

5. Viking Pump, Inc., a unit of IDEX Corporation.

6. Webster Fuel Pumps & Valves, a division of Capital City Tool, Inc.

Q. **Fuel Maintenance System**

1. Fuel Technologies, International, LLC.
2. Veeder-Root, a Danaher Corporation Company.

R. **Liquid-Level Gage System**

1. Clawson Tank Company.
2. EBW, Inc.
3. Highland Tank & Manufacturing Company, Inc.
4. INCON, Inc.
5. Krueger Sentry Gauge.
6. Tuthill Corporation; Tuthill Transfer Systems; Sotera Systems.
7. Venture Measurement Company, LLC.

S. **Leak-Detection and Monitoring System**

1. Cable and sensor system:
   a. Containment Solutions, Inc.
   b. EBW, Inc.
   c. Highland Tank & Manufacturing Company, Inc.
   d. INCON, Inc.
   e. MSA; Instrument Div.
   f. Perma-Pipe, Inc.
   g. Raychem Corp; Tyco Electronics Corporation.
   h. Tuthill Corporation; Tuthill Transfer Systems; Sotera Systems.
   i. Veeder-Root, a Danaher Corporation Company.
2. Hydrostatic system:
   a. Containment Solutions, Inc.
   b. EBW, Inc.

c. Highland Tank & Manufacturing Company, Inc.

d. INCON, Inc.

e. MSA, Instrument Div.

f. Perma-Pipe, Inc.

g. Raychem Corp; Tyco Electronics Corporation.

h. Tuthill Corporation; Tuthill Transfer Systems; Sotera Systems.

i. Veeder-Root, a Danaher Corporation Company.

55.14. Section 231123—Facility Natural-Gas Piping

A. **Mechanical Couplings**

1. Dresser Piping Specialties, a division of Dresser, Inc.

2. Smith-Blair, Inc.

B. **Corrugated, Stainless-Steel Tubing**

1. OmegaFlex, Inc.

2. Parker Hannifin Corporation, the Parflex Division.

3. Titeflex.

4. Tru-Flex Metal Hose Corp.

C. **Plastic Mechanical Couplings**

1. Lyall, R. W. & Company, Inc.

2. Mueller Co.; Gas Products Div.

3. Perfection Corporation; a subsidiary of American Meter Company.

D. **Steel Mechanical Couplings**

1. Dresser Piping Specialties; Division of Dresser, Inc.

2. Smith-Blair, Inc.

E. **Bronze Ball Valves—Two-Piece, Full-Port, or Regular Port, with Bronze Trim**

1. BrassCraft Manufacturing Company; a Masco company.

2. Conbraco Industries, Inc.; Apollo Div.

3. Lyall, R. W. & Company, Inc.

4. McDonald, A. Y. Mfg. Co.

5. Perfection Corporation, a subsidiary of American Meter Company.

F. **Bronze Plug Valves**

1. Lee Brass Company.

2. McDonald, A. Y. Mfg. Co.

G. **Cast-Iron, Nonlubricated Plug Valves**

1. McDonald, A. Y. Mfg. Co.

2. Mueller Co.; Gas Products Div.

3. Xomox Corporation, a Crane company.

H. **Cast-Iron, Lubricated Plug Valves**

1. Flowserve.

2. Homestead Valve, a division of Olson Technologies, Inc.

3. McDonald, A. Y. Mfg. Co.

4. Milliken Valve Company.

5. Mueller Co., Gas Products Div.

6. R&M Energy Systems, a unit of Robbins & Myers, Inc.

I. **Polyethylene (PE) Ball Valves**

1. Kerotest Manufacturing Corp.

2. Lyall, R. W. & Company, Inc.

3. Perfection Corporation, a subsidiary of American Meter Company.

J. **Automatic Gas Valves**

1. ASCO Power Technologies, LP; Division of Emerson.

2. Eaton Corporation; Controls Div.

3. Eclipse Combustion, Inc.

4. Honeywell International, Inc.

5. Johnson Controls.

K. **Electrically Operated Valves**

1. ASCO Power Technologies, LP, a division of Emerson.

2. Eclipse Combustion, Inc.

3. Magnatrol Valve Corporation.

4. Parker Hannifin Corporation; Climate & Industrial Controls Group; Skinner Valve Div.

5. Watts Regulator Co., a division of Watts Water Technologies, Inc.

L. **Service Pressure Regulators**

1. Actaris.

2. American Meter Company.

3. Fisher Control Valves and Regulators, a division of Emerson Process Management.

4. Invensys.

5. Richards Industries, the Jordan Valve Div.

M. **Line Pressure Regulators**

1. Actaris.

2. American Meter Company.

3. Eclipse Combustion, Inc.

4. Fisher Control Valves and Regulators, a division of Emerson Process Management.

5. Invensys.

6. Maxitrol Company.

7. Richards Industries, Jordan Valve Div.

N. **Appliance Pressure Regulators**

1. Canadian Meter Company, Inc.

2. Eaton Corporation, Controls Div.

3. Harper Wyman Co.

4. Maxitrol Company.

5. SCP, Inc.

O. **Service Meters**

1. Diaphragm-type service meters:
   a. Actaris.

   b. American Meter Company.

   c. Invensys.

2. Rotary-type service meters:
   a. American Meter Company.

   b. Invensys.

3. Turbine meters:
   a. American Meter Company.

   b. Invensys.

4. Service-meter bars:
   a. Actaris.

   b. American Meter Company.

   c. Lyall, R. W. & Company, Inc.

   d. McDonald, A. Y. Mfg. Co.

   e. Mueller Co., Gas Products Div.

   f. Perfection Corporation, a subsidiary of American Meter Company

5. Service-meter bypass fittings:
   a. Lyall, R. W. & Company, Inc.

   b. Williamson, T. D., Inc.

55.15. Section 231126—Facility Liquefied-Petroleum Gas Piping

A. **Mechanical Couplings**

1. Dresser Piping Specialties, a division of Dresser, Inc.
2. Smith-Blair, Inc.

B. **Corrugated, Stainless-Steel Tubing**

1. OmegaFlex, Inc.
2. Parker Hannifin Corporation, Parflex Division.
3. Titeflex.\Tru-Flex Metal Hose Corp.

C. **Plastic Mechanical Couplings**

1. Lyall, R. W. & Company, Inc.
2. Mueller Co., Gas Products Div.
3. Perfection Corporation, a subsidiary of American Meter Company.

D. **Steel Mechanical Couplings**

1. Dresser Piping Specialties; Division of Dresser, Inc.
2. Smith-Blair, Inc.

E. **Bronze Ball Valves—Two-Piece, Full-Port, or Regular Port, with Bronze Trim**

1. BrassCraft Manufacturing Company, a Masco company.
2. Conbraco Industries, Inc., Apollo Div.
3. Lyall, R. W. & Company, Inc.
4. McDonald, A. Y. Mfg. Co.
5. Perfection Corporation, a subsidiary of American Meter Company.

F. **Bronze Plug Valves**

1. Lee Brass Company.
2. McDonald, A. Y. Mfg. Co.

G. **Cast-Iron, Nonlubricated Plug Valves**

1. McDonald, A. Y. Mfg. Co.
2. Mueller Co., Gas Products Div.

3. Xomox Corporation, a Crane Company.

H. **Cast-Iron, Lubricated Plug Valves**
1. Flowserve.
2. Homestead Valve, a division of Olson Technologies, Inc.
3. McDonald, A. Y. Mfg. Co.
4. Milliken Valve Company.
5. Mueller Co., Gas Products Div.

I. **Polyethylene Ball Valves**
1. Kerotest Manufacturing Corp.
2. Lyall, R. W. & Company, Inc.
3. Perfection Corporation, a subsidiary of American Meter Company.

J. **Hydrostatic Relief Valves**
1. Engineered Controls International, Inc.; RegO Products.
2. Fisher Control Valves and Regulators, a division of Emerson Process Management.
3. Murray Equipment, Inc.
4. Sherwood, a division of Harsco Corporation.

K. **Automatic Gas Valves**
1. ASCO.
2. ASCO Power Technologies, LP, division of Emerson.
3. ASCO Valve Canada, division of Emerson Electric Canada Limited.
4. Eaton Corporation, Controls Div.
5. Eclipse Combustion, Inc.
6. Honeywell International Inc.
7. Johnson Controls.

L. **Electrically Operated Valves**
1. ASCO.

2. ASCO Power Technologies, LP, a division of Emerson.

3. Eclipse Combustion, Inc.

4. Magnatrol Valve Corporation.

5. Parker Hannifin Corporation; Climate & Industrial Controls Group; Skinner Valve Div.

6. Watts Regulator Co., a division of Watts Water Technologies, Inc.

M. **Service Pressure Regulators**

1. Actaris.

2. American Meter Company.

3. Fisher Control Valves and Regulators, a division of Emerson Process Management.

4. Invensys.

5. Richards Industries, Jordan Valve Div.

N. **Line Pressure Regulators**

1. Actaris.

2. American Meter Company.

3. Eclipse Combustion, Inc.

4. Fisher Control Valves and Regulators, a division of Emerson Process Management.

5. Invensys.

6. Maxitrol Company.

7. Richards Industries, Jordan Valve Div.

O. **Appliance Pressure Regulators**

1. Canadian Meter Company, Inc.

2. Eaton Corporation, Controls Div.

3. Harper Wyman Co.

4. Maxitrol Company.

5. SCP, Inc.

P. **Service Meters**

1. Diaphragm-type service meters:
   a. Actaris.

   b. American Meter Company.

   c. Invensys.

2. Rotary-type service meters:
   a. American Meter Company.

   b. Invensys.

3. Turbine meters:
   a. American Meter Company.

   b. Invensys.

4. Service-meter bars:
   a. Actaris.

   b. American Meter Company.

   c. Lyall, R. W. & Company, Inc.

   d. McDonald, A. Y. Mfg. Co.

   e. Mueller Co.; Gas Products Div.

   f. Perfection Corporation, a subsidiary of American Meter Company.

5. Service-meter bypass fittings:
   a. Lyall, R. W. & Company, Inc.

   b. Williamson, T. D., Inc.

