Building Services III
Lecture 5

Central Plants

Central plants as seen in the earlier lecture are of three types basically, one is the direct expansion type, chilled water and VRF systems. What is so special about Central plants? These are usually large air conditioning plants assembled at the site. These plants are used for big buildings such as hotel, theatres, hospitals, large office complexes and factories. They are designed for accurate control of all the parameters of comfort and as the name implies, they are in the central location in the plant room which could be in the basement of a building. There are three basic types; Variable refrigerant flow systems, DX systems and Chilled water systems. The DX and Chilled water systems are further subdivided into Vapour compression units and Vapour Absorption units. We will be looking at vapour compression units and they are further classified into three types based on the type of chiller or compressor you use. They are reciprocating units, air and water cooled; Centrifugal units, water cooled only and Screw type units, air and water cooled.

Let us look at how the Direct Expansion system works. In this system, air is cooled and conditioned in the plant room. This treated air is then pumped to various parts of the building. The air returning from the air conditioned area is sucked through a coil-fin arrangement by a fan. Refrigerant inside the coil picks up the heat from this air and evaporates. The cold air is pumped back to the air conditioned space. In the DX plans, the place where this heat exchange takes place is called air handling unit. This type of system typically uses ducting. passing through the structure to various parts of the building to be air conditioned. The second type which is called the Chilled water system - here the refrigerant and water interaction takes place and that is why it is called the Chilled water system. The refrigerant in the shell or tube depending on the shell and tube heat exchanger evaporates by picking up the heat from the water which is in the other portion of the heat exchanger. This chilled water is then circulated to the various water air heat exchange, which is called fan coil units or air handling units. The system is also preferred where multiple zones are to be cooled like a hotel or a hospital. In this chilled water systems, because chilled water is required, people go in for packaged chillers to provide for the chilled water. Such chillers are typically mounted on a frame and comprise a compressor with its drive motor, a condenser and a shell and tube heat exchanger. Depending on the type of compressor used, these chillers can be classified as a reciprocating chiller, a screw chiller or a centrifugal chiller. Where the absorption system is used, the chillers are called Absorption Chillers. This is how they look, the diagram on the left is a Reciprocating filler, the one on the right is a Centrifugal chiller. On the bottom left we have the Absorption chiller and on the right, Screw-type chiller. Amongst the available variety of chillers, how do we decide upon a particular type based on the application? It is very simple, you have to choose your chiller based on the tonnage, the AC load or the heat load. For typical application, 30 to 100 ton, you can go for a Scroll-type compressor which uses refrigerant air type R22, really good in energy efficiency, the initial cost per ton is low and it is easily maintainable. When the tonnage increases or goes above 40 within 300, you can opt for the Reciprocating Compressor type Chiller. It is also highly energy efficient and also low cost and easy maintenance. If the runnage is more than 300 tons, you have to go in for a screw-type chiller and if it is more than 500 tons, you have to opt for Centrifugal Chillers and any load above 500, you have to opt for Absorption chillers. We saw in the same reciprocating chiller and the absorption chillers; all have these two types of cooling systems; air and water cool. How does this help? Why do we have these two types? In the air cooled system, the heat from the conditioned area is transferred to the cold refrigerant warming it up. This warm refrigerant then sheds the heat to the air outside in the Air Cooled Condenser. This is pretty much the similar operation in a normal split air conditioner whereas the condenser is cooled by external air. From the floor chart, you'd notice that the hot air from the air conditioned space evaporates the refrigerant in the evaporator. Then the refrigerant goes to the compressor. From there it goes to the air cooled, finned coil condenser where it dissipates the heat to the outside air. In the water cooled type, the heat from the conditioned area is transferred to the cold refrigerant warming it up. This warm refrigerant transfers the heat to water in the Water Cooled Condenser thereby warming the water. This warm water in turn transfers the heat to the atmosphere through the cooling tower. Here, there is a two-step process when compared to the earlier type. Here is hot air in the air conditioned space, evaporates the refrigerant and the refrigerant passes through the compressor, then goes to the water cooled, shell and tube condenser. There, this refrigerant transfers heat to the water. Then this water goes to the cooling tower to get cooled. How the condenser gets cooled in an air cool condenser? By blowing or sucking air through it, in an air cool condenser and by pumping water through it in a Water cooled condenser.

