BUILDING ENERGY SYSTEMS AND AUDITING

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Week - 02

Lecture - 06

Lecture 06: HVAC Systems

So, welcome to the NPTEL course on Building Energy Systems and Auditing. So, today we will be starting our module 2. So, in module 1, we just had an introductory course and introductory discussions on the properties of air and the thermal properties of the materials. In module 2, we will discuss the different types of building energy systems, and in the first lecture of module 2, which is lecture number 6. We will discuss the HVAC systems.

So, HVAC stands for heating, ventilation, and air conditioning. So, in that, we mostly cover the air conditioning systems, which are predominantly applicable in our country, a tropical country. We will see the mechanical cooling systems available, mainly the cooling systems in air conditioning, types of air conditioning systems, and the psychrometric calculations for the cooling load. So, there is a mistake over here, and we will rectify that mistake when it is circulated to you. So, in the air conditioning systems, we all know that it is because of the thermal comfort.

So, if the indoor air temperature and the humidity are unbearable. And, of course, in some of the conditioned areas, we require maintaining a temperature that is below the outdoor temperature or so on. So, in those conditions, we go for the air conditioning systems, which come under the mechanical ventilation system. So, comfort parameters, if you see, we will discuss them maybe in some other chapter. It mostly depends upon the temperature and the humidity.

And of course, it is required; it depends upon the air flow distributions and all. In the general scenario, we can have a design goal to keep a particular space temperature around 20° to 24°. We can also see that humidity will be around 55° ± 5, so around 50° to 60° is very comfortable. It is a kind of condition from the humidity point of view. If it is very highly humid or has very high values like more than 75 or so, it is sometimes unbearable.

It will cause sweating and all those kinds of issues. If it is less, it is also sometimes not good. It will cause some kind of very dry skin scenarios as well. We also sometimes see the air quality, which means how much pressure has to be injected in a particular space, rated in CFM (cubic feet per minute) in that unit.

We discussed in the last lecture that we have to actually consider health ventilation as well, where we have to maintain a standard level of oxygen and carbon dioxide balance. We also require some kind of air movement distribution, and due to the air movement distribution, there are a lot of energy losses. Because it is an air flow, there is also some kind of noise created, and the decibel value of that particular noise level, the noise criteria, is kept at almost 20 to 40 NC. So, in the mechanical cooling system, it is actually a vapor compression refrigeration cyclic system. It has a compressor which will compress the particular refrigerant, and then there is a condenser which is going to condense it. So, the state of the refrigerant will change from vapor to solid, from solid to liquid, and again to vapor. In that process, there is also an evaporator, and a change of temperature occurs. These high-pressure releases heat, and low pressure absorbs it. This particular phenomenon is a thermodynamic phenomenon, and based on that, this particular cycle is operated. That cycle is called the refrigeration cycle. We will not discuss that cycle in detail because it is not within our scope of discussion. So, only what we will see is how much What are the types of air conditioning, and how the cooling load can be calculated based on the psychometric criteria as well.

So, there are different types of refrigerants, which are chemicals that actually flow through these particular cyclic tubes or this particular refrigerant cycle, and that will help us to cool the air. So initially, in the early days, we actually used chlorofluorocarbons (CFCs) or hydrochlorofluorocarbons (HCFCs), which are nowadays not used because of some kind of environmental reasons. So, nowadays we use hydrofluorocarbons, and they have some kind of designated classified names like R410A. The cooling load is calculated or expressed in a unit as tons of refrigeration or refrigerant ton or T or TR, whatever you may say. Now, when we go to purchase any AC.

Window AC or any split AC, we will actually ask that fellow to provide me a 2-ton AC. What is these 2 tons? These 2 tons actually comes from the unit, which is defined as the last line if you just read. That means if you want to have one ton, one ton means one

American short ton, which is equal to almost about 2000 lb. So, 2000 lb of ice, if you want to melt it within 24 hours, within 24 hours, I am going to melt 2000 lb of ice.

How much? The energy, not energy, how much power is required, how much kilowatt power is required, so that is equal to one tonnage of refrigeration, one TR or one RT, whatever you may say, but the important thing is that if you just multiply and all those, it is actually going to be 3,516 W. That means almost 3.5 kW. So, we can say that one ton of refrigeration is almost equal to 3.5 kW. This is very, very important.

