BASICS OF HEATING VENTILATION & AIR CONDITIONING

HVAC

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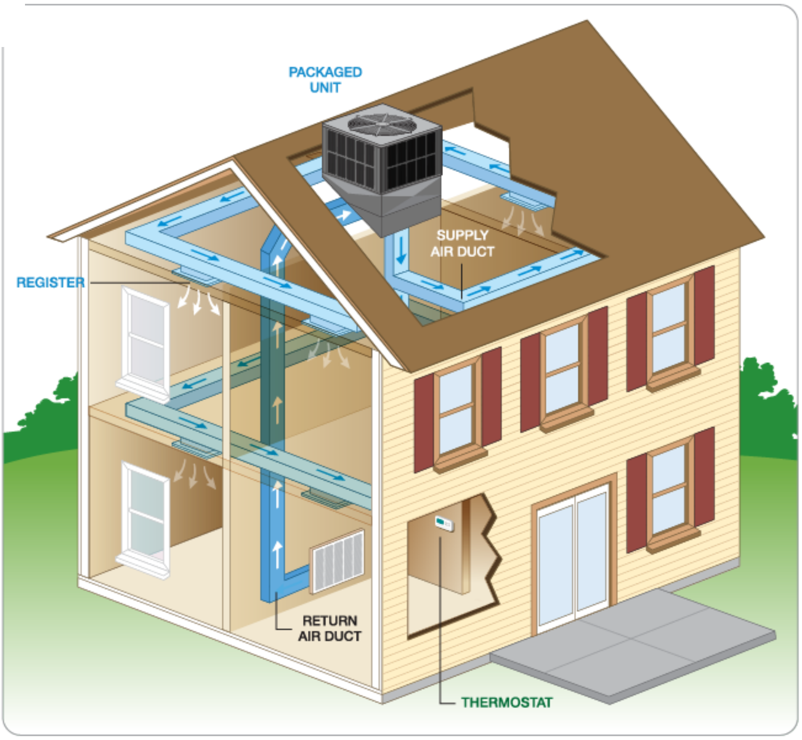

FOR BIGINNERS

HEATING VENTILATION & AIR CONDITIONING

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HEATING VENTILATION AND AIR CONDITIONING

“The Purpose of Life Is not to be Happy only for Yourself”
It Is to Be Useful, To Be Honorable, To Be Compassionate, and to Have It Make Some Difference That You Have Lived and Lived Well.”
“No One Has Ever Become Poor by Giving.”
But Few of Us Realize the Benefit of Giving.

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Section 1 - Introduction To HVAC

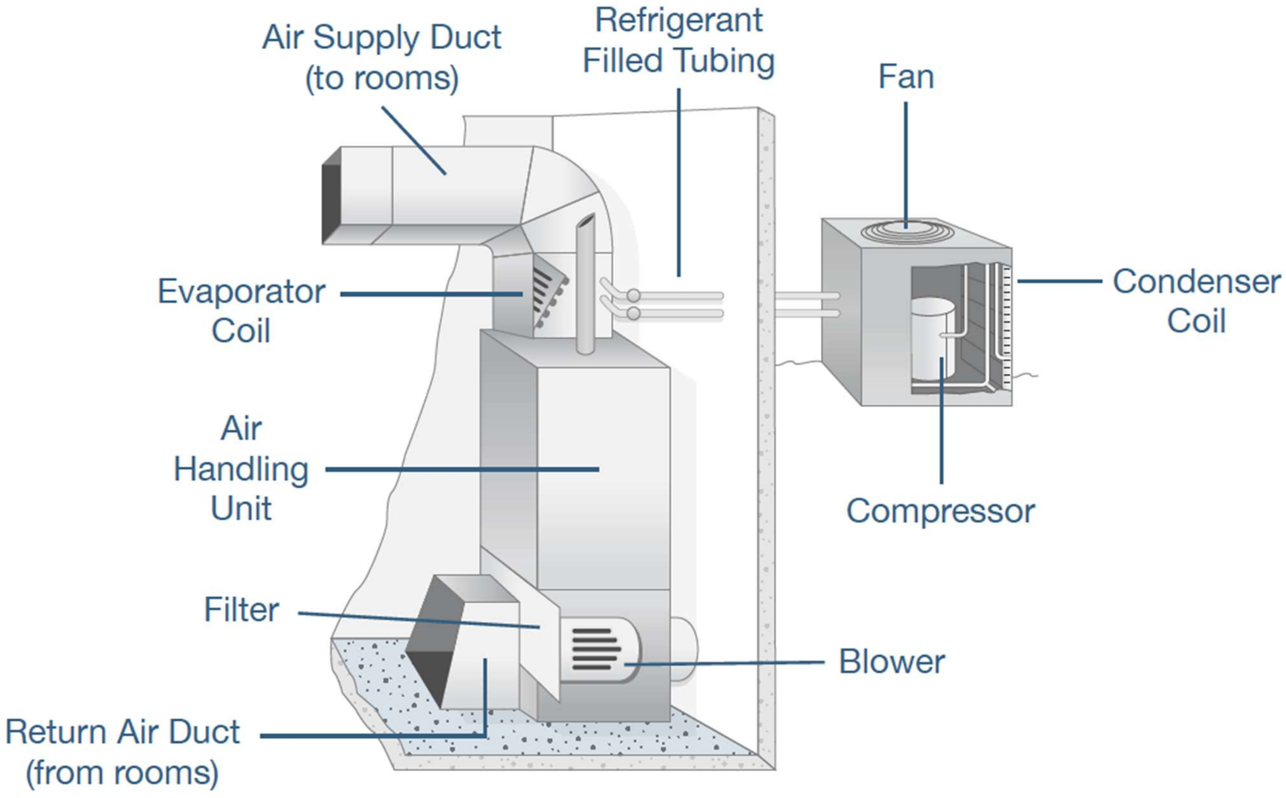
Purpose of this Section:

1. Define HVAC (heating, ventilating and air conditioning).
2. Describe the purposes of HVAC.
3. Name and describe the seven major air-conditioning processes.
4. Identify five main aspects of a space that influence an occupant's comfort.

1.1 Overview

Heating, Ventilating and Air Conditioning, HVAC, is a huge field. HVAC systems Cooling equipment varies from the small domestic unit to refrigeration machines that are 10,000 times the size.

This Section will introduce the fundamental concepts that are used by designers to make decisions about system design, operation, and maintenance.



HVAC is a common term that people use, and most have a general idea of what it's referring to. On the other hand, what exactly does HVAC mean? And, how does it apply to your home? Petro Home Services provides full home services in addition to our HVAC solutions, and we can give you the lowdown on HVAC basics.

The purpose of an HVAC system is more than just warming or cooling a space. Instead, it serves to improve indoor air quality and provide comfort for everyone inside a building. While there are several different types of HVAC systems, they all begin with the same essentials.

1.2 History of HVAC

For millennia, people have used fire for heating and the natural air draft ensured the ventilation for the occupants. However, as central furnaces with piped steam or hot water became available for heating, the need for separate ventilation became apparent.

WORLD'S FIRST TAKE-HOME AIR CONDITIONER

...new PHILCO ¾-hp Bantam 12—smallest room air conditioner made!

Here's the best hot-weather news you've ever heard!

Philco brings you an air conditioner so small you can carry it home—yet it's a giant in cooling capacity.

Install the ¾-hp Philco Bantam 12 in only 15 minutes. You can even do it yourself! Then sit back and forget about heat and humidity.

There's never been anything like the Bantam 12. It does everything bulky, old-fashioned air conditioners can do. Yet all this comfort and compactness costs less than most ordinary ¾-hp units.

Start being comfortable today! See or telephone your Philco dealer this very minute. Tell him you want a Philco Bantam 12 right away.

TAKE IT HOME TODAY BE COOL TONIGHT!

You can install it yourself. Only four screws are needed to hold the Philco Bantam 12 in place. Everything you need comes in the box. Meets most landlord requirements; runs on ordinary house voltage (110-115v), takes less current than a toaster!

Big capacity cooling—¾ hp. The new Philco Bantam 12 has all the luxury features you find on big air conditioners—2-speed fan, Automatic Temperature Control, adjustable grilles.

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By the 1880s, refrigeration became available for industrial purposes. initially the **Two** main uses were **freezing meat** for transport and **making ice.** However, in the early 1900s there was a new initiative to keep buildings cool for comfort.

The term "air conditioning" has gradually changed, from meaning just cooling, to the total control of:

1. Temperature
2. Moisture in the air (humidity)
3. Supply of outside air for ventilation
4. Filtration of airborne particles
5. Air movement in the occupied space

Air-conditioning technology has developed since 1900 through the joint accomplishments of science and engineering. Advances in thermodynamics, fluid mechanics, electricity, electronics, construction, materials, medicine, controls and social behavior are the building blocks to better engineered products of air conditioning.

Historical accounts are not required as part of this course but, for the enjoyment and perspective it provides, it is worth reading an article such as "Milestones in Air Conditioning," by Walter A. Grant or the book about Willis Carrier, *The Father of Air-Conditioning*.

1.3 Scope of Modern HVAC

1. ***Indoor air quality*** is one that directly affects us. In many countries the indoor-air-quality in buildings is too poor and unsatisfactory. The causes and effects of this poor quality are extremely complex.

2. ***Greenhouse gas emissions*** and the destruction of the earth's protective *ozone layer* are concerns that are stimulating research. New guidelines are evolving that encourage: recycling; less energy usage; and low polluting materials, particularly refrigerants. All these issues have a significant impact on building design, including HVAC systems.

3. ***Energy conservation*** is an ongoing challenge to find new ways to reduce consumption in new and existing buildings without compromising comfort

1.4 Introduction to Air-conditioning Process

There are ***seven main processes required*** to achieve full air conditioning and These processes are:

1. ***Heating*** — the process of adding thermal energy the space for the purposes of raising or maintaining the temperature of the space.

2. ***Cooling*** — the process of removing thermal energy from the space for the purposes of lowering or maintaining the temperature of the space.

3. ***Humidifying*** — the process of adding moisture to the air in the space for the purposes of raising or maintaining the moisture content of the air.

4. ***Dehumidifying*** — the process of removing moisture from the air in the space for the purposes of lowering or maintaining the moisture content of the air.

5. ***Cleaning*** — the process of removing particulates and biological contaminants from the air delivered to the space for the purposes of improving or maintaining the air quality.

6. ***Ventilation*** — the process of exchanging air between the outdoors and the conditioned space for the purposes of diluting the gaseous contaminants in the space.

   Ventilation can be achieved either through:
   - *Natural ventilation:* it is driven by natural draft, like when you open a window.
   - *Mechanical ventilation*. Can be achieved by using fans to draw air in from outside or by fans that exhaust air from the space to outside.

7. ***Air Movement*** — the process of circulating and mixing air through conditioned spaces in the building for the purposes of achieving the proper ventilation and facilitating the thermal energy transfer.

1.5 Objective

What is your system to achieve…?

Often, the objective is to provide a comfortable environment for the human occupants, but there are many other possible Purpose: creating a suitable environment for farm animals; regulating a hospital operating room; maintaining cold temperatures for frozen food storage; or maintaining temperature and humidity to preserve wood and fiber works of art. Whatever the situation, it is important that the objective criteria for system success are clearly identified at the start of the project, because different requirements need different design considerations.

Example 1: *Hospital operating room*. This is a critical environment, often served by a dedicated air-conditioning system.

The design Purpose include:

_Heating, to avoid the patient from becoming too cold.
_Cooling, to prevent the members of the operating team from becoming too hot.
_Control adjustment by the operating team for temperatures between 65°F (Fahrenheit) and 80°F.
_ humidifying, to avoid low humidity
_ Dehumidifying, to minimize any possibility of mold
_ Cleaning the incoming air with very high efficiency filters, to remove any airborne organisms that could infect the patient.
_ Ventilating, to remove airborne contaminants
_ Providing steady air movement from ceiling supply air outlets down over the patient for exhaust near the floor, to minimize contamination of the operating site.

Example 2: *Preserving wood and fiber works of art*. The Purpose in this environment are to minimize any possibility of mold, by keeping the humidity low, and to minimize drying out, by keeping the humidity up. In addition, it is important to minimize the expansion and contraction of specimens that can occur as the moisture content changes.

1.6 Environment for Human Comfort

the variety of factors that influence the comfort of an individual must be highly considered. *Figure 1.1* is a simplified diagram of the three main groups of factors that affect comfort?

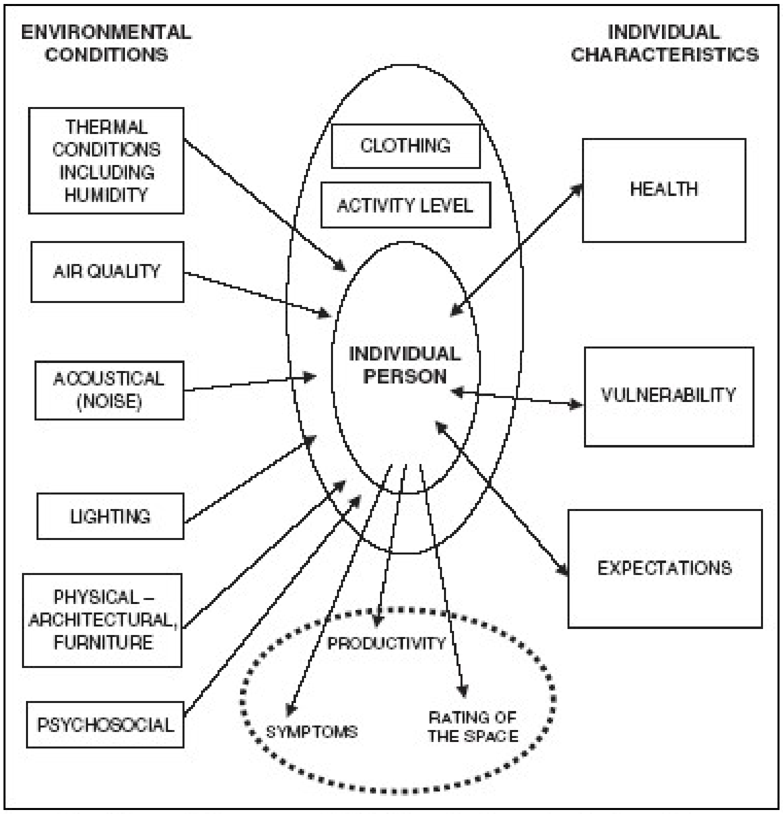


Figure 1.1 Personal Environment Model (adapted with permission from "The construct of comfort: a framework for research" by W.S. Cain[5])

1. ***Thermal conditions*** include the air temperature. Air Speed, air movement, and other conditions

2. ***The air quality*** in a space is affected by pollution from the occupants and other contents of the space. the amount of outside air brought into the space to dilute the Pollutants.

3. ***The acoustical environment*** may be affected by outside traffic noise, other occupants, equipment, and the HVAC system. A designer may have to be very careful to limit the noise according to building's nature and importance.

4. ***The lighting*** influences the HVAC design, since all lights give off heat.

5. ***The physical aspects*** of the space that have an influence on the occupants include both the architectural design aspects of the space, and the interior design.

6. ***The psychosocial*** situation, the interaction between people in the space, is not a design issue.

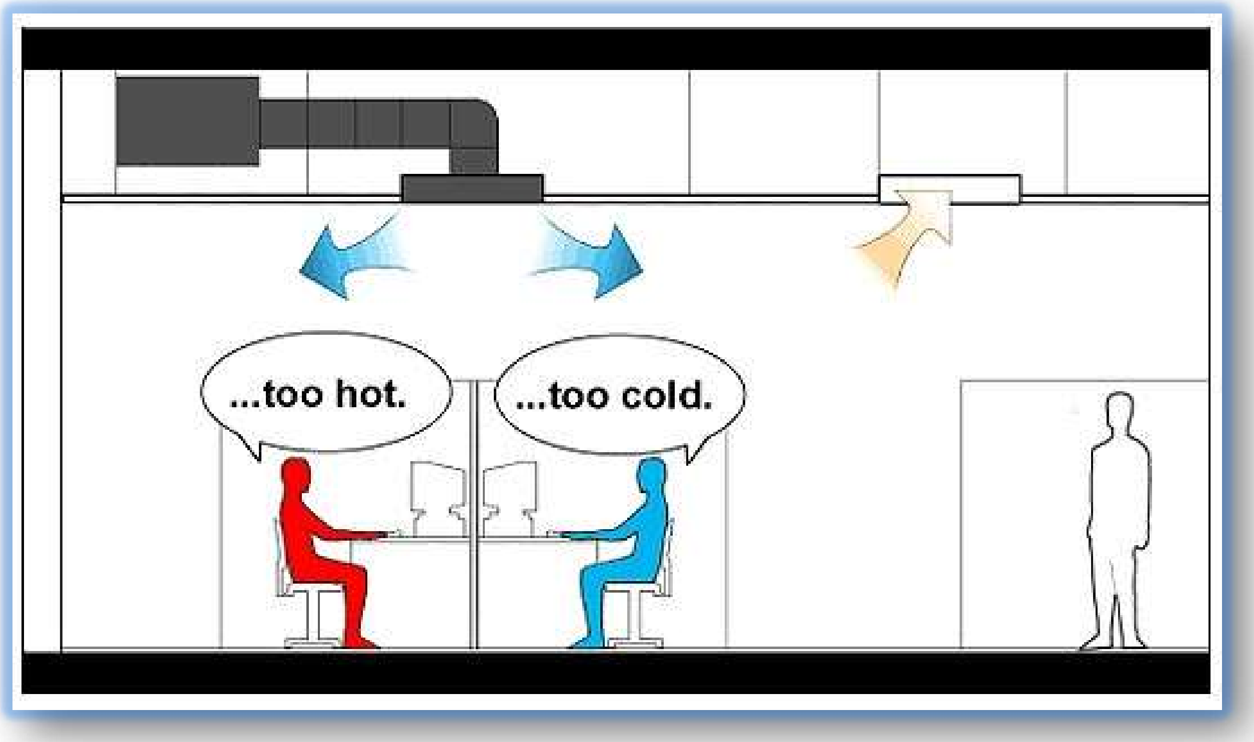
1.6.2 Characteristics of the Individual that Influence Comfort

All people bring with them health, vulnerabilities and expectations

1.6.3 Clothing and Activity as a function of Individual Comfort

The third group of factors influencing comfort is the amount of clothing and the activity level of the individual.

In the summer, in many business offices, managers wear suits with shirts and jackets while staff members may have bare arms, and light clothing. The same space may be thermally comfortable to one group and uncomfortable to the other.



Section 2-Introduction of HVAC Systems

Purpose of this Section:

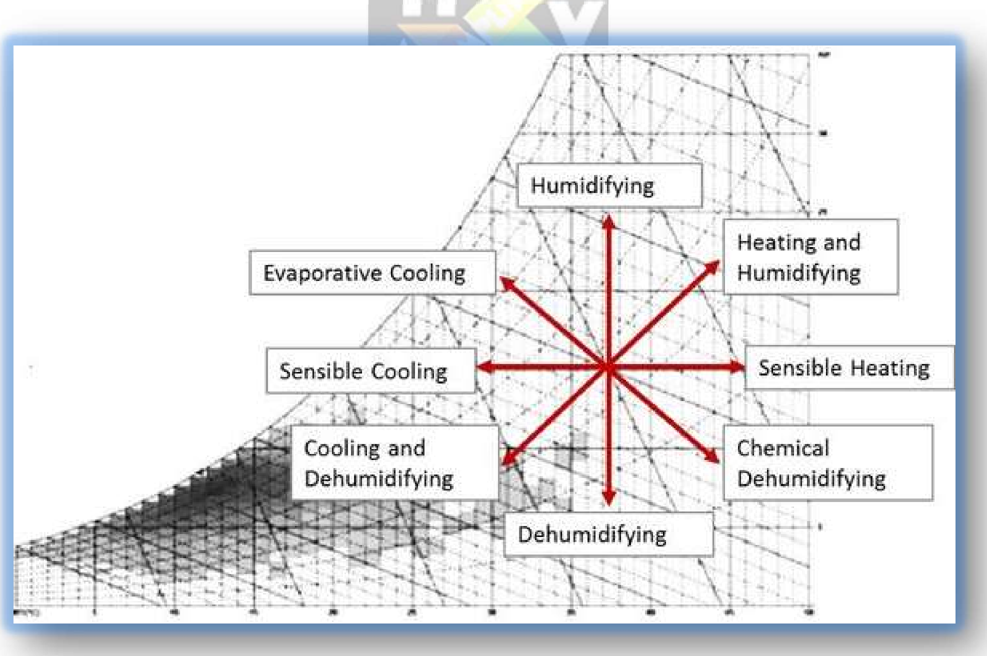
1. Understand and describe the major concepts of the psychrometric chart.
2. Define the main issues to be considered when designing a system.
3. Name the four major system types and explain their differences.
4. Describe the main factors to be considered in a matrix selection process.

2.1 Introduction

In this Section we will consider How the air conditioning processes are described graphically in the psychrometric chart. and How these processes are combined to form an air-conditioning system. The range of heating, ventilating and air-conditioning systems. and How system choices are made.

2.2 Introducing the Psychrometric Chart

The relationships between temperature, moisture content, and energy are most easily understood using a visual aid called the "**psychrometric chart**."
The psychrometric chart is an industry-standard tool that is used to visualize the interrelationships between dry air, moisture and energy.



The Design of the Psychrometric Chart

The psychrometric chart is built upon **Two** simple concepts:
1. Indoor air is a mixture of dry air and water vapor.
2. There is a specific amount of energy in the mixture at a specific temperature and pressure.

Psychrometric Chart Concept 1:

" Indoor Air is a Mixture of Dry Air and Water Vapor"

The quantity of water vapor in air is expressed as "**pounds of water vapor per pound of air**."
This ratio is called the **"humidity ratio,"** abbreviation W and the units are pounds of water/pound of dry air, **lbw/lbda**, often abbreviated to lb/lb. psychrometric charts are printed based on standard pressure at sea level.

-To understand the relationship between water vapor, air and temperature, we will consider **Two** conditions:

First Condition: The temperature is constant, but the quantity of water vapor is increasing. If the temperature remains constant, then, as the quantity of water vapor in the air increases, the humidity increases. However, at every temperature point, there is a maximum amount of water vapor that can co-exist with the air. The point at which this maximum is reached is called the **saturation point**. If more water vapor is added after the saturation point is reached, then an equal amount of water vapor condenses.

Second Condition: The temperature is dropping, but the quantity of water vapor is constant.
If the air is cooled sufficiently, it reaches the **saturation line**. If it is cooled even more, moisture will condense out and dew forms. This temperature, at which the air starts to produce condensation, is called the **dew point temperature**.

Relative Humidity
Figure 2.1 is a plot of the maximum quantity of water vapor per pound of air against air temperature. The X-axis is temperature. The Y-axis is the proportion of water vapor to dry air, measured in pounds of water vapor per pound of dry air.
Saturation line: The curved "maximum water vapor line ,it is also known as **100% relative humidity**, abbreviated to **100% R.H.**

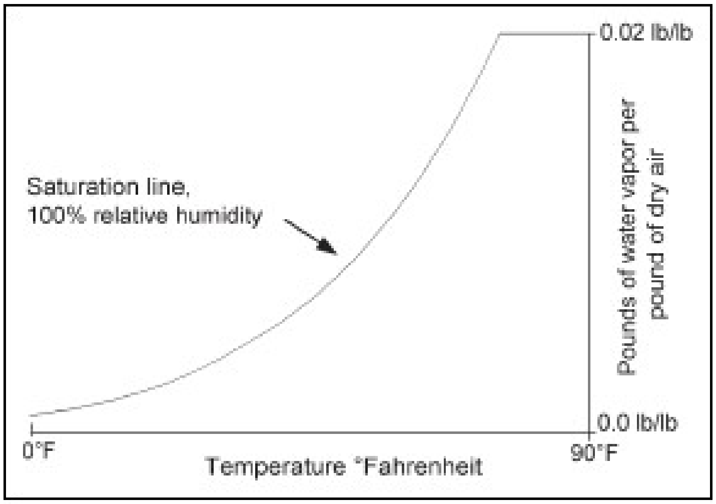


Figure 2.1 Psychrometric Chart – Saturation Line

Psychrometric Chart Concept 2:

There is a specific amount of energy in the air mixture at a specific temperature and pressure.

There is a specific amount of energy in the air water-vapor mixture at a specific temperature. The energy of this mixture is dependent on **Two** measures:
1. The temperature of the air.
2. The proportion of water vapor in the air.

There is more energy in air at higher temperatures. The addition of heat to raise the temperature is called adding "**sensible heat.**" There is also more energy when there is more water vapor in the air. The energy that the water vapor contains is referred to as its "**latent heat.**"

The measure of the total energy of both the sensible heat in the air and the latent heat in the water vapor is commonly called "**enthalpy.**" Enthalpy can be raised by adding energy to the mixture of dry air and water vapor.

This can be accomplished by adding either or both:

- Sensible heat to the air.
- More water vapor, which increases the latent heat of the mixture.

On the psychrometric chart, lines of constant enthalpy slope down from left to right as shown in *Figure* 2.2 and are labeled "Enthalpy." The zero is arbitrarily chosen as zero at 0°F and zero moisture content. The unit measure for enthalpy is **British Thermal Units per pound of dry air**, abbreviated as **Btu/lb**.

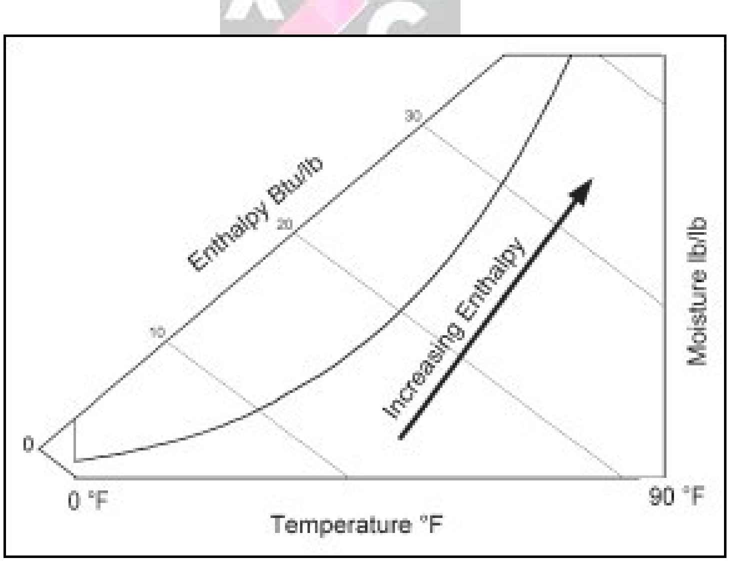


Figure 2.2 Psychrometric Chart – Enthalpy

Heating

The process of heating involves the addition of sensible heat energy. note that the process line is **horizontal** because no water vapor is being added to, or removed from the air, we are just heating the mixture.

Humidification

The addition of water vapor to air is a process called “**humidification.**”
Humidification occurs when water absorbs energy, evaporates into water vapor, and mixes with air. The energy that the water absorbs is called “**latent heat.**”

There are two ways for humidification to occur:

1. Water can be heated. When heat energy is added to the water, the water is transformed to its gaseous state, steam, that mixes into the air. In *Figure 2.6*, the vertical line, from Point 1 to Point 2, shows this process. The heat energy, 3.5 Btu/lb, is put into the water to generate steam (vaporize it), which is then mixed with the air.

In practical steam humidifiers, the added steam is hotter than the air and the piping loses some heat into the air. Therefore, the air is both humidified and heated due to the addition of the water vapor. This combined humidification and heating is shown by the dotted line which slopes a little to the right in *Figure 2.6*.

2. Water can evaporate by spraying a fine mist of water droplets into the air. The fine water droplets absorb heat from the air as they evaporate. In an evaporative humidifier, the evaporating water absorbs heat from the air to provide its latent heat for evaporation. As a result, the air temperature drops as it is humidified. The process occurs with no external addition or removal of heat. It is called an **adiabatic process**. Since there is no change in the heat energy (enthalpy) in the air stream, the addition of moisture, by evaporation, occurs along a line of constant enthalpy.

The process of evaporative cooling can be used very effectively in a hot, dry desert climate to pre-cool the incoming ventilation air.

Cooling and Dehumidification

Cooling is most often achieved in an air-conditioning system by passing the moist air over a cooling coil. As illustrated in *Figure 2.3*, a coil is constructed of a long serpentine pipe through which a cold liquid or gas flows. This cold fluid is either chilled water, typically between 40°F and 45°F, or a refrigerant. The pipe is lined with fins to increase the heat transfer from the air to the cold fluid in the pipe. *Figure 2.3* shows the face of the coil, in the direction of airflow.

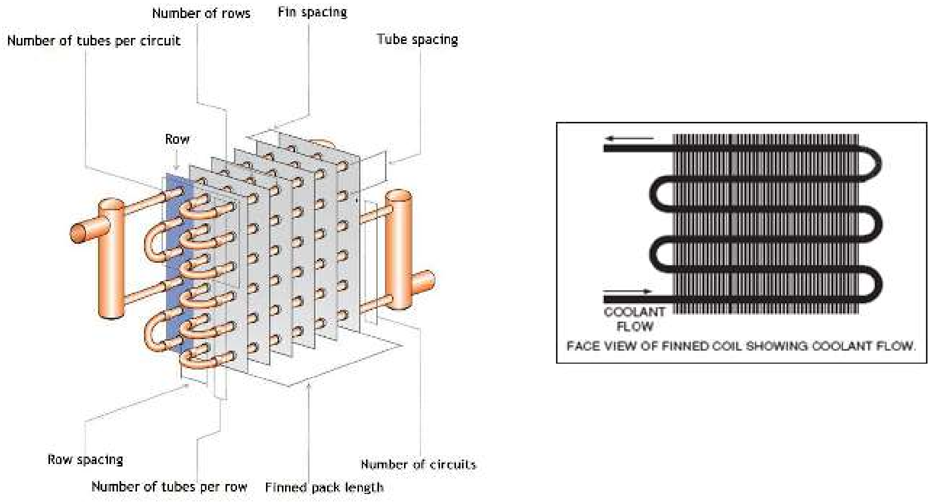


Figure 2.3 Cooling Coil

There are two results. First, the cooling coil cools the air as the air passes over the coils. Second, because the cooling fluid in the coil is usually well below the saturation temperature of the air, moisture condenses on the coil, and drips off, to drain away. This process reduces the enthalpy, or heat, of the air mixture and increases the enthalpy of the chilled water or refrigerant. In another part of the system, this added heat must be removed from the chilled water or refrigerant to recool it for reuse in the cooling coil.

The amount of moisture that is removed depends on several factors including:

1. The temperature of the cooling fluid
2. The depth of the coil
3. Whether the fins are flat or embossed
4. The air velocity across the coil.

2.3 Basic Air-Conditioning System

Figure 2.4 shows the schematic diagram of an air-conditioning plant. The majority of the air is drawn from the space, mixed with outside ventilation air and then conditioned before being blown back into the space.
The ratio of outside ventilation air to return air typically varies from 15 to 25% of outside air. There are, however, systems which provide 100% outside air with zero recirculation.

The components, from left to right, are:
Outside Air Damper: which closes off the outside air intake when the system is switched off.

Mixing chamber: where return air from the space is mixed with the outside ventilation air.

Filter: which cleans the air by removing solid airborne contaminants (dirt).

Heating coil: which raises the air temperature to the required supply temperature.
Cooling coil: which provides cooling and dehumidification.

Humidifier: which adds moisture, and which is usually controlled by a **humidistat**

Fan: to draw the air through the resistance of the system and blow it into the space.

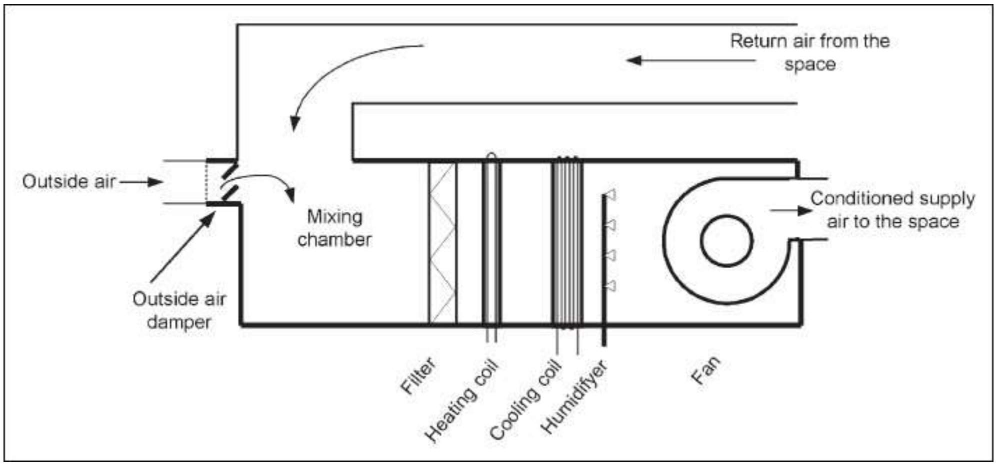


Figure 2.4 Air-Conditioning Plant

Economizer Cycle

In many climates there are substantial periods of time when cooling is required and the return air from the space is warmer and moister than the outside air. During these periods, you can reduce the cooling load on the cooling coil by bringing in more outside air than that required for ventilation. This can be accomplished by expanding the design of the basic air-conditioning system to include an **economizer**. The economizer consists of three (or four) additional components as shown in *Figure 2.5.*

Expanded air intake and damper: sized for 100% system flow.

Relief air outlet with automatic damper: to exhaust excess air to outside.

Return air damper: to adjust the flow of return air into the mixing chamber.

Return fan in the return air duct (Optional): The return fan is often added on economizer systems

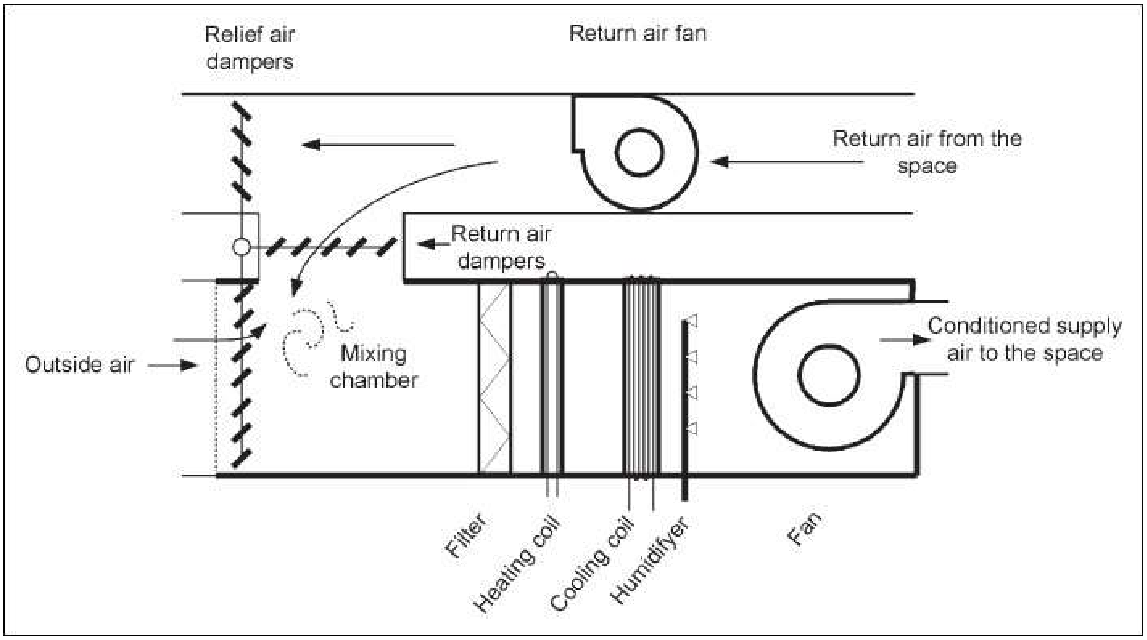


Figure 2.5 Air-Conditioning Plant with Economizer Cycle

2.4 Zoned Air-Conditioning Systems

When a system is designed to provide independent control in different spaces, each space is called a "**zone**." A zone may be a separate room. A zone may also be part of a large space. For example, a theatre stage may be a zone, while the audience seating area is a second zone in the same big space this need for zoning leads us to the four broad categories of air-conditioning systems, and consideration of how each can provide zoned cooling and heating.

The four systems are:

1. All-air systems
2. Air-and-water systems
3. All-water systems
4. Unitary, refrigeration-based systems

System 1: All-air Systems

All-air systems provide air conditioning by using a tempered flow of air to the spaces. These all-air systems need substantial space for ducting the air to each zone.