Q. **Storage Containers**

1. American Welding & Tank.

2. Hanson, Roy E. Jr. Mfg.

3. Trinity Industries, Inc.

4. United Industries Group, Inc.

R. **Pumps**

1. Blackmer, a Dover Resources company.
2. Corken, Inc., a unit of IDEX Corporation.

S. **Vaporizers**

1. Algas-SDI.
2. Alternate Energy Systems, Inc.
3. Ely Energy, Inc.
4. Ransome Manufacturing, a division of Meeder Equipment Company.

T. **Air Mixers**

1. Algas-SDI.
2. Alternate Energy Systems, Inc.
3. Ely Energy, Inc.
4. Ransome Manufacturing, a division of Meeder Equipment Company.

55.16. Section 232113—Hydronic Piping

A. **Copper, Mechanically Formed Tee Option: T-DRILL Industries Inc.**

B. **Grooved Mechanical-Joint Fittings and Couplings**

1. Anvil International, Inc.
2. Tyco Fire Products LP; Grinnell Mechanical Products.
3. Victaulic Company of America.

C. **Steel Pressure-Seal Fittings: Victaulic Company of America.**

D. **Bronze, Calibrated-Orifice, Balancing Valves**

1. Armstrong Pumps, Inc.
2. Autoflow.
3. Bell & Gossett Domestic Pump, a division of ITT Industries.
4. DeZurik.

5. Flow Design Inc.
6. Griswold Controls.
7. Rockwell.
8. Sarco.
9. Taco.
10. Tour & Andersson; available through Victaulic Company of America.
11. Grooved balancing valves:
    a. Anvil International, Inc.
    b. Tyco Fire Products LP; Grinnell Mechanical Products.
    c. Victaulic Company of America.

E. **Cast-Iron or Steel, Calibrated-Orifice, Balancing Valves**
1. Armstrong Pumps, Inc.
2. Autoflow.
3. Bell & Gossett Domestic Pump, a division of ITT Industries.
4. DeZurik
5. Flow Design, Inc.
6. Griswold Controls.
7. Rockwell.
8. Sarco.
9. Taco.
10. Tour & Andersson; available through Victaulic Company of America.
11. Grooved balancing valves:
    a. Anvil International, Inc.
    b. Tyco Fire Products, LP; Grinnell Mechanical Products.
    c. Victaulic Company of America.

F. **Diaphragm-Operated, Pressure-Reducing Valves**

1. Amtrol, Inc.
2. Armstrong Pumps, Inc.
3. Bell & Gossett Domestic Pump, a division of ITT Industries.
4. Conbraco Industries, Inc.
5. Spence Engineering Company, Inc.
6. Watts Regulator Co., a division of Watts Water Technologies, Inc.

G. **Diaphragm-Operated Safety Valves**

1. Amtrol, Inc.
2. Armstrong Pumps, Inc.
3. Bell & Gossett Domestic Pump, a division of ITT Industries.
4. Conbraco Industries, Inc.
5. Spence Engineering Company, Inc.
6. Watts Regulator Co., a division of Watts Water Technologies, Inc.

H. **Relief Valves**

1. Crosby.
2. Farris.
3. Kunkle.
4. Lonnergan.

I. **Automatic Flow-Control Valves**

1. Bell & Gossett Domestic Pump, a division of ITT Industries.
2. Flow Design, Inc.
3. Griswold Controls.

J. **Manual and Automatic Air Vents**

1. Amtrol, Inc.
2. Armstrong Pumps, Inc.

3. Bell & Gossett Domestic Pump, a division of ITT Industries.

4. Taco.

K. **Expansion Tanks**

1. Amtrol, Inc.

2. Armstrong Pumps, Inc.

3. Bell & Gossett Domestic Pump, a division of ITT Industries.

4. Taco.

5. Thrush Company, Inc.

6. Wood Industries.

L. **Air Separators**

1. Amtrol, Inc.

2. Armstrong Pumps, Inc.

3. Bell & Gossett Domestic Pump, a division of ITT Industries.

4. Taco.

M. **Chemical Shot Feeders**

1. Burnham Chemical Feed Systems.

2. Cleaver Brooks.

3. Neptune Chemical Pump Co.

4. J.L. Wingert Company.

N. **Strainers**

1. Boylston.

2. McAlear.

3. Metraflex.

4. Mueller.

5. Nicholson.

6. Sarco.

7. Spence.

8. Tate Tempco.

9. Grooved strainers:
    a. Anvil International, Inc.

    b. Tyco Fire Products, LP; Grinnell Mechanical Products.

    c. Victaulic Company of America.

O. **Inhibited Glycols**
1. Dow Chemical Company.

2. Interstate Chemical Company.

55.17. Section 232123—Hydronic Pumps

A. **Close-Coupled, In-Line Centrifugal Pumps**
1. Armstrong Pumps, Inc.

2. Aurora Pump; Division of Pentair Pump Group.

3. Bell & Gossett; Division of ITT Industries.

4. Grundfos Pumps Corporation.

5. PACO Pumps.

6. Patterson Pump Co., a subsidiary of The Gorman-Rupp Co.

7. Peerless Pump; a Member of the Sterling Fluid Systems Group.

8. Taco, Inc.

9. Thrush Company, Inc.

10. Weinman, a division of Crane Pumps & Systems.

B. **Close-Coupled, End-Suction Centrifugal Pumps**
1. Armstrong Pumps, Inc.

2. Aurora Pump; Division of Pentair Pump Group.

3. Bell & Gossett, a division of ITT Industries.

4. Goulds Pumps; Water Technologies Group.
5. PACO Pumps.
6. Patterson Pump Co., a subsidiary of The Gorman-Rupp Co.
7. Peerless Pump, a member of the Sterling Fluid Systems Group.
8. Taco, Inc.
9. Thrush Company Inc.
10. Weinman, a division of Crane Pumps & Systems.

C. **Separately Coupled, Horizontal, In-Line Centrifugal Pumps**

1. Armstrong Pumps Inc.
2. Aurora Pump, a division of Pentair Pump Group.
3. Bell & Gossett, a division of ITT Industries.
4. Grundfos Pumps Corporation.
5. PACO Pumps.
6. Peerless Pump, a member of the Sterling Fluid Systems Group.
7. Taco, Inc.
8. Thrush Company, Inc.

D. **Separately Coupled, Vertical, In-Line Centrifugal Pumps**

1. Armstrong Pumps Inc.
2. Aurora Pump, a division of Pentair Pump Group.
3. Bell & Gossett, a division of ITT Industries.
4. PACO Pumps.
5. Patterson Pump Co., a subsidiary of The Gorman-Rupp Co.
6. Thrush Company Inc.
7. Weinman, a division of Crane Pumps & Systems.

E. **Separately Coupled, Base-Mounted, End-Suction Centrifugal Pumps**

1. Armstrong Pumps, Inc.

2. Aurora Pump, a division of Pentair Pump Group.

3. Bell & Gossett, a division of ITT Industries.

4. PACO Pumps.

5. Peerless Pump, a member of the Sterling Fluid Systems Group.

6. Taco, Inc.

7. Thrush Company Inc.

8. Weinman, a division of Crane Pumps & Systems.

F. **Separately Coupled, Base-Mounted, Double-Suction Centrifugal Pumps**

1. Armstrong Pumps Inc.

2. Aurora Pump, a division of Pentair Pump Group.

3. Bell & Gossett, a division of ITT Industries.

4. PACO Pumps.

5. Patterson Pump Co., a subsidiary of The Gorman-Rupp Co.

6. Peerless Pump, a member of the Sterling Fluid Systems Group.

7. Taco, Inc.

8. Weinman, a division of Crane Pumps & Systems.

G. **Separately Coupled, Vertical-Mounted, Double-Suction Centrifugal Pumps**

1. Armstrong Pumps, Inc.

2. Aurora Pump, a division of Pentair Pump Group.

3. Bell & Gossett, a division of ITT Industries.

4. PACO Pumps.

5. Peerless Pump, a member of the Sterling Fluid Systems Group

6. Taco, Inc.

H. **Separately Coupled, Vertical-Mounted, Turbine Centrifugal Pumps**

1. Armstrong Pumps, Inc.
2. Aurora Pump, a division of Pentair Pump Group.
3. Bell & Gossett, a division of ITT Industries.
4. PACO Pumps.
5. Patterson Pump Co., a subsidiary of The Gorman-Rupp Co.
6. Weinman, a division of Crane Pumps & Systems.

I. **Automatic Air Conditioning Condensate Pump Units**

1. Aurora Pump, a division of Pentair Pump Group.
2. Little Giant Pump Co., a subsidiary of Tecumseh Products Co.
3. MEPCO (Marshall Engineered Products Co.).

J. **Suction Diffusers and Triple Duty Valves**

1. Armstrong Pumps, Inc.
2. Bell & Gossett Domestic Pump, a division of ITT Industries.
3. PACO Pumps.
4. Peerless Pump, a member of the Sterling Fluid Systems Group.
5. Taco, Inc.
6. Grooved suction diffusers and triple duty valves:
    a. Anvil International, Inc.
    b. Tyco Fire Products LP; Grinnell Mechanical Products.
    c. Victaulic Company of America.

55.18. Section 232213—Steam and Condensate Heating Piping

A. **Dielectric Unions**

1. Capitol Manufacturing Company.
2. Central Plastics Company.

3. Hart Industries International, Inc.
4. Watts Regulator Co., a division of Watts Water Technologies, Inc.

B. **Dielectric Flanges**
1. Capitol Manufacturing Company.
2. Central Plastics Company.
3. Watts Regulator Co., a division of Watts Water Technologies, Inc.
4. Wilkins; Zurn Plumbing Products Group.

C. **Dielectric-Flange Kits**
1. Advance Products & Systems, Inc.
2. Calpico, Inc.
3. Central Plastics Company.
4. Pipeline Seal and Insulator, Inc.

D. **Stop-Check Valves**
1. Crane Co.
2. Jenkins Valves, a Crane Company.
3. Lunkenheimer Valves.
4. A.Y. McDonald Mfg. Co.