Because mostly we will find that the cooling load will be estimated in and from there, we have to go to the TR and then we have to purchase or whatever. So, the types of air conditioning systems depend upon a lot of parameters. We have to see what the total air conditioning load is, and based on that, we decide which type of air conditioning system we will have to purchase or establish in our building. The design of the building, how much is it spread?

What is the verticality of the building? How many floors are there? Are all floors required to have air conditioning? The proximity to the surrounding buildings, because we have to place a proper location in the site plan, a particular place for the chillers, cooling towers, and all those. The height and visibility of the equipment.

The initial capital cost, yes, that has to be one of the deciding factors, aesthetics, and long-term life cycle cost. So, running a particular system also requires some kind of cost. So that is also going to be checked before you decide. Now, in the types, we have many. We have window, split, or distributed systems.

Window and split are individual. So, we can say it is a small scale or small and medium scale, and we can go for split. But the window is definitely a small scale. Only in my room, I can provide one or two, something like that. But if I want to have a large scale,

maybe a hospital, maybe an airport, maybe a shopping mall, maybe an office building, maybe an institute, a lecture hall, a theater, or whatever. We should not think of either split or maybe the window. We have to think of the distributed system. So, those are the window ACs. All of you know that one. It comes in a package form, with the condenser, compressor, and evaporator inside it. The split air conditioner has a rooftop unit, an outdoor unit, and an indoor unit, which is your split AC. But if you see the distributed systems, which are actually going to be applicable for all the buildings that have a very high amount of cooling demand or so.

So, we can have three types of systems. One is the air-cooling system. That means I am going to cool the air itself. Actually, finally, we have to cool the air. But before we cool the air, there may be different ways of cooling the air.

So, one is directly cooling the air, which is the air-cooling system. The second one is the chilled water-cooling system. That means I am using chilled water or cooled water to cool the air. And the third one is the refrigerant system. So, I am sending the refrigerant to different places, different spaces, and cooling the air.

So, all of these have their own advantages and disadvantages. So, practically speaking, what you have to employ depends on your initial capital investment, the total size and span of the building, the verticality, the running cost, the total amount of load or the TR or the tonnage of refrigeration you want to support—everything you have to consider. So, the distributor system. So, if you see the air-cooling system and the chilled water-cooling systems, these are actually going to cool the air. And by virtue of sending the treated air to your different spaces—your classrooms, your laboratories, your auditoriums—we can have two ways.

One is the constant air volume (CAV) system. So, as the name suggests, you are sending a constant volume of air to every room. No fluctuations. That is number one.

And number two, it can be a variable air volume system, VAV systems. So, depending upon the requirement, we can send a larger amount or a higher amount of air flow in some rooms and maybe a lower amount in some other rooms. So, that depends upon how I am going to suppose there are a series of classrooms or so I may go with the CAV kind of system because the capacity is the same, the dimensions are the same, and the cooling load requirements are the same. So, why do I not go for a constant air volume? But if there are fluctuations like occupancy fluctuations, fluctuations in the room dimensions, or fluctuations in the need of the temperature inside, some may have similar requirements to laboratories, but one lab requires a little less temperature, and one lab requires moderate cooling temperature.

So, I have to go with the variable air volume kind of scenario. The refrigerant systems which will have variable refrigerant flow, VRF or VRV, variable refrigerant volume, both are the same systems. So, if I see the air-cooling systems, what happens is the indoor air is taken in. That goes to a kind of chiller plant where I am going to chill with some cold-water loop, hot water loop, like that with a refrigerant-based chilling system. So, we have two things, a chiller and a cooling tower.

Again, I am not going to discuss that. That comes under the HVAC services. And just to give you a kind of brief idea, that chilled air is taken to the AHUs, the air handling units. These AHUs are located in different places on a floor depending upon the length of the floor you want to go for any kind of air conditioning, and also definitely vertically on each floor. From the air handling unit, we again boost up the air by some fan, so cool air will now go through some supply duct to different rooms. And we may have a VAV damper in it.

So, a VAV damper is a type of damper located at each inlet point in any room that will control how much variable volume of air has to be thrown into that particular room. And finally, it goes to the grills, and from there, it can go into the room. It will be circulated inside the room, and then from that circulation, we have a return air duct. We can take the return air through a return air fan. We have to take that air and can keep it just before it enters the cooling tower again.

Because the return air duct will have a lower temperature compared to the outdoor air. So, I can mix the outdoor air and the return air. And I can actually save some amount of energy because, after mixing the return air and outdoor air, the resultant temperature of the air will be slightly lower compared to the outdoor air. And then, that air I can again take to the chiller and process it. But there are some restrictions given by the code.