Q (Btu) =Constant * mass flow* temperature difference

$Q\ (\text{Btu}) = \text{Constant} * \text{cfm} * ({}^{\circ}\text{F}_{\text{zone}} - {}^{\circ}\text{F}_{\text{Supply air}})$

To change the heating or cooling capacity of the air supply to one zone, the system must either alter the supply temperature, °F, or alter the flow, cfm, to that zone.

Reheat system: The simplest, and least energy efficient system, is the constant volume reheat system. *(not used anymore)*

Variable Air Volume (VAV) System: *Figure* 2.6 illustrates another zoned system, called a Variable Air Volume system, VAV system, because it varies the volume of air supplied to each zone.
Variable Air Volume systems are more energy efficient than the reheat systems. *(VAV is widely used)*

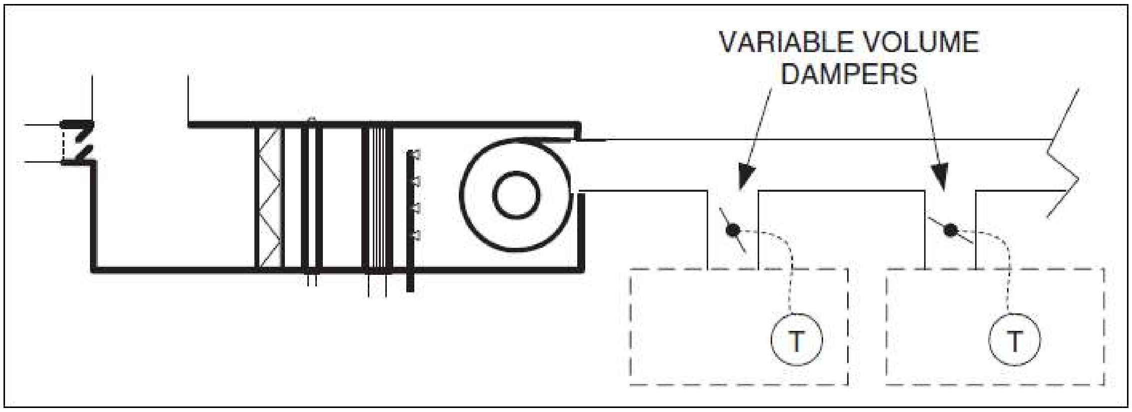


Figure 2.6 Variable Air Volume (VAV) System

System 2: Air-and-water Systems

Another group of systems, air-and-water systems, provide all the primary ventilation air from a central system, but local units provide additional conditioning.

The primary ventilation system also provides most, or all, of the humidity control by conditioning the ventilation air. The local units are usually supplied with hot or chilled water. These systems are particularly effective in perimeter spaces.

System 3: All-water Systems

When the ventilation is provided through natural ventilation, by opening windows, or other means, there is no need to duct ventilation air to the zones from a central plant. This allows all processes other than ventilation to be provided by local equipment supplied with hot and chilled water from a central plant. These systems are grouped under the name "**all-water systems**."

System 4: Unitary, Refrigerant-based Systems

The final type of system uses local refrigeration equipment and heaters to provide air conditioning. They are called "**unitary refrigerant–based systems**" The window air-conditioner is the simplest example of this type of system.

2.5 Choosing an Air-Conditioning System

Each of the four general types of air-conditioning systems has numerous variations, so choosing a system is not a simple task. The factors that influence system choice are:

1. Building design
2. Location issues
3. Utilities: availability and cost
4. Indoor requirements and loads
5. Client issues

Building Design

The design of the building has a major influence on system choice.

Location Issues

The building location determines the weather conditions that will affect the building and its occupants. For the specific location we will need to consider factors like:

peak summer cooling conditions-summer humidity-peak winter heating conditions-wind speeds-sunshine hours-typical snow accumulation depths

Utilities: Availability and Cost

The choice of system can be heavily influenced by available utilities and their costs to supply and use. The cost of electricity may be very high at peak periods, encouraging the design of an electrically-efficient system with low peak-demand for electricity.

Indoor Requirements and Loads

The location effects and indoor requirements provide all the necessary information for load calculation for the systems.

The thermal and moisture loads: Occupants' requirements and heat output from lighting and equipment affect the demands on the air-conditioning system.

Outside ventilation air: The occupants and other polluting sources, such as cooking, will determine the requirements.

Zoning: The indoor arrangement of spaces and uses will determine if, and how, the system is to be zoned.

Client Issues

Buildings cost money to construct and to use. Therefore, the designer has to consider the clients' requirements both for construction and for in-use costs. For example, the available construction finances may dictate a very simple system.

Alternatively, the client may wish to finance a very sophisticated, and more expensive system to achieve superior performance, or to reduce in-use costs.

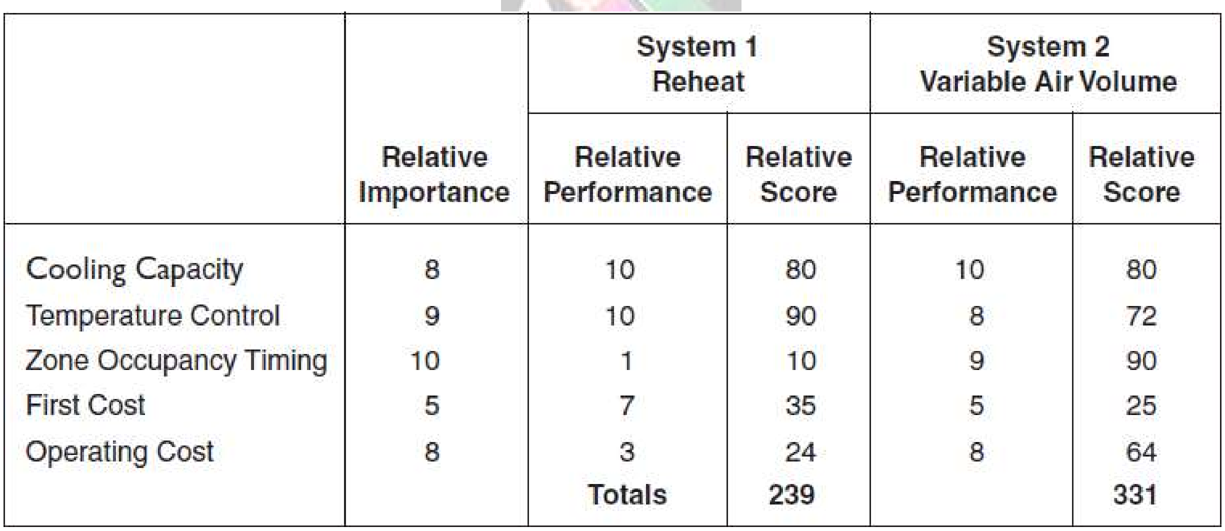
System Choice

While all the above factors are considered when choosing a system, the first step in making a choice is to calculate the system loads and establish the number and size of the zones. Understanding of the loads may eliminate some systems from consideration. For example, in warm climates where heating is not required only systems providing cooling need be considered.

2.6 System Choice Matrix

The matrix method of system choice consists of a list of relevant factors that affect system choice and a tabular method of comparing the systems under consideration.

Figure 2.7 provides an illustration of the matrix method of choosing a system.



		System 1 Reheat		System 2 Variable Air Volume	
	Relative Importance	Relative Performance	Relative Score	Relative Performance	Relative Score
Cooling Capacity	8	10	80	10	80
Temperature Control	9	10	90	8	72
Zone Occupancy Timing	10	1	10	9	90
First Cost	5	7	35	5	25
Operating Cost	8	3	24	8	64
		Totals	239		331

Figure 2.7 Matrix for Systems Choice

Section 3 - Thermal Comfort

Purpose of this Section:

1. List seven factors influencing thermal comfort.
2. Explain why thermal comfort depends on the individual as well as the thermal conditions.
3. Choose acceptable thermal design conditions.

3.1 Introduction: What is Thermal Comfort?

Thermal comfort is primarily controlled by a building's heating, ventilating and air-conditioning systems, though the architectural design of the building may also have significant influences on thermal comfort.

Standard 55 defines thermal comfort as *"that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation."*

3.2 Seven Factors Influencing Thermal Comfort

The *Seven* factors that affect thermal comfort are:

Personal

1. Activity level

2. Clothing

Individual Characteristics

3. Expectation

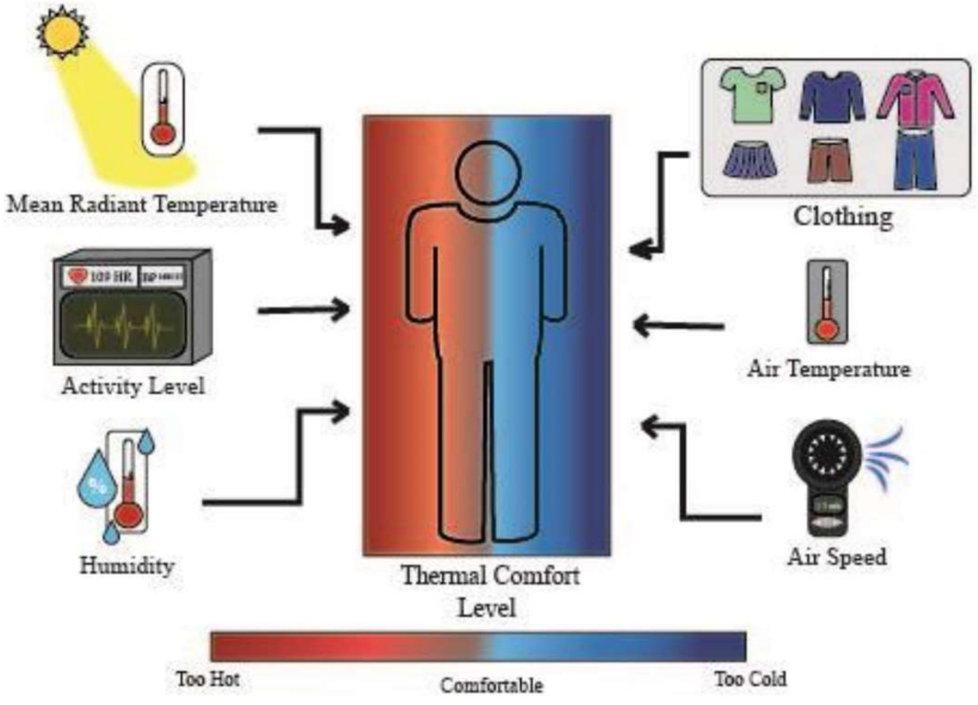
Environmental Conditions and Architectural Effects

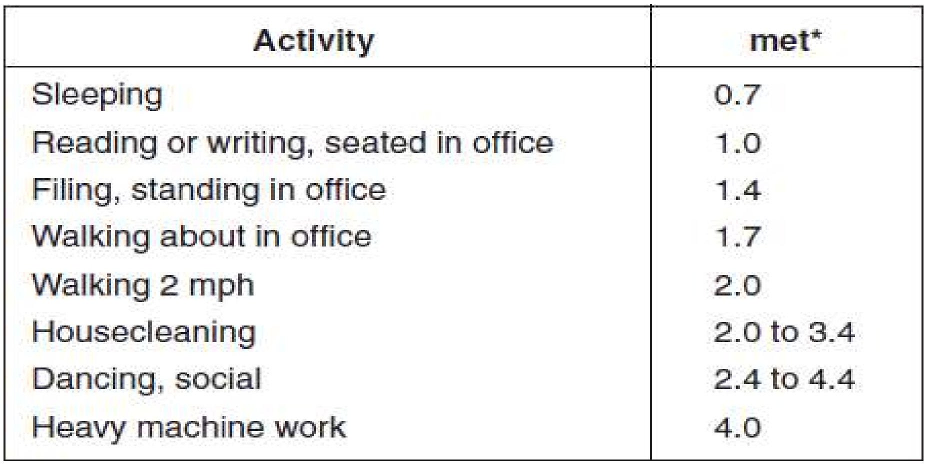
4. Air temperature

5. Radiant temperature

6. Humidity

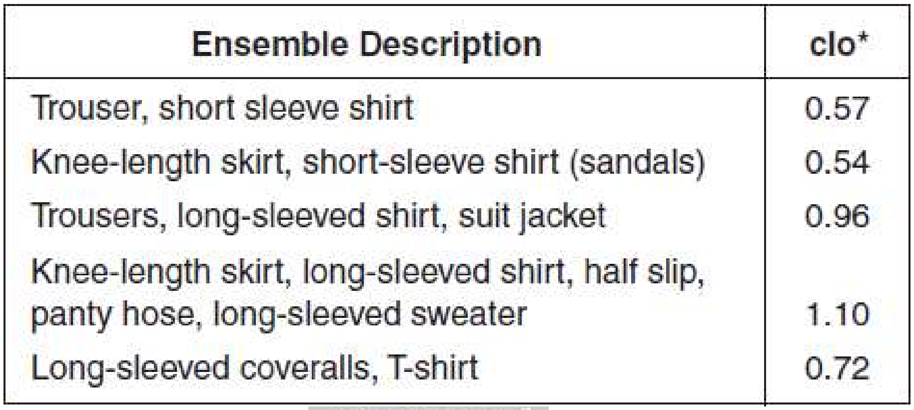
7. Air speed





Activity	met*
Sleeping	0.7
Reading or writing, seated in office	1.0
Filing, standing in office	1.4
Walking about in office	1.7
Walking 2 mph	2.0
Housecleaning	2.0 to 3.4
Dancing, social	2.4 to 4.4
Heavy machine work	4.0

Figure 3.1 Typical Metabolic Heat Generation for Various Activities



Ensemble Description	clo*
Trouser, short sleeve shirt	0.57
Knee-length skirt, short-sleeve shirt (sandals)	0.54
Trousers, long-sleeved shirt, suit jacket	0.96
Knee-length skirt, long-sleeved shirt, half slip, panty hose, long-sleeved sweater	1.10
Long-sleeved coveralls, T-shirt	0.72

Figure 3.2 Typical Insulation Values for Clothing Ensembles

3.3 Conditions for Comfort

Standard 55 deals with indoor thermal comfort in normal living environments and office-type environments, it does not deal with occupancy periods of less than 15 minutes.

When considering issues of comfort, the Standard addresses two situations:

1. **Buildings with occupant-operable windows**
2. **Buildings with mechanically conditioned spaces**

3.4 Managing Under Less Than Ideal Conditions

1. ***Elevated Air Speed***
   Increasing the air speed over the body causes increased cooling. Elevated air speed can be used to advantage to offset excessive space temperatures.

2. ***Draft***
   Draft discomfort depends on air temperature, velocity and turbulence. In general, the steadier the draft the less the discomfort

3. ***Vertical Temperature Difference***
   Vertical temperature difference between feet and head typically occurs in heated buildings. Warm air is less dense and tends to rise. Therefore, a warm air supply tends to rise, leaving the lower portion of the space cooler.

4. ***Floor Surface Temperatures***
   Floor surface temperatures should be within the range 66–84°F for people wearing shoes and not sitting on the floor.

5. ***Cyclic Temperature Changes***
   In a space that is controlled by an on/off thermostat that reacts slowly to temperature change, the space can experience a significant temperature range in a short time. The occupants can perceive this variation as discomfort.

6. ***Radiant Temperature Variation***
   Radiant temperature variation is acceptable, within limits. People are generally quite accepting of a warm wall, but warm ceilings are a source of discomfort if the ceiling radiant temperature is more than 9°F above the genera radiant temperature.

In any room, whether private, public or professional, the temperature (heat / freshness) is a key element to consider the room as being comfortable. The perception of this thermal comfort depends on three types of factors which are:

- The temperature felt as it is “felt” by the person, evaluated by taking the average between the ambient air temperature and the temperature of the walls.

- Elements related to the air and more precisely its moisture content and whether or not there are drafts,

- The elements related to the person: how she is dressed (warmly or not) and her level of activity or passivity during her stay in the room.

Section 4- Ventilation and Indoor Air Quality

Purpose of this Section:

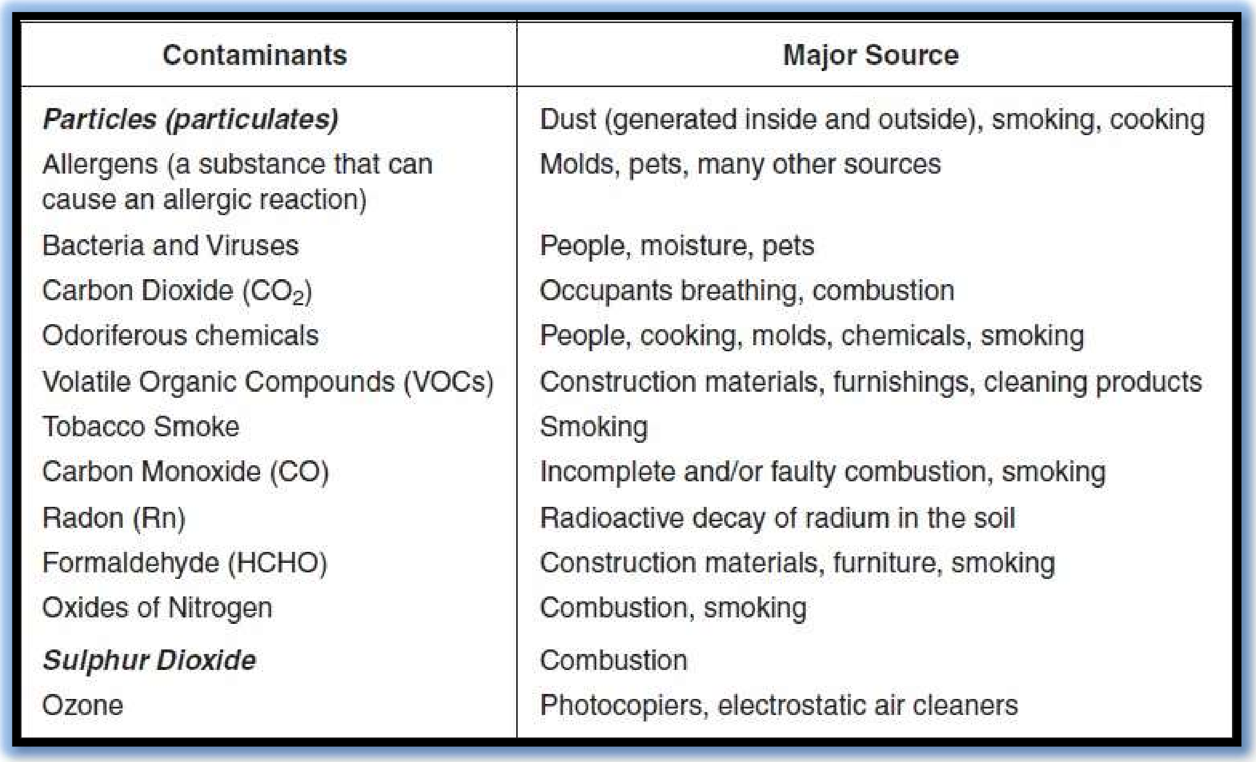
1. List, and give examples of the four types of indoor air contaminants
2. Describe the three methods of maintaining indoor air quality
3. Understand the criteria for filter selection
4. Understand the main concepts of the ASHRAE Standard 62.1-2004

4.1 Introduction

In this Section, we will be discussing an important factor which is Indoor Air Quality, IAQ. The maintenance of indoor air quality (IAQ) is one of the major Purpose of air-conditioning systems because IAQ problems are a significant threat to health and productivity.

4.2 Air Pollutants and Contaminants

Air pollutants and contaminants are unwanted airborne constituents that may reduce the acceptability of air. The number and variety of contaminants in the air is enormous. Some contaminants are brought into the conditioned space from outside, and some are generated within the space itself. *Figure 4.1* lists some of the most common indoor air contaminants and their most common sources.



Contaminants	Major Source
Particles (particulates)	Dust (generated inside and outside), smoking, cooking
Allergens (a substance that can cause an allergic reaction)	Molds, pets, many other sources
Bacteria and Viruses	People, moisture, pets
Carbon Dioxide (CO_2)	Occupants breathing, combustion
Odoriferous chemicals	People, cooking, molds, chemicals, smoking
Volatile Organic Compounds (VOCs)	Construction materials, furnishings, cleaning products
Tobacco Smoke	Smoking
Carbon Monoxide (CO)	Incomplete and/or faulty combustion, smoking
Radon (Rn)	Radioactive decay of radium in the soil
Formaldehyde (HCHO)	Construction materials, furniture, smoking
Oxides of Nitrogen	Combustion, smoking
Sulphur Dioxide	Combustion
Ozone	Photocopiers, electrostatic air cleaners

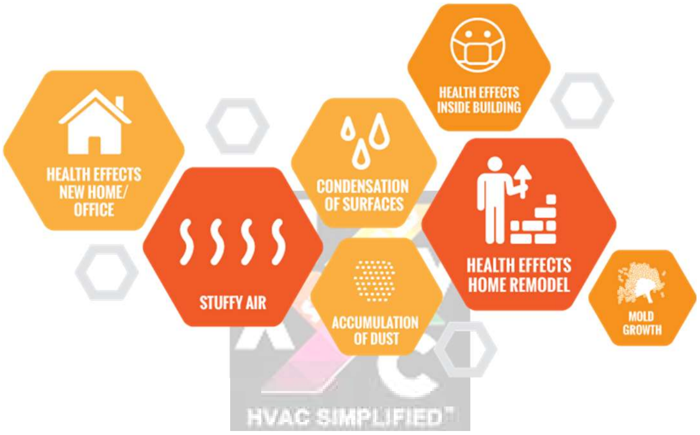
Figure 4.1 Common Air Contaminants

4.3 Indoor Air Quality Effects on Health and Comfort

The HVAC designer and building operator may take different approaches to contaminants that can be detrimental to health and those that are merely annoying. Although it is the annoying aspects that will draw immediate attention from the occupants, it is the health affecting contaminants that are of the utmost short- and long-term importance.

It is useful to think of contaminants in terms of the following classes of effect:

1. ***Fatal in the short term:*** (These include airborne chemical substances, such as carbon monoxide, or disease-causing bacteria and other biological contaminants. Legionella)
2. ***Carcinogenic*** *(cancer causing substances)*
3. ***Health threatening*** (such as allergens, volatile organic compounds, bacteria, viruses, mold spores, ozone and particulates)
4. ***Annoying, with an impact on productivity and sense of well-being***



4.4 Controlling Indoor Air Quality

Maintaining acceptable IAQ depends on the judicious use of three methods:

1. Source control
2. Filtration
3. Dilution

4.4.1 Source Control

The most important method of maintaining acceptable indoor air quality is by controlling sources of contaminants and pollutants. Sources can be controlled by restricting their access to the space, either by design or by appropriate maintenance procedures, and by exhausting pollutants that are generated within the space

4.4.2 Filtration

Filtration is the removal of contaminants from the air. Both particulate (particles of all sizes) and gaseous contaminants can be removed, Particulate filters work by having the particles trapped by, or adhere to, the filter medium. The actual performance of a filter depends on several factors, including particle size, air velocity through the filter medium, filter material and density, and dirt buildup on the filter The *Figure 4.2* shows a sample of particles and their range of size.

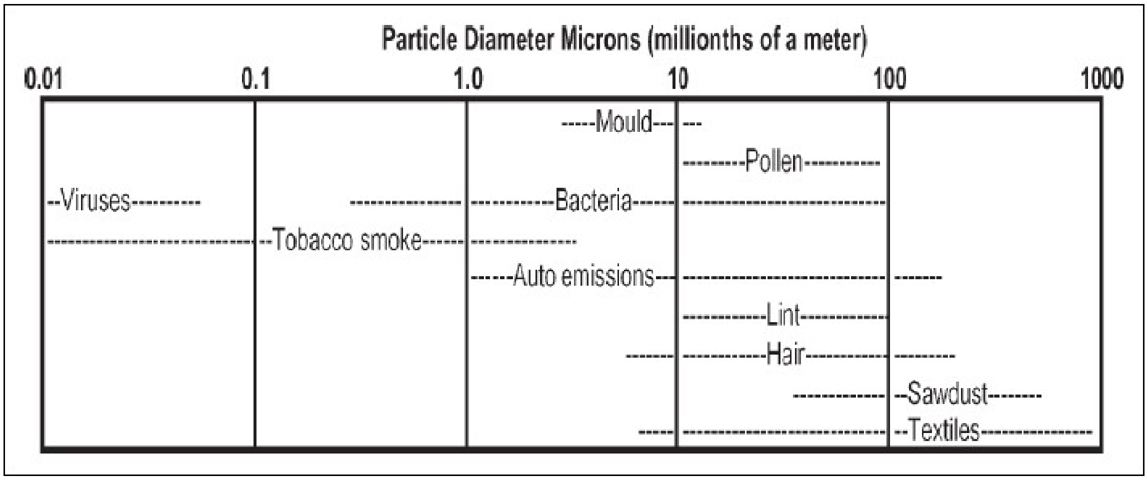
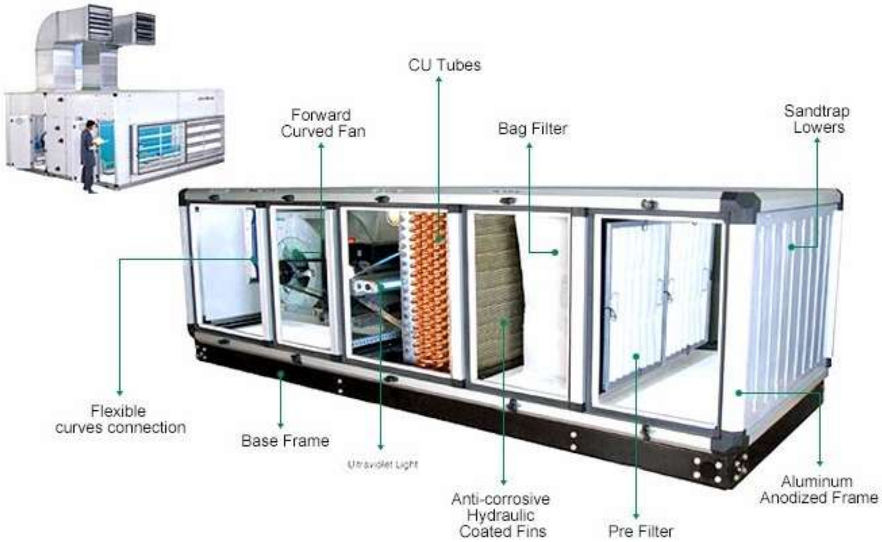


Figure 4.2 Particle Diameter, Microns (millionths of a meter)

a new standard was introduced, ASHRAE 52.2-1999 *Method for Testing General Ventilation Air- Cleaning Devices for the Removal Efficiency by Particle Size*5. It is based on using a particle counter to count the number of particles in twelve different size fractions. This data is used to classify a filter into one of 20 "Minimum Efficiency Reporting Values" called MERV. The least efficient filter is MERV 1 and the most efficient, MERV 20. *Figure 4.3* shows typical filters with their range of performance and typical applications.



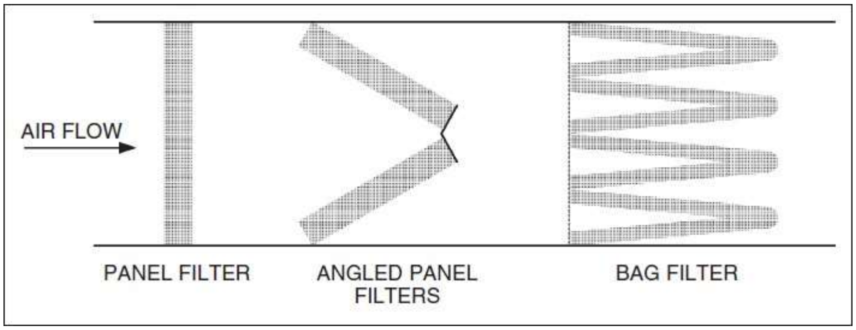
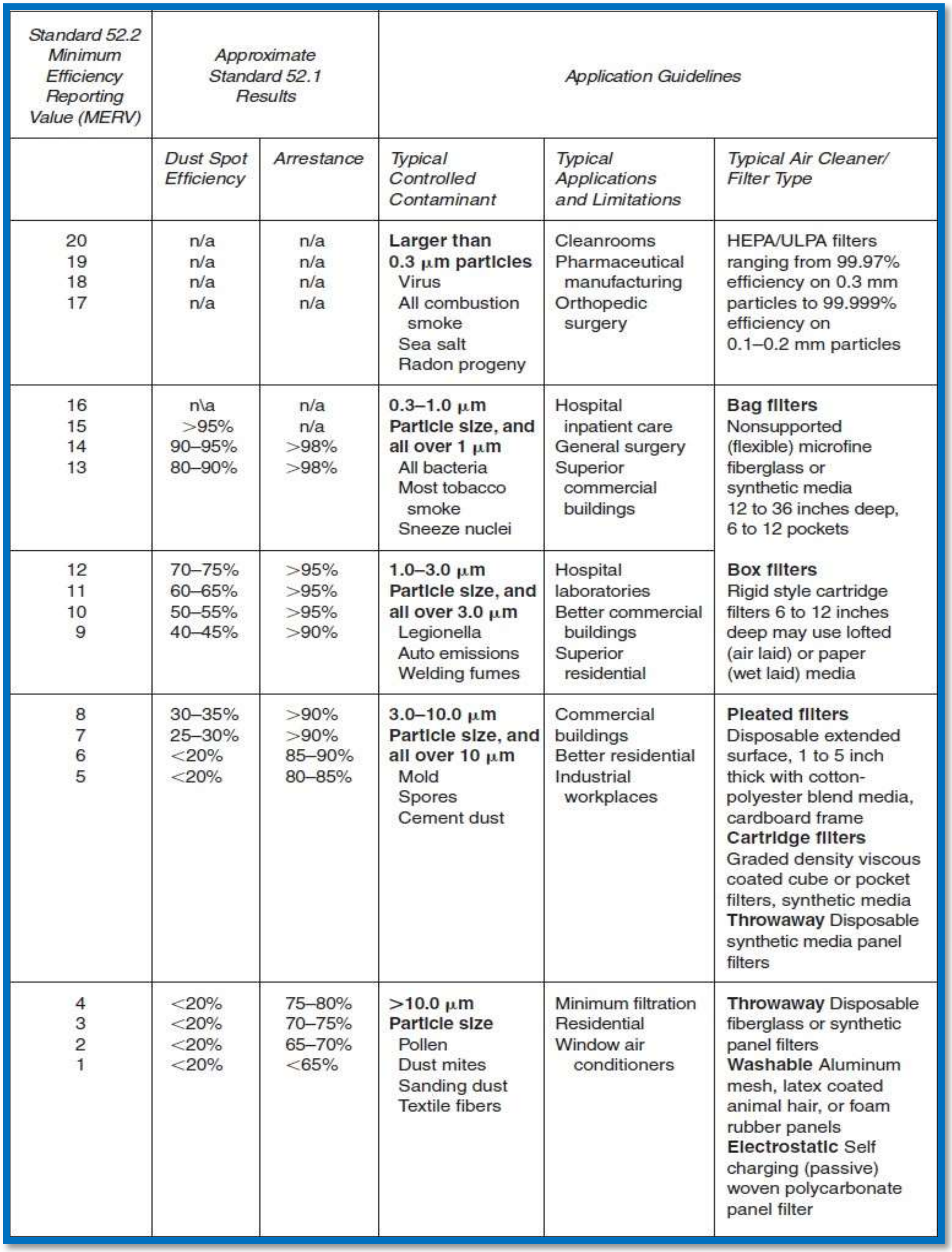


Figure 4.3 Basic Filter Media Filter Arrangements



Standard 52.2 Minimum Efficiency Reporting Value (MERV)	*Approximate Standard 52.1 Results*		*Application Guidelines*		
	Dust Spot Efficiency	*Arrestance*	*Typical Controlled Contaminant*	*Typical Applications and Limitations*	*Typical Air Cleaner/ Filter Type*
20 19 18 17	n/a n/a n/a n/a	n/a n/a n/a n/a	**Larger than 0.3 µm particles** Virus All combustion smoke Sea salt Radon progeny	Cleanrooms Pharmaceutical manufacturing Orthopedic surgery	HEPA/ULPA filters ranging from 99.97% efficiency on 0.3 mm particles to 99.999% efficiency on 0.1–0.2 mm particles
16 15 14 13	n\a >95% 90–95% 80–90%	n/a n/a >98% >98%	**0.3–1.0 µm Particle size, and all over 1 µm** All bacteria Most tobacco smoke Sneeze nuclei	Hospital inpatient care General surgery Superior commercial buildings	**Bag filters** Nonsupported (flexible) microfine fiberglass or synthetic media 12 to 36 inches deep, 6 to 12 pockets **Box filters** Rigid style cartridge filters 6 to 12 inches deep may use lofted (air laid) or paper (wet laid) media
12 11 10 9	70–75% 60–65% 50–55% 40–45%	>95% >95% >95% >90%	**1.0–3.0 µm Particle size, and all over 3.0 µm** Legionella Auto emissions Welding fumes	Hospital laboratories Better commercial buildings Superior residential	
8 7 6 5	30–35% 25–30% <20% <20%	>90% >90% 85–90% 80–85%	**3.0–10.0 µm Particle size, and all over 10 µm** Mold Spores Cement dust	Commercial buildings Better residential Industrial workplaces	**Pleated filters** Disposable extended surface, 1 to 5 inch thick with cotton-polyester blend media, cardboard frame **Cartridge filters** Graded density viscous coated cube or pocket filters, synthetic media **Throwaway** Disposable synthetic media panel filters
4 3 2 1	<20% <20% <20% <20%	75–80% 70–75% 65–70% <65%	**>10.0 µm Particle size** Pollen Dust mites Sanding dust Textile fibers	Minimum filtration Residential Window air conditioners	**Throwaway** Disposable fiberglass or synthetic panel filters **Washable** Aluminum mesh, latex coated animal hair, or foam rubber panels **Electrostatic** Self charging (passive) woven polycarbonate panel filter

Figure 4.4 Filter Test Performance and Applications

Filter Characteristics

Let us return to the three main filter characteristics:

1. Efficiency in removing dust particles of varying sizes
2. Resistance to airflow
3. Dust-holding capacity

4.4.3 Dilution

In most places the outside air is relatively free of pollutants, other than large dust particles, birds, and insects. When this air is brought into a space, through a screen and filter to remove the coarse contaminants, it can be used to dilute any contaminants in the space. We also need a small supply of outside air to provide us with oxygen to breathe and to dilute the carbon dioxide we exhale.

4.5 The Use of Carbon Dioxide to Control Ventilation Rate

All versions of the Standard allow for reduced ventilation when the population density is known to be lower. For example, the ventilation for a movie theatre must be sized for full occupancy, although the theatre may often be less than half-full. In these "less-than-full" times it would save energy if we could reduce the ventilation rate to match the actual population. In the versions of Standard 62 that preceded 2004, the ventilation rates were based on cfm/person. As a result, the ventilation could be adjusted based on the number of people present.

Conveniently for the purposes of measurement, people inhale air that contains oxygen and exhale a little less oxygen and some carbon dioxide.

The amount of carbon dioxide, CO2, that is exhaled is proportional to a person's activity: more CO2 is exhaled the more active the person. This exhaled CO2 can be measured and used to assess the number of people present.

In our movie theatre, the people (assume adults) are all seated and the metabolic rate is about 1.2 met. At 1.2 met, the average CO2 exhaled by adults is 0.011 cfm. At the same time as the people are exhaling CO2, the ventilation air is bringing in outside air with a low level of CO2

This process can be expressed in the formula: VCspace
= N + VCoutside (*Equation 4-1*)
where V = volume of outside air, cfm, entering the space
Coutside = concentration, ft^3/ft^3, of CO2 in outside air
N =volume of CO2 produced by a person, cfm Cspace=
concentration, ft^3/ft^3, of CO_2 in exhaust air

For the movie theatre example (the same as the hotel assembly-room) the required ventilation rate is 15 cfm per person. Inserting the values for V and N produces:
VCspace = N + VCoutside
15 cfm . Cspace =0.011 cfm + 15 cfm. Coutside 15
cfm .Cspace -15 cfm . Coutside = 0.011 cfm
(15 cfm . Cspace - 15 cfm . Coutside)/15 cfm =0.011 cfm/15 cfm Coutside -
Cspace =0.011/15 (ft^3/ft^3)
Coutside - Cspace = 0.000733 (ft^3/ft^3)

This is about 700 parts per million of CO2 in the exhaust air Note that this calculation is based on the ventilation for one person and the CO2 produced by one person. The result is the same, regardless of how many people are in the space, since everything is proportional.

In our theatre, we can install a CO2 sensor to measure the CO2 level, and connect it to a controller to open the outside air dampers to maintain the CO2 level at no higher than 1000 ppm. In this way the outside air provided matches the requirements of the people present. If the outside CO2 concentration is above 300 ppm, then our controller, set at 1000 ppm, will cause over-ventilation rather than under-ventilation.in this process CO2 is used as a **surrogate** indicator for the number of people present.