E. **Strainers**
1. Boylston.
2. McAlear.
3. Metraflex.
4. Mueller.
5. Nicholson.
6. Sarco.
7. Spence.
8. Tate Tempco.

F. **Steam Control Valves and Regulators**

1. Leslie.
2. Spirax Sarco, Inc.

G. **Bronze, Brass, and Cast-Iron Safety Valves**

1. Armstrong International, Inc.
2. Crosby.
3. Farris.
4. Kunkle Valve, a Tyco International Ltd. Company.
5. Lonnergan.
6. Spirax Sarco, Inc.
7. Watts Water Technologies, Inc.

H. **Pressure-Reducing Valves**

1. Armstrong International, Inc.
2. Fisher.
3. Hoffman Specialty, a division of ITT Industries.
4. Leslie Controls, Inc.
5. Masoneilan.
6. Spence Engineering Company, Inc.
7. Spirax Sarco, Inc.

I. **Steam Traps (Thermostatic, Thermodynamic, Float and Thermostatic, Inverted Bucket)**

1. Armstrong International, Inc.
2. Dunham-Bush, Inc.
3. Hoffman Specialty, a division of ITT Industries.
4. Spirax Sarco, Inc.
5. Sterling.

J. **Thermostatic Air Vents and Vacuum Breakers**

1. Armstrong International, Inc.
2. Dunham-Bush, Inc.
3. Hoffman Specialty, a division of ITT Industries.
4. Spirax Sarco, Inc.
5. Sterling.

K. **Steam Meters**

1. EMCO Flow Systems; Division of Advanced Energy Company.
2. ISTEC Corp.
3. Preso Meters, a division of Racine Federated, Inc.
4. Spirax Sarco, Inc.

L. **Steam Condensate Meters**

1. Central Station Steam Co.
2. Lincoln Meter Company.

M. **Steam Separators**

1. Penn Separator Corporation.
2. Spence Engineering Company, Inc., a division of Circor International, Inc.
3. Spirax Sarco, Inc.

N. **Flash Tanks, Blowdown Tanks (Separators), and Condensate Coolers**

1. Cemline Corporation.
2. Colton Industries.
3. Penn Separator Corporation.
4. Shippensburg Pump Company (Shipco).
5. Wessels Company.

55.19. Section 232223—Steam Condensate Pumps

A. **Electric-Driven Steam Condensate Pumps**

1. Aurora Pump, a division of Pentair Pump Group.
2. Domestic Pump, a division of ITT Industries.
3. Shippensburg Pump Company (Shipco).
4. Skidmore Division, Vent-Rite Valve Corp.
5. Spence Engineering Company, Inc., a division of Circor International, Inc.
6. Spirax Sarco, Inc.
7. Sterling, Inc.
8. Weinman.

B. **Pressure-Powered Steam Condensate Pumps**

1. Armstrong Fluid Handling, a division of Armstrong International, Inc.
2. MEPCO (Marshall Engineered Products Co.).
3. Nicholson Steam Trap, a division of Spence Engineering Company, Inc.
4. Shippensburg Pump Company (Shipco).
5. Spence Engineering Company, Inc., a division of Circor International, Inc.
6. Spirax Sarco, Inc.

C. **Condensate Storage Units**

1. Adamson Global Technology Corporation.
2. Buffalo Tank Company, Inc.
3. Cemline Corporation.
4. Cleaver Brooks.
5. Crane-Cochrane.
6. Wessels Company.

55.20. Section 232300—Refrigerant Piping

A. **Refrigerants**

1. Atofina Chemicals, Inc.
2. DuPont Company, Fluorochemicals Div.
3. Honeywell, Inc.; Genetron Refrigerants.
4. INEOS Fluor Americas LLC.

B. **Refrigeration System Specialties**

1. Alco Controls.
2. Henry Valve.
3. Parker Hannifin.
4. Sporlan Valve.

55.21. Section 232500—HVAC Water Treatment

A. **Water Treatment Companies**

1. Anderson Chemical Co, Inc.
2. Aqua-Chem, Inc., Cleaver-Brooks Div.
3. Barclay Chemical Co.; Water Management, Inc.
4. Chardon Labs.
5. GE Betz.
6. ONDEO Nalco Company.

B. **HVAC Makeup Water Softener**

1. Cleaver Brooks.
2. Cocran.
3. Columbia Water Conditioning Systems, Inc.
4. CSI, a division of Chandler Systems, Inc.
5. Culligan International.
6. Diamond Water Conditioning.
7. Elgin.

8. Environmental Dynamics Corporation.
9. Marlo Incorporated.
10. Parker Boiler Company.
11. Rainsoft Div., Aquion Partners L. P. Water King.

C. **RO Equipment for HVAC Makeup Water**

1. Cleaver Brooks.
2. Cocran.
3. Columbia Water Conditioning Systems, Inc.
4. CSI, a division of Chandler Systems, Inc.
5. Culligan International.
6. Diamond Water Conditioning.
7. Elgin
8. Environmental Dynamics Corporation.
9. Marlo Incorporated.
10. Parker Boiler Company.
11. RainSoft Div., Aquion Partners L. P. Water King.

D. **Filtration Equipment**

1. LAKOS, a division of Claude Laval Corporation.
2. Miami Filter LLC.
3. PEP Filters, Inc.
4. Puroflux Corporation.
5. United Industries, Inc.

E. **Water Filters**

1. Filterite.
2. Filter Specialists, Inc.

3. Filtration Systems, a division of Mechanical Mfg. Corporation.

4. Parker Hannifin Corp., Process Filtration Div.

5. Paul Filter Corporation.

6. PEP Filters, Inc.

7. RainSoft Div., Aquion Partners L. P.

8. USFilter.

9. 3M Filtration Products.

F. **Centrifugal Separators**

1. Culligan International.

2. Griswold Controls.

3. LAKOS, a division of Claude Laval Corporation.

4. PEP Filters, Inc.

5. USFilter.

6. 3M Filtration Products.

55.22. Section 233113—Metal Ducts

A. **Single-Wall Rectangular Ducts and Fittings: SMCNA HVAC Duct Construction Standards**

B. **Double-Wall Rectangular Ducts and Fittings**

1. McGill AirFlow, LLC.

2. Sheet Metal Connectors, Inc.

C. **Single-Wall Round and Flat-Oval Ducts and Fittings**

1. McGill AirFlow, LLC.

2. SEMCO Incorporated.

3. Sheet Metal Connectors, Inc.

4. Spiral Manufacturing Co., Inc.

D. **Double-Wall Round and Flat-Oval Ducts and Fittings**

1. McGill AirFlow, LLC.
2. SEMCO Incorporated.
3. Sheet Metal Connectors, Inc.

E. **Fibrous-Glass Duct Liner**

1. CertainTeed Corporation; Insulation Group.
2. Johns Manville.
3. Knauf Insulation.
4. Owens Corning.

F. **Flexible Elastomeric Duct Liner**

1. Aeroflex USA, Inc.
2. Armacell, LLC.
3. Rubatex International, LLC.

G. **PVC Coated Galvanized Steel Ducts**

1. Metal Manufacturing, Inc.
2. United McGill.

H. **Halar Coated Stainless Steel Ducts**

1. Fabtech Incorporated.
2. GDS Manufacturing Co.
3. PSI.
4. Viron.

I. **Teflon Coated Stainless Steel Ducts**

1. Fabtech Incorporated.
2. GDS Manufacturing Co.
3. PSI.
4. Viron.

55.23. Section 233116—Nonmetal Ducts

A. **Fibrous-Glass Ducts and Fittings**

1. CertainTeed Corporation; Insulation Group.
2. Johns Manville.
3. Knauf Insulation.
4. Owens Corning.

B. **Thermoset FRP Ducts and Fittings**

1. ATS Products, Inc.
2. Beverly-Pacific.
3. Corrosion Products.
4. Environmental Corrections.
5. Fiber Dyne.
6. Harrington.
7. McGill AirFlow, LLC.
8. Perry Fiberglass Products, Inc.
9. Spunstrand, Inc.
10. Viron.

C. **FRP Resins**

1. Atlac Type 711-05 AS.
2. Dion Corres 9300FR.
3. Hetron FR992.
4. Derakane 510A.
5. Interplastics VE8440.

D. **PVC Ducts and Fittings**

1. General Plastics, Inc.
2. GPK Products, Inc.

3. Harvel Plastics, Inc.
4. Kroy Industries, Inc.
5. Northern Pipe Product, Inc., an Otter Tail Company.
6. Plastinetics, Inc.
7. Spears Manufacturing Company.

55.24. Section 233119—HVAC Casings

A. **Manufactured Casings**

1. Acoustical Surfaces, Inc.
2. AeroSonics, Inc., a division of TUTCO, Inc.
3. Buffalo Air Handling.
4. CertainTeed Corp., Insulation Group.
5. CLEANPAK International.
6. Gale Corp.
7. Industrial Acoustics Company.
8. Industrial Noise Control, Inc.
9. McGill AirSilence, LLC.
10. SEMCO Incorporated.
11. United Sheet Metal Co.
12. Vibro-Acoustics.

B. **Fibrous-Glass Casing Liner**

1. CertainTeed Corp., Insulation Group.
2. Johns Manville.
3. Knauf Insulation.
4. Owens Corning.

C. **Flexible-Elastomeric Casing Liner**

1. Aeroflex USA, Inc.
2. Armacell, LLC.
3. Rubatex International, LLC.

55.25. Section 233300—Air Duct Accessories

A. **Backdraft, Pressure Relief, and Barometric Relief Dampers**

1. Air Balance Inc., a division of Mestek, Inc.
2. American Warming and Ventilating, a division of Mestek, Inc.
3. Duro Dyne Inc.
4. Greenheck Fan Corporation.
5. Nailor Industries Inc.
6. Pottorff, a division of PCI Industries, Inc.
7. Ruskin Company.
8. SEMCO Incorporated.
9. Vent Products Company, Inc.

B. **Manual Volume Dampers**

1. Air Balance Inc., a division of Mestek, Inc.
2. American Warming and Ventilating, a division of Mestek, Inc.
3. McGill AirFlow LLC.
4. METALAIRE, Inc.
5. Nailor Industries Inc.
6. Pottorff, a division of PCI Industries, Inc.
7. Ruskin Company.
8. Vent Products Company, Inc.

