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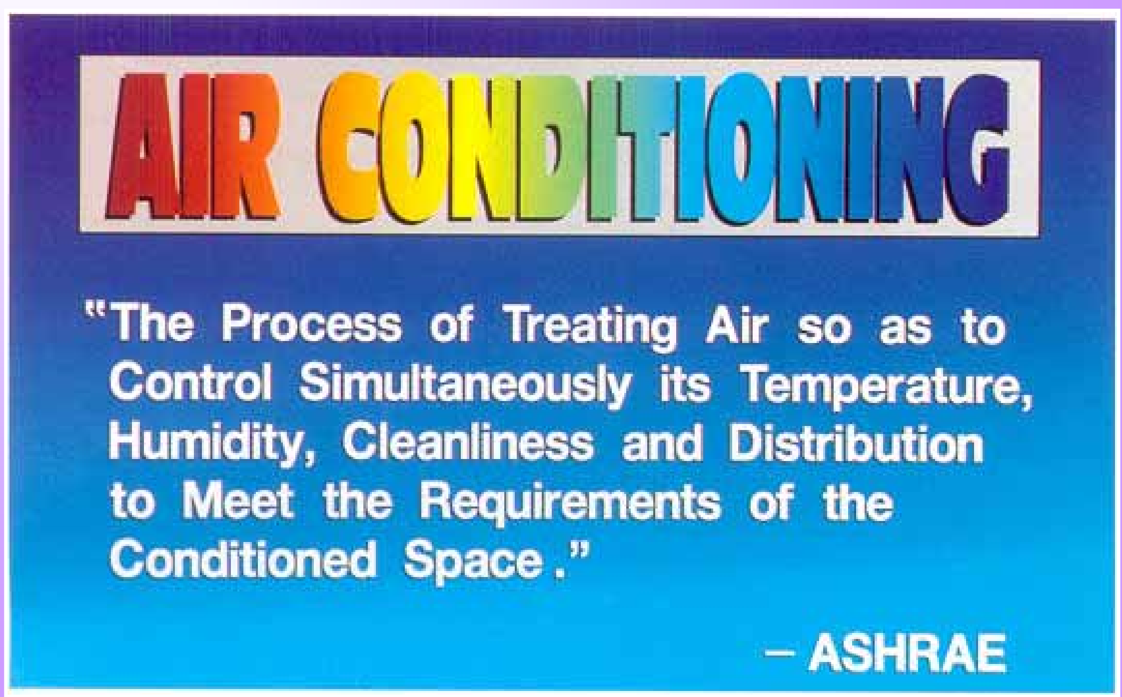
Section 1: Body Comfort



What is air conditioning ?

- **Improve industrial process**

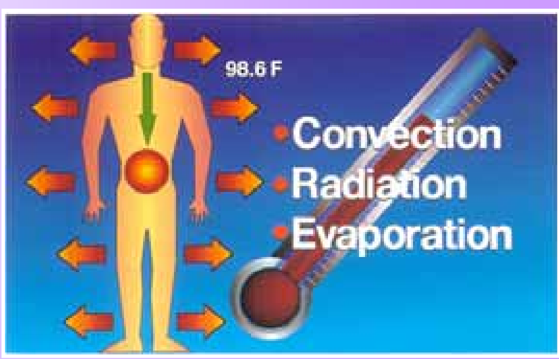
  Determined by nature of process

- **Maintain human comfort**

  Determined by requirements of human body

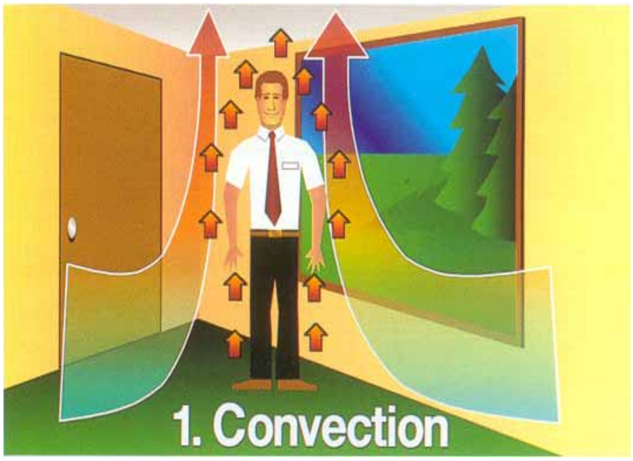
Body Comfort

What is it that makes a person feel hot or cold? The human body burns food to provide heat and energy in a process called metabolism, in much the same way an automobile engine burns gasoline, providing heat and energy. The excess heat we generate must be given off from our body at a rate necessary to maintain our normal temperature of 37^o C.



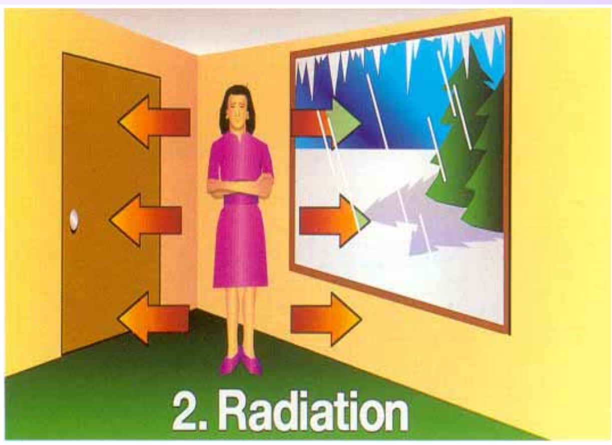
This heat transfer takes place constantly, every second, every day of the year, in three ways by convection, by radiation, and by evaporation.

Convection



When heat is given off by convection, the air close to the body becomes warmer than the air away from the body. Since warm air is lighter than cool air, it floats upward. As it does, it is replaced by the cooler air. As this cooler air absorbs body heat, it too floats upward.

Radiation



The second way the body loses heat is by radiation. Heat radiates directly from the body to any cooler object, just as the rays of the sun travel through space to warm the surface of the earth. Heat may be lost from the body's skin to a wall, ceiling, or any object which is cooler than the body.

Evaporation

Evaporation is the third way the body gives off heat. Moisture or perspiration is discharged through the pores of the skin. As this moisture evaporates, it absorbs heat from the body.

In other words, it cools the body by transferring body heat to the surrounding air. One can readily feel the effect of evaporation by rubbing alcohol on the skin. Because alcohol vaporizes at a lower temperature than perspiration, the body feels cooler.

Relative Humidity

Evaporation from the body goes on constantly whether or not we sense it. When drops of perspiration can be seen, the body is producing more heat than it can reject by evaporation.

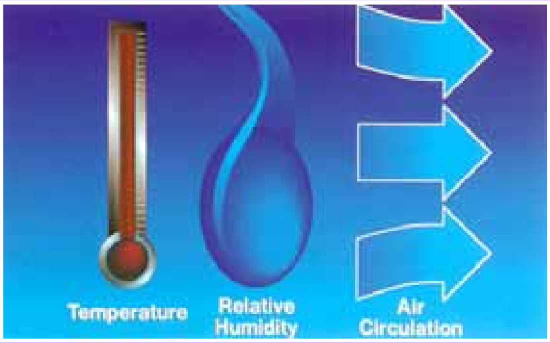
This may occur when the moisture content of the air, in other words, the relative humidity becomes too high for the air to accept water vapor at the rate needed.

Body Comfort

All three methods of giving off heat, convection, radiation and evaporation are normally used at the same time.

However, depending on surrounding conditions, one method may be called upon to do a major share of the job.

Body Comfort



Temperature, relative humidity, and air motion are three conditions that affect the body's ability to reject heat.

Changes in each of these surrounding conditions will speed up or slow down convection, radiation, or evaporation.

Temperature

First, air temperature. Heat always flows from a place of higher temperature to one of lower temperature. The greater the temperature difference, the faster the flow of heat.

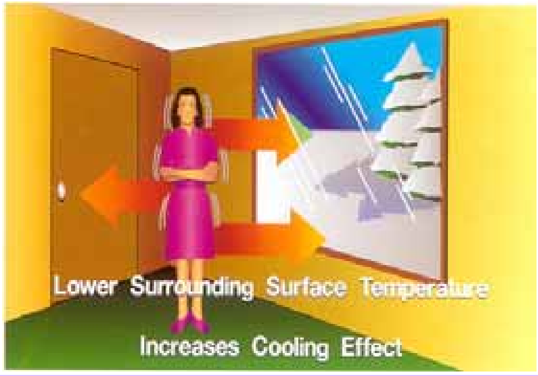
If the difference is too great, the body may lose heat more rapidly than it should; discomfort is the result. We feel cold.