This calculation assumes a perfect world. As we all know, this is a false assumption. The main assumptions are:

1-**Perfect mixing**. Mixing is usually quite good but some ventilation air may not reach the occupied space.

2-**Steady state.** It will take from 15 minutes to several hours for the CO2 concentration to become really steady. The length of time depends on the volume of space per person. In densely populated spaces, steady state can be reached quite quickly, but in low population density areas, it can take hours.

3-**An even distribution of people in the space**. If people are clumped together then the level will be higher in their area and lower in the less densely occupied parts of the space

Section 5 - Zones

Purpose of this Section:

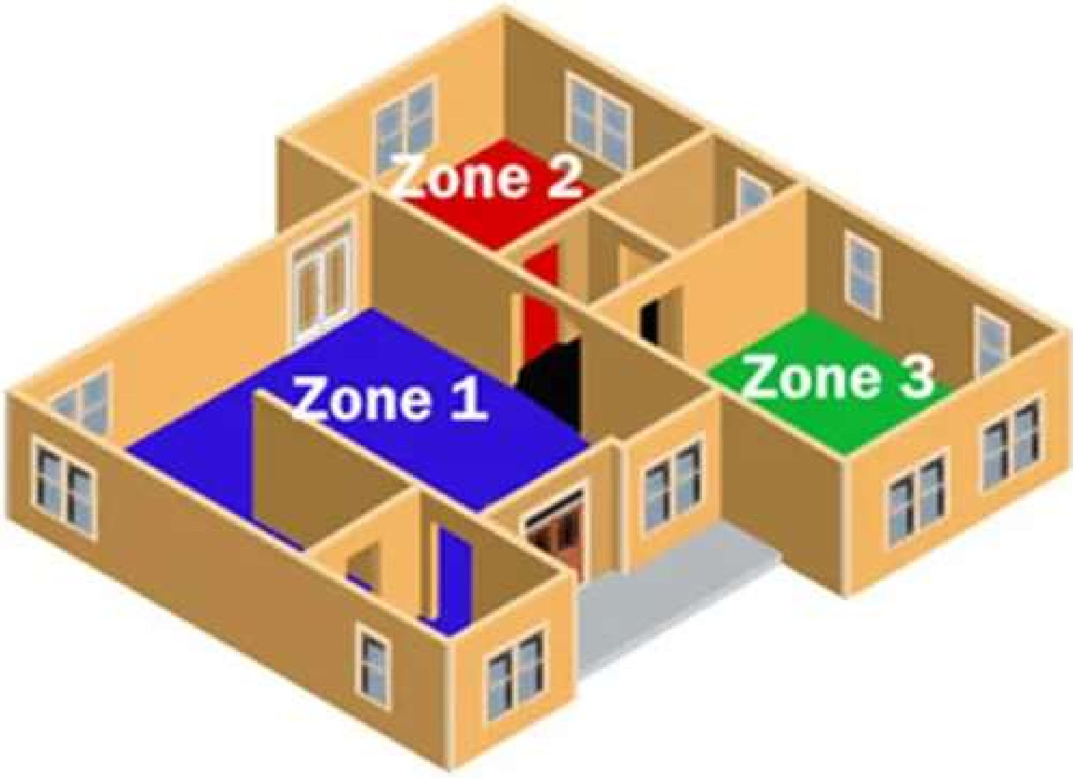
1. Define a space and give examples of spaces.
2. Define a zone and give examples of zones.
3. List a number of reasons for zoning a building and give examples of the reasons.
4. Make logical choices about where to locate a thermostat.

5.1 Introduction

In order to maximize thermal comfort, systems can be designed to provide independent control in the different spaces, based on their users and requirements.

Each space or group of spaces that has an independent control is called a "**zone**."

In this Section, we consider what constitutes a zone, the factors that influence zone choices, and the issues concerning location of the zone thermostat.

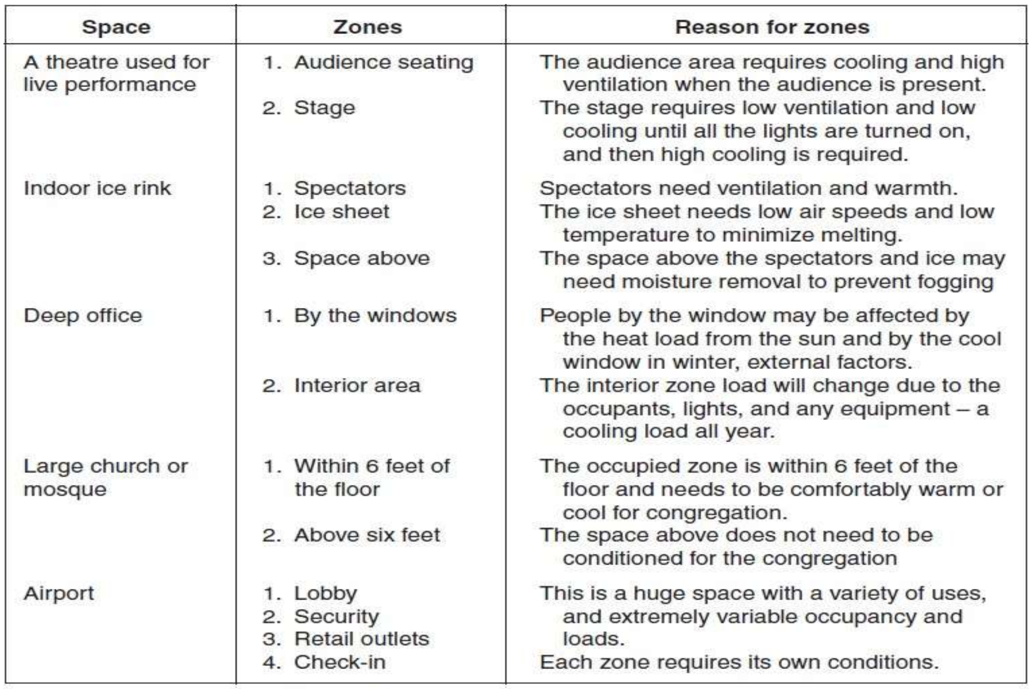


5.2 What is a Zone?

"**Space**" is a part of a building that is not necessarily separated by walls and floors. A space can be large, like an aircraft hanger, or small, like a personal office.

A "**zone**" is a part of a building whose HVAC system is controlled by a single sensor. The single sensor is usually, but not always, a thermostat.

Some examples of spaces and zones are shown in ***Figure 5.1.***



Space	Zones	Reason for zones
A theatre used for live performance	1. Audience seating	The audience area requires cooling and high ventilation when the audience is present.
	2. Stage	The stage requires low ventilation and low cooling until all the lights are turned on, and then high cooling is required.
Indoor ice rink	1. Spectators	Spectators need ventilation and warmth.
	2. Ice sheet	The ice sheet needs low air speeds and low temperature to minimize melting.
	3. Space above	The space above the spectators and ice may need moisture removal to prevent fogging
Deep office	1. By the windows	People by the window may be affected by the heat load from the sun and by the cool window in winter, external factors.
	2. Interior area	The interior zone load will change due to the occupants, lights, and any equipment – a cooling load all year.
Large church or mosque	1. Within 6 feet of the floor	The occupied zone is within 6 feet of the floor and needs to be comfortably warm or cool for congregation.
	2. Above six feet	The space above does not need to be conditioned for the congregation
Airport	1. Lobby 2. Security 3. Retail outlets 4. Check-in	This is a huge space with a variety of uses, and extremely variable occupancy and loads. Each zone requires its own conditions.

Figure 5.1 Examples of Spaces and Zones

5.3 Zoning Design

There are several types of zones. These zones are differentiated based on what is to be controlled, the most common control parameters are: thermal (temperature), humidity, ventilation, operating periods, freeze protection, pressure and importance.

The most common reason for needing zones is variation in thermal loads.

Consider the simple building floor plan shown in *Figure 5.2*. Let us assume it has the following characteristics:

- Well-insulated
- A multi-story building, identical plan on every floor
- Provided with significant areas of window for all exterior spaces
- Low loads due to people and equipment in all spaces
- Located in the northern hemisphere

we will first consider the perimeter zone requirements on intermediate floors due to changes in thermal loads. These changes can occur because of the movement of the sun around the building during the course of a sunny day.

The designer's objective is to use zones to keep all spaces at the set-point temperature. The **set- point temperature** is the temperature that the thermostat is set to maintain.

Early in the morning, the sun rises in the east. It shines on the easterly walls and through the east windows into spaces NE and SE. Relative to the rest of the building, these spaces, NE and SE, need more cooling to stay at the set-point temperature.

As the morning progresses towards midday, the sun moves around to the south so that the SE, S and

SW spaces receive solar gain. However, the solar heat load for the NE space has dropped, since the sun has moved around the building.

As the afternoon progresses, the sun moves around to the west to provide solar gain to spaces SW and NW.

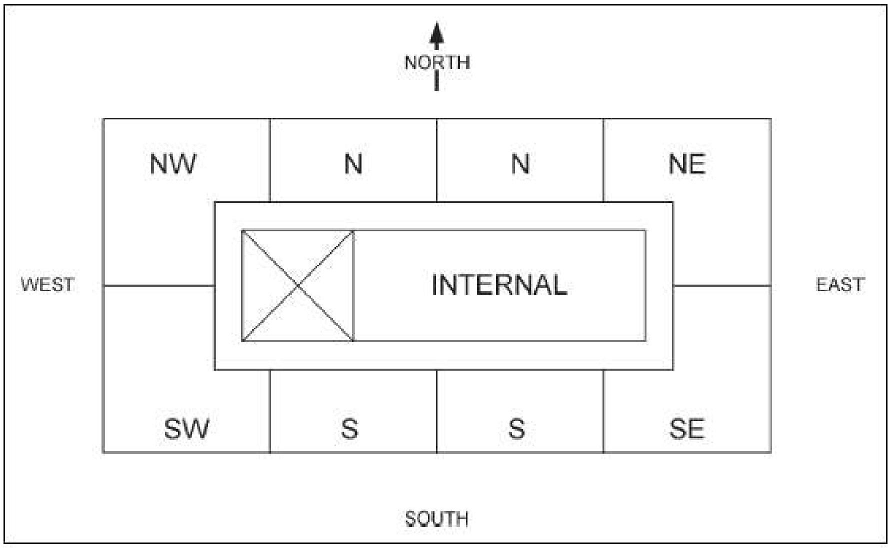


Figure 5.2 Building Plan

Zoning Design Considerations

While most of the spaces have been experiencing a period of solar gain, the two N spaces have had no direct solar gain. Thus, the load in the two N spaces is only dependent on the outside temperature and internal loads, these two factors are approximately the same for each space. Therefore, these two N spaces could share a common thermostat to control their temperature the two S spaces have similar thermal conditions with high solar gain Both of the two S spaces could also share a thermostat, since they have similar solar and other loads.

The remaining spaces: NE, SE, SW, and NW, all have different solar gains at different times. In order to maintain the set-point temperature, they would each need their own thermostat.

Thus, if we wanted to deal with the solar gain variability in each of these eight spaces, we would need six zones. Note that this discussion is considering zoning on the basis of only solar loads.
In real life there may not be enough funds allocated for six zones. Thus, the designer might combine the two N spaces with the NE space; on the basis that a little overheating in NE space in the early morning would be acceptable.

Then the choice is between N and NE spaces for the thermostat location. Since it is generally better to keep the majority happy, the designer would choose to put the thermostat in an N space. However, if the designer knew that the NE space was going to be allocated to an important person, the choice could be to put the thermostat in the NE space! In a similar way the two S spaces and the SE space could be combined.

Interior and Roof Zones

The discussion so far has ignored both the internal zone and the effect of the roof. The internal zones on intermediate floors are surrounded by conditioned spaces. As a result, they never need heating, are not affected by solar gain and need cooling when occupied all year. In a cool climate this can often create a situation where all exterior zones require heating but the interior zones still require cooling. The different behavior of interior zones can be dealt with by putting them on a separate system.

Choosing zones is always a cost/benefit trade-off issue. In an ideal world, every occupant would have control of their own part of the space. In practice the cost is generally not warranted. As a result, the designer has to go through a selection process, but in a real building the designer must consider all relevant factors.

Common factors are outlined below:

1-Thermal Variation

Solar gain-Wall or roof heat gains or heat losses-Occupancy-Equipment and associated heat loads-

Freeze protection in cold climates

2-Ventilation with Outside Air

Occupancy by people-Exhausts from washrooms-Exhausts from equipment and fume hoods

3-Time of Operation

Timed-On demand – manual control or manual start for timed run.

4-Humidity

High humidity in hot humid climates for mold protection

Museum and art gallery requirements for good humidity control.

5-Pressure

Air flows from places at a higher pressure to places at a lower pressure.

A difference in pressure can be used to control the movement of airborne contaminants in the building. For example, in a hospital, the tuberculosis (TB) patient rooms can be kept at a negative pressure Conversely, a photographic processing laboratory is kept at a positive pressure to minimize the entry of dust.

6-Zoning Problems

One recurring problem with zoning is changes in building use after the design has been completed. If there are likely to be significant changes in layout or use, then the designer should choose a system and select zones that will make zone modification as economical and easy as practical.

5.4 Controlling the Zone

The most common zone control device is the thermostat. It should be placed where it is most representative of the occupants' thermal experience. A thermostat is usually mounted on the wall. It is designed to keep a constant temperature where it is, but it has no intelligence; it does not know what is going on around it. The following are some of the issues to be aware of when choosing the thermostat location.

_ *Mounting the thermostat in a location where the sun can shine* on it will cause it to overcool the zone when the sun shines on it.

_ *In many hotels, the thermostat is mounted by the door to the meeting room*, If the door is left open, a cold or warm draft from the corridor can significantly influence the thermostat.

_ *In some conference or assembly rooms, the thermostat is mounted above lighting dimmer switches*.

_ *Mounting a thermostat on an outside wall* can also cause problems. If the wall becomes warm due to the sun shining on it, the thermostat will lower the air temperature to compensate.

_ *There are times when heat from equipment can offset the thermostat*. A computer mounted on a desk under a thermostat can easily generate enough heat to cause the thermostat to lower the air temperature.

_ *If the thermostat is mounted where it is directly affected by the heating or the cooling of the space*, it will likely not maintain comfortable conditions.

_ *Lastly, mounting a thermostat near an opening window* can also cause random air temperature variations as outside air blows, or does not blow, over the thermostat.

Humidity

While this discussion has been all about thermostats and poor temperature control, the issues are very similar for humidity, which is controlled by **humidistat**.

Section 6-Single Zone Air Handlers and Unitary Equipment

Purpose of this Section:

1. Identify the main components of a single zone air handler and describe their operation.
2. Describe the parameters that have to be known to choose an air-conditioning air-handling unit.
3. Describe how the vapor compression refrigeration cycle works.
4. Identify the significant issues in choosing a single-zone rooftop air conditioning unit.
5. Understand the virtues of a split system.

6.1 Introduction

In this Section we are going to consider packaged single-zone air-conditioning equipment, examine issues of system choice and provide a general description of system control issues.

The single zone air handler, or air-handling unit, often abbreviated to **AHU**. The air handler draws in and mixes outside air with air that is being recirculated, or returned from the building, called **return air**. Once the outside air and the return air are mixed, the unit conditions the mixed air, blows the conditioned air into the space and exhausts any excess air to outside, using the return-air fan.

6.2 Examples of Buildings with Single-zone Package Air-Conditioning Units

Figure 6.1 shows four identical single-story buildings, A, B, C, and D. Each has a single-zone package air-conditioning unit (marked "**AHU**") located on the roof.

Building A: This unit has only an electrical supply. This single electrical supply provides all the power for heating, cooling, humidifying, and for driving the fans.

Building B: This unit has the electrical supply for cooling, humidifying, and for driving the fans, while the gas line, shown as "gas supply," provides heating.

Building C: This unit has the electrical supply for cooling, humidifying, and for driving the fans. It also has supply and return hot-water pipes coming from a boiler room in another building. The unit contains a hot-water heating coil and control valve, which together take as much heat as needed from the hot water supply system.

Building D: In the same way, there may be a central chiller plant that produces cold water at 42°F – 48°F, called **chilled water**. This chilled water is piped around the building, or buildings, to provide the air-handling units with cooling. Like the heating coil and control valve in Building C, there will be a cooling coil and control valve in each unit, to provide the cooling and dehumidification.

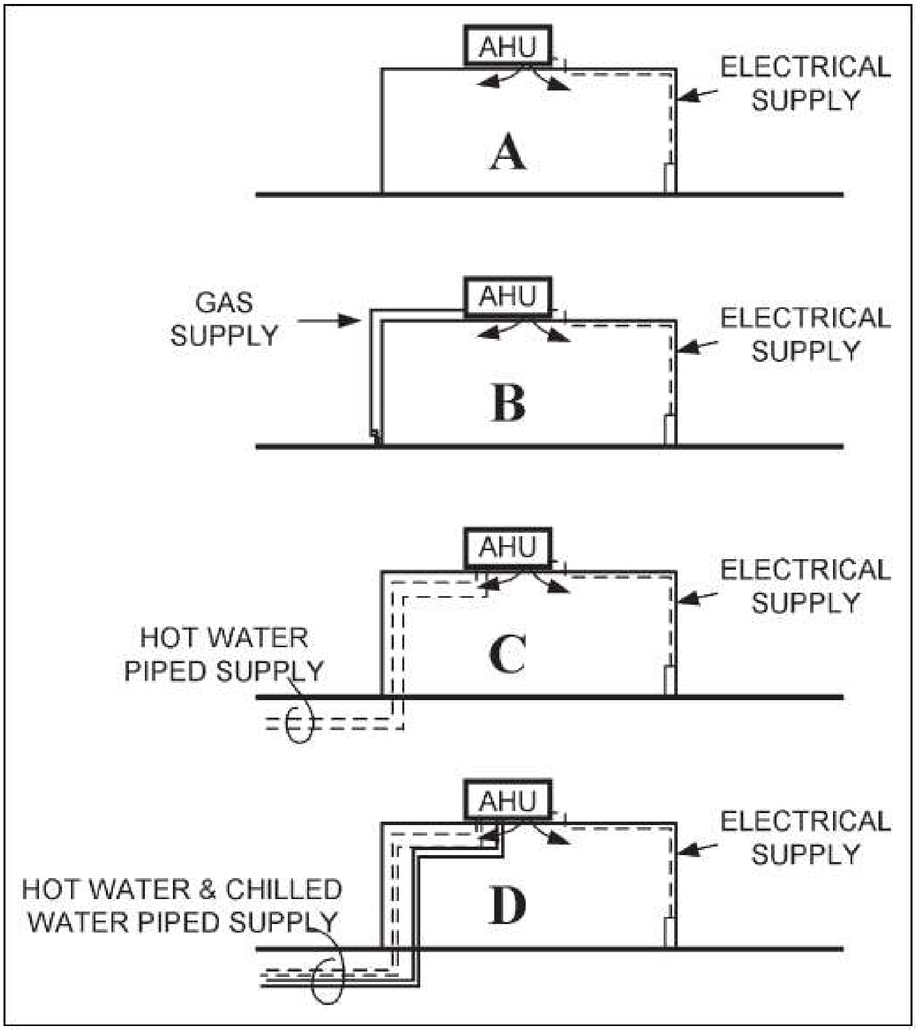


Figure 6.1 Single Zone Rooftop Air-Conditioning Unit, Energy Supplies

6.3 Air-Handling Unit Components

Figure 6.2 shows the basic air-handler unit with the economizer cycle.

In the following section we will go through each of the components in the unit, This unit is typically referred to as the **single-zone air handler**.

The overall functions of the air-handler are to draw in outside air and return air, mix them, condition the mixed air, blow the conditioned air into the space, and exhaust any excess air to outside.

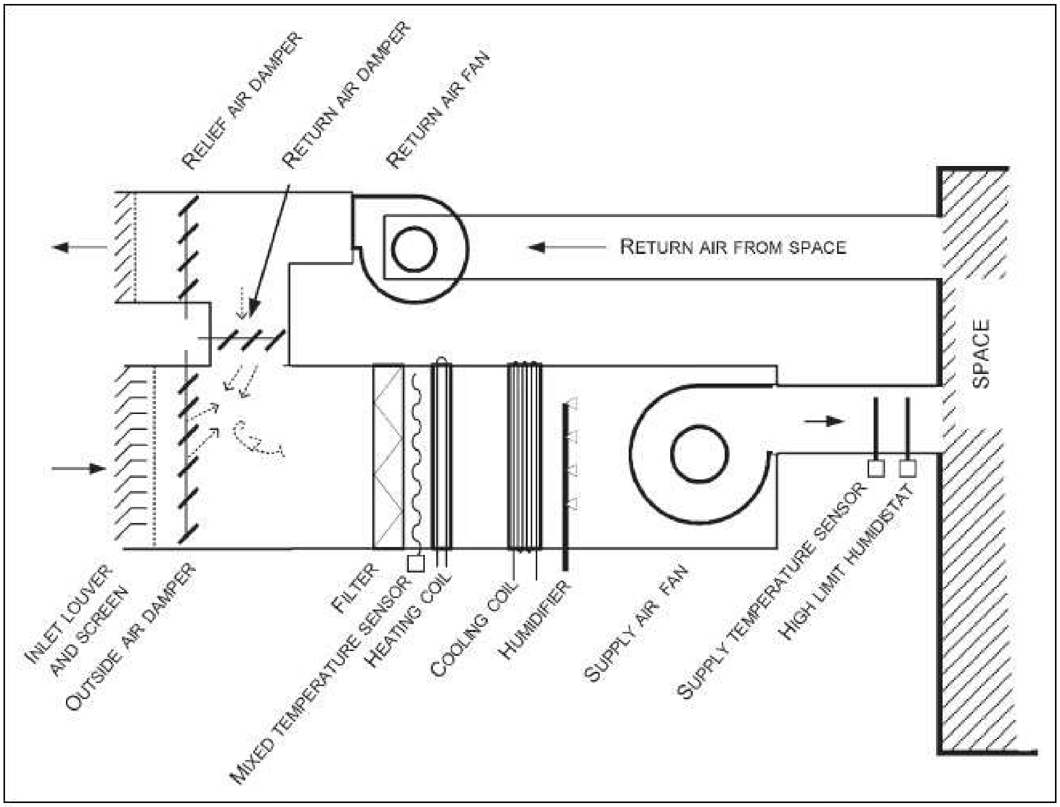


Figure 6.2 Air-Conditioning System: Single-Zone Air Handler

Air Inlet and Mixing Section

The inlet louver and screen restrict entry into the system. The inlet louver is designed to minimize the entry of rain and snow. A very simple design for the inlet louver is shown in the diagram. Maintaining slow air-speed through the louver avoids drawing rain into the system.
A parallel blade damper is shown for both the outside air damper and the relief air damper.

These dampers direct the air streams toward each other, causing turbulence and mixing. Mixing the air streams is extremely important in very cold climates, since the outside air could freeze coils that contain water as the heating medium

It is also possible to install opposed blade dampers:

These do a better job of accurately controlling the flow, but a rather poorer job of promoting mixing.

Some air will be exhausted directly to the outside from washrooms and other specific sources. The remainder will be drawn back through the return air duct by the return air fan and either used as return air, or exhausted to outside through the relief air damper. This exhausted air is called the **relief air**. It is common, therefore, to link the outside-air damper, the return-air damper and the relief air dampers and use a single device, called an **actuator**, to move the dampers in unison.

Mixed Temperature Sensor

Generally, the control system needs to know the temperature of the mixed air for temperature control. A mixed-temperature sensor can be strung across the air stream to obtain an average temperature. If mixing is poor, then the average temperature will be incorrect. To maximize mixing before the temperature is measured, the mixed temperature sensor is usually installed downstream of the filter.

When the plant starts up, the return air flows through the return damper and over the mixed temperature sensor. Because there is no outside air in the flow, the mixed-air temperature is equal to the return-air temperature. The dampers open, and outside air is brought into the system, upstream of the mixed-air sensor. If the outside temperature is higher than the return temperature, as the proportion of outside air is increased, the mixed-air temperature will rise. Conversely, if it is cold outside, as the proportion of outside air is increased, the mixed-air temperature will drop. In this situation, it is common to set the control system to provide a mixed-air temperature somewhere between 55 and 60°F. The control system can simply adjust the position of the dampers to maintain the set mixed temperature.

For example, consider a system with a required mixed temperature of 55°F and return temperature of 73°F. When the outside temperature is 55°F, 100% outside air will provide the required 55°F. When the outside air temperature is below 55°F, the required mixed temperature of 55°F can be achieved by mixing outside air and return air. As the outside temperature drops, the percentage required to maintain 55°F will decrease. If the return temperature is 73°F, at 37°F there will be 50% outside air, and at 1°F, 20% outside air.

If the building's ventilation requirements are for a minimum of 20% outside air, then any outside temperature below 1°F will cause the mixed temperature to drop below 55°F. In this situation, the mixed air will be cooler than 55°F and will have to be heated to maintain 55°F.
The mixed-air temperature-sensor will register a temperature below 55°F. The heating coil will then turn "on" to provide enough heat to raise the supply-air temperature to 55°F.
Now let us consider what happens when the outside-air temperature rises above 55°F. Up to 73°F, the temperature of the outside air will be lower than the return air, so it would seem best to use 100% outside air until the outside temperature reaches 73°F. In practice, this is not always true, because the moisture content of the outside air will influence the decision.

Filter

All packaged units include as least minimal filters. Often it is beneficial to specify better filters.

Heating Coil

Some systems require very high proportions, or even 100% outside air. In most climates this will necessitate installing a heating coil to raise the mixed air temperature. The heat for the heating coil can be provided by electricity, gas, water or steam.

The electric coil is the simplest choice, but the cost of electricity often makes it an uneconomic one.

A gas-fired heater often has the advantage of lower fuel cost, but control can be an issue. Inexpensive gas heaters are "on-off" or "high-low-off" rather than fully modulating. As a result, the output temperature has step changes.

Hot water coils are the most controllable, but there is a possibility that they will freeze in cold weather. If below-freezing temperatures are common, then it is wise to take precautions against coil freezing.

Cooling Coil

Cooling is usually achieved with a coil cooled by cold water, or a refrigerant, the cold water is normally between 42°F and 48°F. There are numerous refrigerants that can be used, whether using chilled water or a refrigerant, the coil will normally be cooler than the dew point of the air and thus condensation will occur on the coil. This condensation will run down the coil fins to drain away.

Humidifier

A humidifier is a device for adding moisture to the air. The humidifier can either inject a **water-spray** or **steam** into the air.

Humidifier

The water-spray consists of very fine droplets, which evaporate into the air, the supply of water must be from a **potable** source, fit for human consumption.

The alternative is to inject ***Steam*** into the air stream. Again, the steam must be potable. The humidifier will normally be controlled by a humidistat, which is mounted in the space or in the return airflow from the space.

The unit control logic will then be:

- Humidifier off when unit off.
- Humidifier off when cooling in operation.
- Humidifier controlled by space humidistat when unit in operation.
- Humidifier to shut down until manually reset if high limit humidity sensor Operates.

Fan

The fan provides the energy to drive the air through the system. There are two basic types of fan, the **centrifugal**, and the **axial**.

Centrifugal fan: air enters a cylindrical set of rotating blades and is centrifuged, thrust radially outwards, into a scroll casing. This fan is a very popular choice due to its ability to generate substantial pressure without excessive noise.

1- **Axial fan**: where the air passes through a rotating set of blades, like an aircraft propeller, which pushes the air along. This is a simpler, straight-through design that works really well in situations that require high volumes at a low pressure-drop.

2- ***Return Fan:*** A return fan is usually included on larger systems, unless there is some other exhaust system to control building pressure. If there is no return fan, the building will have a pressure that is a bit above ambient (outside).

6.4 Refrigeration Equipment

Refrigeration equipment is used to transfer heat from a cooler place to a warmer place. In the domestic refrigerator, the refrigeration equipment absorbs heat from inside the refrigerator and discharges heat into the house. On a much larger scale, refrigeration machines are used to chill water that is then pumped around buildings to provide cooling in air-conditioning systems.
The heat removed from the water is expelled into the atmosphere through a hot, air-cooled coil, or by evaporating water in a cooling tower.

The domestic refrigerator and most other refrigeration systems use the same basic process of vapor compression and expansion.

The vapor compression refrigeration system comprises four components: ***Compressor, Condenser, Expansion valve, and Evaporator***. *Figure 6.3* shows the arrangement.

1- ***Compressor***—which compresses refrigerant vapor to a high pressure, making it hot in the process.

2- ***Condenser***—in which air or water cooling reduces the temperature of the refrigerant sufficiently to cause it to condense into liquid refrigerant and give up its latent heat of evaporation.

3- ***Expansion valve***—which allows a controlled amount of the liquid refrigerant to flow through into the low-pressure section of the circuit.

4- ***Evaporator***—in which air or water heats the liquid refrigerant so that it evaporates (boils) back into a vapor as it absorbs its latent heat of evaporation.

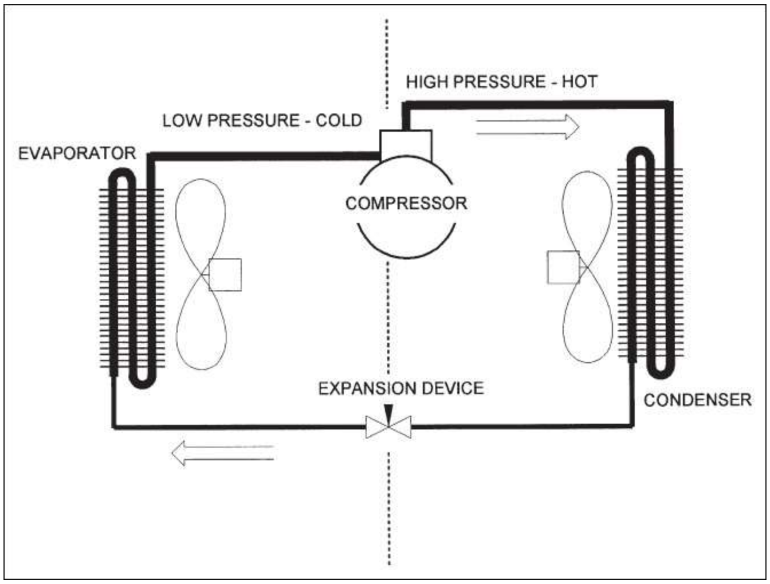


Figure 6.3 Basic Vapor Compression Refrigeration Cycle

As the refrigerant flows round and round the circuit, it picks up enthalpy, heat, at the evaporator and more heat as it is compressed in the compressor.
The sum of the evaporator and compressor enthalpy is rejected from the condenser.

The system effectiveness is higher, the greater the ratio of evaporator enthalpy to compressor enthalpy. One wants the most heat transferred for the least compressor work. The enthalpy flow into and out of the refrigerant is shown in the *Figure 6.4*.

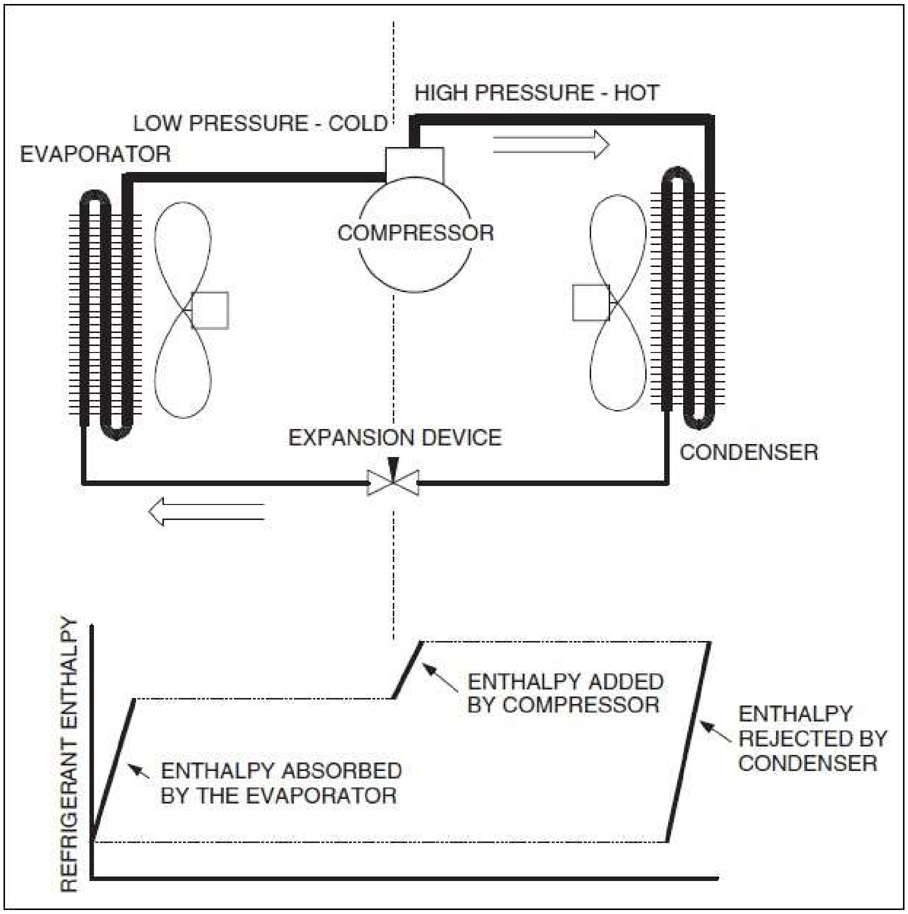


Figure 6.4 Enthalpy Flow in Vapor Compression Refrigeration Cycle

Moving up in size from the domestic refrigerator to the window air conditioner, *Figure 6.5* shows the refrigeration circuit with a box around it. The evaporator fan draws room air over the evaporator coil to cool it. The condenser is outside and the condenser fan draws outside air over the condenser coil to reject heat into the outside air.

The capacity of the unit is highest when the inside and outside temperatures are close to each other. The refrigerator and the window air conditioner have air flowing across both the evaporator and condenser to achieve heat transfer. Many systems use water as an intermediate heat-transfer medium. The evaporator coil can be in a water-filled shell to produce chilled water. This chilled water can then be piped around the building, or even from building to building, to provide cooling as and where it is needed.

Water can also be used on the condenser side of the refrigeration system, Here the condenser heats the water, which is generally then pumped to one or more cooling towers.

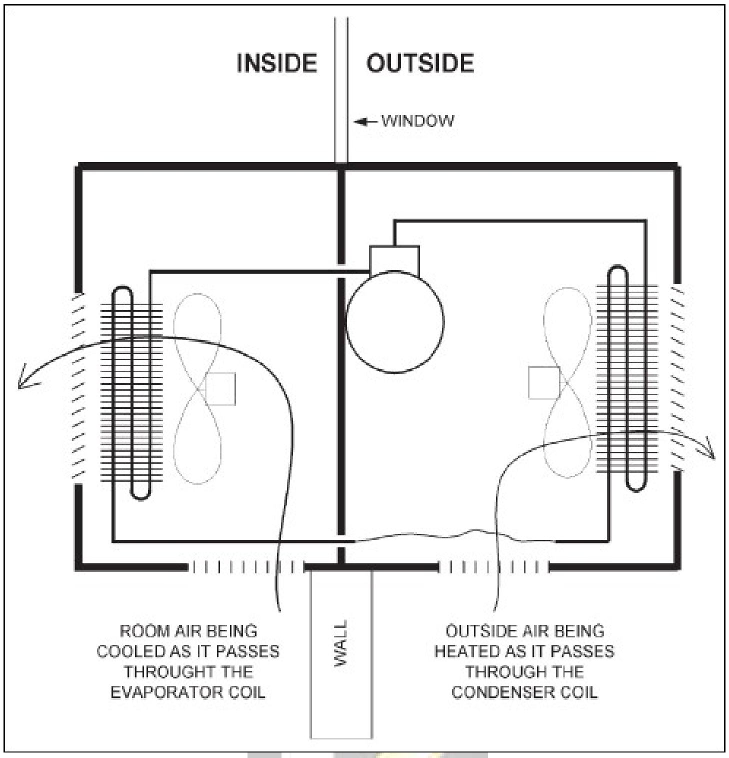


Figure 6.5 Window Air Conditioner

Heat Pump

There are times when the reverse process is valuable, If the outside temperature is not too cold, one could install a window air conditioner back-to-front. Then, it would cool outside and warm inside. The total heat rejected to the inside would be the sum of the electrical energy put into the compressor, plus heat absorbed from the outside air. It would be pumping the heat into the space – hence we call it a **heat pump**.

6.5 System Performance Requirements

Before choosing a system, you need an understanding of the types of loads you want the system to manage. Typically, the summer cooling-loads will be the main determinant of the choice of unit. The heating loads are usually easily dealt with by choosing a suitable heater to go with the chosen unit.

The summer loads, though, will be dependent on several, somewhat interrelated factors:

Outside summer design temperature. This affects the cooling load in three ways:

Interior load-Outside air temperature-Effectiveness of the refrigeration system.

