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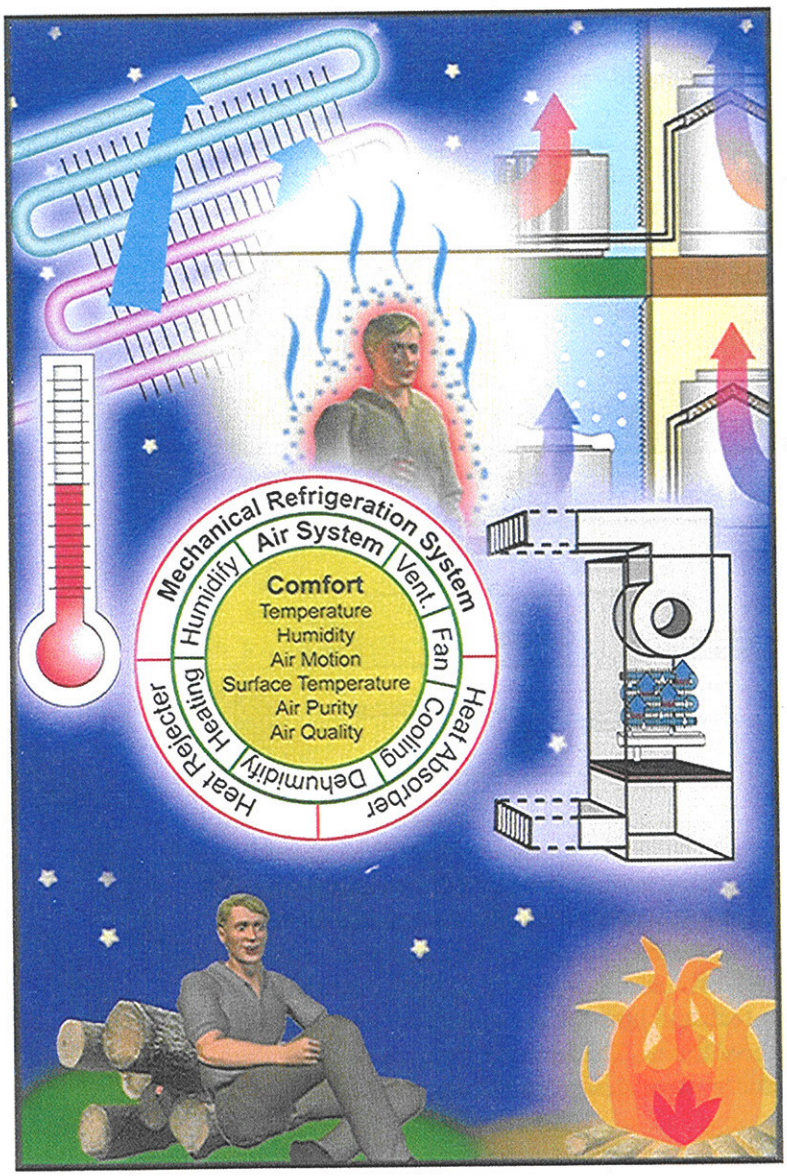


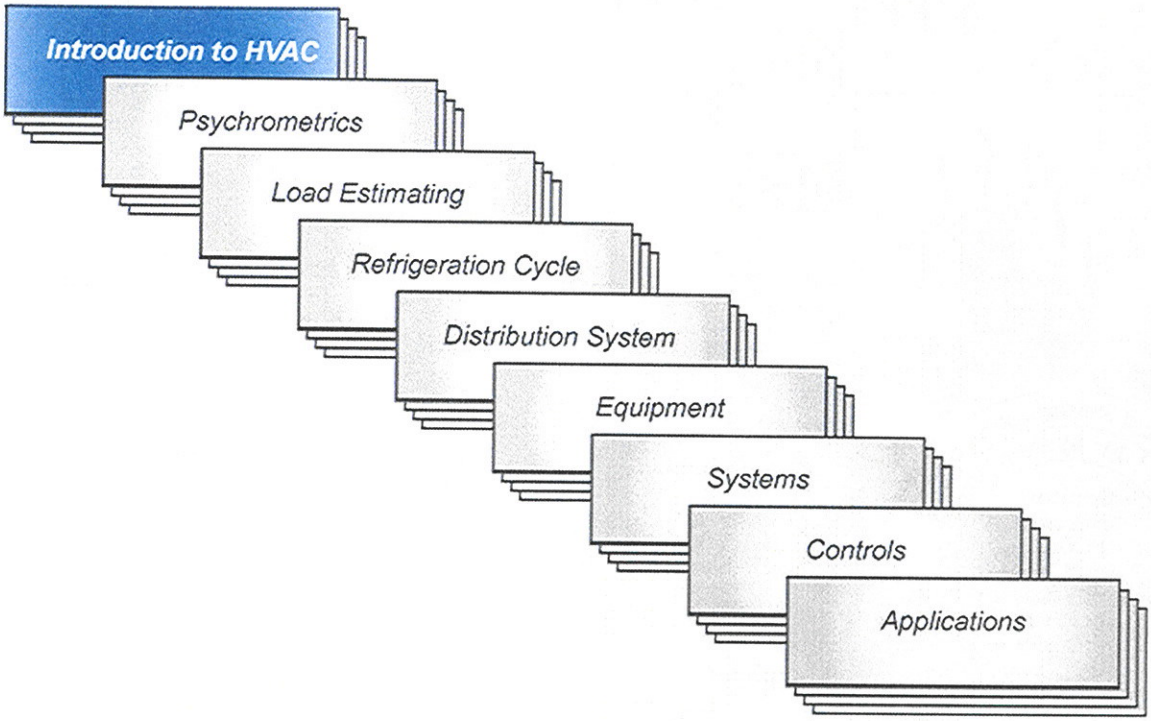
INTRODUCTION TO HVAC

ABCs of Comfort

Technical Development Program

Technical Development Programs (TDP) are modules of technical training on HVAC theory, system design, equipment selection and application topics. They are targeted at engineers and designers who wish to develop their knowledge in this field to effectively design, specify, sell or apply HVAC equipment in commercial applications.

Although TDP topics have been developed as stand-alone modules, there are logical groupings of topics. The modules within each group begin at an introductory level and progress to advanced levels. The breadth of this offering allows for customization into a complete HVAC curriculum – from a complete HVAC design course at an introductory-level or to an advanced-level design course. Advanced-level modules assume prerequisite knowledge and do not review basic concepts.



The Carrier TDP modules deal primarily with the design and operation of comfort air conditioning. To design these comfort air-conditioning systems, it is first necessary to understand what comfort is, and how a system designer can influence the human perception of comfort. The "ABCs of Comfort" is a module of the introductory series and is intended to introduce system designers to the parameters that influence human comfort, and how the air system and mechanical refrigeration system work together to control these conditions. The material presented helps the designers determine one of the first objectives of the system design, which is to establish the comfort standards for the project.

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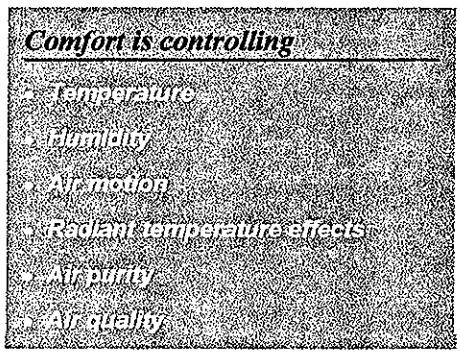
Introduction

HVAC is the business of providing comfort. In order to design a ***comfort*** system, one must first understand what comfort is. This training module will introduce the principles of ***human comfort***, the environmental factors that influence comfort, and how air conditioning works to maintain comfort. It will also explain how to determine the comfort specifications for a project.

We will begin by defining human comfort and the six environmental factors that influence our perception of comfort. These factors are: temperature, ***humidity***, air motion, radiant temperature, ***ventilation*** (air quality) and contaminant control (air purity). Each of us perceive comfortable levels of these factors in different ways, and each of these factors has limits that an HVAC system must maintain. However, there is no absolute mix of conditions that will assure that every person is comfortable in every situation. It is the designer's responsibility to understand the requirements, then to identify an HVAC system that will maintain these conditions within acceptable limits. This design often requires a trade-off in design, cost, complexity, and comfort.



In order to define comfort specifications, the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (***ASHRAE***) has developed a comfort chart. This chart will be explained later on in this module.

We will also explore how total air-conditioning systems are actually two interdependent systems: the air system and the ***mechanical refrigeration system***. Finally, the primary function of the components of these systems will be explained.

Why Do We Need Air Conditioning?

There are two purposes for conditioning the air: comfort air conditioning and ***process air conditioning***.



Figure 1

Comfort depends on how the space is used.

Process Air Conditioning

The purpose of process air conditioning is to improve an industrial process so that the quality or quantity of the product is improved. For example, the printing process requires certain air conditions to maintain high quality standards. This also applies to pharmaceutical and electronic equipment assembly areas or in refrigeration (food preservation) applications. In these applications, when air conditions are out of the desired range, product quality and reliability suffer. The conditions to be maintained are fixed by the nature of the process or material being handled. The number of variables controlled and the acceptable range of those variables vary greatly from process to process.

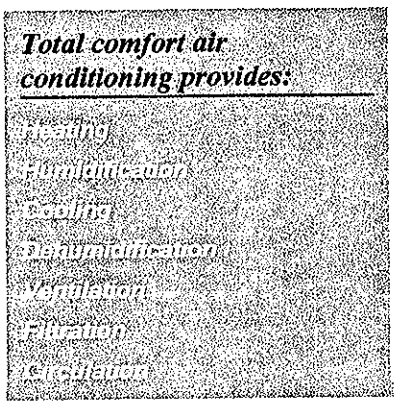
Comfort Air Conditioning

The second, basic reason for conditioning air is to maintain indoor conditions that are considered comfortable to the occupants. This process is called comfort air conditioning.

While comfort air conditioning focuses on people, process air conditioning focuses on a product or process, if the people are comfortable as well, so much the better. This module will focus on comfort air conditioning.

Comfort

Most people think of cooling when air conditioning is mentioned, but it means much more than that. Total comfort air conditioning is provided by a system that will ***heat***, ***humidify***, ***cool***, ***dehumidify***, ventilate, ***filter***, and circulate indoor air in a controlled manner to achieve a desired set of conditions. Most air-conditioning systems do only a partial job of controlling these comfort variables. But, at the very least, all systems must maintain temperature, humidity, and air motion within an acceptable range to be perceived as acceptable. Comfortable temperature ranges from 68 to 78 degrees Fahrenheit (°F), with 75° F being a typical design goal. Humidity is comfortable from 30 to 60 percent relative humidity, with 50 percent being a typical design goal in the cooling season.



An explanation of how the human body regulates temperature and how space conditions affect human comfort will help in understanding why these conditions represent good design goals.

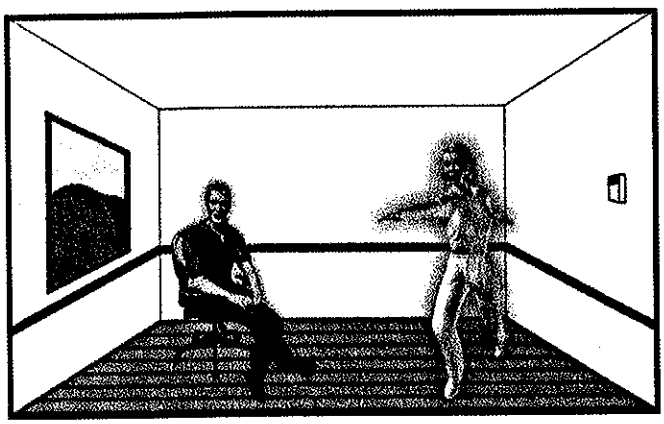


Figure 2

People generate heat depending on activity.

Body Temperature Control

The food we eat acts as fuel, which our body converts to useful energy. In addition to energy, heat is also produced. Whether you are digesting food, raising your arm, or using your eyes, energy is used and heat is generated. The more vigorous the activity, the greater the heat generated.

Our bodies are designed to function in a healthy manner at an inner body temperature of about 98.6° F. In order to maintain that temperature, any excess heat must be rejected. In a conditioned space, the body always generates more heat than needed to keep the inner body temperature at 98.6° F. Therefore, heat is rejected from our bodies constantly. Four ways our bodies transfer heat to the air around us are by conduction, convection, radiation, and evaporation.

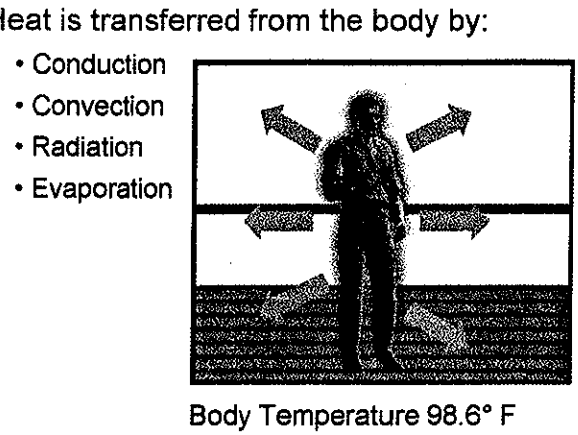


Figure 3

Heat is transferred from the body by four processes.

Conduction

Conduction is the transfer of heat directly through a substance or from one substance to another as heat flows from a higher temperature area to a lower one. The flame of the candle heats the end of the metal bar. The heat moves along the bar, from the higher temperature area to the lower temperature area, by conduction.

The heat is conducted into the fingers of the person holding the bar if the process is allowed to continue. Also, the heat from the bar is conducted to the cooler air surrounding it. The heat from the flame is conducted to the bar, through the bar, from the bar into the fingers, as well as into the air.

Likewise, in a conditioned space, heat generated by a person is conducted to the objects the person touches and to the air surrounding them.

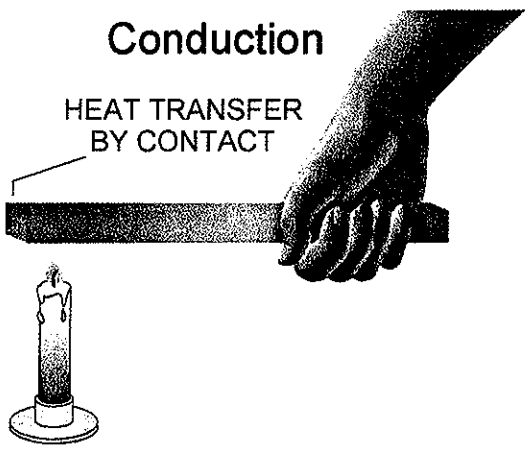
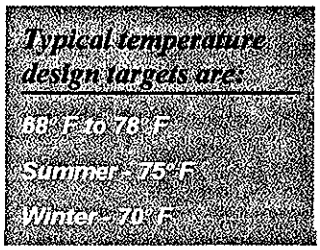


Figure 4

Conduction – Heat Transfer by Contact



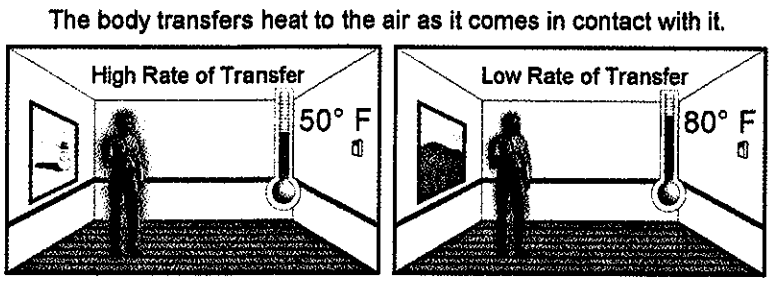


Figure 5

Air temperature controls conduction.

When the temperature is too low, occupants will complain about feeling cold. When the air temperature is too warm, they will complain about feeling hot. Consequently, the basic device used to control the amount of heating or cooling capacity delivered by a comfort air-conditioning system is a temperature controller, called a ***thermostat***. It is located in the conditioned space.

Temperatures considered comfortable vary with the level of activity, clothing, and personal preference. The design range for comfortable temperature for normally clothed people who are involved in sedentary, or near-sedentary activities that occur in an office, school, theater, restaurant, retail shop, hospital or residence is about 68 - 78° F. A typical design target for heating is about 70° F and for cooling it is about 75° F. This will be explored further later in this module.

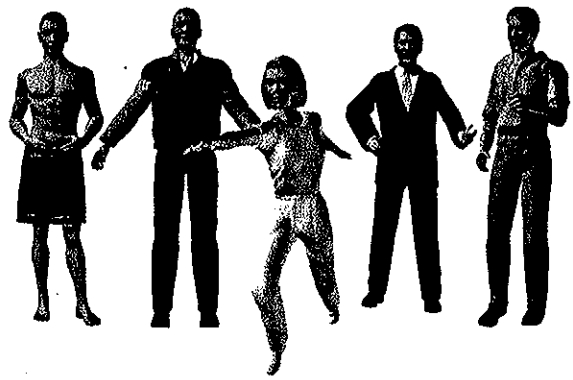


Figure 6

Clothing insulates our body, slowing conduction.

Clothing slows down the conduction process by adding insulation to our bodies. In the cooling season, adding insulation is not advisable because it slows down the conduction process necessary to reject excess heat. In the heating season, clothing helps to reduce body heat loss, adding to comfort.

However, there is a practical limit to how much clothing can be added before people feel uncomfortable because their body movement is restricted. In sedentary occupations, most efforts to create comfort with a space temperature below 70° F have been unsuccessful.

Convection

Our bodies also transfer heat by ***convection***. Convection is heat transfer by the movement of a fluid (gas or liquid) from one place to another. Heated molecules within a flowing medium, such as air, carry their heat directly to a new area. Thus, convection air currents carry heat to our body or away from it. Convection currents are easy to see in a pan of water being heated on a stove, especially just before boiling begins. Natural convection currents like these are also called density currents because their movement is caused by differences in fluid density that are a result of temperature differences. Warmer fluids are less dense and tend to rise, while cooler fluids are denser and tend to fall. Even though we cannot see them, convection currents operate in the air around us, very much like they do in a pan of water.

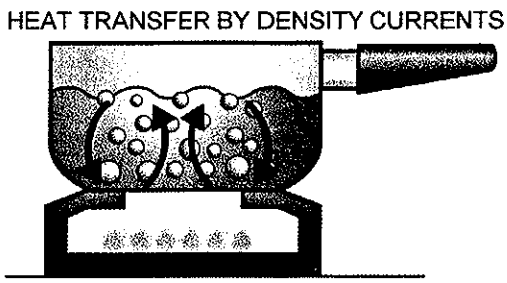


Figure 7

Convection – Heat Transfer by Density Currents

Natural air convection currents form around our bodies in a conditioned space. As body heat is conducted into the air close to us, it becomes warmer than the air farther away. Since warm air is lighter, or less dense, than cool air, the warm air floats upward. The warm air is replaced by cooler air, and the process continues.

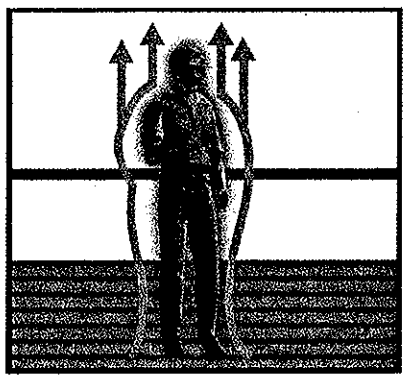
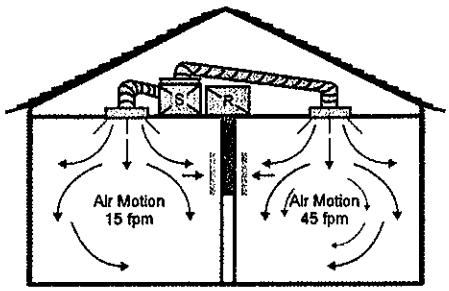


Figure 8

Natural Convection – Warm Air Rises Upward

When fans are used, the convection process is forced rather than natural. Using fans allows the convection process to move along more rapidly than it would by natural means.

Forced air systems send air from a fan through a supply ***ductwork*** system and out the supply ***diffusers*** located in the ceiling, wall or floor of the air-conditioned space. Return ***grilles*** pull the room air into a return ductwork system that takes the air back to the central equipment for conditioning. Then the fan sends the air back to the space again.



Forced-convection: convective motion is caused by a fan. Air motion influences comfort.

Figure 9

Forced Convection – Fans Provide Air Motion

The way the supply air diffusers and return air grilles are selected and laid out in the conditioned space is called ***room air distribution***. Room air distribution uses forced convection currents to assure comfort. If air moves too slowly, temperatures within the space will be uneven and the occupants may feel stuffy. If the air moves too rapidly, complaints about draftiness and feeling cold might be expressed.

Air Motion Comfort:

Comfortable air motion depends on the clothing of the occupants and their activity. For normally clothed people who are involved in sedentary, or near-sedentary activities, a reasonable target for room air motion is 15 to 45 feet per minute (fpm). When supply diffusers are selected, located, and ducted according to manufacturer's recommendations, this design goal is easily achieved.

Radiation

Radiation is the third way heat is transferred from our bodies to conditioned spaces. Radiant heat travels from a warmer object to a colder object without heating up the area in between. For example, a camper sitting in front of a fire on a cold night can get warmed even though the air between him and the fire remains cold. Some of the fire's radiant heat travels to the camper, striking him, and warming the side of his body facing the fire.

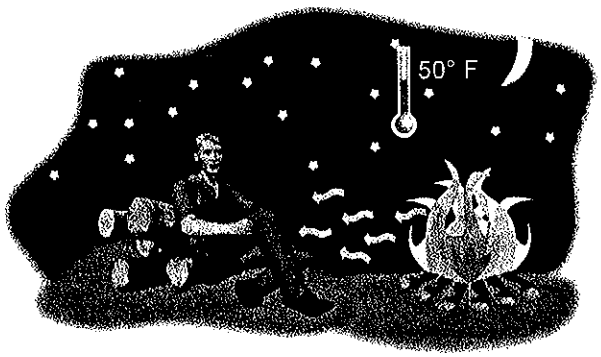


Figure 10

Radiation – Heat Transfer by Electromagnetic Waves

Just as the radiant heat of the campfire flowed to the cooler camper, radiant heat can also flow from our bodies to cooler surfaces surrounding us in conditioned spaces. For instance, body heat will flow from the man standing in the room to the colder outside window behind him, by means of ***radiation***. The colder the window is, the more rapidly the heat leaves his body.