Temperature

Conversely, the higher the air temperature, the slower the rate of heat transfer. As the air temperature approaches body temperature, the body loses heat less rapidly through convection. If the heat can't be dissipated, we start to feel hot.

As you can see, air temperature has an important effect on comfort.

Radiation

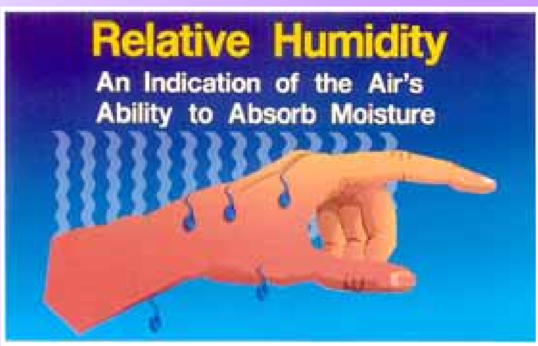


The temperature of surrounding surfaces is also important because it affects the rate of radiation. The lower the temperature of the adjacent surface, the more cooling effect the body will feel through radiation.

And, of course, radiation is slowed down as the temperature of the adjacent surface approaches body temperature.

Evaporation

As mentioned earlier, there are conditions other than surrounding temperatures that affect the body's ability to reject heat. Relative humidity affects the amount of heat the body can give off through evaporation.



Relative humidity is a measure of how much moisture is in the air. You could say it's an indication of the air's ability to absorb more moisture.

Relative Humidity

For example, when we say that the air has a relative humidity of 50%, we are saying that the air at this specific temperature contains half the amount of moisture it can actually absorb.

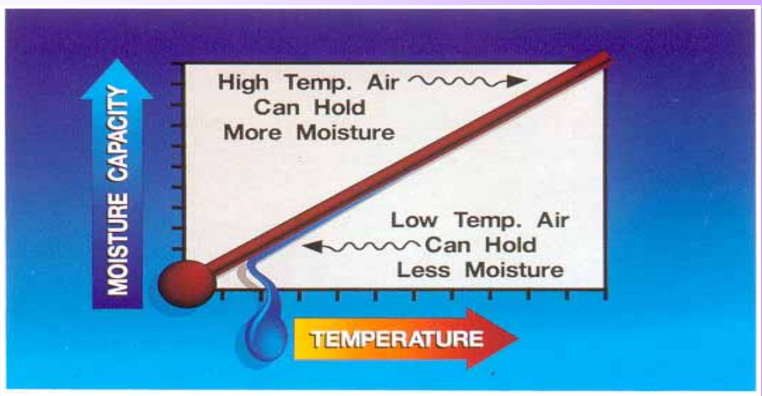
Relative humidity of 100% indicates that the air contains all of the water vapor it can hold at its present temperature. Air at 100% relative humidity is commonly called "saturated."

Ideal Conditions

If there were no air motion, the layer of air closest to the body would soon approach saturation. Its relative humidity would increase to the point where it could no longer absorb water vapor.

At this point, evaporation from the body would almost stop and discomfort would result.

Relative Humidity



Because relative humidity has a direct correlation to temperature, any time the temperature is raised or lowered, the relative humidity or moisture content of the air will also change. Cool air has less capacity to hold moisture than does warm air.

Relative Humidity vs. Comfort

When the surrounding air has a low relative humidity, the body is able to give off more heat through evaporation.

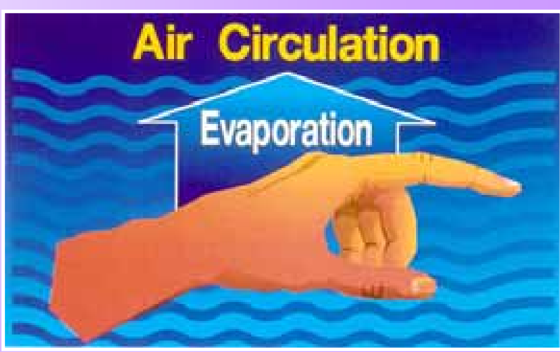
Conversely, when the relative humidity is high, the body is less able to give off heat.

Ideal Conditions

Experience has shown that while the acceptable conditions of comfort vary from person to person, temperatures somewhere between 22^o and 26^{o}C and 50% relative humidity are satisfactory to most of us.

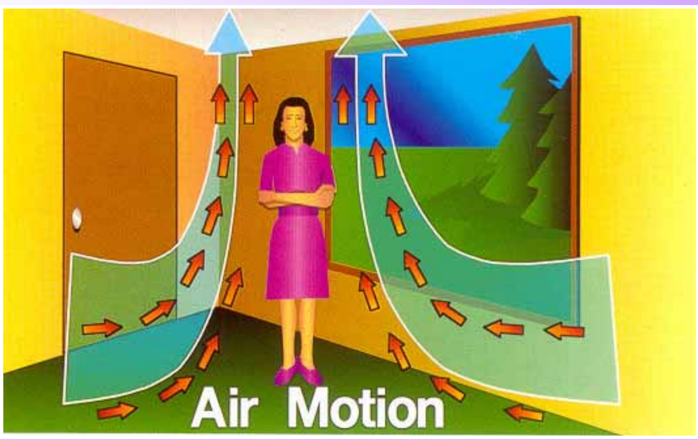
Air Motion

Air motion is the third condition that affects heat rejection from the body. One result of air motion is an increase in the rate of evaporation. As we've seen, evaporation depends on the ability of the air to absorb moisture.



Air moving across the body forces away saturated air, allowing more moisture to evaporate from the skin, cooling it.

Air Motion

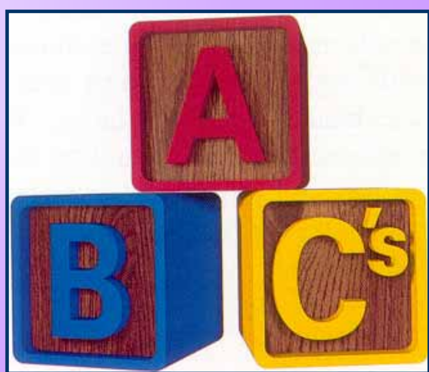


Air motion also speeds up the convection process by removing the warm air close to the body and carrying away the heat that's been given up. Air in motion may also remove heat from walls, ceilings, and other surfaces surrounding the body.

Ideal Conditions

The comfort of the human body depends on three major factors:

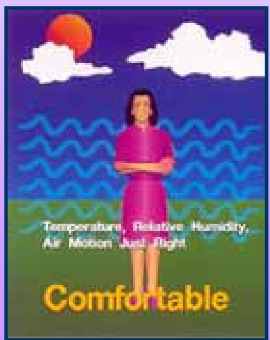
- **Temperature,**
- **Relative humidity,**
- **Air motion.**

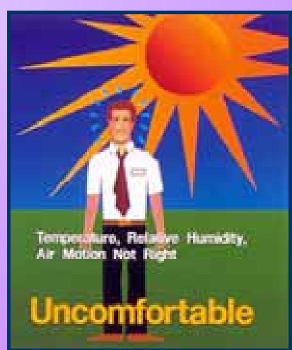


Section 2: The Air Cycle

The Air Cycle

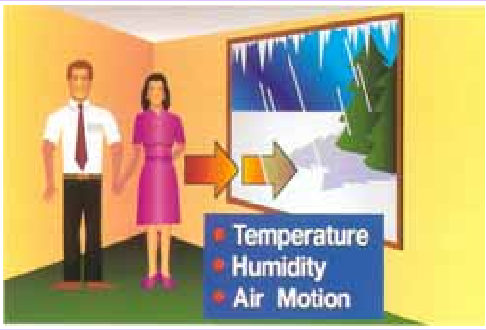
When outdoors, we must depend on changes of clothing and the whims of nature for comfort. If the combination of temperature, relative humidity, and air motion happens to be just right, and if these conditions allow our bodies to reject excess heat and no more, we feel comfortable. If the combination isn't just right, we are uncomfortable.





The Air Cycle

We can't change outside conditions, but when we are in an enclosed space, we can control our comfort. If this enclosed space existed in complete isolation, and if it were perfectly insulated, all we'd have to do is remove exactly the amount of heat given off by the body. That is, remove heat at the same rate at which the body must reject heat to be comfortable.



But it's not that simple. There are other factors affecting the temperature, humidity, and air motion in an enclosed space.

Load Factors

Such everyday essentials as lighting, cooking, laundering, and bathing all add their share to the overall heating and humidity load.

All of these factors contribute to slowing down the body's ability to give off heat.

Load Factors

Of course, there is no perfectly insulated room. Heat from the sun enters through radiation. Outside temperature affects the wall temperatures. Air enters the building, either through leaks; or it's brought in mechanically for ventilation.

Besides affecting the temperature and humidity, this outside air brings in dirt and other foreign materials. So, many factors influence temperature, humidity, air purity, and air motion.

