Building Services III
Lecture 3

Air Cycle

Before Air Cycle, we have Condensate cycle. The Condensate cycle is nothing but similar to the vapour compression cycle. It is nothing special. Hence, we shall skip to the Air cycle. In the air cycle, the refrigeration systems use air as their refrigerant. In the previous lecture we saw, the refrigerant uses the air medium to cool the condition in space. Here in the air cycle, the air is used as a medium. Here, the air is compressed and expanded to create heating in cooling capacity. These were used on board ships and by food producers and retailers to provide cooling for their food stores in the past. Air is compressed and then heat is removed, this air is then expanded to a lower temperature than before it was compressed. Work is taken out of the air by an expansion turbine, which removes energy as the blades that are driven round by the expanding air. Basically, air does the function of the refrigerant here, in the air cycle.

Next is the chilled water and the cooling water cycle. Here, this chilled water plays two roles. One is, it helps in cooling the different spaces. It gets cooled in the first place. Water is chilled or cooled in the chiller where the refrigerant is used as a medium to absorb thereby cooling the water. This cooling cool water is circulated in tubes and piping into various spaces, thereby cooling the different spaces. The second part is water is used to cool the condenser. In the previous lecture we talked about water cooled condensers,the cooling tower etc, where water absorbs the heat rejected by the condenser, then it goes to the cooling tower, it gets cooled, comes back and the cycle repeats.

Let us look into detail, how this water as a cooling medium, water as a cooling condenser works. At first, we shall look at the Chilled Water Cycle. The chiller centralizes three heat exchanging cycles - the refrigeration cycle, the chilled water process and the cooling water process. The chiller creates chilled water in a centralized building location that can be distributed for water usage and air conditioning purposes. The chiller is an all-in-one system that operates under the vapour compression cycle, using refrigerants as the working fluid. What happens in the Chilled water cycle? The chilled water loop transports through the distribution network to supply the air handlers or air handling units in other words with cooling for air conditioning. This water first enters a chiller evaporator where the low pressure refrigerant is sprayed evenly over the surfaces of the tubes that contain the chilled water. The heat transfer process transfers the energy from the water to the refrigerant as the water passes through the evaporator. So basically there is warm water that is going through the tubes or pipes. When the refrigerant is sprayed on top of it, the refrigerant absorbs the heat from the water, thereby cooling the water and then this cold water is transported to different aries. After the water has travelled the length of the evaporator, the resulting chilled water is sent to designated destinations. The chilled water is distributed throughout the building via a piping network leading to each tenant space.

The chilled water piping is heavily insulated. When you transfer chilled water, the condensation happens, when there is contact with the external air, when there is a temperature difference between the external and internal and there is also a possibility of this condensate water affecting the other systems and leaking. To prevent that and to prevent the external temperature from affecting the chilled water, the insulation is covered with a vapour barrier, which is impervious to moisture. One more more air handlers serve each tenant. An air handler is a sheet metal box that contains a fan and a cooling coil with aluminium fins bonded to the copper tubing to increase the heat transfer area. Most chilled water air handlers contain a section called a mixing box which is a sheet metal section with two openings in it. There is a duct connected to each opening and a damper located with each opening. The duct is basically used to transport this supply air, return air and get air from the space. The damper is to open and close when there is no air supply or there is some issue, like a fire or whatever, the damper closes so that the air supply cuts off, thereby preventing the fire from spreading through the duct. Damper plays the role of closing and opening and prevents any transfer of fire, fumes or smoke. One duct is used to bring return air from the conditioned space back to the air handler. The second duct is connected to the outdoors and is used to introduce outdoor air for ventilation purposes. Naturally, there is a circulation happening here. The air from the conditioning space is taken into the air handling unit, there is also supply of fresh air from outdoors, these two are mixed and then sent into the conditioned space. The fan runs continuously, drawing a mix of outdoor air and return air through the air filters. The air is then cooled as it passes over cold coils. As we saw earlier, the water that runs through the tubes, is cooled by the refrigerant that is sprayed on top. This cooled water cools the air which comes in contact with the coils. Chilled water flow to the cooling coil is controlled by a motorized valve. There is valve which controls the flow, whenever there is a requirement for cooling, this valve controls the flow of water required to the space. If the space temperature is at or below the setpoint of the thermostat, the motorized valve closes. Basically, there will have a thermostat which will sense or measure the temperature of the space that is to be air conditioned and the occupants can set the thermostat to whichever temperature they want. Based on this thermostat set point, if the temperature is higher inside the space, the cooled water is sent to cool the space. When it reaches the required temperature, the motorized valve shuts off the water supply. If the thermostat is not satisfied, the motorized valve opens causing chilled water to flow through the coil. This is the picture of an air handling unit. It is a sheet metal box with coils and a fan, this is the air handling unit.

