BUILDING ENERGY SYSTEMS AND AUDITING

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Week - 02

Lecture - 09

Lecture 09: Low Energy Cooling Systems - I

Welcome to the Building Energy Systems and Auditing course on NPTEL. We are in module number 2, where we are discussing the various types of building energy systems. In the past three lectures, we have discussed the HVAC system. The lighting system and also some of the electrical systems, including the pumps, escalators, and elevators. This lecture, the fourth one, and the next lecture, which is the fifth of this particular module, we will be discussing some of the passive cooling strategies and also low-energy cooling strategies.

So, today in this 9th lecture, we will discuss two things: one of the different types of low-energy cooling systems and also the earth air tube. So, as in when we call some energy-efficient design, we always refer to cementing systems, one is the passive cooling system and one is the low-energy cooling system. So, what is a passive cooling system? Passive cooling systems are actually based on some design philosophy which is driven by nature and also by some kind of natural energy flow that is going to be adopted in our building design. And traditionally, we have a lot of strategies that include the sun path diagram, the thermal mass, a certain amount of airflow, natural airflow in the building, shading devices, orientation of the building, etcetera.

And we try to design the building in such a way that we can take the maximum advantage of these nature-based cooling components and elements, and that will go on to reduce our indoor air temperature, the indoor humidity, or indoor comfort parameters also. Then what is the low-energy system, the low-energy cooling system? It is a conventional type of energy system that we have discussed, maybe in the HVAC or maybe in other types of systems. Conventional energy resources, just like electricity, can be used. But there will be certain component changes in that particular system.

Suppose, as you know, that the HVAC system is actually based on the refrigeration cycle. So, in that particular cycle, there are different components, and then some of the components we change, we manipulate, or we may have some kind of modification. Based on that modification, the energy requirement will be less, and we will get some benefit out of it. So, it is based on some kind of modification, and in terms of the psychometric advantages, I have written down over here. So, whatever those advantages are, we can discuss them in the next slide.

So, suppose this is the psychometric chart. So, in that chart, as we all know, if the state of a particular air moves in a horizontal direction. So, there will be either sensible heating or there may be sensible cooling. So, this is one of the axes. So, this is definitely going to take care of a lot of energy, or maybe it could definitely be used, I mean, if you want to cool it or you probably want to heat a particular air from one state to the other, keeping the humidity ratio the same, you need to do a lot of energy expenditure.

The other perpendicular axis is the humidification axis. So, here you see in this black color axis or the black color arrow. So, from one point to the other point, up and down, you may move. By moving that particular up and down, we are not going to change the DBT; DBT will remain the same, but the humidity ratio is going to change. So, the relative humidity is going to increase if you go up.

And by virtue of that, you will actually either have to take some kind of latent heat or you have to remove some kind of latent heat. So, this removal and the implementation of the latent heat will also take some of the energy because, as we all know, this particular axis is the axis of the enthalpy. Energy axis or so. So, any change from here to here or from here to here will have some kind of change of energy, right? So, if this is so, then these are the two such axes, and there are another two such axes which are inclined axes.

So, this is the green axis if you see. This is the evaporative cooling and the chemical dehumidification axis. Here, both things are actually going simultaneously. That means there is a sensible heat change, which is an increase or decrease, and also there is a change in the humidity ratio. But the important thing is that this particular axis, suppose I am going to

have three points: one central point and two further end points. So, here, as it is parallel—sorry, I am sorry, it is perpendicular to the energy axis or the enthalpy axis—there will be almost no change or negligible change of energy. STAT is one of the psychrometric advantages we can take, and we can manipulate that to think of something like passive cooling systems or maybe low-energy cooling systems also. So, there are another two axes which exist: heating and humidification and cooling and humidification, but those axes also take a considerable amount of energy in that particular way. It increases or decreases the sensible heat, and it also increases or decreases the humidity ratio or the change of the RH will take place.

So, let us discuss some of the types of low-energy cooling systems because we will discuss two or three low-energy cooling systems, and also, we will discuss one of the passive cooling systems in these consecutive two lectures. The first one is evaporative cooling. Evaporative cooling, as you understand, is the green axis of whatever we have discussed in the last slide. By virtue of evaporation, we increase the humidity ratio, decrease the sensible heat consumption of a particular mass of air, and that we can feel better, but definitely, that particular system can be adopted in hot and dry climates. So, there are two types of evaporative cooling systems: one is called direct, and another is called indirect; we will come to that.

The next one is the desiccant system. So, the desiccant system is another dehumidification system where we can dehumidify or sometimes humidify, and that we can actually have in two ways: there are some kinds of solid desiccants, and sometimes we can use liquid desiccants; we will have some graphical representation of that in the next slide. We have a radiant cooling system. So, that is another different type of cooling system, which is also very economical and comes under the low-energy cooling system strategies. So, we will discuss that in the next lecture.