Outside summer design humidity. The outside design humidity will be a factor in the ventilation air load and the removal of moisture from any air that leaks into the building

Inside summer design temperature and humidity. The warmer and damper the inside is allowed to be, the smaller the difference between inside and outside, hence the lower the load on the system. This is particularly important when you are making system choices.

Inside summer generation of heat and moisture. These will be added to the building loads to establish the total loads on the system.

Summer ventilation requirements. The higher the ventilation requirements, the greater the load due to cooling and dehumidifying the outside air that is brought in.

Decision Factors for Choosing Units

1-The initial cost to purchase and install versus the ongoing cost of operation and maintenance.

2-Load versus capacity

Loads: *are the calculated building requirements*

Capacity: *is the plant Equipment's ability to handle the load.*

6.6 Rooftop Units

A typical rooftop system is diagrammed in *Figure 6.6*. The return air is drawn up into the base of the unit and the supply air is blown vertically down from the bottom of the unit into the space below. As an alternative, the ducts can project from the end of the unit to run across the roof before entering the building.

The major advantages of rooftop units are:

- *No working parts in the occupied space*—so maintenance can be carried out without disrupting activities.
- *No space is built for the unit*—which saves construction costs.
- *No delay for detailed manufacturer design work*—because the unit is pre-designed.
- *No wide access during construction*—because the unit is outside the building envelope, the contractor does not have to keep an access available for the unit to be moved in during construction.

The disadvantages of rooftop units are:

- *Critical units must be maintained regardless of the weather conditions*—That means that maintenance could be required in heavy rain, snow, or high winds.
- *Choice of performance is limited to the available set of components*—This is often not enough of a problem to make the unit unacceptable, and can frequently be overcome by using a split unit.

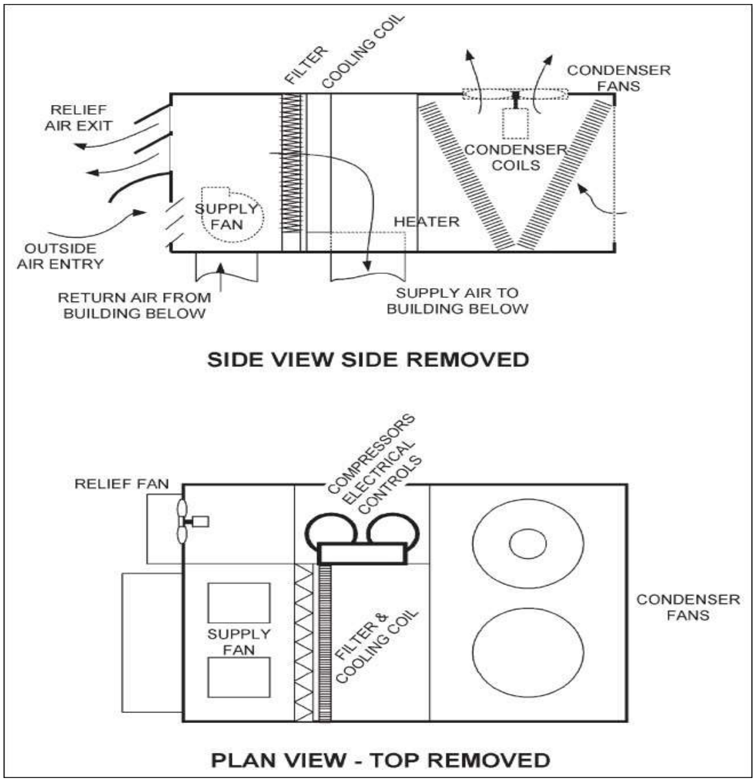


Figure 6.6 Rooftop Unit

6.7 Split Systems

In the split system, the compressor condenser part of the refrigeration system is chosen separately from the rest of the system and connected by the refrigerant lines to the air system, which includes the evaporator. The pipes, even with their insulation, are only inches in diameter, compared to ducts that are, typically, feet in diameter. The separation of the two parts of the refrigeration system to produce the split system is diagrammed in *Figure 6.7*. The system can range in size from the small residential systems where the inside coil is mounted on the furnace air outlet to substantial commercial units serving a building.

The split system allows the designer a much greater choice of performance.

The other main advantage of the split system is that it allows the air handling part of the unit to be indoors, where it is easier to maintain and does not need to be weatherproofed. The noise of the compressor is outside and can be located at some distance from the air-handling unit.

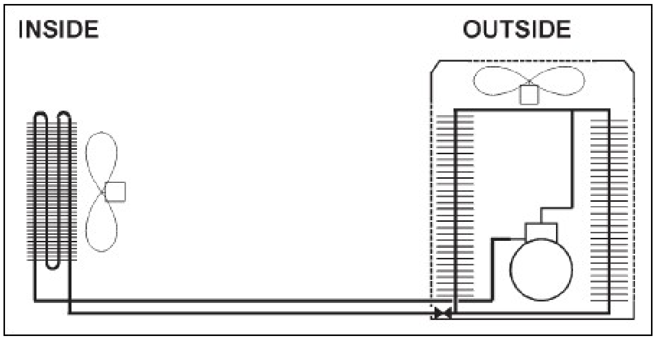
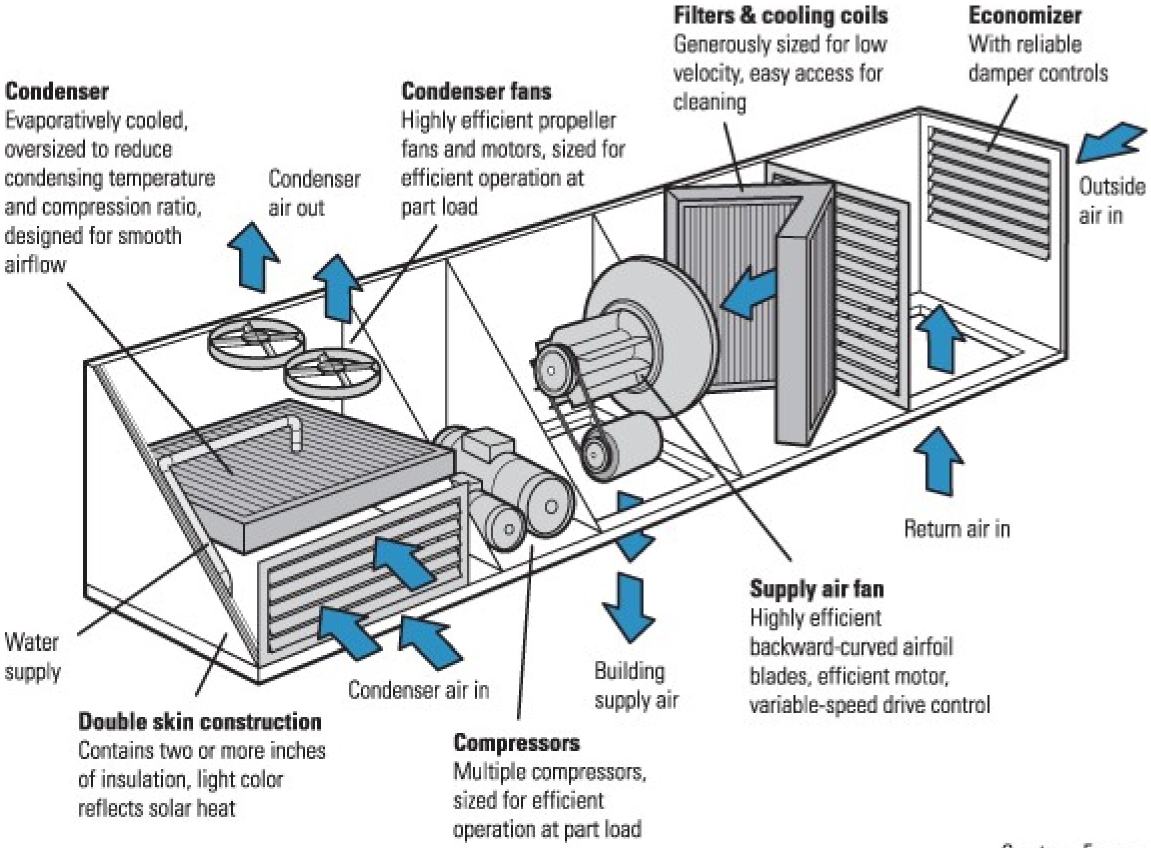


Figure 6.9 Split System



Courtesy: E SOURCE

The Figure shows Components and features of efficient packaged rooftop unit design

Section 7 - Multiple Zone Air systems

Purpose of this Section:

1. Identify, describe and diagrammatically sketch the most common all-air air-conditioning systems.
2. Understand the relative efficiency or inefficiency of each type of multiple zone air system.
3. Explain why systems that serve many zones, and that have a variable-supply air volume, are more energy-efficient than those with constant-supply volumes.

7.1 Introduction

In the last Section, we considered two types of single zone direct expansion systems: the packaged rooftop system and the split system. The direct-expansion refrigeration rooftop unit contained all the necessary components to condition a single air supply for air-conditioning purposes.
These same components can be manufactured in a wide range of type and size.

As an alternative to a rooftop unit, they can be installed indoors, in a mechanical room, with the different components connected by sheet-metal ducting.
Both the packaged rooftop unit and the inside, single-zone unit produce the same output: a supply of treated air at a particular temperature.

The heating or cooling effect of this treated airflow, when it enters a zone, is dependent upon ***TWO*** *factors:*
1-**The flow rate** (measured in cfm).
2-**The temperature** difference between the supply air and the zone temperature

When the unit is supplying one space, or zone, the temperature in the zone can be controlled by:

- Changing the air volume flow rate to the space.
- Changing the supply air temperature.
- Changing both air volume flow and supply air temperature.

In many buildings, the unit must serve several zones, and each zone has its own varying load. To maintain temperature control, each zone has an individual thermostat.
Air-conditioning systems that use just air for air conditioning are called “all-air systems”.
These all-air systems have a number of advantages:

- Centrally located
- Least infringement on conditioned floor space
- Greatest potential for the use of an economizer cycle
- Zoning flexibility and choice
- Full design freedom
- Generally good humidity control

All-air systems generally have the following disadvantages:

- Increased space requirements
- Construction dust- Closer coordination required

7.2 Single-Duct, Zoned Reheat, Constant Volume Systems

The **reheat system** is a modification of the single-zone system. The reheat system permits zone control by reheating the cool airflow to the temperature required for a particular zone. *Figure 7.1* shows a reheat system, with ceiling supply diffusers in the space.

The reheat coil is located close to the zone and it is controlled by the zone thermostat. Reheat coils are usually hot water or electric coils When primary air passes quickly over a vent, it draws some room air into the vent. This process is called **induction**.

The Induction Reheat Unit shown in *Figure 7.2* shows the primary supply of air, blown into the unit and directed through the induction nozzle. The reduced aperture of the nozzle forces the air to speed up and move quickly to the unit exit, into the room. As the primary air passes quickly past the reheat coil, it draws air from the room into the unit. The room air passes across the reheat coil and mixes with the primary air.

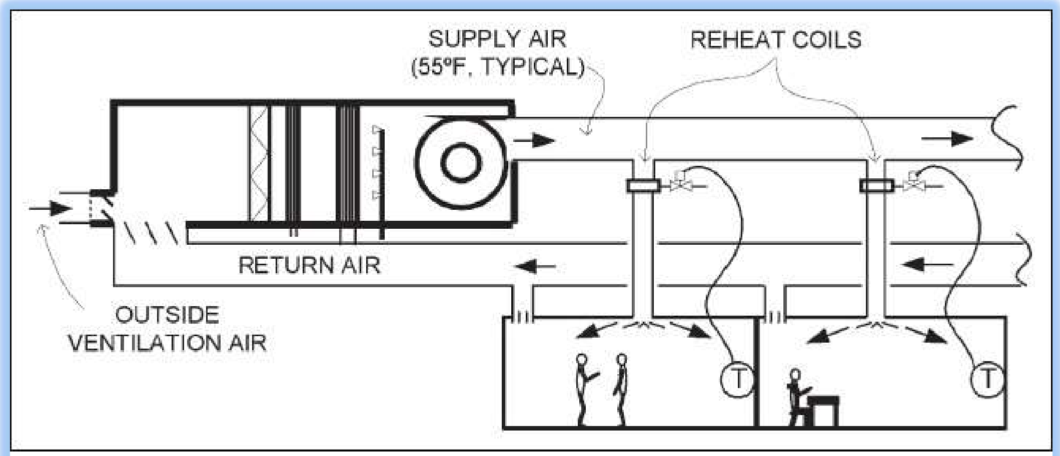


Figure 7.1 Reheat System

"The problem with all reheats systems is their energy inefficiency, so they are expensive systems to run. Generally, when the load is less than the peak cooling load, the cooling effect and the reheat are working against each other to neutralize their contributions."

7.3 Single-Duct, Variable Air Volume Systems

For cooling-only situations, it would be ideal to supply only as much cooling and ventilation as the zone actually requires at the particular moment. A system that comes close to the ideal is the **variable-air-volume** system “**VAV**”.

The variable air volume system is designed with a volume control damper, controlled by the zone thermostat, in each zone. This damper acts as a throttle to allow more or less cool air into the zone. The VAV system adjusts for varying cooling loads in different zones by individually throttling the supply air volume to each zone.

In a VAV system, as the zone becomes cooler, the cooling load decreases and the cool airflow to the zone decreases. Eventually it reaches the minimum value necessary for adequate ventilation and air supply.

Figure 7.4. When this minimum airflow is reached, if the zone is still too cool, heating is provided by a thermostatically controlled reheat coil or a baseboard heater.

This means there may be some energy wasted in the VAV system, due to heating and cooling at the same time. However, this energy waste is far less than in the terminal reheat system, since the cooling ventilation air is reduced to a minimum before the heating starts.

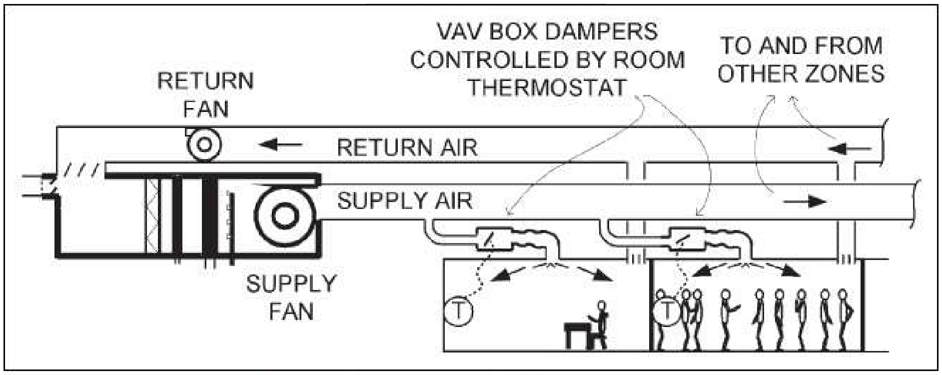


Figure 7.4 Variable Air Volume System

In systems where the fan speed is reduced to reduce the volume flow, the fan power drops substantially as the flow reduces. This reduction in fan power is a major contribution to the economy of the VAV system.
VAV systems may have variable volume return air fans that are controlled by pressure in the building or are controlled to track the supply-fan volume flow.
In small systems, the variable-volume supply may be achieved by using a relief damper, called a “**bypass**,” at the air-handling unit. The bypass allows air from the supply duct through a control damper into the return duct, as shown in *Figure 7.5*.
As the zones reduce their air requirements, the bypass damper opens to maintain constant flow through the supply fan. This arrangement allows for the constant volume required by the refrigeration circuit. For smaller systems, this method can provide very effective zone control without creating problems that may occur when the airflow is varied across the direct expansion refrigeration coil. Unfortunately, this system keeps the fan working at near full load.

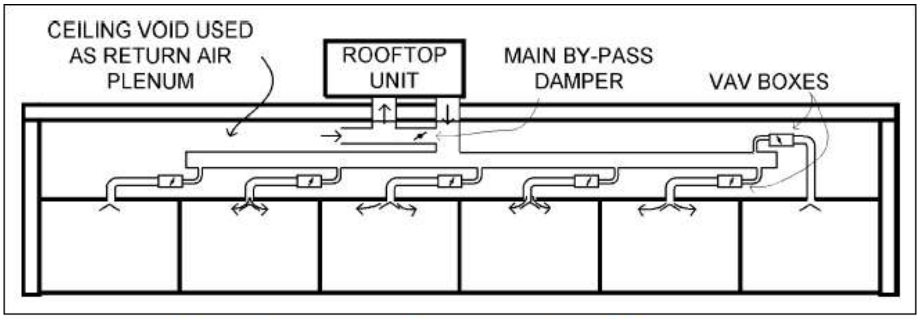


Figure 7.5 Variable Air Volume System With Bypass

VAV Advantages

1. *Initial costs are low* because the system only requires single runs of duct and a simple control at the end of the duct.
2. *Operating costs are low* because the volume of air, and therefore the refrigeration and fan power, closely follow the actual load of the building.

VAV Problems

1. poor air circulation in the conditioned space at lower flows
2. dumping of cold air into an occupied zone at low flows
3. inadequate fresh air supplied to the zone.

7.4 By-pass Box Systems

Where the main supply unit must handle a constant volume of air, **by-pass boxes** can provide a variable volume of air to the zones served. The bypass boxes can be used on each zone, or a single central by-pass can be used with variable volume boxes serving each zone.

Figure 7.6 shows the use of the by-pass box on each zone. A thermostat in each zone controls the damper in the by-pass box serving the zone. The flow of air to each box is essentially constant. The bypass box, shown on the left, is set for full flow to the zone.

The zone thermostat controls how much of the air is directed into the zone and how much is by-passed into the return-air system. In many buildings, the return can be via the space above the dropped ceiling, the **ceiling plenum**, and then, via a duct, back to the return of the air-handling unit.

With the by-pass system, it is important to keep the ceiling plenum at a negative pressure, so that the excess cooling air does not leak into the zone. But the danger of keeping the ceiling at negative pressure, though, is that this can cause infiltration of outside air through the walls and roof joints, resulting in moisture and load challenges.

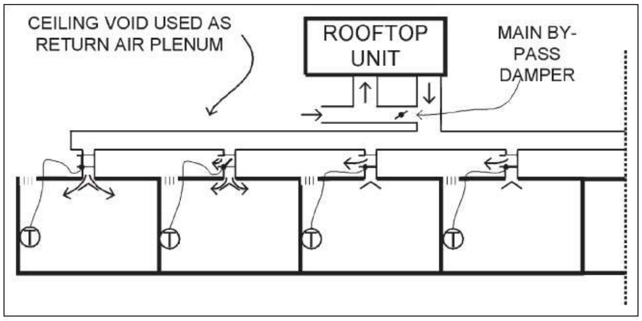


Figure 7.6 By-Pass Boxes on Each Zone

7.5 Constant Volume Dual-Duct, All-Air Systems

A dual-duct system employs a different approach for establishing zone control.
In a dual-duct system, cooling and heating coils are placed in separate ducts, and the hot and cold air flow streams are mixed, as needed, for temperature control within each zone.

In this system, the air from the supply fan is split into two parallel ducts, downstream of the fan. One duct is for heating and the other for cooling. A layout of three zones of a dual-duct system is shown in *Figure 7.7*.

The duct with the heating coil is known as the hot deck, and the duct with the cooling coil is the cold deck. These constant volume dual-duct systems usually use a single, constant-volume supply fan to supply the two ducts.

The dual-duct system can also be drawn diagrammatically as shown in *Figure 7.8*. Satisfy yourself that the two figures show the same system, although they look very different.

Dual-duct systems achieve the zoned temperature control by mixing the hot and cold air streams in a dual-duct box while maintaining a constant airflow The combined energy use leads to energy inefficiency, which is the biggest disadvantage of dual-duct systems.

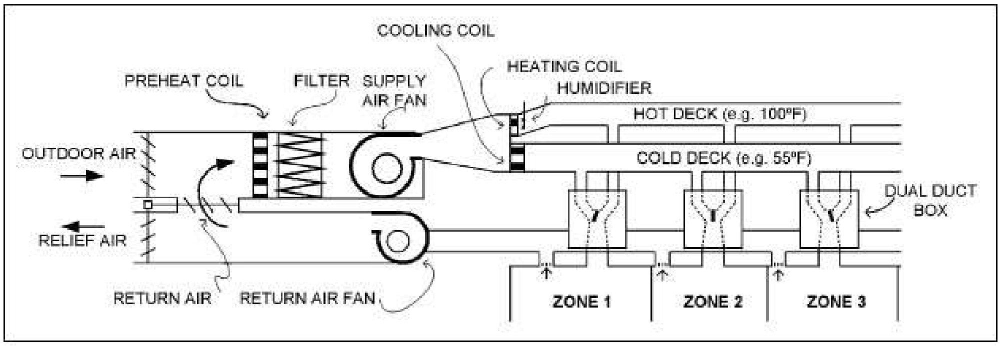


Figure 7.7 Dual-Duct System, Double Line Diagram

The energy inefficiency may be reduced by these methods:

1. Minimizing the temperature of the hot deck using control logic based on zone loads or outside temperature.
2. Raising the cold deck temperature when temperature and humidity conditions make it practical.
3. Using variable volume dual-duct mixing boxes.

The system also has a high first cost, since it requires two supply ducts. These two ducts need additional space above the ceiling for the second supply duct and connections.

Due to the relatively high installation and operating costs, dual-duct systems have fallen out of favor except in hospitals and laboratories, where their ability to serve highly variable sensible-heat loads at constant airflow make them attractive. Another advantage of dual-duct systems is that there are no reheat coils near the zones, so the problems of leaking hot water coils is avoided.

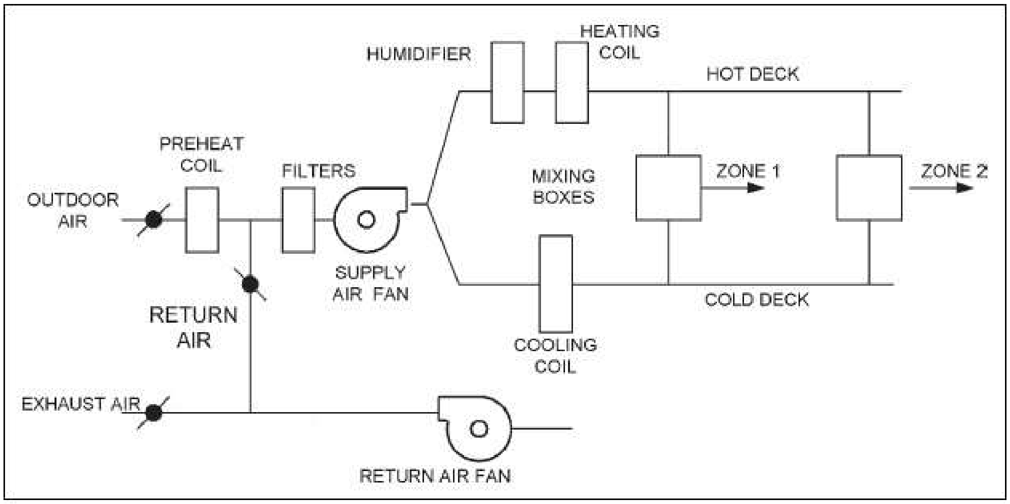


Figure 7.8 Dual-Duct System, Single Line Diagram

The dual-duct system delivers a constant volume of air, with varying percentages of hot and cold air, as shown in *Figure 7.9*.

For the room temperature setpoint range, also known as the throttling range, of 70°F to 72°F, the thermostat will control the hot-air flow linearly, from 100% at 70°F to 0% at 72°F. Outside the throttling-temperature range, the flow is either all hot air or all cold air.

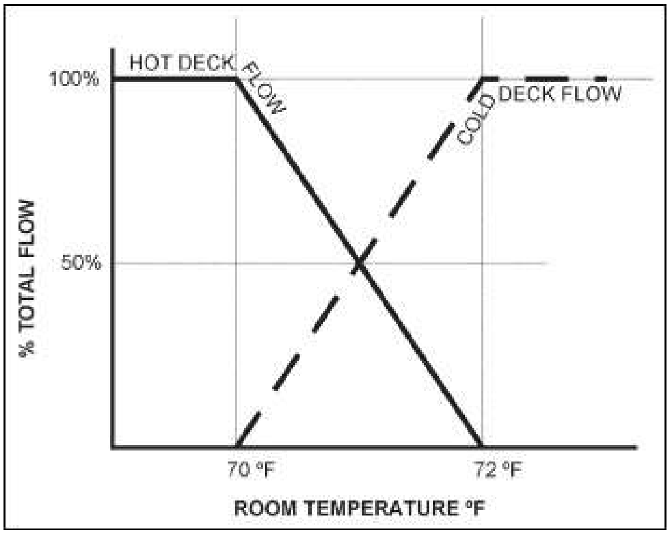


Figure 7.9 Air Flow in a Dual-Duct System

In *Figure 7.10*, there is a different view of the same process over the throttling range.
There are two plots. One plot, the solid line, shows how the delivered air temperature will vary as the thermostat controls the percentage mixture of hot and cold streams.

The delivered air-temperature scale is on the right-hand side of the graph, and the room-temperature scale is on the horizontal axis.
At a room temperature of 70°F and below, with 100% hot air, the delivery temperature is at 110°F. At a room temperature of 72°F and above, with 100% cold air, the delivery temperature is 55°F. At room temperatures between 70° and 72°F, the delivery temperature varies linearly with the room temperature.

The second plot in *Figure 7.10*, the dashed line, is that of the net cooling or heating power delivered to the zone to meet the load.

Above the mid-height, there is net heating and below mid-height, there is net cooling.
It is important to observe that, because this is a constant volume system, *zero power* does **not** mean *zero energy use*. Zero power corresponds to an equal amount of heating and cooling.

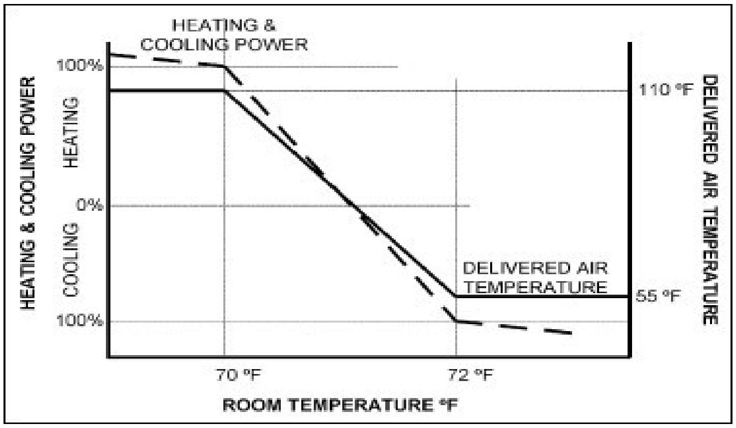


Figure 7.10 Delivered Air Temperature in a Dual-Duct System

7.6 Multizone Systems

The multizone system is thermodynamically the same as the dual-duct system, they both involve mixing varying proportions of a hot-air stream with a cold-air stream to obtain the required supply temperature for that zone.

In the multizone system, as shown in *Figure 7.11*, the mixing occurs at the main air-handling unit. The basic multizone system has the fan blowing the mixed air over a heating coil and a cooling coil in parallel configuration, In the multizone system, the heating and cooling airflows are mixed in the air-handling unit at the coils using pairs of dampers.

As in the dual-duct system, a certain amount of energy inefficiency occurs because the air is being both heated and cooled at the same time.

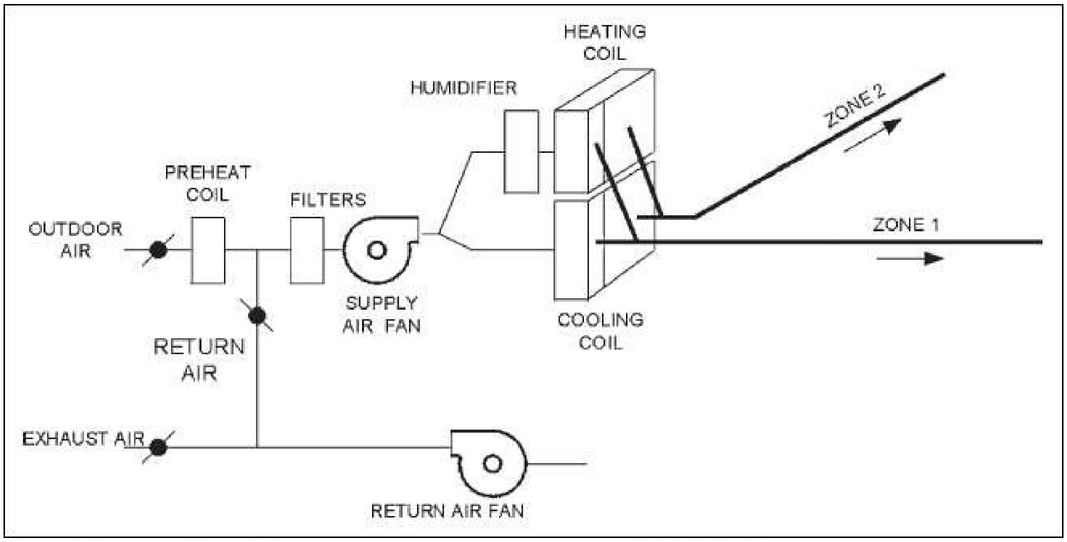


Figure 7.11 Mixing at the Air Conditioning Unit in a Multizone System

7.7 Three-deck Multizone Systems

The three-deck multizone system is a possible solution to overcome the energy inefficiency of the overlapping use of heating and cooling in a traditional multizone system.

The three-deck system is similar to the dual-duct and multizone systems, except that there is an additional (third) air stream that is neither heated nor cooled. Hot and cold air are never mixed in the three-deck system. Instead, thermal zones that require cooling receive a mixture of cold and neutral air, and thermal zones that require heating receive a mixture of hot and neutral air. The air flow control is shown in *Figure 7.12*. Thus, the three-deck system avoids the energy waste due to the mixing of hot and cold air streams.

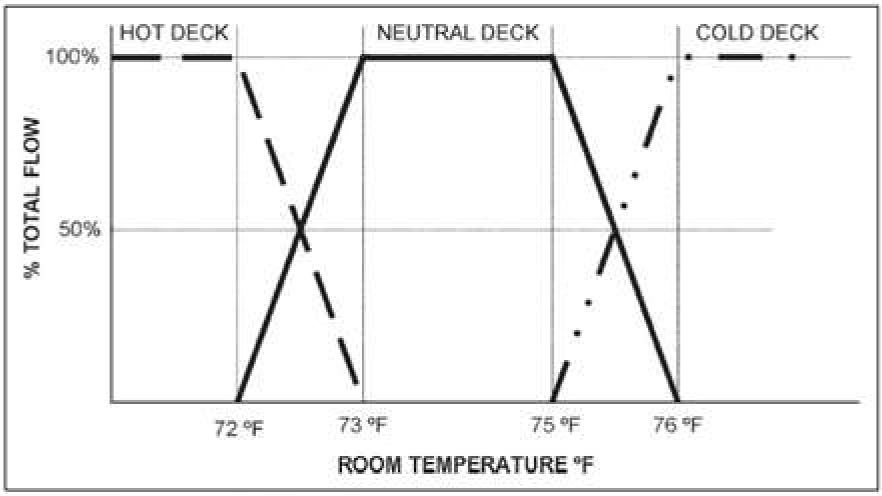


Figure 7.12 Air Flow for Three-deck, Multizone System

7.8 Dual-Duct, Variable Air Volume Systems

The dual-duct, variable air volume (VAV) system provides the thermal efficiency of the VAV system while generally maintaining higher air flows, and thus better circulation of air in the room, when heating is required.

The difference is that the air is not drawn into the building by a constant volume fan, but it is split into two air streams that flow through two variable-volume fans. One air stream passes through a heating coil and one through a cooling coil. The two air streams are then ducted throughout the building.

The variation of flow in the dual-duct, variable-air-volume system is shown in *Figure 7.13*. This diagram indicates equal volume flows for both heating air and cooling air.

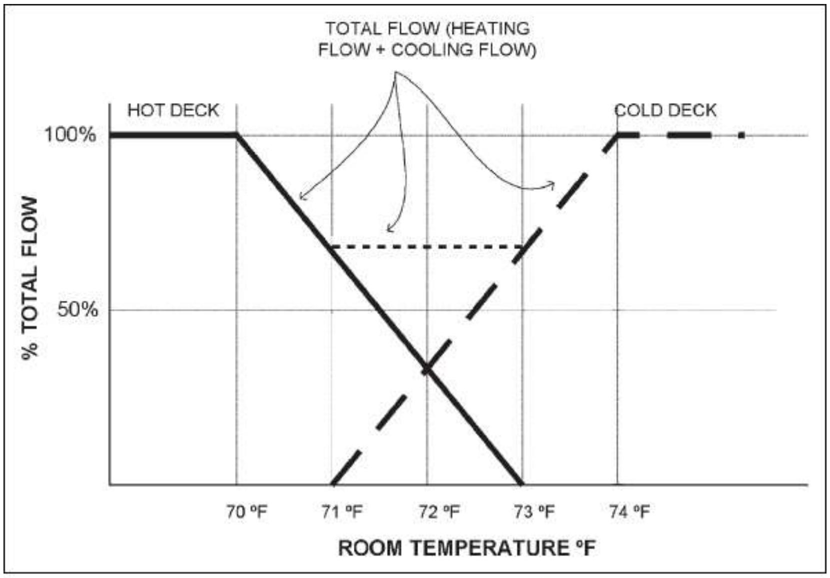


Figure 7.13 Air Flow for a Dual-Duct, Variable Air Volume System

7.9 Dual Path Outside Air Systems

This Section has shown that the outside ventilation air being mixed with return air before being processed and supplied to the building. This mixing method works well in cooler, dryer climates. This does not work as well in warm/hot, humid climates. The reason is very simple: the main cooling coil cannot remove enough moisture without overcooling the whole air stream. What is required is high moisture removal without full cooling.

An effective way around this problem is to use a **Dual path system**.

The outside air comes in through a separate, dedicated cooling coil before mixing with the return air. This dedicated outdoor air coil has two functions:

1. Dehumidification: to dehumidify the outside air to a little below the required space-moisture content.

2. Cooling: to about the same temperature as the main coil, when the main coil is at maximum cooling.

Section 8 - Hydronic Systems

Purpose of this Section:

1. Describe five types of hydronic systems.
2. Explain the main benefits of hydronic systems.
3. Discuss some of the challenges of hydronic systems.
4. Explain the operation and benefits of a water-source heat pump system.

8.1 Introduction

In this Section we are going to consider systems where water-heated and/or water-cooled equipment provide most of the heating and/or cooling.

In some buildings, these systems will use low-pressure steam instead of hot water for heating. Throughout the rest of this Section, we will assume that hot water is being used as the heating medium.

Because of their ability to produce high output on an 'as-needed basis,' hydronic systems are most commonly used where high and variable sensible heating and/or cooling loads occur. These are typically Perimeter zones.

Hydronic systems advantages:

1. Noise reduction
2. Economy, due to limited operational costs
3. Economy due to limited first costs
4. Energy efficiency

Hydronic systems disadvantages:

1. Ventilation
2. System failure
3. Humidity

8.2 Natural Convection and Low Temperature Radiation Heating Systems

The very simplest water heating systems consist of pipes with hot water flowing through them. The output from a bare pipe is generally too low to be effective, so an extended surface is used to dissipate more heat. There is a vast array of heat emitters. A small selection of types is shown in *Figures 8.1* and *8.2*.