This is a simple layout of the air handling unit. This is the conditioned space, there is a space to keep to the air handling unit. You might have seen in buildings, in office complexes and shopping malls, there is a space called AH Unit that houses this sheet metal box. There is a connection between the conditioned space and the AHU room. One, there is a duct that goes from the air handling unit, which is the supply air to the conditioned space. Then, there is a return air duct, usually these happen above the false ceiling since most of us might have not seen it. This is the supply air duct to the conditioned space and then there is a return air duct from the conditioned space, an input for some outside air, some fresh air. Basically, this is because, if you keep recycling the same air, it becomes stale and there is a possibility of causing some air borne diseases, reducing the indoor air quality, to compensate for all of those things, you give a supply of outside air that is fresh air.

Let us look at the components of the air handling unit in the following slides. The important components are fans, ducts and dampers. These are the dampers, the ones added in yellow. The dampers close and open depending on the requirement. This is the duct that takes return air from the spaces. This is the opening or input for the outside air. If there is more air from outside, the return air and after the filtration and all those things, there is relief air that goes out. After the outside air and the return air mixes, then they are supplied back to the spaces, cooled here and sent to the spaces. Here, there is an additional component known as the filler like I told earlier, the filter helps filter the airborne dust particles and lastly, we have the heating coil. In cold countries, you need to heat the space and not cool, you can use the same AHU the same process of heating, whereby you just need the heating coil. Instead of the air passing through the cooling coils, it passes through the heating coil here, thereby releasing hot air to the space. Lastly, the one component here is the humidifier, as we know, the air that comes from inside, the return air as well as the outside air, if there isn't enough moisture content, you need to add some humidity to it. Else, it will become very dry. They have another component call the humidifier that supplies air to the spaces. These are the basic components of an air handling unit. This is the chilled water cycle.

Cooling Water Cycle

Next, we will move to the cooling water cycle. Here, the second water-based system uses a constant source of water to condense the refrigerant vapour called condenser water. In the previous case, this chilled water was used to cool the water in the air handling unit and the air conditioning space eventually. But here, the water is used to cool the condenser. We have already seen in the previous lecture that condensers can be air cooled and water cooled types. This cooling water cycle talks about this water cooled condenser type. The building maintains a cooling tower that is used to cool the condenser water and pump to circulate the water. In the vapour compression cycle, when the refrigerant runs through the condenser, heat is rejected from the refrigerant to heat a separate flow of water. The heat that is rejected from the condenser is absorbed by this water and then this heated water is taken to the cooling tower to cool it. The heated water is then sent to the cooling tower to be cooled. The refrigerant remains at the same pressure through the condenser but exits at a lower temperature and then flows through an expansion valve that lower the pressure of the refrigerant causing it to evaporate. We have seen the last process. The next step is, when the refrigerant evaporates, it draws heat from the warmer water in the evaporator, which cools the water. In this particular step, they talk about the chilled water cycle where the refrigerant evaporates by drawing heat from the warm water in the evaporator, thereby cooling the water and thereby cooling the space. The temperature of the cooling water rises in the condenser as a result of the heat transfer from the condensing refrigerant. Once the heated water exits the condenser, it is pumped to the cooling tower and the cycle repeats.

Let us look at the cooling tower, how does it function. In the cooling tower, the cooling tower is sent down to the wet deck. Then, the air is blown through the wet deck to evaporate a portion of the cooling water. The water that is not evaporated continues to flow down into the cold water basin. Makeup water is added to replace the evaporated water and all of the fluid is then sent back to the centralized utility plant for reprocessing. Let us look at a sketch of a cooling tower.

You can now correlate everything you've learnt now. The red color represents hot water. From the condenser, it is taken to the cooling tower, from the top it is sprayed down and there are different plates here like fins, to break the water into small particles and on the sides you have lewers like aluminium louvers or metal louvers. which allow the air to circulate. This induces a draft of air and there is a propeller fan that keeps rotating and removing the moisture from the air. Thereby, evaporation happens. After whatever water is evaporated, the remaining water falls into the sump, it is already cooled by now and then this cooled water is once again sent back to the condenser to cool the condenser. This is how the cooling tower works. The principle based on which the cooling tower works is called the 'Counterflow principle'. The counterflow principle is used in cooling towers. Here, the water falls downwards and the louvers serve to break the water into droplets that are easier to cool. Upward air flow is provided by fans that can be cycled during cold weather to maintain proper water temperature. Cooling towers normally drop the water temperature about ten degrees. This is the image depicting the cooling tower used in large scale buildings.