Here, we see in detail how an air cooled condenser works. An air cooled condenser consists of a set of finned copper tubes and a fan to draw or blow the air through this finned coil arrangement. The hot gas flows through the condenser inside the tubes while air is blown or sucked through the finned tube arrangement by a fan. The air which is normally at a temperature 10 degree C to 12 degree C, lower than the gas, picks up the heat from the gas making it condense inside the tube. Air cooled condenser is very common for window, split and packaged air conditioners and are now becoming popular for central plants also. This is a schematic view of an air cool condenser where you have the fin and coil arrangement and the refrigerant passes through a pipe or a tube and air is blown through this pipe and fin and coil arrangement. Thereby, picking up heat from the arrangement and allowing it to condense. This is a schematic diagram showing the different components in an air cooled condenser.

Now, we will look at the operation of the water cooled condenser. In a water cooled condenser, water is pumped through the tubes of a shell and tube condenser using a water pump and the refrigerant is passed through the shell. This condenser is also called 'Heat Exchanger' because this is where refrigerant and the water exchange heat with each other. On giving away some of its heat to the water, the refrigerant condenses in the shell. The water, which gains some heat in the heat exchanger, travels to the 'cooling water' where part of the water evaporates in contact with air, cooling the remaining water which is one again circulated through the heat exchanger. This is a schematic diagram of a cooling tower. Here, you see the condenser from which there is the shell and tube condenser from which there is a water pump to pump the hot water into the cooling tower. Then this hot water passes through the tube to the top of the cooling water and these are all slits on the cooling tower and from the top, the hot water is sprayed through spray nozzles and through this lewer or fin arrangement, the natural air, the atmospheric air passes through thereby cooling these droplets of water or evaporating these droplets of water and the remaining cool air gets collected in the sump here and is then sent back to the condenser.

In a water cooled air conditioned system, the heat from the room is transferred to the evaporator, from where it is transferred to the condenser, and from the condenser to the cooling water which finally transfers the heat into the atmosphere. In the cooling tower, the water is sprayed through nozzles in the air, the water becomes small droplets and evaporates, thereby losing heat and becoming cool. This cool water falls into a sump tank at the bottom of the cooling tower from where it is pumped into the shell and tube condenser and the cycle repeats again. There are two different types of cooling towers; Atmospheric or Natural Draft towers - in these towers, the water is sprayed into the tower and the droplets of the water cool as the natural air currents passing through the cooling tower. In the Forced Draft towers - towers use a motor and fan to pull or push a constant volume of air through the tower. The water is sprayed through nozzles into the draft thereby evaporating rapidly and cooling the rest of the water. This is the forced draft cooling tower. Here, the air is forced into the cooling tower, thereby the evaporation happens and the water gets cooled in comparison to the earlier type.

Here the quality of water is very important for the performance of the air conditioning system. Hard water causes scaling thereby decreasing the efficiency of the heat transfer in the condenser. Some water is required to make up for the water which evaporates and also the portion of the water that is blown away by the wind. This is referred to as 'makeup water'. Water cooled condensers and cooling towers are not normally used where the water is available in plenty. The normal make-up water requirement for air conditioning applications is 15 litres/hr/ton refrigeration.

Air Handling Units

It is a centrifugal type fan that pumps air. The fan is usually located in the air handler/ water coil cabinet. Its purpose is to create a pressure differential so that the air from the conditioned space is drawn to the unit. The air is passed through a filter first to remove dust particles and then over the cooling oils or chilled water tubes where the heat is rejected. This cooled and dehumidified air is then drawn into the suction side of the fan and discharged back into the conditioned space. A damper arrangement in the suction side of the AHU is kept a little open to drawn in fresh air. This is how an air handling unit works. This is how it looks like. The construction of the air handling unit is a sheet steel cabinet which houses the cooling coil and blower fan. The motor is mounted on the outside of the cabinet and drives the blower by a pulley-belt arrangement. Depending on their application, AHUs vary in size from small/medium sized packaged units to large walk in models. There are two types of AHUs, the 'single skin' and the 'double skin' type. The 'single skin' AHUs have a single layer cabinet and are usually placed inside an AHU room. It is advisable to insulate the room so that the air in the AHU does not pick up heat from the outside warm air. Keeping the AHU in an insulated room also features the sound levels in the conditioned space. In the double skin type, it has an inner cabinet and an outer cabinet. The layer of insulation is sandwiched between two cabinets. Though these AHUs are more expensive than the single skin type, they have the following advantages; because of the insulation the cool air inside does not gain heat from the surrounding air, thereby improving the efficiency of the plant. They are more silent because the thermal insulation also acts like an acoustic insulation. They do not 'sweat' on the outside and can be kept in the non-air conditioned space thereby saving on the cost of a separate planet/ AHU room. If you look at these advantages, the initial cost spent on this is worthwhile.