C. **Control Dampers**

1. Air Balance Inc., a division of Mestek, Inc.
2. American Warming and Ventilating, a division of Mestek, Inc.
3. Arrow United Industries, a division of Mestek, Inc.
4. Duro Dyne Inc.
5. Greenheck Fan Corporation.
6. McGill AirFlow, LLC.
7. Nailor Industries, Inc.
8. Pottorff, a division of PCI Industries, Inc.
9. Ruskin Company.
10. SEMCO Incorporated.
11. United Air/Safe Air.
12. Vent Products Company, Inc.
13. Young Regulator Company.

D. **Fire Dampers, Smoke Dampers, Fire/Smoke Dampers, and Ceiling Dampers**

1. Air Balance, Inc., a division of Mestek, Inc.
2. Arrow United Industries, a division of Mestek, Inc.
3. Greenheck Fan Corporation.
4. McGill AirFlow, LLC.
5. Nailor Industries, Inc.
6. Pottorff, a division of PCI Industries, Inc.
7. Ruskin Company.
8. Vent Products Company, Inc.
9. Ward Industries, Inc., a division of Hart & Cooley, Inc.

E. **Flange Connectors**

1. Ductmate Industries, Inc.

2. Nexus PDQ; Division of Shilco Holdings, Inc.

3. Ward Industries, Inc., a division of Hart & Cooley, Inc.

F. **Duct Silencers (Sound Attenuators)**

1. Aero Sonics

2. Commercial Acoustics

3. Gale Corp.

4. Industrial Acoustics Company (IAC)

5. Industrial Noise Control, Inc.

6. Koppers.

7. McGill AirFlow LLC.

8. Ruskin Company.

9. SEMCO Incorporated.

10. Vibro-Acoustics.

11. Vibration Mountings, Inc.

G. **Sound Attenuators (Active Noise Control): Digisonix**

H. **Turning Vanes**

1. Ductmate Industries, Inc.

2. Duro Dyne, Inc.

3. METALAIRE, Inc.

4. SEMCO Incorporated.

5. Ward Industries, Inc., a division of Hart & Cooley, Inc.

I. **Remote Damper Operators**

1. Pottorff, a division of PCI Industries, Inc.

2. Ventfabrics, Inc.

3. Young Regulator Company.

J. **Duct Mounted Access Doors**

1. American Warming and Ventilating, a division of Mestek, Inc.
2. Ductmate Industries, Inc.
3. Greenheck Fan Corporation.
4. McGill AirFlow, LLC.
5. Nailor Industries Inc.
6. Pottorff; a division of PCI Industries, Inc.
7. Ventfabrics, Inc.
8. Ward Industries, Inc., a division of Hart & Cooley, Inc.

K. **Duct Access Panel Assemblies**

1. Ductmate Industries, Inc.
2. Flame Gard, Inc.
3. 3M.

L. **Flexible Connectors**

1. Ductmate Industries, Inc.
2. Duro Dyne, Inc.
3. Ventfabrics, Inc.
4. Ward Industries, Inc., a division of Hart & Cooley, Inc.

M. **Flexible Ducts**

1. Ductmate Industries, Inc.
2. Genflex.
3. McGill AirFlow, LLC.
4. Thermaflex.
5. Ward Industries, Inc., a division of Hart & Cooley, Inc.
6. Wiremold.

N. **Duct Security Bars**

1. Carnes.
2. KEES, Inc.
3. Lloyd Industries, Inc.
4. Metal Form Manufacturing, Inc.
5. Price Industries.

55.26. Section 233413—Axial HVAC Fans

A. **Tubeaxial and Vaneaxial Fans**

1. Acme Engineering & Mfg. Corp.
2. Aerovent, a Twin City Fan Company.
3. American Coolair Corp.
4. Barry Blower Div., Penn Ventilation Companies, Inc.
5. Bayley Fans, a division of Lau Industries, Inc.
6. Carnes Company HVAC.
7. Chicago Blower Corporation.
8. Cincinnati Fan.
9. Greenheck Fan Corporation.
10. Industrial Air, a division of Lau Industries, Inc.
11. Joy.
12. Loren Cook Company.
13. New York Blower Company.
14. Trane.
15. Woods Fan Company.

B. **Mixed Flow Fans**

1. Loren Cook Company.

2. Greenheck Fan Corporation.
3. Howden Fan Co.
4. New Philadelphia Fan Co.

C. **Tubular Centrifugal Fans**

1. Aerovent, a Twin City Fan Company.
2. Barry Blower Div., Penn Ventilation Companies, Inc.
3. Greenheck Fan Corporation.
4. New York Blower.
5. Peerless.

55.27. Section 233416—Centrifugal HVAC Fans

A. **Airfoil, Backward Inclined, and Forward Curved Centrifugal Fans**

1. Acme Engineering & Mfg. Corp.
2. Aerovent, a Twin City Fan Company.
3. Barry Blower Div., Penn Ventilation Companies, Inc.
4. Bayley Fans, a division of Lau Industries, Inc.
5. Carrier Corporation.
6. Chicago Blower Corporation.
7. Cincinnati Fan.
8. Greenheck Fan Corporation.
9. Industrial Air, a division of Lau Industries, Inc.
10. Loren Cook Company.
11. New York Blower Company.
12. Trane.

B. **Plenum or Plug Fans**

1. Acme Engineering & Mfg. Corp.

2. Aerovent, a Twin City Fan Company.
3. Barry Blower Div., Penn Ventilation Companies, Inc.
4. Bayley Fans, a division of Lau Industries, Inc.
5. Carrier Corporation.
6. Chicago Blower Corporation.
7. Cincinnati Fan.
8. Greenheck Fan Corporation.
9. Industrial Air, a division of Lau Industries, Inc.
10. Loren Cook Company.
11. New York Blower Company.
12. Trane.

55.28. Section 233423—HVAC Power Ventilators

A. **Utility Set Fans**
1. Aerovent, a Twin City Fan Company.
2. American Coolair Corp.
3. Bayley Fans, a division of Lau Industries, Inc.
4. Carnes Company HVAC.
5. Industrial Air, a division of Lau Industries, Inc.
6. Loren Cook Company.
7. New York Blower Company.
8. Trane.

B. **Centrifugal Roof Ventilators and Upblast Centrifugal Roof Ventilators**
1. Acme Engineering & Mfg. Corp.
2. Aerovent, a Twin City Fan Company.

3. American Coolair Corp.
4. Carnes Company HVAC.
5. Greenheck Fan Corporation.
6. Loren Cook Company.

C. **Axial Roof Ventilators**

1. Acme Engineering & Mfg. Corp.
2. Aerovent, a Twin City Fan Company.
3. American Coolair Corp.
4. Bayley Fans, a division of Lau Industries, Inc.
5. Carnes Company HVAC.
6. Greenheck Fan Corporation.
7. Industrial Air, a division of Lau Industries, Inc.
8. Loren Cook Company.
9. New York Blower Company.

D. **Upblast Propeller Roof Exhaust Fans**

1. Acme Engineering & Mfg. Corp.
2. Aerovent, a Twin City Fan Company.
3. American Coolair Corp.
4. Carnes Company HVAC.
5. Cincinnati Fan.
6. Greenheck Fan Corporation.
7. Industrial Air, a division of Lau Industries, Inc.
8. Loren Cook Company.
9. New York Blower Company.

E. **Centrifugal Wall Ventilators**

1. Acme Engineering & Mfg. Corp.
2. Aerovent, a Twin City Fan Company.
3. American Coolair Corp.
4. Carnes Company HVAC.
5. Greenheck Fan Corporation.
6. Loren Cook Company.

F. **Ceiling-Mounting Ventilators**

1. American Coolair Corp.
2. Broan Mfg. Co., Inc.
3. Carnes Company HVAC.
4. Greenheck Fan Corporation.
5. Loren Cook Company.
6. Penn Ventilation.

G. **In-Line Centrifugal Fans**

1. Acme Engineering & Mfg. Corp.
2. American Coolair Corp.
3. Bayley Fans, a division of Lau Industries, Inc.
4. Carnes Company HVAC.
5. Greenheck Fan Corporation.
6. Loren Cook Company.

H. **Propeller Fans**

1. Acme Engineering & Mfg. Corp.
2. Aerovent, a Twin City Fan Company.
3. American Coolair Corp.
4. Bayley Fans, a division of Lau Industries, Inc.

5. Carnes Company HVAC.

6. Chicago Blower Corporation.

7. Cincinnati Fan.

8. Greenheck Fan Corporation.

9. Industrial Air, a division of Lau Industries, Inc.

10. Loren Cook Company.

11. New York Blower Company.

I. **Ceiling Type Fans**

1. Greenheck Fan Corporation

2. Loren Cook.

3. Penn Ventilator Company.

55.29. Section 233433—Air Curtains

A. **Berner International Corp.**

B. **Cambridge Engineering, Inc.**

C. **KING.**

D. **Loren Cook Company.**

E. **Marley Engineered Products.**

F. **Mars Air Products, Dynaforce Division.**

G. **Mars Air Products, Mars Air Door Division.**

55.30. Section 233600—Air Terminal Units

A. **Single and Dual Duct Air Terminal Units—Commercial**

1. Anemostat, a Mestek Company.

2. Carnes.

3. Carrier.

4. Environmental Technologies, Inc., Enviro-Air Div.
5. Krueger.
6. METALAIRE, Inc.; Metal Industries Inc.
7. Nailor Industries of Texas Inc.
8. Price Industries.
9. Titus.
10. Trane.

B. **Single and Dual Duct Air Terminal Units—Hospitals, Laboratories**

1. Anemostat, a Mestek Company.
2. Krueger.
3. Nailor Industries of Texas Inc.
4. Price Industries.
5. Titus.

C. **Fan-Powered Air Terminal Units—Commercial**

1. Anemostat, a Mestek Company.
2. Carnes.
3. Carrier.
4. Environmental Technologies, Inc., Enviro-Air Div.
5. Krueger.
6. METALAIRE, Inc., Metal Industries Inc.
7. Nailor Industries of Texas Inc.
8. Price Industries.
9. Titus.
10. Trane.

D. **Fan-Powered Air Terminal Units—Hospitals, Laboratories**

1. Anemostat, a Mestek Company.
2. Krueger.
3. Nailor Industries of Texas Inc.
4. Price Industries.
5. Titus.

E. **Induction Air Terminal Units**

1. Price Industries.
2. Tuttle & Bailey.

F. **Laboratory Air Valves**

1. American Auto-matrix.
2. Auto Flow.
3. CMR Controls, a division of C.M. Richter Ltd.
4. Phoenix Controls Incorporated.
5. Tek-Air.
6. TSI Incorporated.
7. Siemens Building Technologies, Inc.

