All HVAC Formula

PART 5

Equations

5.01 Cooling and Heating Equations

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

$$H_S = 1.1 \times CFM \times \Delta T$$

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

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

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

$$H_T = H_S + H_L$$

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

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

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

H_S = Sensible Heat (Btu/Hr.)
H_L = Latent Heat (Btu/Hr.)
H_T = Total Heat (Btu/Hr.)

ΔT = Temperature Difference (°F.)

$\Delta W_{GR.}$ = Humidity Ratio Difference (Gr.H_2O/Lb.DA)
$\Delta W_{LB.}$ = Humidity Ratio Difference (Lb.H_2O/Lb.DA)

Δh = Enthalpy Difference (Btu/Lb.DA)

CFM = Air Flow Rate (Cubic Feet per Minute)
U = U-Value (Btu/Hr. Sq. Ft. °F.)

A = Area (Sq. Ft.)
SHR = Sensible Heat Ratio

H_{FG} = Latent Heat of Vaporization at Design Pressure (*1989 ASHRAE Fundamentals*)

5.02 R-Values/U-Values

$$R = \frac{1}{C} = \frac{1}{K} \times Thickness$$

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

R = R-Value (Hr. Sq. Ft. °F./Btu.)
U = U-Value (Btu./Hr. Sq. Ft. °F.)
C = Conductance (Btu./Hr. Sq. Ft. °F.)
K = Conductivity (Btu. In./Hr. Sq. Ft. °F.)
ΣR = Sum of the Individual R-Values

5.03 Water System 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/Hr.)
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)

5.04 Air Change Rate Equations

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

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

AC/HR.	=	Air Change Rate per Hour
CFM	=	Air Flow Rate (Cubic Feet per Minute)
VOLUME	=	Space Volume (Cubic Feet)

5.05 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)

5.06 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	=	Flow through Duct (CFM)
A	=	Area of Duct (Sq. Ft.)
W	=	Width of Duct (Inches)
H	=	Height of Duct (Inches)
D_{EQ}	=	Equivalent Round Duct Size for Rectangular Duct (Inches)
A	=	One Dimension of Rectangular Duct (Inches)
B	=	Adjacent Side of Rectangular Duct (Inches)

5.07 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	=	In. W.G.
BHP	=	Break 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

5.08 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	=	Ft. H_2O
BHP	=	Break 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 in Psi
VH	=	Velocity Head in Ft.
V	=	Velocity in Ft./Sec.
g	=	Acceleration due to Gravity (32.16 Ft./Sec^2)

5.09 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—1989 ASHRAE Fundamentals)

5.10 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 (Gallons/Minute)

CFM = Air Flow Rate (Cu.Ft./Minute)
SpV = Specific Volume of Air (Cu.Ft./Lb.DA)

$\Delta W_{LB.}$ = Specific Humidity ($Lb.H_2O/Lb.DA$)
$\Delta W_{GR.}$ = Specific Humidity ($Gr.H_2O/Lb.DA$)

5.11 Humidification

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

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

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

$GRAINS_{REQ'D}$ = Grains of Moisture Required ($Gr.H_2O/Cu.Ft.$)
$POUNDS_{REQ'D}$ = Pounds of Moisture Required ($Lb.H_2O/Cu.Ft.$)

CFM = Air Flow Rate (Cu.Ft./Minute)
SpV = Specific Volume of Air (Cu.Ft./Lb.DA)

$W_{GR.}$ = Specific Humidity ($Gr.H_2O/Lb.DA$)
$W_{LB.}$ = Specific Humidity ($Lb.H_2O/Lb.DA$)

5.12 Humidifier Sensible Heat Gain

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

H_S = Sensible Heat Gain (Btu/Hr.)
Q = Steam Flow (Lb.Steam/Hr.)
ΔT = Steam Temperature – Supply Air Temperature (F.)
L = Length of Humidifier Manifold (Ft.)