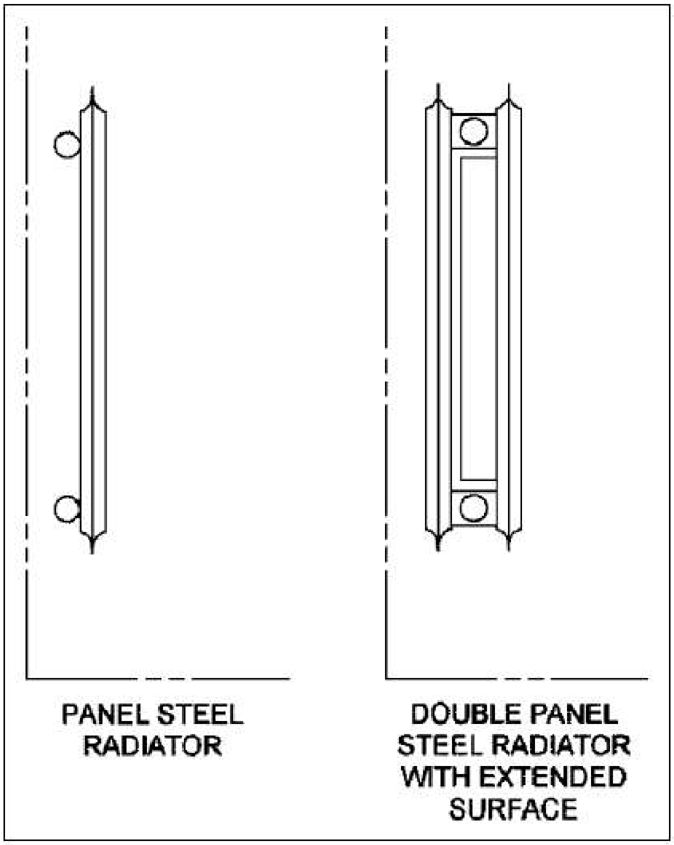


Figure 8.1 Wall-Mounted Single and Double Panel Radiators

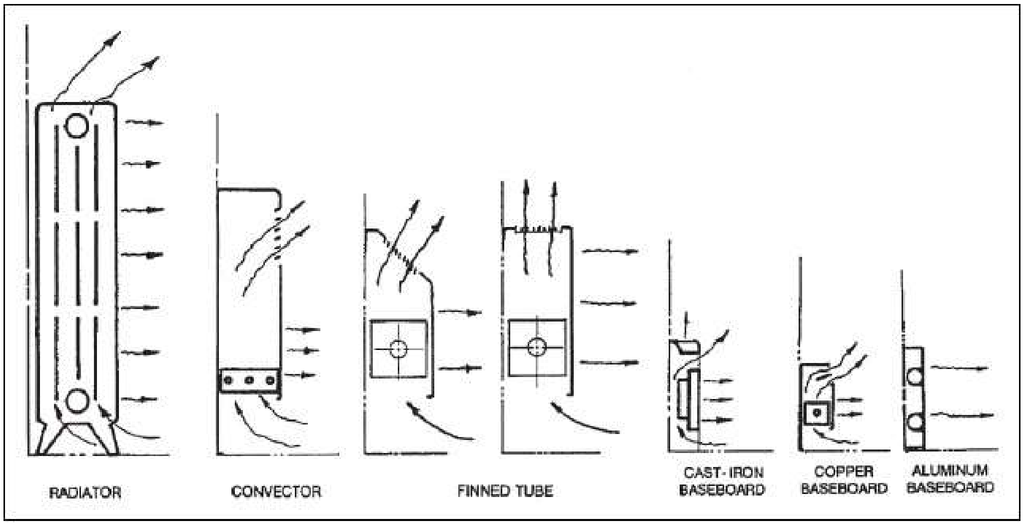


Figure 8.2 Terminal Units

Varying the Water Flow

Local zone control can be achieved by throttling the water flow. The simplest way to achieve this is with a self-contained control valve, mounted on the pipe. This valve contains a capsule of material that experiences large changes in volume, based on room temperature. As the temperature rises, the material expands and drives the valve closed.

A better, but more expensive, method of control is a wall thermostat and water control valve Control by modulating, or adjusting, the water flow works best when the load is high and the flow is high.

Varying the Water Temperature

The heat loss through a wall or window is proportional to the temperature difference across the wall or window. Thus, one can arrange a control system to increase the water temperature as the outside temperature falls, so that the heat output from the water will increase in step with the increase in heating load. This control system is called **Outdoor reset**.

Meeting Ventilation Requirements

These hydronic heating systems do not provide any ventilation air from outside. When water systems are in use, ventilation requirements can be met in one of 3 ways:

1. **Open Windows**: Water systems are often used with occupant-controlled windows (opening windows)
2. **Window Air conditioners**: One step up from heating and opening windows is heating and the window air-conditioner.
3. **Separate ventilation systems with optional cooling**: The alternative is to install a separate system to provide ventilation and, if needed, cooling. This is a very common design in cooler climates

Many office buildings operate only five days a week, twelve hours a day, so the air system can be turned off for 108 hours and only run 60 hours a week, saving 64% of the running hours of the ventilation system. *Figure 8.3* shows perimeter fan coils which provide heating and cooling plus a ventilation system using the corridor ceiling space for the ventilation supply duct.

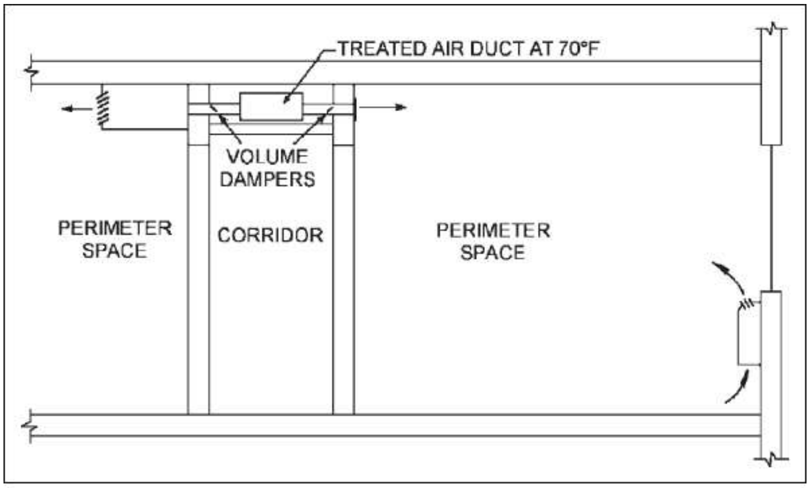


Figure 8.3 Ventilation from a Separate Duct System

8.3 Panel Heating and Cooling

The floor or ceiling of the space can be used as the heater or cooler. A floor that uses the floor surface for heating is called a **radiant floor**.

The radiant floor is heated by small-bore plastic piping. The output can be adjusted from area to area by adjusting the loop spacing, typically 6 to 18 inches, and circuiting the pipe loop.

Figure 8.4 Shows concrete radiant Floor

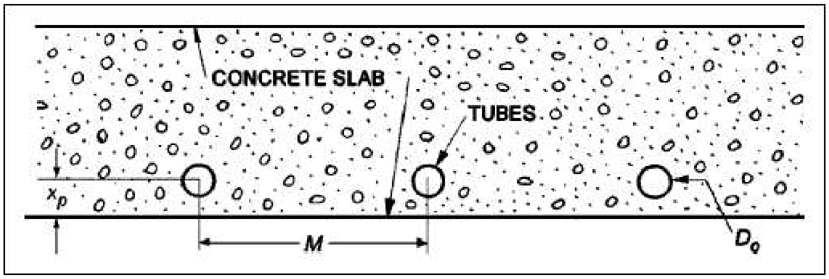


Figure 8.4 Concrete Radiant Floor

Control is usually achieved by outdoor reset of water temperature and individual thermostats for each zone.

The system can also be installed in outside pavement by using an inhibited glycol (anti-freeze) mixture instead of plain water. This can be used to prevent icing of walkways, parking garage ramps and the floor of loading bays that are open to the weather.

There are many designs; one is shown in *Figure 8.5*. The system has the advantage of taking up no floor or wall space and it collects no more dirt than a normal ceiling, making it very attractive for use in hospitals and other places that must be kept very clean.

8.4 Fan Coils

Up to now, the systems we have considered are passive (no moving parts) heating and cooling systems. We will now consider fan coils. As their name suggests, these units consist of a fan and a coil. Fan coils can be used for just heating or for both heating and cooling. In heating-only fan coils, the heating coil usually has fairly widely spaced fins so a lint filter is not critical. In dusty, linty environments, this may necessitate occasional vacuuming of the coil to remove lint buildup. Fan coils can be mounted against the wall at the ceiling.

A typical fan-coil unit is illustrated in *Figure 8.6*.

When the fan-coil is used for heating, the hot water normally runs through the unit continuously. Some heat is emitted by natural convention, even when the fan is "off." When the thermostat switches the fan "on," full output is achieved. A thermostat within the unit works well in circulation areas, such as entrances and corridors, where temperature control is not critical, and temperature differential is large. Generally, in occupied spaces, a room thermostat should be used to control the unit, to provide more accurate control.

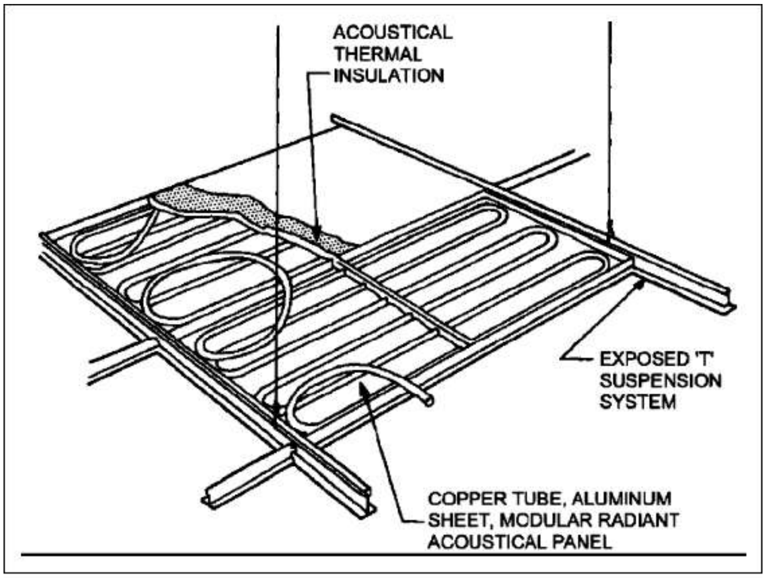


Figure 8.5 Example of Ceiling Radiant Panels

Some units are provided with two or three speed controls for the fan, allowing adjustment in output of heat and generated noise. Many designers will choose a unit that is designed to run at middle speed, to minimize the noise from the unit. Another way to minimize noise from the unit is to mount the unit in the ceiling space in the corridor and duct the air from the unit into the room.

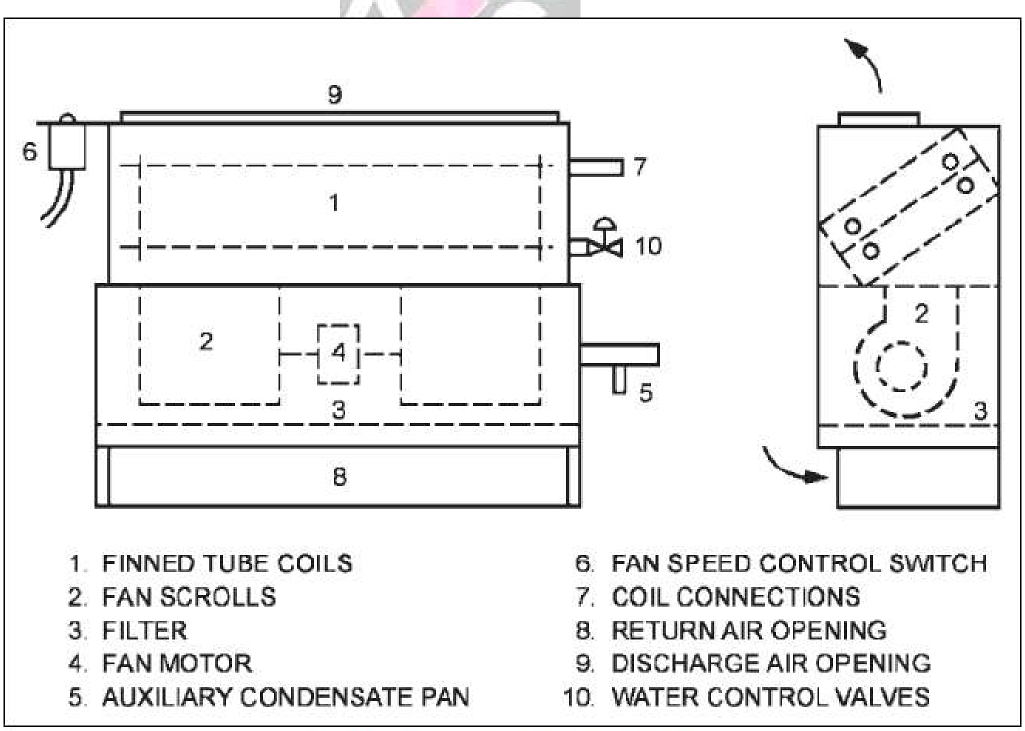


Figure 8.6 Typical Fan-Coil Unit

Hot-water fan coils:
These are an ideal method of providing heat to the high, sporadic, loads in entrances. In cold climates, if the outside door does not close, the unit can freeze, so it is wise to include a thermostat that prevents the fan from running if the outflow water temperature drops below 120°F.

Fan-coils may be run on an outdoor-reset water system, but this limits their output and keeps the fan running more than if a constant, say 180°F, water temperature is supplied to the unit.

Changeover system:
The same fan coil can be used for heating or for cooling, but with chilled water instead of hot water. This is called a changeover system.

Four-Pipe system:
As an alternative design to a changeover system, the unit can include two coils, heating and cooling, each with its own water circuit.

This is called a four-pipe system, since there are a total of four pipes serving the two coils. This system is more expensive to install but it is a more efficient system that completely avoids the problem of timing for change over from heating to cooling.

8.5 Two Pipe Induction Systems

When air moves through a space with speed, additional air from the space is caught up in the flow, and moves with the flow of the air. When this occurs, the room air that is caught up in the flow is called **entrained air**, or **secondary air**.

The two-pipe induction system uses ventilation air at medium pressure to entrain room air across a coil that either heats or cools. The ventilation-air, called **primary air**, is supplied at medium pressure and discharged through an array of vertical-facing nozzles. The high-velocity air causes an entrained flow of room air over the coil and up through the unit, to discharge into the room.

The coil in the induction unit is heated or cooled by water.

A lint filter should be provided to protect the coil. This filter will need to be changed regularly, so good access to the front of the unit is required.

The induction unit produces some noise due to the high nozzle velocity.

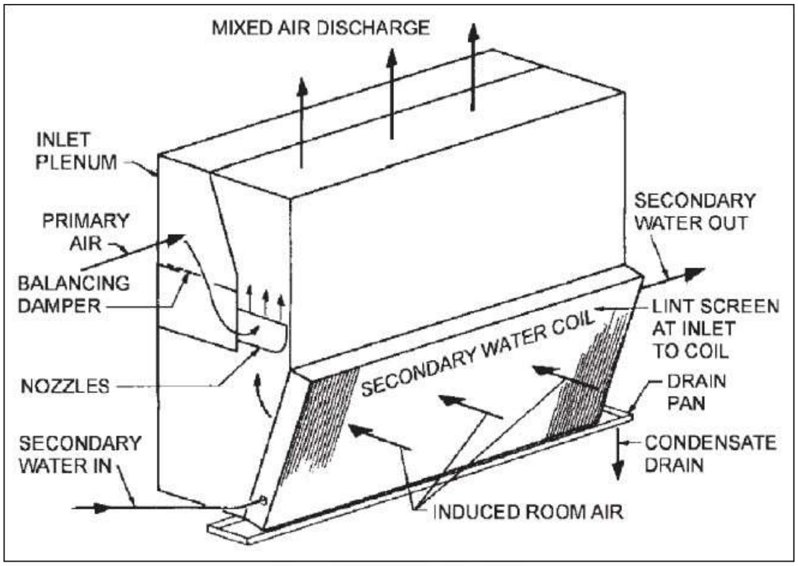


Figure 8.7 Induction Unit

8.6 Water Source Heat Pumps

Water source heat pumps are reversible refrigeration units. The refrigeration circuit is the one we considered in Section 6 except that one coil is water cooled/heated instead of air cooled/heated. The heat pump can either transfer heat from water into the zone or extract heat from the zone and reject it into water.

This ability finds two particular uses in building air conditioning:

*1- **The Use of Heat from the Ground***

There is a steady flow of heat from the core of the earth to the surface. As a result, a few feet below the surface, the ground temperature remains fairly steady. In cool climates, well below the frost line, this ground heat temperature may be only 40°F, but in the southern United States it reaches 70°F.

*2- **The Transfer of Heat around a Building***

The second use of heat pumps in building air conditioning is the water loop heat pump system. Here each zone is provided with one or more, heat pumps, connected to a water pipe loop around the building.

As Shown in *Figure 8.8*, there is a boiler to provide heating and a cooling tower to reject heat when the building has a net need for heating or cooling. The boiler, or tower, is used when required to maintain the circulation water within the set temperature limits.

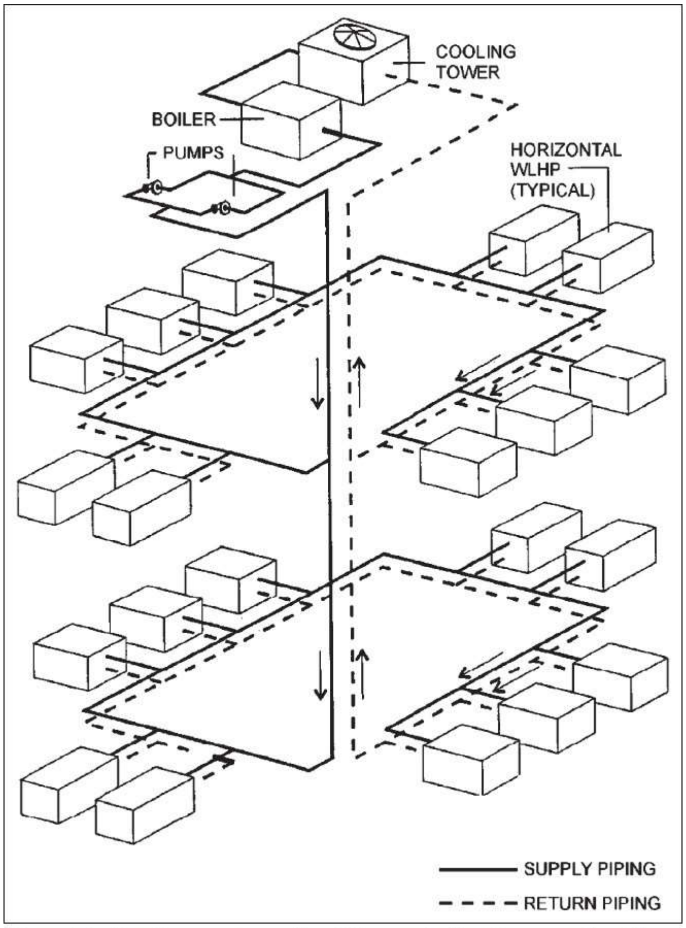
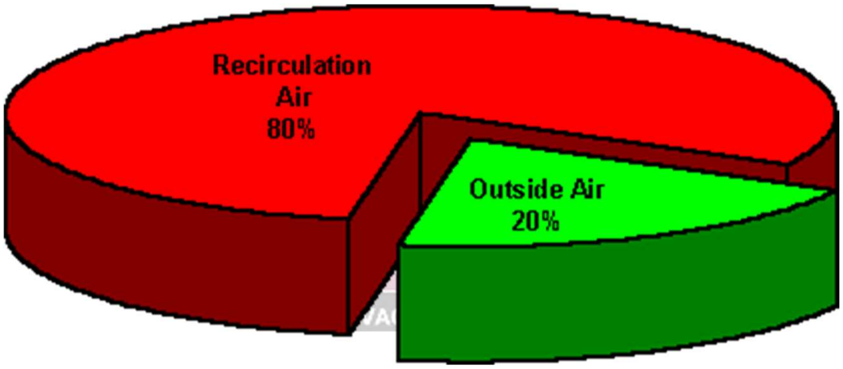


Figure 8.8 Heat Recovery System Using Water-to-Air Heat Pumps in a Closed Loop

Hydronic Radiant Heating and Cooling

Hydronic Radiant Cooling (Commercial Buildings)

Cooling of non-residential buildings equipped with All-Air Systems significantly contributes to the electrical energy consumption and to the peak power demand. Part of the energy used to cool buildings is consumed by the fans that transport cool air through the ducts. This energy heats the conditioned air, and therefore adds to the internal thermal cooling peak load. Scientists at LBNL found that, in the case of the typical office building in Los Angeles, the external loads account for only 42% of the thermal cooling peak. At that time, 28% of the internal gains were produced by lighting, 13% by air transport, 12% by people, and 5% by equipment. The implementation of better windows, together with higher plug loads due to increased use of electronic office equipment, have probably caused these contributions to change to some extent since then.



Fraction of Outside Air and Recirculation Air for conventional All-Air-System

HVAC systems are designed to maintain indoor air quality and provide thermal space conditioning. Traditionally, HVAC systems are designed as All-Air Systems, which means that air is used to perform both tasks. DOE-2 simulations for different California climates using the California Energy Commission (CEC) base case office building show that, at peak load, only 10% to 20% of the supply air is outside air. Only this small fraction of the supply air is in fact necessary to ventilate the buildings in order to maintain a high level of indoor air quality. For conventional HVAC systems the difference in volume between supply air and outside air is made up by recirculated air. The recirculated air is necessary in these systems to keep the temperature difference between supply air and room air in the comfort range. The additional amount of supply air, however, often causes draft as well as indoor air quality problems due to the distribution of pollutants throughout the building.

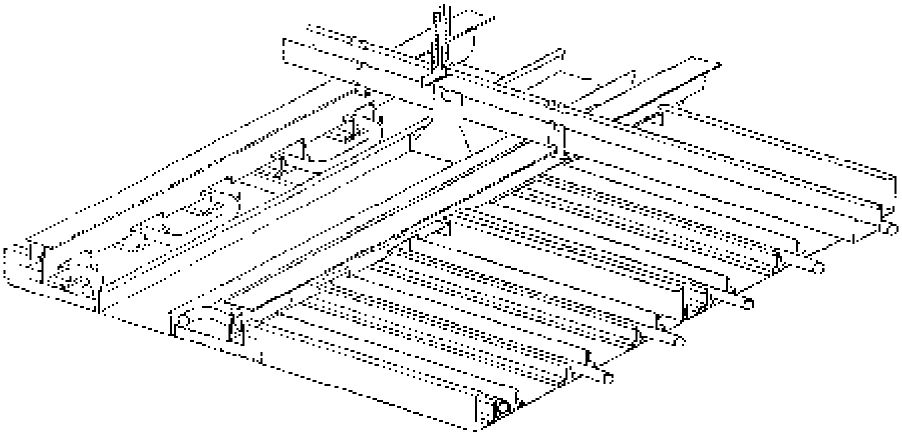
All-Air Systems achieve the task of cooling a building by convection only. An alternative is to provide the cooling through a combination of radiation and convection inside the building. This strategy uses cool surfaces in a conditioned space to cool the air and the space enclosures. The systems based on this strategy are often called Radiative Cooling Systems, although only approximately 60% of the heat transfer is due to radiation. If the cooling of the surfaces is produced using water as transport medium, the resulting systems are called Hydronic Radiant Cooling Systems (HRC Systems). By providing cooling to the space surfaces rather than directly to the air, HRC Systems allow the separation of the tasks of ventilation and thermal space conditioning. While the primary air distribution is used to fulfill the ventilation requirements for a high level of indoor air quality, the secondary water distribution system provides thermal conditioning to the building. HRC Systems significantly reduce the amount of air transported through buildings, as the ventilation is provided by outside air systems without the recirculating air fraction. Due to the physical properties of water, HRC Systems remove a given amount of thermal energy and use less than 5% of the otherwise necessary fan energy. The separation of tasks not only improves comfort conditions, but increases indoor air quality and improves the control and zoning of the system as well. HRC Systems combine temperature control of the room surfaces with the use of central air handling systems.

Due to the large surfaces available for heat exchange in HRC Systems (usually almost a whole ceiling, and sometimes whole vertical walls), the temperature of the coolant is only slightly lower than the room temperature. This small temperature difference allows the use of either heat pumps with very high coefficient of performance (COP) values, or of alternative cooling sources (e.g., indirect evaporative cooling), to further reduce the electric power requirements. HRC Systems also reduce problems caused by duct leakage, as the ventilation air flow is significantly reduced, and the air is only conditioned to meet room temperature conditions, rather than cooled to meet the necessary supply air temperature conditions. Furthermore, space needs for ventilation systems and their duct work are reduced to about 20% of the original space requirements. Beside the reduction of space requirements for the shafts that house the vertical air distribution system, floor-to-floor height can be reduced, which offsets the initial cost of the additional system.

The thermal storage capacity of the coolant in HRC Systems helps to shift the peak cooling load to later hours. Because of the hydronic energy transport, this cooling system has the potential to interact with thermal energy storage systems (TES) and looped heat pump systems.

Hydronic Cooling Systems

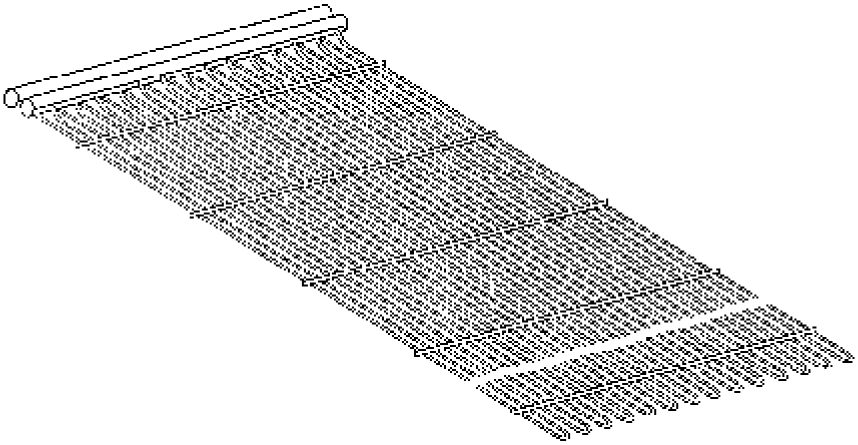
Most of the HRC Systems belong to one of three different system designs. The most often used system is the panel system. This system is built from aluminum panels with metal tubes connected to the rear of the panel.



Suspended Panels Figure courtesy of Flakt

The connection between the panel and the tube is critical. Poor connections provide only limited heat exchange between the tube and the panel, which results in increased temperature differences between the panel surface and the cooling fluid. Panels built in a "sandwich system" include the water flow paths between two aluminum panels (like the evaporator in a refrigerator). This arrangement reduces the heat transfer problem and increases the directly cooled panel surface. In the case of panels suspended below a concrete slab, approximately 93% of the cooling power is available to cool the room. The remaining 7% cools the floor of the room above.

Cooling grids made of small plastic tubes placed close to each other can be imbedded in plaster, gypsum board, or mounted on ceiling panels (e.g., acoustic ceiling elements).



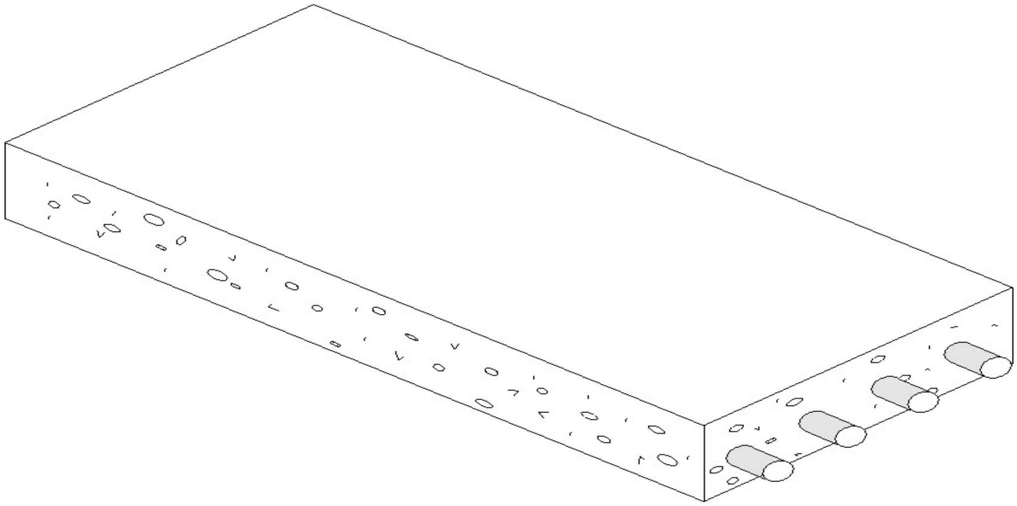
Capillary Tubes Figure courtesy of KaRo Information Service

This second system provides an even surface temperature distribution. Due to the flexibility of the plastic tubes this system might be the best choice for retrofit applications. It was developed in Germany and has been on the market for several years. When the tubes are imbedded in plaster, the heat transfer from above is higher than in the case of cooling panels.

The heat transfer to the concrete couples the cooling grid to the structural thermal storage of the slab. Plastic tubes mounted on suspended cooling panels show thermal performance comparable to the panel systems described above. Tubes imbedded in a gypsum board can be directly attached to a wooden ceiling structure without a concrete slab. Insulation must be applied to reduce cooling of the floor above.

A third system is based on the idea of a floor heating system. The tubes are imbedded in the core of a concrete ceiling. The thermal storage capacity of the ceiling allows for peak load shifting, which provides the opportunity to use this system in association with alternative cooling sources. Due to the thermal storage involved, the control of this system is limited. This leads to the requirement of relatively high surface temperatures to avoid uncomfortable conditions in the case of reduced cooling loads. The cooling power of the system is therefore limited. This system is particularly suited for alternative cooling sources, especially the heat exchange with cold night air. The faster warming of rooms with a particular high thermal load can be avoided by running the circulation pump for short times during the day to achieve a balance with rooms with a lower thermal load.

Due to the location of the cooling tubes in this system, a higher portion of the cooling is applied to the floor of the space above the slab. Approximately 83% of the heat removed by the circulated water are from the room below the slab, while 17% are from the room above.



Concrete Core Conditioning

Obviously, these three system types can also be used to heat a building.

Source: http://epb.lbl.gov/thermal/hydronic.html

Section 9- Hydronic System

Purpose of this Section:

1. Knowing the general operation and some of the pros and cons of steam distribution systems.
2. Knowing the main piping-layout options, pumping requirements and characteristics of Hot water heating systems.
3. Knowing the popular piping arrangements and characteristics of Chilled water systems.
4. Knowing the behavior of a condenser, condenser requirements, and cooling tower operation of Open water systems.

9.1 Introduction

This Section will introduce you to the basic layout options for heating and cooling piping arrangements that distribute water or steam, their hydronic characteristics.

In each case, a flow of water or steam is distributed from a either a central boiler or a **chiller**, the refrigeration equipment used to produce chilled water, to the hydronic circuits. The hydronic circuits circulate the water or steam through the building, where it loses or gains heat before returning to be re-heated or re-cooled.

9.2 Steam

Steam results from boiling water. As the water boils, it takes up latent heat of vaporization and expands to about 1,600 times its original volume at atmospheric pressure. Steam is a gas, and in a vessel, it quickly expands to fill the space available at a constant pressure throughout the vessel. In this case, the relevant space is the boiler(s) and the pipe that runs from the boiler and around the building. The pipe rapidly fills with steam, and the pressure is virtually the same from end to end under no-flow conditions.

When the steam gives up its latent heat of evaporation in an end-use device, such as a coil, fan coil, or radiator, it condenses back to water, and the water is called **"condensate."** This condensate is removed from the steam system by means of a **"steam trap**." Traps are typically thermostatic or float operated.

Thermostatic Trap: In the thermostatic trap, a bellows is used to hold the trap exit closed when heated by steam. The bellows is filled with a fluid that boils at just below the steam temperature. When the trap fills with air or condensate, the temperature drops and the bellows contract, letting the air or condensate flow out. As soon as the air or condensate is expelled and the trap fills with steam, the heated bellows expands, trapping the steam.

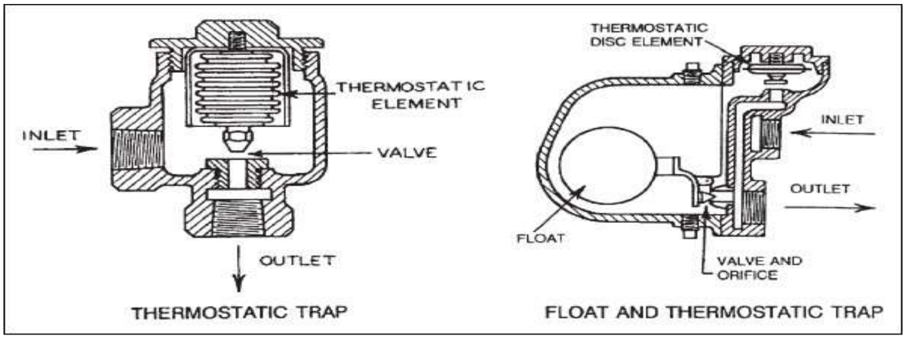


Figure 9.1 Steam Traps

Float and Thermostatic Trap: This versatile trap uses the much higher density of condensate to lift a float to open the trap and release the large quantities of condensate produced under startup and high-load periods. When filling the system, large volumes of air must be vented. The thermostatic element works well for this function. During operation at low loads, the float functions well to drain the slow accumulation of condensate.

Figure 9.2 shows the main components of a small steam system. The condensate is pumped into the boiler where it is boiled into steam. The steam expands down the main and into any heater that has an open valve. As the heater gives off heat, the steam condenses. The condensate collects at the bottom of the heater and is drained away by the trap.

Steam systems are divided into two categories:
Low-pressure systems operate at no more than 15 **"psig"**,
High-pressure systems operate above 15 psig.

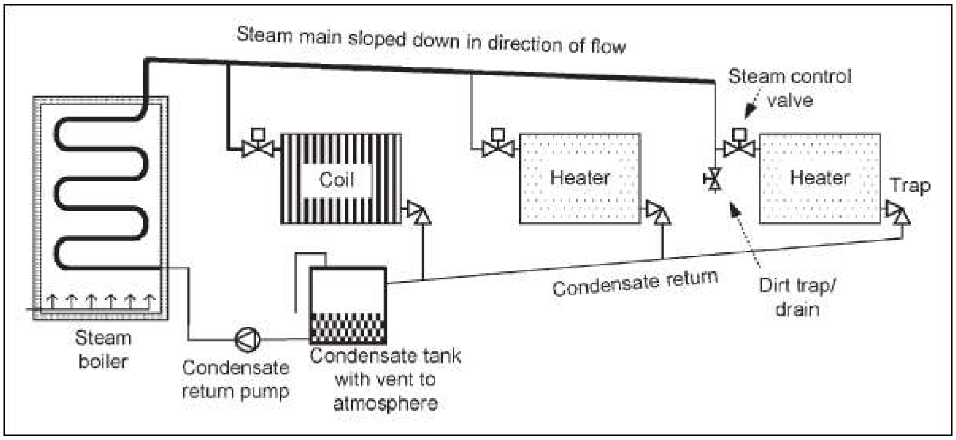


Figure 9.2 Steam System

Safety Issues

In order to maintain the system pressure, the boiler output needs to be continuously balanced with the load. Because steam has the capacity to expand at high velocity in all directions, a poor boiler operation can cause an accident.

The American Society of Mechanical Engineers wrote strict codes for the manufacture of steam boilers and associated piping and equipment. Those codes have drastically reduced the number of failures in North America.

Steam systems need to be installed carefully, maintaining a downward slope of 1 in 500 to avoid condensate collecting, called **ponding**, in the steam pipe.

The advantages of steam are:
1-Very high heat transfer.
2- No need for supply pumps.
3- Easy to add loads because the system adjusts to balance the loads.

9.3 Water Systems

The advantages of water over steam include the fact that water is safer and more controllable than steam.

Water is safer because the system pressure is not determined by continuously balancing the boiler output with load, and because water does not have the capacity to expand at high velocity in all directions.

Water is more controllable for heating since the water temperature can easily be changed to modify the heat transfer.

Water System Design Issues: Pipe Construction

Water for heating and cooling is transferred in pipes that are generally made of steel, copper or iron. Steel is normally a less expensive material and is most popular for sizes over 1 inch. Copper is a more expensive material but it is very popular at 1 inch and narrower.

Water System Design Issues: Pipe Distribution

Heating or cooling water can be piped around a building in two ways, either “**direct return**” or “**reverse return**.” The direct return is diagrammed in *Figure 9.3*.

There is friction to the water flowing through the pipes and the water favors the path of least resistance.

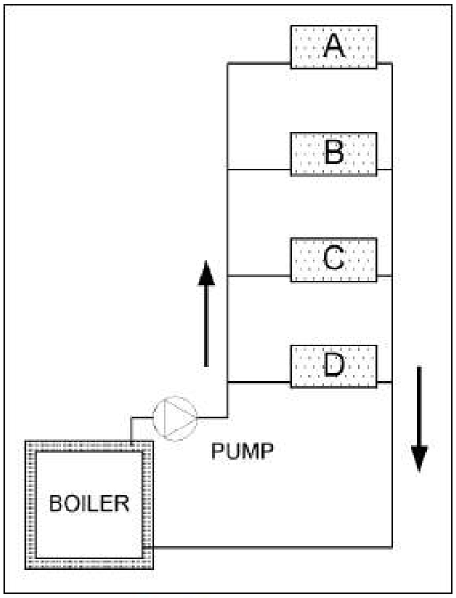


Figure 9.3 Direct Return Piping

In order to have the same flow through all the heaters, extra resistance has to be added to heaters B, C and D. Adding balancing valves, as shown in *Figure 9.4*, makes this possible After the system has been installed, a balancing contractor will adjust the balancing valves to create an equal flow through heaters A and B, then an equal low through heaters Aand C and finally an equal flow through heaters A and D.