This return air system cannot be applied in hospitals because it will actually take the same germs and mix them with the fresh air, which can then be circulated again. It can be circulated from one ward to another ward. So, that is why it is not recommended for hospitals, nursing homes, and all return air systems. We always have to inject fresh air. Also, in chemical labs,

We do not go for the return air because in chemical labs, biochemical labs, or maybe biotechnology labs, you know, there are some contaminations in the air. If the contaminations are recirculated by return air to every floor, everywhere in the other parts of the institute, or other labs, other classrooms, and all, this will be really dangerous. So that is why we always inject fresh air in those scenarios. In the case of the refrigerant system, we actually pump the refrigerant to the building, not the air directly. That refrigerant is definitely going to be cooled, and it may come around 4 to 6°, that kind of temperature, and that will go to the different units in the particular room. The number of units may differ depending upon your load, and also the flow of the refrigerant can differ depending upon the load. Those particular units are called the fan coil units or the FCUs, which look like indoor split air conditioning units, but they have an outdoor unit which is can be kept on the rooftop, any balcony, or any other areas. It can actually circulate and cool a considerable number of rooms or areas by virtue of that. And due to the heat exchange process, because it has a fan unit, as its name suggests, a fan coil unit is a coil, and a coil is a heat exchanger.

The fan will suck the inside air from the space, and this hot air of the space is circulated through the heat exchanger. When it comes in again, it will be cool, so treated air like that will go on. By virtue of this heat exchange process, the refrigerant temperature will again be high, and it will be taken to the other pipe and it will go to the air conditioning unit, where again it has to go through condensation, compression, evaporative processes, and all. Again, it will be so. It is a closed-loop kind of cycle. So again, let us see one small problem. It appeared in the 2019 GATE examination. It was stated that a room having dimensions 12 x 10 x 3.5 is required to be mechanically ventilated by an air conditioner Fine. The temperature difference between the outdoor and the indoor supply air is almost 12°C. So, we have to actually decrease the temperature by 12°C.

Consider 3 air exchanges per hour. The volumetric specific heat of the air is given as something that is 1250, which is very close to 1300. So, sometimes it may differ. Assume one ton of refrigeration is equal to 3.5 kW, which is the capacity of the air conditioner of the tier. So, what I can do is I can now find out three things. Actually, we have to find out the skew. How much meter cube per second?

Isn't it? So, I have to find out. I know the volume of the room. I know how much air exchange per hour. So, that gives me the volume of the room into the number of air exchanges by 3600, which will give me directly.

This, I think, I have done like that. Yes, it is three-number air exchange, volume of the room, 3600 gives me. 0.35 meter per meter cube per second, so that is so I have to find out the Q, which is this Q already I got into this, the specific heat of the air multiplied by the Δ T. Because this is I got in meter cube per second, and the unit of the specific heat is J/m^3 °C, and this is °C is my ΔT, so °C will cancel, this will go to cancel, so this will be joule per second, which is equal to watt. So, the Q I will get it from the watt, so I have just done that one. 0.35 is my V. This is my specific heat, and 12°C is the Δ T. So, I require 5.25 kilowatt, and I divide that by 3.5.

So, I got 1.5 TR will be the capacity. So, let us do these things from some psychrometric chart operation. We have discussed the psychrometric in the last lecture in our first module. So, and there also, we have discussed something on how to change state from one state to another.

So, I have taken an airflow rate of 5 cubic meters per second for a building. And the outdoor air is at 35°C and the RH is at 70%. And I have to treat that air to a lower temperature of 20°. From 35° to 20° and the RH has to be from 70 to 30. So, I have the psychrometric chart.

I have to plot this one to see what the properties of air are at point A with 35° and 70 percent RH. So, I need to know some of the things. I need to know how much the specific volume of the air is. So, that is 0.91. You can actually do it on that particular website that I mentioned in the last lecture or get a printout of the psychrometric chart and plot point A to see how much the SV is.

So, actually, this should not be SA; it should be the SV ratio, which is the specific volume. I will correct it, which is 0.91 m^3/kg of dry air, and the enthalpy at point A is 100. So, I also need to know the state of point B, the treated one. So, that is a 20° and 30% RH combination. So, that gives me the specific volume at point B as 0.835 m^3/kg of air, and the enthalpy is 31. So, I have to decrease the enthalpy from 100 KJ/kg to 31 KJ/kg, and the specific volume reduces from 91.91 m^3/kg to 0.83 or something over a flow rate of some volume of metric flow rate of 5. So, the energy required is V divided by SVA into EAY. The V is what? V is your meter cube per second. See, I am just creating some kind of a unit balance of this particular area, this particular statement that is this, which is your Q. And what is your SV?