We have geothermal cooling and also passive downdraft evaporative cooling. Of course, passive downdraft evaporative cooling is one type of evaporative cooling system. So, we will discuss passive downdraft evaporative cooling in the next lecture, and today we will also discuss geothermal cooling systems. So, now let us see the first two: desiccant and evaporative cooling. So, the first one is direct evaporative cooling systems; we just discussed that there are two types of evaporative cooling systems: one is direct, and one is indirect.

The working principle is that There is a pad which is a moist kind of pad, and warm air passes through that particular pad, and it becomes cool, warm air, and also very dry, relatively less humid air, and as it is moist, this particular pad is moist. The wetted pad will take some amount of moisture, some amount of vapor from that, and it becomes cool because there is a latent heat loss from the warm air. So, which is a desert cooler kind of desert cooler. So, climate suitability is hot and dry, and you need a supply fan, you need a pump for water.

It has to be regularly pumped and wet to this particular pad. And other things, a water reservoir you require, you require the wetted pad or the evaporative media. So, this is a direct system. In case of the indirect systems, there are two passages of air. So, one is the horizontal direction, suppose that is the warm air and the cool air, what we have discussed, and another one may be another way, that is an air stream secondary path that will actually again flow, and by that particular flow there will be some amount of humidity imparted in the warm air, and that particular humidity will be taken care of by the method of cooling.

So, in indirect systems, incoming outside air is cooled without raising the humidity. So, there will be some kind of humidity control because whatever humidity is actually gained by this warm air will be taken care of by the secondary air stream. So, this is also going to be useful for the hot and dry climate, and almost all kinds of components require only one heat exchanger and some exhaust fan is extra required. So, as you see, these systems are going to use some kind of a

Electrical energy definitely, but by virtue of this, the pattern and the components we have provided in this particular system require a little less amount of conventional energy sources. Now, next, we will discuss this desiccant. So, there are two types: solid and liquid. In the solid desiccant systems, what happens? The air actually passes through this desiccant wheel.

So, if you see the lower part of the arrow. So, it passes through this desiccant wheel, and this will actually take moisture out. This particular system is going to be fruitful in warm and humid climates where there is a lot of humidity in the air. So, whenever I take warm and humid air through this desiccant wheel, the desiccant wheel has some chemicals that will absorb the moisture, and it is also cooled down somewhat, and then finally, it passes through the thermal cooler, which is again a heat exchanger.

So, finally, what I am getting in my conditioned space is two levels of treatment. One is that the humidity is less, which is taken care of by the desiccant wheel, and the second is that the temperature is also less, which is taken care of by this thermal cooler. Now, this particular air will be circulated and then it will act as return air, and it will pass through a thermal heater, which will again increase the heat, and then again, it will go through the desiccant wheel, where it will take this particular moisture in, so the desiccant wheel is now balanced. It will be somewhere in the lower part, as you see it has actually absorbed moisture, and the upper part, the other part of the cyclic operation, it will be actually the leave, or it will transfer this particular moisture to the air, which will be going out as wet air outside.

So, finally, it will be hot, and some kind of wet air will be going outside. So, this is the system of the desiccant system. It is a dehumidification kind of system. The next one is the liquid desiccant system.

In the liquid desiccant system, this is a little bit complex. So, there is a cycle of the liquid desiccant. So, if I take hot and humid air here, as these red arrows show, it will go up, and there is a particular thermal exchanger there. Through that, it will cool down, and the liquid desiccant will spray from the top to the bottom. When the liquid sprays and the air passes through from the bottom, there will be contact, and due to that contact, it will lose moisture. So, dry and cool air will come out, and that will be the treated air.

So, it will be dry. So, there will be less humidity, and it will also be cool. So, it can again be used in warm and humid climates. In the other part of the desiccant system, where I have to again get some recovery, recovery of the liquid desiccant. So, this, you see, is the black color.

This black color arrow line and arrow is the desiccant flow, and it will actually come in the bottom part of this particular first box or the first container. From there, there is a green color arrow that is coming out, and if you see, this is going to be a heat exchanger. Again, it will go to this particular second chamber where it will the cool air will be coming, and there will be hot air coming out. From there, it will again release the moisture out, and then it can be used for the second cycle of operation. So, you see in both cases what happened is that the liquid desiccant or maybe the solid desiccant in the first phase It will actually absorb moisture. And in the second case, the reverse kind of technique is being adopted through the heating arrangement, and then it will lose the moisture again. It is ready to take further moisture in.

So, that is the process, and here in this process, it has used the liquid chemical desiccant as a chemical. So, this particular Process is called the liquid desiccant system. So, next, let us discuss a little bit more elaborately this earth air tube concept. The earth air tube concept is a geothermal process.