Next up, we have an equipment called Fan Coil Units. This is a sheet metal cabinet that houses a Chilled water coil constructed out of copper tubes and aluminium fins, a blower with monitor and an Air filter, these are the different components within the fan coil unit. The Fan coil units are generally used in multiple areas like hotel rooms. There are to be cooled independently, until a central air conditioning plant. Here, in the previous types, a continuous supply of a particular temperature of air that is spread to all rooms irrespective of the load required. But whereas in buildings like hotels where sometimes a room is occupied, sometimes not occupied. Some guests require more cooling, some require less cooling . You can make yourself a fan coil unit to control all these aspects. Here what happens is, the water is chilled centrally and pumped to various parts of the building through insulated pipes. The chilled water enters the FCU, where the heat exchange takes place between the room air and the chilled water in the coil. Air is passed over the coils using a three speed blower motor, mounted in the FCU. The air speed can be controlled by choosing the blower motor speed, from a selector switch in a conditioned space. To finally close this, a thermostat is also mounted in the air conditioned space. A thermostat controls a solenoid valve, that closes when the desired temperature is reached, thereby shutting off the flow of chilled water into the FCU water coil. Once the temperature in the room rises, the thermostat activates the solenoid valve which opens allowing the chilled water to flow into the coil again. Thereby, cooling the space.

Next we will look at a VAV or a VRV system. What is a VAV? A VAV is nothing but a variable-air-volume system or VRV is a variable-refrigerant-flow-system in a single-path system that controls the zone temperature by modulating airflow while maintaining constant supply air temperature. This is the same central system where conditioned air is supplied into a space like a FCU. This VRV system has separate SUs for each and every space to be air conditioned and depending on the load there a sensor that can sense the requirement whether it is fully loaded or not loaded and such. Based on that it sends signals to the FCU here and thereby you can shut off or open the cool air supply to the room. VAV terminal units are located at each zone. Adjust the quantity of air reaching each zone depending on its load requirements. Those are the terminal units that does the job. Reheat coils may be included to provide required heating for perimeter zones. VAV boxes provide constant or variable airflow depending on the temperature demands of the space. As the temperature rises, the VAV damper opens to send a designed amount of airflow to the space or room. You might have a question, this works very similar to the normal FCU or a chill water system, how does it differ from that or what is the advantage? Here, in the VRV system, all the ducts are connected to one central outdoor unit. This outdoor unit is a rack of multiple compressors and depending on the load the number of compressors will run. Basically, the major power consumption is done by a compressor in an air conditioning system. In a central system, irrespective of the load, irrespective of the requirement, the entire system runs throughout the day, thereby increasing our electricity bills. Whereas in a VAV system, there are smart, intelligent sensors which can sense which room is loaded and which room isn't. Depending on that, it can bring down the load of the entire system, thereby shutting off the required compressors. Thereby you have a lot of power saving, that's why people settle for the VRV systems. These systems have a high initial cost but usually you can recover the cost while the system runs over the years.

Next we look into the lower temperature application - basically, this deals with refrigeration for food preservation. Fruits and vegetables are perishable commodities. If not stored at recommended temperatures after harvesting, they rot in a short time by chemical reactions, bacterial attack or water loss. Improperly stored fruits and vegetables lose nutritional value over a period of time. Changed physical appearance or taste also affects their consumer appeal. As you already might know, we used to get farm fresh vegetables, the same day the farmer harvests the vegetables and brings it to the market, we bought it. But now a days, in the context of departmental stores and big shopping malls, people have started having big cool rooms and warehouses where they collect a whole load of vegetables and fruits and store them there and supply it ot the different branches across different cities. Here, refrigeration plays a very important role in today's business context. Refrigeration helps in preserving fruits and vegetables by storing at low temperatures to slow down decay and natural metabolic processes. Meat, fish products and precooked foods also have limited life because of enzyme activities, bacterial attack and ageing. Low temperatures are very effective in limiting these reactions. Similarly, ice cream, other dairy products, bakery products and beverages need to be stored at low temperatures for long term use. These are the different low temperature applications in refrigerators.