Cooling Load

If conditions in the room are such that the body cannot give off heat quickly enough, we say we have a cooling load.

To maintain comfort, we have to change conditions to allow heat to flow from the body at a comfortable rate. .

Heating Load

If heat is being removed from the body too quickly as a result of existing conditions, we say that we have a heating load.

In this case, we would have to change conditions to REDUCE the rate of heat loss from the body.

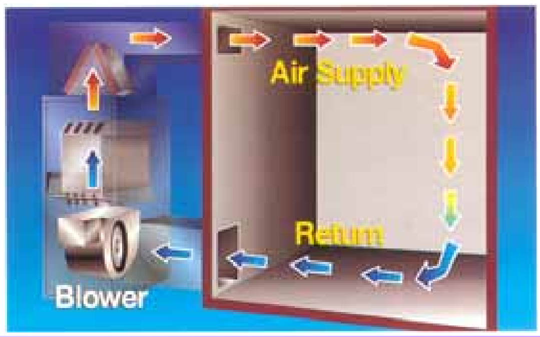
System Control

Changing the conditions that affect comfort is the job of the air conditioning system, a system for controlling air motion and either adding or taking away heat and humidity.

The terms "heating load" and "cooling load" are used for convenience. Actually, the system controls all three of the conditions affecting the body's rate of heat loss: temperature, humidity, and air motion.

System Control

A modern air conditioning system controls these conditions by circulating the proper quantity of air, at the right temperature and humidity, with a fan or blower.



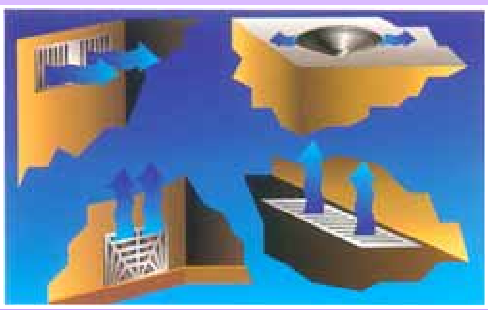
If there's a heating load, the system adds heat. It also adds humidity when necessary. If there's a cooling load, the system removes heat and humidity.

Let's see just how our system maintains comfort conditions.

Air Motion

The air motion in the room is affected by these openings through which the conditioned air is sup- plied to the room. The number, type, size, shape and location of the openings all have an affect on air motion.

After the air has been distributed through the room, an equal amount of air must be removed from the room so more air can be supplied.

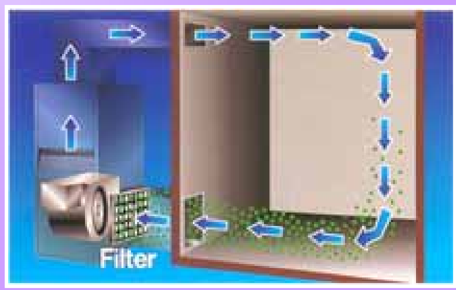


The air is removed through a return air opening and re- turned to the system.

Filtration

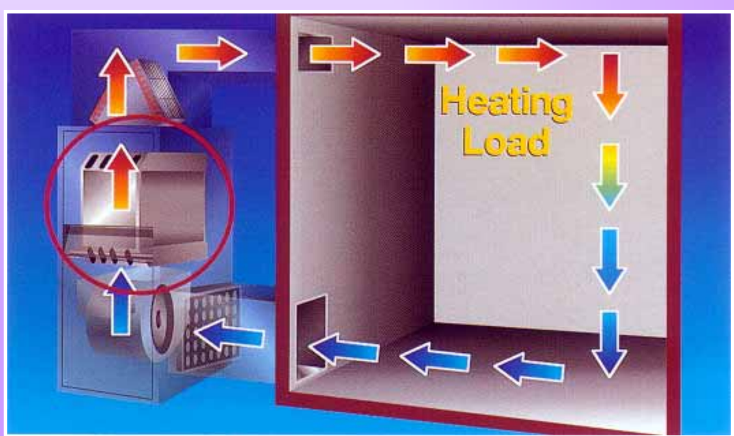
Because we are circulating the air utilizing a mechanical system, we have a chance to perform one other important function. Everyone wants the air they breathe to be clean, so a filter is added to the system to remove dust and dirt. Many types of filters are available, but they all provide a very fine screen or "media" that strains unwanted dust and particles from the air.

At this point, the supply and return air are at room temperature and humidity. What happens with the air now depends on whether the room has a cooling load or a heating load.



Heating

If there's a heating load, additional heat must be supplied to make up for the heat lost from the room. The air conditioning system adds this heat, raising the temperature of the supply air above the room temperature. There are two commonly used methods of heating air.



Direct Heating

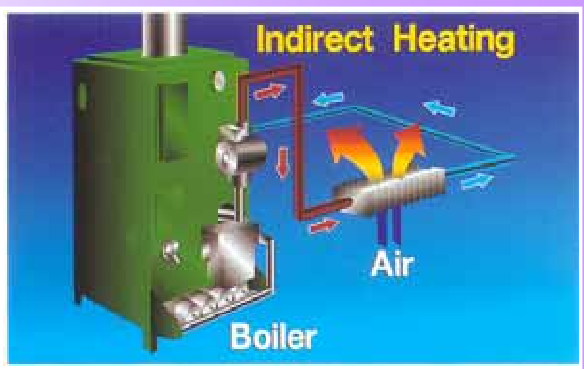
A popular method is "direct" heating, where heat supplied by burning either gas or oil is transferred to the room air through a metal heat exchanger in a furnace.

The warm air is supplied to the room where it gives up its heat. The air is then returned to the system to continue the cycle.

Indirect Heating

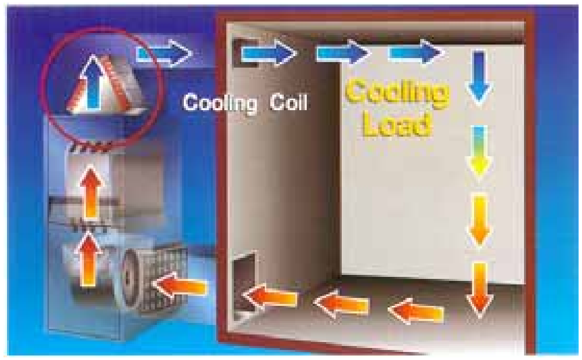
Another way is to pass the air through hot water or steam coils that are connected to a boiler. This is called "indirect" heating.

The air passing over the surface of the coil absorbs heat to replace the heat that was given off in the room.



Cooling

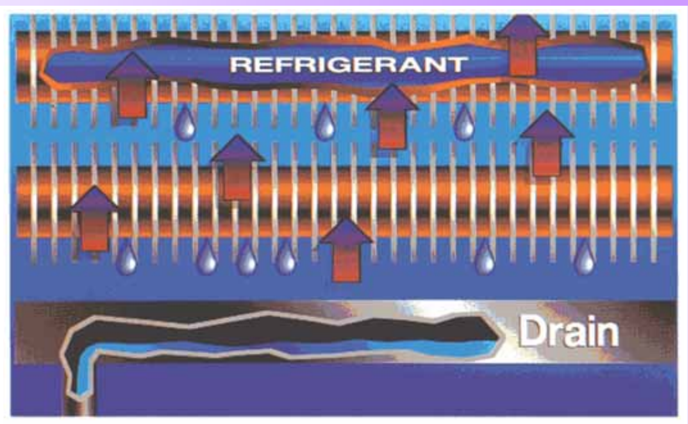
When there's a cooling load, we want the supply air to be cooler and drier than the room air so it can absorb the heat and humidity given off by the body and other load factors.



Once that happens, the air must be cooled and dehumidified by the air conditioning system before the air is used again.

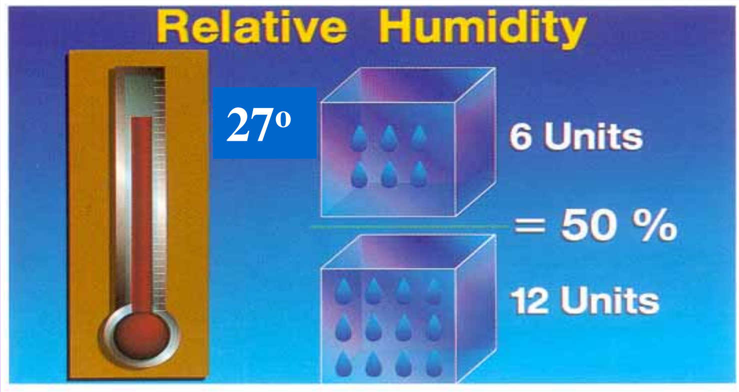
Cooling

This is accomplished by passing the air over a cooling coil, or evaporator. As the air passes over the cooling surfaces, heat from the air is absorbed by the refrigerant in the coil.