Next, we will look at the different Refrigerant control devices. There are several different types of refrigerant controls but they all serve to control the amount of liquid refrigerant entering the evaporator. Basically, that is the role they play. They control the amount of refrigerant, liquid refrigerant entering the evaporator, this is their primary purpose. The type of control used in a system depends upon the application. For different applications we use different systems. Shown here are four most popular types.

The first is the Metering device. It is fitted at the Expansion valve. Meters correct the amount of refrigerant to the evaporator. It is installed in the liquid line at the inlet of the evaporator. Common devices are automatic expansion valve, thermostatic expansion valve and fixed bore like the capillary tube. This same expansion valve has a metering device. It is used to maintain a pressure difference between the High Pressure side which is the Condenser side and the Low pressure side which is the Evaporator side.

One of the types of Expansion valves are - Thermostatic Expansion valves. The purpose of the Thermostatic expansion valve is that it maintains a constant evaporator superheat. If the evaporator superheat is high, the valve will open. The Superheat ensures that no liquid refrigerant leaves the evaporator.

Next is a similar device called the Capillary tube metering device. Here, this metering device controls the refrigerant flow by pressure drops across it and the diameter length of the tube determines the flow at a given pressure. Depending on the length of the tube, the pressure is maintained. It does not maintain evaporator pressure or superheat, it doesn't do it and there are no moving parts to wear out.

Lastly, we will look at the Solenoid valve. It is also one of the types of valve which controls the flow of the refrigerant. The Solenoid valve is used to stop the flow of the refrigerant within the system. It controls the flow of refrigerant to multiple sections of evaporator. To prevent the refrigerant from migrating through the system when the compressor is shut off. The Solenoid valve opens up the refrigerant. When the compressor is shut off, when the system is not on, Solenoid valve is closed whereby the refrigerant doesn't move to the evaporator.

Electric Motor

Next, we will be looking at the Electric Motor. We have looked at all these components in the Vapour compression cycle; the condenser, compressor, evaporator, expansion device, receiver, etc. But to operate, to make it function, you need an electric motor. This is a basic simple electric motor which helps in operating this compressor. Let us see the basic working principle of an electric motor. It is a current carrying coil in a magnetic field and it experiences a turning effect. This is a schematic diagram. N represents north pole and S represents South pole, the two poles of a magnet. The coil in the centre is connected to a variable power supply and when it is in the magnetic field, it rotates, it experiences a turning effect. When a current carrying conductor i.e a metal coil is placed in a magnetic field, there is an interaction between the magnetic field produced by the current and the permanent field, which leads to a force being experienced by the conductor. There is a magnetic field between these two magnets, the permanent field here, leads to a force which in turn rotates the conductor. The magnitude of the force on the conductor depends on the magnitude of the current which it carries, which is quite obvious. The force is a maximum when the current flows perpendicular to the field as in figure A and it is zero when it flows parallel to the field, as in figure B. This is a schematic diagram which shows the motion of a current carrying loop in a magnetic field. As I already explained, this represents the north pole of a magnet and this, the south pole of a magnet. This is the conductor or the metal coil. It is connected to brushers and the brushes are connected to a power supply. Once the power supply is given, it rotates in the magnetic field. Let us look at the different parts of a motor. Armature or rotor, Commutator which is fixed to this rotor. Next, are the brushes which are fixed to the commutator. Next, is the Axle which helps in keeping the Armature in place. Next are the field magnets which are on either sides, that create a magnetic field.

Now, let us go into the detailed components like the Armature. The armature is an electromagnet made by coiling thin wire around two or more poles of a metal core. It is nothing but a thin wire that is bound on a metal core. The armature has an axle and the commutator is attached to the axle. The black one is the axle and the green semicircle arcs are the commutators. When you run electricity into this electromagnet, it creates a magnetic field in the armature that attracts and repels the magnets in the stator. So the armature spins through 180 degrees. To keep it spinning, you have to change the poles of the electromagnet. It has to be constantly changed, else it won't spin.

The Commutator and the Brushes - the commutator is simply a pair of plates attached to the axle. Here in the image, you can see the commutator, the green arcs which are a pair of plates attached to the axle. These plates provide the two connections for the coil of the electromagnet. They provide the connections, they are connected to the electromagnet. The commutator and brushes work together to let current flow to the electromagnet and also to flip the direction that the electrons are flowing at just the right moment. They play two roles, to keep the electromagnet in rotation. Also to flip the direction of the electrons. The contacts of the commutator are attached to the axle of the electromagnet, so they spin with the magnet. This is an actual picture of a simple motor. You can see the electromagnet, the thin coils around the metal piece and then you can see the casing, the metal axle.