So, the concept is If you go a little bit below the surface of the earth or the surface of any site or any soil surface, maybe around 6 to 12 to 14 feet below, the temperature at that particular zone will remain constant throughout the year. So, that particular constant temperature will be almost about 15° to 27°, depending upon so many things, of course. The outside temperature depends upon the soil, moisture content, and all those other factors, but it will remain almost constant throughout the year. So, the heat transfer can take place in that particular zone. That means, in the time of summer, suppose I go back to the next slide, suppose this is the earth, and below the earth, I have some kind of arrangement of metal pipes. And through the metal pipes, the air is circulating.

Which air? Now it is from the air which is from the ambient air from some suction points. So, I am taking it in and that air is passing through that particular below surface, 6 feet to 12 feet below, and it is circulating. So, as the ambient air is having maybe a little bit high temperature, maybe around 35° centigrade, and this below that is 27°C or so, whatever is the temperature of the soil. So, definitely there is a heat exchange.

So, this 35° air, which is the outdoor air, when it passes through and it comes out, it may come out with maybe 31° or something like that. So, there is a drop between the ambient air of 4° to 5° or maybe a little bit more. So, this is the concept behind the earth air tube, and then I can actually use that particular 31° or the treated air, which means it is just after the earth air tube treated air. So, I have already the temperature of the outside air dropped down by 4° to 5°. And then I can take it to my centralized air conditioning unit and I can use electricity to further cool it and send it back to the building also.

So, my total amount of energy expenditure will be less. So, this is the temperature gradient. Ambient air temperature will be definitely high, and there is a drop in the air temperature due to the cooling effect of this particular earth air or the geothermal condition, and the EAT, that is earth air tube air, will be at a lower temperature, and I can use that one. So, there are some on site, I have to put some suction points. Those are the suction points, and from that dotted line curve, dotted lines are the schematic view of the pipes that were laid in this particular site. And from there, there will be some kind of a collecting point, a collection manhole, and from there I will take that to the yellow color box indicating my centralized AC unit and this.

The blue color shapes the rectangles, and whatever that is, it is my building. So, these are the suction points, and this is the collection manhole. So, the air will Air with a high temperature will come in. Suppose I have just now told you, suppose it is 35° centigrade, this is my earth air tube.

So, it is moving, and by virtue of a long distance moved by virtue of a high contact time, it will lose heat and will be collected over here as 31°C or so. And it will be channeled to the centralized AC unit, and from there, I may send 22° or whatever that may be further below, but at least my total pressure on the centralized AC unit will be less. So, I have some photographs; you can see those are the installations of the earth air tube. So, it should have a very long space available on your site, and definitely, the length of the pipe has to be more because you need time to take care of this kind of heat exchange.

So, it can be useful for large projects like buildings having very large landscape areas, you have a university campus, you have a big hospital, and it also has lawns and all those kinds of things. So, in those kinds of scenarios, you can definitely go for some kind of door there too. Some people say that this is not going to be a very fruitful system, but you have to adapt that particular system to the typical site or maybe the project. Every project cannot give a successful result if you employ the Earth Air Tube.

For smaller buildings or smaller projects, no, it has to be a larger site area, campus area, or something like a lawn area. So, for that, you have to ensure that the particular thing is well equipped or so. So, the effectiveness of the earth tube depends on the ground temperature, the depth of the tube, the diameter of the tube, how the tubes are arranged, the inlet temperature, outlet temperature, and the thermal conductivity of the pipe, which is very essential. It has to be a metal pipe. Very quickly, it should exchange the heat or so. The velocity of the air, the flow rate inside the air, should be very slow.

Of course, not so slow that it cannot draft a proper amount of outlet air for the requirement of the flow for your air conditioning purpose. So, there should be a moderate kind of flow and definitely the system efficiency. So, here we see there is a kind of tradeoff between the heat exchange process. So, in the first box, whatever I have written down is that the surface area of the pipe, if it is higher, it will increase the heat transfer rate and the contact time. And if the airflow is higher, it will definitely increase the heat transfer.

The tube material has to be highly thermally conductive to increase the thermal or heat transfer. So, therefore, we have to optimize the tube length so that it will give us the economy and also some kind of efficiency of the system. So, after a certain length, a certain amount of dispersion or movement, the heat exchange rate will fall down. So, we should not go beyond that length. So, we also have to consider the pressure drop because then the draft will not be proper.

So, length and all these things have to be taken care of. So, the efficiency of the systems will be given by this formula: (Ti – To)/(Ti – Ts), where Ti is the inlet temperature, how much is the outside air temperature through the inlet. To is the outlet temperature, which is after moving through the earth air tubes, how much is the temperature of the air which is in the outlet, and Ts is the soil temperature. We also try to find out the COP. COP is the coefficient of performance of the system, where it is defined as Q by W, where Q is your thermal benefit, how much benefit I am getting. By virtue of this system and divided by W, which is some work I have to do, some energy expenditure by a fan or some kind of a pumping system I have to provide.