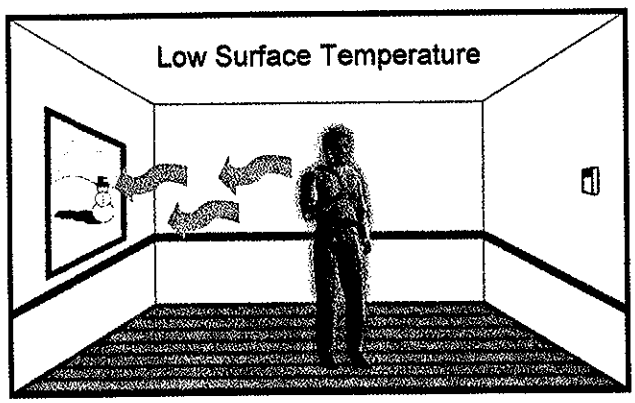


Figure 11

Radiation – Warmth radiates from the body toward cooler surfaces.

Conversely, radiant heat can flow from a surface to our bodies when the surface is warmer than our body. Even when the air temperature surrounding us is acceptable, the temperature of the surfaces surrounding us can cause discomfort because of radiant heat flow if those surfaces are very cold or hot.

The surface temperature of the ceiling, walls, floor, and glass that surrounds us is determined largely by how well insulated they are. The better the insulation, the closer the inside surface temperature will be to the inside air temperature. The closer the surface temperatures are to the room air temperature, the more comfort is enhanced.

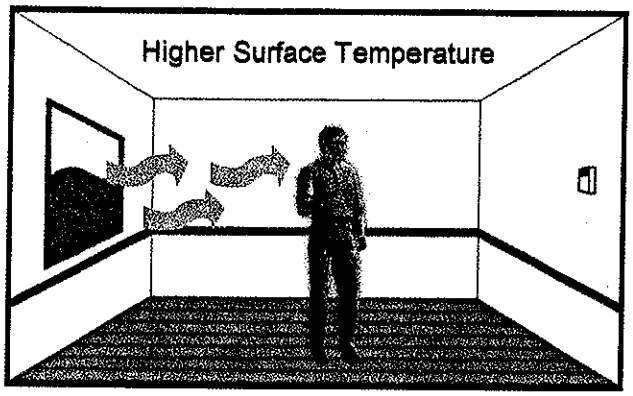


Figure 12

Radiation – Higher surface temperatures radiate toward the body.

Surface Temperature Comfort:

Ideal surface temperatures to minimize radiant heat loss are 70° to 80° F.

Therefore, quality construction reduces discomfort caused by radiant heat loss from our bodies in the winter. It also reduces discomfort caused by radiant heat gain to our bodies in the summer.

The ideal comfort situation exists when the average temperature of all the surfaces surrounding the occupant is between 70 and 80° F. Adequate wall and ceiling insulation, multiple layers of glass, and internal or external solar shading devices all help to achieve this ideal situation. Substantial space temperature adjustment is required to maintain comfort when surface temperatures are much different than the space air temperature. For instance, a building with poorly insulated outside walls and single glass may have to be set for 78° F space temperature in the winter to give the same feeling of comfort as a well insulated space with triple glass set at 70° F.

Likewise, a poorly insulated building without adequate solar shading may have to be set for 68° F in the summer to provide the same feeling of comfort as a well insulated building with adequate solar shading set at 75° F.

Besides the comfort incentive, energy costs for air conditioning add another important motivation for providing adequate building insulation and glass quality. In most cases, the energy impact of high quality construction is well known, but the comfort aspect is often forgotten. The energy penalty of inadequate insulation and poor glazing is compounded when the thermostat is reset in an attempt to restore comfort.

Here are some reasonable minimum guidelines for insulation and glazing in residential construction with outside temperatures at -10° F and 95° F and a space temperature of 75° F in both summer and winter.

Barrier	Minimum	Surface Temp.* Summer/Winter	Example Construction
Walls	R-11 U-0.099	76.4° F / 69.3° F	Wood frame with sheathing and siding, ½-in. sheetrock inside, 3½-in. fiberglass insulation
Roof	R-19 U-0.036	75.5° F / 72.9° F	Sheetrock ceiling on bottom of wooden trusses, 6-in. fiberglass insulation above ceiling
Floor Slab	R-5 U-0.231	78.1° F / 61.6° F	Closed-cell foam board slab between foundation and floor slab runs vertically down below frost lines
Doors	U-0.39	76.4° F / 60.5° F	All closures weather-stripped from factory
Single Glass	U-1.13	90.4° F / 10.0° F	Single glass (pane) window
Single Glass w/Storm	U-0.49	81.6° F / 46.7° F	Single glass (pane) window with storm

* Outside Summer 95° F with 75° F inside
Outside Winter -10° F with 75° F inside

Figure 13

Typical Residential Surface Temperatures

Commercial construction guidelines are similar. Here is a table with the same type information but for common commercial construction, again at -10° F and 95° F with a 75° F space in both summer and winter.

Solar heat absorbed by the surface can make these temperatures much higher. This will be dealt with in more detail later.

Barrier	Minimum	Surface Temp.* Summer/Winter	Example Construction
Walls	U-0.124 U-0.580	76.7° F / 67.8° F 82.9° F / 41.6° F	Steel frame masonry
Roof	R-16 U-0.095	76.2° F / 70.1° F	Steel frame insulation over deck
Floor Slab	U-0.360 U-0.322	79.8° F / 70.2° F 79.3° F / 66.4° F	Steel joist masonry
Doors	U-0.70	80.4° F / 51.9° F	Swinging type
Single Glass	U-1.22	89.6° F / 5.3° F	Single pane window less than 40% glass
Double Pane Glass	U-0.64	83.7° F / 38° F	Double pane glass

* Outside Summer 95° F with 75° F inside
Outside Winter -10° F with 75° F inside

Figure 14

Typical Commercial Surface Temperatures

Evaporation

Evaporation is the fourth way heat is transferred from our bodies to the conditioned spaces we occupy. Moisture, in the form of perspiration, is given off through the pores of our skin. As this moisture evaporates, it turns into invisible water vapor. The body provides the heat necessary to accomplish this change of state, from water to vapor. Each pound of water evaporated absorbs about 1000 ***British thermal units (Btu)*** of heat from the body. Evaporation from our bodies goes on constantly, whether it is visible or not. When you see drops of perspiration on your skin, your body is producing more heat than it can reject at the normal rate.

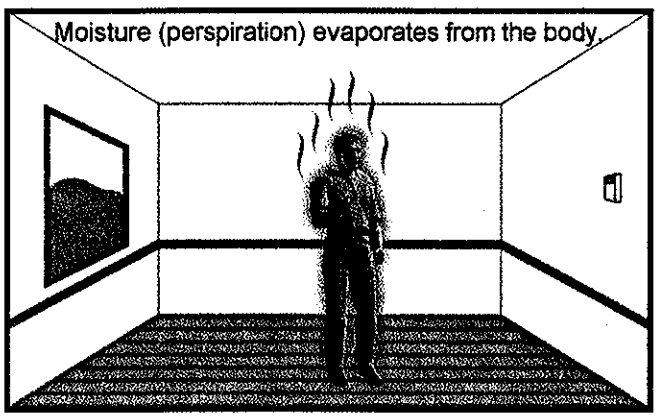


Figure 15

Evaporation helps control body heat.

Convection currents affect evaporation. If there were no air motion, the layer of air closest to your body would soon absorb most of the water vapor it could hold. If this happened, the evaporation process would come to a halt. Moving air prevents the build-up of a blanket of moist air around you.

Convection currents move the air that has absorbed evaporated moisture away from your body. Behind that air comes drier air that allows the evaporation process to continue. The faster the air flows over your body, the more rapidly evaporation takes place and, therefore, the greater the sensation of coolness you feel. While convection currents affect evaporation in an important way, relative humidity affects it most of all.

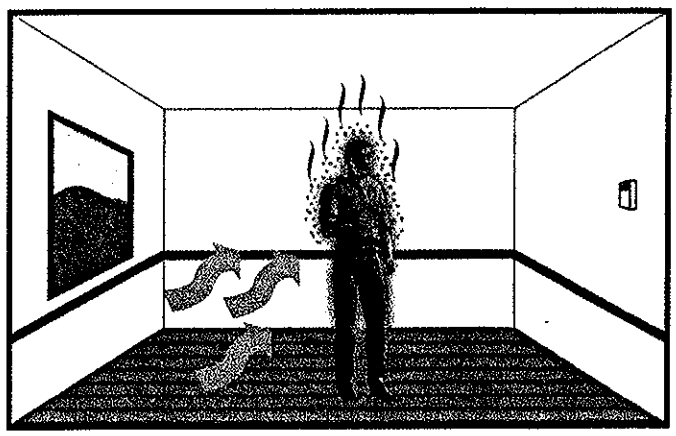
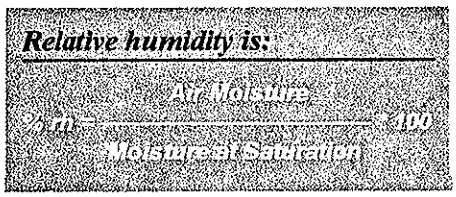


Figure 16

Convection currents increase the evaporation rate.

Relative Humidity and Comfort

Relative humidity is a measure of how much moisture is in the air. In reality, it is a ratio that indicates the ability of the air to absorb more moisture, expressed as a percent.



The lower the percent, the lower the moisture content in the air and the greater the air's ability to absorb more moisture. Since relative humidity influences comfort in an important way, let's take a closer look at it.

Since each pound of water evaporated from our skin removes about 1000 Btu from our bodies, evaporation is an important means for keeping us cool. The relative humidity of the air surrounding us sets a limit on how fast evaporation can take place. The more humid the air, the slower evaporation will progress. The less humid, the more rapidly evaporation will progress.

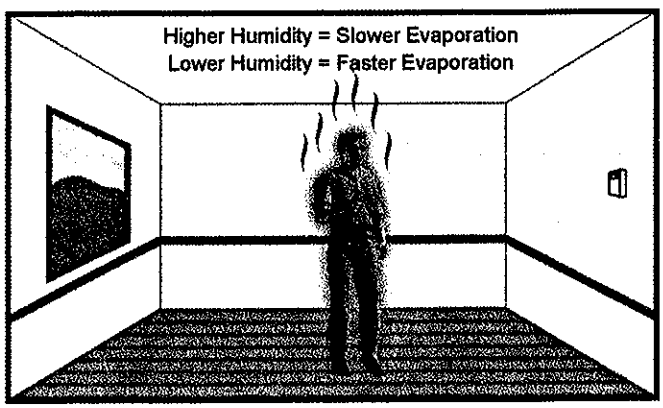


Figure 17

Humidity affects the rate of evaporation.

There is an upper limit to the water vapor any specific volume of air can hold. Air is said to be saturated or at saturation when it reaches that level. Air is saturated with all the water vapor it can hold without having the water change state from a vapor (a gas) into a liquid or a solid. When that limit is exceeded, the vapor turns to liquid, forming droplets of condensation. Outdoors it shows up as fog, rain, sleet, or snow.

Consider the air in the room illustrated. Obviously, there is no rain or fog in the room, so the air is at a condition, which is at or less than saturation. When the temperature of the air is measured, it is found to be 70° F. We will need some more information to determine how close to saturation the air is.

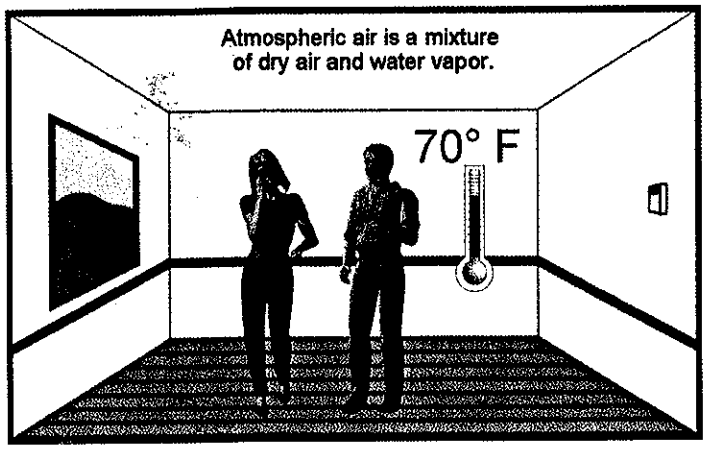


Figure 18

Air is a mixture of dry gases and water vapor.

Air has weight. The dry gases in air, as well as its water vapor, contribute to that weight. The amount it weighs per unit of volume (space) is its density, which is expressed as pounds per cubic foot of air (lb/ft^3). Mostly it is temperature that influences air density. Warmer air is less dense. Colder air is denser.

The amount of volume, or space, one pound of air takes up is its specific volume. Density and specific volume are like flip sides of the same coin. Mathematically speaking, specific volume is the reciprocal of density (specific volume = 1/density). Likewise, density is the reciprocal of specific volume (density = 1/specific volume). As density increases, specific volume decreases, and vice versa.

Figure 19 gives you an appreciation of the specific volume of a typical sample of air and water vapor mixture in an air-conditioned room. The sample shown has a specific volume of 13.3 cubic feet per pound. In other words, one pound of air at the conditions in this room takes up a space the size of a cube that is about 28½ inches on each side. The density of the same air sample is 0.075 pounds per cubic foot (1/13.3). This moist air sample is about the same weight as four packs of chewing gum.

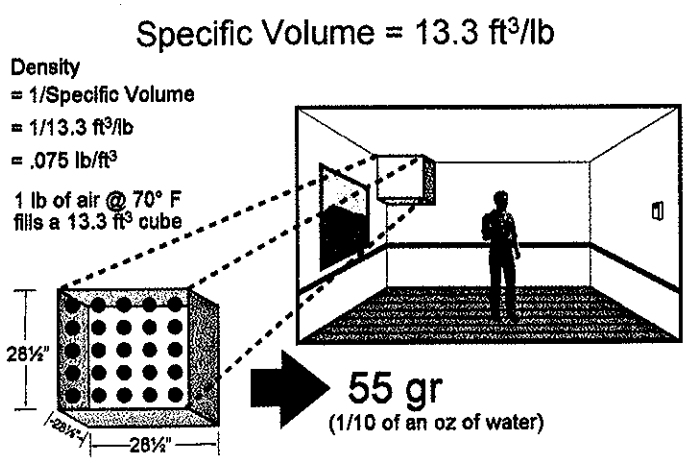


Figure 19

One pound of air and water mixture containing 55 grains of moisture.

When the moisture of the air is measured, it is determined to be about 55 grains of water vapor per pound of dry air. This is a very small amount of water vapor, since there are 7000 grains in a pound of water. So in this example, each pound of dry air contains about 1/10 of an ounce in the form of water vapor. So in this example, each pound of dry air contains about 1/10 of an ounce in the form of water vapor. If the air were at 50° F and the same 55 grains of moisture, the air would be saturated.

1 lb water = 7000 gr

Air at 50° F and 100% relative humidity has 55 grains, or 1/10 ounce about the weight of two sheets of paper.

If this same pound of 70° F air was saturated with water vapor, it could hold a maximum of 110 grains of water vapor. Psychrometrics is required to determine the maximum amount of water vapor the air sample can hold. Psychrometrics is the study of dry air and water vapor mixtures, the kind we find in any room. The psychrometric chart shows how the ***specific humidity*** of our air sample is determined to be 110 grains per pound at saturation. Following the 70-degree dry bulb line vertically up to the saturation line (100 percent rh), and over to the right gives the value of 110 grains per pound of dry air.

The air sample is not saturated since it only contains 55 grains of water vapor per pound of dry air, rather than 110 grains.

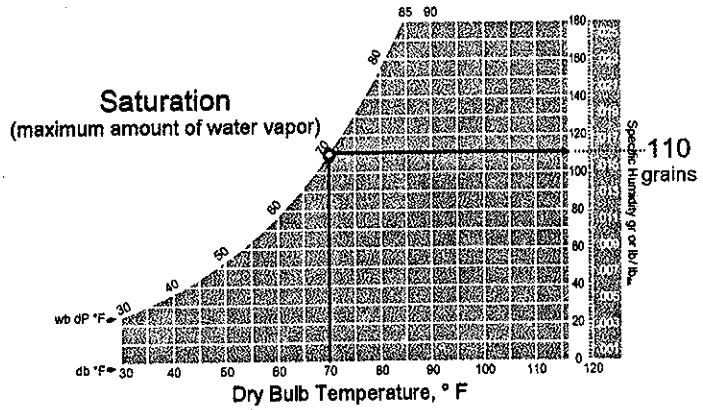


Figure 20

A psychrometric chart is used to determine saturation.

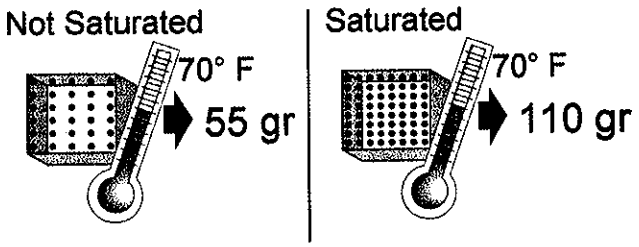


Figure 21

Air Sample – Not Saturated and Saturated

To find the relative humidity of the air, divide the amount of moisture the sample contains (55 grains per pound) by the maximum amount it could hold at saturation (110 grains per pound), and multiply by 100 to get the percent. The answer is 50 percent for the illustrated room. Therefore, the room conditions are 70° F and 50 percent relative humidity (rh).

Because the air has a 50 percent rh, you know that it contains half as much water vapor as it could hold if it were saturated. Since the moisture holding ability of air is influenced by temperature, the relative humidity of the air in the room changes if its temperature changes.

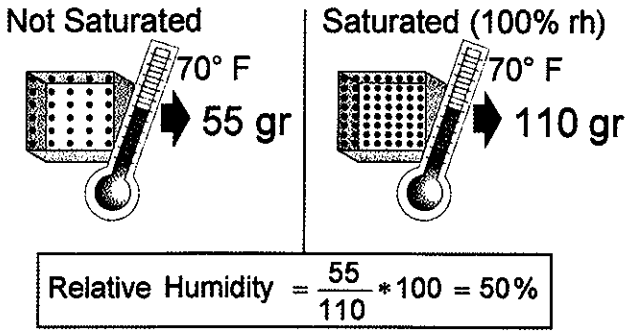


Figure 22

Relative Humidity of 70° F Moist Air

Let's raise the temperature to 92° F. Since no more water vapor has been added, the actual moisture content, also called specific humidity, is still 55 grains per pound of dry air (gr/lb). However, warm air has a greater ability to hold moisture than cool air. At 92° F, a pound of dry air holds approximately 220 grains of water vapor when saturated.

The relative humidity of the air sample is now only 25 percent, as shown. One pound of 70° F air is 50 percent of the way to being saturated when containing 55 grains of water vapor, but when heated to 92° F, it is only 25 percent of the way to saturation. Air at 92° F can hold twice the moisture as 70° F air.

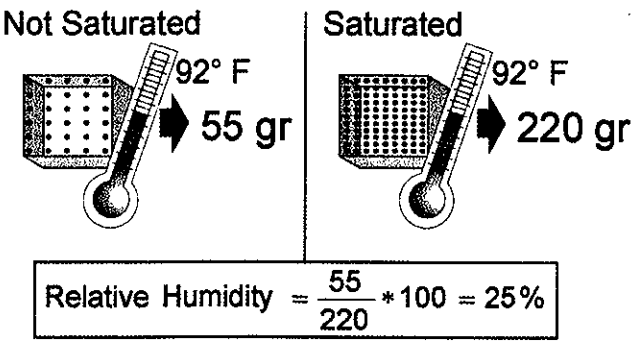


Figure 23

Relative Humidity of the Same Air at 92 F.

As previously illustrated, cold air can hold less moisture than warm air. A practical application of this fact can be seen in heated spaces situated in cold climates. The air within a building always starts out being outdoor air. The moisture within the building is a combination of what comes in from outside plus the vapor added by people, cooking, washing, and water exposed to the indoor air. If a building has good vapor barriers, some of the moisture added internally can be retained; but if the barriers are poor, most of the moisture leaks out rather rapidly.

If the outdoor air is 20° F and 50 percent rh, as shown here, its specific humidity is only about 7.5 grains per pound. Its specific humidity is very low at 50 percent rh because cold air can hold very little water vapor before becoming saturated. When this same air comes inside by leakage (***infiltration***), or is brought in through ventilation, it still contains 7.5 grains per pound, but drops way down to 7 percent rh at 70° F. It will not take much air this dry to drop the space relative humidity below the lower limit for comfort, which is about 30 percent.

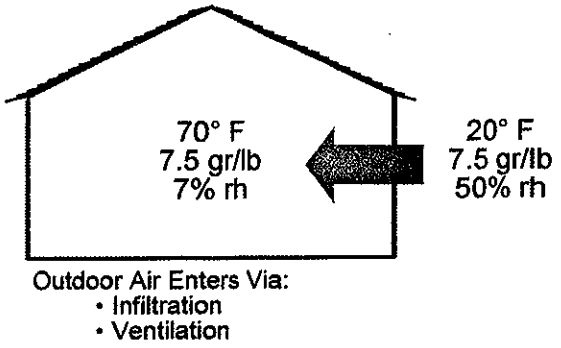


Figure 24

Infiltration of outside air lowers space relative humidity.

During the heating season, evaporation works against us. The heating system is used to limit the loss of heat from our bodies by heating the air, but evaporation is accelerating body heat loss as the air becomes drier. Consequently, a ***humidifier*** becomes an important part of a total comfort air-conditioning system installed in a cold climate.

If the air around your body has a low relative humidity, your body will be able to give off more heat through evaporation than if there is a high relative humidity. Lowering the relative humidity speeds up evaporation. Increasing relative humidity slows it down.

Comfortable relative humidity ranges from about 30 percent to 60 percent, with an ideal goal in the cooling season being 50 percent. Relative humidity of 55 percent is a more reasonable goal for climates with a moderately humid climate. Relative humidity of 60 percent is the limit for high humidity climates.

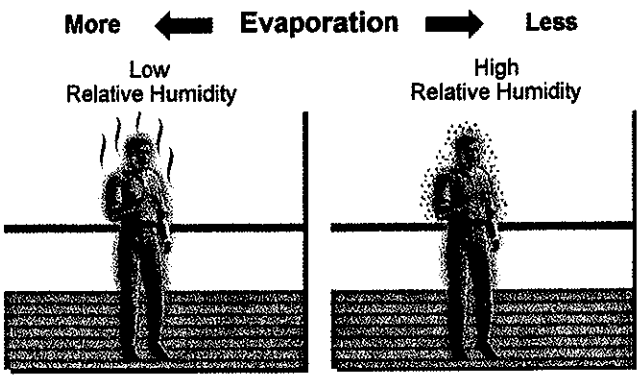


Figure 25

Relative humidity influences the rate of evaporation.