G. **Integral-Diffuser Air Terminal Units**

1. Acutherm.
2. Kreuger.
3. Price.
4. Titus.
5. Thermal Products Corp.
6. Warren Technology.

55.31. Section 233713—Diffusers, Registers, and Grilles

A. **Diffusers, Registers, and Grilles—Commercial**

1. Anemostat Products, a Mestek company.
2. Carnes.
3. Hart & Cooley Inc.
4. Krueger.
5. METALAIRE, Inc.
6. Nailor Industries Inc.
7. Price Industries.
8. Titus.
9. Tuttle & Bailey.

B. **Diffusers, Registers, and Grilles—Hospital/Laboratory**

1. Anemostat Products; a Mestek company.
2. Krueger.
3. Price Industries.
4. Titus.

C. **Continuous Tubular Diffuser**

1. DuctSox Corp.
2. Patron Products Inc.

55.32. Section 233723—HVAC Gravity Ventilators

A. **Louver Penthouses**

1. Acme Engineering & Mfg. Corp.
2. Aerovent, a Twin City Fan company.
3. American Warming and Ventilating, a division of Mestek, Inc.
4. Arrow United Industries, a division of Mestek, Inc.
5. Carnes.
6. Greenheck Fan Corporation.

7. Loren Cook Company.

8. Penn Ventilation.

B. **Roof Hoods**

1. Acme Engineering & Mfg. Corp.

2. Aerovent, a Twin City Fan company.

3. Carnes.

4. Greenheck Fan Corporation.

5. Loren Cook Company.

C. **Louvers**

1. Air Balance, Inc.

2. Airline Products.

3. Airstream Products.

4. American Warming and Ventilating, Inc.

5. Arrow United Industries.

6. Construction Specialties, Inc.

7. Phillips Industries, Inc.

8. Ruskin.

55.33. Section 233813—Commercial-Kitchen Hoods

A. **Exhaust Hood Fabrication**

1. Captive-Aire Systems.

2. Gaylord Industries, Inc.

3. Grease Master, a division of Custom Industries, Inc.

4. Greenheck Fan Corporation.

5. Halton Company.

6. Vent Master, a division of Garland Commercial Ranges Ltd.

B. **Wet-Chemical Fire-Suppression System**

1. Ansul Incorporated, a Tyco International Ltd. Company.
2. Badger Fire Protection.
3. Kidde Fire Systems.
4. Pyro Chem.

55.34. Section 234100—Particulate Air Filtration

A. **Air Filters, Electrostatic Air Cleaners, and Filter-Holding Systems**

1. AAF International.
2. Bioclimatic, Inc.
3. CRS Industries, Inc., CosaTron Div.
4. Farr Co.
5. Flanders/CSC Corp.
6. Flanders Filters, Inc.
7. International Air Filtration Corporation.
8. Mine Safety Appliances.
9. NiCon Filter Corp., Continental Air Filter Div.
10. Purafil, Inc.
11. Puralator.

B. **Filter Gauges**

1. Airguard Industries, Inc.
2. Dwyer Instruments, Inc.

55.35. Section 235100—Breechings, Chimneys, and Stacks

A. **Listed Chimney Liners**

1. Heat-Fab, Inc.

2. Industrial Chimney Company.

3. Metal-Fab, Inc.

4. Selkirk Inc.; Selkirk Metalbestos and Air Mate.

B. **Listed Type-B and BW Vents**

1. Cleaver-Brooks, a division of Aqua-Chem, Inc.

2. Hart & Cooley, Inc.

3. Heat-Fab, Inc.

4. Industrial Chimney Company.

5. Metal-Fab, Inc.

6. Selkirk Inc.; Selkirk Metalbestos and Air Mate.

7. Van-Packer Company, Inc.

C. **Listed Type-L Vents**

1. Heat-Fab, Inc.

2. Industrial Chimney Company.

3. Metal-Fab, Inc.

4. Selkirk Inc.; Selkirk Metalbestos and Air Mate.

5. Van-Packer Company, Inc.

D. **Listed Special Gas Vents**

1. Heat-Fab, Inc.

2. Metal-Fab, Inc.

3. Selkirk Inc.; Selkirk Metalbestos and Air Mate.

E. **Listed Building-Heating-Appliance Chimneys**

1. Cleaver-Brooks, a division of Aqua-Chem Inc.

2. Heat-Fab, Inc.

3. Industrial Chimney Company.

4. Metal-Fab, Inc.

5. Selkirk Inc.; Selkirk Metalbestos and Air Mate.

6. Van-Packer Company, Inc.

F. **Listed Grease Ducts**

1. Heat-Fab, Inc.

2. Industrial Chimney Company.

3. Metal-Fab, Inc.

4. Selkirk Inc.; Selkirk Metalbestos and Air Mate.

5. Van-Packer Company, Inc.

G. **Listed, Refractory-Lined Metal Breechings and Chimneys**

1. Van-Packer Company, Inc.

2. Warren Environment, Inc.

55.36. Section 235113—Draft Control Devices

A. **Draft Inducer Fans**

1. EXHAUSTO, Inc.

2. Field Controls LLC; Venting Solutions Company.

3. Tjernlund Products, Inc.

4. Wing Draft Inducers, a subsidiary of Smiths Industries.

B. **Mechanical-Draft Vent Fans**

1. EXHAUSTO, Inc.

2. Field Controls LLC; Venting Solutions Company.

3. Tjernlund Products, Inc.

4. Wing Draft Inducers, a subsidiary of Smiths Industries.

C. **Vent Exhaust Fans**

1. EXHAUSTO, Inc.

2. Field Controls LLC; Venting Solutions Company.

3. Tjernlund Products, Inc.

D. **Barometric Dampers**
   1. EXHAUSTO, Inc.
   2. Field Controls LLC; Venting Solutions Company.
   3. Tjernlund Products, Inc.
   4. Wing Draft Inducers, a subsidiary of Smiths Industries.

E. **Vent Dampers**
   1. Effikal International Inc.
   2. Field Controls LLC; Venting Solutions Company.
   3. Johnson Controls, Inc.; Controls Group.

F. **Combustion-Air Fans**
   1. EXHAUSTO, Inc.
   2. Field Controls LLC; Venting Solutions Company.
   3. Tjernlund Products, Inc.

55.37. Section 235213—Electric Boilers

A. **Acme Engineering Prod. Inc.**

B. **Brasch.**

C. **Bryan Steam, LLC.**

D. **Cemline Corporation.**

E. **Cleaver-Brooks, a division of Aqua-Chem, Inc.**

F. **Fulton Boiler Works, Inc.**

G. **Indeeco.**

H. **Lattner Boiler Manufacturing.**

I. **Lochinvar Corporation.**

J. **Patterson-Kelley.**

K. **Precision Boilers.**

L. **PVI Industries, LLC.**

55.38. Section 235216—Condensing Boilers

A. **Fulton Boiler Works, Inc.**

B. **Hydrotherm, Inc., a division of Mestek, Inc.**

C. **AERCO International.**

D. **Heat Transfer Products, Inc.**

E. **Laars Heating Systems, a division of Waterpik Technologies, Inc.**

F. **Lochinvar Corporation.**

55.39. Section 235223—Cast-Iron Boilers

A. **Burnham Hydronics.**

B. **H.B. Smith**

C. **Hydrotherm, Inc.; a division of Mestek, Inc.**

D. **Lennox Industries Inc.**

E. **Peerless Boilers.**

F. **Slant/Fin Corp.**

G. **Smith Cast Iron Boilers.**

H. **Weil-McLain; a United Dominion Company.**

55.40. Section 235233—Water-Tube Boilers

A. **Finned Water-Tube Boilers**

1. Hydrotherm, Inc., a division of Mestek, Inc.
2. Laars Heating Systems, a division of Waterpik Technologies, Inc.

3. Lochinvar Corporation.

4. Patterson-Kelley.

5. Precision Boilers.

6. Raypak.

7. Smith, A. O. Water Products Company.

8. Triad.

B. **Steel Flexible Water-Tube Boilers**

1. Bryan Steam, LLC.

2. Cleaver-Brooks, a division of Aqua-Chem, Inc.

3. Parker Boiler Company.

C. **Steel Water-Tube Boilers**

1. Babcock & Wilcox.

2. Cleaver Brooks.

3. Keeler.

55.41. Section 235239—Fire-Tube Boilers

A. **Horizontal, Fire-Tube Boilers**

1. Burnham Hydronics.

2. Cleaver-Brooks, a division of Aqua-Chem, Inc.

3. Johnston.

4. Lattner Boiler Manufacturing.

5. Superior Boiler Works, Inc.

6. York Shipley.

B. **Vertical, Fire-Tube Boilers**

1. Fulton Boiler Works, Inc.

2. Lattner Boiler Manufacturing.

3. Patterson-Kelley.

4. Precision Boilers.

5. PVI Industries, LLC.

55.42. Section 235313—Boiler Feedwater Pumps

A. **Feedwater Units**

1. Bryan Boilers; Bryan Steam, LLC.

2. Cleaver-Brooks, a division of Aqua-Chem, Inc.

3. Domestic Pump; a unit of ITT Fluid Technology.

4. Lattner Boiler Manufacturing.

5. Parker Boiler Co.

6. Shippensburg Pump Co., Inc.

7. Skidmore.

8. Superior Boiler Works, Inc.

9. U.S. Deaerator Co.

B. **Feedwater Unit with Vacuum Producer**

1. Domestic Pump, a unit of ITT Fluid Technology.

2. Shippensburg Pump Co., Inc.

3. Skidmore.

4. U.S. Deaerator Co.

55.43. Section 235316—Deaerators and Feedwater Heaters

A. **Bryan Steam LLC.**

B. **Cleaver-Brooks; Div. of Aqua-Chem Inc.**

C. **Deaerating Designs; a division of Precision Boilers, Inc.**

D. **Industrial Steam; Custom Steam and Pressure Vessel Systems.**

E. **Permutit.**

F. **Skidmore.**

G. **U.S. Deaerator Co.**

55.44. Section 235400—Furnaces

A. **Gas-Fired Furnaces, Noncondensing**

1. Bryant Heating & Cooling Systems, a division of United Technologies Corp.
2. Carrier Corporation, a division of United Technologies Corp.
3. Goodman Manufacturing Company, LP
4. Lennox Industries Inc.
5. Rheem Manufacturing Company; Air Conditioning Division.
6. Ruud Air Conditioning Division.
7. Trane.
8. York International Corp., a division of Unitary Products Group.