At the same time, water vapor condenses on the coil. That is, it turns into liquid water, which is then drained off. In order to understand what causes this condensing, or dehumidifying, action, we need to look a little closer at "relative humidity."

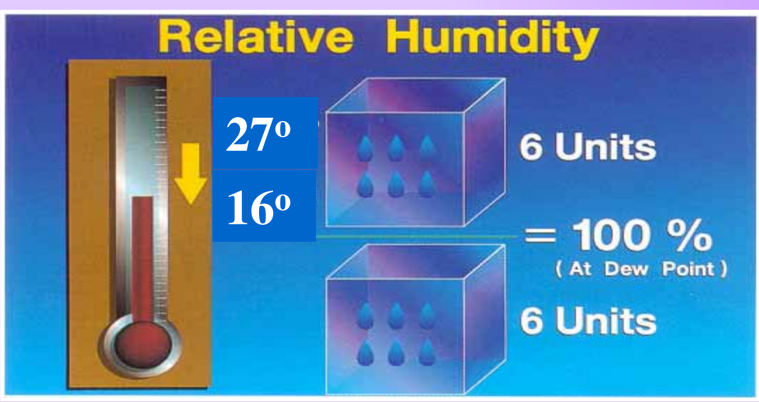
Relative Humidity



Relative humidity, as you will recall, is a measure of the actual moisture content of air in relation to its capacity to hold moisture. So, if the air in a 27º C room is capable of holding 12 units of moisture per cubic foot, and its actual moisture content is six units, its relative humidity is 50%.

Relative Humidity

We also learned that the cooler air is, the less moisture it can hold. If we reduce the temperature in our example to 16º C, we see that the moisture- carrying capacity is now six units. Since the actual moisture content is also six units, the relative humidity is now 100%. This is also known as the saturation or, "dew point."



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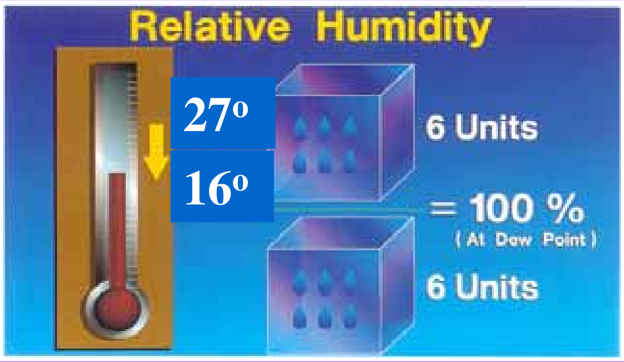
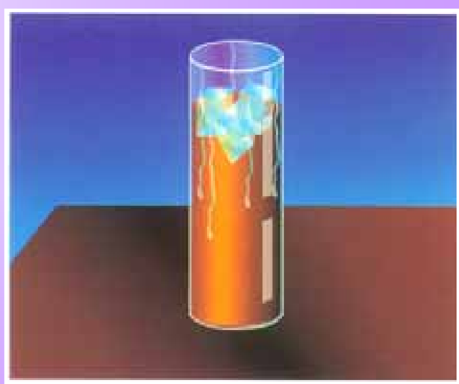


At the dew point, the air is holding all the moisture it can for that temperature; or to put it another way, the relative humidity is 100%.

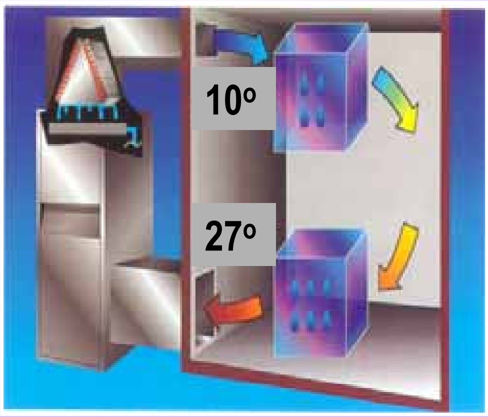
Relative Humidity

If we reduce the temperature of the air, it is no longer able to "hold" all that water vapor so some of the water is squeezed out of the air, or condensed.

It's the same phenomenon you've seen on a hot day when humid air comes in contact with a cold drink. The outside of the glass sweats as water condenses out of the surrounding air.



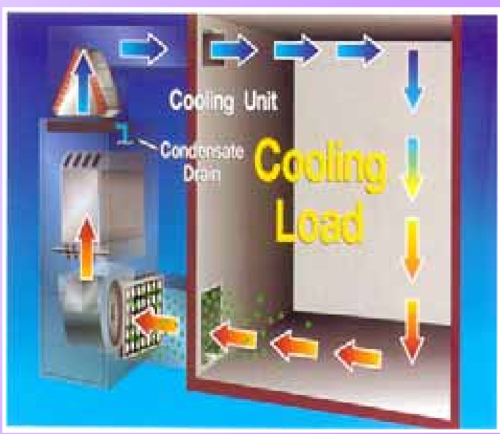
Cooling – Two Modes



The same thing happens with a cooling coil. When the air around it is saturated with moisture, the excess moisture condenses on the coil. From there, it is drained out of the system. The air supplied to the house at 10^o C is cooler and drier than the 27^o C return air.

The cooling function of the air conditioning system actually serves two purposes; it absorbs heat and removes water.

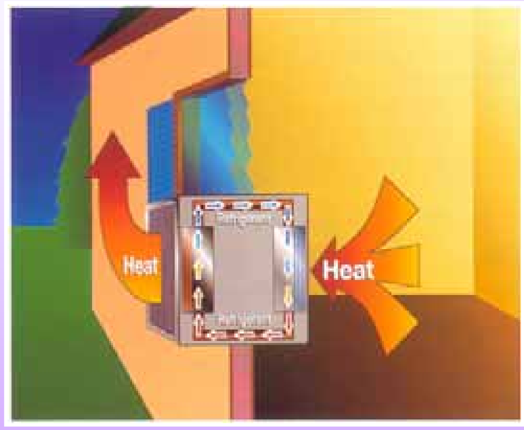
Cooling - Summary



Here, in summary, is what happens to the air when there's a cooling load in the space to be conditioned: cool, dry, clean air is circulated through the room where it absorbs heal and moisture. This air then returns to the system where it is filtered and the cooling coil removes the heat and water vapor that were picked up in the conditioned space.

The condensed water vapor, known as condensate, is drained off., the cycle is then repeated.

Section 3:The Refrigeration Cycle

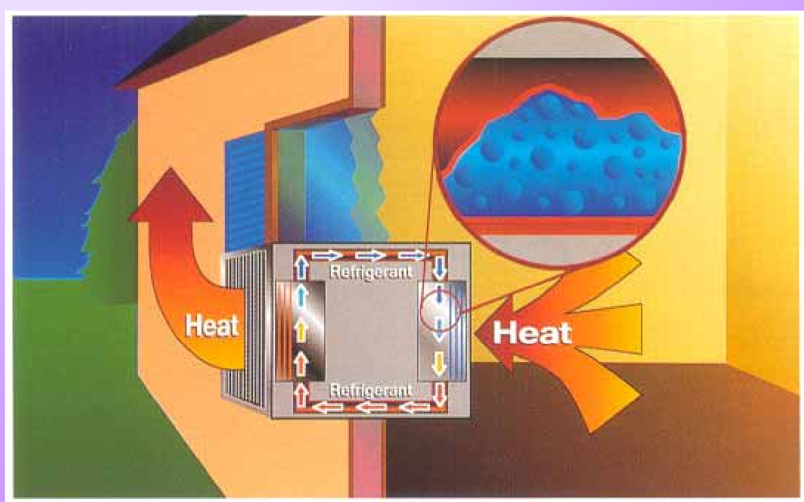


It's easy to think of an air conditioning system as something that produces "coldness." Actually, it is more accurate to think of it in terms of removing heat. The heat in a room is transferred to the cold refrigerant flowing through an air conditioner coil.

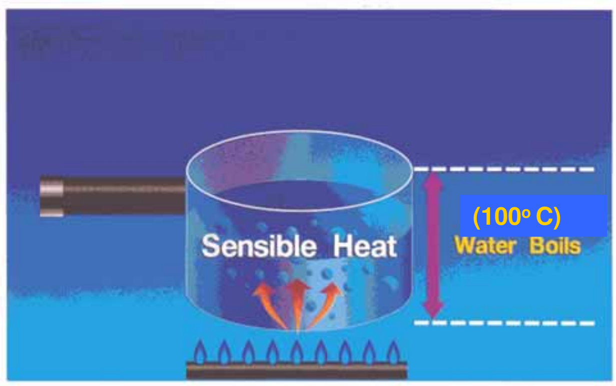
The heat in the refrigerant is moved to the outdoors where it is released to the air through another coil, called a "condenser." That is the basic concept of all air conditioning systems.