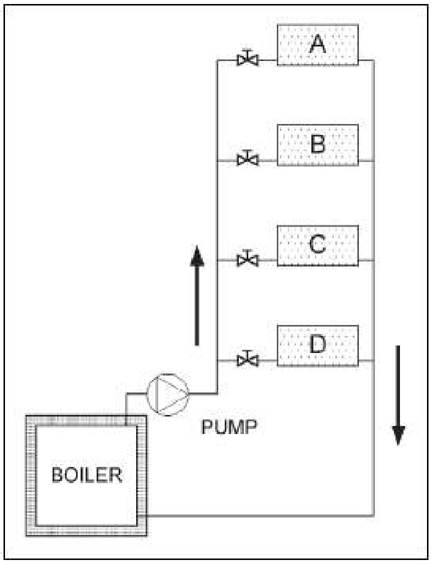


Figure 9.4 Direct Return Piping with Balancing Valves

The reverse return as shown in *Figure* 9.5. Here the pipe length for the flow loop **boiler:pump** : **heater** : **boiler** is the same for all heaters. As a result, the flow will be the same in each heater; the piping is self-balancing.

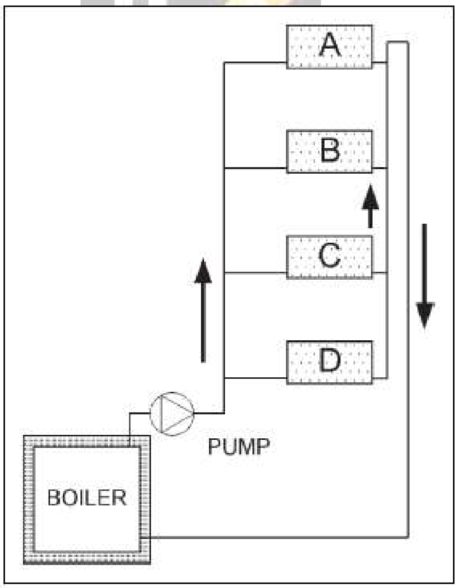


Figure 9.5 Reverse Return Piping

Water System Design Issues: Flow

The resistance to water flow in pipes, called the **head,** is dependent on several factors including surface roughness, turbulence, and pipe size. When we design a system, we calculate the expected resistance for the design flow in each part of the circuit. The sum of the resistances gives the total resistance, or **system head**.

Under normal flow rates, the resistance rises by a factor of 1.85 to 1.9 as the flow rises (flow^1.85 to flow^1.9). Doubling the flow increases the resistance about three and a half times.

The actual **head loss** in pipes is normally read from tables, to avoid repetitive complex calculations. Based on this table data and the knowledge that the head is proportional to flow1.85 we can plot the **system curve** of flow or capacity, versus head.

Pump manufacturers plot the pump head against flow or capacity to produce a **pump curve**. A pump curve and calculated system curve are shown in *Figure* 9.6.

The **operating point** for this pump will be at the intersection of the two curves. In practice, the system curve often turns out to be higher or lower than the calculated design.

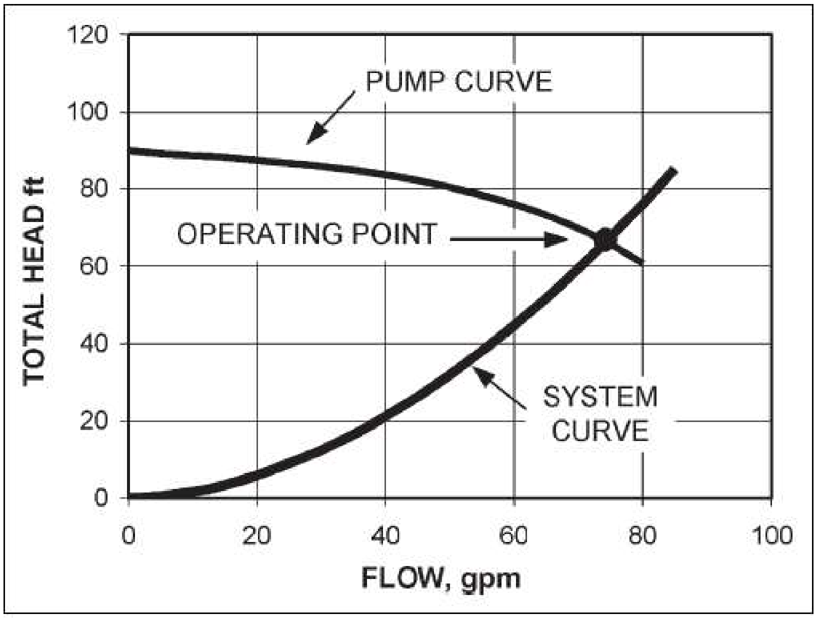


Figure 9.6 System and Pump Curves

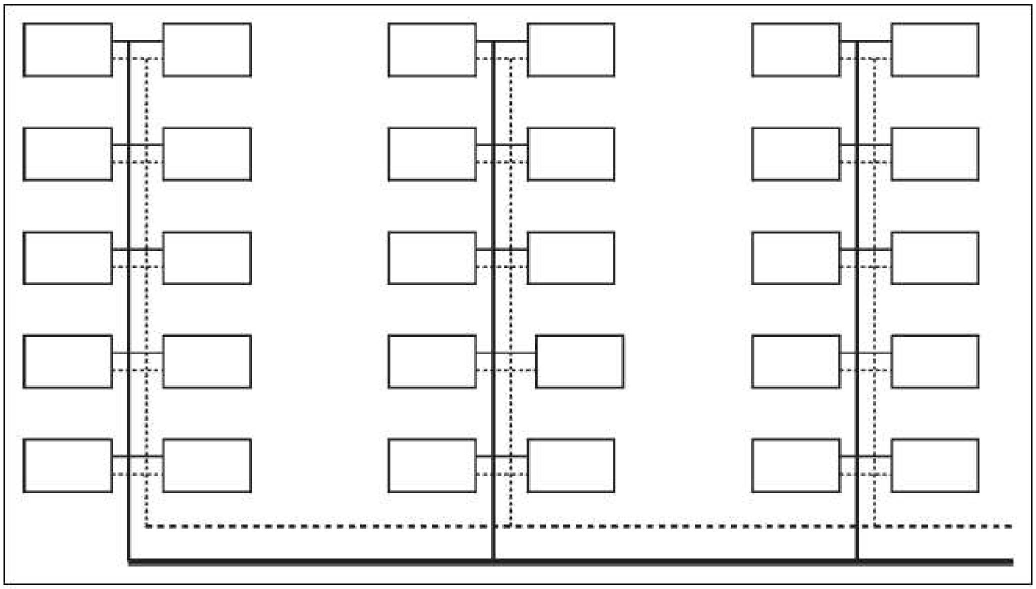


Figure 9.7 Multiple Risers

in the building with a reverse return loop around every floor. This works well for heat pumps mounted in the ceiling, with the pipes running in the ceiling.

Conversely, it often does **not** work very well for equipment, such as radiators, fan coils and induction units, mounted near the floor at the perimeter of the building. For these, multiple risers around the building may be a better solution, as shown in *Figure 9.7*.

9.4 Hot Water

Within buildings, hot water is the fluid that is most commonly used for heat distribution. The amount of heat that is transferred is proportional to the temperature difference between supply and return. Maximizing the supply-return temperature difference minimizes the water quantity and pipe size requirements.

Pipes should be insulated to avoid **wasteful** heat loss. Thus pipes in the boiler room should be insulated, but pipes in a zone that is feeding a radiator may not need to be insulated, since the heat loss just adds to the radiator output.

9.4.1 Energy Efficiency in Hot Water Systems

There are many ways to control and increase energy efficiency in the hot water systems. The control method that we will discuss is the **outdoor reset**, a common control strategy that takes advantage of the temperature differential between the cold outside and the warm inside the building to adjust the heat output. Then we will consider pumps and the energy savings that we can obtain through reducing the flow in hot water systems, The heat loss from a building in cold weather is proportional to the difference between the temperature inside the building and the temperature outside the building.

Methods of varying pump Capacity:

1-**Varying Pump Speed:** Variable speed drives are now readily available and can be used to adjust pump speed according to load. The pump curve remains the same shape, but shrinks as the speed reduces. Typical pump curves for various speeds are shown in *Figure 9.8*.

The figure also shows the **pump shaft power**, which is the power used by the pump, without consideration of any bearing or motor inefficiencies.

2-**Pumps In Parallel** Another way to reduce flow is to use two identical pumps in parallel. Each pump experiences the same head, and their flows add to equal the system flow. A check valve is included with each pump, so that when only one pump is running, the water cannot flow backwards through the pump that is “off.” The piping arrangement is shown in *Figure 9.9*.

With both pumps running, the design flow is at the system operating point.

When one pump is shut off, the flow and head drop to the single pump curve as shown in *Figure 9.8*.

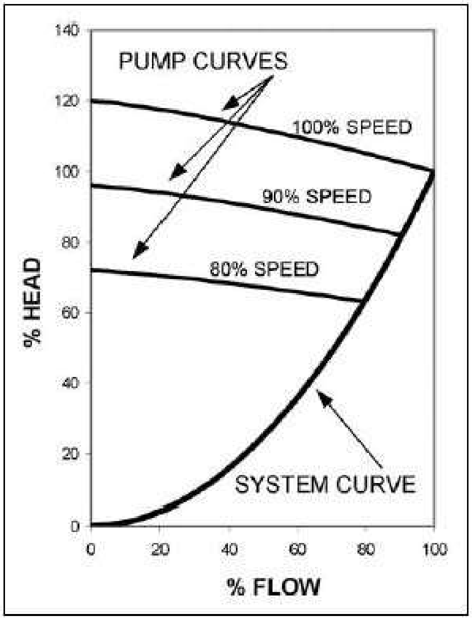


Figure 9.8 Variable Speed Pump Curves

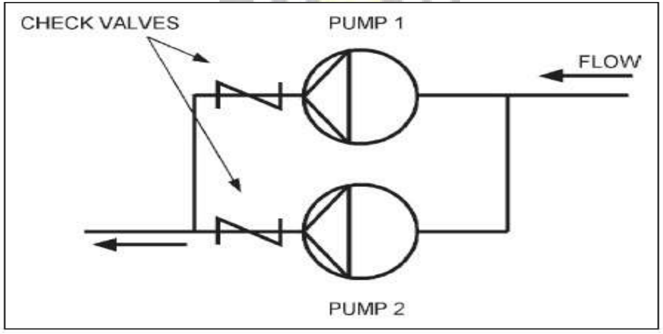


Figure 9.9 Pumps in Parallel

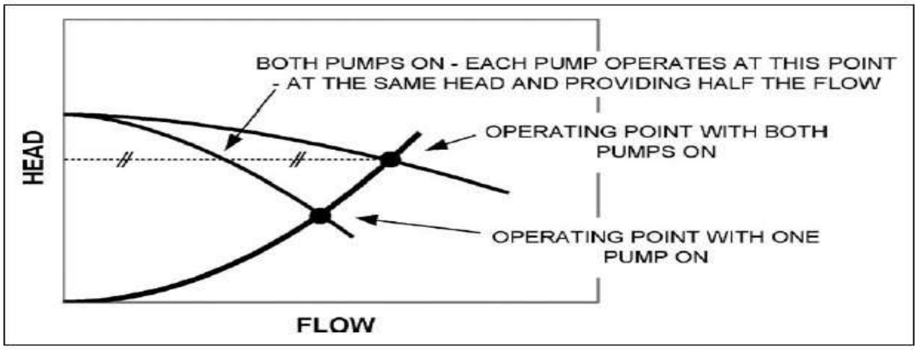


Figure 9.10 Operating Conditions for Parallel Operation

9.5 Chilled Water System

Chilled water typically has a supply temperature of between 42°F and 48°F.
Historically, the return temperature was often chosen to be 10°F above the flow temperature. With the higher cost of fuel and the concern over energy usage, it is usually cost effective to design for a higher difference of 15°F or even 20°F. The higher return temperatures require larger coils, and create challenges when high dehumidification is required.

On the other hand, doubling the temperature difference halves the volume flow, and, consequently, reduces the purchase cost of piping and pumps, as well as substantially reducing ongoing pumping power costs.

Chillers: The refrigeration equipment used to produce chilled water, mostly use a direct expansion evaporator. Therefore, the flow must be maintained fairly constant to prevent the possibility of freezing the water.
A diagram of two chillers and loads is shown in *Figure 9.11*. The two chillers are piped in parallel in their own independent pipe loop, shown bold in the Figure.
The loads in *Figures 9.11* and *9.12* are shown as having two way valves which have no flow when they are closed. If all the valves were to close, the pump would be pumping against a closed circuit. To avoid problems occurring when this happens, a bypass valve is shown across the end of each branch circuit to allow a minimum flow under all conditions.

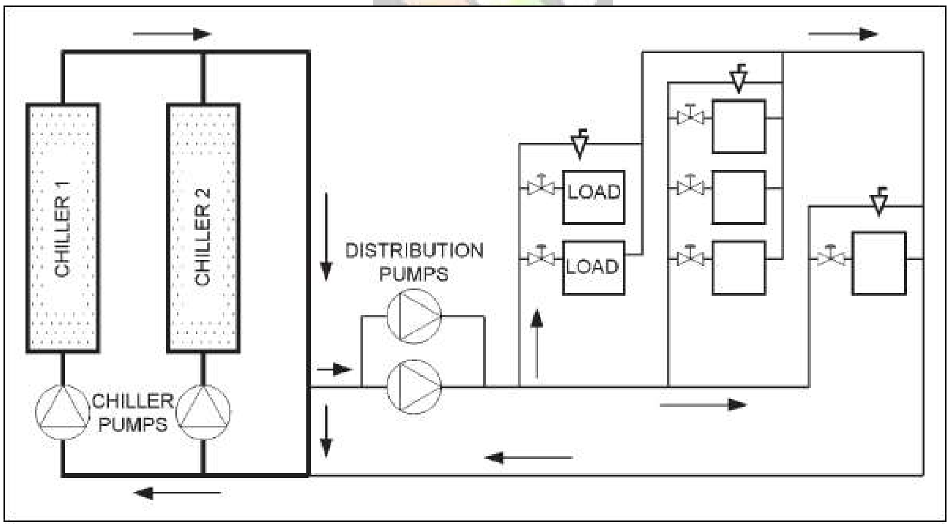


Figure 9.11 Chiller System with Decoupled Flows

In *Figure 9.12* each secondary loop has its own pump, which is sized to deal with its own loop resistance and the main loop resistance. This system allows pumps 1, 2, and 3 to be run independently, when necessary, to serve their own loads.

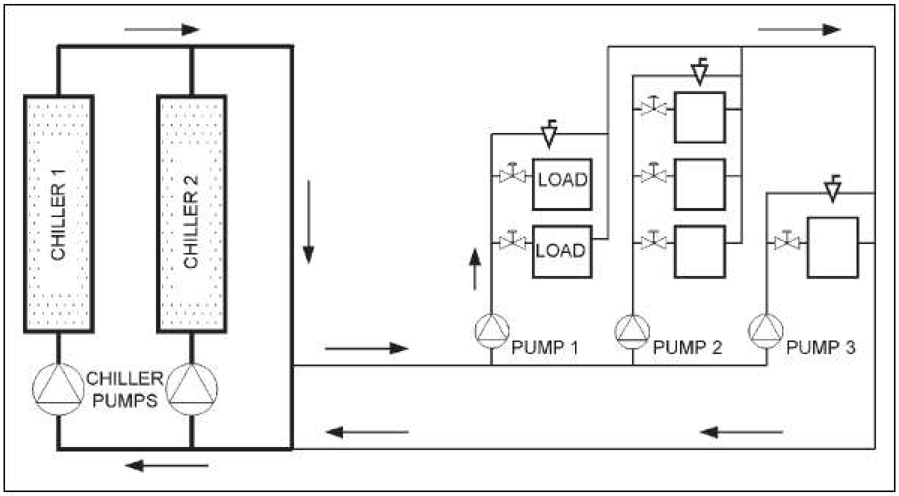


Figure 9.12 Distributed Secondary Pumping

9.6 Condenser Water

Condenser water is water that flows through the condenser of a chiller to cool the refrigerant. Condenser water from a chiller typically leaves the chiller at 95°F and returns from the **cooling tower** at 85°F or cooler.

In *Figure 9.13* the hot, 95°F, water from the chiller condenser flows in at the top. It is then sprayed, or dripped, over fill, before collecting in the tray at the bottom. Air enters the lower part of the tower and rises through the tower, evaporating moisture and being cooled in the process, before exiting at the top.

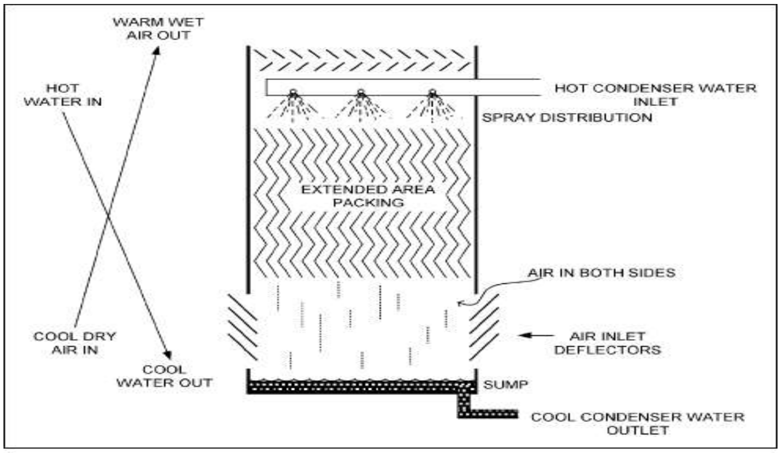


Figure 9.13 Evaporative Cooling Tower

There are Two types of cooling towers :

1. **open-water system.** An open-water system is one with **two**, or more open water surfaces.
2. **closed-water system** has only one water surface.

Figure 9.14 shows an outline elevation of the complete cooling tower and chiller condenser water circuit.

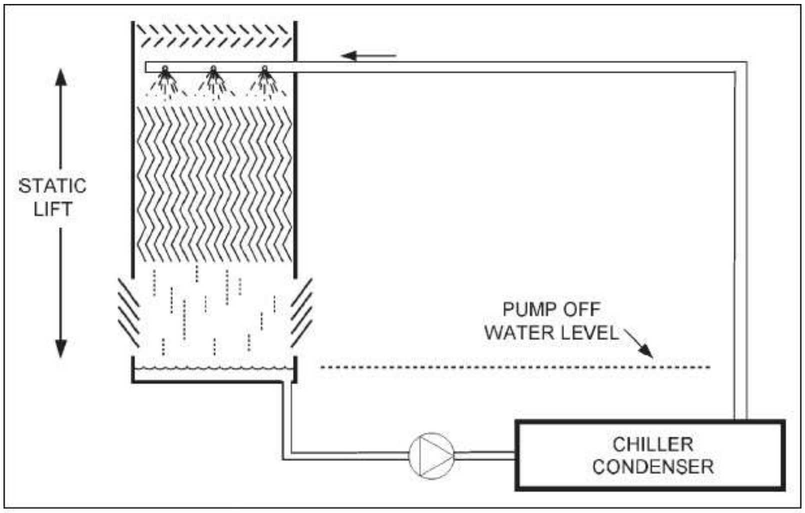


Figure 9.14 Open Water Circuit

The water loop has two water surfaces, one at the top water sprays and one below at the sump water surface. When the pump is "off," the water will drain down to an equal level in the tower sump and in the pipe riser, as indicated by the horizontal dotted line in *Figure 9.14*.

When the pump starts, it first has to lift the water up the vertical pipe before it can circulate it. The distance that the pump has to lift the water is called the "**static lift**."

Once running, the pump has to provide the power to overcome both the static lift and the head, to overcome friction, to maintain the water flow.

Figure 9.15 shows a closed water circuit. It is shown with one water surface open to the atmosphere. Whether the pump runs or not, the water level stays constant. When the pump starts, it only has to overcome friction to establish and maintain the water flow. When the pump stops, the flow stops, but there is no change in the water level in the tank.

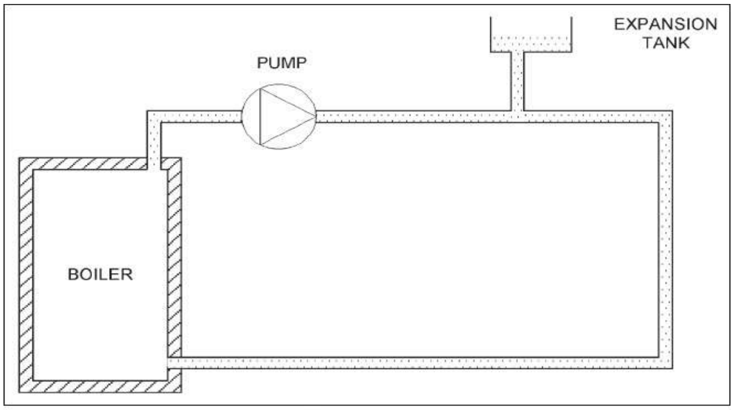


Figure 9.15 Closed Water Circuit

Cooling Tower Design

Although KaV/L can be calculated, designers typically use charts found in the Cooling Tower Institute Blue Book to estimate KaV/L for given design conditions. It is important to recall three key points in cooling tower design:

1. A change in wet bulb temperature (due to atmospheric conditions) will not change the tower characteristic (KaV/L)
2. A change in the cooling range will not change KaV/L
3. Only a change in the L/G ratio will change KaV/L

Where KaV/L = tower characteristic
K = mass transfer coefficient (lb water/h ft^2)
a = contact area/tower volume
V = active cooling volume/plan area
L = water rate (lb/h ft^2)

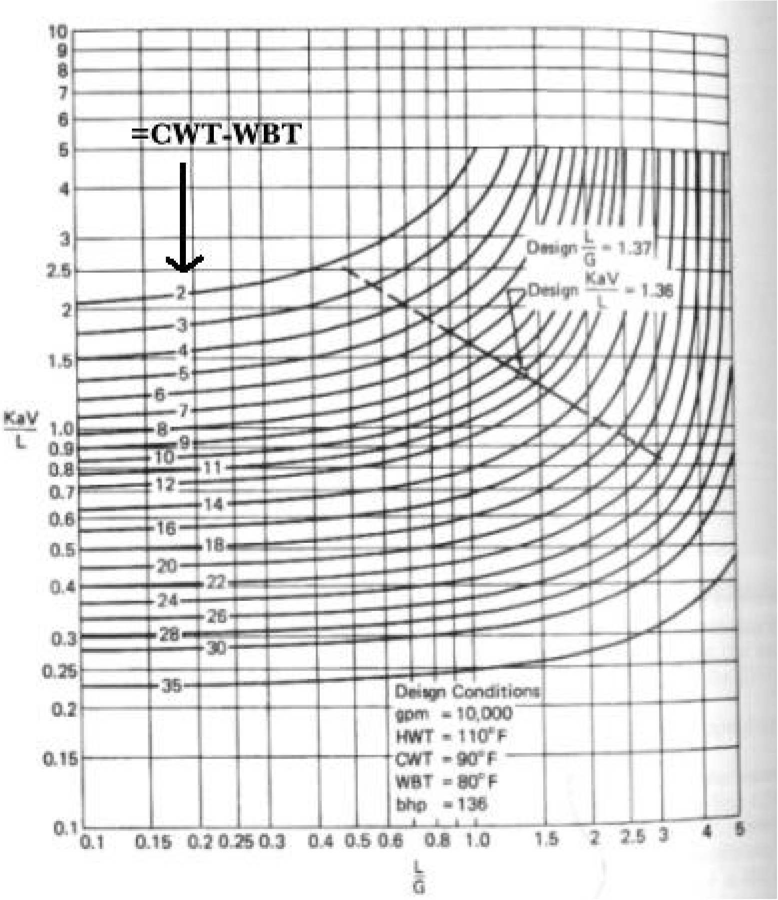


Figure Shows: A Typical Set of Tower Characteristic Curves

The straight line shown in Figure 7 is a plot of L/G vs KaV/L at a constant airflow. The slope of this line is dependent on the tower packing, but can often be assumed to be -0.60. Figure 7 represents a typical graph supplied by a manufacturer to the purchasing company.

From this graph, the plant engineer can see that the proposed tower will be capable of cooling the water to a temperature that is 10 °F above the wet-bulb temperature. This is another key point in cooling tower design. Cooling towers are designed according to the highest geographic wet bulb temperatures. This temperature will dictate the minimum performance available by the tower.

As the wet bulb temperature decreases, so will the available cooling water temperature. For example, in the cooling tower represented by Figure 7, if the wet bulb temperature dropped to 75 °F, the cooling water would still be exiting 10 °F above this temperature (85 °F) due to the tower design.

Below is the summary of steps in the cooling tower design process in industry. More detail on these steps will be given later.

1. Plant engineer defines the cooling water flowrate, and the inlet and outlet water temperatures for the tower.
2. Manufacturer designs the tower to be able to meet this criterion on a "worst case scenario" (ie. during the hottest months). The tower characteristic curves and the estimate is given to the plant engineer.
3. Plant engineer reviews bids and selects

Design Considerations

Once a tower characteristic has been established between the plant engineer and the manufacturer, the manufacturer must design a tower that matches this value.

The required tower size will be a function of:

1. Cooling range
2. Approach to wet bulb temperature
3. Mass flowrate of water
4. Web bulb temperature
5. Air velocity through tower or individual tower cell
6. Tower height

In short, nomographs such as the one shown on page 12-15 of Perry's Chemical Engineers' Handbook 6th Ed. utilize the cold-water temperature, wet bulb temperature, and hot water temperature to find the water concentration in gal/min ft^2. The tower area can then be calculated by dividing the water circulated by the water concentration. General rules are usually used to determine tower height depending on the necessary time of contact:

Approach to Wet Bulb (^{0}F)	Cooling Range (^{0}F)	Tower Height (ft)
15-20	25-35	15-20
10-15	25-35	25-30
5-10	25-35	35-40

Operation Considerations

Water Make-up

Water losses include evaporation, drift (water entrained in discharge vapor), and blowdown (water released to discard solids). Drift losses are estimated to be between 0.1 and 0.2% of water supply.

Evaporation Loss = 0.00085 * water flowrate(T_1-T_2) (5)
Blowdown Loss = Evaporation Loss/(cycles-1) (6)
where cycles is the ratio of solids in the circulating water to the solids in the make-up water
Total Losses = Drift Losses + Evaporation Losses + Blowdown Losses (7)

Cold Weather Operation

Even during cold weather months, the plant engineer should maintain the design water flowrate and heat load in each cell of the cooling tower. If less water is needed due to temperature changes (ie. the water is colder), one or more cells should be turned off to maintain the design flow in the other cells. The water in the base of the tower should be maintained between 60 and 70 °F by adjusting air volume if necessary. Usual practice is to run the fans at half speed or turn them off during colder months to maintain this temperature range.

Where: T_1 = hot water temperature (°F or °C)
T_2 = cold water temperature (°F or °C)
T = bulk water temperature (°F or °C)

Source: http://www.cheresources.com/ctowerszz.shtml

Section 10 - Central Plants

Purpose of this Section:

1. Discussing some advantages and disadvantages of central plants.
2. Identifying the main types of boiler and sketch a twin boiler circuit.
3. Describing the operation of chillers, and be able to sketch a dual chiller installation.
4. Understanding the operation of cooling towers and what affects their performance.

10.1 Introduction

In a central plant, the boilers and chillers are located in a single space in the building, and their output is piped to all the various air-conditioning units and systems in the building.

Their initial cost is often higher than packaged units but it requires less maintenance than numerous smaller package systems and the equipment usually has a longer life.

The equipment's used in the central plant are:

1-**Boilers** are pressure vessels and their installation and operation are strictly prescribed by codes.

2-**Chillers** come in a huge range of sizes and types, The job of the chiller is to remove heat from the chilled water and reject it to the condenser. The condensers are often water-cooled by a cooling tower.

3-**Cooling towers** are devices used to cool water by evaporation. Water is sprayed or dripped over material with a large surface area, while outdoor air is drawn through.

10.2 Central Plant Versus Local Plant in a Building

There is no rule about when a central plant is the right answer or when distributed packages or systems should be used. Circumstances differ from project to project, The good designer will assess each project on the merits of that situation and involve the client in making the most suitable choice for the project.

Here are some true statements in favor of central plants. Read them. Can you think of a reason why each one of them might, in some circumstances, be wrong, or irrelevant?
Let us consider each of these statements in turn.

"It is easy to have someone watching the plant if it is all in one place."

This statement is true if visual inspection of the plant is useful. A hundred years ago, the look and sound of the plant were the best, and only, indicators of performance. Now, in the 21st century, plant is much more complex and we have excellent monitoring equipment available at a reasonable price.

So instead of paying someone to physically watch the central plant, the building owner can pay someone to monitor the performance of, not just the central plant, but all the plant, regardless of where it is located in the buildings.

"The large central plant equipment is always more efficient than small local plant,"
This generally true but not always relevant. For example, an apartment building might have a large central boiler that provides both hot water for heating, and domestic hot water. In winter this is an efficient system.

However, throughout the summer the boiler will be running sporadically at very low load. It will take a considerable amount of energy The unit has a high efficiency at full load but when its efficiency is averaged over the year, "**seasonal efficiency**,"

10.3 Boilers

Boilers come in a vast range of types and sizes. The critical design factor is pressure. Boilers are fitted with safety valves that release the steam or water if the pressure rises significantly above the design pressure.
A "low-pressure" steam boiler operates at a pressure of no more than **15 psig,**

Boiler Components

1-**The combustion section** is the space in which the fuel-air mixture burns.

2-**The heat-transfer section.** This section comprises the two upper spaces in *Figure 10.1*, where the hot gases pass right to- left and then left-to-right, before exiting to go up the flue.

In large boilers, the heat transfer section will be fabricated of cast iron sections that are bolted together, or of welded steel plate and tubes, in smaller, particularly domestic, boilers, the heat-transfer section may be fabricated from copper, aluminum or stainless-steel sheet. Boilers can be designed for any fuel: electricity, gas, oil, or coal is the most usual.

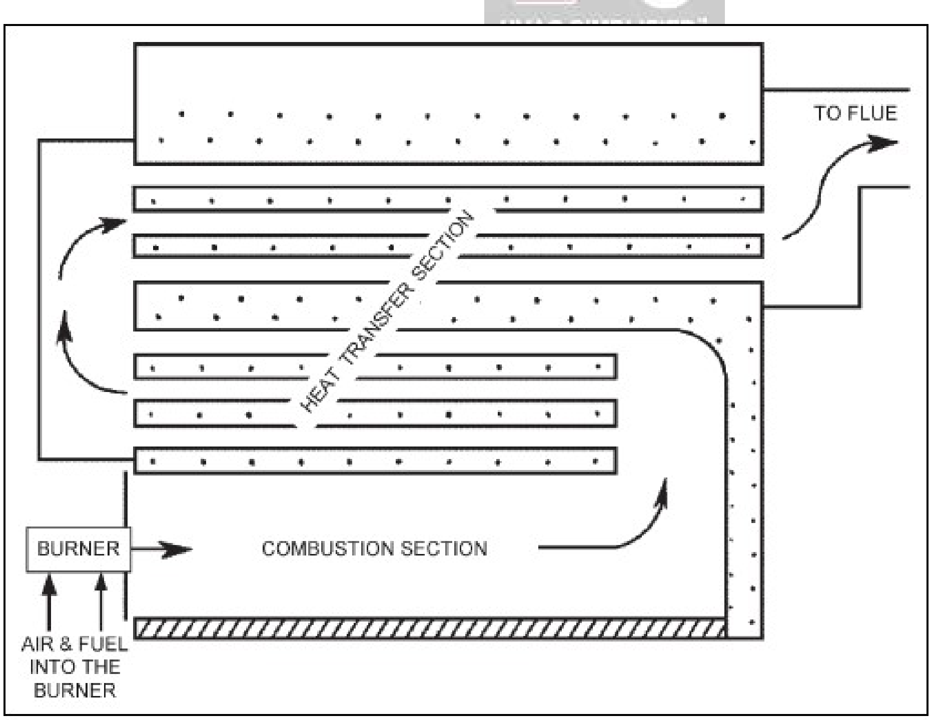


Figure 10.1 Three-Pass Commercial Water Tube Boiler

In all boilers, there is a need to modulate the heat input. Gas and oil burners may be cycled "on" and "off."

On larger units, a modulating burner will usually be installed that can adjust the output from 100% down to some minimum output. The burner modulation range is called the "**turn-down ratio**," which is the ratio between full "on" and the lowest continuous operation. A burner that can operate at anywhere from 100% output down to 10% output has a 10:1 turn-down ratio.

Figure 10.2 shows a hot water system with two boilers.
-The boilers
-Two pumps
-A pressure tank
-A spring-loaded safety valve
-A low water detector/cutout

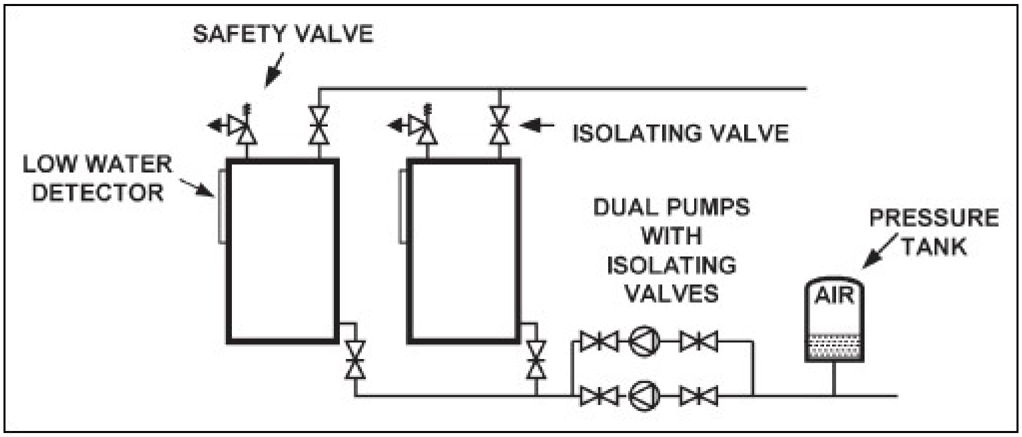


Figure 10.2 Hot Water Heating System with Two Boilers

In steam systems, the makeup water must be treated to remove oxygen and dissolved solids before it enters the boiler. This is to prevent the boiler from filling with dissolved solids, since steam (pure water) is continuously boiled off.

The steam is very corrosive, so a chemical treatment is included to offset the corrosive characteristics. Thus, there is a need for frequent monitoring, since any failure of treatment can cause problems in the boiler and distribution systems.

10.4 Chillers

Shown in *Figure 10.3*, is fundamentally the same as the basic refrigeration circuit Instead of the evaporator and condenser being air-cooled, they are now water-cooled.

Chilled water: The water that flows through the evaporator coil gives up heat, and becomes cooler.

Condenser water: The water that flows through the condenser, becomes warmer and is piped away to a cooling tower to be cooled

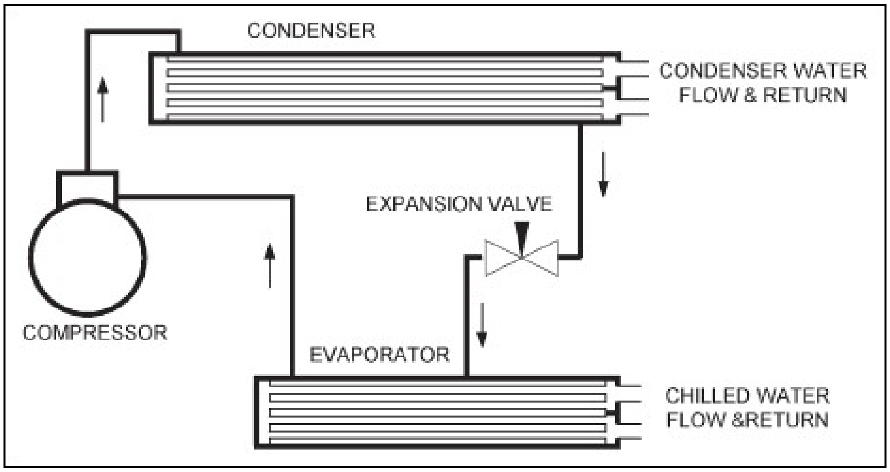


Figure 10.3 Water Chiller with Water Cooled Condenser

The size of the cooling load determines the requirements for chiller capacity. The standard measure of chiller capacity is the **ton**.

Ton refrigeration: a heat absorption capacity of 12,000 Btu per hour.