In the cooling season, when relative humidity is above 60 percent, people often complain of being uncomfortable, regardless of the space temperature. It is often true that a space with a slightly warmer temperature but lower relative humidity is perceived to be more comfortable than one with a lower temperature but higher relative humidity. Since cooling systems dehumidify the air only when the ***compressor*** is running, it is important to avoid oversizing equipment more than about 20 percent to avoid excessive humidity at partial ***cooling load***. Oversized systems spend too much time with the compressor cycled off to do a good job of dehumidifying the indoor air. This is especially important in humid, summer climates. Humidity levels above 60 percent have the potential to create indoor air quality issues in addition to comfort complaints.

Comfortable humidity levels

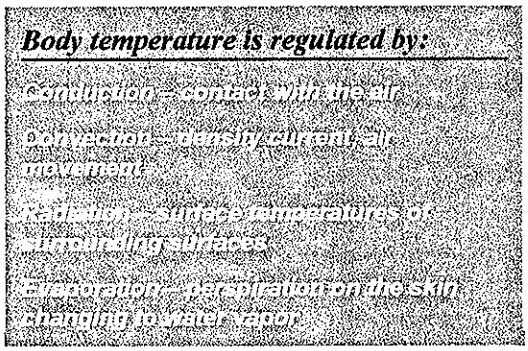
are in the range of 30 % to 60 %, with a target of 50 % for summer design. Levels above 60 % can become an IAQ concern because of mold growth.

Heating season goals for relative humidity are limited by the severity of the winter climate and the insulation and glazing quality of the building. When the outdoor temperature drops, cold outside walls and windows can cause moisture to condense as liquid water, damaging walls, draperies, moldings, and floor coverings. It is wisest to reset the humidistat, which controls the humidifier, according to outside temperature. If the humidity level is not reset, a practical design goal for locations with a winter design temperature not less than 10° F is 30 percent. Milder climates may tolerate somewhat higher humidities, as shown.

Outdoor Temperature	Outdoor Relative Humidity	Maximum Indoor Humidity
-10° F	30 to 70	20%
0° F	30 to 70	25%
10° F	30 to 70	30%
20° F	30 to 70	35%
30° F	30 to 70	40%

Figure 26

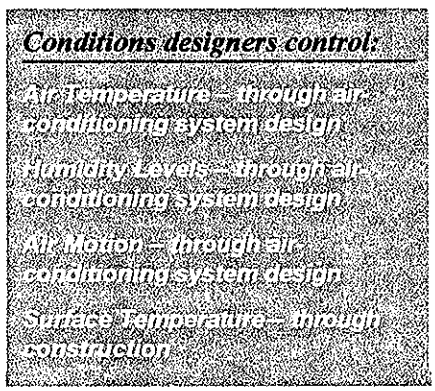
Recommended Maximum Winter Humidity Levels



Body Regulation and Space Control

Now we will summarize human comfort as it pertains to air conditioning by relating the four ways our bodies transfer heat to four building conditions the air-conditioning designer can control.

Conduction, convection, radiation, and evaporation, the four ways our bodies transfer heat to the environment, occur simultaneously. These methods work together attempting to maintain our bodies in a comfortable state. As we have seen, there are several conditions within the space that help our bodies achieve the comfort they are trying to maintain.



These conditions include air temperature, space relative humidity, air motion, and surface temperature of outside barriers. The designer of a comfort air-conditioning system can influence air temperature, space relative humidity, and air motion so that comfort is assured for most people in most circumstances. The goal of the comfort air-conditioning designer is to engineer systems that maintain these conditions within a reasonable range at a reasonable cost and energy usage. Proper attention must be given to the ***air system*** and ***mechanical refrigeration system*** to achieve this goal. First we will examine the air system and then the mechanical refrigeration system. Both are equally important.

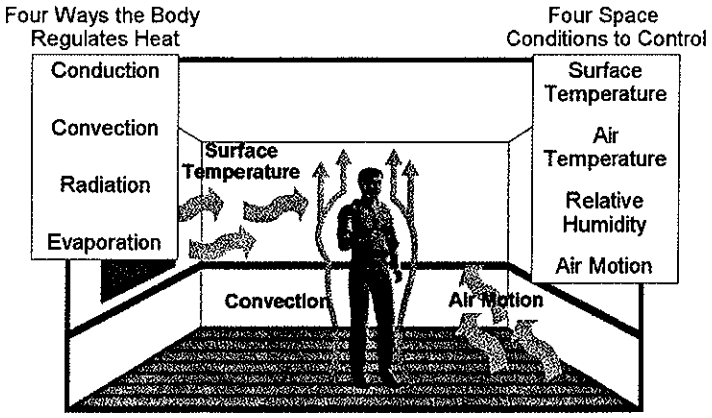


Figure 27

Body Temperature Regulation and Space Control

It can be noted from the discussion that comfort parameters have acceptable control ranges. Some of these are the result of personal preferences, and some are the result of seasonal variations.

People dress differently in summer than they do in winter, which influences the insulating value provided by clothing. It is typical for people to dress in lighter clothes with less insulating value in the summer, making higher temperatures acceptable. This variation can result in temperatures perceived as comfortable in one season as not being acceptable in another.

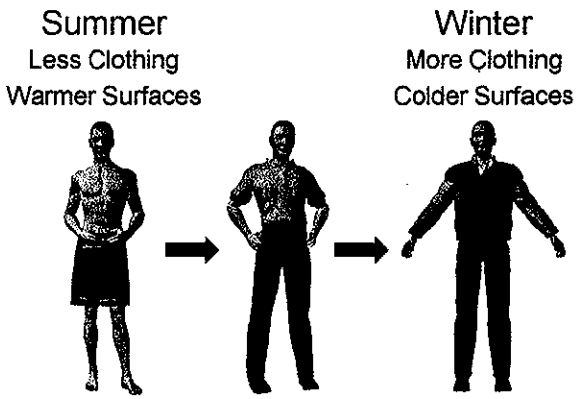


Figure 28

Clothing levels vary by season.

Similar results are observed with transmission loss and gains. It is not uncommon to have greater temperature difference inside to outside in winter than summer. This can result in conditions like colder glass temperatures that require higher space temperatures to compensate for the additional radiant heat loss.

For the designer this means it is important to evaluate conditions for all seasons of the year. This is true even when a space requires cooling all year round in order to be sure the selected comfort criteria is maintained.

Comfort Chart

ASHRAE has conducted considerable research on what constitutes comfort. The results are a comfort chart that can be used by the designer to select the appropriate comfort conditions for any occupancy, activity level, or season.

Since the conditions that define optimum comfort depend on individual preferences, dress, activity, and body function, it is impossible to have one specific number that satisfies everyone. To account for human differences, studies have been done using a large number of people to define what people perceive as comfortable.

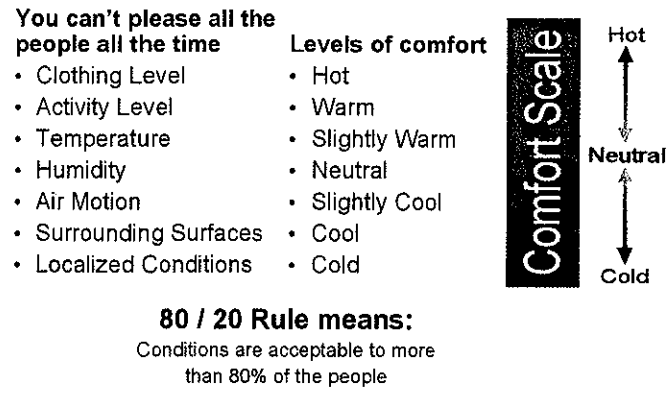


Figure 29

Comfort is subjective and depends on many variables.

Each of four comfort variables has been tested along with dress, activity, and localized conditions to determine what range of each is considered acceptable. The results of these tests have resulted in the development of the ASHRAE Comfort Standard, ASHRAE 55. This standard can serve as the designer's guide in determining the indoor comfort requirements for a project.

As is done with many studies that involve human judgment, the 80/20 rule is used. This rule is, when greater than 80 percent of the people are satisfied with the conditions, then the conditions are considered acceptable. In reality, since comfort is so subjective and a function of numerous variables, a 10 percent dissatisfaction level is used for acceptability with each individual comfort condition. This should result, when all conditions are considered, in meeting the 80/20 rule.

Comfort perception varies considerably, so a seven-step scale is used to evaluate the level of comfort. The subjects of the studies rate comfort as, hot, warm, slightly warm, neutral, slightly cool, cool and cold. Results then are based on a 90 percent rating of those conditions.

As discussed, temperature and humidity have the greatest influence on comfort and are the primary controllable functions of air-conditioning systems. The comfort envelope defines a range of acceptable temperature and humidity. Other conditions that influence comfort are assumptions and corrections to the values in the chart. Air motion, surrounding surface temperatures, clothing levels, activity level, and local conditions, such as floor-to-ceiling temperature difference, cycles per hour, and temperature drift, are assumptions on which the chart is based.

Designers can then use the chart and the modifications, which account for the other variables, to select the design conditions appropriate for the project.

Clothing Level

Clothing acts as an insulator inhibiting the ability of the body to dissipate heat. This can both help and hinder in the ability to maintain comfort. The more layers and the heavier clothing people have on, the less heat the body will be able to dissipate. The insulating value of clothing is measured in ***CLO*** units, or clothing insulating value. One CLO unit is equivalent to an R-value (resistance to heat flow) of 0.88 Btu/(h * ft^2 * F), or about equal to wrapping the body in a ¼ inch of cellular foam insulation.

- Clothing is an insulator
- Insulating value is measured in CLO – Clothing Insulation Value
- Varies from summer to winter with lower value in areas with less annual variation

Typical Values
Summer 0.35 – 0.6
Winter 0.8 – 1.2

Business Suit – 1.0 CLO



Figure 30

The insulating value of clothing is measured in CLO units.

Tables have been established for typical clothing assemblies based on men and women and typical dressing situations. These tables are found in ASHRAE Standard 55 and The ASHRAE Fundamentals Handbook. When the assemblies for the project are not listed, a table of CLO values for different clothing pieces is provided. The CLO value of the assembly can be estimated by adding individual component CLOs using a formula.

As discussed earlier, people have different dressing habits in summer and winter. The comfort chart assumes a CLO value of 0.5 for summer dress and 0.9 for winter dress. These values are typical for most office and retail applications. As a guideline, typical values of 0.35 to 0.60 in summer and 0.8 to 1.2 in winter are appropriate.

Activity Level

The activity level of the people in a space also affects the perceived comfort level for temperature and humidity. Activity level is measured in metabolic rate units (***MET***), and is used to calculate the heat energy produced by the body. One MET is equivalent to a heat generation rate of 18.4 Btuh/ft^2. The average body is 19 ft^2, therefore, the body generates approximately 350 Btuh per MET or about 420 Btuh per person for performing standard office tasks.

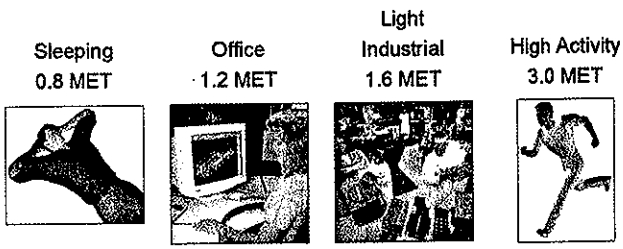


Figure 31

Activity level is measured in MET (Metabolic Rate Temperatures) and can be less for higher activity levels.

Typical levels vary from 0.8 MET when sleeping, to 3.0 MET doing heavy activity. The values in the comfort chart are based on an activity level representative of people seated at rest and doing typical office work. The metabolic rate for this activity level is 1.2 MET.

The average human body

The higher the activity level the lower the temperature generally found acceptable. Designers may be able to adjust design conditions to account for this. However, people often compensate for the activity in their dress. When designing, you must anticipate the impacts of both the activity and compensation of clothing to activity level.

Effective Temperature

Humidity has a significant impact on comfort. People commonly feel comfortable at a lower temperature in winter if the humidity is higher. Conversely, in the summer people feel more comfortable at a higher temperature if the humidity is lower.

To account for this difference, the concept of ***effect temperature*** is used. The effective temperature is dry bulb and relative humidity that feel the same as that dry bulb temperature at 50 percent relative humidity. Notice the lines on the comfort chart below reflect this concept.

- Humidity affects how we perceive comfort
- Effective temperature (ET) is the temperature and humidity that feels the same as that dry bulb temperature at 50% relative humidity
- In winter we feel more comfortable at a lower temperature if the dew point is higher
- In summer we feel more comfortable at a higher temperature if the dew point is lower

Figure 32

Effective Temperature

The Comfort Chart

ASHRAE has plotted, on the psychrometric chart, an envelope of the acceptable range of temperature and humidity based on clothing and activity levels in a typical office environment. This data allows the designer to select operating conditions that should achieve the 80/20 rule for comfort. The effective temperature results in the sloping angle to the sides of both the upper and lower limits of the operative temperature. The impact of clothing can be seen in the difference in the limit values being different for summer and winter.

- Do not exceed 60% rh
- Lower limit rh is not required but it affects comfort
- Energy codes require 5 degrees between cooling and heating set points

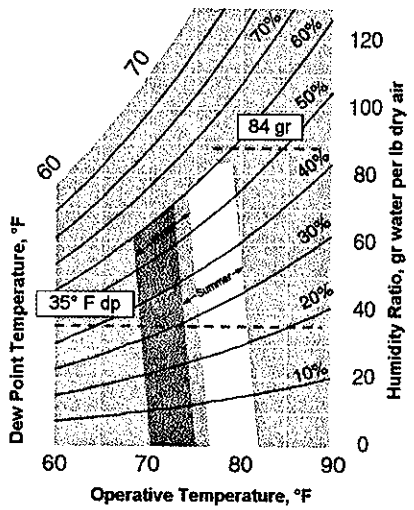


Figure 33

ASHRAE Comfort Chart

Notice that the line does not extend above 60 percent relative humidity or 84 grains. Above 60 percent, comfort is usually compromised and the potential for mold growth and indoor air quality issues are likely. A dotted line at 35° F dew point represents a design goal for a lower limit of space humidity. However, the current ASHRAE comfort envelope has removed the lower limit requirement due to concerns over condensation on cold walls and glass. Several studies have shown that maintaining the space humidity at the line represented by the 35° F dew point will help avoid complaints often associated with very dry air.

Also notice that the summer and winter conditions overlap in the 73° F to 75° F range. One might assume that this temperature range then would be a good compromise for both winter and summer with one set point for both. However, energy codes require a 5-degree temperature difference between summer and winter control points. Designers need to consider both the summer and winter control set points.

Conditions that Impact Comfort

A number of conditions could exist that will impact comfort if the settings from the comfort chart are applied. The first is the impact of air motion. When the air motion is increased the evaporation is also increased. As a result, in areas where the higher air motion can be tolerated, the temperature may be up to 7° F higher than indicated in the chart. This has the most impact in high activity level applications. For lower activity levels, like the office environment, this should be less than 5.5° F.

While air motion helps with the cooling effect, airflow that exceeds the velocity limits shown may result in drafts that could be objectionable. This is the case if air motion is such that papers move on a desk. Air velocity in excess of 100 fpm is not recommended.

- Air Motion
  - Control temperature can be compensated by up to 7° F
  - Drafts over 100 fpm maintain between 25 and 40 fpm, depending on temperature, turbulence and activity level
- Head-to-Toe difference of 5° F
- Temperature Cycling > 4° F/hour
- Temperature Drifts > 1° F/hour

Figure 34

Non-uniform Impacts

Another phenomenon that can result in discomfort is too great a thermal gradient from head to toe. Warm air rises and cold air settles based on the thermal density currents. With a great difference in this temperature, discomfort is sensed even when the temperatures at both extremes are within the comfort zone. A head-to-toe temperature difference should not exceed 5° F.

People are also sensitive to the time rate of change in temperature. Many systems control capacity by cycling stages of cooling or heating capacity. It has been determined that this rate should not exceed a change of greater than 4° F based on a maximum of one cycle every 15 minutes. The peak-to-peak differences in cycles per hour should also not exceed 2° F. These issues are associated with the system's ability to control temperature at part load conditions.

A similar issue is related to the amount of intentional drift or ***swing*** a system is allowed to exhibit. Drift is intentionally letting the control temperature not meet the thermostat set point. This can be done by offset in the thermostat or by control strategies that reduce cooling capability during the occupied hours. To maintain comfort, the temperature drift should not exceed 1° F per hour.

The final impact on how comfort is perceived is the impact of radiant surface temperatures. When the temperature of one surface is warmer than another surface it radiates heat energy to the cooler surface. If we consider a room and a person in the room, if their body is at a higher temperature than all the surfaces in the room, the body will radiate heat energy to all the surfaces. In most actual applications each of the room surfaces is at different temperatures.

Radiant heat exchange is governed by three key principles. First, the heat transfer is based on the temperature difference between the body and the surface. The greater the temperature difference the greater the heat transfer. The second principle is that the heat transfer is a function of the distance squared so the further away the surface is from the person the less the impact. Third, the heat transfer is a function of the absorption (ability to absorb heat) of the surface and the angle between surfaces. It should be obvious that the calculation of radiant effects is very complicated. While the equations are available to calculate the radiant impacts, a few simple rules will help designers maintain comfort under most conditions.

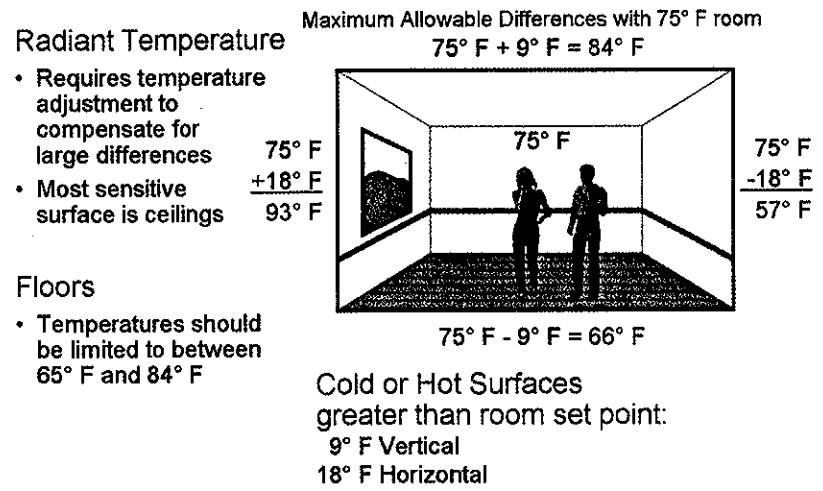


Figure 35

Surface Temperatures Influence Comfort

People tend to be most sensitive to ceiling temperatures. If the ceiling and floor temperatures are within 9° F of the room control point, and wall, glass, and other horizontal surfaces are within 18° F, comfort conditions should be maintained.

Floor temperatures present a similar problem, and with normal footwear if the floor temperature is kept between 65° F and 84° F, comfort conditions should not be compromised.

Comfort System Requirements

Now that comfort standards have been defined, how does a designer go about determining what the actual requirements should be for a project?

Figure 36 shows a form with the data a designer should consider in preparing the comfort requirements for a project. One of the first steps in design is to define the comfort requirements and the ranges acceptable to the owner. Ranges that are tighter than actually required can result in excess cost, both initially and for operation. Likewise, understated requirements result in occupants who are uncomfortable, unhappy, and often less productive.

The first step is to identify the type of space by usage and the activity to be performed. Buildings often have several spaces with different activity and usages; requirements need to be established for each.

Comfort Design Standards

Space / Activity						
Temperature	Occupied		Unoccupied		Throttling Range	Swing
	Design	Min	Design	Min		
Summer						
Winter						
Humidity	Design	Max	Min			
Summer						
Winter						
Air Motion	Max	Min	Notes			
fpm						
Ventilation	Occupied		Unoccupied		Notes:	
	Design	Min	Min			
cfm						
Direct Exhaust						
Filtration	Condition		MERV	Type	Other	
Radiant Surfaces	Glass	Wall	Floor	Roof	Other	
Summer						
Winter						
Acoustics	Room RC		Other Notes:			
Notes:						

Figure 36

Defining Comfort Requirements

Next, determine temperatures that should be maintained in the space. Temperature can be determined from the comfort chart with the appropriate adjustments for activity level, clothing and the like. It is necessary to consider a temperature requirement at four operational points, both for summer and winter. First, occupied temperature both an upper (cooling) and lower (heating) control point during summer operation must be determined. Remember that a 5° F offset is normally required between heating and cooling. The second set is the control point for unoccupied conditions for both heating and cooling. Most commercial buildings require that the set point of the thermostat be ***setup*** for cooling and ***setback*** for heating. In some buildings, not all these heating and cooling conditions are controlled during certain seasons of the year. For example, heating may not be available during summer seasons, or during summer unoccupied periods, cooling may be shutoff and the space temperature allowed to drift to whatever temperature it will. The strategies used are often dependent on the location of the project.

The same set of four conditions also needs to be evaluated in winter operation. Remember, because of the conditions reflected on the comfort chart, the conditions may be different for each season. When making the temperature decisions think about changes in activity level and clothing during each of the seasons.

Finally for temperature, consider how much ***throttling range***, or thermostat drift, will be allowed. Also consider the amount of temperature swing allowed. Swing is the intentional offset in space temperature above the thermostat setting. These two items are how much above or below the selected control setting a temperature can be and still be considered in range. Typically, no more than 3 degrees should be allowed for either of these two items.

In a similar manner the humidity requirements for the space need to be determined. Consider here special requirements that may exist because of materials in the space or activity. In some cases, even though the prime function of the design is comfort, materials and processes in the space require certain temperature and humidity ranges. In selecting humidity requirements, use caution that a maximum of 60 percent or less can be maintained to help avoid indoor air quality problems. On the lower end of the humidity scale, consider if humidification might be required. In typical office spaces, conditions within the comfort chart are normally acceptable. Humidity levels can be specified in terms of relative humidity or a dew point. Dew point is more appropriate when the absolute level of humidity in the space must be held to a set limit.

Next, consider the air motion. If it is traditional office space, then the range of 15 to 45 fpm is acceptable. But, if greater air motion can be used to compensate for the temperature level this is a time to consider it.