The Refrigeration Cycle

What makes the cooling coil cold? Actually, it's because a refrigerant is boiling inside the coil. Confusing? Let's see just how it works.



Sensible Heat

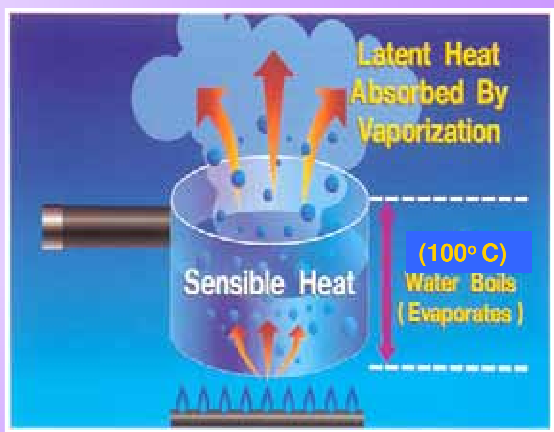


To understand the principle, we'll start with a pot of water. As the water absorbs heat, its temperature rises until it reaches the boiling point of 100º C.

The heat absorbed while the water is changing temperature is called "sensible heat," since it can be sensed, or read, on a thermometer.

Latent Heat

As the water boils, it absorbs still more heat, but the temperature doesn't change. This heat is called "latent heat," since the change is not measurable. Instead of raising the temperature, the heat is used in changing the water from a liquid to a vapor.

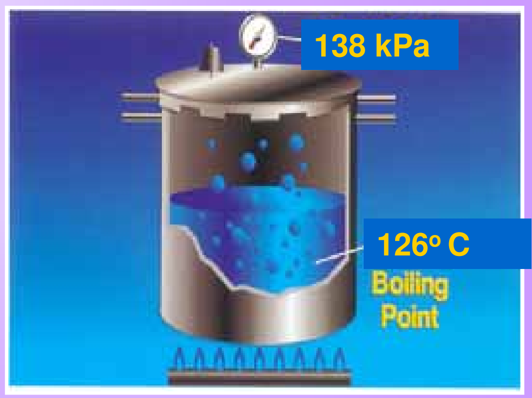


This physical principle is one key to operation of refrigeration systems ... the ability of a liquid to absorb a large amount of heat as it vaporizes.

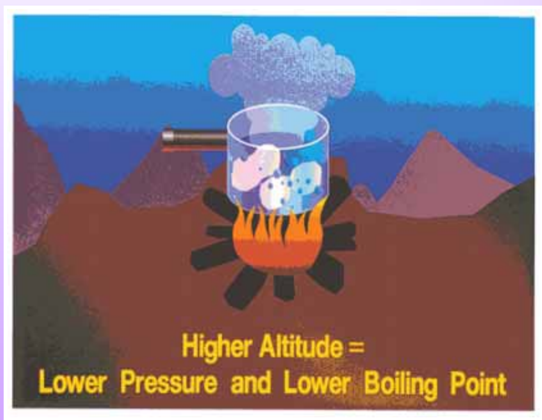
Pressure vs.Temperature

The second physical principle that is important is that the boiling point of a liquid can he changed by changing the pressure.

For example, the increased pressure in a pressure cooker causes water to boil at a higher temperature, cooking food more quickly.



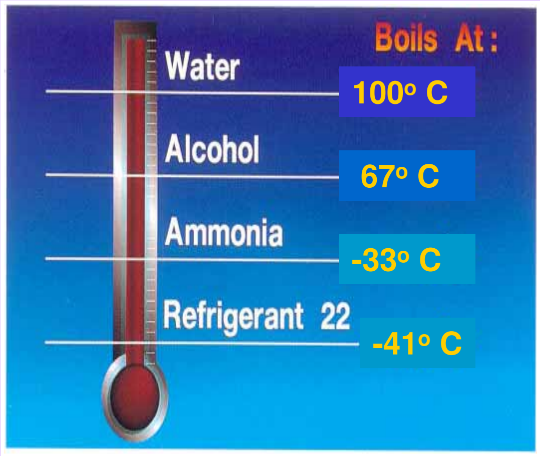
Pressure vs.Temperature



In contrast, a person on a mountain top will have trouble cooking potatoes in an open pan because of the low pressure and resultant low boiling temperature at the higher altitude.

Boiling Point

There are other liquids that have much lower boiling points. At normal atmospheric pressure, ammonia, a refrigerant used in commercial refrigeration, boils at –33° C. A refrigerant known as R-22 boils at –41° C.



Because R-22 is one of the refrigerants commonly used in air conditioning, we'll use it in an example to see just what happens inside the cooling coil.

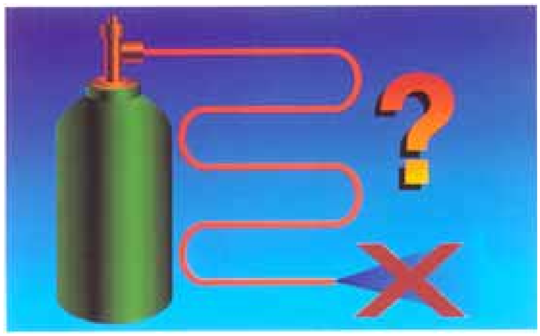
Cooling Coil

The cooling coil is also called an evaporator, because the refrigerant boils or evaporates inside the coil as it absorbs heat from the air passing over the coil. The refrigerant continues to boil as it travels through the coil, until it's completely vaporized.

In the process of vaporizing, the refrigerant absorbs a large amount of heat, just as water did in its transition to steam. During the evaporation process, the refrigerant changes from a cold liquid to a cool gas as it absorbs heat from the room air passing over it.

Refrigerant

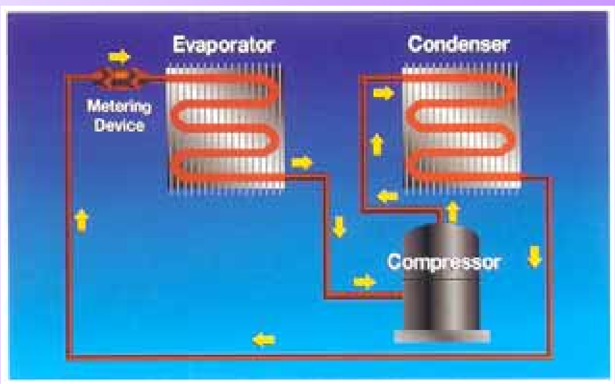
What happens to the refrigerant after it leaves the coil?



If we had an unlimited supply of liquid refrigerant at negligible cost, we could simply keep adding more into the coil. Because of cost and potential damage to the environment, however, this is not feasible.

Complete Refrigeration System

To make a complete air conditioning system that is capable of reusing refrigerant, we need more than an evaporator, or cooling coil.



We need a compressor, a metering device, and some type of condenser. These parts move the refrigerant and regulate its flow in a process that removes the heat that has been absorbed by the refrigerant, enabling the evaporator to use the refrigerant over and over.

Compressor

The compressor does two things to the cool, low pressure refrigerant vapor in the evaporator. First, it pulls the cold gas from the evaporator through a pipe connection called a "suction line." This maintains the refrigerant pressure in the evaporator at the level required to maintain its boiling or vaporization temperature, at the proper point for effective heat transfer.

Next, the compressor "compresses" the cool refrigerant gas drawn from the evaporator.

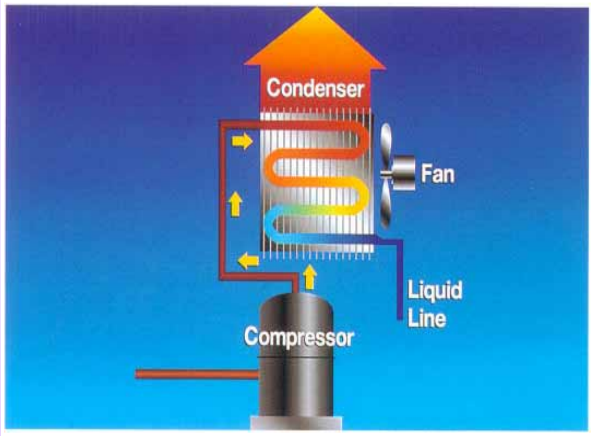
Compressor

Because of the interlocking relationship between pressure and temperature, the increase in pressure caused by the compressor results in a significant increase in temperature. The refrigerant at the compressor discharge is, therefore a hot, high pressure gas, perhaps 82° C at 1794 kPa using refrigerant R-22.

This is a critical step in the process, because the refrigerant must be hotter than the outside air in order for heat transfer to occur at the condenser.

Heat Rejection

The hot gas leaving the compressor discharge flows through the condensing coil. Relatively cooler outdoor air, circulated over the condensing coil by a fan, picks up the heat and disperses it outdoors.