B. **Gas-Fired Furnaces, Condensing**

1. Bryant Heating & Cooling Systems, a division of United Technologies Corp.
2. Carrier Corporation, a division of United Technologies Corp.
3. Goodman Manufacturing Company, LP
4. Lennox Industries Inc.
5. Rheem Manufacturing Company; Air Conditioning Division.
6. Ruud Air Conditioning Division.
7. Trane.
8. York International Corp., a division of Unitary Products Group.

C. **Oil-Fired Furnaces**

1. Carrier Corporation, a division of United Technologies Corp.

2. Lennox Industries Inc.

3. Rheem Manufacturing Company; Air Conditioning Division.

4. Ruud Air Conditioning Division.

5. York International Corp., a division of Unitary Products Group.

D. **Electric Furnaces**

1. Bryant Heating & Cooling Systems, a division of United Technologies Corp.

2. Carrier Corporation, a division of United Technologies Corp.

3. Lennox Industries Inc.

4. Rheem Manufacturing Company; Air Conditioning Division.

5. Ruud Air Conditioning Division.

6. York International Corp., a division of Unitary Products Group.

55.45. Section 235513—Fuel-Fired Duct Heaters

A. **Lennox Industries, Inc.**

B. **Modine Manufacturing Company.**

C. **Reznor/Thomas & Betts Corporation.**

D. **Sterling HVAC Products, a division of Mestek Technology, Inc.**

55.46. Section 235523—Gas-Fired Radiant Heaters

A. **Tubular Infrared Heaters**

1. Combustion Research Corporation.

2. Reznor/Thomas & Betts Corporation.

3. Roberts-Gordon, Inc.

4. Sterling HVAC Products, a division of Mestek Technology, Inc.

B. **High-Intensity Infrared Heaters**

1. Combustion Research Corporation.

2. Reznor/Thomas & Betts Corporation.

3. Roberts-Gordon, Inc.

4. Sterling HVAC Products, a division of Mestek Technology, Inc.

55.47. Section 235533—Fuel-Fired Unit Heaters

A. **Gas-Fired Unit Heaters**

1. Lennox Industries, Inc.

2. Modine Manufacturing Company.

3. Reznor/Thomas & Betts Corporation.

4. Sterling HVAC Products, a division of Mestek Technology, Inc.

B. **Oil-Fired Unit Heaters**

1. Modine Manufacturing Company.

2. Reznor/Thomas & Betts Corporation.

3. Sterling HVAC Products, a division of Mestek Technology, Inc.

55.48. Section 235700—Heat Exchangers for HVAC

A. **Shell-and-Tube Heat Exchangers**

1. Amtrol, Inc.

2. Armstrong Pumps, Inc.

3. ITT Industries; Bell & Gossett.

4. Patterson-Kelley.

5. Taco, Inc.

6. Thrush Company, Inc.

B. **Plate and Frame Heat Exchangers**

1. Alfa Laval Thermal, Inc.

2. Armstrong Pumps, Inc.

3. Baltimore Air Coil.

4. ITT Industries; Bell & Gossett.

5. Paul Mueller Company.

6. Tranter PHE, Inc.

C. **Brazed Plate and Frame Heat Exchangers**

1. Alfa Laval Thermal, Inc.

2. Armstrong Pumps, Inc.

3. Baltimore Air Coil

4. ITT Industries; Bell & Gossett.

5. Paul Mueller Company.

6. Tranter PHE, Inc.

D. **Ice Storage Systems**

1. Baltimore Air Coil.

2. Calmac.

3. Turbo.

4. Marley Cooling Technologies; an SPX Corporation.

E. **Steam Generators—Unfired, Steam to Steam, High Temperature Hot Water to Steam**

1. API Ketema.

2. Cemline Corporation.

3. Power and Process Control Corporation.

4. Thermaflow Engineering Company.

55.49. Section 236200—Packaged Compressor and Condenser Units

A. **Condensing Units, Air Cooled**

1. Carrier Corporation; Carrier Air Conditioning Div.

2. Lennox Industries, Inc.
3. McQuay International.
4. Rheem Manufacturing; Air Conditioning Div.
5. Trane.
6. York International Corp.

B. **Condensing Units, Water Cooled**
   1. Carrier Corporation; Carrier Air Conditioning Div.
   2. McQuay International.
   3. Trane.
   4. York International Corp.

55.50. Section 236313—Air-Cooled Refrigerant Condensers

A. **Bohn Refrigeration Products; Heatcraft, Inc.**

B. **Carrier Corporation; Carrier Air Conditioning Div.**

C. **Dunham-Bush, Inc.**

D. **McQuay International.**

E. **Trane.**

F. **York International Corp.**

55.51. Section 236333—Evaporative Refrigerant Condensers

A. **Baltimore Aircoil Company.**

B. **Recold.**

55.52. Section 236413.13—Direct-Fired Absorption Water Chillers

A. **Broad Corporation.**

B. **Carrier; a United Technologies Company.**

C. **Hitachi International.**

D. **Trane.**

E. **YORK International Corporation.**

55.53. Section 236413.16—Indirect-Fired Absorption Water Chillers

A. **Carrier Corporation; a United Technologies company.**

B. **Trane.**

C. **YORK, a Johnson Controls company.**

55.54. Section 236416—Centrifugal Water Chillers

A. **Carrier Corporation; Carrier Air Conditioning Div.**

B. **McQuay International.**

C. **Trane.**

D. **York International Corp.**

55.55. Section 236419—Reciprocating Water Chillers

A. **Packaged Water-Cooled Water Chillers**

1. Bohn.
2. Dunham-Bush.
3. Carrier Corporation; Carrier Air Conditioning Div.
4. McQuay International.
5. Trane.
6. York International Corp.

B. **Packaged Air-Cooled Water Chillers**

1. Bohn.
2. Dunham-Bush.
3. Carrier Corporation; Carrier Air Conditioning Div.
4. McQuay International.
5. Trane.
6. York International Corp.

55.56. Section 236423—Scroll Water Chillers

A. **Packaged Water-Cooled Water Chillers**
   1. Carrier Corporation; Carrier Air Conditioning Div.
   2. McQuay International.
   3. Trane.
   4. York International Corp.

B. **Packaged Air-Cooled Water Chillers**
   1. Carrier Corporation; Carrier Air Conditioning Div.
   2. McQuay International.
   3. Trane.
   4. York International Corp.

55.57. Section 236426—Rotary-Screw Water Chillers

A. **Packaged, Water-Cooled, Single-Compressor Chillers**
   1. Carrier Corporation; Carrier Air Conditioning Div.
   2. Dunham-Bush, Inc.
   3. Trane.
   4. York International Corp.

B. **Packaged, Water-Cooled, Multiple-Compressor Chillers**

1. Carrier Corporation; Carrier Air Conditioning Div.

2. Dunham-Bush, Inc.

3. Trane.

4. York International Corp.

C. **Packaged, Air-Cooled Chillers**

1. Carrier Corporation; Carrier Air Conditioning Div.

2. Dunham-Bush, Inc.

3. McQuay International.

4. Trane.

5. York International Corp.

55.58. Section 236427—Medical, Laboratory, and Process Chillers

A. **ArtiChill, Inc.**

B. **Filtrine Manufacturing Company.**

C. **Liebert Corporation.**

55.59. Section 236500—Cooling Towers

A. **Closed-Circuit, Evaporative Cooling Towers (Forced Draft, Induced Draft)**

1. Baltimore Aircoil Company.

2. Evapco, Inc.

3. Marley Cooling Technologies; an SPX Corporation.

B. **Open-Circuit, Cooling Towers (Forced Draft, Induced Draft)**

1. Baltimore Aircoil Company.

2. Evapco, Inc.

3. Marley Cooling Technologies; an SPX Corporation.

4. Tower Tech, Inc.

C. **Ejector Cooling Towers**

1. Baltimore Aircoil Company.
2. Evapco, Inc.
3. Marley Cooling Technologies; an SPX Corporation.

55.60. Section 237200—Air-to-Air Energy Recovery Equipment

A. **Heat Wheels**

1. American Energy Exchange, Inc.
2. AAON, Inc.
3. Loren Cook Company.
4. SEMCO Incorporated.
5. Trane.

B. **Heat-Pipe Heat Exchangers**

1. Applied Air, a company of Mestek Technology, Inc.
2. Des Champs Technologies.
3. Engineered Air.
4. Gaylord Industries, Inc.
5. Heat Pipe Technology, Inc.

C. **Fixed-Plate Sensible Heat Exchangers**

1. American Energy Exchange, Inc.
2. Des Champs Technologies.
3. Engineered Air.
4. Exothermics, a brand of Eclipse, Inc.
5. RenewAire, LLC.
6. United Air Specialists, Inc., a CLARCOR company.

D. **Fixed-Plate Total Heat Exchangers**

1. Mitsubishi Electric Sales Canada, Inc.
2. RenewAire, LLC.

E. **Packaged Energy Recovery Units**

1. American Energy Exchange, Inc.
2. Applied Air, a company of Mestek Technology, Inc.
3. Des Champs Technologies.
4. Engineered Air.
5. Gaylord Industries, Inc.
6. Greenheck Fan Corporation.
7. Loren Cook Company.
8. Mitsubishi Electric & Electronics USA, Inc.; HVAC Advanced Products Division.
9. Mitsubishi Electric Sales Canada, Inc.
10. RenewAire, LLC.
11. SEMCO Incorporated.
12. Trane.
13. Wing, L. J.; Mestek Technology, Inc.