Next, we will look at the equipment sizes. This is a chart that talks about the Chiller sizes. The left shows the water-cooled Screw chillers on the right it shows, Air-cooled flooded Chillers. Depending upon the tonnage, the figure or the number in read talks about the tonnage and these are the different sizes, the length depth and height of the chiller. This is a chart showing the cooling tower sizes, once again based on the tonnage, the height and diameter of the cooling tower is decided. The tonnage is around 5 - 300 and the sizes vary.

Next, this is a particular brand model of AHU. Once again based on the tonnage of the British thermal unit, the 15TH and for the air quantity, the CFM. Based on that, you decide on the dimension of the AHU and its corresponding motor size and its electricity load is shown here. This chart shows the sizes of packaged and ductable units available in the market. Here they detail or mention about the Ceiling suspended units, the required tonnage and their corresponding indoor unit size and outdoor unit size and the number of outdoor units required per indoor unit. For example, when you go for higher tonnage like 11 or 10 and for this size of indoor unit, you might need two numbers of this size of the outdoor unit. Similarly, for higher tons like 17, 22 tons, you might need outdoor units. Incase of floor mounted units, these are the different sizes for the indoor unit and the number of outdoor for the indoor.

We will then squeeze as the space requirements for mechanical and electrical equipment. This chart can be used as a thumb rule. The total mechanical electrical space that is require in general is 4 - 9 % in general for all high-rise buildings. In apartments and schools it goes upto 5% of the total area of the apartment and for office buildings it is 7.5% of the total area and laboratories occupy as big as 10% of the total area. There is a breakup of the above total percentage, the plumbing items require 10 % to 20% of the lower-floor gross building area. The Electrical requirements require 20% to 30% and the heating and air conditioning, this is what is important for this particular subject. For heating and air conditioning, it requires 60% to 80% of the above 4% to 9% of the total area. Out of 4% to 9% that you allocate for mechanical equipment, as big as 60% to 80% is occupied by the heating and air conditioning equipments.

This tabular columns shows the air intake/ exhaust openings for maximum air velocities on the net free area.

Duct Design

Next, we will move on to the Duct design. One important component in this entire central system is the duct. So, what are these ducts? Ducts are generally made of GI i.e Calvinist or Aluminium sheet metal. Practical ducts can either be rectangular in section or circular. Rectangular ducts are more in common. We opt for circular duct when the same is to be an exposed duct, without being covered by side boxing or false ceiling. Otherwise, rectangular ducts are very common. There is an Indian standard for the fabrication of ducts - IS 655 specifies gauge of sheet metal required, flange specification bracing angle specification for various sizes of ducts. One important factor that you have to consider in a duct is the aspect ratio. The ratio between the larger side to the smaller side. In simple terms, the ratio between the length by the breadth of the duct. The length by breadth or the aspect ratio of a good duct should not have an aspect ratio of more than 4. Here, we look at different ducts that are available in the market and their aspect ratios. All these ducts which you are seeing in this tabular column can carry equal air quantity of 9000 CFM under a friction drop of 0.1" for every 100 ft of duct. Given this constant parameter, these are the various possibilities of duct sizes. You have 30 x 30, 46 x 20, 60 x 17; all these sizes and these are corresponding aspect ratios. This is the cross section area in sq ft per duct. This approximate cost of the duct. Next will be the limits for the aspect ratio. In other words, what will be the pros and cons of a particular aspect ratio. The aspect ratio is one. Say if length by breadth are equal, x by x, it is excellent but an impractical duct. As all of us know as designers, ducts occupy a lot of our ceiling space. Even though we give very high ceilings for commercial buildings, after we do all this AC ducting and false ceiling, the remaining wall space becomes very small or short, which spoils the aesthetic looks. That's why we discuss a lot of these AC air conditioners on these duct sizes. We have to know what are the different pros and cons of different aspect ratios. As we see, disaster ratio one is not practical because we cannot give such a huge ceiling space for the duct to run. When the aspect ratio increases, it goes more than 4 or lesser than 7, you have the 'compromised as no other way out duct', as AC consumptions call it. Once the aspect ratio goes beyond 7, it is either worstly designed or badly designed duct. It will be a very flat and wide duct which will have a lot of air conditioning losses and inefficient functioning of the system.