5.13 Expansion Tanks

$$CLOSED \quad V_T = V_S \times \frac{\left[\left(\frac{\nu_2}{\nu_1}\right) - 1\right] - 3\alpha\Delta T}{\left[\frac{P_A}{P_1} - \frac{P_A}{P_2}\right]}$$

$$OPEN \quad V_T = 2 \times \left\{\left(V_S \times \left[\left(\frac{\nu_2}{\nu_1}\right) - 1\right]\right) - 3\alpha\Delta T\right\}$$

$$DIAPHRAGM \quad V_T = V_S \times \frac{\left[\left(\frac{\nu_2}{\nu_1}\right) - 1\right] - 3\alpha\Delta T}{1 - \left(\frac{P_1}{P_2}\right)}$$

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

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./Lb.H_2O) *1989 ASHRAE Fundamentals,* Chapter 2, Table 25 or Part 27, Properties of Air and Water
V_2 = SpV of H_2O at T_2 (Cu. Ft./Lb.H_2O) *1989 ASHRAE Fundamentals,* Chapter 2, Table 26 or Part 27, Properties of Air and Water
α = Linear Coefficient of Expansion

$\alpha_{STEEL} = 6.5 \times 10^{-6}$
$\alpha_{COPPER} = 9.5 \times 10^{-6}$

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 Lb. Systems	45–125 Psi
250 Lb. Systems	125–225 Psi

5.14 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

$OA = EA \qquad RFA = 0$

For Economizer Cycle

$OA = SA = EA + RFA \qquad RA = 0$

5.15 Efficiencies

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

$$EER = \frac{BTU\ OUTPUT}{WATTS\ INPUT}$$

Turndown Ratio = Maximum Firing Rate: Minimum Firing Rate
(i.e., 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%

5.16 Cooling Towers and Heat Exchangers

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

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

$$\mathrm{RANGE = EWT - LWT}$$

EWT	=	Entering Water Temperature (°F)
LWT	=	Leaving Water Temperature (°F)
AWB	=	Ambient Wet Bulb Temperature (Design WB, °F)
HS	=	Hot Side
CS	=	Cold Side

5.17 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 (Hr. Sq.Ft. °F./Btu.)
U	=	U-Value (Btu./Hr. Sq.Ft. °F.)
IA	=	Inside Airfilm
OA	=	Design Outside Air Temperature
DP	=	Dew Point

5.18 Electricity

$$KVA = KW + KVAR$$

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 = Break Horsepower
MHP = Motor Horsepower
EFF = Efficiency
M/D = Motor Drive

A. Single Phase Power:

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

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

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

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

B. 3-Phase Power:

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

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

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

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

5.19 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 above.

5.20 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 9, Ventilation Rules of Thumb.

B. Completely Enclosed Equipment Rooms:

$$CFM = 100 \times G^{0.5}$$

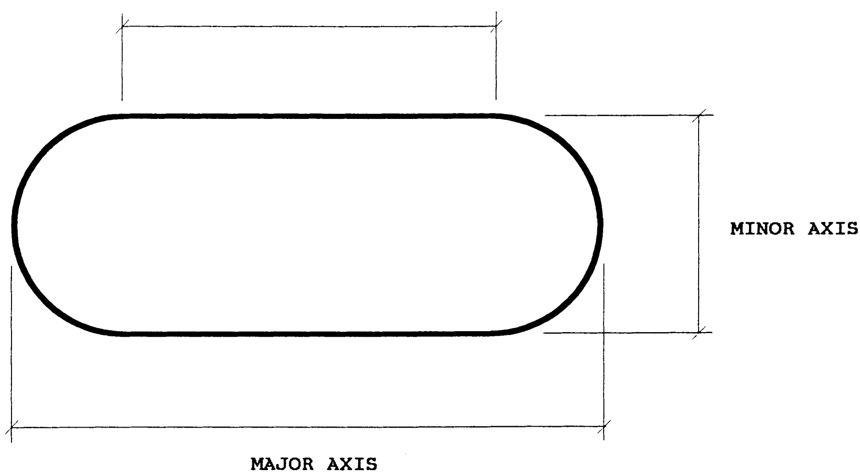
CFM = Exhaust Air Flow Rate Required (Cu.Ft./Minute)
G = Mass of Refrigerant of Largest System (Pounds)

C. Partially Enclosed Equipment Rooms:

$$FA = G^{0.5}$$

FA = Ventilation Free Opening Area (Sq.Ft.)
G = Mass of Refrigerant of Largest System (Pounds)