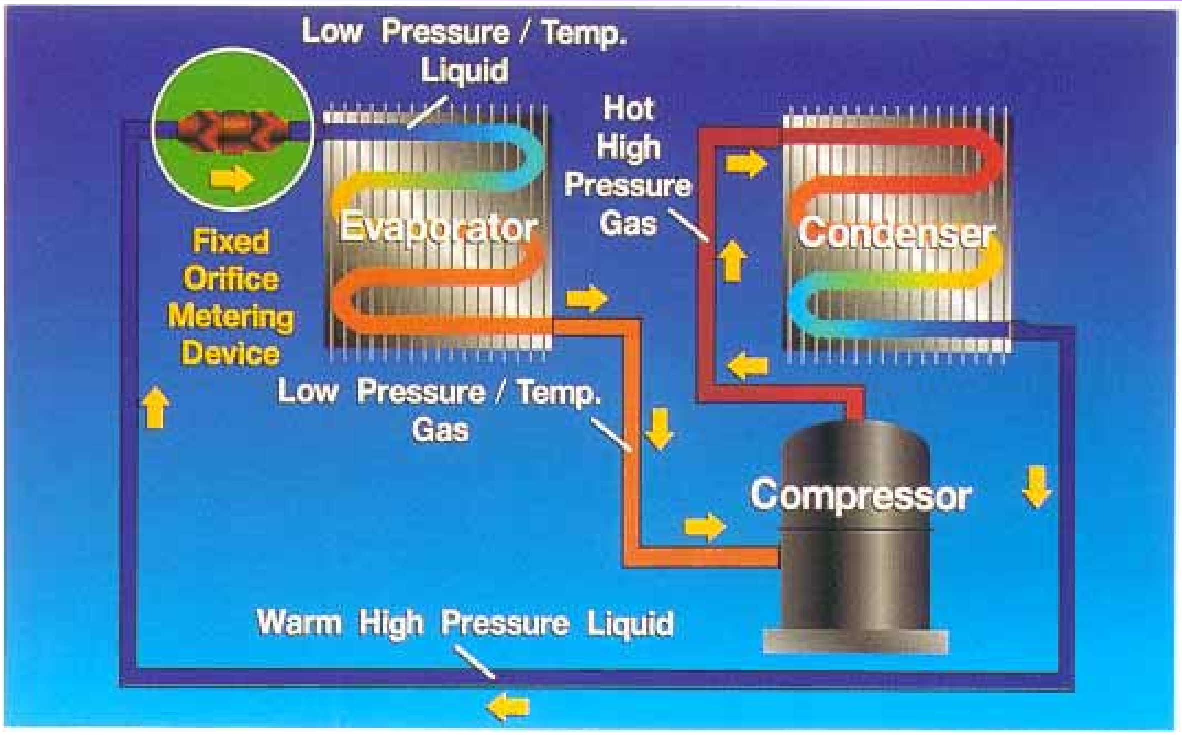
The heat removal process causes the refrigerant to return to a liquid state as it leaves the condenser, moving toward the metering device in the liquid line.

Metering (Expansion) Device

There are several types of metering devices used to regulate the flow of refrigerant into the evaporator. This one is a fixed-orifice metering de- vice, which is commonly used on residential and light commercial systems. Thermostatic expansion valves are also used to regulate refrigerant flow.

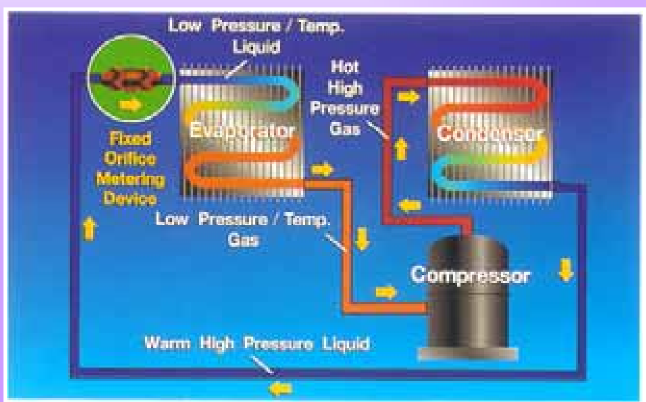
In the metering device, the liquid refrigerant passes through a narrow opening, or orifice, into a larger chamber. The expansion causes a pressure drop, thus lowering the refrigerant pressure and temperature.

Refrigeration Cycle



Refrigeration Cycle

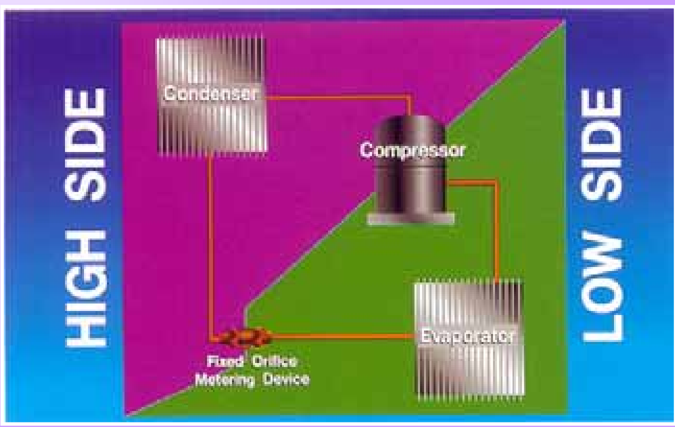
The refrigerant entering the evaporator is, therefore, a low temperature, low pressure liquid that will boil and absorb heat when warmed by the air from the conditioned space. In a typical R-22 system, the refrigerant entering the evaporator is about 4º C. The heat added to the refrigerant in the evaporator coil then causes it to boil at this temperature.



High Side – Low Side

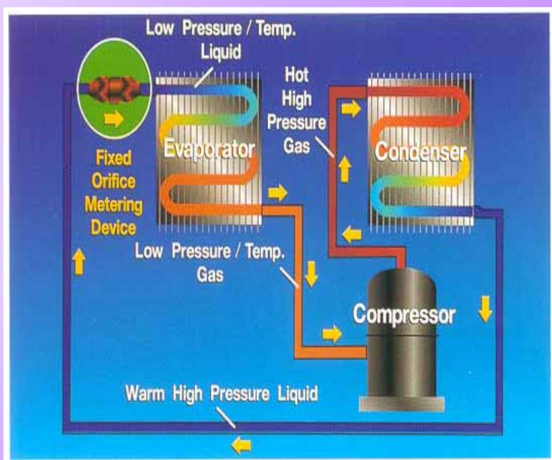
You may have heard the term “high side” and "low side" used in reference to air conditioning equipment. The compressor and metering device divide the system into high pressure and low pressure sections.

Components and piping in the high side will contain hot refrigerant because of the high pres- sure. The low side will be cold because it's at low pressure.



Refrigeration Cycle

Now you can understand how air is cooled and dehumidified by the refrigeration cycle. While we have covered only the fundamentals, they form the basis for every kind of system, from automobile air conditioners through the largest commercial systems.

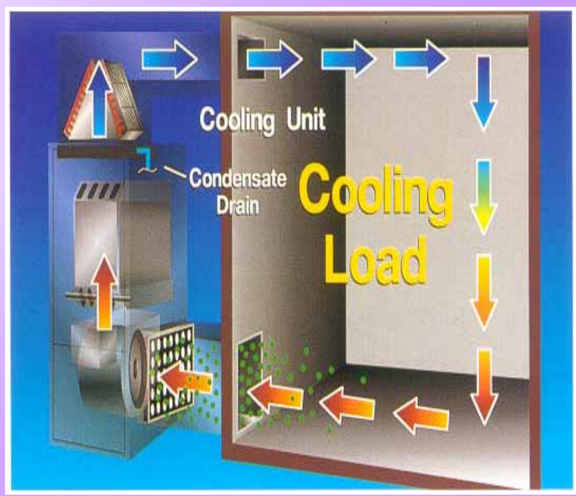


liquid, and the metering device reducing the pressure to convert the hot liquid into a cold liquid entering the evaporator.

Cooling Cycle

Now you can understand how air is cooled and dehumidified by the refrigeration cycle.

While we have covered only the fundamentals, they form the basis for every kind of system, from automobile air conditioners through the largest commercial systems.



Capacity

Before leaving the refrigeration cycle, there are three air conditioning terms you should understand. They are used as a measurement of capacity or equipment efficiency. First, the BTU.

A BTU, or British Thermal Unit, is "a quantity of beat" used to measure cooling or heating capacity. One BTU is the amount of heat needed to raise the temperature of one pound of water one degree Fahrenheit. In manufacturers' catalogs, smaller units like room air conditioners, condensing units or furnaces are usually rated in BTU's per hour. The larger the BTU rating, the more capacity a particular model has and the more cooling or heating it can provide. For instance, a 7500 BTU room air conditioner has 50% more capacity than one listed at 5000 BTU's per hour.