So, that is your W. So, whatever your expenditure and what is your gain is your Q. So, the gain versus expenditure is a ratio, and definitely, the gain has to be more; otherwise, why should I go for adopting that? If Q is more than W, COP is greater than 1, it is efficient, and if it is less than 1, then it is an inefficient system. So, let us solve a small numerical problem. So, I have given the data. So, in the data, I have given the room, I have stated that this room needs 6 air exchanges per hour.

So, I can calculate how much is the flow of the air, and I have assumed that 50% of the outdoor air is treated through the EAT, and the 50 % is the normal. So, the 50% of the air I will take through the earth air tube, and I will drop down the temperature. The outdoor ambient temperature is 38°C, quite high, and the indoor temperature I want to retain as 25°C. So, and I have estimated that a 5-degree centigrade temperature drop will be achieved by the EAT. So, a 5° drop means the 50% of the 38° air, when it passes through, I will expect 38 - 5, that is 33°, will be the temperature of the EAT.

And soil temperature is 27°, and the specific heat volume and pipe diameter are all given. The last line, whatever I have written, is that to operate this system, I need two fans of 140 watts each and one pump of 1000 watts. So, I have to find out the coefficient of performance, the velocity of the air in the tube, and the efficiency of the EAT system. Inside the tube, the efficiency of the EAT system and the daily savings in energy are also to be determined. So, this is the flow.

So, now we know how to find out that one by the 6 air exchanges or so, and the flow rate is also 1.25 m^3. This is through the EAT because half of the air is from the EAT. So, by virtue of this heat loss equation, if you see, the first one is V multiplied by A, which is your velocity in meters per second, multiplied by the area of the pipe in m^2. So, finally, it gives you m^3/s, which is your flow rate. So, I have mentioned in the last part that it is nothing but this Q, which is the flow rate in m^3/s, and Sb is the specific heat, which is mentioned, and this Ti - To is the temperature difference.

Heat loss is calculated using this flow rate Q, this S V, and this temperature delta T. I have told you that because of this particular process, a 5° temperature loss is being found, and the work done by the system includes two fans of 140 watts and one pump of 1000 watts. So, that much work expenditure is due to the work, and the coefficient of performance is 6.1, which is very good, I mean, more than 1 and a very good number. So, this much is the work expenditure. So, 6.1 is my coefficient of performance. So, 6.1 is my coefficient of performance.

Similarly, I have found the cross-sectional area, I can find the velocity of the air, I know the Q, I know the area. So, I can find the velocity of the air, and I can also find the efficiency of the system because I know everything. I know the outdoor temperature, the inlet temperature is 38, and the outlet temperature has a 5° drop. So, 33° and 27° is the soil temperature. So, the efficiency of the system is 0.45.

Similarly, now I can find out how much energy is required or so. So, through the EAT system, I can find out that that the first one, whatever I found out, is that if there is no EAT system. So, only all the 100% air is actually treated by your air conditioning unit. So, your total flow rate is 2.5, that is your Q, this is your SV, and this is your delta T, 13°, because why 13°? It is 38° to your 25°.

So, that is your 13-degree temperature drop if you do not have any kind of EAT system. So, this is 325 kW-hours, your total energy demand for 8 hours of operation. But if you are using an EAT system, then 50% of the Q, that is the flow, will have a 13-degree drop, and another 50% of this is 50% of overall, this is 50% of overall. is an 8-degree drop because why 8°? Because this EAT temperature is now down to 33°, and your set point temperature is 25. So, there is an 8-degree drop.

So, it is working for 8 hours. So, you have to actually calculate your expenditure, which will be around 262.5 kWh. So, what is your total benefit? What is the total benefit for these 8 hours of operation? I have deducted 325 - 262.5, but also, I deduct 1.12 x 8 because this 1.12 is nothing but your work done. So, that also has to be taken into account. So, finally, your total amount of benefit from this system is 52.26 kWh, which is very good. So, that is why it is called a low-energy cooling system.

You are getting the same effect, a 25° temperature, but a portion of the the air is treated through the earth air tube, and you are dropping the temperature by 5°. That means you are using some kind of energy for running the fan and the pump, but still, you are having a 52.26 kWh benefit. This example will show that an earth tube is beneficial, but of course, it has some of its own disadvantages. I have already discussed that, and those disadvantages are that you have to be very careful about choosing the particular project. So, low-energy cooling systems operate by alternating a few components of the conventional systems to reduce energy consumption, and the earth tube is one of those.

Thank you very much.