Ventilation requirements are often dictated by building codes. This phase of the design is a good time to check the requirements and determine the required airflows. ASHRAE requirements allow for airflows to meet both the building requirements and the requirements for people. The building requirement is air to purge the gases that outgas from building materials and maintenance activities. The people requirement is for oxygen replacement and odor dilution. This is addressed in greater detail in other TDP modules. These are minimums and greater rates may be required in some instances. Also, be sure to note any air that is being exhausted directly from the space. Lab and kitchen hoods, bath and kitchen fans and exhaust fans from processes may remove air from the space. Ventilation air, by definition, must at least replace this amount of air.

Any special requirements in terms of filtration should be addressed in the selection of comfort criteria. An example is activities occurring in the space that generate some type of particulate or gaseous contaminant that needs to be filtered. This is a good time to define these issues and what levels of filtration may be required. Filters can be used for particulate, gaseous, and biological contaminants.

In this phase of the design, it is a good time to evaluate if some of the surfaces may present radiant problems in either heating or cooling. Calculate surface temperatures for the surfaces that may present a problem. Since the HVAC systems can only be designed to compensate for this problem, it may be early enough in design that the building materials or design can be modified to help overcome potential problems.

Finally, consider any acoustical requirements of the space. This issue is covered more completely in TDP-901, Vibration and Acoustics. All six of the conditions related to comfort have now been considered for the project.

Defining Comfort Conditions

First, let's look at defining the comfort conditions in a typical office environment. Temperatures are selected based on the ASHRAE comfort chart. Notice a 5-degree difference is maintained between heating and cooling, and a lower winter temperature is selected to account for typical clothing difference in the two seasons. It has been determined that this project does not need to provide unoccupied cooling in the winter and does not require heating in the summer.

Comfort Design Standards

Space / Activity	Office					
Temperature	Occupied		Unoccupied		Throttling Range	Swing
	Design	Min	Design	Min		
Summer	75	70	85	0	1 1/2	0
Winter	70	68	0	60		
Humidity	Design	Max	Min			
Summer	50	60				
Winter	None		None			
Air Motion	Max	Min	Notes			
fpm	30	15				
Ventilation	Occupied		Unoccupied		Notes:	
	Design	Min	Min			
cfm	20 / P	0.25 / ft²	0			
Direct Exhaust	0.25 / ft²					
Filtration	Condition		MERV	Type	Other	
	Standard		6	Pleat		
Radiant Surfaces	Glass	Wall	Floor	Roof	Other	
Summer	84F @ 95F					
Winter	38F @-10F				35 % glass	
Acoustics	Room RC		Other Notes:			
	RC 35 - N					
Notes:						

Figure 37

Example of Comfort Requirements for an Office

Humidity requirements are again from the ASHRAE comfort chart. Typical of many office environments the design team has decided that humidification will not be provided.

Air motion is the typical design range of 15 to 45 fpm.

Ventilation air provides 20 cfm/person in the occupied period and 0.25 cfm/ft^2 during the unoccupied period. The bathroom fans exhaust the same amount as the building ventilation requirement.

The building has no special filtration requirements.

The glass selected has a summer design surface temperature of 84° F or 9 degrees above the room, about half the maximum allowed. However, the winter temperature has a 30-degree difference and this is a potential problem. Maybe better glass could be specified. If not, the winter heating set point may need to be increased.

In a different application we have a light manufacturing area. In this case the manufacturing area is working with cardboard boxes. Again the primary goal of air conditioning is the comfort, and productivity of the workers. However, because of the paper boxes and the process, a few special requirements are necessary.

Higher temperatures are allowed because the workers are more active than the office workers in the last example. Humidity, however, has a lower limit because of handling paper; in this case winter humidification may be required.

Other special requirements are that an exhaust hood on the curing oven requires 300 cfm of exhaust air, and because of the curing process of the glue, continuous ventilation is required. The boxes also generate a lot of paper particle dust. To control this, a better filtration system is required. With this information, a comfort design chart similar to the one for the office can be generated.

After going through this process for all the building spaces the designer has a good picture of what the total air-conditioning design must do to maintain comfort. In the next section the two interdependent elements of the air-conditioning system and the components of each will be examined.

This completes our coverage of basic human comfort. Before you continue, please complete the Work Session 1. Work session answers can be found in the back of the book.

Comfort Design Standards

Space / Activity	Box Manufacturing Area					
Temperature	Occupied		Unoccupied		Throttling	Swing
	Design	Min	Design	Min	Range	
Summer	78	70	0	0	2	3
Winter	68	65	0	55		
Humidity	Design	Max	Min	Storage Requires Min of 25%		
Summer	45	55				
Winter	30		25			
Air Motion	Max	Min	Notes			
fpm	30	15				
Ventilation	Occupied		Unoccupied		Notes:	
	Design	Min	Min			
cfm	20 / P	0.5 / ft^2	.025 / ft^2		Oven Exhaust	
Direct Exhaust	300 cfm					
Filtration	Condition		MERV	Type	Other	
	High Particle		10	Bags		
Radiant Surfaces	Glass	Wall	Floor	Roof	Other	
Summer	84F @ 95F			83F @ 95F		
Winter	38F @-10F				35 % glass	
Acoustics	Room RC		Other Notes:			
	RC 50 - N					
Notes:						

Figure 38

Example of Comfort Requirements for Light Manufacturing

Air-Conditioning Systems

Now that comfort has been addressed, as well as the controllable space conditions that determine comfort, we will turn our attention to the air-conditioning system. First we will present the systems approach to air-conditioning design. Then we will deal with the air system to show how load is absorbed by conditioned air as well as how air is treated to provide air motion, ventilation, filtration, heating, cooling and dehumidification. Finally, the mechanical refrigeration system, which provides the capacity necessary to cool and dehumidify the air supplied to the conditioned space, will be discussed.

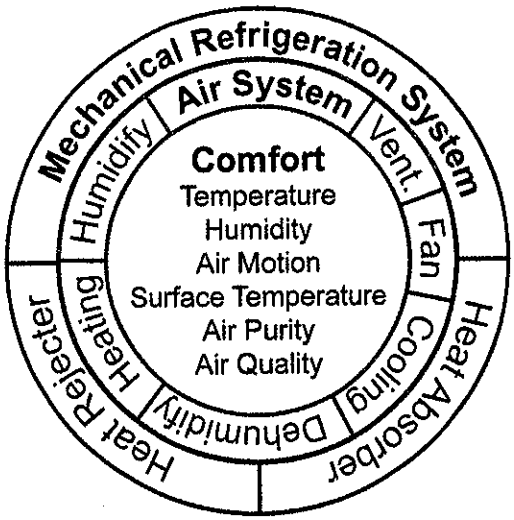
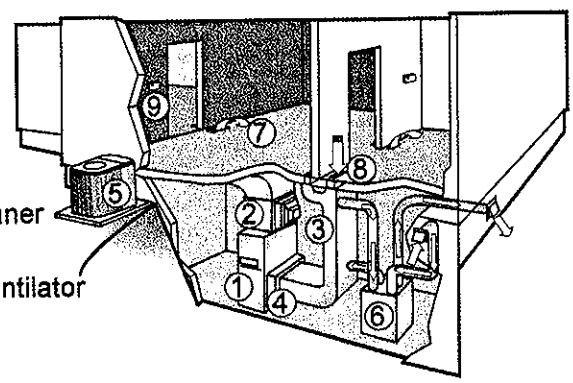


Figure 39

Interaction of Comfort to Air and Refrigeration Systems

Many air-conditioning system designers think in terms of components. However, the systems that provide the maximum comfort for the money invested are those designed by people who think in terms of systems and subsystems rather than components.

Not only does a systems approach benefit the customer, but it also makes air-conditioning design easier to understand. Once the basic systems, subsystems, and components are understood, the large array of options offered in our industry can be easily recognized as variations on a few basic themes.



1. Furnace
2. Evaporator
3. Humidifier
4. Electronic Air Cleaner
5. Condensing Unit
6. Heat Recovery Ventilator
7. Supply Diffusers
8. Return Grilles
9. Comfort Controls
   - Thermostat
   - Humidistat
   - HRV Controller

Figure 40

Typical Residential System Components

The residential air-conditioning system shown here illustrates these concepts quite well. Many types of ***air handlers*** and condensing units exist. But even though their size, shape and location may change, these components provide the same function and relate to other components in their respective systems the same way whether a 3-ton residential system or a 60-ton commercial system is considered.

Since several components are interconnected as a system, the action of one component affects many or all of the others in some way. Thus, decisions made in selecting or installing one component affect the other components. Trade-offs are involved when making system decisions. What is beneficial for one component may be disadvantageous for another. The designer who uses a systems approach makes choices which produce the greatest benefit for the system overall.

Some components belong to more than one system. For example, the ***evaporator*** (cooling coil) is part of three systems: the air system, the mechanical refrigeration system, and the cooling system. Since such components have multiple purposes, they must perform acceptably in all systems in which they occur and in all modes of operation.

As a part of the air system, the evaporator must be selected and installed in a way that permits an even flow of supply air through it. Also, its air pressure drop, when wet, must be included in the summary of resistances to airflow that the fan must overcome.

As part of the mechanical refrigeration system, the evaporator must be piped correctly to the ***refrigerant metering device*** and condensing unit to ensure reasonable internal operating temperatures for the evaporator at both full and partial cooling loads.

System	Components	Subsystems
Air System	Furnace Evaporator Electronic Air Cleaner Humidifier Heat Recovery Ventilator Supply Diffusers Return Grilles	Ductwork Electrical Power Wiring Electrical Control Wiring
Mechanical Refrigeration System	Evaporator Compressor Condenser Metering Device	Refrigerant Piping Condensate Piping Electrical Power Wiring Electrical Control Wiring
Heating System	Furnace or Fan Coil Humidifier Thermostat Humidistat Heat Recovery Ventilator HRV Controller	Ductwork Gas/Oil Piping Flue Gas Venting Electrical Power Wiring Electrical Control Wiring Condensate Piping
Cooling System	Furnace or Fan Coil Evaporator Metering Device Condensing Unit Thermostat Heat Recovery Ventilator HRV Controller	Ductwork Condensate Piping Refrigerant Piping Electrical Power Wiring Electrical Control Wiring

Figure 41

Comfort systems consist of systems, components and subsystems.

As a part of the cooling system, the evaporator must combine with the metering device and condensing unit to produce adequate, but not excessive, capacity. Both sensible and latent cooling loads must be met. The condensate, which accumulates as the evaporator cools the air, must be removed from the coil and properly disposed.

Air System

Let's start our study of the air-conditioning system with the air system.

When we are outside, we depend on clothing and weather patterns for our comfort. If the combination of temperature, relative humidity, air motion, and clothing is within a reasonable range, we feel comfortable. Our bodies reject just the right amount of heat to maintain our inner temperature in a stable way. But if the combination of these conditions is not right, discomfort results. If clothing cannot solve the comfort problem, there is nothing we can do to change the outside conditions. Comfort is not achieved.

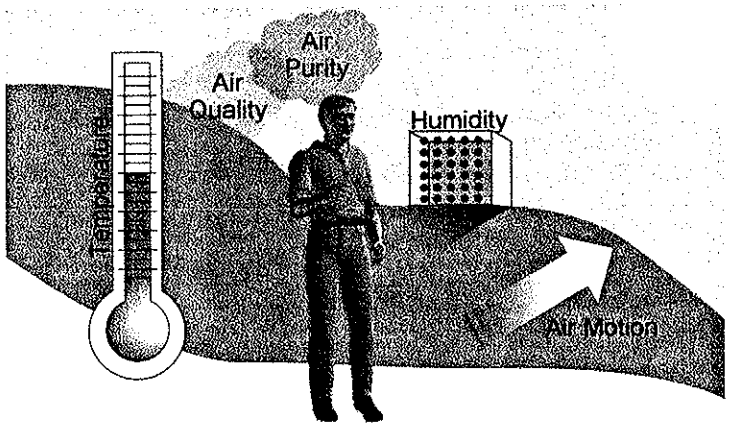


Figure 42

The air system controls five conditions of space comfort.

Building Loads

When we seek shelter in an enclosed space, we can control the air conditions in a way that assures comfort over a very broad range of outside conditions. If the building was perfectly isolated from outside effects, and only people were present, we could maintain comfort by simply removing the heat given off by the people. But, in reality, the situation is not that simple. No matter how diligently the building designer strives to insulate the building from outside effects, it is still influenced.

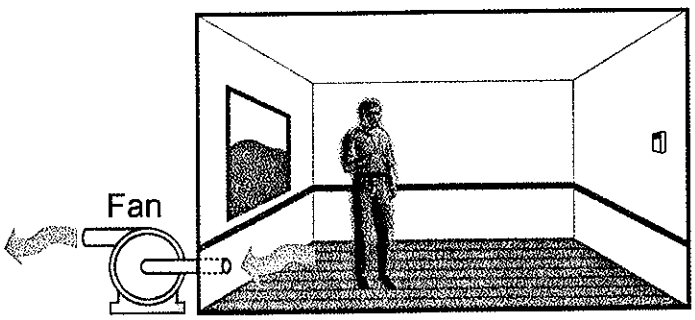


Figure 43

In a perfect world, only heat generated by people would need to be removed.

In addition to body heat, other heat gains enter the space from within the building. Electric lights, appliances, computers, copy machines, heated food and drinks, and any equipment that is motor-driven adds heat to the air within the building. All these items tend to increase the temperature and some of them increase the humidity of the indoor air, slowing down the body's ability to reject heat, and eventually causing discomfort. The problem does not end with internal effects.

- People
- Lights
- Motors
- Appliances
- Cooking
- Computers
- Process

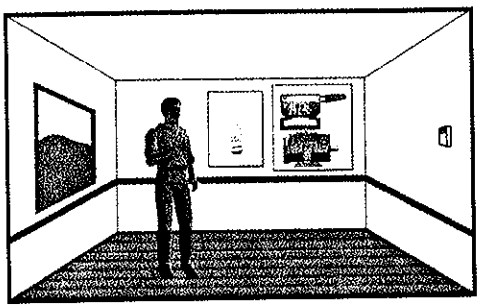


Figure 44

Internal Heat Gains

No building is perfectly isolated from outside effects. Sunlight enters the space in the form of radiant heat energy through windows or glass walls, and glass doors. Once sunlight strikes an object inside, it turns into heat that moves into the air by conduction and convection. Sunlight also strikes some parts of the exterior of the building. Outside walls and roofs that are sunlit warm up and conduct heat into the building. All these effects are called solar loads.

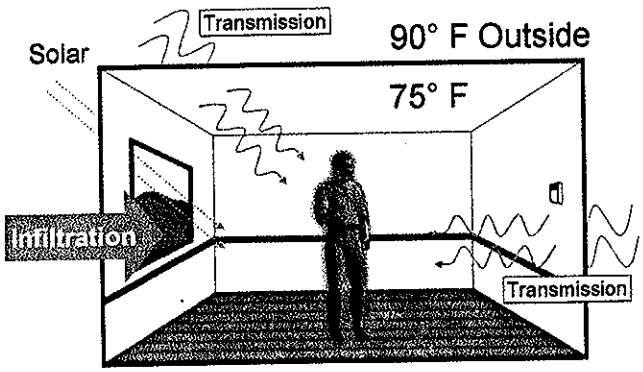


Figure 45

External Heat Gains

Infiltration vs. Ventilation

Likewise, when the outside air temperature is higher than the inside temperature, heat is conducted inward, through all exterior building barriers, adding further to the heat entering the building. Heat transferred in this way is called ***transmission load***.

Outdoor air infiltrates (leaks) into the building through cracks around windows and doors. Fans that mechanically ventilate the space also bring in outdoor air. Since the temperature and humidity of the outdoor air is often quite different than the indoor air, infiltration and ventilation can change indoor temperature and humidity in a significant way. The air-conditioning system must offset the outdoor air load in order to maintain comfortable inside conditions.

Together, the outside effects of solar, transmission, infiltration and ventilation, along with the inside effects of people, lights and equipment determine the amount of heat entering or leaving the building per unit of time. This rate of heat transfer is called the load of the building. It is expressed in British thermal units per hour (Btuh). Just as the total of all these effects is called load, each of the outside and inside components that make up the total load also is called a load (e.g. solar load, transmission load, lighting load, equipment load, people load, and outdoor air load).

Any effect that increases space temperature or humidity is called a cooling load. Solar load, people, equipment, and lighting are always cooling loads, as shown in the example illustrated in Figure 46.

Any effect that decreases space temperature is called a ***heating load***. Transmission, infiltration and ventilation are heating loads when the outside temperature is below the inside temperature. Transmission, infiltration, and ventilation are cooling loads when the outside temperature is above the inside temperature

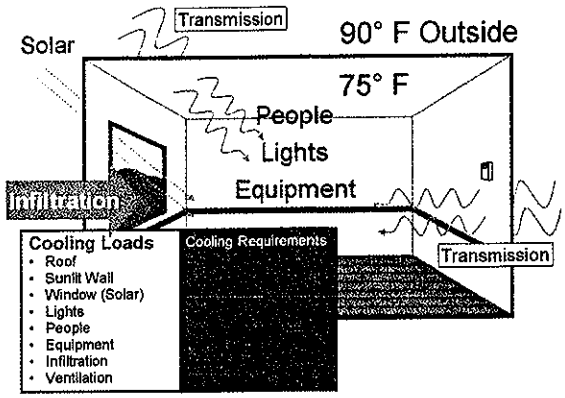


Figure 46

Building Loads – Internal Gains Plus External Gain

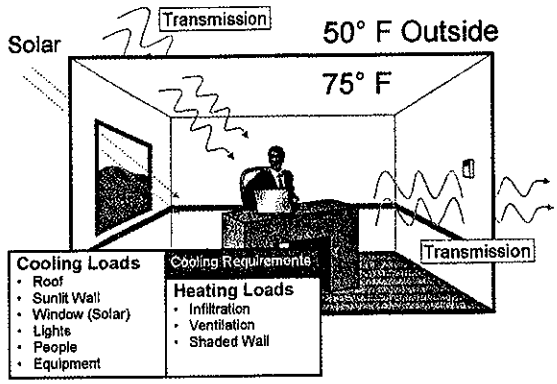


Figure 47

Cooling Loads – If Heat Gains are Greater than Heat Losses

Cooling load vs. heating load

The total load of the building is the combined result of all the individual load components working together. Often, inside and outside conditions combine in such a way that cooling load components exist at the same time as heating load components as shown in Figure 47.

If the combined result causes heat to enter the building more rapidly than it leaves, the entire building is said to have a cooling load. The space temperature and humidity will climb unless something is done to reject heat and moisture from the indoor air. This is the case in the example illustrated.

Since it is 50° F outside, the outside wall that is not sunlit has a heating load. Likewise, outdoor air that comes into the building represents a heating load since the outside air temperature is below the inside air temperature. At the same time, the sunlit glass, wall, and roof present a cooling load, as do the computer (equipment), lighting, and the person in the room. In this case, the cooling loads outweigh the heating loads.

Likewise, if the combination of all load components causes heat to leave the building more rapidly than it enters it, the entire building has a heating load. The space temperature and humidity will fall unless something is done to add heat and humidity to the indoor air.

In the example, the lights, people and any equipment provide cooling loads. However, the heating load components outweigh the cooling load components. The roof, walls, window, and any outdoor air that comes into the building are all heating loads. Since it is nighttime, there is no solar load. The building has a heating load under these conditions.

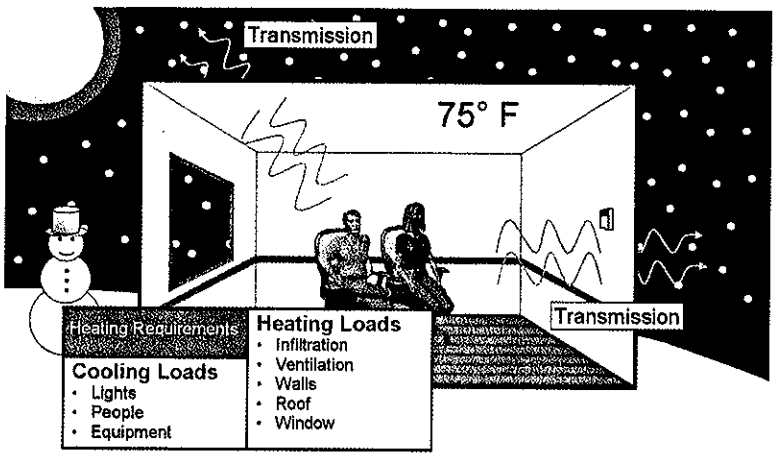


Figure 48

Heating Loads – If Heat Losses Exceed Heat Gains

Air System – Components

The job of the air-conditioning system is to match the heating or cooling load with heating or cooling capacity necessary to maintain desirable inside conditions. Many heating-only systems accomplish this by using a boiler with ***convective baseboard*** heaters. No fan is required. The same thing is accomplished with baseboard electric resistance heat.

When cooling, dehumidifying, filtering and direct control of air motion are required, however, an air system becomes essential. Only with the air system can the space temperature, humidity, and air motion be simultaneously controlled, year round.

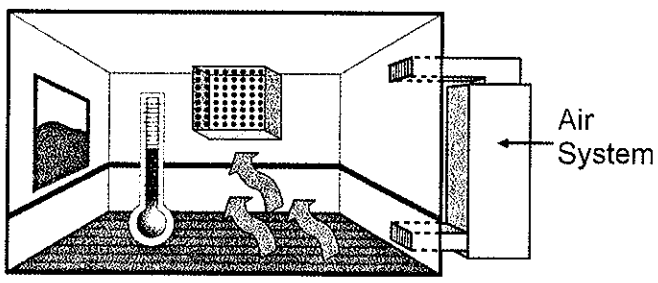


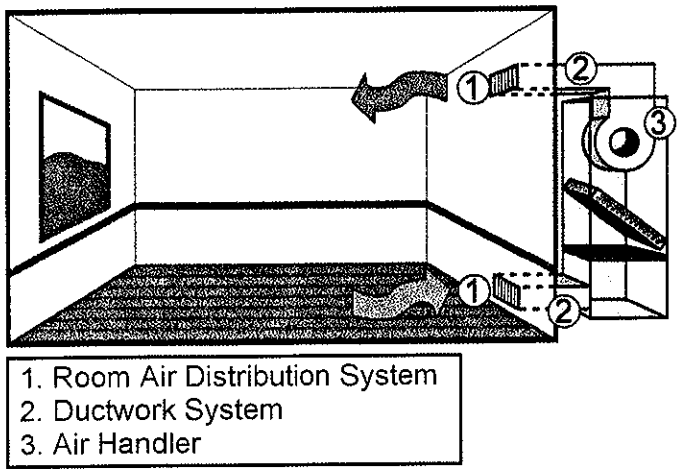
Figure 49

Air systems maintain air motion, temperature, and humidity.

