Demystifying HVAC

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A Layman's Guide to How an HVAC System Works

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Basic Concepts:

In order to understand how a commercial HVAC system operates, one needs to understand a few basic physics concepts which will be explained here.

I. **In order to raise the temperature of something; we must add energy in the form of heat.**

II. **Heat must travel from a high temperature body to a lower temperature body.** Think of what occurs when you wrap your hand around a cold water bottle.

III. **There is no such thing as cooling.** We don't cool a substance. We can allow heat to transfer from a warm substance to a cooler substance as described above. **We can also force the transfer of heat from a cooler substance to a warmer substance with the addition of some mechanical energy**. For our purposes, <u>this defines the mechanical cooling process that conditions the air in the majority of our homes and commercial buildings.</u> It is actually the process of transferring heat from one substance to another, at conditions that are maintained by the addition of energy, which cools the air in these spaces.
This concept can sound a little nebulous, but it will make sense later on.

IV. **Huge quantities of heat transfer** are required to **change the state of a substance (solid, liquid, vapor)**, as compared with the quantity of heat transfer required to change the temperature of the same substance. It takes one BTU (sounds like HVAC now doesn't it?) to raise the temperature of one pound of water one degree Fahrenheit. (As a matter of fact, that happens to be the definition of a BTU.) It takes 760 BTU'S to evaporate, or boil off one pound of water. The change of state requires that 760 times as much energy be added as would be required to change the temperature of the same quantity of liquid one-degree Fahrenheit.

Air Conditioner Operation:

Now that we have gone over the basic physics concepts, let's apply those concepts to air conditioning. Most buildings are served by rooftop units, split systems, or chilled water systems. Each of these systems draws air from the conditioned space utilizing a device known as a "blower". A blower is simply a fan that has the ability to move air from one place to another against some sort of resistance. Air from the conditioned space enters a grille (called a "return air grille") and is drawn by the blower into a cabinet, which encloses the components of the air conditioner. This "return air" is usually mixed with "outdoor air" as it enters the cabinet.

Outdoor air is introduced to provide oxygen for respiration of occupants and to dilute any contaminants in the air within the conditioned space. If the equipment only circulated, the same air between the air conditioning unit and the conditioned space, theoretically, the occupants would eventually replace all the oxygen in the air with carbon dioxide by simply breathing.

So, the equipment is designed to mix sufficient quantities of outdoor air with the air we have returned from the space, to obtain oxygen levels required to maintain life, and to dilute odors and pollutants. Some sophisticated systems actually measure the carbon dioxide levels within the conditioned space and vary the quantity of outdoor air introduced based on the CO_2 levels measured. This strategy is called "Demand Controlled Ventilation."

As air enters the unit cabinet it passes through a porous media known as an "air filter". The filter strains out a percentage of the solid particles that are contained within the air stream. The purpose of the air filter is to prevent these particles from building up on the components within the system and to prevent them from being spewed back into the conditioned space. The majority of the particles are coming from the conditioned space. People are always blaming the air conditioner for making the ceilings dirty when it is actually particulate matter from the space which is making the air conditioner dirty.

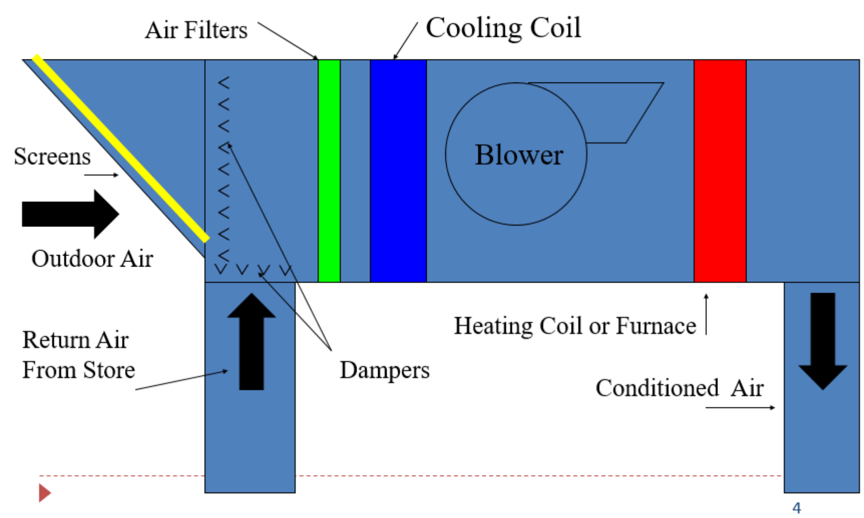
Heating:

If the temperature in the conditioned space is below the desired temperature (known as the "set-point") a device called a "thermostat" tells the air conditioning unit to add heat to the mixture of return air and outdoor air. The thermostat is nothing more than a temperature sensitive element that turns on the heat when it's too cold and turns on the cooling when it's too hot. "Setback thermostats" have the ability to use different set points at different times of the day or night. In a commercial building, these set points are selected for occupied and unoccupied periods.

"Energy Management Systems (EMS)," perform the same functions as setback thermostats, as well as other functions, using electronic temperature sensors and allow operators to monitor system operation and make adjustments remotely.

So, if the thermostat determines that the space needs to be warmed, the air conditioning unit adds heat to the air being circulated by the blower. When hot water or steam is used for heating, these substances flow through pipes embedded in plates or fins. The combination of pipes and fins is called a "finned coil". The blower draws or blows air over the fins, and the hot water or steam flows through the pipes. In this manner, heat is transferred from the liquid or vapor to the air without the two ever coming in direct contact with one another. We could just run the hot water or steam through the pipes, and blow air over the exterior of the pipes, but the addition of fins produces what's known as an extended surface, which allows for much more efficient heat transfer. This is another way of saying that the addition of fins allows us to transfer more heat in a smaller area. In this type of heating system, the thermostat usually controls a valve that allows or interrupts the flow of the vapor or liquid into the finned coil. Typically, we find this type of heating on split systems and chilled water systems where an "air handler" containing heating and cooling coils, as well as the blower, is located within the conditioned space. Sometimes, hydronic “hot water heating” systems are actually filled with a mixture of glycol, commonly known as antifreeze, and water, in lieu of being filled with water alone. This is done to prevent freezing of coils and piping and the damage that can occur.

In some systems, rather than operating a valve, the thermostat's call for heat will close a large electromagnetic switch called a “contactor”. The contactor then allows power to flow to an electric heating element. This coiled Nichrome wire is nothing more than an overgrown toaster element that adds heat to the air the blower forces over it.



Most rooftop units serving commercial buildings in this country provide heat by burning natural gas or propane. Typically, a mixture of natural gas and air are ignited and drawn into a tubular assembly called a “heat exchanger” by small fan called a “draft inducer”. If we think of the pipes within the heating coil described earlier, we eliminate the fins, and we allow those pipes to grow till they're about 2" in diameter, we have what is known as a heat exchanger. Combustion of the fuel /air mixture occurs within the heat exchanger and the draft inducer exhausts the products of combustion, which are normally Carbon Dioxide and water vapor. The blower pushes or pulls air over the outside of the pipes that form the heat exchanger, and the temperature of the air is raised.

Natural gas is actually mixed with air in a device called a “burner” which injects the burning mixture into the heat exchanger. Gas flow to the burner(s) is controlled by an electrically operated “gas valve”. An “igniter” produces a spark or a ceramic device is heated to light the flame of the pilot burner. The “control module” makes certain that gas flow to the "pilot" is interrupted if the pilot flame goes out. In addition, the "control module" makes certain that main burner gas only flows when a pilot flame is present to ignite the gas leaving the main burners. A "high limit switch", breaks power to the gas valve if the heat exchanger gets too hot, and a "rollout switch," breaks power to the gas valve if the burning gases are not fully pulled into the heat exchanger.

Natural gas furnaces like the one described above are either built into "packaged rooftop" "units", added to air handlers as stand alone devices called "duct furnaces", or combined with fans and called "unit heaters".

Sometimes, commercial buildings are heated with equipment called "heat pumps." These are not to be confused with "centrifugal pumps" or "circulators" used to circulate hot water in systems that use a boiler. Heat pumps are also called "reverse cycle air conditioners", because they transfer heat from the outdoors to the conditioned space, even though the outdoor temperature may be lower than the indoor temperature. These systems are best understood when discussing the cooling cycle and will be addressed in the next section. Let it suffice to say that if we turned a window air conditioner end for end, it would blow warm air into the conditioned space and discharge cold air to the outdoors. Actually, "heat pump" is the perfect description of what any air conditioner is as it pumps heat from one area to another, but more on that later.