Capacity

1kW = 3412 BTU's

kW	Approx BTU’s
2.6	9,000
3.5	12,000
4.7	16,000
6.5	22,000
7.1	24,000

Capacity

The second term is the TON of refrigeration. Larger units are usually rated in tons. The term "TON" comes from the days when ice was the main method for providing cooling capacity. One TON = 3.5 kW.

A TON of cooling capacity is equivalent to the amount of heat required to melt one ton of ice at 0^{o} C (32' F) in a 24-hour period. One ton of refrigeration is equal to 12,000 BTU's per hour. A ten-ton rooftop unit has a cooling capacity of 120,000 BTU's per hour (35 kW) .

EER & COP (Efficiency)

BTU's, TONS and kW are ratings of capacity. The third term that you will often hear is EER, Energy Efficiency Ratio, or COP, Coefficient of Performance. Both EER and COP are measures of how efficiently the air conditioning unit performs. EER is usually applied to the cooling efficiency, and COP to the heating efficiency. Lower efficiency units cost more to operate, because they use more energy to provide equivalent cooling.

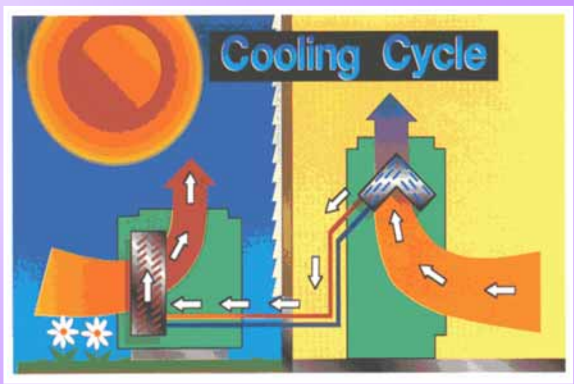
$$EER = \frac{BTU/HR\ OUTPUT}{kW\ INPUT}$$

$$COP = \frac{kW\ OUTPUT}{kW\ INPUT}$$

Heat Pump

During the cooling season, the heat pump operates as an air conditioner. Its operating cycle is essentially the same as that previously described- heat from warm room air is transferred to the cold refrigerant in the indoor coil.

It is then pumped to the outdoor coil where it is rejected from the refrigerant to the outdoor air.



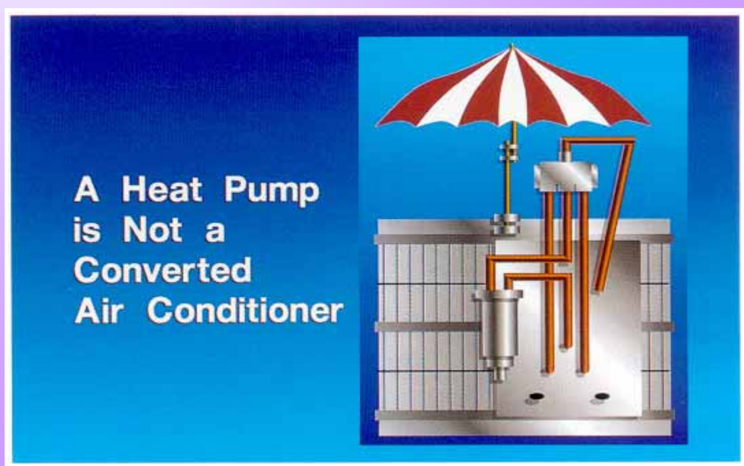
Heat Pump

During the heating season, heat is moved from the outdoor air, through the same refrigerant system, to the indoor air.

Therefore, it shouldn't be surprising that there are some equipment differences that distinguish a heat pump from a cooling only air conditioner.

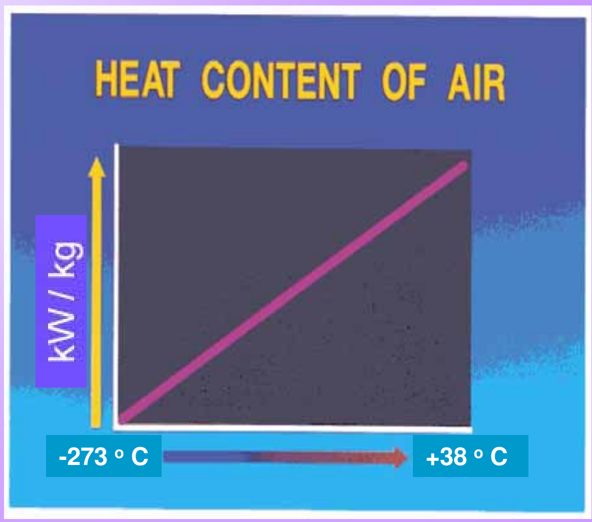
Heat Pump

However, it's not just a matter of adding a few different parts to an air conditioner. All of the basic components - coils, compressor, and metering devices, must be specially designed for double duty.



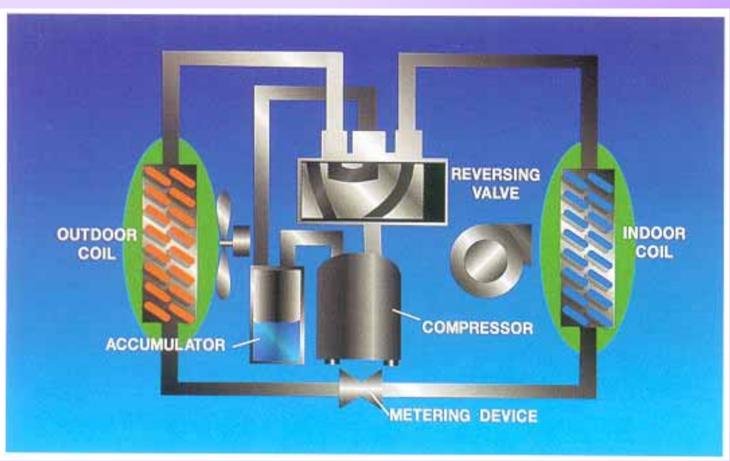
Heat Pump

The big operational difference is in the heating cycle. It's based on the fact that there is some heat in the air at any temperature above Absolute Zero, which is –273° C; and that it's possible to extract that heat from the outdoor air and use it to heat an indoor area. .

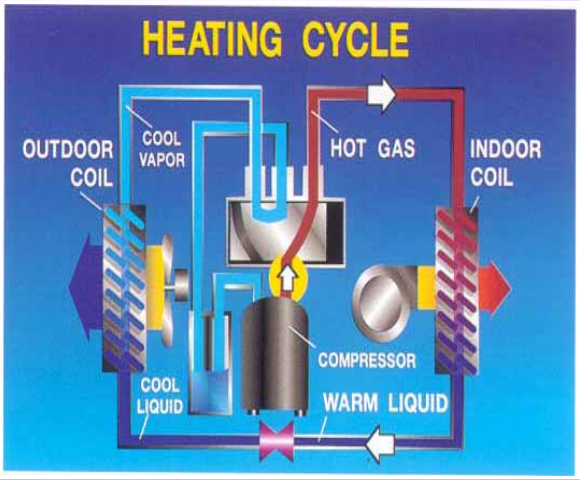


Reversing Valve

In the heating mode, the refrigerant cooling cycle previously described is reversed by a component unique to the heat pump, the "reversing valve." But the operating cycle is essentially the same.



Reversing Valve



When heating is required, the reversing valve routes the hot gas discharge from the compressor to the indoor coil which now acts as a condenser. The heat given off by the refrigerant as it condenses is transferred to the relatively cooler indoor space.

This is known as reverse cycle heating, because the cooling cycle is reversed, with the evaporator becoming a condenser and the condenser acting as an evaporator.

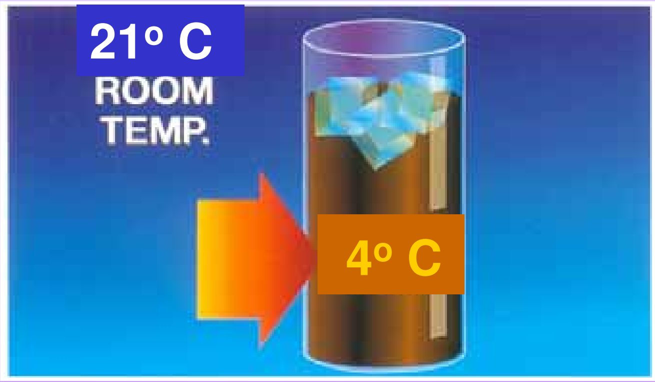
Heat Transfer

The heat pump demonstrates the principle that heat will always flow from a warmer surface or area to a cooler surface or area.