Actually, a comfort air-conditioning system must simultaneously maintain, within a reasonable range, all three air conditions affecting the rate of heat loss from our bodies: temperature, humidity, and air motion. The system also must provide adequate air quality by properly ventilating and filtering the indoor air.

A comfort air-conditioning system controls these parameters by moving air through the building. The air system accomplishes this task. The air system is usually made up of three subsystems: the room air distribution system, the ductwork system and the air handler. The air handler ***circulates*** the proper quantity of air, at the right temperature, humidity, and purity to maintain the desired conditions.

The following section shows how the air system maintains comfort conditions in the air-conditioned spaces within the building.



1. Room Air Distribution System
2. Ductwork System
3. Air Handler

Figure 50

An air system is made up of the room air distribution system, the ductwork system, and the air handler.

Room Air Distribution

The room air distribution system is made up of the supply air outlets and return air inlets in the conditioned spaces of the building. The air motion in a room is affected by the openings through which conditioned air is supplied. These supply air outlets are usually called diffusers or ***registers***.

The number, size, shape, and location of the supply air diffusers all affect room air motion significantly. The air distribution aspect of comfort air-conditioning design is very important, yet it is often neglected. The very best equipment will perform only as well as the air distribution system that supports it. Proper design of ductwork and return openings are also vitally important but will not offset errors made in the selection and layout of the supply diffusers.

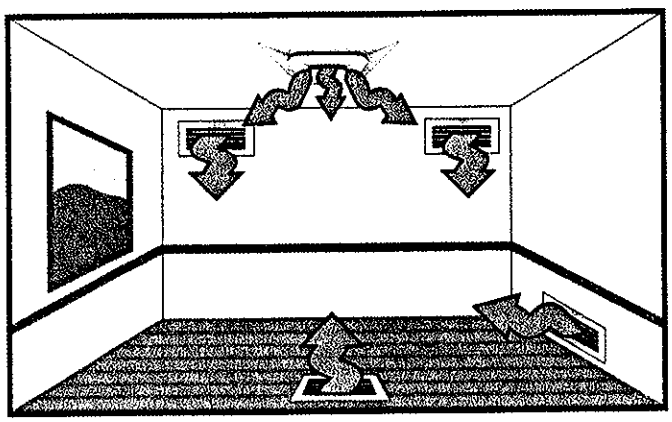


Figure 51

Supply Diffusers and Registers

Return air openings are usually called grilles. The total airflow capacity, measured in cubic feet per minute (cfm) of the return grilles must be at least equal to the total airflow capacity of the supply diffusers because the air returned becomes supply air after being conditioned by the air handler. The performance of the return grilles is less sensitive to location and number than supply diffusers.

At the air handler, air returned from the conditioned space is mixed with outdoor air (ventilated), filtered and heated or cooled, as the building load indicates. The first treatment the return air receives when it enters the air handler is an improvement of its quality by mixing it with outdoor air.

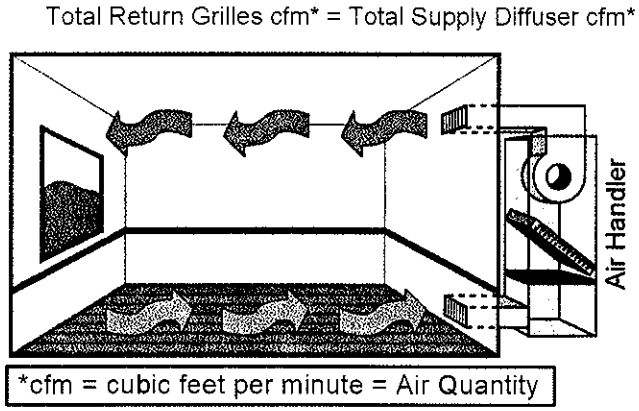


Figure 52

Return Grilles – air provided must be equal to air removed.

Ventilation

The process of mixing outdoor air with return air at an air handler and supplying it to the building spaces is called mechanical ventilation. It dilutes odors and pollutants in the conditioned spaces of the building. It also replaces oxygen used by people as they breathe the air in the space.

Many residential systems lack mechanical ventilation. They rely on infiltration to do the job instead. Ventilation is considered so important that some commercial systems are supplemented by a separate system that provides only ventilation air. Also, ventilation is being included on an increasing number of tightly constructed residences.

While mechanical ventilation is not the norm on residential systems or some small-zone commercial equipment, it is required on commercial systems.

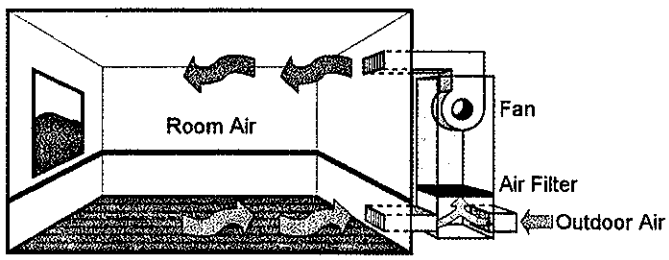


Figure 53

Mechanical ventilation replaces oxygen and dilutes odors.

Filtration

After return and outdoor air are mixed to provide ventilation, it is drawn through a filter, which purifies the air. Many types of filters are available. At the least, they remove dust and dirt from the air before conditioning and supplying it to the space. More efficient filters that remove pollen, bacteria, smoke and even harmful and irritating gases, are available. After mixing and filtration, the air is ready to be heated or cooled, and humidified or dehumidified.

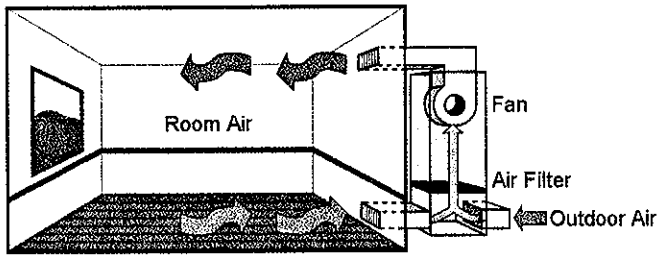


Figure 54

Filtration purifies the mixed return and outdoor air.

Heating

If there is a heating load, heat must be added to the air to make up for the heat lost from the room. A heating coil within the air handler adds this heat, raising the temperature of the supply air above the room temperature. Air typically leaves the supply diffusers at a temperature of 90 - 140° F. As shown here, the heat exchanger that adds heat to the air can be located on the discharge side of the fan in a ***blow-thru*** configuration. It also can be located on the inlet side of the fan in a ***draw-thru*** configuration. Residential air handlers usually put the heat exchanger in the blow-thru arrangement. Commercial products vary the heat exchanger's location based on size and style of equipment.

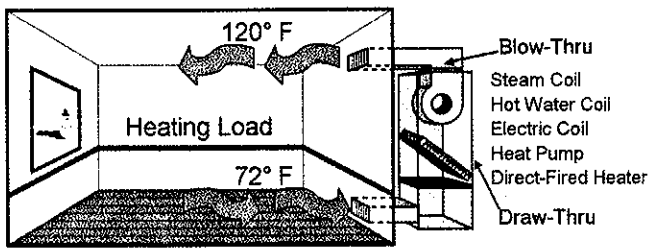
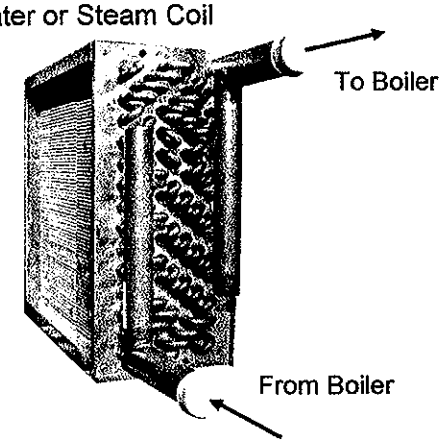


Figure 55

Heating Locations – before (draw-thru) or after (blow-thru) the fan

1. Hot Water or Steam Coil



There are four common methods of heating air within an air handler. One way is to pass air through a hot water or steam coil that is connected to a boiler. As the air passes over the surface of the coil, it absorbs heat from the coil. The heat in the air will be used to offset heat loss as it circulates through rooms with a heating load.

Figure 56

Hot Water or Steam Heating Coils

Another way to heat the air is with an electric resistance heating coil. The wire elements of the heater heat up due to resistance when electricity passes through them. As the air passes over them, it absorbs the heat and carries it to the conditioned space.

2. Electric Resistance Heating Coil

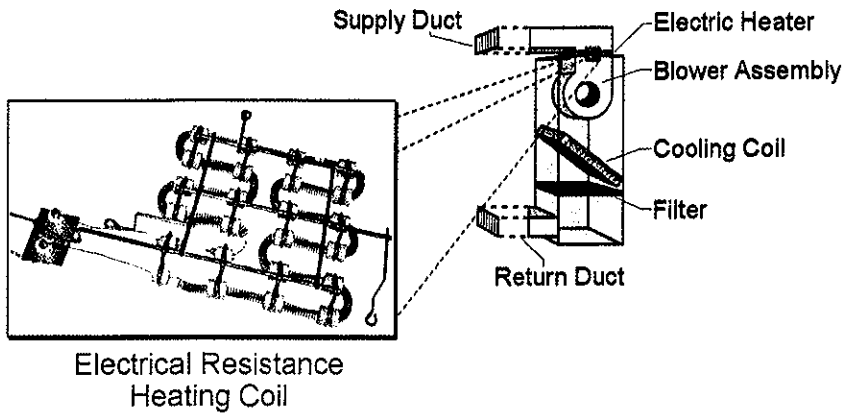


Figure 57

Electric Resistance Heating Coil

Another popular way to heat electrically is with a ***heat pump*** coil. It uses much less electricity than electric resistance heaters. The heat pump indoor coil looks just like a cooling coil. In fact, it does double duty, serving as a cooling coil in the cooling mode and as a heating coil in the heating mode. It accomplishes this by a reversal of the ***refrigerant*** flow in the mechanical refrigeration system. An electric resistance heater usually accompanies the heat pump indoor coil for the times when the heat pump coil cannot supply the needed heating capacity.

3. Heat Pump Indoor Coil (Heat/Cool)

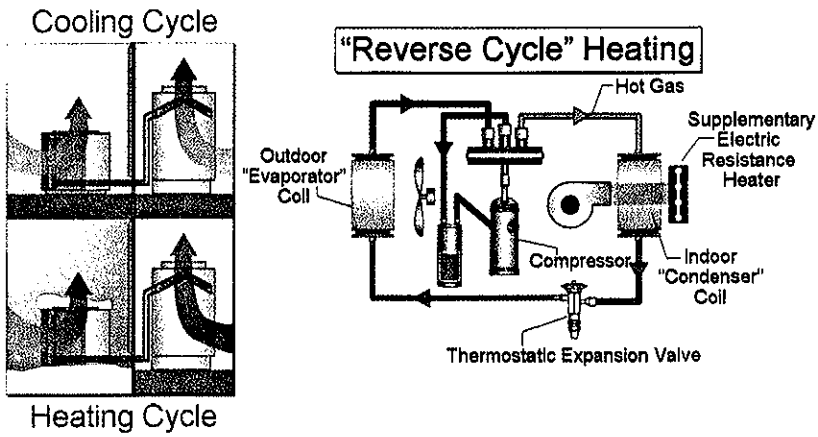


Figure 58

Reverse Cycle Heat Pump

Finally, air may be heated by a flame within a heat exchanger over which the air flows. This approach is called direct-fired or fossil fuel-fired heating since fossil fuels are burned in the heat exchanger over which the air handler circulates air. Oil, natural gas, and liquefied propane (LP) gas are the fossil fuels used. Direct-fired heat exchangers are usually located on the discharge side of the air handler fan. This approach is popular for residences and small commercial applications using upflow, downflow or horizontal furnaces. It is also popular for commercial jobs using roof-mounted packaged equipment.

4. **Direct-Fired Heat Exchanger** (Natural Gas, Oil, LP Gas)

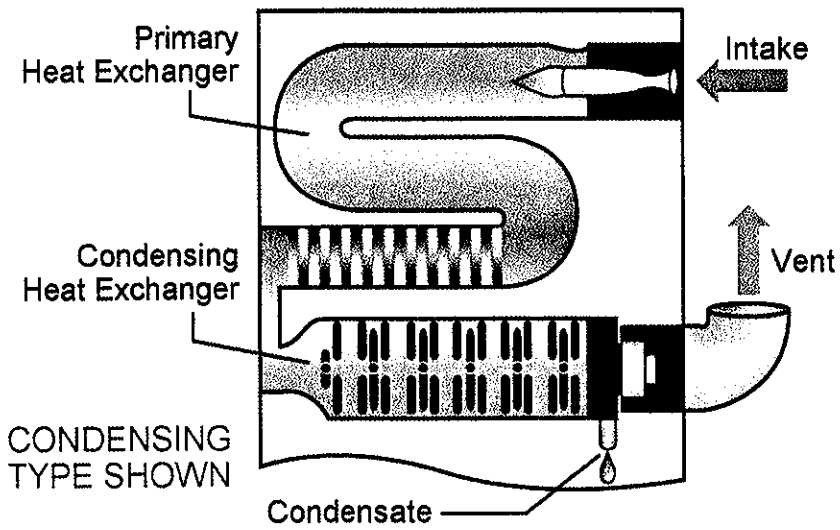


Figure 59

Gas Heaters – Direct-Fired, Gas, Oil, LP

Cooling

When there is a cooling load, air must be supplied at a lower temperature and humidity than the air in the conditioned space. This allows the supply air to absorb heat and humidity while maintaining acceptable space conditions. The air supplied to the space absorbs heat added by solar, transmission and infiltration loads from outside as well as from people, equipment, and lights from inside. It also absorbs humidity added by the infiltration of outdoor air, plus humidity added from the inside by people, hot foods, and liquids. The air handler must remove this heat and humidity so that the air can be used to condition the space again.

The air handler removes heat and humidity by passing the air through a cooling coil. The coil is made up of metal tubes with thin, metal sheets, called fins, attached to them. Cool refrigerant or water flows through the cooling coil, absorbing heat from the air passing over its tubes and fins, thus cooling the air. This module covers the internal workings of the refrigerant evaporator, not the chilled water type of cooling coil.

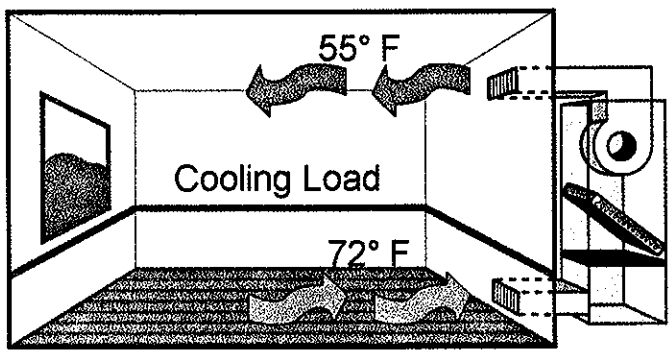


Figure 60

Cooling Air Handler

Moisture is removed from the air that flows over the cooling coil because some of the water vapor in the air turns into liquid as it hits the cold coil. As the water vapor condenses, the air is dehumidified and the condensate (liquid water) is collected and drained away from the air handler. The following example helps to demonstrate why this dehumidifying process takes place.

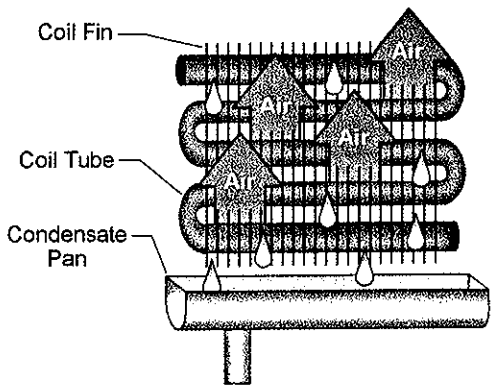


Figure 61

Cooling and Dehumidifying Coil

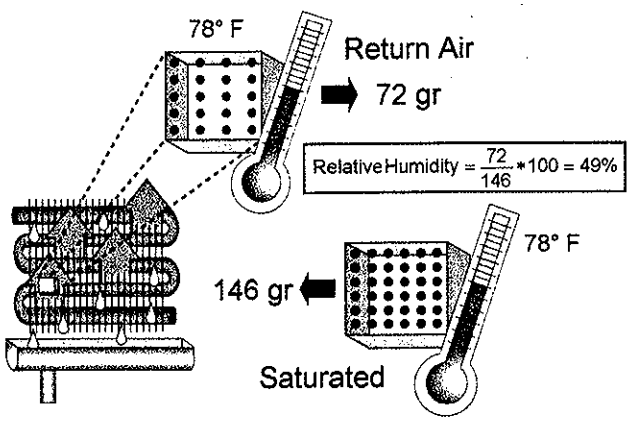


Figure 62

Relative Humidity of Return Air

If a residential system uses no ventilation air, the air enters the cooling coil approximately at room conditions. Assume that the return air conditions are 78° F and 72 grains per pound. Air at 78° F can hold 146 grains per pound of moisture when saturated with water vapor. Therefore, the ***relative humidity*** (rh) of the air entering the cooling coil is approximately 49 percent (72/146 * 100). As it enters the cooling coil, the return air is not even close to being saturated.

However, as the return air begins to pass through the cooling coil, the air temperature drops. Colder air can hold less water vapor than warmer air, so the relative humidity of the air climbs as it passes through the cooling coil. Air at 72 grains per pound (gr/lb) will have a relative humidity of 100 percent at about 58° F. At that temperature, the air will be saturated. So, if the air leaves our coil at 55° F, it will be saturated, but its specific humidity at 55° F will be 64 gr/lb at 100 percent rh. That's about 8 gr/lb below the entering air condition of 72 gr/lb. Therefore, moisture was removed from the air by the coil. Now the supply air can enter the room and absorb more moisture. Let's see how the coil removed the moisture.

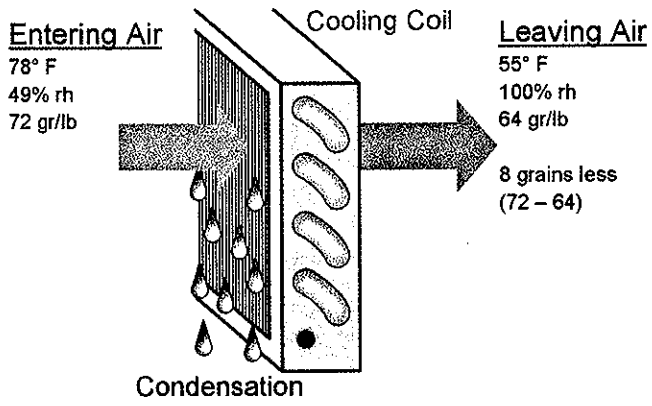


Figure 63

Cooling and Dehumidifying – Relative humidity increases, but actual moisture (grains) decreases.

At peak cooling load, most cooling coils run at a surface temperature of about 52-58° F. The air leaves the cooling coil at about 53-60° F. A typical leaving air temperature is 55° F, which will be used for this example.

The saturation temperature of the air entering the cooling coil is 58° F, as noted. At 58° F, all of the water is held within the air as vapor. If the air temperature drops below the saturation temperature of the entering air (58° F), some of the moisture within it will change from vapor into liquid.

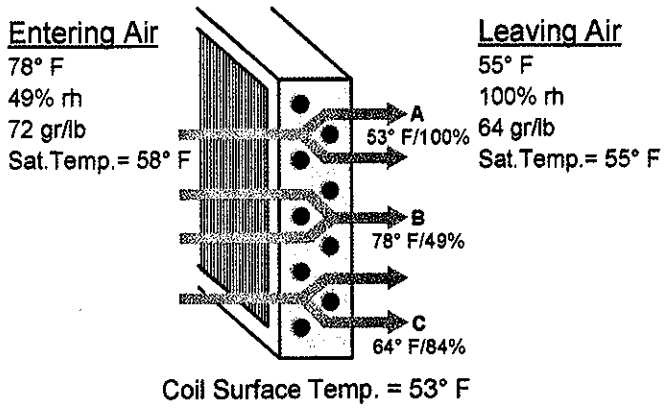


Figure 64

Actual coil performance is a mixture of several airstreams.

The air leaving the coil is really a mixture of several air streams at various conditions. Air that comes in closer contact with the coil tubes and fins mixes with air that slips by farther away. The air that is farther away from the tubes and fins is less affected by the coil surface than the air that contacts it more directly.

In reality, none of the air is brought all the way down to the surface temperature of the coil and none of it slips through totally unaltered. However, the illustration helps to show that the leaving air condition is a mixture of several airstreams treated to various degrees. The illustration also shows why various air-cooling coils have different efficiencies.

Evaporator coil terms:

Airstream "A" comes in direct contact with a coil tube. It drops to the coil surface temperature, 53° F. This is well below the saturation temperature of the entering air (58° F). Therefore, moisture is condensed on the coil tube and fin(s) connected to it. This air leaves the coil at 53° F, saturated. Airstream "B" goes through the coil without touching a fin or tube. It may come out just about the way it went in, at 78° F/49% rh with a 58° F saturation temperature. Airstream "C" leaves the coil at a condition somewhere between "A" and "B."

Air cooling coils are designed so that the vast majority of the air passing through them comes in direct contact with the coil tubes and fins. As demonstrated in the example, the leaving air temperature (55° F) is much closer to the coil surface temperature (53° F) than it is to the entering air temperature (78° F).

The air that passes through without contacting the coil is called bypassed air. It can be expressed as a decimal fraction or percent of the total air, in which case it is called ***bypass factor***.