Cooling With Economizer Cycle:

If the thermostat determines that the temperature within the building is too high, it will signal the HVAC unit to provide "cooling". If outdoor air temperatures are below 60° Fahrenheit, outdoor humidity levels are low, and the unit has the capability; a set of "dampers" will open and another set will close allowing up to 100% outdoor air to be brought into the conditioned space, and allowing the return air to be exhausted. The blower is now taking air from outside and bringing it into the building, which forces the warm return air from the conditioned space to be "exhausted". The controls and dampers that enable this process of free cooling with outdoor air are called an "outside air economizer." The effect is the same as opening the top and bottom of a double hung window, but with better control and distribution.

If the outdoor air temperature or humidity levels are too high to allow sufficient cooling with economizer operation, the thermostat's call for cooling will result in a call for another process that will reduce the temperature of the air being circulated by the blower. (mechanical cooling, or cooling with chilled water)

Cooling with Chilled Water:

If the system uses a "chilled water air handler", the thermostat will cause a valve to open, allowing water at a temperature of approximately 45°F to enter an extended surface finned coil similar to the heating coil described earlier. As air passes over the coil, heat is removed from the air and is transferred to the chilled water being circulated through the pipes. The concepts discussed at the beginning of this article now come into play in a small way. **We are not cooling the air; we are transferring heat from the air to the chilled water.** In addition, only about 60% to 80% (depending on the application) of the heat being transferred results in a change in temperature of the air passing over the coil. The balance of the heat being transferred from the air is used to condense water vapor from the air as its temperature falls below the dewpoint. The concept that described the large quantity of heat transfer associated with a change in state now comes into play. If we must add 760 BTU per pound to change water from a liquid to a vapor, then we must remove 760 BTU per pound to change water vapor back into a liquid. Thus, depending on the water vapor content of the air passing over the cooling coil, a greater or lesser quantity of heat must be transferred to bring the air down to a temperature where it will be suitable for lowering the temperature of the site. This is due to the fact that the temperature of the air cannot be brought down below the dewpoint, so moisture must be removed from the air to lower the dewpoint. The portion of the heat transferred which results in a change in temperature of the air is known as sensible heat, and the portion which results in reducing the water vapor content of the air is called "latent heat". The process of reducing the water vapor content of the air is defined as "dehumidification".

A "chilled water system" is usually designed with a flow rate that allows the temperature of the chilled water to rise 10°F to 15°F as it flows through the coil. The airside is usually designed for a discharge air temperature between 50ºF and 55ºF. On a chilled water system, if your supply air temperature is above 58°F, it usually means that the unit is not receiving sufficient chilled water flow.

Mechanical Cooling:

As stated earlier the majority of low rise commercial buildings today are served by rooftop units or split systems. They employ a process known as a "vapor compression cycle," to move heat from the air within the conditioned space to the outdoors. This process is also known as "direct expansion" (DX) cooling for reasons that are beyond the scope of this article. Another name commonly used for this process is "mechanical cooling." This same process is used in household refrigerators to move heat from within the box to the air in your kitchen.

The key to the operation of a vapor compression cycle is the fact that there is a large quantity of heat associated with the change in state of a substance. Specifically, when a substance boils, or "evaporates" (turns from a liquid into a vapor), it absorbs large quantities of heat from its surroundings; and when a substance "condenses" (turns from a vapor into a liquid) it gives up large quantities of heat to its surroundings.

In a vapor compression cycle, a substance known as a refrigerant is boiled off in a component called an "evaporator." The evaporator is an extended surface finned coil similar to the chilled water coil described above. Liquid refrigerant enters the tubes or pipes of the evaporator and air from the conditioned space is passed over the exterior of the tubes. Heat is transferred from the air through the fins and tubes to the refrigerant. As the refrigerant absorbs heat, it begins to evaporate or boil hence the term evaporator coil. Makes sense that the evaporation takes place in the evaporator doesn't it?