The unit of SV is your meter cube by kg. And what is your enthalpy? Enthalpy is your, sorry, it is your kilojoule per kg. So, V, this is, sorry, this is not Q, this is V. So, V by specific volume into enthalpy is nothing but meter cube by second is my V exchange rate. Meter cube by kg, which is your SV multiplied by kilojoule per kg.

So, this kg gets cancelled, this meter cube gets cancelled. So, it will be kilojoule per second, which is your kilowatt. So, I can use this to change of kilowatt and I will find out that this much kilowatt. So, 364 kW is required to do required to it is is our cooling load for to maintain a five-meter cube per second is very high very high five-meter cube per second is very high flow that much of a rate of flow and there is a drastically decrease of temperature and humidity so 300 and something 364 kW if I divide this by 3.5 is almost about 10

Almost 100 tonnage of refrigeration is required to do that. So, we have another example that has two sources. Suppose I have two sources, A and B. From source A, I am taking the rate of flow at 1 meter cube per second. From source B, I am taking the air at 0.5-meter cube per second. Now, these two sources have two different temperatures: 42° and 20% RH, whereas source B is much cooler at 15°, and of course, the RH is high at 60%. You may think of source A as my outdoor source and source B as my return air source. The mixed air has to have some temperature, the resultant temperature, and I have to further cool it to 25°C and 50% RH.

So I have to find out how much energy is required from A to B and whatever. So what I did is I have to first plot these two points. That means this is my source A point. This is my source B point. I have to draw a line between source A and source B. I have to measure this line in true centimeters and divide that line to get the resultant point of the mixed line such that BC is to AC.

The new point will be C. So, it will be the rate of airflow of source A to source B. So, my C point is somewhere here. Because my source A gives me a higher part and source B gives me a lower part of the rate. So, it has to be just opposite. So, if both air sources are having the same amount of inflow, 0.5 and 0.5 or 1 and 1, then point C will be exactly at the center. But as A has a higher amount of

1 meter cube per second whereas the b is 0.5, so the resultant will be near to a, and that will be how much near that is dividing the as per the 2 is to 1 ratio or so. Then I got the, I am sorry, this is going to be the point c. I will check and I will send it to the correct one. So, the point C is there, and the point D, which is my new point, which I have to cool to 25° and 50 percent. So, that is also there, and I have to find out the properties at point C and point D, S V, and the E D, and I have to use the same equations. As earlier, I have done for the earlier, so in a similar way, the volume divided by the specific volume rate of the ventilations divided by the specific volume in the enthalpy of point C and point D. So, I got almost about 8 kilowatt hours is the energy required. So here, I have done the second part of the problem, energy required for cooling that outside air taken as source A only. If I want to have the source A only, I don't want to mix it with the source B, so all the 1.5-meter cube per second air from the source A only, then the shift will be from source A point A to point D. It will not go via point C, so I have to find out what is the

The air property is at point A. Point D property already I have noted down. So, I have used the energy required, the deviation from point A to point B. All these things I have taken out from the psychometric chart. And I see the energy required is 26.57. Earlier it was 8 only because I have been mixing the cool air return air, cool air, and then the resultant air temperature is close to D, but here I have to use the outside air. Suppose it is in the case of a hospital, I cannot use the return air; I have to use the outside air only, so I have to actually expend almost 26.57 kW. So, if I want it for 5 hours, In the case of the first case, I have to actually 5 hours of operation time of the particular building, almost 92.62 kW hours will be saved because these are only the A source; this is for the A plus B source.

So, there is a difference per hour of kW, multiplied by 5, will be almost 92 kWh, that is the unit of electricity, almost 1 unit, 100 units of electricity will be saved. So, I have used these references, and let us conclude with this, namely the air conditioning systems we have discussed. There are three types: refrigerant-based, air cooling, and water chilled water-based cooling, and we also see the air conditioning cooling load calculation by virtue of some psychometric chart and some temperature and the relative humidity based on that. If you have some doubt, please ask in the forum. We can come to you, and we can actually give you the solutions. And if you have some kind of problem understanding that one, we can definitely get in touch with you.

Thank you very much.