The main difference between chillers is the type of compressor:

Reciprocating units: Small compressors, very much like an automobile engine, with pistons compressing the refrigerant.

Positive-displacement: They are Larger units that may have screw or scroll compressors. since they have an eccentric scroll or screw that traps a quantity of refrigerant and squeezes it into a much smaller volume as the screw or scroll rotates.

Centrifugal compressor: Are used for 75 tons up to the largest machines, It has a set of radial blades spinning at high speed that compress the refrigerant.

Maintenance work can be carried out during the cooling season during times of low load.
A variable chilled water flow arrangement is shown in *Figure 10.4*. The chillers are shown with the condensers dotted, since they are not relevant to the chilled water circuit.

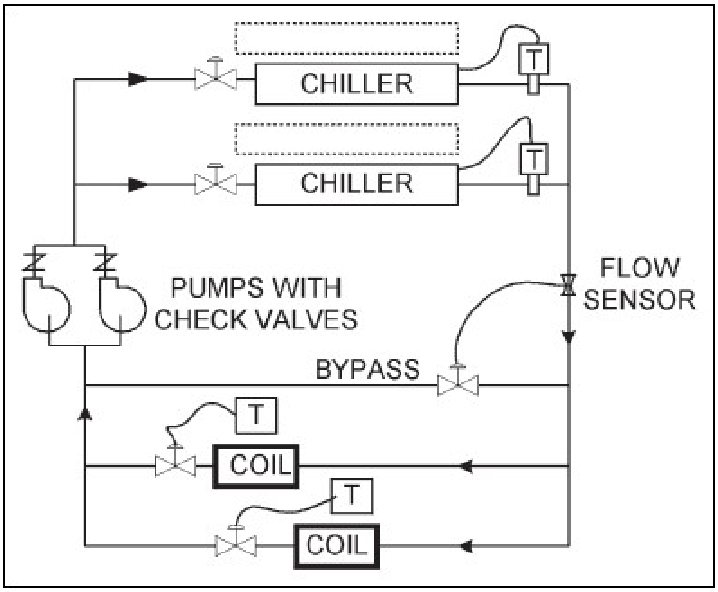


Figure 10.4 Two Chiller Piping with Constant Chiller Flow

Load estimation is quite accurate nowadays, so chillers should be sized to match the estimated load without a 'safety' factor.
If the chiller is a little undersized, there will be a few hours more a year when the chilled water temperature will drift up a bit. This is generally far better than over-sizing due to economic reasons.

10.5 Cooling Towers

Cooling towers are a particular type of big evaporative cooler

The following description details the sequence of activity in the natural-draft tower, shown in *Figure 10.5*

1. Hot water (typically at 95°F,) is sprayed down onto an extended surface "**fill**."
2. The water coats the fill surface and flows down to drop into the sump at the bottom.
3. At the same time, air is entering near the bottom and rising through the wet fill.
4. Some of the descending water evaporates into the rising air and the almost saturated air rises out of the tower.
5. The latent heat of evaporation, absorbed by the water that does evaporate, cools the remaining water.
6. The cooled water in the sump is then pumped back to the chiller to be reheated.

The cooling performance and consistency of operation under various weather conditions can be greatly improved by using a fan to either drive (forced draft) or draw (induced draft) the air through the cooling tower.

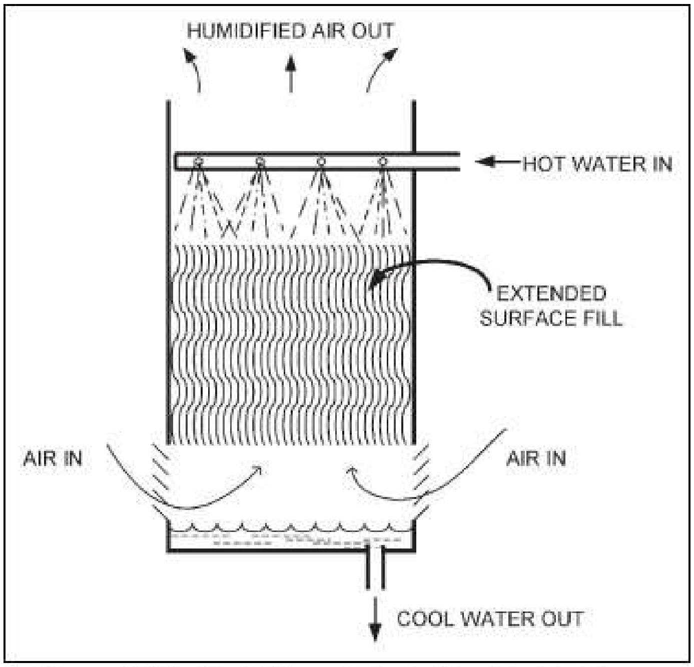


Figure 10.5 Typical Natural-Draft Open Cooling Tower

An array of sheets, called "**drift eliminators**" is included to catch the drops and return the water to the spray area.

In the open cooling tower, the condenser water is exposed, or open, to the air and it will collect dirt from the atmosphere. Strainers will remove the larger particles but some contamination is inevitable. This contamination can be avoided by using a closed-cooling tower, as is shown in *Figure 10.6*.

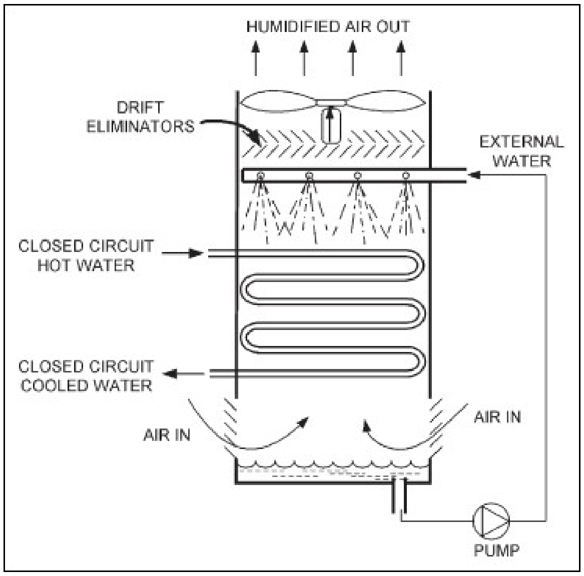


Figure 10.6 Induced Draft, Closed Circuit Cooling Tower

Here, the fluid to be cooled is contained in a coil of pipe in place of the fill. This closed tower is an induced-draft tower (the fan draws the air through the tower) and includes drift eliminators.

In a typical cooling tower, at full load, the closed-circuit fluid, water or refrigerant, can be cooled 30–35°F cooler than with an air-cooled coil. This substantially increases the performance of the refrigeration system.

Operation of the cooling tower:

On the left, the warm water is falling and becoming cooler while on the right, air rises through the tower and becomes more saturated with water vapor. The evaporating water absorbs its latent heat of evaporation from the surrounding air and water before it is carried up and out of the tower in the flow of air. In effect, the air is a vehicle for removing the evaporated water.

The cooling performance of the tower is dependent on the enthalpy of the ambient air entering the tower.

Figure 10.7 shows the basic operation of the cooling tower.

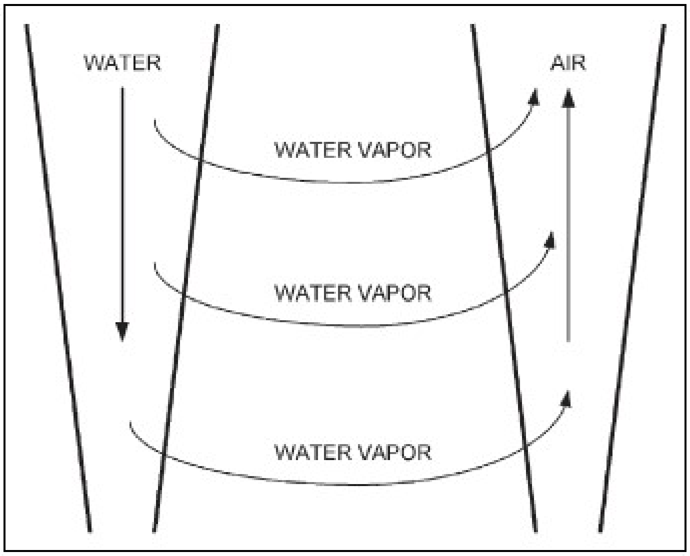


Figure 10.7 Flow of Water, Water Vapor, and Air in a Cooling Tower

Look at *Figure 10.8*, and consider these **two scenarios**:

Scenario 1: Air at Condition 1, enters the tower and is heated and humidified and leave the tower virtually saturated at Condition 3. As the water cools, it provides heat to raise the air temperature

In thus case :

Total latent heat of evaporation _ Reduction in water enthalpy _ air cooling effect

Scenario 2: When warmer air, at roughly the same enthalpy, enters the tower at Condition 2, it will be cooled and humidified as it passes through the tower to leave at Condition 3. The reduction in air temperature is achieved through additional evaporation.

In this case:

Total latent heat of evaporation _ Reduction in water enthalpy _ air heating effect

10.6 Extras

How to Choose a Chiller

Chillers provide heat removal for a wide variety of processes and equipment. When properly sized and selected, a chiller increases production speed and accuracy, protects valuable process equipment, and reduces water consumption and related costs. If it is undersized, the chiller will never cool properly; if it is oversized, it will be inefficient due to excessive cycling. In addition to having an adequate cooling capacity, the chiller must deliver the cooling fluid at the proper pressure and flow rate.
Here are the four basic factors that affect chiller sizing and selection:

1. Desired coolant temperature. This is the coolant temperature at the inlet of your process or equipment. It is important to measure the temperature at this point to allow for coolant heating as it travels from the chiller to the process. The longer the distance to be covered, the higher the potential heat gain. This heat gain can be minimized by insulating the cooling line and positioning the chiller as closely as practical to the equipment or process being cooled.

2. Heat load. This is the amount of heat that needs to be removed. It is usually expressed in BTU/hour or watts. The heat load value is often provided by the equipment manufacturer. If not, it can be calculated using the following formula:

Heat load = Flow rate x Fluid density x Fluid specific heat x Constant x T°

		BTU/hour	Watts
Flow rate	=	Gallons/minute	Liters/minute
Fluid density	=	Pounds/gallon	Grams/liter
Fluid specific heat	=	BTU/pound°F	Joules/gram°C
Constant	=	60	0.016666667
⌉ T° = the difference between the inlet and outlet temperatures of the equipment being cooled	=	°F	°C

Properties of Common Cooling Fluids

Fluid	Fluid Density		Specific Heat	
	Lbs/gal	Grams/liter	BTU/lb°F	Joules/gram°C
Water @ 77° (25°C)	8.333	1000	1	4.181
50% water, 50% propylene glycol @ 50°F (10°C)	8.744	1049.25	0.835	3.493
50% water, 50% ethylene glycol @ 50°F (10°C)	8.992	1078.72	0.776	3.245

It is generally recommended that 20 to 50% be added to the calculated heat load to provide a safety factor if the chiller will be operated at ambient temperatures above 68°F (20°C) or at high altitude, or if the heat output of the device is variable. This will also provide a margin of safety for future cooling needs. That said, resist the temptation to build more of a safety margin into your chiller than is necessary; an oversized chiller will not cool your equipment any more effectively but will cost more to purchase and operate.

3. Coolant flow and pressure. These parameters are normally provided by the equipment manufacturer and are a function of the surface area and the heat transfer characteristics of the process/material being cooled. It is crucial that your chiller deliver coolant at the proper flow rate and pressure — if the flow rate or pressure is too high, the equipment being cooled may be damaged; if it is too low, the heat removal will be inadequate. Your chiller supplier can help you specify the type and size of coolant pump most suitable for your needs.

4. Condenser heat dissipation. The final factor influencing chiller/heat exchanger selection is how the heat removed

will be dissipated. Devices with air-cooled condensers exhaust heat into the surrounding air and require only power and ventilation for operation. Devices with water-cooled condensers transfer heat to the facility's cooling water supply.

Chillers with remote condensers (i.e., the condenser is located outside the facility) are also available. These are quieter, require less space, and do not add heat to the building interior, thus reducing summer cooling costs.

However, they are more expensive to install and are not easily relocated.

Naturally, there are other factors — such as ambient temperature, heating capability, remote temperature tracking, DI water capability, etc. — that affect how a chiller is ultimately configured. PolyScience will take all these into consideration when helping you select the best chiller for your particular application.

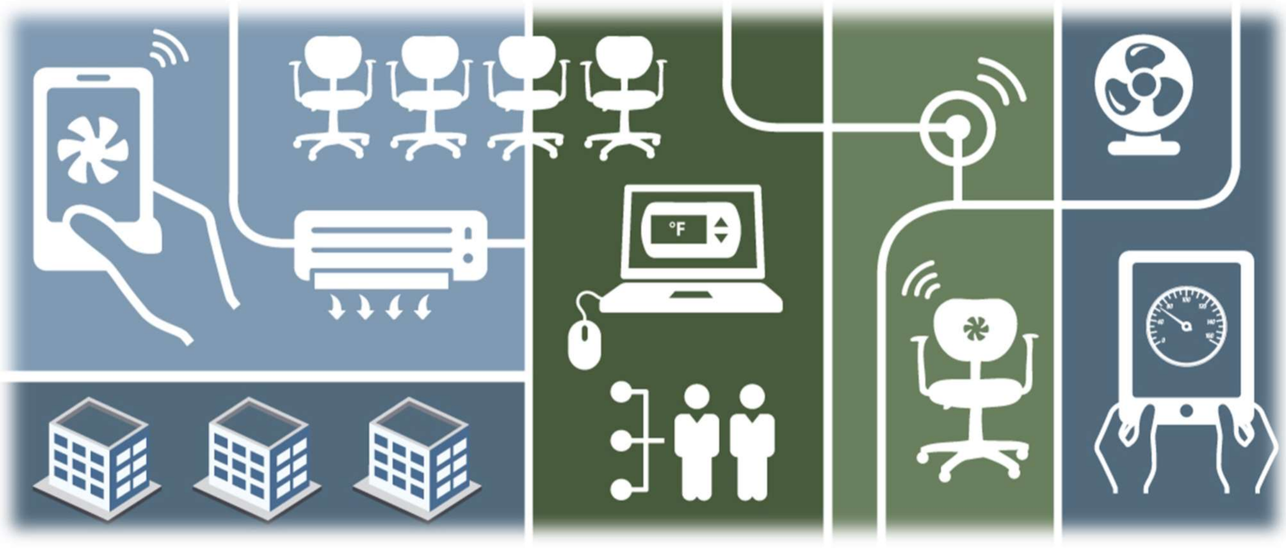
If possible, please have the following information when you contact us:

- Desired coolant temperature at the inlet to your equipment or process
- Anticipated heat load, as calculated or specified by the equipment manufacturer
- Cooling fluid flow rate and pressure requirements
- Internal heat dissipation, space, and portability needs
- Environmental factors (such as ambient temperature, air cleanliness, etc.)
- Special requirements, such as remote temperature tracking or DI piping

Section 11 – HVAC Controls

Purpose of this Section:

1. Explaining the following terms: normally open valve, modulating, proportional control, controlled variable,
   Set point, sensor, controller, and controlled device.
2. Describing an open control loop and a closed control loop and explain the difference between them.
3. Explaining how the DDC system replaces conventional controllers.
4. Listing the four main DDC point types and give an example of each one.
5. Explaining how the knowledge in a DDC system can be put to good use.



11.1 Introduction

Every piece of equipment that we have introduced in this course requires controls for operation. Some equipment, such as a rooftop package unit, will likely come with factory-installed controls, except for the thermostat. The thermostat has to be mounted in the space and wired to the packaged unit. In other built-up systems, every control component may be specified by the designer and purchased and installed under a separate contract from the rest of the equipment.

Whether the controls are a factory package or built-up on site, well-designed controls are a critical part of any HVAC system.

Design considerations for controls choices include availability of expertise in maintenance and operations of the controls, repair and maintenance expense budgets and capital costs of control equipment.

Control Types:

Self-powered Controls:

require no external power. Various radiator valves and ceiling VAV diffusers have self-powered temperature controls. These units are operated by the expansion and contraction of a bellows that is filled with a wax with a high coefficient of expansion.

Electric Controls:
Are powered by electricity. There are two types:
-*On/off Electric Controls* (The electric thermostat is the most common example).

-*Modulating Electric Controls* (provide variable control).

Pneumatic Controls:
are controls that use air pressure: the signal transmission is by air pressure variation and control effort is through air pressure on a diaphragm or piston.

The controller will compare the thermostat line pressure with the setpoint pressure and, based on the difference, adjust the pressure to the heating valve to open, or to close, the valve. The heating valve will typically have a spring to drive it fully open and the increasing air pressure will close the valve against the spring.

The valve is called a "**normally open**" valve, since failure of the air system would have air pressure fall to zero and the spring would open the valve. A "**normally closed**" valve is the opposite, with the spring holding it closed until the air pressure opens the valve.

Electronic Controls:
use varying voltages and currents in semiconductors to provide modulating controls.

Direct Digital Controls, DDC:
are controls operated by computer processors. The computer processor uses a software program of instructions to make decisions based on the available input information. The processor operates only with digital signals and has a variety of built-in interface components so that it can receive information and output control signals.

11.2 Basic Control

1- The simplest of controls, "on-off." the element being controlled is either "on," or "off."
2- Modulating controls. (Modulating means 'variable'. One type of modulating control is **proportional control**. This is best explained with a 'hands-on' demonstration.

Now let's consider some HVAC examples.
There are two types of control "**closed loop**" and "**open loop**." Let us start by considering the main components of a closed loop control as shown in *Figure 11.1*.

The top half of the figure illustrates a simple air heating control loop. A temperature sensor measures the temperature of the heated air and sends that information to the controller. The controller is also provided with the required setpoint (similar to the setting on the front of a room thermostat). The controller first compares the measured temperature with the setpoint and, based on the difference, generates an output signal to the valve.

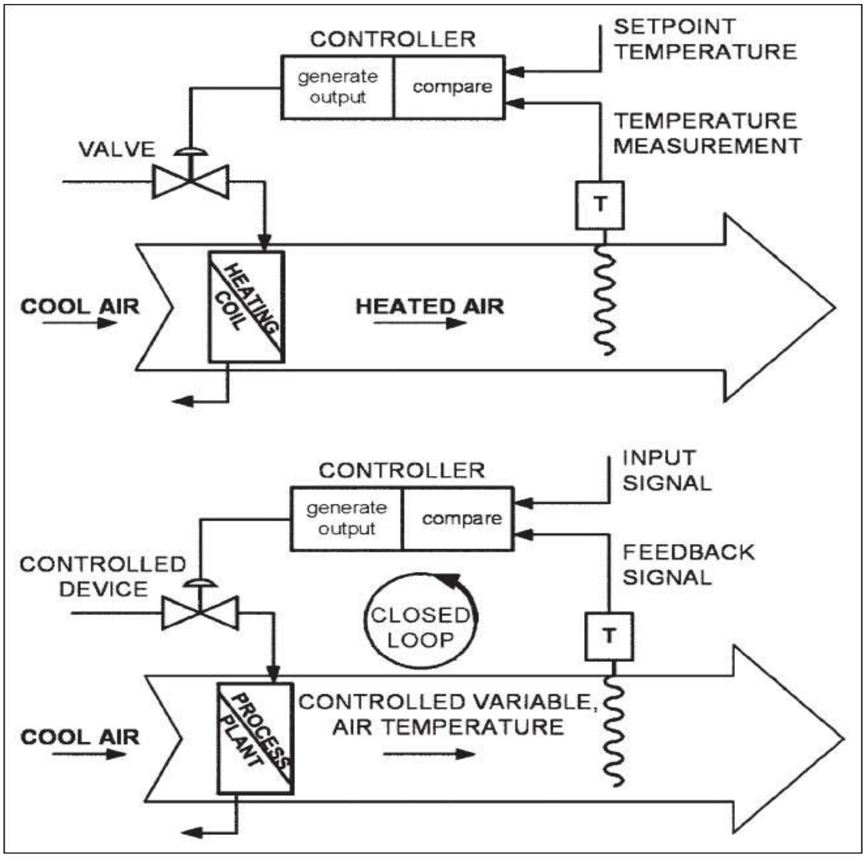


Figure 11.1 Closed Loop Control

The lower part of the figure is the same process with the generic names for the parts of the control loop.

The "**controlled variable**" is the variable, in this case, temperature, that is being controlled. Controlled variables are typically temperature, humidity, pressure and fan or pump speed.

The "**setpoint**" is the desired value of the controlled variable. In this example it is the air temperature that is required. The "**sensor**" measures the controlled variable and conveys values to the controller. in this case the sensor measures temperature.

The "**controller**" seeks to maintain the setpoint. The controller compares the value from the sensor with the setpoint and, based on the difference, generates a signal.
The "**controlled device**" responds to signals received from the controller to vary the process So far, we have been discussing closed loop control controller makes continuous adjustments in order to maintain conditions that are close to the setpoint.

Another type of control called "**open loop**" control, where there is no feedback. *Figure 11.2* illustrates the same closed control loop as in *Figure 11.1*, but with outdoor reset added. The ambient (outdoor) temperature sensor provides.

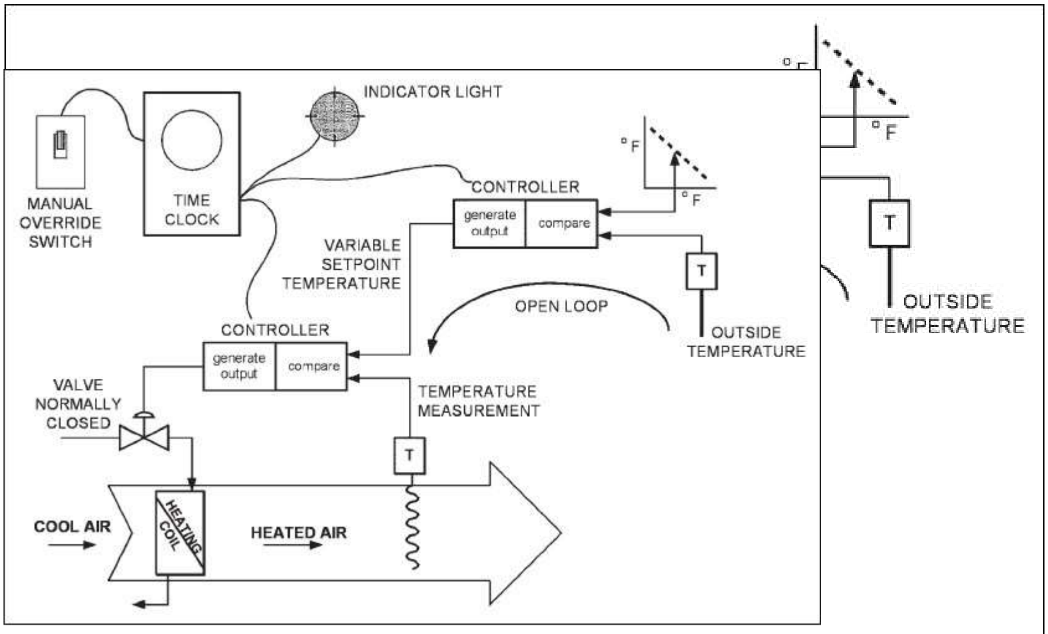


Figure 11.3 Controls with Time Clock Added

Figure 11.2 Open and Closed Control Loops

11.3 Typical Control loops

Having considered the basics of control loops in the previous section, now lets look at some real, more complete, control loops. We will start by adding time control, another open loop, to our previous example, as *Figure 11.3*.

A time clock now provides power to the controllers according to a schedule. Typical commercial thermostats include the 5–1–1 time clock function. 5–1–1 means that they have independent time schedules for the 5 weekdays, 1 for Saturday, and 1 for Sunday. This issue of staging controls so that energy use is minimized is important in many areas. An example is the sequencing of control in a VAV box with a reheat coil. A VAV system provides cold air for cooling and ventilation. Should a zone require less cooling than is provided at the minimum airflow for ventilation, then the reheat coil is turned on. In the control system for the box,

There are two important requirements:

1. The heating coil must only be activated at minimum airflow.
2. There must be minimal cycling between 'coil on' and 'coil off'.

As an example, the box and controller actions are shown in *Figure 11.4*. Starting on the left, when the space is cold, the controller opens the heating valve fully. As the zone warms up, the controller closes the heating valve.

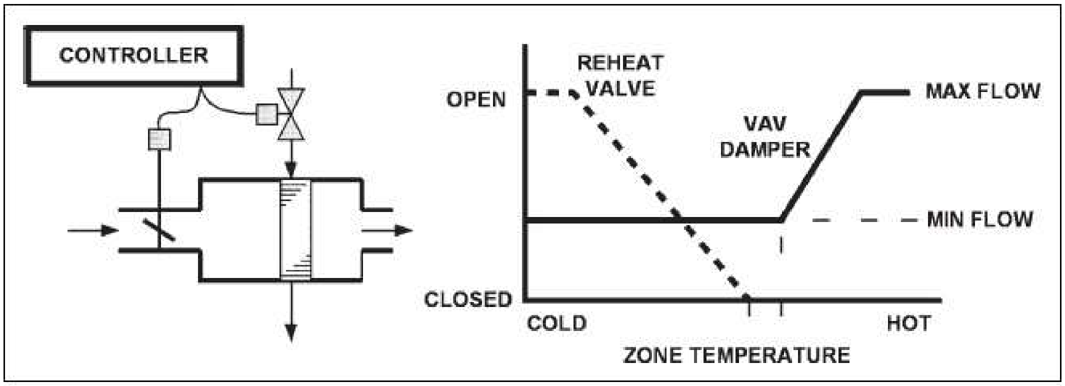


Figure 11.4 VAV Box with Reheat

11.4 Introduction to Direct Digital Control, DDC

A small computer processor operates Direct Digital Controls, DDC. ‘Digital’ means that they operate on a series of pulses, In the DDC system, all the inputs and outputs remain, however, they are not processed in the controllers, but are carried out in a computer, based on instructions called the “**control logic**.”

Figure 11.5, which follows, is the same control diagram that we saw in *Figure 11.3*, but with the controlling components

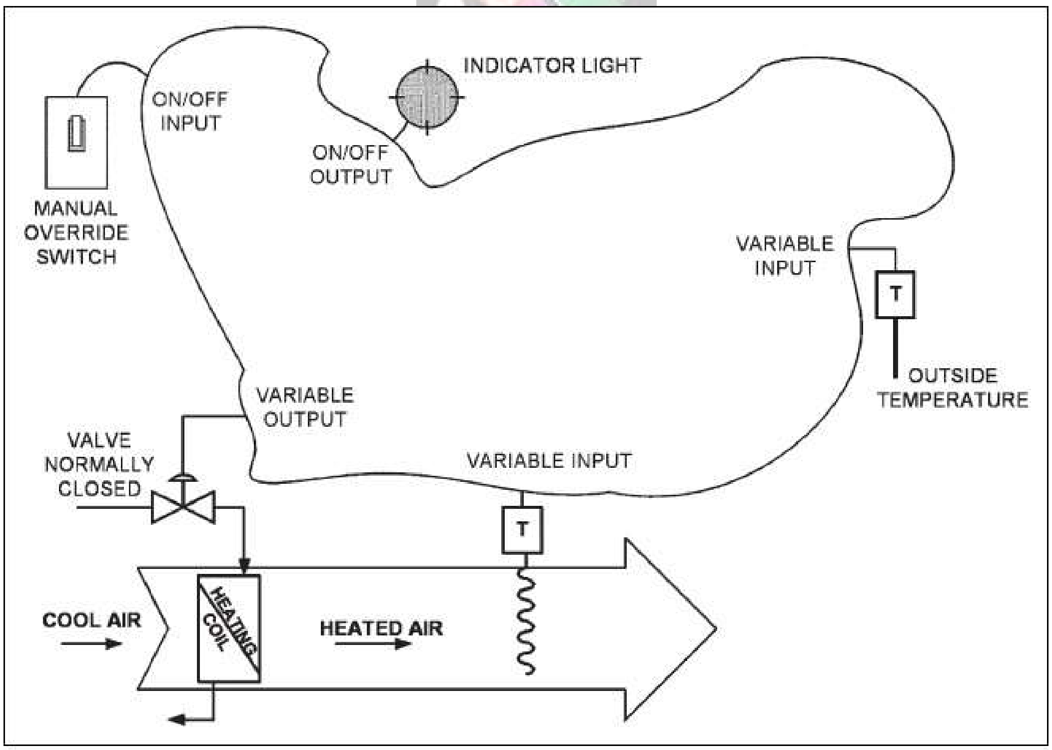


Figure 11.5 Control Scheme (from 11–3) without Controlling Components

In *Figure 11.5*, each input to or output from the DDC computer has been identified as one of the following:
-On/off input
-On/off output
-Variable input
-Variable output

These are the four main types of input and output in a control system. Let's consider each one briefly in terms of a DDC system.

On/off input. (Manual switch) A switch, a relay, or another device closes, making a circuit complete. in terms of DDC terms it is generally called a "**Digital Input**,"

On/off output (power to light) the on/off output either provides power or it does not. The lamp is either powered, 'on', or not powered, 'off'. In a similar way, this is called a "**Digital Output**,"

Variable input.(temperature from sensor) A varying signal, such as temperature, humidity or pressure, is called an "analogue" signal. In DDC terms, the input signal from an analogue is called an "**Analogue Input**,"

Variable output(power to the valve).the variable output to open or close a valve, to adjust a damper, or to change fan speeds, is an "**Analogue Output**,".

11.5 Direct Digital Control of an Air-Handler

In this section we are going to consider a constant-volume air-handler serving a single zone, designated '001'. The air handler uses space temperature for control, with no mixed air control.
To specify a DDC control system, ideally, one produces three things:

1. A schematic of the system with the control points labeled, *Figure 11.6*
2. A list of control points with their characteristics, *Figure 11.7*
3. A schedule of operations

Sequence of Operation

Schedule: Provide calendar/time schedule with minimum of three occupied periods each day.

Unoccupied: When calendar schedule is in unoccupied mode, and if space temperature is above 60°F, the fan shall be off, heating valve closed, cooling valve closed. If space temperature falls below 60°F, then the outside dampers and cooling valve to stay closed, heating valve to 100% open, and start fan. When space temperature reaches 65°F, turn fan off and heating valve closed.

Occupied: When calendar schedule is in occupied mode, the fan shall be turned on and after 300 seconds, the heating valve, outside air dampers and cooling coil shall be controlled in sequence to maintain space temperature at 72°F.

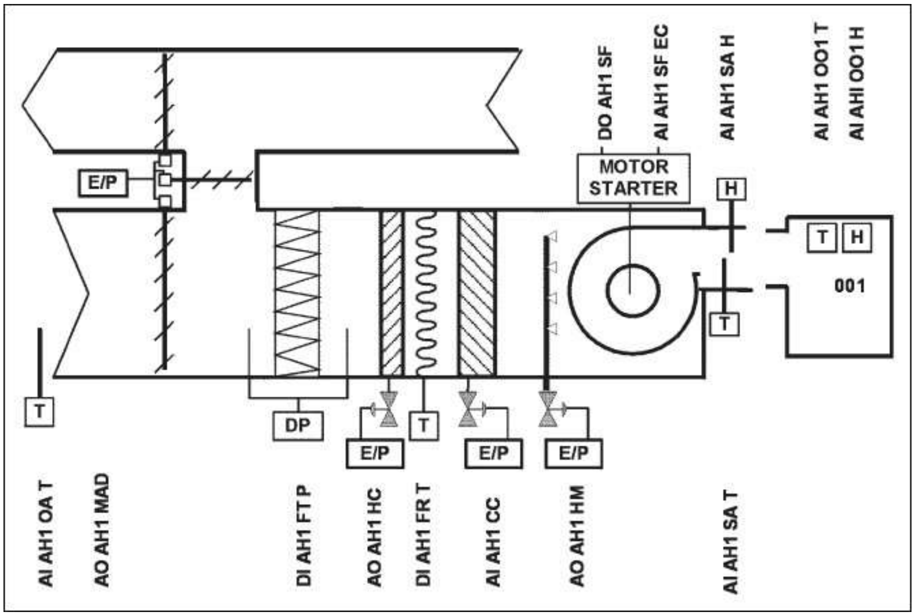
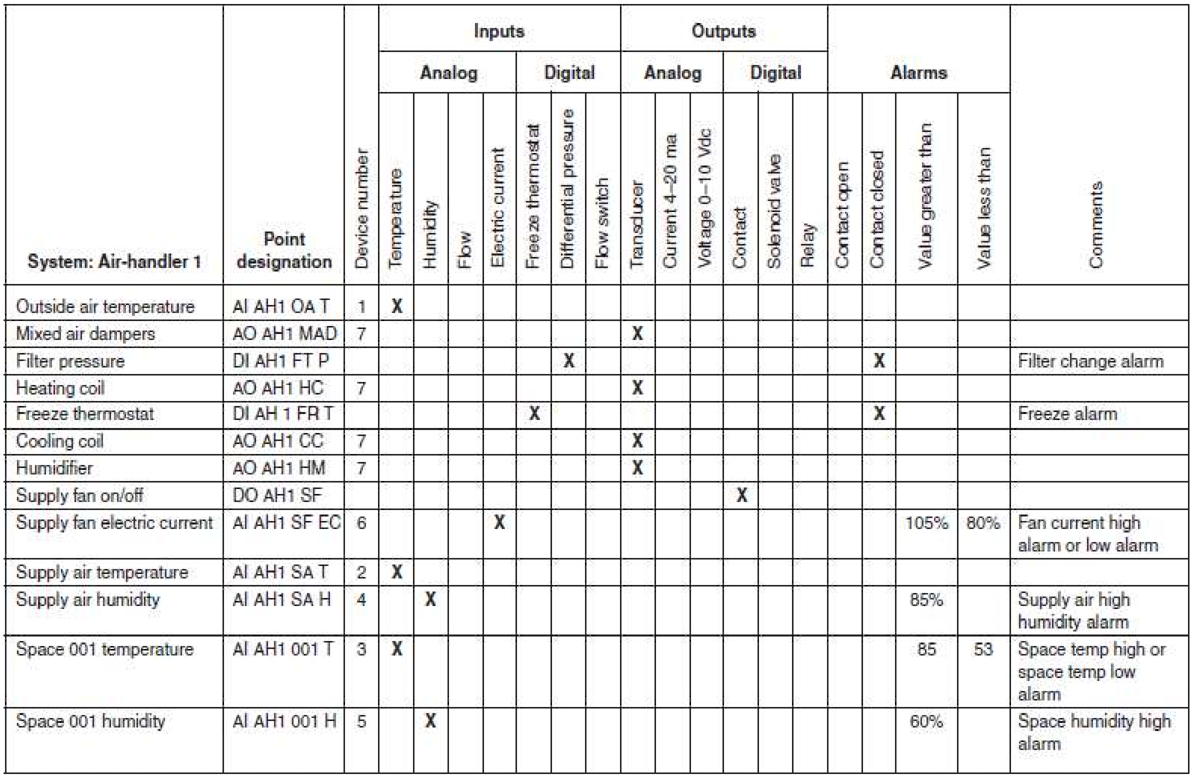


Figure 11.6 System Schematic



			Inputs							Outputs						Alarms				
			Analog				Digital			Analog			Digital							
System: Air-handler 1	Point designation	Device number	Temperature	Humidity	Flow	Electric current	Freeze thermostat	Differential pressure	Flow switch	Transducer	Current 4–20 ma	Voltage 0–10 Vdc	Contact	Solenoid valve	Relay	Contact open	Contact closed	Value greater than	Value less than	Comments
Outside air temperature	AI AH1 OA T	1	X																	
Mixed air dampers	AO AH1 MAD	7								X										
Filter pressure	DI AH1 FT P							X									X			Filter change alarm
Heating coil	AO AH1 HC	7								X										
Freeze thermostat	DI AH 1 FR T						X										X			Freeze alarm
Cooling coil	AO AH1 CC	7								X										
Humidifier	AO AH1 HM	7								X										
Supply fan on/off	DO AH1 SF												X							
Supply fan electric current	AI AH1 SF EC	6				X												105%	80%	Fan current high alarm or low alarm
Supply air temperature	AI AH1 SA T	2	X																	
Supply air humidity	AI AH1 SA H	4		X														85%		Supply air high humidity alarm
Space 001 temperature	AI AH1 001 T	3	X															85	53	Space temp high or space temp low alarm
Space 001 humidity	AI AH1 001 H	5		X														60%		Space humidity high alarm

Figure 11.7 Control Points and Characteristics

The control sequence shall be: heating valve fully open at 0% and going to fully closed at 33%, at 34% the dampers will be at their minimum position of 20% and will move to fully open at controller 66%, the cooling valve will be fully closed until 66% and will be fully open at 100%

Economizer control: When the outside temperature is above 66°F, the outside air dampers shall be set back to minimum position of 20%, overriding the room controller requirement.