5.21 Equations for Flat Oval Ductwork



$$FS = MAJOR - MINOR$$

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

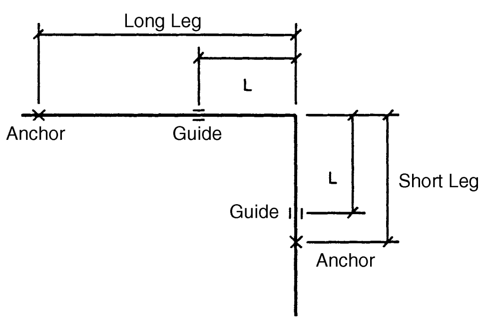
$$P = \frac{(\pi \times MINOR) + (2 \times FS)}{12}$$

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

FS	=	Flat Span Dimension (Inches)
MAJOR	=	Major Axis Dimension [Inches (Larger Dimension)]
MINOR	=	Minor Axis Dimension [Inches (Smaller Dimension)]
A	=	Cross-Sectional Area (Square Feet)
P	=	Perimeter or Surface Area (Square Feet per Lineal Feet)
D_{EQ}	=	Equivalent Round Duct Diameter

5.22 Pipe Expansion Equations

A. L-Bends:



L-Bends

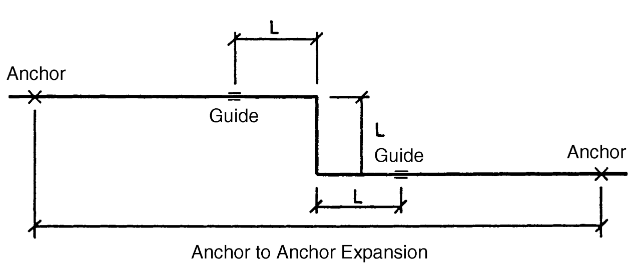
$L = 6.225 \times \sqrt{\Delta D}$

$F = 500\ LB./PIPE\ DIA. \times PIPE\ DIA.$

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 32, Appendix D

B. Z-Bends:



Z-Bends

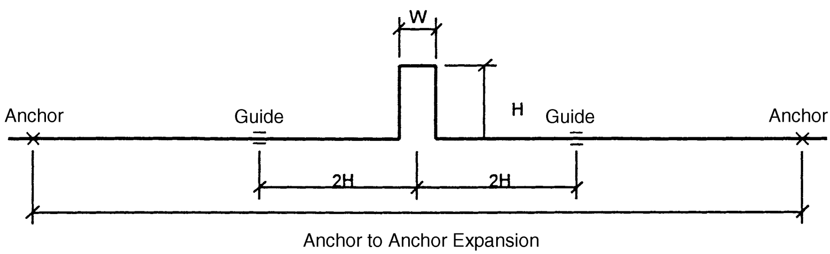
$L = 4 \times \sqrt{\Delta D}$

$F = 200 - 500\ LB./PIPE\ DIA. \times PIPE\ DIA.$

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 32, Appendix D.

C. U-Bends or Expansion Loops:



U-Bends or Loops

$$L = 6.225 \times \sqrt{\Delta D}$$

$$F = 200\ LB./PIPE\ DIA. \times PIPE\ DIA.$$

$$L = 2H + W$$

$$H = 2W$$

$$L = 5W$$

L = Length of Loop 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 32, Appendix D.

5.23 Steam and Condensate Equations

A. General:

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

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

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

$$LB.\ STM.\ COND./HR. = \frac{GPM \times 500 \times SP.GR. \times C_P \times \Delta T}{L}$$

$$LB.\ STM.\ COND./HR. = \frac{CFM \times 60 \times D \times C_P \times \Delta T}{L}$$

B. Approximating Condensate Loads:

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

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

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

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_P	=	Specific Heat of Gas or Liquid (Btu/Lb)
		Air $C_P = 0.24$ Btu/Lb
		Water $C_P = 1.00$ Btu/Lb
L	=	Latent Heat of Steam (Btu/Lb. at Steam Design Pressure)
ΔT	=	Final Temperature minus Initial Temperature
EDR	=	Equivalent Direct Radiation

5.24 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 Feet of Pipe (Psig/100 feet)
W	Steam Flow Rate (Lbs./Hour)
ID	Actual Inside Diameter of Pipe (Inches)
D	Average Density of Steam at System Pressure (Lbs./Cu. Ft.)
V	Velocity of Steam in Pipe (Feet/Minute)
A_{INCHES}	Actual Cross Sectional Area of Pipe (Square Inches)
A_{FEET}	Actual Cross Sectional Area of Pipe (Square Feet)

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/Lb.)
H_{SCR}	Sensible Heat at Condensate Return Pressure (Btu/Lb.)
H_{LCR}	Latent Heat at Condensate Return Pressure (Btu/Lb.)
W	Steam Flow Rate (Lbs./Hr.)
W_{CR}	Condensate Flow based on percentage of Flash Steam created during condensing process (Lbs./Hr.). Use this flow rate in steam equations above to determine condensate return pipe size.