For instance, a cup of hot coffee at 66º C when set down in a 21º C kitchen will start to cool. Heat will flow from the warm cup to the cooler air around it.

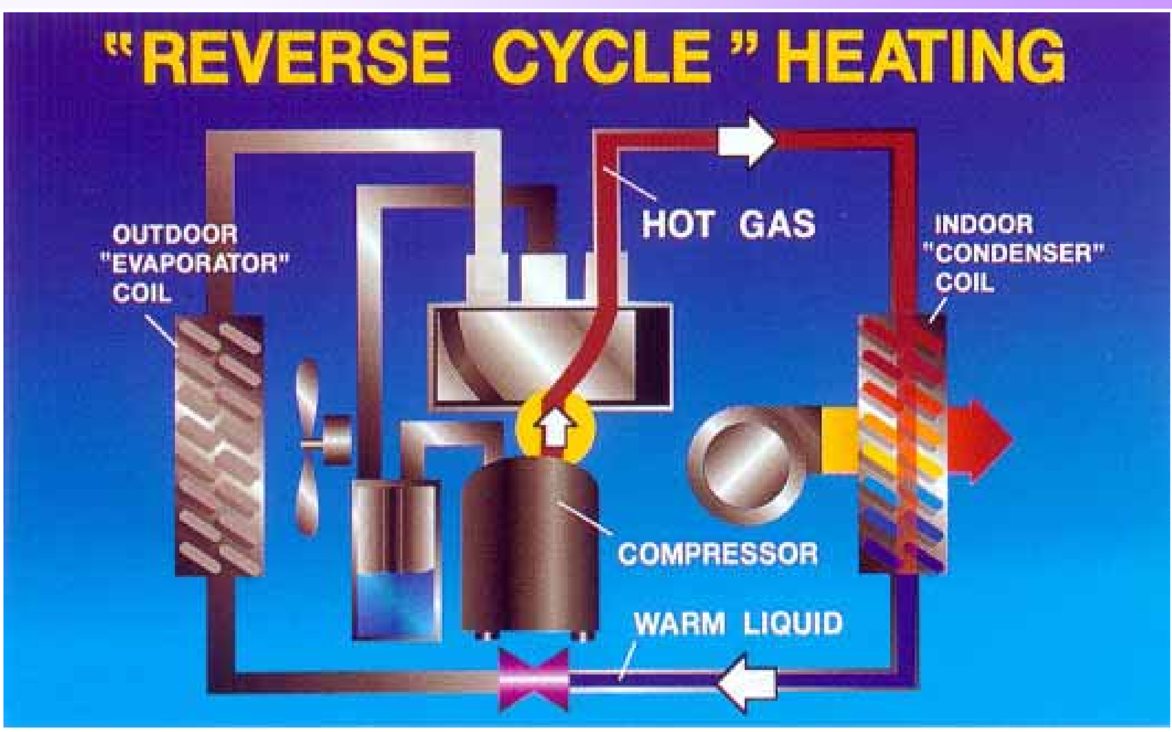
Heat Transfer

If you started with a glass of iced coffee at 4º C, then heat would flow from the 21º C kitchen toward the cooler glass. If you took the glass of iced coffee outside on a -7º C day, then heat would flow from the cool glass to the cold outdoor air.



As long as the two temperatures are different, heat will always flow from the warmer to the cooler one.

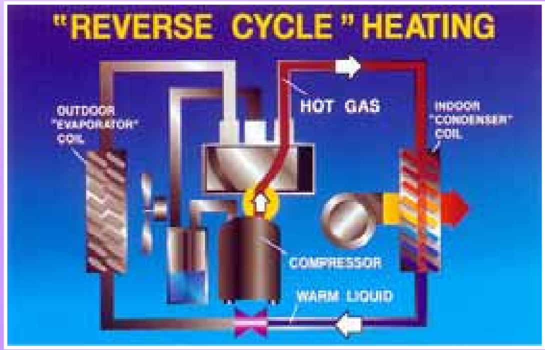
Heat Pump



Heat Pump

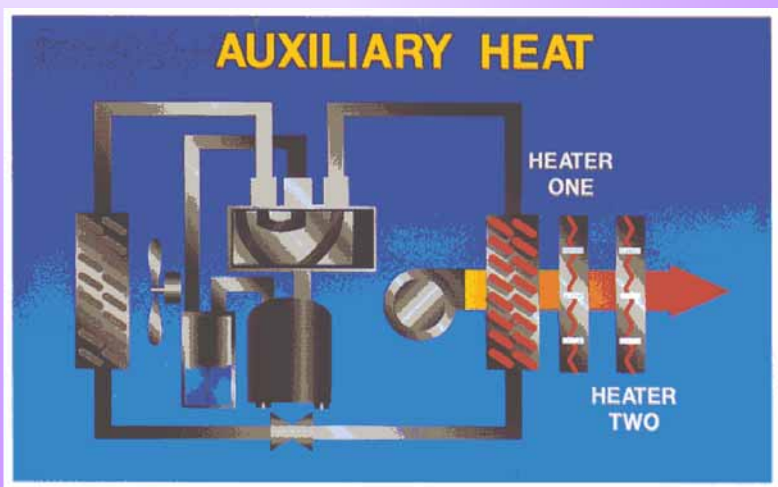
It's the same way with heat pumps. As long as the refrigerant in the outdoor coil is cooler than the outdoor air, heat will flow from the air into the refrigerant as it evaporates. After picking up heat from the outdoor air, the refrigerant is compressed to a higher pressure and higher temperature by the compressor.

The heat is then transferred from the indoor coil to the room air, keeping the occupants warm and comfortable.



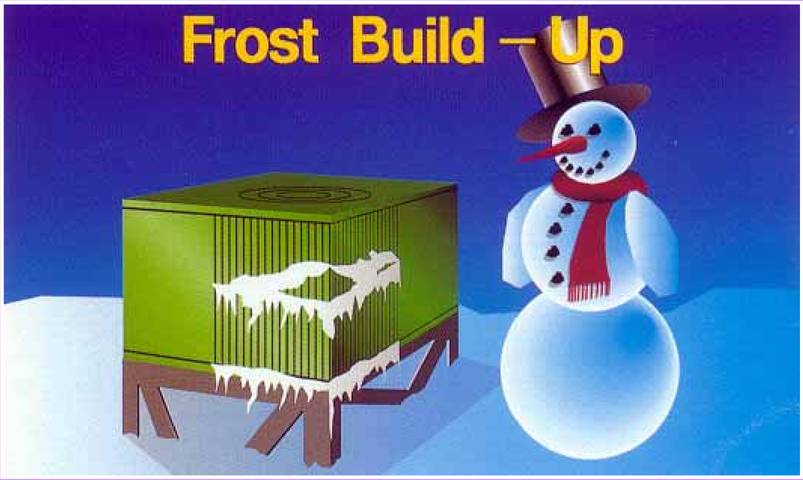
Auxiliary (Booster) Heaters

When used in cold climates, heat pimps are equipped with auxiliary (booster) electric heaters for added heat on very cold days, and to provide heat if required during the defrost mode.



Frost

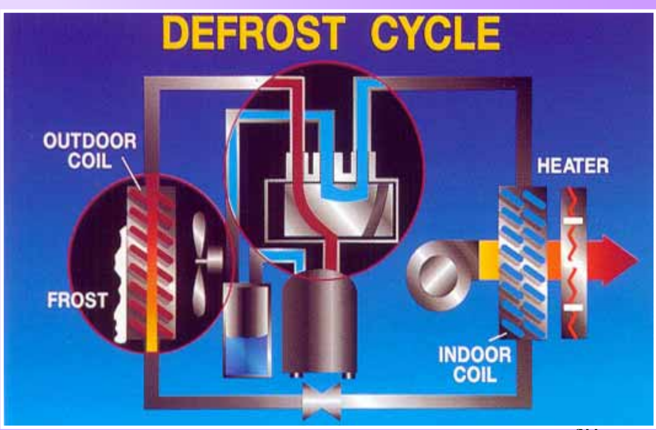
Because the outdoor coil is colder than the out- door air, moisture will condense on the outdoor coil and then freeze. The ice build-up can reduce heating capacity.



Defrost Cycle

While in heating, a heat pump will, therefore, have a defrost mode. In defrost, the reversing valve enables the unit to go into the cooling mode for a short time. Hot compressor discharge gas is directed through the outdoor coil for 10 minutes or so. During this period, the unit is not providing reverse cycle heat.

Auxiliary electric heaters are used at this time to maintain comfort. In many systems, they will automatically cycle on during the defrost mode.



Defrost Cycle

Heat pumps are truly units for all seasons. Properly installed and maintained, they provide reliable and economical heat in most climates.