In our example, about 92 percent of the air is directly contacted by the coil surface: ([78° F - 55° F] ÷ [78° F - 53° F]). Only 8 percent passes through without contacting the coil surface: ([55° F -53° F] ÷ [78° F - 53° F]), making its bypass factor 0.08. A lower bypass factor means that more of the air passing through the coil comes in direct contact with the coil surface, improving cooling and dehumidification efficiency. Higher bypass factors decrease cooling and dehumidification efficiency.

$$\text{Contact Factor} = \frac{(78° F - 55° F)}{(78° F - 53° F)} = 0.92 = 92\%$$

$$\text{Bypass Factor} = \frac{(55° F - 53° F)}{(78° F - 53° F)} = 0.08 = 8\%$$

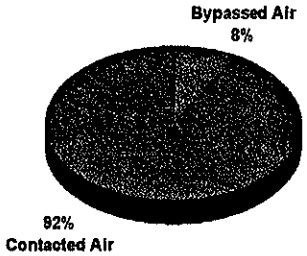


Figure 65

Bypass and Contact Factors

To lower bypass factor:

Bypass factors for comfort air-conditioning equipment vary from about 0.01 to about 0.20. A typical figure for most applications is about 0.08. Anything that increases the amount of air in contact with the coil surface will reduce the bypass factor and improve the heat absorbing efficiency of the coil, especially its ability to dehumidify.

The speed, or velocity, in feet per minute (fpm), at which air travels through the coil affects bypass factor. The slower the air moves through the coil, the better chance the air has to come in contact with the coil surface. Therefore, lower air velocity means lower bypass factor. Air velocity through the cooling coil can be reduced by selecting a larger coil or by selecting a system that can provide the necessary cooling capacity at lower airflow quantity (cfm). Bypass factor is seldom considered directly when selecting cooling equipment. Instead, the manufacturer's capacity ratings include the effect of bypass factor, without directly mentioning it. Nevertheless, the bypass factor concept helps you to understand why systems with oversized evaporators perform most efficiently.

For all cooling equipment, reduced airflow (cfm) means reduced coil velocity and total cooling capacity. However, the coil's ability to remove moisture (its latent cooling capacity) increases at lower airflow and velocity while its ability to reduce the supply air temperature (its sensible cooling capacity) decreases.

The closer together the coil tubes and fins are, the less air passes through untreated. This reduces bypass factor. When selecting applied commercial air handlers, the air-conditioning designer can select various types of mixing boxes, filters, heating coils, cooling coils, fans, and accessories for any given unit size. This allows the designer the ability to select various types of cooling coils, with a differing number of coil tube rows and fin spacing, which directly affects bypass factor. So, to a limited extent, the engineer using an applied air handler can directly select bypass factor. When using other types of air handlers, there is only one coil type offered for each capacity size. There is no choice of bypass factor.

Now compare the supply air conditions entering the room with the conditions in the example room. This shows how the supply air absorbs heat and humidity from the room in the cooling mode. For the sake of simplicity, we will assume that the conditions of the air supplied to the room are the same as the conditions leaving the cooling coil.

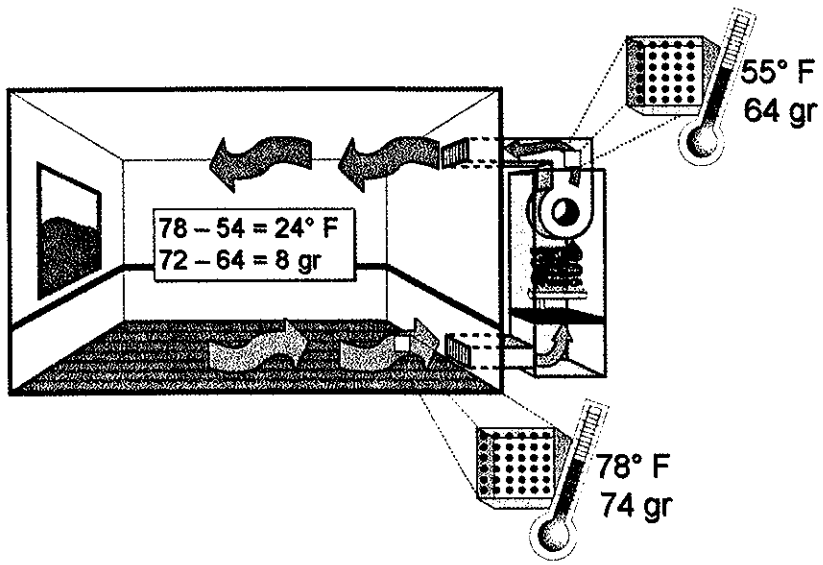


Figure 66

Supply Air Absorbing Heat and Humidity

The 55° F supply air is cooler than the 78° F room air. Therefore, the supply air absorbs heat in the room as it rises to 78° F. The supply air is also drier than the room air. It enters at 64 gr/lb, allowing each pound of air circulated to absorb 8 grains of water vapor from the room before arriving at the 72 gr/lb room condition.

In summary, when there is a cooling load in the space, cool, dry, clean air is circulated through the room where it absorbs heat and moisture. The same quantity of air is returned to the air handler that is supplied to the room. The air entering the air handler is mixed with outdoor ventilation air, when ventilation is provided, then filtered and sent to the cooling coil (evaporator), which removes heat and moisture. The condensate water goes down the drain, and

the cooling coil absorbs the heat. As long as there is a cooling load on the conditioned space and cooling capacity is provided to match that load, the cycle repeats itself.

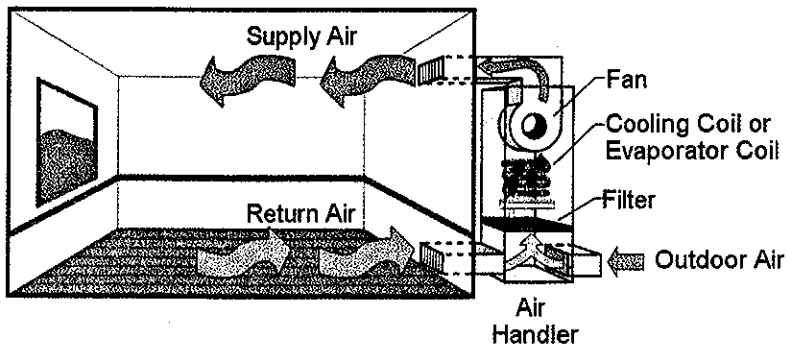


Figure 67

Air System Components

This completes our review of the air system, which is part of the air-conditioning system. As you read the next section, keep in mind that the cooling coil in the air system is the same as the evaporator coil described in the next section, the mechanical refrigeration system. This completes our coverage of the air system. Before you continue, please complete the Work Session 2 found at the back of the book.

Mechanical Refrigeration System

Mechanical refrigeration

When studying comfort air conditioning, a question that often arises is, "What makes the cooling coil cold?" The answer is, the mechanical refrigeration system. This section explains the process going on within the coil that makes the coil cold.

The mechanical refrigeration system is the portion of the air-conditioning system that provides cooling capacity. It can also provide heating capacity if a reverse cycle heat pump is used.

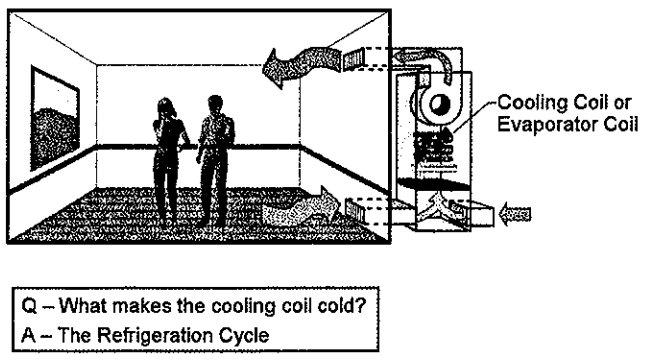


Figure 68

The refrigeration cycle provides cooling capacity and dehumidification.

Change of State Provides the Capacity

The cooling coil is cold because refrigerant is boiling at a low temperature inside the coil.

The basic physical principle behind the heat absorption by the cooling coil in a mechanical refrigeration system can be illustrated by heating a pot of water. As the water absorbs heat, its temperature rises until it reaches the boiling point. At sea level, water boils at 212° F. The heat absorbed by the water, while its temperature is rising, is called ***sensible heat***. We can measure sensible heat processes with a thermometer.

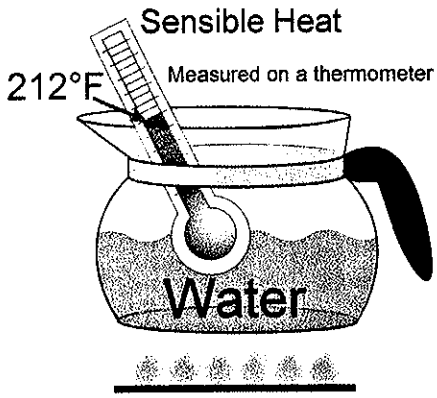


Figure 69

Sensible heat can be directly measured.

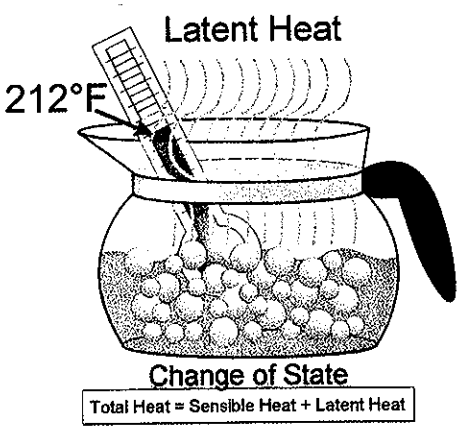


Figure 70

Latent heat changes the state and cannot be directly measured.

As the water boils, it absorbs still more heat, but the temperature does not change. The heat absorbed when a substance changes state at a constant temperature is called latent heat. You cannot measure latent heat with a thermometer because it happens at a constant temperature. Yet, it is a much bigger heat addition than the sensible heat addition required to raise its temperature to the boiling point.

Instead of raising the temperature of the water, latent heat causes the water to change state from a liquid to a vapor. This process can be observed by watching bubbles form within the body of the liquid. The vapor rising up from the pot contains both sensible and latent heat. The total heat of any fluid (liquid or gas) is its sensible heat plus its latent heat.

The first principle that makes mechanical refrigeration possible is the ability of a liquid to absorb a large amount of latent heat as it changes state at a constant temperature to become a vapor. In simple, everyday terms, this is the boiling process, but it is called evaporation in mechanical refrigeration terminology.

Conversely, a vapor must reject a large amount of heat when changing state at a constant temperature to become a liquid. This process is called condensing.

Instead of water, as used in the illustration, a chemical compound, called a refrigerant is the fluid used in the mechanical refrigeration system to accomplish this latent heat transfer. Also, instead of using an unsealed pot as a container, the mechanical refrigeration system uses a sealed cooling coil, called the evaporator, where the boiling process takes place. Instead of a burner providing the heat necessary to boil the water in the pot, air or water flowing over the evaporator provides the heat necessary to cause the refrigerant to boil. As a result, the air or water gives up heat to the refrigerant within the evaporator. The air or water leaves the evaporator at a cooler temperature than when it began to flow over it.

The second principle that makes mechanical refrigeration possible is that changing its pressure can change the boiling temperature of a liquid. The pressure scale most commonly used to measure refrigerants is pounds per square inch gauge (psig). It is the pressure read on the service technician's gauge manifold set.

Water can be used to illustrate how boiling point is determined by pressure.

Water, at a pressure of 20 pounds per square inch above atmospheric pressure (psig) boils at 258° F, instead of 212° F. If the pressure is equal to standard atmospheric pressure (0 psig), it boils at less than 212° F.

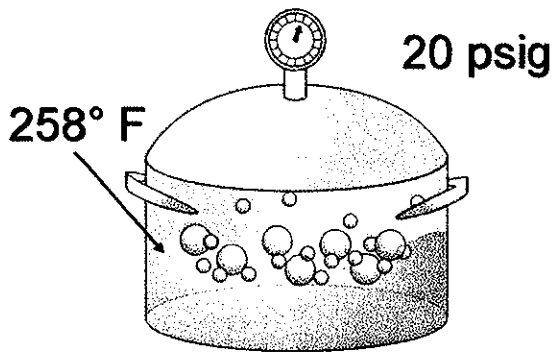


Figure 71

Pressure affects the boiling point.

Water has the same characteristics of a refrigerant, but the boiling point of water is much too high for conventional mechanical refrigeration. However, absorption refrigeration equipment uses an absorbing chemical and heat to create a refrigeration cycle that allows water to be used as a refrigerant (R-718) at very low pressures.

Four principles of mechanical refrigeration:

Heat will only flow from a higher temperature to a lower temperature.

The greatest amount of heat energy occurs during a change of state.

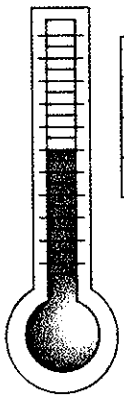
The boiling point of a substance is dependent on the pressure.

Flow only occurs if there is a pressure difference.

Raising the pressure of a fluid increases its boiling point and lowering it decreases its boiling point. The boiling point of a fluid used as a refrigerant is called its saturation temperature. Whether it is evaporating from a liquid into a gas or condensing from a gas into a liquid, it does so at the saturation temperature that matches the pressure for the refrigerant used.

Refrigerants used in the mechanical refrigeration cycle are chemical compounds that have much lower boiling points at standard atmospheric pressure than water.

R-134a (HFC-134a) boils at -15° F. HFC-134a is designed for automotive air conditioning, household refrigerators and freezers, comfort air conditioners, and transport and commercial refrigeration. R-22 (HCFC-22), presently the most commonly used refrigerant for comfort air conditioning, boils at -41° F. Refrigerant HFC-410A, a replacement for HCFC-22, boils at -62° F. Because HCFC-22 is still a commonly used refrigerant for both commercial and residential comfort work, it is used in the following sections to illustrate the mechanical refrigeration system. Comparisons are made to HFC-410A where appropriate. The mechanical refrigeration systems will function the same, however, pressures are much higher.



Water	212° F
HFC-134a	-15° F
HCFC-22	-41° F
HFC-410A	-62° F

Figure 72

Refrigerants and Boiling Points at Atmospheric Pressure

Components of the System

In most systems, the cooling coil is also called the evaporator because the refrigerant boils, or evaporates, inside the coil as it absorbs heat from the air passing over it. The refrigerant absorbs a great deal of heat as it changes state from a liquid into a vapor. The refrigerant continues to boil as it travels through the coil, until it is completely vaporized. Thus, it changes from a cold liquid to a cold vapor as it absorbs heat. The cooling action of the refrigeration cycle results from this latent heating of the refrigerant by the air, called evaporating.

The desired boiling point, or saturated evaporator temperature, is maintained by the proper combination of refrigerant type and pressure maintained in the evaporator. The manufacturer provides capacity rating data for the appropriate refrigerant at various saturation temperatures that match certain pressures. The combined action of the compressor and the metering device maintain the desired pressure in the evaporator.

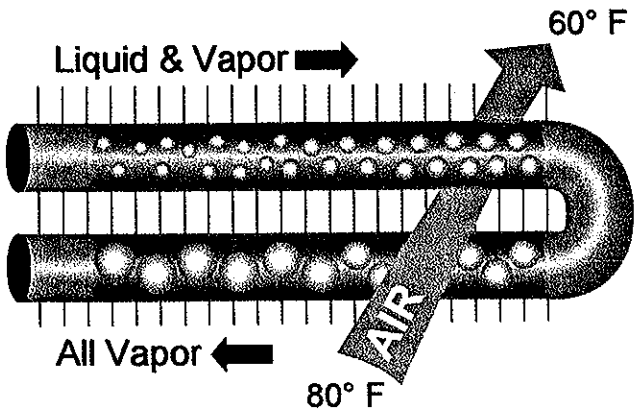


Figure 73

An evaporator absorbs the heat from the air.

If the environment or cost was not a concern, we could keep adding refrigerant to the evaporator in proportion to the cooling load and no other parts would be needed for the refrigeration cycle. However, our environment is such a major concern that such a strategy is illegal. Additionally, refrigerant prices prohibit such a wasteful action.

The rest of the mechanical refrigeration system makes it possible to use the same refrigerant over and over again. In addition to the evaporator, the major components of any mechanical refrigeration system include the compressor, a ***condenser*** and a metering device. In this case, the metering device is a ***thermostatic expansion valve*** (TXV), but many other types exist.

The same refrigerant that changes state from a vapor to a liquid in the ***condenser***, condensing at about 120° F, also changes state from a liquid into a vapor in the evaporator, evaporating at about 40° F. In order for the refrigerant to have such different saturation temperatures in two areas of the same system, there must be two different pressure zones.

The compressor and metering device work together to create a high-pressure zone, called the ***high side*** of the system, and a low-pressure zone, called the ***low side*** of the system. The high side includes the compressor discharge, hot gas line, condenser, liquid line, and the inlet side of the metering device. The low side includes the outlet side of the metering device, evaporator, suction line, and compressor inlet.

For an HCFC-22 system operating at an outside temperature of 95° F and supplying 55° F air to the conditioned space, a typical low side saturation temperature is about 40° F, which matches a pressure of about 68 psig. A typical high side saturation temperature is about 120° F, which matches a pressure of about 260 psig.

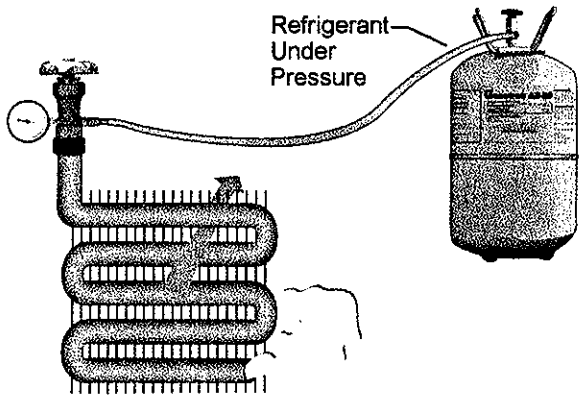


Figure 74

An open cycle would require only an evaporator.

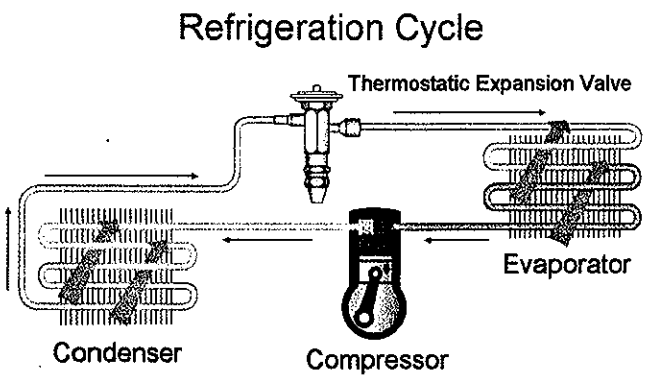


Figure 75

A closed cycle requires four basic components.

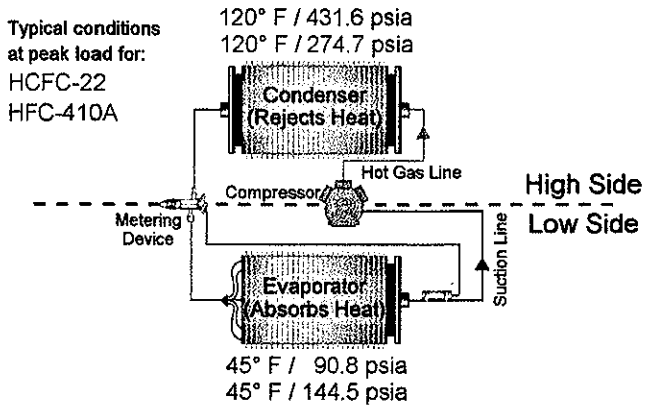


Figure 76

High Side/Low Side – Two Pressure Zones

For comparison, if HFC-410A is used, it will have the same condensing and evaporating temperatures but higher pressures for both.

Now we will follow the refrigerant flow around the system. Once it has changed into a vapor in the evaporator, it goes to the compressor.

Many types of compressors are used for comfort air conditioning: ***reciprocating compressor***, ***scroll compressor***, ***screw compressor***, ***rotary compressor*** and ***centrifugal compressor***. The reciprocating type will be used in this discussion to demonstrate the function of the compressor. The first function of the compressor is to draw refrigerant vapor away from the evaporator as the vapor is formed. The vapor is carried to the compressor through a refrigerant pipe called the suction line. By removing vapor as it is formed, the compressor maintains the evaporator at the pressure necessary to boil refrigerant at the proper temperature, in this case 40° F, at 68 psig (120 psig for HFC- 410A).

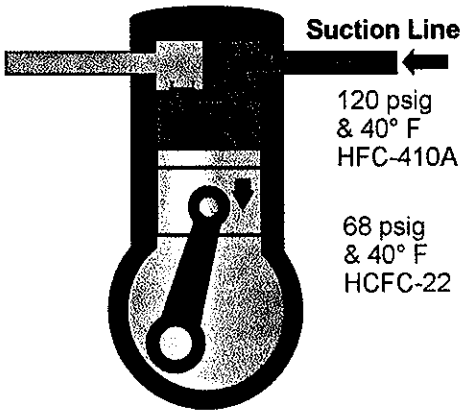


Figure 77

A compressor draws vapor from the evaporator – suction.

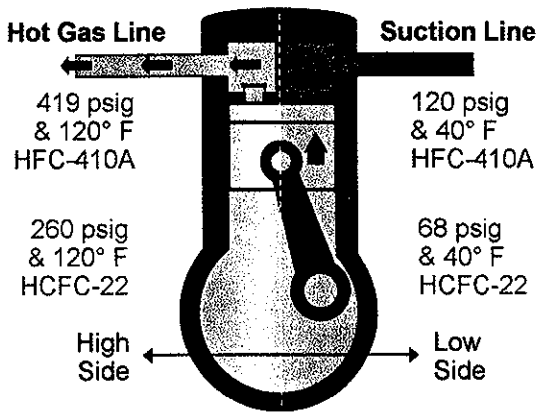


Figure 78

The compressor then raises the pressure – discharge

The other function of the compressor is to raise the pressure, and thus the saturation temperature of the refrigerant, high enough to reject the heat contained in the refrigerant at the condenser. The compressor is a dividing line in the mechanical refrigeration cycle for two pressure zones. It separates the low side that is the low-pressure, low-temperature zone to which the evaporator belongs, from the high side, which is the high-pressure, high-temperature zone to which the condenser belongs.

The high-pressure, high-temperature gas leaving the compressor travels through a refrigerant pipe called the hot gas line into the condenser. The purpose of the condenser is to do just the opposite of the evaporator. The condenser rejects heat from the refrigerant that was absorbed in the evaporator. It also rejects the heat added by compressing the gas at the compressor. In order to have the heat flow from the refrigerant within the condenser to the air or water flowing over it, the refrigerant must be hotter than the air or water.