5.25 Psychrometric Equations

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

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

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

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

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

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

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

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

W	=	Specific Humidity (Lb.H_2O/Lb.DA or Gr.H_2O/Lb.DA)
W_{ACTUAL}	=	Actual Specific Humidity (Lb.H_2O/Lb.DA or Gr.H_2O/Lb.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 (Lb./Sq.Ft.)
P	=	Total Absolute Pressure of Air/Water Vapor Mixture (Lb./Sq.Ft.)
P_{SAT}	=	Saturation Partial Pressure of Water Vapor at the Dry Bulb Temperature (Lb./Sq.Ft.)
RH	=	Relative Humidity (%)
H_S	=	Sensible Heat (Btu/Hr.)
H_L	=	Latent Heat (Btu/Hr.)
H_T	=	Total Heat (Btu/Hr.)
m	=	Mass Flow Rate (Lb.DA/Hr. or Lb.H_2O/Hr.)
c_P	=	Specific Heat (Air: 0.24 Btu/Lb.DA, Water: 1.0 Btu/Lb.H_2O)
T_{DB}	=	Dry Bulb Temperature (°F.)
T_{WB}	=	Wet Bulb Temperature (°F.)
ΔT	=	Temperature Difference (°F.)
ΔW	=	Specific Humidity Difference (Lb.H_2O/Lb.DA or Gr.H_2O/Lb.DA)
Δh	=	Enthalpy Difference (Btu/Lb.DA)
L_V	=	Latent Heat of Vaporization (Btu/Lb.H_2O)

5.26 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 5.5 Feet)
2. Determine heat pick-up time in hours from Owner.
3. Determine pool water temperature in degrees F. from the Owner. If Owner does not specify 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 Btu/Hr/Sq.Ft.°F. in the equation below assumes a wind velocity of 3.5 mph. If a wind velocity of less than 3.5 mph is used, multiply equation by 0.75; for 5.0 mph multiply equation by 1.25; and for 10 mph multiply equation by 2.0.
6. Pool Heater Equations:

$$H_{POOL\ HEATER} = H_{HEAT\text{-}UP} + H_{SURFACE\ LOSS}$$

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

$$H_{SURFACE\ LOSS} = 5.5\ BTU/HR.\ SQ.\ FT.\ °F. \times \Delta T_{WATER/AIR} \times POOL\ AREA$$

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

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

$$T_{INITIAL} = 50\ °\mathrm{F}$$

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

H = Heating Capacity (Btu/Hr.)
ΔT = Temperature Difference (°F.)

5.27 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.)

5.28 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 above.

5.29 Relief Valve Vent Line Maximum Length

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

$$P_1 = 0.25 \times [(PRESSURE\ SETTING \times 1.1) + 14.7]$$

$$P_2 = [(PRESSURE\ SETTING \times 1.1) + 14.7]$$

L = Maximum Length of Relief Vent Line (Feet)
D = Inside Diameter of Pipe (Inches)
C = Minimum Discharge of Air (Lbs./Min.)

5.30 Relief Valve Sizing

A. Liquid System Relief Valves and 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 and 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 (Lb./Hr.):

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

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 (Square Inches)
2. GPM = Required Relieving Capacity at Flow Conditions (Gallons per Minute)
3. W = Required Relieving Capacity at Flow Conditions (Lbs./Hr.)
4. SCFM = Required Relieving Capacity at Flow Conditions (Standard Cubic Feet per Minute)
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
   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 overpressure of 16 percent or 4 Psi, whichever is greater.
3. For superheated steam, the correction factor values listed below 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)

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
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

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 are shown in the table on the preceding page:

5.31 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 (Square Inches)
W_P = Weight of Pipe per Foot (Pounds)
W_W = Weight of Water per Foot (Pounds)
T = Pipe Wall Thickness (Inches)
ID = Inside Diameter (Inches)
OD = Outside Diameter (Inches)
OSA = Outside Surface Area per Foot (Square Feet)
ISA = Inside Surface Area per Foot (Square Feet)
A_M = Area of the Metal (Square Inches)

5.32 English/Metric Cooling and Heating Equations Comparison

$$H_S = 1.08 \frac{Btu\ Min}{Hr\ Ft^3\ °F} \times CFM \times \Delta T$$

$$H_{SM} = 72.42 \frac{KJ\ Min}{Hr\ M^3\ °C} \times CMM \times \Delta T_M$$

$$H_L = 0.68 \frac{Btu\ Min\ Lb\ DA}{Hr\ Ft^3\ Gr\ \mathrm{H_2O}} \times CFM \times \Delta W$$

$$H_{LM} = 177{,}734.8 \frac{KJ\ Min\ Kg\ DA}{Hr\ M^3\ Kg\ \mathrm{H_2O}} \times CMM \times \Delta W_M$$

$$H_T = 4.5 \frac{Lb\ Min}{Hr\ Ft^3} \times CFM \times \Delta h$$

$$H_{TM} = 72.09 \frac{Kg\ Min}{Hr\ M^3} \times CMM \times \Delta h_M$$

$$H_T = H_S + H_L$$

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

$$H = 500\ \frac{Btu\ Min}{Hr\ Gal\ °F} \times GPM \times \Delta T$$

$$H_M = 250.8\ \frac{KJ\ Min}{Hr\ Liters\ °C} \times LPM \times \Delta T_M$$

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

$$\frac{AC}{HR_M} = \frac{CMM \times 60 \frac{Min}{Hr}}{VOLUME_M}$$

$$°C = \frac{°F - 32}{1.8}$$

$$°F = 1.8\ °C + 32$$

H_S	=	Sensible Heat (Btu/Hr.)
H_{SM}	=	Sensible Heat (KJ/Hr.)
H_L	=	Latent Heat (Btu/Hr.)
H_{LM}	=	Latent Heat (KJ/Hr.)
H_T	=	Total Heat (Btu/Hr.)
H_{TM}	=	Total Heat (KJ/Hr.)
H	=	Total Heat (Btu/Hr.)
H_M	=	Total Heat (KJ/Hr.)
ΔT	=	Temperature Difference (°F.)
ΔT_M	=	Temperature Difference (°C.)
ΔW	=	Humidity Ratio Difference (Gr.H_2O/Lb.DA)
ΔW_M	=	Humidity Ratio Difference (Kg.H_2O/Kg.DA)
Δh	=	Enthalpy Difference (Btu/Lb.DA)
Δh	=	Enthalpy Difference (KJ/Lb.DA)
CFM	=	Air Flow Rate (Cubic Feet per Minute)
CMM	=	Air Flow Rate (Cubic Meters per Minute)
GPM	=	Water Flow Rate (Gallons per Minute)
LPM	=	Water Flow Rate (Liters per Minute)
AC/HR.	=	Air Change Rate per Hour, English
AC/HR.$_M$	=	Air Change Rate per Hour, Metric
AC/HR.	=	AC/HR.$_M$
VOLUME	=	Space Volume (Cubic Feet)
$VOLUME_M$	=	Space Volume (Cubic Meters)
KJ/Hr	=	Btu/Hr × 1.055
CMM	=	CFM × 0.02832
LPM	=	GPM × 3.785
KJ/Lb	=	Btu/Lb × 2.326
Meters	=	Feet × 0.3048
Sq. Meters	=	Sq. Feet × 0.0929
Cu. Meters	=	Cu. Feet × 0.02832
Kg	=	Pounds × 0.4536

1.0 GPM	=	500 Lb. Steam/Hr.
1.0 Lb.Stm. /Hr	=	0.002 GPM
1.0 Lb.H_2O/Hr	=	1.0 Lb.Steam/Hr.
Kg/Cu. Meter	=	Pounds/Cu. Feet × 16.017 (Density)
Cu. Meters/Kg	=	Cu. Feet/Pound × 0.0624 (Specific Volume)
Kg H_2O/Kg DA	=	Gr H_2O/Lb DA/7,000 = Lb. H_2O/Lb DA

5.33 Cooling Tower 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.)

5.34 Motor Drive Formulas

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

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

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