In addition to the main components described earlier. Let us look at all the controlled devices needed for the normal operation. We will see how do these devices operate under normal conditions. When a system is off, the refrigerant is waiting in the condenser. For to it enter the evaporator, the solenoid valve must first open. The signal to open the valve must come from the room thermostat which makes a contact with the valve when the room temperature is higher than what is set by the occupants. Some systems have a timer which puts off a system when a building is unoccupied. Others have an outside thermostat that prevents the refrigerant system to switch on when the outside temperature is too cold. The compressor will only start when the timer and the outside thermostat allow it to do so. The liquid refrigerant starts to flow towards expansion valve, at this point it is at high pressure. You can see the refrigerant flowing through the side glass as it flows through the refrigerant, it is filtered to remove the possible residues or metal particles. The liquid refrigerant at high pressure thus arrives at the expansion valve which is said to lower the pressure, to obtain the temperature required in the evaporator. The expansion valve is also a floor controlled valve. It controls the amount of the refrigerant entering the evaporator depending upon the evaporation rate. The evaporation rate varies with the amount of air to be cooled. The air temperature and the degree of humidity in the air as it passes through the evaporator. The expansion valve measures the evaporation rate by means of a bulb located at the evaporator. This bulb measures the amount of superheat of the refrigerant. As the degrees of superheat increases, it means that the refrigerant is evaporating faster than it enters the evaporator, expansion valve, then it opens more to increase the flow. However, the number of degrees of superheat drop means that the evaporation is flooded with liquid refrigerant. The expansion valve will reduce the flow until superheat returns to the desired range. Usually, 8 - 12 Fahrenheit for thermostatic expansion valves or electronic valves operate with superheat range of 4 - 6 degree fahrenheit. You will notice that the expansion valve also receives a pressure signal also measured at the evaporator outlet. This allows the expansion valve to adjust to the pressure drop in the refrigerant as it goes through the evaporator. The pressure drop lowers the evaporation temperature slightly and could give a false superheat reading if it were not compensated for. Under normal working conditions, the level of refrigerant stabilizes in the evaporator, so that the flow of liquid is proportional to the amount of heat will be absorbed. The compressor starts up at the same time as the solenoid valve opens. The compressor startup is also regulated via a pressure control that measures the minimum pressure needed to be present at the compression suction inlet. This is the cut-in pressure. This pressure is usually reached when the compression starts up because the remaining refrigerant in the evaporator has evaporated while the compressor is off. This control is useful to prevent the compressor from starting when there is not enough refrigerant coming into the compressor from the evaporator. The compressor can be shut off from one of the three following controls. The first is the room thermostat. This thermostat shuts off the compressor if the ambient temperature is lower than the set-point temperature. The second is the pressure control that measures the minimum required pressure at the suction inlet. This means too little refrigerant is coming from the evaporator, the compressor will be stopped. This is the cut off pressure. The third is the pressure control that measures the pressure at the discharge outlet. It is called the high pressure cut-out. When the discharge pressure is too high, the compressor shuts down. This may indicate that, there is an operating problem that could damage the mechanical components. Under normal operating conditions, the compressor runs as along as the thermostat does not reach the desired temperature. The gaseous refrigerant which is drawn in from the evaporator is compressed to a high pressure. The refrigerant temperature then arises instantly with the increase in pressure and the refrigerant flows through the condenser. In order to try to adapt to the variable flow of the compressant arriving at the compressor. Some systems use multiple compressors. As the flow of refrigerant increases, the suction pressure increases which in turn a large number of compressors to start up. The condenser receives the gaseous refrigerant at high pressure and high temperature from the compressor. The function of the condenser is to condense the refrigerant in order to return it to the evaporator. The condenser and compressor fans operate simultaneously. It is the air from outside that absorbs the condensation heat. The function of the inverted 'u' trap located at the condenser inlet is to reduce the hammer effect caused by the sudden arrival of the massive refrigerant in the condenser. This usually occurs when the compressor starts up. The inverted 'u' trap also holds back the liquid refrigerant and prevents it from returning to the compressor when the compressor is off. Refrigerant reaches the bottom of the condenser as a liquid at high pressure and high temperature. As soon as this happens, it again passes through the expansion valve to re-enter the evaporator at the required temperature and pressure. The refrigeration cycle continues to operate as long as the room thermostat indicates that there is a need for cooling.