Demystifying HVAC

By Ron Prager

A Layman's Guide to How an HVAC System Works

The basic concepts:

In order to understand how a commercial HVAC system works, we need to remember a few basic concepts that you probably learned way back in high school physics. The first concept is that in order to raise the temperature of something; we must add energy in the form of heat. Easy so far, right?

The second concept is that heat must travel from a high temperature body to a lower temperature body. Sort of what happens when your wife decides to place her cold feet on some warm part of your anatomy. Still makes sense yes?

The next concept is a little more difficult, There is no such thing as cooling. We don’t cool a body. We can allow heat to transfer from a warm body to a cooler body as described above. We can also force the transfer of heat from a cooler body to a warmer body with the addition of some mechanical energy. For our purposes, <u>this is the mechanical cooling process that conditions the air in the majority of your stores.</u> It is actually the process of transferring heat from one substance to another, at conditions that are maintained by the addition of energy, that cools the air. This concept is a little nebulous, but it will make sense later on.

The last concept, important to this discussion, is the fact that 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 that760 times as much energy be added as would be required to change the temperature of the liquid one-degree.

Air Conditioner Operation:

Now lets get to your air conditioner. Most retail stores are served by rooftop units, split systems, or chilled water systems. Each of these systems draws air from your store with 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 your store 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 some quantity of outdoor air as it enters the cabinet. This is due to the fact that people require oxygen to breathe. If we just kept recirculating the same air between the air conditioning unit and your store, the customers would use up all of the oxygen in the air and would no longer be able to spend their money. So, we add enough outdoor air to the air we've taken out of the store to maintain oxygen levels required to maintain life, and to dilute odors and pollutants. As the 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 being circulated. The purpose of the air filter is to prevent these particles from building up on components within the system and to prevent them from being spewed back into your store. (Which, by the way, is where the majority of the particles came from to begin with) People are always blaming the air conditioner for making the ceilings dirty when it's actually particulate matter from the store, which is making the air conditioner dirty. However, we'll save that one for another article.

Heating:
If the temperature in the store 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. This 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. Usually, in a retail store there are occupied set points and unoccupied set points.

So, if the thermostat determines that the store needs to be warmed, the air conditioning unit <u>adds heat</u> 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 liquid or vapor 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 vapor or liquid 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 store. Usually, this air handler is hung above the ceiling of the space.

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 retail stores in this country are heated with natural gas. 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 in diameter till they're about 2" in diameter, we have what is known as a heat exchanger. The fuel burns within the heat exchanger and the draft inducer exhausts the products of combustion, which are normally Carbon Dioxide and water vapor. Our old friend 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. The balance of the components of the gas heating system include the gas valve which controls the flow of gas to the burners. The burners are where the air and fuel are mixed together before they are ignited. The igniter produces a spark 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, and when the temperature of the heat exchanger is below a safe limit.

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.

There is one more system used to provide heat to a retail space. This system is known as a heat pump or as reverse cycle air conditioning. It is best understood when discussing the cooling cycle and so we'll deal with it in the next section. Let it suffice to say that if we turned an air conditioning system end for end, we could use it to heat our store. Actually, "heat pump" is the perfect description of what an air conditioner is, and how it works, but more on that later.

Cooling With Economizer:
If the thermostat determines that the temperature within the store is too high, it will signal the HVAC unit to provide "cooling." If outdoor air temperatures are below 55° Fahrenheit, 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 store and allowing the return air to be exhausted. Our old friend the blower is now taking air from outside and bringing it into the store which forces the warm return air from the store to be exhausted. The controls and dampers that enable this process of free cooling with outdoor air are called an "outside air economizer."

If the outdoor air temperature is such that economizer operation is not possible, 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.

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 we 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% (depending on the application) of the heat being transferred results in a change in temperature of the air passing over the coil. The other 40% 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 store. 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. (Just in case you want to impress someone.)
The chilled water system is usually designed with a flow rate that allows the temperature of the chilled water to rise 10ºF with the heat it has removed from 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:
The vast majority of retail stores are served by rooftop units or split systems that employ a process known as a vapor compression cycle to move heat from the store air to the outdoors. This process is also known as DX (Direct Expansion) cooling for reasons that are beyond the scope of this article. Another name commonly used for this process is mechanical cooling.

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 return air from the store is blown over the exterior of the tubes. Heat is transferred from the air through the fins and pipes 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:
If we lived in a world where 300ºF were considered comfortable, (like Dallas over the past two summers) we could use water as our refrigerant. We could pass room air at a temperature of 300ºF over our evaporator, and allow water to evaporate within the tubes at a temperature of 212ºF, 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 300ºF-room air to 260ºF. In a world where 300ºF is considered comfortable, 260ºF 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 <u>compressor.</u> Sounds like HVAC again, doesn't it? Since water would probably be hard to come by in a 300ºF world, 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 280ºF and we need to remove enough heat from this vapor to condense it back into a liquid.

If we go back to high school physics one more time, I'll bet that you learned that the temperature at which a liquid boils increases with pressure. Remember that an open pot of water at sea level boils at 212ºF. 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. In our 300ºF world, 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 320ºF outdoor air in our 300º world. If we raise the pressure of the water vapor to obtain a boiling point of 340ºF, we can easily transfer heat to the outdoor air with the use of another finned coil called a condenser. 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.

The R22 Vapor Compression Cycle:
Vapor compression cycles in our world where 70ºF 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 35ºF and 40ºF. Most commercial packaged systems use refrigerant R22, which evaporates at this temperature at a pressure between 60 PSIA and 70 PSIA. This allows the coil to operate at a temperature between 40ºF and 50Fº. 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 store 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 200 PSIA and 350 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 a restrictor.

The above constitutes a complete description 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 systems 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.

In a future article, we’ll explore typical HVAC malfunctions, their causes, and their effect on different components within the system. The information in that article, as well as the HVAC repair work that facility managers approve on a daily basis, will be explained using the preceding information as a foundation.