For example, with an air-cooled condenser, if the outdoor air temperature is 95° F, the refrigerant temperature has to be about 25° F higher, or 120° F. HCFC-22 boils at 120° F at a pressure of about 260 psig (419 psig for HFC-410A). At this pressure, the refrigerant gas can reject heat to the cooler air (95° F) flowing over the condenser coil, condensing back into a liquid so that it can be reused in the evaporator the next time around the cycle. Like the evaporator, the condenser is designed primarily to do a latent heat transfer process that changes the state of the refrigerant.

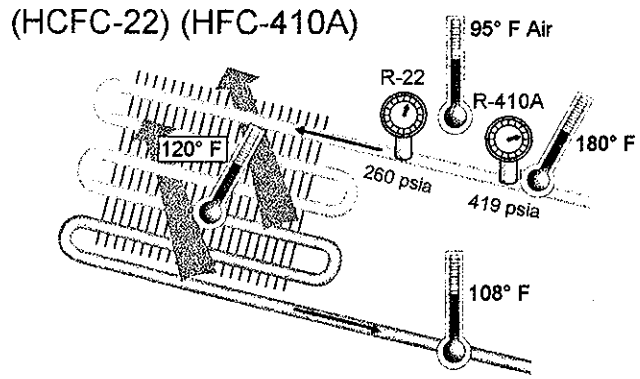


Figure 79

The condenser removes the heat and condenses the refrigerant to a high temperature liquid.

Water-cooled condensers come in various forms, but they work on the same principle as the air-cooled variety. Since water-cooled condensers are more efficient, the condensing temperature of the refrigerant only needs to be about 15° F higher than the average condenser water temperature. Since the example shows cooling tower condenser water entering at 85° F and leaving at 95° F, the average condenser water temperature is 90° F. Therefore, the required condenser refrigerant (saturation) temperature is 105° F (90 + 15° F). The condenser water rises about 10° F, from 85° F to 95° F, as it absorbs the heat rejected by the condenser. The leaving condenser water is re-cooled for reuse by a device called the cooling tower.

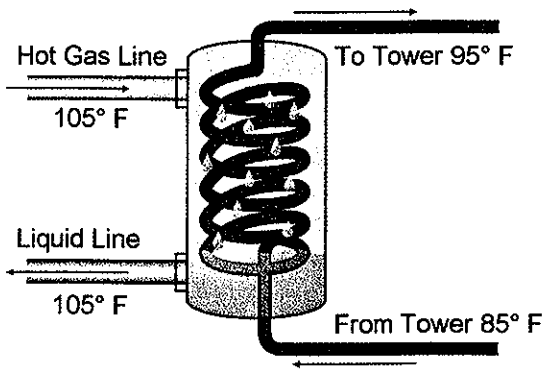


Figure 80

Water-Cooled Condenser Example

At this point in its journey through the mechanical refrigeration system, the refrigerant has been changed back into a liquid in the condenser, but it is still too hot (120° F in the air-cooled example) to be used in the evaporator (40° F).

The liquid refrigerant flows from the condenser to the metering device, in this case a thermostatic expansion valve, by way of a refrigerant pipe called the liquid line. At the metering device the refrigerant undergoes a rapid pressure reduction, from about 260 psig in the condenser to 68 psig in the evaporator (120 psig and 419 psig for HFC-410A, respectively).

As a result, the saturation temperature of the refrigerant drops from 120° F to 40° F. Now the refrigerant is ready to absorb heat, once again, in the evaporator. The refrigerant leaves the metering device as a low-pressure, low-temperature mixture of mostly liquid with a bit of vapor mixed in. Just as the compressor divided the high side from the low side of the system, the metering device also separates the two pressure zones.

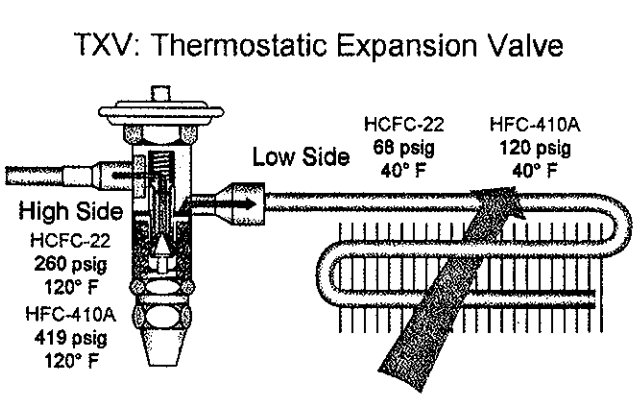
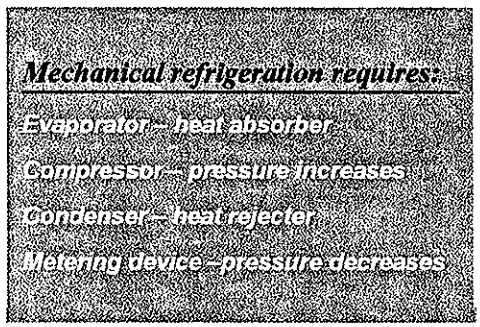


Figure 81

Metering Device

In summary, the refrigerant boils into vapor in the evaporator as it absorbs heat from the air passing over its tubes and fins. The compressor takes that vapor and raises its pressure and temperature. The refrigerant changes back into a liquid in the condenser as its heat is rejected to the air or water flowing over the condenser tubes and fins. The metering device reduces the pressure and temperature of the refrigerant to the level found in the evaporator. The refrigerant cycle repeats as long as the mechanical refrigeration system is operating to provide capacity for the air-conditioned space.



You can see how air is cooled and dehumidified by the mechanical refrigeration system within an air-conditioning system. The air and mechanical refrigeration systems work together to provide the sensible and latent heat removal capacities necessary to maintain acceptable temperature and humidity levels in the occupied area.

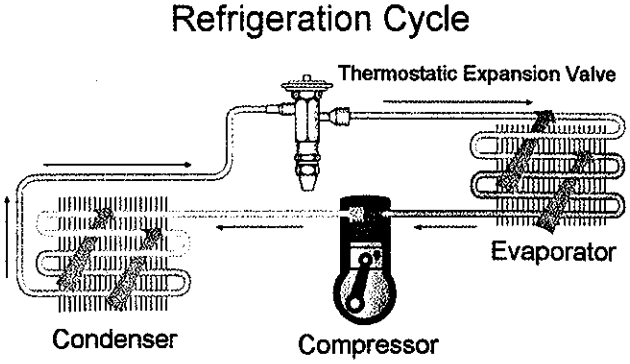


Figure 82

The refrigeration cycle works to cool and dehumidify air.

Summary

This module has covered foundational information about heating, ventilating, and air-conditioning design and service work. These same principles hold true for air-conditioning systems that vary in size from a room air conditioner to the largest commercial system. The style, size, and design of each component or system will vary from system to system, but the basic principles still hold true for each.

When a comfort air-conditioning system is designed, the engineer should decide what the goals are for maintaining the variables in the conditioned area that most directly affect comfort. Temperature, humidity, and air motion are always important. The surface temperature of the conditioned space is also very important but usually beyond the influence of the air-conditioning engineer. Each of these variables influences the rate at which heat is rejected from our bodies by conduction, convection, radiation, and evaporation, thereby affecting human comfort.

The design of the air system will determine whether the capacities of the heating and humidifying equipment and the mechanical refrigeration system are properly delivered to the areas being conditioned. If the capacity is not properly distributed, the temperature, humidity, and air motion goals the designer determined would not be achieved. Systems thinking during the system selection, load estimating, equipment selection, room air distribution design, duct design, and piping design steps of the design process will help to ensure good system performance at a reasonable cost.

This completes our coverage of the mechanical refrigeration system. Please complete Work Session 3.

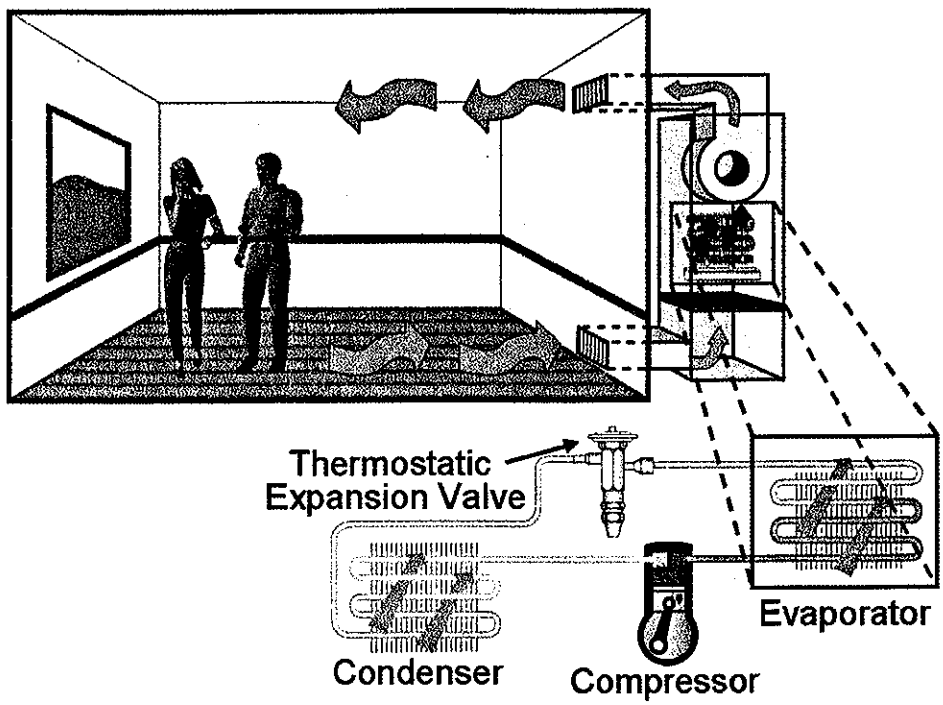


Figure 83

Systems work together.

Work Session 1

Multiple-choice questions may have more than one correct answer; identify all correct selections.

1. True or False? The two reasons for conditioning air are for people or things. Comfort air conditioning is for people. Process air conditioning is for things. _____

2. A total comfort air-conditioning system maintains which of the following air conditions within a comfortable range? _____

   a) Temperature
   b) Humidity
   c) Air motion
   d) Air purity

3. A typical comfort design goal for indoor temperature is _____° F. (Give one number or range.)

4. A typical comfort design goal for indoor relative humidity in the summer is _____ percent (Give one number or range.)

5. Which of the following methods of heat transfer is not used by our bodies to maintain comfort? _____

   a) Evaporation
   b) Insulation
   c) Convection
   d) Conduction

6. Which of the following space conditions affect(s) heat loss from our body by conduction? _____

   a) None, our bodies do not lose heat by conduction.
   b) Relative humidity
   c) Surface temperature of walls, windows, and ceiling
   d) Air temperature

7. Which of the following space conditions affect(s) heat loss from our bodies by evaporation? _____

   a) None, our bodies do not lose heat by evaporation.
   b) Air motion
   c) Relative humidity
   d) Surface temperature of walls, ceiling and windows

8. True or False? The only significant disadvantage of a poorly insulated building is high-energy usage. _____

9. Relative humidity tells you: _____

   a) the exact amount of moisture in each pound of dry air in grains/pound.
   b) how close the air is to being saturated with water vapor.
   c) how much more moisture the air is able to hold, expressed as a percent.
   d) the amount of moisture in the air compared to what it could hold at its maximum.

10. Air with a water content of 55 grains/pound has a relative humidity of 50 percent at 70° F but only 25 percent at 92° F because: _____

   a) the grains change as temperature changes.
   b) as temperature increases, air becomes denser.
   c) cooler air can hold more water vapor than warmer air.
   d) warmer air can hold more water vapor than cooler air.

11. True or False? Increasing relative humidity makes one feel warmer, all other conditions being equal. _____

12. Which combination will make a person feel warmest? _____

   a) Decrease temperature, increase humidity, decrease air motion.
   b) Increase temperature, increase humidity, increase air motion.
   c) Increase temperature, decrease humidity, decrease air motion.
   d) Increase temperature, increase humidity, decrease air motion.

Work Session 2

Multiple-choice questions may have more than one correct answer; identify all correct selections.

1. True or False? With proper air conditioning, comfort can be assured over a broad range of outside conditions for people located in an enclosed shelter. _____

2. True or False? Internal loads always add to the heat in a building. They are always heating loads. _____

3. Which of the following internal effects produce load in a building? _____

   a) Furniture
   b) Ventilation
   c) People
   d) Lights

4. Which of the following external effects can create either a cooling or heating load in a building depending on the weather? _____

   a) Transmission
   b) Equipment
   c) Infiltration
   d) Solar load

5. A building has a cooling load when the: _____

   a) Outside temperature is above 40° F.
   b) Combined load components cause heat to enter the building more rapidly than it leaves.
   c) Thermostat is turned down.
   d) Combined load components cause heat to leave the building more rapidly than it enters.

6. Air system design requires decisions about which of the following building conditions? _____

   a) Building insulation
   b) Humidity
   c) Temperature
   d) Air quality

7. Room air distribution design is the process of: _____

   a) selecting and make the air ductwork.
   b) predicting how the fan will operate.
   c) locating the thermostat(s).
   d) selecting and locating supply and return air openings.

8. True or False? Moisture is removed from the air that flows over the cooling coil because some of the water vapor in the air turns into liquid as it hits the cold coil. _____

9. The difference between infiltration and ventilation is that infiltration is: _____

a) mechanically controlled while ventilation just happens.

b) something that just happens, but ventilation is mechanically controlled.

c) the outward leakage of air from the building while ventilation is the inward leakage from the outside.

d) a way to dilute indoor odors and pollutants and to replace oxygen, but ventilation is not.

10. In heating mode, at about what temperature should the air leave the supply diffusers? _____

a) 80° F

b) 110° F

c) 160° F

d) 200° F

11. Which of the following methods are commonly used to heat air in the air handler? _____

a) Heat wheel

b) Hot water coil

c) Absorber

d) Gas-fired heat exchanger

e) Solar grid

12. To maintain the desired temperature and relative humidity in an air-conditioned space with a cooling load, the supply air must have its temperature: _____

a) equal to the space temperature, but its humidity below it.

b) and humidity equal to the space temperature and humidity.

c) below the space temperature, but its humidity equal to it.

d) and humidity below the space temperature and humidity.

13. To dehumidify the air returning from a building, the cooling coil must have its surface temperature: _____

a) below the temperature of the return air.

b) below the saturation temperature of the return air.

c) equal to the saturation temperature of the room air.

d) below the temperature of the fluid running through it.

14. Which of the following actions can a system designer take to change the efficiency with which a cooling coil cools and dehumidifies the air returned from a building?

_____

a) Change the fan speed.

b) Choose a different coil.

c) Turn up the thermostat.

d) Insulate the ductwork.

Work Session 3

Multiple-choice questions may have more than one correct answer; identify all correct selections.

1. Latent heat is: _____

   a) measurable with a thermometer.
   b) what happens when you heat water from 55° F to 210° F.
   c) what happens when water boils.
   d) more important in the refrigeration cycle than sensible heat.

2. As the pressure on a fluid (liquid or gas) increases, its boiling point: _____

   a) increases.
   b) decreases.
   c) remains unchanged.
   d) may or may not change.

3. The four basic components of the mechanical refrigeration cycle include the: _____, _____, _____, and _____.

4. The evaporator: _____

   a) rejects heat as refrigerant boils from a liquid into a vapor within it.
   b) absorbs heat as refrigerant boils from a liquid into a vapor within it.
   c) rejects heat as refrigerant changes from a vapor into a liquid within it.
   d) absorbs heat as refrigerant changes from a vapor into a liquid within it.

5. Which of the following components divides the high side from the low side of the system? _____

   a) Receiver
   b) Compressor
   c) Suction line accumulator
   d) Metering device

6. To provide cooling, why isn't refrigerant just pumped from a tank through an evaporator and out into the air? _____

   a) It is too damaging to our environment.
   b) It would not work for cooling. Without being enclosed, the evaporator would not cool the air flowing over it.
   c) It is too complicated.
   d) It is too expensive.

7. The refrigerant line entering the compressor is the: _____

   a) suction line.
   b) liquid line.
   c) hot gas line.
   d) condensate line.

8. The refrigerant line leaving the condenser is the: _____

   a) suction line.
   b) liquid line.
   c) hot gas line.
   d) condensate line.

9. The compressor: _____

   a) pumps liquid refrigerant.
   b) lowers the pressure and temperature of the refrigerant within the cycle.
   c) draws refrigerant out of the condenser.
   d) raises refrigerant pressure and temperature.

10. A typical high side saturation temperature at peak cooling load for a system using a water-cooled condenser is about: _____

    a) 50° F.
    b) 70° F.
    c) 105° F.
    d) 120° F.

11. A typical low side saturation temperature at peak cooling load is about: _____

    a) 50° F.
    b) 40° F.
    c) 30° F.
    d) 20° F.

Appendix

Comfort Conditions Form

Table of Design Conditions

Glossary

Work Session Answers

Comfort Conditions Form

Space/Activity						
Temperature	Occupied		Unoccupied		Throttling Range	Swing
	Design	Min	Design	Min		
Summer						
Winter						
Humidity	Design	Max	Min			
Summer						
Winter						
Air Motion	Max	Min	Notes			
fpm						
Ventilation	Occupied		Unoccupied		Notes:	
	Design	Min	Min			
cfm						
Direct Exhaust						
Filtration	Condition		MERV	Type	Other	
Radiant Surfaces	Glass	Wall	Floor	Roof	Other	
Summer						
Winter						
Acoustics	Room RC		Other Notes			
Notes:						

Table of Design Conditions

Category	Temperature		Relative Humidity		Supply Air		Sound	Ventilation			Occupancy	Filters	Exhaust
	Summer °F	Winter °F	Summer %	Winter %	Speed fpm	Changes / hour	NC or RC(N)	cfm / Person	cfm / ft^2	Default / Person	People / 1000 ft^2	Eff. % MERV	cfm or cfm/ft^2
Lodging (Hotels, Motels, Resorts, Dormitories)													
Bedroom / living room	74 - 78	74 - 76	50 - 60	30 - 35	25 - 45	4 - 10	25 - 35	5	0.06	11	10	10-15%	20 - 50/rm
Barracks	74 - 78	74 - 76	50 - 60	NR	25 - 45	4 - 10	25 - 35	5	0.06	8	20	10-15%	20-50/Fixture
Conference room	74 - 78	70 - 74	50 - 60	20 - 30	30 - 50	12 - 15	40 - 50	5	0.06	6	50	MERV 6	NS
Kitchen general	82 - 88	70 - 74	65 max	NR	30 - 50	12 - 15	40 - 50	5	0.06	6	10	MERV 6	0.70 / ft^2
Kitchen pastry	76	70 – 74	65 max	NR	30 – 50	12 – 15	40 – 50	5	0.06	6	10	MERV 6	0.70 / ft^2
Lobbies	80	72	50 – 60	20 – 30	30 – 45	NS	35 – 45	5	0.06	11	10	MERV 8	NS
Kitchen private	74 – 78	70 – 74	65 max	NR	30 – 50	12 – 15	40 – 50	5	0.06	6	2	MERV 6	0.30 / ft^2
Hallways	80	72	50 – 60	20 – 30	30 – 45	NS	35 – 45	5	0.06	11	10	MERV 8	NS
Guest rooms	74 – 78	74 – 76	50 – 60	30 – 35	25 – 45	4 – 10	25 – 35	5	0.06	11	10	10 – 15%	20 – 50/rm
Multi-purpose	74 – 78	70 – 74	50 – 60	20 – 30	30 – 50	12 – 15	40 – 50	5	0.06	6	120	MERV 6	NS
Office areas	74 – 78	70-74	50 – 60	20 – 30	25 – 45 0.7-2 cfm/ft^2	4 – 10	30 – 45	5	0.06	17	5	30 – 60	NS
Laundry	85	65	60	NR	50 +	10 – 12	NR	7.5	0.06	11	20	8	As Req.
Office Buildings													
Office	74 – 78	70 – 74	50 – 60	20 – 30	25 – 45 0.7-2 cfm/ft^2	4 – 10	30 – 45	5	0.06	17	5	30 – 60	NR
Reception	74 – 78	70 – 74	50 – 60	20 – 30	25 – 45 0.7-2 cfm/ft^2	4 – 10	30 – 45	5	0.06	7	30	30 – 60	NR
Data entry	74 – 78	70 – 74	50 – 60	20 – 30				5	0.06	6	60	30 – 60	NR
Lobbies	80	72	50 – 60	20 – 30	30 – 45	NS	35 – 45	5	0.06	11	10	30 – 60	NR
Computer rooms	74 – 78	70 – 74	50 – 60	20 – 30				5	0.06	20	4	30 – 60	NR
Toilets	74 – 78	70 – 74	50 – 60	20 – 30	30 – 45	NS	NR	NS	0.12	NS	NS		50-70/Fixture