55.61. Section 237313—Modular Indoor Central Station Air Handling Units

A. **Air Enterprises, Inc.**

B. **Buffalo Air Handling.**

C. **Carrier Corporation, a member of the United Technologies Corporation Family.**

D. **Engineered Air.**

E. **Mammoth, Inc.**

F. **McQuay International.**

G. **Trane.**

H. **YORK International Corporation.**

55.62. Section 237314—Custom Indoor Air Handling Units

A. **Acousti Flo.**

B. **Air Enterprises.**

C. **Buffalo Air Handling.**

D. **Cambridgeport.**

E. **Gamewell.**

F. **Gaylord Industries.**

G. **Governair.**

H. **Ingenia.**

I. **Mammoth.**

J. **SEMCO Incorporated.**

K. **Trane.**

L. **YORK International Corporation.**

55.63. Section 237333—Indoor Indirect-Fuel-Fired Heating and Ventilating Units

A. **AbsolutAire, Inc.**

B. **Applied Air; Mestek, Inc.**

C. **BessamAire, Inc.**

D. **Cambridge Engineering, Inc.**

E. **Captive-Air Systems, Inc.**

F. **Des Champs Laboratories Incorporated, a unit of Entrodyne Corporation.**

G. **Engineered Air.**

H. **Greenheck Fan Corporation.**

I. **Jackson & Church, a division of Donlee Technologies, Inc.**

J. **KING.**

K. **Modine Mfg. Co., Commercial HVAC&R Division.**

L. **Rapid Engineering, Inc.**

M. **Reznor-Thomas & Betts Corporation, Mechanical Products Division.**

N. **Trane.**

O. **Weather-Rite, Inc.**

55.64. Section 237339—Indoor, Direct Gas-Fired Heating and Ventilating Units

A. **AbsolutAire, Inc.**

B. **Applied Air; Mestek, Inc.**

C. **BessamAire, Inc.**

D. **Cambridge Engineering, Inc.**

E. **Captive-Air Systems, Inc.**

F. **Des Champs Laboratories Incorporated, a unit of Entrodyne Corporation.**

G. **Engineered Air.**

H. **Greenheck Fan Corporation.**

I. **Jackson & Church, Division of Donlee Technologies, Inc.**

J. **KING.**

K. **Modine Mfg. Co., Commercial HVAC&R Division.**

L. **Rapid Engineering, Inc.**

M. **Reznor-Thomas & Betts Corporation, Mechanical Products Division.**

N. **Sterling Gas; Mestek, Inc.**

O. **Trane.**

P. **Weather-Rite, Inc.**

55.65. Section 237413—Packaged, Outdoor, Central-Station Air-Handling Units

A. **AAON, Inc.**

B. **Carrier Corporation.**

C. **Engineered Air.**

D. **McQuay International.**

E. **Trane.**

F. **YORK International Corporation.**

55.66. Section 237414—Custom Outdoor Air Handling Units

A. **AcoustiFLO**

B. **Air Enterprises.**

C. **Buffalo Air Handling.**

D. **Cambridgeport.**

E. **Gamewell.**

F. **Gaylord Industries.**

G. **Governair.**

H. **Ingenia.**

I. **Mammoth.**

J. **SEMCO Incorporated.**

K. **Trane.**

L. **YORK International Corporation.**

55.67. Section 237433—Packaged, Outdoor, Heating and Cooling Makeup Air-Conditioners

A. **AAON, Inc.**

B. **Des Champs Laboratories, Incorporated.**

C. **Reznor-Thomas & Betts Corporation, Mechanical Products Division.**

55.68. Section 238113—Packaged Terminal Air-Conditioners

A. **Carrier Corporation, a United Technologies company.**

B. **ClimateMaster, Inc.**

C. **Friedrich Air Conditioning Co.**

D. **General Electric Company, GE Consumer & Industrial—Appliances.**

E. **McQuay International.**

F. **Mitsubishi.**

G. **Suburban Manufacturing Company, a subsidiary of AIRXCEL, Inc.**

H. **Trane.**

55.69. Section 238119—Self-Contained Air-Conditioners

A. **Self-Contained Air-Conditioners (Larger than 15 Tons)**

1. Carrier Air Conditioning, a division of Carrier Corporation.
2. Engineered Air.
3. McQuay International.
4. Trane.

B. **Water-Cooled, Self-Contained Air-Conditioners (15 Tons and Smaller)**

1. Carrier Air Conditioning, a division of Carrier Corp.
2. Engineered Air.
3. McQuay International.
4. Trane.

C. **Remote Air-Cooled, Self-Contained Air-Conditioners (15 Tons and Smaller)**

1. Carrier Air Conditioning, a division of Carrier Corp.
2. Engineered Air.
3. McQuay International.
4. Trane.

D. **Integral Air-Cooled, Self-Contained Air-Conditioners (15 Tons and Smaller)**

1. McQuay International.
2. Trane.

E. **Integral Air-Cooled, Wall-Mount Self-Contained Air-Conditioners (15 Tons and Smaller)**

1. Bard Manufacturing Co.
2. Stulz Air Technology Systems, Inc.

55.70. Section 238123—Computer-Room Air-Conditioners

A. **Floor-Mounted Units**

1. APC
2. Compu-Aire, Inc.
3. Data Aire, Inc.
4. Koldwave, Inc., a Mestek company.
5. Liebert Corporation.
6. Stulz-ATS.

B. **Ceiling-Mounted Units**

1. APC
2. Compu-Aire, Inc.
3. Data Aire, Inc.
4. Koldwave, Inc., a Mestek company.
5. Liebert Corporation.
6. Stulz-ATS.

C. **Console Units**

1. APC
2. Compu-Aire, Inc.
3. Data Aire, Inc.
4. Koldwave, Inc., a Mestek company.
5. Liebert Corporation.
6. Stulz-ATS.

55.71. Section 238126—Split-System Air-Conditioners

A. **Carrier Air Conditioning, a division of Carrier Corporation.**

B. **Comfortmaker.**

C. **Friedrich Air Conditioning Company.**

D. **Koldwave, Inc.**

E. **Lennox Industries, Inc.**

F. **Mitsubishi Electric Sales Canada, Inc.**

G. **Mitsubishi Electronics America, Inc., HVAC Division.**

H. **Mitsubishi Heavy Industries America, Inc., Air-Conditioning & Refrigeration Division, Inc.**

I. **Sanyo Fisher (U.S.A.) Corp.**

J. **Trane.**

K. **York International Corp.**

55.72. Section 238146—Water-Source Unitary Heat Pumps

A. **Concealed Water-Source Heat Pumps**

1. Carrier Corporation.
2. ClimateMaster, Inc.
3. Hydro-Temp Corporation, Inc.
4. Mammoth, Inc.
5. McQuay International.
6. Trane.

B. **Vertical-Stack Water-Source Heat Pumps**

1. ClimateMaster, Inc.
2. Trane.

C. **Rooftop Water-Source Heat Pumps**

1. Carrier Corporation.
2. ClimateMaster, Inc.
3. Hydro-Temp Corporation, Inc.
4. Mammoth, Inc.
5. McQuay International.
6. Trane.

D. **Exposed, Console Water-Source Heat Pumps**

1. Carrier Corporation.
2. ClimateMaster, Inc.
3. Hydro-Temp Corporation, Inc.

4. Mammoth, Inc.

5. McQuay International.

6. Trane.

E. **Unit Ventilator Water-Source Heat Pumps**

1. Trane.

55.73. Section 238213—Valance Heating and Cooling Units

A. **Electric Radiant Heaters**

1. Berko Electric Heating, a division of Marley Engineered Products.

2. Chromalox, Inc., a division of Emerson Electric Company.

3. Markel Products, a division of TPI Corporation.

4. Omega Engineering, Inc.

5. QMark Electric Heating, a division of Marley Engineered Products.

B. **Prefabricated Electric Radiant Heating Panels**

1. Aztec.

2. Berko Electric Heating, a division of Marley Engineered Products.

3. Markel Products, a division of TPI Corporation.

4. QMark Electric Heating, a division of Marley Engineered Products.

C. **Hydronic Heating and Cooling Panels**

1. AIRTEX Radiant Systems, a division of Engineered Air Ltd.

2. Rosemex Products.

3. Sun-El Corporation.

55.74. Section 238216—Air Coils

A. **Water Coils**

1. Aerofin Corporation.

2. Carrier Corporation.

3. Dunham-Bush, Inc.

4. Heatcraft Refrigeration Products LLC, Heat Transfer Division.

5. Trane.

B. **Steam Coils**

1. Aerofin Corporation.

2. Carrier Corporation.

3. Dunham-Bush, Inc.

4. Heatcraft Refrigeration Products LLC, Heat Transfer Division.

5. Trane.

C. **Refrigerant Coils**

1. Aerofin Corporation.

2. Carrier Corporation.

3. Dunham-Bush, Inc.

4. Heatcraft Refrigeration Products LLC, Heat Transfer Division.

5. Trane.

D. **Electric Coils**

1. Brasch Manufacturing Co., Inc.

2. Chromalox, Inc., Wiegand Industrial Division; Emerson Electric Company.

3. Dunham-Bush, Inc.

4. INDEECO.

5. Trane.

E. **Integral Face and Bypass Coils—Water and Steam**

1. Aerofin Corporation.

2. Wing, L J; Mestek Technology, Inc.

55.75. Section 238219—Fan Coil Units

A. **Airtherm, a Mestek Company.**

B. **Carrier Corporation.**

C. **Engineered Air Ltd.**

D. **Environmental Technologies, Inc.**

E. **International Environmental Corporation.**

F. **McQuay International.**

G. **Trane.**

H. **YORK International Corporation.**

55.76. Section 238223—Unit Ventilators

A. **Carrier Corporation.**

B. **Engineered Air Ltd.**

C. **McQuay International.**

D. **Nesbitt Aire, Inc.; PEF Industries, Inc.**

E. **Trane.**

55.77. Section 238233—Convectors

A. **Electric Baseboard Radiators**

1. Berko Electric Heating, a division of Marley Engineered Products.
2. Chromalox, a division of Emerson Electric Company.
3. Indeeco.
4. Markel Products, a division of Marley Engineered Products.
5. Marley Electric Heating, a division of Marley Engineered Products.
6. Qmark Electric Heating, a division of Marley Engineered Products.