Water As A Refrigerant:

It is difficult to envision a cooling process that uses a boiling liquid to "cool a space," however let's say we are visiting an imaginary planet where temperatures of 300°F were considered comfortable, On that planet, we could easily use water as our refrigerant. We could pass room air at a temperature of 300°F over our evaporator, and allow water to evaporate within the tubes at a temperature of 212°F, as long as the pressure in the tubes was kept at atmospheric pressure. Each pound of water that evaporated would absorb 760 BTU's of heat from the air passing over the coil. We would have no problem making this system drop the temperature of our 300°F room air to 260°F. On a planet where 300°F is considered comfortable, 260°F would indeed be considered cool.

As our "refrigerant" (water in this case) evaporated, we would have to replace the vaporized water with more liquid water so that the heat removal process could continue. We would probably do this by pumping the water vapor out of our evaporator to make room for more liquid. Because we're pumping a vapor, and not a liquid, we call this pump a "compressor." Sounds like HVAC again, doesn't it? Since water would probably be hard to come by on a 300°F planet, it would probably be beneficial to use the same water (refrigerant) over and over again. The problem is, we have water vapor at a temperature of approximately 280°F and we need to remove enough heat from this vapor to condense it back into a liquid.

If we can go back to physics one more time, the temperature at which a liquid boils increases with pressure. An open pot of water at sea level boils at 212°F. If we seal the pot we create a "pressure cooker" and we raise the boiling point as we raise the pressure. The "boiling point" is the same as the point at which "vapor condenses". On our 300°F planet, we would like to transfer large quantities of heat from our water vapor. We know that heat will only flow from a warm body to a cooler body, and the body we have to absorb this heat is the 320°F outdoor air on our 300°F planet. If we raise the pressure of the water vapor to obtain a boiling point of 340°F, we can easily transfer heat to the outdoor air with the use of another finned coil called a "condenser coil". In the condenser, our refrigerant (water) gives up heat to the outdoor air and condenses back into a liquid. Once again, it makes sense that the refrigerant condenses in the condenser.

In order to make the heat transfer process between the finned condenser coil and the outdoor air more efficient, we add a fan to blow the outdoor air over the condenser coil that is known as a "condenser fan". The liquid exiting the condenser is now at a high pressure because we had to raise the condensing temperature high enough to be able to reject heat to the outdoor air.

If we allowed this high pressure liquid into the evaporator, it would transfer heat to the coil rather than removing heat by boiling off. However, if we add a valve or "metering device", in the pipe that leads from the condenser to the evaporator, we can adjust the rate of liquid flow to the evaporator. This will maintain the refrigerant in the evaporator at a pressure low enough to ensure that it vaporizes at a temperature low enough to remove heat from the evaporator coil.

Now let's come back to planet Earth, where we maintain a comfortable indoor temperature of 70°F using a different refrigerant that goes through the same cycle as described above.

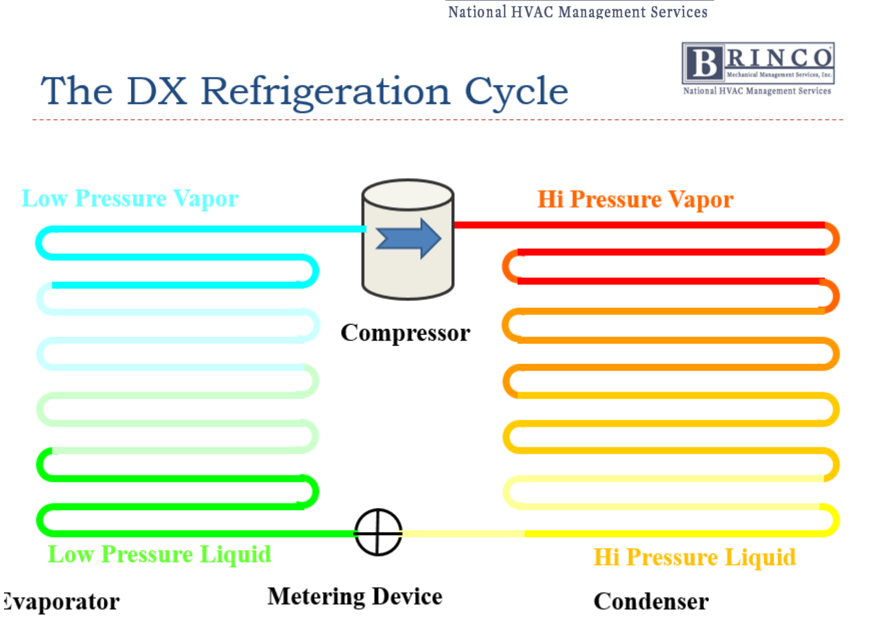
The R410A Vapor Compression Cycle:

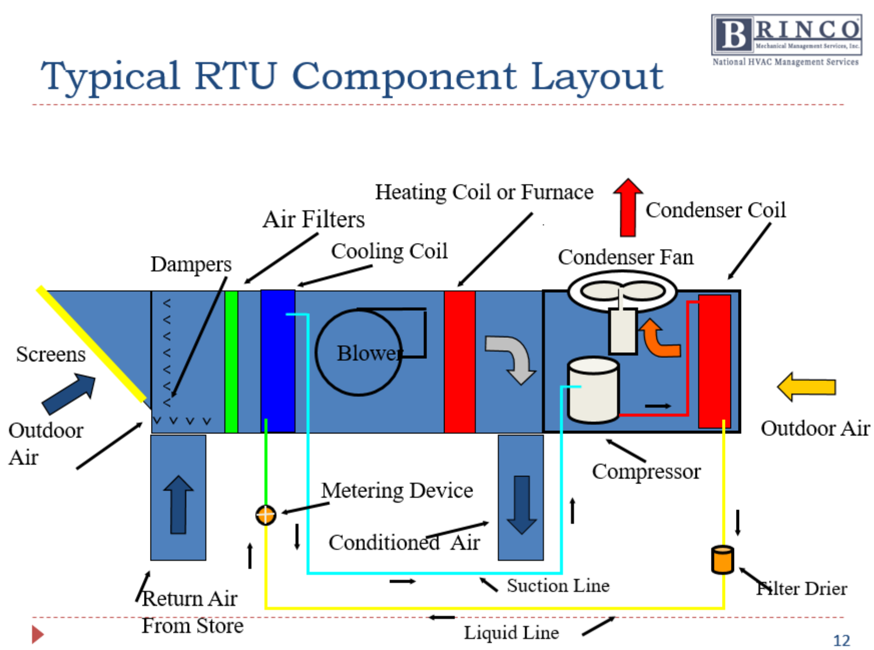
Vapor compression cycles in our world where 70°F is considered comfortable, operate exactly the same as the system described above. The only difference is that they use a refrigerant that evaporates and condenses at lower temperatures than water.

In a typical air conditioning system, the refrigerant (Freon) is vaporized in the evaporator at a temperature between 35°F and 40°F. Most commercial packaged systems today use refrigerant R410A, which evaporates at this temperature at a pressure between 107 PSI (pounds per square inch) and 118 PSI. This allows the coil surface to operate at a temperature between 40°F and 50F°. This temperature is low enough to remove water vapor from (dehumidify) the air passing over the coil as well as lowering the temperature of the air.

In our 70°F world, we need the ability to transfer the heat removed from the air in the conditioned space air to the outdoor air, which may reach temperatures of 110°F. Therefore, the system is designed to operate with a "high side pressure" between 315 PSI and 500 PSIA. This allows the refrigerant to reject heat to the high temperature outdoor air and condense from a vapor into a liquid at a temperature of approximately 125°F.

Once again, a metering device is utilized to maintain the desired pressure difference and control the flow of refrigerant between the high and low sides of the system. (Condenser and Evaporator) This metering device can be an "expansion valve", a "capillary tube", or an "orifice".





"Heat pumps", were mentioned earlier as "reverse cycle air conditioners". If one installed an arrangement of valves that allowed the refrigerant flow to be redirected so that the evaporator became the condenser and vice versa, our air conditioner would remove heat from the outdoors and transfer it to the indoor air. This is exactly how a heat pump operates.

The above constitutes a basic overview of the operation of an HVAC system. All other components are auxiliary and are used to control the operation of the systems within safe limits and maintain system cleanliness.

The operation of the system is simply an application of basic physics and thermodynamics. Using this knowledge, the facility manager can begin to appreciate how the operation and failure of each component affects the other components within the system and the operation of the overall system. The need for devices such as low ambient accessories, which control the pressure within the condenser when outdoor temperatures drop can only be understood when one understands the theory behind the vapor compression cycle. The causes of compressor failure are easily explained when one understands the pressures and temperatures associated with a normally operating system. Any malfunction or lack of maintenance, which causes these pressures and temperatures to vary from the norm, can cause damage to a compressor.