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Category	Temperature		Relative Humidity		Supply Air		Sound	Ventilation			Occupancy	Filters	Exhaust
	Summer °F	Winter °F	Summer %	Winter %	Speed fpm	Changes / hour	NC or RC(N)	cfm / Person	cfm / ft^2	Default / Person	People / 1000 ft^2	Eff. % MERV	cfm or cfm/ft^2
Conf. Room	74 – 78	70 – 74	50 – 60	20 – 30	30 – 50	12 – 15	40 – 50	5	0.06	6	50	30 – 60	NR
Storage	80	72	50 – 60	20 – 30	30 – 45	NS	NR	NS	0.12	NS	1	10 – 15	1.00
Parking Garage	80 – 100	40 – 55	NR	NR	30 – 75	4 – 6	35 – 50	NR	NR	NR	NS	10 – 15	0.75
Break room	74 – 78	70 – 74	55 – 60	20 – 30	25 – 30	8 – 12	35 – 40	7.5	0.18	9	100	35 +	0.30
Corridors	80	72	50 – 60	20 – 30	30 – 45	NS	35 – 45	5	0.06	11	10	MERV 8	NS
Residence – Single Family, Multi-Family, Apartment, Manufactured Housing													
Living areas	74 – 78	74 – 76	50 – 60	30 – 35	25 – 45	4 – 10	25 – 35	5	0.06	11	10	10-15%	20-50/rm
Kitchens	74 – 78	74 – 76	50 – 60	30 – 35	25 – 45	4 – 10	25 – 35	5	0.06	11	10	10-15%	0.30
Baths	74 –78	74 – 76	50 – 60	30 – 35	25 – 45	4 – 10	25 – 35	5	0.06	11	10	10-15%	50 cfm int. 20 cfm cont.
Retail													
Sales-main	74 – 78	70 – 74	50 – 60	20 – 30	25 – 30	8 – 12	35 – 50	7.5	0.60	16	15	MERV 6	NR
Sales-upper	74 – 78	70 – 74	50 – 60	20 – 30	25 – 30	8 – 12	35 – 50	7.5	0.60	16	50 – 100	MERV 6	NR
Mall common spaces	74 – 78	70 – 74	50 – 60	20 – 30	25 – 30	8 – 12	35 – 50	7.5	0.06	9	40	MERV 6	NR
Barber shop	74 – 78	70 – 74	50 – 60	20 – 30	25 – 30	8 – 12	35 – 50	7.5	0.06	10	25	MERV 6	0.50
Salon	74 – 78	70 – 74	50 – 60	20 – 30	25 – 30	8 – 12	35 – 50	20	0.12	25	25	MERV 6	0.60
Clothing stores	74 – 78	70 – 74	50 – 60	20 – 30	25 – 30	8 – 12	35 – 50	7.5	0.06	11	20	MERV 6	NR
Drug store	74 – 78	70 – 74	50 – 60	20 – 30	25 – 30	8 – 12	35 – 50	5	0.18	23	10	MERV 6	NR
Pet shop	74 – 78	70 – 74	50 – 60	20 – 30	25 – 30	8 – 12	35 – 50	7.5	0.18	26	10	MERV 6	0.90
Banks	74 – 78	70 – 74	50 – 60	20 – 30	25 – 30	8 – 12	35 – 50	7.5	0.60	17	30	MERV 6	NR
Photo Studio	74 – 78	70 – 74	50 – 60	20 – 30	25 – 30	8 – 12	35 – 50	5	0.12	17	10	MERV 6	1.00
Supermarket	74 – 78	70 – 74	50 – 60	20 – 30	25 – 30	8 – 12	35 – 50	7.5	0.06	15	8	MERV 6	NR
Coin-op laundries	74 – 78	70 – 74	50 – 60	20 – 30	25 – 30	8 – 12	35 – 50	7.5	0.06	11	20	MERV 6	NR
Convenience stores	74 – 78	70 – 74	50 – 60	20 – 30	25 – 30	8 – 12	35 – 50	7.5	0.60	15	10	MERV 6	NR
Bakeries	74 – 78	70 – 74	50 – 60	20 – 30	25 – 30	8 – 12	35 – 50	7.5	0.60	19	13	MERV 6	NR
Public restrooms	74 – 78	70 – 74	50 – 60	20 – 30	25 – 30	8 – 12	35 – 50	7.5	0.60	NS	NS	MERV 6	50-70/Fixture

Category	Temperature		Relative Humidity		Supply Air		Sound	Ventilation			Occupancy	Filters	Exhaust
	Summer °F	Winter °F	Summer %	Winter %	Speed fpm	Changes / hour	NC or RC(N)	cfm / Person	cfm / ft^2	Default / Person	People / 1000 ft^2	Eff. % MERV	cfm or cfm/ft^2
Florists	74 - 78	70 - 74	50 - 60	20 - 30	25 - 30	8 - 12	35 - 50	7.5	0.60	11	20	MERV 6	NR
Gift shop	74 - 78	70 - 74	50 - 60	20 - 30	25 - 30	8 - 12	35 - 50	7.5	0.60	11	20	MERV 6	NR
Jewelry store	74 - 78	70 - 74	50 - 60	20 - 30	25 - 30	8 - 12	35 - 50	7.5	0.60	11	20	MERV 6	NR
Restaurants												MERV 6	NR
Kitchen	82 - 88	70 - 74	65 max	NR	30 - 50	12 - 15	40 - 50	5	0.06	6	10	MERV 6	0.70 / ft^2
Fast food	78	70 - 74	50	20 - 30	50	12 - 15	40 - 50	7.5	0.18	9	100	MERV 8	NR
Formal	74 - 78	70 - 74	55 - 60	20 -30	25 - 30	8 - 12	35 - 40	7.5	0.18	9	70	MERV 8	NR
Bars	74 - 78	70 - 74	50 - 60	20 – 30	30	15 – 20	35 - 50	7.5	0.18	9	100	MERV 8	NR
Cafeterias	78	70 - 74	50	20 -30	50	12 - 15	40 - 50	7.5	0.18	9	100	MERV 8	NR
Sports and Entertainment													
Auditoriums	74 - 78	70 - 74	50 - 60	20 - 30	30	6 - 8	35 - 50	5	0.06	5	150	35+	0.50
Bowling alleys	75 - 78	70 - 74	50 - 55	20 - 30	50 @ 6'	10 - 15	40 - 50	10	0.12	13	40	10 - 15	0.50
Gym / Sports complex	74 - 78	70 - 74	50 - 60	20 - 30	30	6 - 8	35 - 50	NS	0.30	NS	NS	35	0.50
Spectator areas	74 - 78	70 - 74	50 - 60	20 - 30	30	6 - 8	35 - 50	7.5	0.06	8	150	35	NS
Gambling Casinos	74 - 78	70 - 74	50 - 60	20 -30	30	6 - 8	35 - 50	7.5	0.18	9	120	35	NS
Libraries	68 - 72	68 - 72	40 - 55	40 - 55	25	8 - 12	35 - 45	5	0.12	17	10	35 - 60	NS
Museums - children's	68 - 72	68 - 72	40 - 55	40 - 55	25	8 - 12	35 - 45	7.5	0.12	11	40	35 - 60	NS
Museums - galleries	68 - 72	68 - 72	40 - 55	40 - 55	25	8 - 12	35 - 45	7.5	0.06	9	40	35 - 60	NS
Swimming pools	75 - 85	75 - 85	50 - 60	50 - 60	30	4 - 6	35 - 50	NS	0.48	NS	NS	SR	NS
Dance floors	74 - 78	70 - 74	50 - 60	20 - 30	30	6 - 8	35 - 50	20	0.06	21	100	35	NS
Health clubs													
Aerobics	74 - 78	70 - 74	50 - 60	20 - 30	30	6 - 8	35 - 50	20	0.06	22	40	35	0.50
Weight	74 - 78	70 - 74	50 - 60	20 - 30	30	6 - 8	35 - 50	20	0.06	26	10	35	0.50
Arcades	74 - 78	70 - 74	50 - 60	20 - 30	30	6 - 8	35 - 50	7.5	0.18	17	20	35	NS
Stage / studio	74 - 78	70 - 74	50 - 60	20 - 30	30	6 - 8	35 - 50	10	0.06	11	70	35	NS

Category	Temperature		Relative Humidity		Supply Air		Sound	Ventilation			Occupancy	Filters	Exhaust
	Summer °F	Winter °F	Summer %	Winter %	Speed fpm	Changes / hour	NC or RC(N)	cfm / Person	cfm / ft^2	Default / Person	People / 1000 ft^2	Eff. % MERV	cfm or cfm/ft^2
Transportation Centers / Correctional Facilities													
Waiting area	74 - 78	70 - 74	50 - 60	20 - 30	25 - 30	8 - 12	35 - 50	7.5	0.06	8	100	MERV 8	NS
Correctional													
Cell	78	72	50	30	25 - 30	6	35 - 50	5	0.12	10	25	MERV 8	1.00
Day room	78	72	50	30	25 - 30	6	35 - 50	5	0.60	7	30	MERV 8	NS
Guard Station	78	72	50	30	25 - 30	6	35 - 50	5	0.60	9	15	MERV 8	NS
Booking	78	72	50	30	25 - 30	8	35 - 50	7.5	0.60	9	50	MERV 8	NS
Assembly Buildings													
Places of worship	78	72	60	30	30 - 45	NS	30 - 40	5	0.06	5	150	MERV 8	NS
Courtroom	78	72	60	30	30 - 45	NS	30 - 40	5	0.06	6	70	MERV 8	NS
Post office	78	72	60	30	30 - 45	NS	30 - 40	5	0.06	6	70	MERV 8	NS
Education													
Classrooms													
Age 5 - 8	78	75	50 - 60	20 - 30	30 - 45	NS	30 - 40	10	0.12	15	25	MERV 8	NS
Age 9 +	78	72	50 - 60	20 - 30	30 - 45	NS	30 - 40	10	0.12	13	35	MERV 8	NS
Lecture	78	72	50 - 60	20 - 30	30 - 45	NS	30 - 40	7.5	0.06	8	65	MERV 8	NS
Fixed-seat lecture	78	72	50 - 60	20 - 30	30 - 45	NS	30 - 40	7.5	0.06	8	150	MERV 8	NS
Art	78	72	50 - 60	20 - 30	30 - 45	NS	30 - 40	10	0.18	19	20	MERV 8	0.70
Science Lab	78	72	50 - 60	20 - 30	30 - 45	NS	35 - 45	10	0.18	17	25	MERV 8	1.00
Wood / metal shops	78	72	50 - 60	20 - 30	30 - 45	NS	35 - 45	10	0.18	19	20	MERV 8	0.50
Computer lab	78	72	50 - 60	20 - 30	30 - 45	NS	30 - 40	10	0.12	15	25	MERV 8	NS
Media center	78	72	50 - 60	20 - 30	30 - 45	NS	30 - 40	10	0.12	15	25	MERV 8	NS
Hallways	80	72	50 - 60	20 - 30	30 - 45	NS	35 - 45	5	0.06	11	10	MERV 8	NS
Daycare	78	75	50 - 60	20 - 30	30 - 45	NS	30 - 40	10	0.18	17	25	MERV 8	NS
Music	78	72	50 - 60	20 - 30	30 - 45	NS	30 - 40	10	0.06	12	35	MERV 8	NS
Multi-use	78	72	50 - 60	20 - 30	30 - 45	NS	30 - 40	7.5	0.06	8	100	MERV 8	NS

Category	Temperature		Relative Humidity		Supply Air		Sound	Ventilation			Occupancy	Filters	Exhaust
	Summer °F	Winter °F	Summer %	Winter %	Speed fpm	Changes / hour	NC or RC(N)	cfm / Person	cfm / ft^2	Default / Person	People / 1000 ft^2	Eff. % MERV	cfm or cfm/ft^2
Health													
Dr. Office	74 - 78	70 - 74	50 - 60	20 - 30	25 - 45	4 - 10	30 - 45	5	0.06	17	5	30-60	NS
Exam rm.	75	75	60	30	NS	6	35 - 45	15	NS	NS	20	MERV 8	NS
Hospital													
Patient room	75	75	50	30	NS	6	25 - 35	25	NS	NS	10	MERV 8	25 to 50
Hallways	78	75	60	30	NS	4	35 - 45	5	0.06	11	10	MERV 6	NS
Exam room	75	75	60	30	NS	6	35 - 45	15	NS	NS	20	MERV 8	NS
Waiting room	74	74	60	30	NS	6	35 - 45	5	0.06	11	10	MERV 8	NS
Operating rooms	62 - 80	62 - 80	45 - 55	45 - 55	NS	25	35 - 45	30	NS	NS	20	SR*	SR*
Recovery / ICU	75	75	45 - 55	45 - 55	NS	6	35 - 45	15	NS	NS	20	SR*	SR*
Autopsy	74	74	60	30	NS	6	35 - 45	NS	.5	NS	20	SR*	SR*
Physical therapy	72 - 80	72 - 80	60	30	NS	6	35 - 45	15	NS	NS	20	SR*	SR*
Industrial													
Light Mfg	78	72	Max 60*	***	NS	***	To 50	15	NS	15	10	MERV 6	***
Med Mfg	78	60	Max 60*	***	NS	***	To 50	15	NS	15	5	MERV 6	***
Heavy Mfg	78	65	Max 60*	***	NS	***	To 75	15	NS	15	3	MERV 6	***
Warehouse	80 - 100	40 - 55	Max 60*	***	NS	1 - 4	To 75	NS	0.12	NS	NS	10 - 35	***

Data in this table is provided as a guideline only, local codes and standards must be complied with. The data is extracted from ASHRAE Standards, the ASHRAE handbook and a number of internal sources, and by no means covers all situations.

- SR – Depends on activity, material or process in the space
- NS – Not specified
- NR – Not required

Glossary

Word	**Definition**
air handling unit (AHU) / air handler	equipment, usually connected to ductwork, to move and condition air; contains components such as fans, cooling coils, heating coils, filters and dampers to control return, outdoor and exhaust air
air system	the components of a comfort air-conditioning system that treat the air to a space; generally these include the fan, supply duct system, exhaust, ventilation dampers, mixing dampers, filtration, cooling coils, heating devices, and humidification capabilities
apparatus dew point (ADP)	the dew point temperature that corresponds to the average effective coil surface temperature
blow-thru	air systems where the fan is located before the cooling coil and air is blown through the coil; the coil is under positive pressure
British thermal unit (Btu))	measure of heat energy; the heat energy of a Btu is approximately that required to raise the temperature of a pound of water from one degree Fahrenheit, from 59° F to 60° F
bypass factor	the ratio of the air that does not contact the coil to the total airflow
centrifugal compressor	nonpositive displacement refrigeration compressor, which depends for pressure rise, at least in part, on centrifugal forces developed by a rotating impeller.
circulate	Function of a comfort air-conditioning system to provide air motion within a space which is uniform and provides adequate mixing of supply and return air at room air velocities which would not be described as drafty or stuffy
CLO	unit of clothing insulation, defined as the thermal insulation necessary to keep a sitting person comfortable in normally ventilated room at 70° F and 50 percent relative humidity. In physical terms, the thermal resistance of one CLO = 0.88° F·ft^2 ·h/Btu
comfort (air conditioning)	Controlling simultaneously space conditions of temperature, humidity, air motion, mean radiant temperature, air purity, and air quality (ventilation/exhaust), for the purpose of satisfying the physical needs of the space occupants
compressor	a component in a refrigerating system that "pumps" the refrigerant and raises its temperature by increasing the pressure above the temperature of the condensing media
condenser	a device in a refrigerating system where refrigerant rejects the heat to the condensing media, either air or water
conduction	heat transfer by which heat is moved from molecule to molecule of a substance or between substances by a chain collision of those molecules
convection	heat transfer within a fluid by the movement of heated molecules from one place to another as the result of density differences
convective baseboard	heaters which create air motion by natural convective heat transfer without any fan; normally electric or hot water and located along the perimeter walls
cool	function of a comfort air-conditioning system to remove heat energy from a space adequate to overcome heat gains and maintain comfort levels
cooling load	the heat gains to a space above the heat losses that the cooling system needs to remove to maintain space temperature; includes both sensible and latent heat gain elements

dehumidifier	air cooler, absorption or adsorption device used to lower moisture content
dehumidify	function of a comfort air-conditioning system to remove moisture from the air in a space at a quantity that maintains space relative humidity at levels within the comfort envelop or as required for a process
diffuser	an air distribution component in the space or air outlet that delivers supply air such that appropriate mixing, conditioning and air motion occurs
draw-thru	air systems where the fan is located after the cooling coil and air is drawn through the coil; the coil is under negative pressure
ductwork	series of interconnected ducts and fittings that delivers air to a space from a remotely located fan then returns it to the fan
effective temperature	a set of temperature and humidity conditions that feel the same as the dry bulb temperature and 50 percent relative humidity
evaporation	change of state from liquid to vapor, from the body regulation of body temperature by the process of evaporation of perspiration
evaporator	a heat exchange coil within a mechanical refrigeration system where the refrigerant is evaporated to absorb heat from the contacting heat source
filter	function of a comfort air-conditioning system to remove particles, gaseous, and biological contaminants which may be in circulation
grille	a covering over the opening of a duct system, normally return air; does not greatly affect the room air distribution.
heat	a form of energy that can be transferred by conduction, convection, or radiation; only transferred from a warmer substance to a colder substance; function of a comfort air-conditioning system to provide heat energy to a space adequate to overcome heat losses and maintain comfort levels
heat pump	air conditioning heating/refrigerating system that will transfer heat; the condenser and evaporator may change roles to transfer heat in either direction by receiving the flow of air or other fluid; a heat pump is used to cool or heat.
heating load	the heat losses from a space above the heat gains that a heating system needs to add to maintain space temperature; it is only sensible
high side	parts subjected to approximately the condenser pressure; discharge side, from compressor discharge to metering device inlet
human comfort	space in which more that 80 percent of the occupants describe the space as comfortable with regard to temperature, humidity, air motion, air purity, air quality and effects of radiant temperature; conditions are a function of activity level, clothing, and time in the space
humidifier	device to add moisture to air
humidify, humidification	function of a comfort air-conditioning system to add moisture to the air in a space at a quantity that will maintain a space relative humidity at levels within the comfort envelope or as required for a process
humidity	the moisture content of air, measured in pounds/pound of dry air, or grains/pound of dry air
HVAC	heating, ventilating and air conditioning; standard abbreviation
infiltration	the leakage of outside air into a structure through doors, cracks, windows, and other openings.

low pressure side (low side)	portion of a refrigerating system operating at approximately the evaporator pressure; suction side, from metering device outlet to compressor suction
mechanical refrigeration system	a system that transfers heat from a colder place to a warmer place by raising the pressure and temperature of a volatile fluid above its condensing temperature; system consists of a refrigerant (volatile fluid), an evaporator (heat absorber), a condenser (heat rejector), a compressor (vapor pump), and a metering device (pressure reducing valve)
MET	unit of metabolic rate of people defined as 18.4 Btu/h·ft^2, which is equal to the energy produced per unit surface area of a seated person at rest. The surface area of an average man is about 19 ft^2
process air conditioning	controlling simultaneously, space conditions to provide temperature, humidity, air motion, air purity, air quality (ventilation/exhaust), and mean radiant temperature, primarily for the purpose of a product or production process in the space; if human comfort is provided, it is a secondary benefit
psychrometrics	the study of air and moisture mixtures.
radiation	transfer of heat energy by electromagnetic waves due to temperatures in the two surfaces; is a function of temperature difference, distance, angle between surfaces, and surface absorption
reciprocating compressor	positive-displacement compressor in which the change in internal volume of the compression chamber(s) is accomplished by the reciprocating motion of one or more pistons.
refrigerant	the medium of heat transfer which picks up heat by evaporating at a low temperature and pressure, and giving up heat on condensing at a higher temperature and pressure
refrigerant metering device	device that controls the flow of liquid refrigerant to an evaporator
register	combination grille and damper assembly over a supply air opening; normally located in the floor or wall
relative humidity	a measure of the moisture content in the air as a percentage of the maximum amount of moisture the air could hold at that dry bulb temperature
room air distribution	the process of providing proper air motion and proper air mixing of room, supply, and ventilation air in a space
rotary compressor	positive displacement compressor in which the change in internal volume of the compression chamber(s) is accomplished by the rotary motion of a positive displacement member(s).
screw compressor	rotary compressor relying on the intermeshing of two helical rotors to produce compression.
scroll compressor	positive-displacement compressor in which the reduction in internal volume of the compression chamber is accomplished by an orbiting scroll (involute spiral) within a mating stationary scroll.
sensible heat	the energy of molecular motion, measured with a standard thermometer; heat which causes a change in temperature
setback	reduction of space temperature for heating during hours when a building is unoccupied, or during periods when lesser demand is acceptable
setup	Increasing the space temperature setpoint for cooling during hours when a building is unoccupied, or during periods when lesser demand is acceptable
specific humidity	ratio of the mass of water to the total mass of dry air in a volume of moist air

swing	change in temperature above the cooling setpoint that is allowed for calculation such that the system is still considered to be in control of the space temperature
thermostat	temperature-sensitive device that automatically opens and closes an electric circuit to regulate the dry bulb temperature of the space with which it is associated
thermostatic expansion valve (TXV)	control device for regulating the flow of refrigerant into a cooling unit, actuated by the changes in evaporator pressure and superheat of the refrigerant leaving the cooling unit; the basic response is to the superheat
throttling range	change in controlled variable (temperature) required to move the thermostat from one of its extreme limits of travel to the other
transmission load	the heat gain or loss to a space that occurs due to a temperature difference between space and outdoor conditions or adjacent room conditions; may be a cooling or heating load
ventilation	process of supplying or removing air by natural or mechanical means to or from any space for the purpose of oxygen replacement or odor dilution; such air may or may not have been conditioned

Work Session Answers

Work Session 1

1. True
2. a), b), c), d)
3. 75° F or 68-78° F (range)
4. 50 percent or 30-60 percent (range)
5. b)
6. d)
7. b) and c)
8. False, comfort is also compromised
9. b), c), d)
10. d)
11. True
12. d)

Work Session 2

1. True
2. False
3. c), d)
4. a), c)
5. c)
6. b), c), d)
7. d)
8. True
9. b)
10. b)
11. b), d)
12. d)
13. b)
14. a), b)

Work Session 3

1. c), d)
2. a)
3. evaporator, compressor, condenser, metering device
4. b)
5. b), d)
6. a), d)
7. a)
8. b)
9. d)
10. c)
11. b)

Prerequisites:

None required.

Learning Objectives:

At the conclusion of this module, participants will be able to:

- Describe the six conditions that influence human comfort.
- List the four processes the body uses to transfer heat.
- Describe how a system designer can control the environment to maintain comfort conditions.
- Describe what environmental control parameters are required from comfort air-conditioning systems.
- List a reasonable range for each of the comfort parameters.
- List the basic components of the air system and the function of each.
- List the four principles that are used to make a mechanical refrigeration system work.
- List the four components of a mechanical refrigeration system and the principles used to create the refrigeration process.
- Explain what measurements can be done to calculate each of the environmental factors.
- Calculate the relative humidity.
- Explain the principle of effective temperature.
- Determine the CLO (clothing insulating value) and MET (Activity – metabolic rate) values.
- List the typical operating parameters of the components of an air system.
- Explain the difference between sensible and latent heat.
- Create a list of comfort design conditions for a project.

Supplemental Material:

Form No.	Color Book	Instructor Presentation	Title
TDP-103	796-027	797-027	Concepts of Air Conditioning
TDP-104	796-028	797-028	Equipment Introduction
TDP-105	796-029	797-029	Comfort Design Steps
TDP-400	796-037	797-037	Principles of Mechanical Refrigeration
TDP-201	796-030	797-030	Psychrometrics, Level 1, Fundamentals
TDP-507	796-048	797-048	Room Air Distribution

Instructor Information:

Each TDP topic is supported with a number of different items to meet the specific needs of the user. Instructor materials consist of a CD-ROM disk that includes a PowerPoint™ presentation with convenient links to all required support materials required for the topic. This always includes: slides, presenter notes, text file including work sessions and work session solutions, quiz and quiz answers. Depending upon the topic, the instructor CD may also include sound, video, spreadsheets, forms, or other material required to present a complete class. Self-study or student material consists of a text including work sessions and work session answers, and may also include forms, worksheets, calculators, etc.



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