B. **Hot-Water or Steam Baseboard Radiators**

1. Dunham Bush.

2. Rittling, a division of Hydro-Air Components.

3. Rosemex.

4. Slant/Fin.

5. Sterling.

6. Ted Reed.

7. Trane.

8. Vulcan.

C. **Electric Finned-Tube Radiators**

1. Berko Electric Heating, a division of Marley Engineered Products.

2. Chromalox, a division of Emerson Electric Company.

3. Indeeco.

4. Markel Products, a division of Marley Engineered Products.

5. Marley Electric Heating, a division of Marley Engineered Products.

6. Qmark Electric Heating, a division of Marley Engineered Products.

D. **Hot-Water or Steam Finned-Tube Radiators**

1. Dunham Bush.

2. Rittling, a division of Hydro-Air Components.

3. Rosemex.

4. Slant/Fin.

5. Sterling.

6. Ted Reed.

7. Trane.

8. Vulcan.

E. **Electric Convectors**

1. Berko Electric Heating, a division of Marley Engineered Products.

2. Chromalox, a division of Emerson Electric Company.

3. Indeeco.

4. Markel Products, a division of Marley Engineered Products.

5. Marley Electric Heating, a division of Marley Engineered Products.

6. Qmark Electric Heating, a division of Marley Engineered Products.

F. **Hot-Water or Steam Convectors**

1. Dunham Bush.

2. Rittling, a division of Hydro-Air Components.

3. Rosemex.

4. Slant/Fin.

5. Sterling.

6. Ted Reed.

7. Trane.

8. Vulcan.

G. **Flat-Pipe Steel Radiators**

1. Embassy Industries, Inc.

2. Panel Radiator, Inc., a division of Hydro-Air Components.

3. Runtal North America, Inc.

55.78. Section 238239—Unit Heaters

A. **Electric Cabinet Unit Heaters**

1. Brasch.

2. Berko Electric Heating, a division of Marley Engineered Products.

3. Chromalox, Inc., a division of Emerson Electric Company.

4. Indeeco.

5. Markel Products, a division of TPI Corporation.

6. Marley Electric Heating, a division of Marley Engineered Products.
7. QMark Electric Heating, a division of Marley Engineered Products.
8. Trane.
9. Vulcan.

B. **Hot Water or Steam Cabinet Unit Heaters**

1. Carrier Corporation.
2. Dunham-Bush, Inc.
3. Engineered Air Ltd.
4. International Environmental Corporation.
5. McQuay International.
6. Modine.
7. Ted-Reed.
8. Trane.
9. Vulcan.

C. **Electric Propeller Unit Heaters**

1. Brasch.
2. Berko Electric Heating, a division of Marley Engineered Products.
3. Chromalox, Inc., a division of Emerson Electric Company.
4. Indeeco.
5. Markel Products, a division of TPI Corporation.
6. Marley Electric Heating, a division of Marley Engineered Products.
7. QMark Electric Heating, a division of Marley Engineered Products.
8. Trane.

D. **Hot Water or Steam Propeller Unit Heaters**

1. Carrier Corporation.

2. Dunham Bush.
3. Engineered Air Ltd.
4. McQuay International.
5. Modine.
6. Reznor.
7. Ted_Reed
8. Trane.

E. **Wall and Ceiling Heaters**
1. Berko Electric Heating, a division of Marley Engineered Products.
2. Chromalox, Inc., a division of Emerson Electric Company.
3. Indeeco.
4. Markel Products, a division of TPI Corporation.
5. Marley Electric Heating, a division of Marley Engineered Products.
6. QMark Electric Heating, a division of Marley Engineered Products.
7. Trane.

55.79. Section 238313—Radiant-Heating Electric Cables

A. **Mineral-Insulated, Series-Resistance Heating Cables**
1. Chromalox, Inc., Wiegard Industrial Division; Emerson Electric Company.
2. Delta-Therm Corporation.
3. Easy Heat, Inc.
4. Pyrotenax, a division of Tyco Thermal Controls.
5. Raychem, a division of Tyco Thermal Controls.
6. Watts Radiant, Inc.

B. **Plastic-Insulated, Series-Resistance Heating Cables**
1. Delta-Therm Corporation.

2. Easy Heat, Inc.

3. Pyrotenax, a division of Tyco Thermal Controls.

4. Raychem, a division of Tyco Thermal Controls.

5. Watts Radiant, Inc.

C. **Self-Regulating, Parallel-Resistance Heating Cables**

1. Chromalox, Inc., Wiegard Industrial Division; Emerson Electric Company.

2. Delta-Therm Corporation.

3. Easy Heat, Inc.

4. Pyrotenax, a division of Tyco Thermal Controls.

5. Raychem, a division of Tyco Thermal Controls.

55.80. Section 238316—Radiant-Heating Hydronic Piping

A. **Pex Pipe and Fittings**

1. IPEX, Inc.

2. REHAU.

3. Slant/Fin Corp.

4. Stadler-Viega.

5. Uponor Wirsbo Co.

6. Vanguard Piping Systems, Inc.

7. Warmboard, Inc.

8. Watts Radiant, Inc., a division of Watts Water Technologies, Inc.

9. Zurn Plumbing Products Group.

B. **Pex/Al/Pex Pipe and Fittings**

1. IPEX Inc.

2. Stadler-Viega.

3. Uponor Wirsbo Co.

4. EPDM Pipe and Fittings.

5. Watts Radiant, Inc., a division of Watts Water Technologies, Inc.

C. **Controls**

1. Danfoss, Inc.

2. IPEX, Inc.

3. REHAU.

4. Slant/Fin Corp.

5. Stadler-Viega.Tekmar Control Systems, Ltd.

6. Uponor Wirsbo Co.

7. Vanguard Piping Systems, Inc.

8. Watts Radiant, Inc., a division of Watts Water Technologies, Inc.

9. Zurn Plumbing Products Group.

D. **Snow Melt Systems**

1. Snow Technologies.

2. Uponor Wirsbo Co.

3. Vanguard Piping Systems, Inc.

4. Watts Radiant, Inc., a division of Watts Water Technologies, Inc.

55.81. Section 238323—Radiant-Heating Electric Panels

A. **Prefabricated Radiant-Heating Electric Panels**

1. Berko Electric Heating, a division of Marley Engineered Products.

2. Markel Products, a division of TPI Corporation.

3. QMark Electric Heating, a division of Marley Engineered Products.

55.82. Section 238413—Humidifiers

A. **Water-Pressure Atomizing Humidifiers**

1. Carel USA, LLC.
2. Herrmidifier.
3. Mee Industries, Inc.

B. **Compressed-Air Atomizing Humidifiers**

1. Carel USA, LLC.
2. Herrmidifier.
3. Mee Industries, Inc.

C. **Steam-Injection Humidifiers**

1. Armstrong International, Inc.
2. Carel USA, LLC.
3. DRI-STEEM Humidifier Company.
4. Herrmidifier.
5. Hygromatik; Spirax Sarco, Inc.
6. Nortec Industries Inc.
7. Pure Humidifier Company.

D. **Self-Contained Humidifiers**

1. Armstrong International, Inc.
2. Carel USA, LLC.
3. Herrmidifier.
4. Hygromatik; Spirax Sarco, Inc.
5. Nortec Industries, Inc.

E. **Heated-Pan Humidifiers**

1. Armstrong International, Inc.
2. DRI-STEEM Humidifier Company.
3. Nortec Industries, Inc.
4. Pure Humidifier Company.

F. **Heat-Exchanger Humidifiers**

1. Armstrong International, Inc.
2. Nortec Industries, Inc.
3. Pure Humidifier Company.

55.83. Section 238416—Dehumidifiers

A. **Desiccant Dehumidification Units**

1. Air Technology Systems, Inc.
2. Governair Corporation.
3. Kathabar, Inc.
4. Munters, Cargocaire Division.

B. **Refrigeration Dehumidification Units**

1. DEC International, Inc.; Therma-Stor Products.
2. DECTRON, Inc.
3. Dehumidifier Corporation of America, Inc.
4. Desert Aire.
5. DryAire Systems Corp.
6. Governair Corporation.
7. Nautica Dehumidifiers, Inc.
8. Nesbitt, a Mestek Company.

55.84. Section 262419—Motor-Control Centers

A. **ABB Power Distribution, Inc.; ABB Control, Inc., Subsidiary.**

B. **Danfoss, Inc.; Danfoss Electronic Drives Div.**

C. **Eaton Corporation; Cutler-Hammer Products.**

D. **General Electric Company; GE Industrial Systems.**

E. **Rockwell Automation; Allen-Bradley Co.; Industrial Control Group.**

F. **Siemens/Furnas Controls.**

G. **Square D.**

55.85. Section 262816—Enclosed Switches and Circuit Breakers

A. **Fusible Switches**

1. Eaton Electrical, Inc.; Cutler-Hammer Business Unit.
2. General Electric Company; GE Consumer & Industrial—Electrical Distribution.
3. Siemens Energy & Automation, Inc.
4. Square D, a brand of Schneider Electric.

B. **Nonfusible Switches**

1. Eaton Electrical, Inc.; Cutler-Hammer Business Unit.
2. General Electric Company.; GE Consumer & Industrial—Electrical Distribution.
3. Siemens Energy & Automation, Inc.
4. Square D, a brand of Schneider Electric.

55.86. Section 262913—Enclosed Controllers

A. **ABB Power Distribution, Inc.; ABB Control, Inc., Subsidiary.**

B. **Danfoss, Inc.; Danfoss Electronic Drives Div.**

C. **Eaton Corporation, Cutler-Hammer Products.**

D. **General Electrical Company; GE Industrial Systems.**

E. **Rockwell Automation; Allen-Bradley Co.; Industrial Control Group.**

F. **Siemens/Furnas Controls.**

G. **Square D.**

55.87. Section 262923—Variable-Frequency Motor Controllers

A. **ABB Power Distribution, Inc.; ABB Control, Inc., Subsidiary.**

B. **Baldor Electric Company (Graham).**

C. **Danfoss, Inc., Danfoss Electronic Drives Div.**

D. **Eaton Corporation, Cutler-Hammer Products.**

E. **General Electric Company; GE Industrial Systems.**

F. **Rockwell Automation; Allen-Bradley Co.; Industrial Control Group.**

G. **Siemens Energy and Automation, Industrial Products Division.**

H. **Square D.**

I. **Toshiba International Corporation.**