Fan Control Alarm: If the fan has been commanded on for 30 seconds, and the fan current is below alarm setpoint 85% of commissioned current, the fan shall be instructed to stop, outside air dampers closed, and heating and cooling valves closed. An alarm of ‘low fan current’ shall be issued.
If the fan has been commanded off for 10 seconds, and the fan current is above the low limit, the fan shall be commanded off, and dampers, heating coil and cooling coil shall be controlled as in occupied mode. An alarm of ‘fan failing to stop’ shall be issued.

Filter alarm: If the filter pressure drop exceeds 0.3 inches water gauge, the filter alarm shall be issued.

Freeze Alarm: If the supply air temperature drops below 45°F, hardware freeze state operates, system changes to unoccupied mode and issues ‘freeze’ alarm.

Manual override: If the manual override is sensed, run in ‘occupied mode’ for 3 hours.

System status: 280 seconds after entering ‘occupied mode’ the room temperature, supply temperature, and ambient temperature shall be recorded along with current date and time.

11.6 Architecture and Advantages of Direct Digital Controls

In many buildings, there will be several systems, often with many more points controlling air-handlers, VAV boxes, heating valves, pumps, boilers and chillers. Wiring from a single huge DDC panel is not a practical option for two reasons. First, failure of the unit means failure of the entire system, and secondly, the wiring becomes very extensive and expensive.

Instead, the system is broken down into smaller panels that are linked together on a communications cable, called a “communications network.” It sounds simple, and it is if the system uses equipment from only one manufacturer. However, when more than one manufacturer is involved, it is not as simple. There are three communication issues that create problems. Let us identify them in terms of human communication first.

Languages

In the controls world, different companies have worked up different languages. There are two ways of enabling communication so that one manufacturer’s equipment can communicate with another manufacturer’s equipment that uses a different programming language. The first is to have an interpreter, called a “**gateway**,” between the two units. The second way is to program an additional, common language into both manufacturers’ units.

Vocabulary and Idea Complexity

Different people learn different sets of words in the same language. For simple, everyday things, like bread and water, everyone learns the words in each language. In addition, different people are trained in different skills.

Consider, for example, when an engineer and an accountant want to discuss the long-term value of a project. They can find themselves having great difficulty communicating, because they have different vocabularies and different thinking skills in the same language.

Transmission Method and Speed

In an attempt to eliminate the cost and challenges of no communication or expensive and limited gateways, ASHRAE produced a communications standard called "**BACnet**." This is a public communications protocol that is designed to allow communication at all levels in a DDC system. It is documented in ASHRAE Standard 135-2004 A Data Communication Protocol for Building Automation and Control Networks2.

The ability of different manufacturers' equipment to work together on a network is called "**interoperability**." To assist in ensuring interoperability and the use of BACnet, a BACnet interoperability association has been formed to test and certify products.

System Architecture

Consider the system illustrated in *Figure 11.8*.

Across the top of the figure is a high-speed network connecting main standalone panels and the operator terminal. In this example, the standalone panel on the left uses a different communication protocol (language) from the protocols used by the other two panels and the operator workstation. Therefore, a gateway (translator) connects the standalone panel on the left to the network. A "gateway" is a processor specifically designed to accept specific information in one protocol and send out the same information in another protocol.

This Section has done no more than introduce you to some of the basics and general ideas of DDC. The system has *advantages* including:

1. Increased accuracy and control performance
2. System flexibility and sophistication that is limited only by your ingenuity .
3. The system ability to store knowledge about the internal behavior over time
4. Remote access to the entire system to modify software, alter control settings, adjust setpoints
5. and schedules via phone or via the Internet.
6. With increased use and the falling price of computer systems in general, DDC is often less expensive than conventional controls.
7. DDC systems are not simple. Qualified maintenance and operations people are critical to ongoing success.
8. Extending an existing system can be a really frustrating challenge due to the frequent lack of interoperability between different manufacturers' products

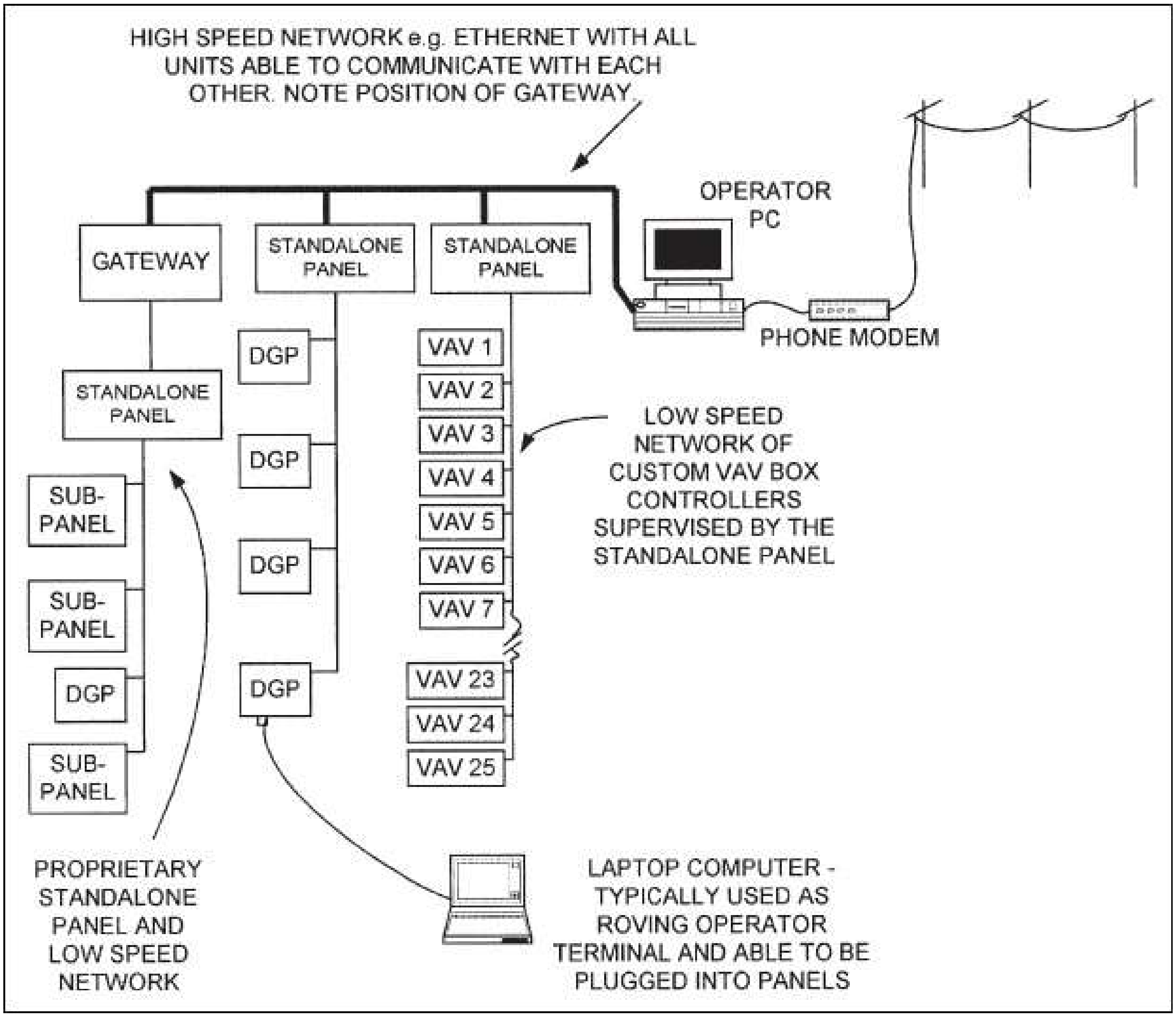


Figure 11.8 DDC System

Section 12 - Energy Conservation Measures

Purpose of this Section:

1. Explain energy conservation and some basic ways of thinking about it.
2. Describing generally the contents of Standard 90.1.
3. Describing the equipment and operation of the heat wheel, heat pipe and runaround methods of heat recovery.
4. Describing the process and be able to provide examples of uses of evaporative cooling.
5. Explaining the significance of building pressure.

12.1 Introduction

During this course we have mentioned and discussed the differences between initial cost and cost-in-use that are relevant to various types of equipment.

In many instances, the savings on the initial cost of equipment is squandered because the equipment is more expensive to run, due to excessive energy costs that are incurred over the life of the building. The objective of energy conservation is to use less energy. Energy conservation should be part of the entire life cycle of a building.

It is important for everyone who participates in the design, operation and maintenance of the building to realize that, however energy efficient the system as initially designed and installed, the energy efficiency will degrade unless it is operated correctly and deliberately maintained.

12.2 Energy Considerations for Buildings

The energy consumption of a building is determined from the very first design decisions through to final demolition.

Conception and Design

In the very beginning of the design process, many architectural choices can be made to significantly increase, or decrease, the energy consumption of a building. For example, large un-shaded windows that face the afternoon sun can greatly increase the cooling load.

It is at the early design stage that the mechanical designer should become seriously involved in the building design as a whole.

Construction

The best possible building plans can be made a mockery by poor construction. The mechanical plant must be installed and set working correctly.

Operation

If the staff does not know how a system is meant to work, there is a very high probability that they will operate it differently and, more than likely, not as efficiently.

Maintenance

With limited maintenance, even the best equipment will falter and fail.

Three Ways to Save Energy

1-Turn it off

This is the simplest and almost always, the least expensive method to implement and it has the highest saving. If a service is not required, I should be turned off Opportunities to "Turn it off" can be found at the design phase and at the operational phase of a building's life cycle.

2-Turn it down

"Turn it down" meaning reduce the amount of heating, cooling or other process while still providing the required service.

There are numerous examples of using "turn it down" as an energy conservation tool. Two that are commonly implemented include:

-Heating reset

-Chilled water temperature reset

3-Turn it in

"Turn it in" means "replace with a new one." This is the third way of saving energy. It is almost always the most difficult to justify, since it is the most costly. It almost never pays in energy savings to replace building fabric

12.3 ASHRAE/IESNA Standard 90.1

ASHRAE and the Illuminating Society of North America (IESNA) wrote ASHRAE/IESNA Standard 90.1 *Energy Standard for Buildings Except Low-Rise Residential Buildings* (Standard 90.1)

The purpose of the Standard is "to provide minimum requirements for energy-efficient design of buildings except low-rise residential buildings." It is a minimum standard and there are some energy reduction programs such as "**Leadership in Energy and Environmental Design, LEED,**" that encourage designs to have a lower energy cost than the Standard prescriptive cost. Note that the LEED program gives no acknowledgement unless design energy cost is at least 15% below the Standard 90.1 requirements.

Prescriptive and Performance Requirements

The Standard is divided into sections that often fall to different designers. The first section of the Standard is the "Administration and Enforcement" section, to help designers and code officials. It then has six prescriptive sections that define the performance of the components of the building. Finally, it concludes with a calculation method, the "Energy Cost Budget Method" section.

The following is a brief introduction to the sections.

Building Envelope

The objective of the Standard is to ensure that design choices are both energy efficient and cost-effective. Therefore, for example, the insulation requirements are more demanding in the colder climates.

The Standard divides climates according to temperature and moisture conditions. The temperature divisions range from the continuously hot, with no heating demands, through to the continuous heating with no cooling requirements. The designer chooses the temperature range relating to the building location, and, on a single page finds the thermal transmission requirements for the building fabric: roofs, walls, floors, doors and fenestration (windows). This is the section for the architect.

Heating, Ventilating, and Air conditioning

For single zone buildings of less than 25,000 ft2 and only one or two floors, there is a simplified approach, due to the limited number of choices that designers can make for equipment. As long as the building is a single zone, with one unit, the code requires that the unit will comply with a few straightforward energy saving requirements.

EER Energy Efficiency Ratio: is the ratio of net cooling capacity in Btu/hour to electrical input in Watts.

IPLV, Integrated Part-Load Value is a weighted average value of EER based on full and part load performance and is used instead of EER on larger electrically driven air-conditioners.

COP, Coefficient Of Performance, is the heat removal to energy input in consistent units. For air-cooled chillers, the minimum requirement is COP of 2.8. However, a water-cooled centrifugal chiller over 300 tons, has a required minimum COP of 6.0, twice the cooling capacity per watt of the air-cooled machine.

Service Water Heating

The section on service water heating covers minimum equipment performance and maximum standby loss. Also detailed are pipe insulation and recirculation requirements.

Lighting

On average, in the USA, buildings use about 35% of their total energy for lighting. This provides a big opportunity for savings.

Energy-Cost Budget Method

The energy-cost budget is a way to allow designers to have the flexibility to design the building according to their needs, as long as it does not cost more in energy than the Standard permits. To use the Energy-Cost Budget Method, the designer is instructed to calculate the energy-cost budget for standard plant equipment, then to compare that to the cost of the energy required by the equipment chosen.

12.4 Heat Recovery

When designing to comply with the Standard, designers can minimize energy use by reducing the energy requirements of a building, and/or by energy recovery. During design, always aim first to minimize energy use before considering energy recovery. The reason is that heat recovery is almost always involved with "**low-grade heat**." Low-grade heat is heat that is at a temperature relatively close to the temperature at which it can be used at all.

Energy Recovery Coils: Run-Around Coils

One way to achieve energy recovery is with run-around energy recovery coils. A typical run-around coil arrangement is shown in *Figure 12.1*.

In summer, the conditioned exhaust air cools the fluid in the exhaust air coil. This fluid is then pumped over to the supply air coil to pre-cool the incoming outside air.

In winter the heat transfer works the other way: the warm exhaust air heats the fluid in the exhaust air coil, which is then pumped over to the supply air coil to heat the cold incoming air.

At intermediate temperatures the system is shut off, since it is not useful. When outside temperatures are below freezing, the three-way valve is used with a glycol anti-freeze mixture in the coils.

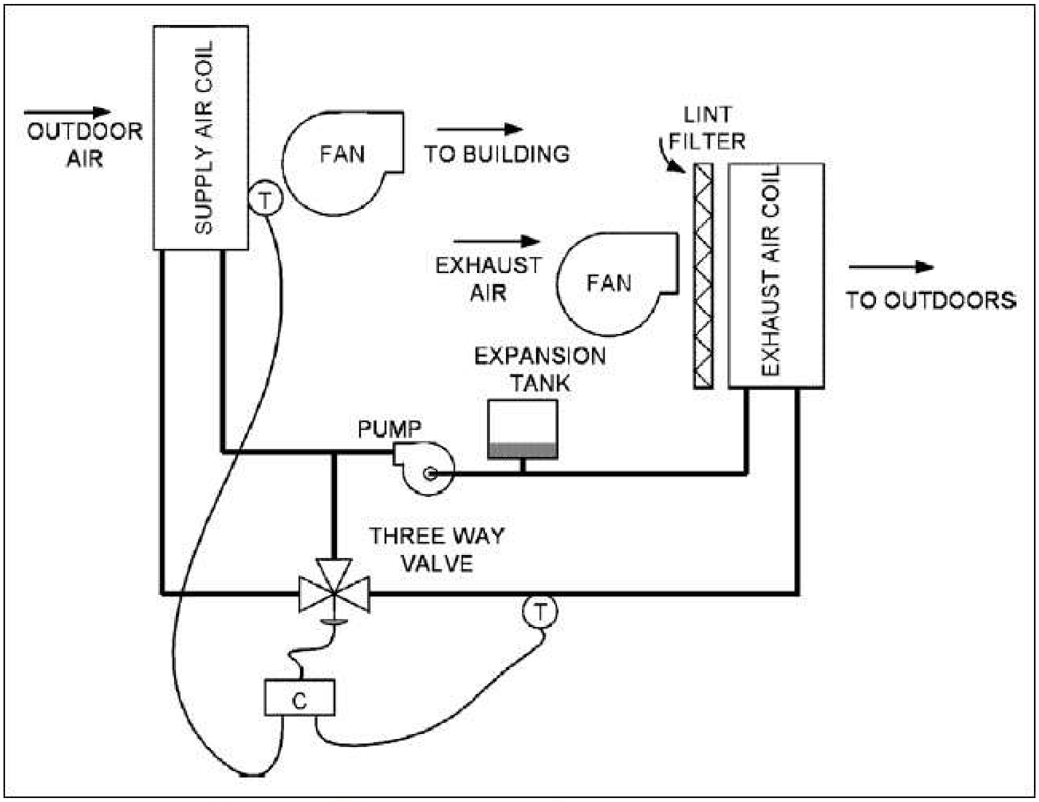


Figure 12.1 Run-Around Energy Recovery Coils

The run-around coil system has three particular advantages:

1. There is no possibility of cross contamination between the two air streams.
2. The two coils do not have to be adjacent to one another
3. The run-around coils only transfer sensible heat, and do not condense the water in the exhaust

Heat Pipes

A heat pipe is a length of pipe with an interior wick that contains a charge of refrigerant, as shown in *Figure 12.2*.

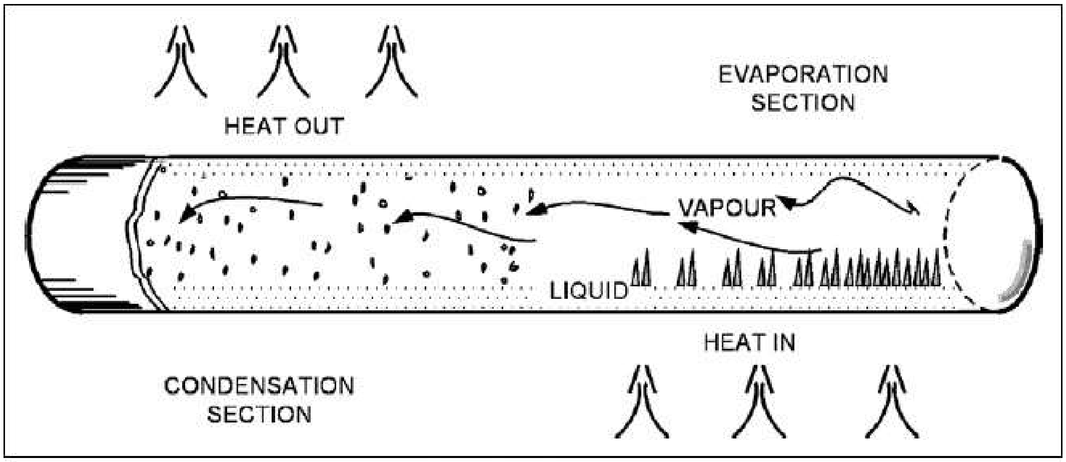


Figure 12.2 Cut Away Section of a Heat Pipe

The type and quantity of refrigerant that is installed is chosen for the particular temperature requirements. In operation, the pipe is approximately horizontal and one end is warmed, which evaporates refrigerant. The refrigerant vapor fills the tube. If the other half of the tube is cooled, the refrigerant will condense and flow along the wick to the heated end, to be evaporated once more.

Figure 12.3 shows a view down onto a unit that is mounted in the relief and intake air streams to an air-handling unit. Flexible connections are shown which facilitate the tipping. To adjust the heat transfer, one end or the other end of the tubes would be lifted.
The outside air is cold as it comes in over the warm coil. This warms the air, and the tube is cooled. The cooled refrigerant inside condenses, giving up its latent heat, which heats the air. The re- condensed refrigerant wicks across to the exhaust side and then absorbs heat from the exhaust air. This heat evaporates the refrigerant back into a vapor which fills the pipe, and is again available to warm the cold outside air.

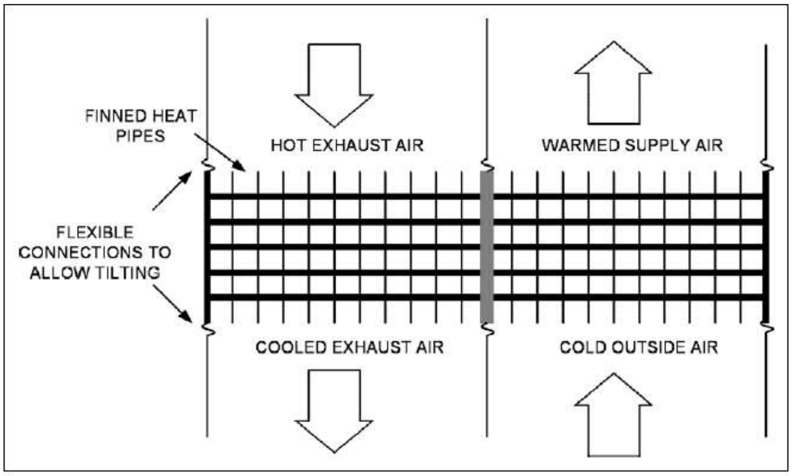


Figure 12.3 Heat Pipe Assembly in Exhaust and Outside Air Entry

Desiccant Wheels

Desiccants are chemicals that are quick to pick up heat and moisture, and quick to give them up again if exposed to a cooler, drier atmosphere. A matrix, as indicated on the left of *Figure 12.4*, may be coated with such a chemical and made up into a wheel several inches thick. In use, the supply air is ducted through one half of the wheel and the exhaust air through the other half.

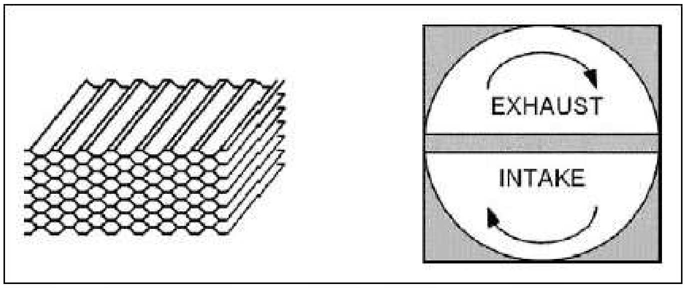


Figure 12.4 Desiccant Wheel Matrix and Operation

12.5 Air-Side and Water-Side Economizers

Air-Side Economizers

The air-side economizer on air-handling units was introduced in the previous Sections. It is the mixing arrangement that allows up to 100% outside air to be drawn in and relieved in order to take advantage of cool outside air, providing "free cooling." Nothing is free! The air-side economizer equipment costs extra to purchase, there are more components to maintain, and, depending on the climate, the hours when the economizer is actually saving cooling energy may be very limited. In climates that are warm and humid, the number of hours when the outside air has a lower enthalpy than the return air enthalpy may be very few. Thus, Standard 90.1 does not require air-side economizers in most of Florida.

Advantages of the air-side economizer:

1. A low air pressure drop.
2. Substantial mechanical-cooling energy savings.
3. Reduced water usage in cooling tower systems.

Disadvantages of the air-side economizer

1. Extra capital cost for the 100% intake and relief air equipment, which includes a return fan on larger systems.
2. A higher ongoing electrical operating expense.
3. A potential requirement for additional humidification during winter operation.

Water-Side Economizers

The water-side economizer consists of a water-cooled coil, located in the air stream just before the mechanical-cooling coil. The coil can be supplied with water directly from the cooling tower or via a plate heat exchanger. If the water is supplied directly from the tower, the water treatment and cleaning process must be of a high standard, to ensure that the valves and coil do not log up with dirt.

If a heat exchanger is used, there is the additional cost of the exchanger, and the heat transfer will be less efficient, since there has to be a temperature rise across the exchanger for it to work. An example for packaged units is shown in *Figure 12.5*. The three-port valve determines how much of the tower water flows through the economizer coil, and the two-port valve determines how much water bypasses the condenser to avoid the condenser being overcooled.
The "**head pressure**" is the pressure in the refrigeration condenser.

Advantages of water-side economizers

1. Water-side economizers reduce compressor energy requirements by precooling the air.
2. Unlike air-side economizers, which need full sized intake and relief ducts for 100% outside air entry or for
3. 100% exhaust, water-side economizers simply require space for two pipes.
4. Unlike the air-side economizer, the water-side economizer does not lower the humidity in winter.
5. Saving on possible humidification costs.

Disadvantages of a water-side economizer

1. Higher resistance to airflow, therefore higher fan energy costs.
2. Increased tower operation with consequent reduction in life.
3. Increased water and chemicals cost.

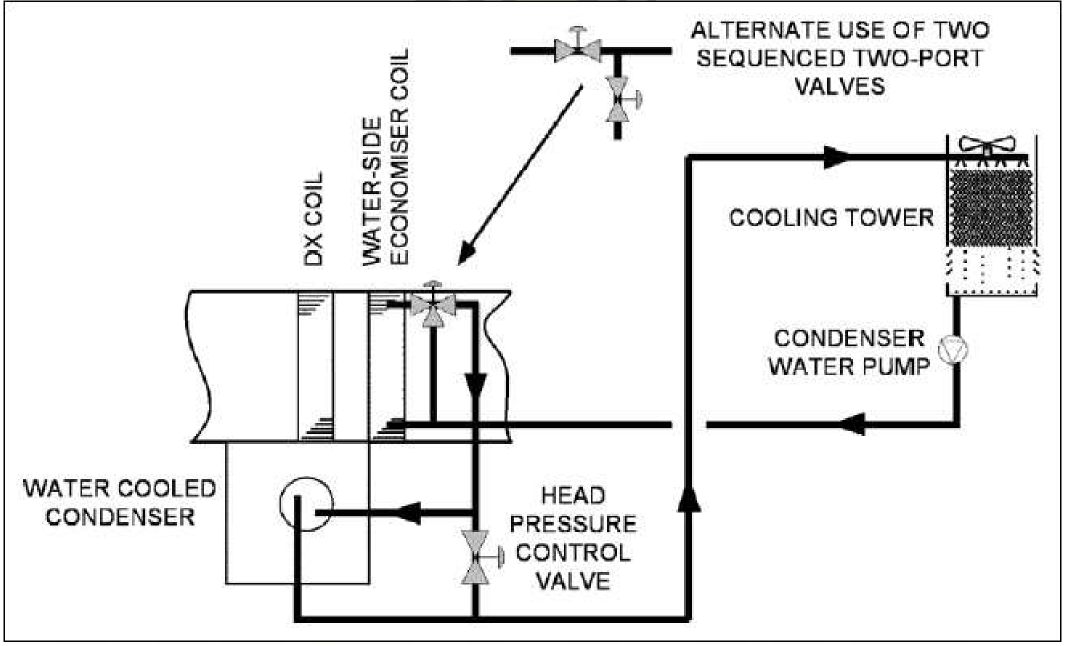


Figure 12.5 Water-Side Economizer and Alternate Use of Two-Port Valves

12.6 Evaporative Cooling

1-*Direct Evaporative Cooling*

The direct evaporative cooler simply evaporates moisture into the air, reducing the temperature at approximately constant enthalpy. In a hot dry climate this process may often be enough to provide comfortable conditions for people. *Figure 12.5* shows the indirect cooler as the "water-side economizer,"

2-*Indirect Evaporative Cooling*

An indirect evaporative cooler uses evaporation to cool a surface, such as a coil, that is then used to cool the incoming air. The indirect evaporative cooler, which reduces both temperature and enthalpy, can be very effective in all but the most extreme conditions.

The two processes are shown on the psychrometric chart, *Figure 12.6*. located before the mechanical cooling coil. That is just one arrangement of two-stage cooling.

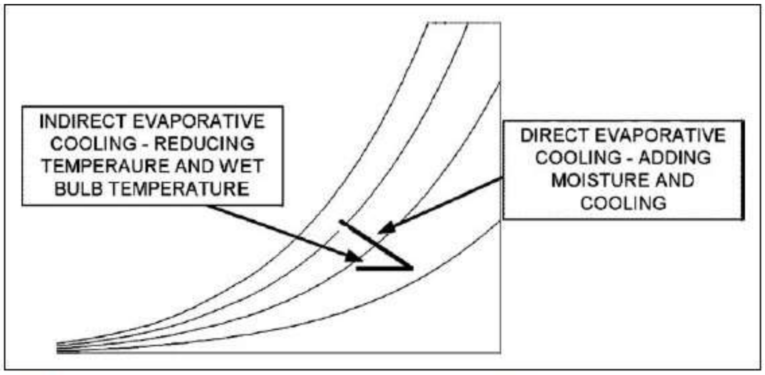


Figure 12.6 Psychrometric Chart Showing Direct and Indirect Evaporative Cooling

Figure 12.7 shows an alternative to this arrangement. In this indirect evaporative-intake cooler, water flows down the outside of the air intake passages. As it flows down, outside air is drawn up over the water causing evaporation and cooling. The cooled water cools the intake air passages and hence the intake air. This is shown diagrammatically on the left side of *Figure 12.7*.

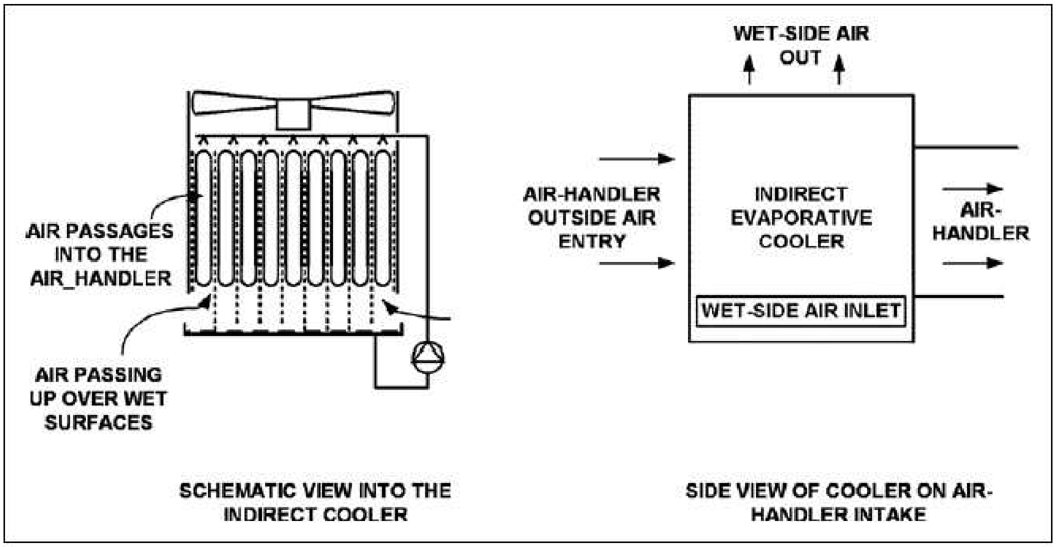


Figure 12.7 Indirect Evaporative Intake Cooler

12.7 Control of Building Pressure

Control of building pressure can have a significant effect on energy use, drafts through exterior doors, and comfort. In a hot and humid climate, it is valuable to keep the building at a slightly positive pressure. This ensures that dry air, from inside the building, enters the walls rather than allowing humid air from outside to enter the building through the wall and likely cause mold growth.

In a cold climate, the building should be kept close to outside pressure, or slightly negative, to prevent the warm, moist air from inside the building from entering the wall where it could and cause condensation or ice.

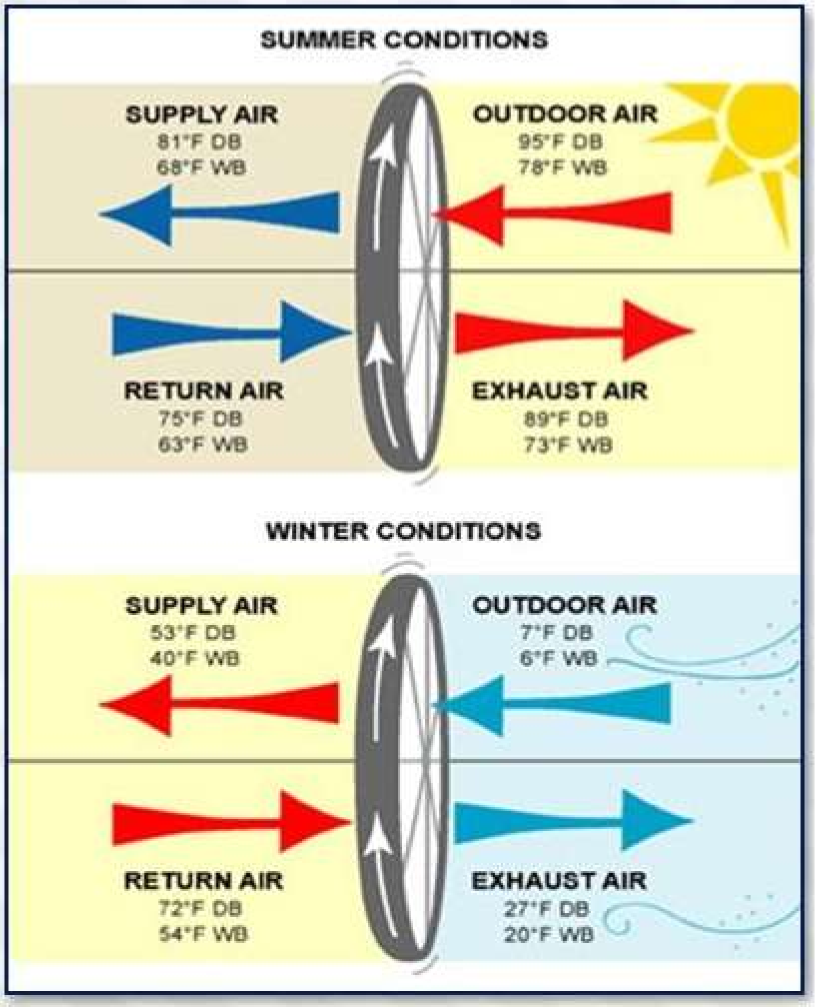
In milder climates, intermediate size plants can be accommodated with "**barometric dampers**." Barometric dampers blow open when there is a slightly greater pressure, than outside at that location in the building 'At that location' is included as a proviso, since the wind can make a huge difference to the pressure at different points around a building. If the wind is blowing towards the damper, it will tend to keep it shut.

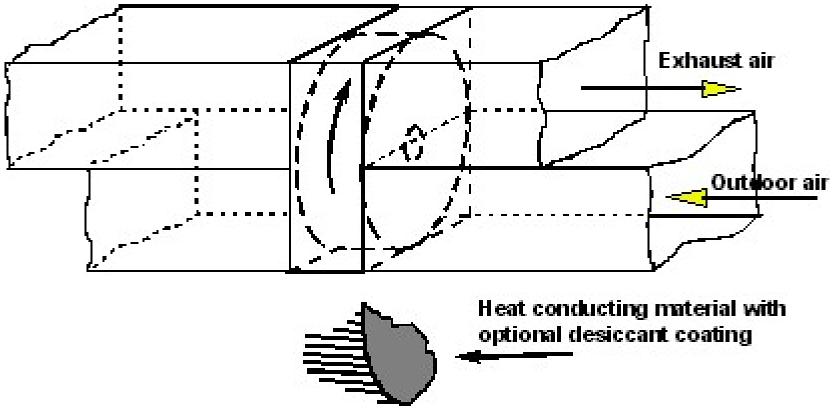
Extras

Enthalpy & Heat Wheels

General:

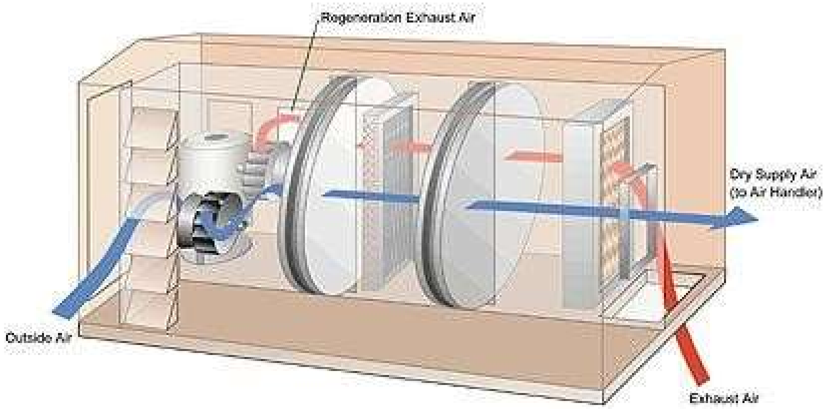
Heat or enthalpy wheels are rotary air-to-air heat exchangers. Adjacent supply and exhaust air counterflow stream each flow through half of the wheel. Heat wheels have a fill that transfers only sensible heat while an enthalpy wheel's fill transfers total heat.





Advantages

- These wheels are quite compact and can achieve high heat transfer effectiveness,
- Heat wheels have a relatively low air pressure drop, typically 0.4 to 0.7 in. of water,
- Freeze protection is not an issue,
- The cooling or heating equipment size can be reduced in some cases.



Source - Engelhard/ICC Corp.

Disadvantages of the use of the heat wheel:

- adds to the first cost and to the fan power to overcome its resistance,
- requires that the two air streams be adjacent to each other,
- requires that the air streams must be relatively clean and may require filtration,
- requires a rotating mechanism that requires it be periodically inspected and maintained, as does the cleaning of the fill medium and any filtering of air streams,
- in cold climates, there may an increase in service needs,
- results in some cross-contamination (mixing) of the two air streams, which occurs by carryover and leakage.

Source: http://cipco.apogee.net/ces/library/tdew.asp