# BUILDING ENERGY SYSTEMS AND AUDITING

**Dr. Shankar Pratim Bhattacharya**

**Department of Architecture and Regional Planning**

**IIT Kharagpur**

**Week - 02**

**Lecture - 10**

## Lecture 10: Low Energy Cooling Systems - II

Welcome to the NPTEL course on Building Energy Systems and Auditing. Today we are in module number 2. In module number 2, we are discussing the topic of building energy systems, and today is the 10th lecture where we will discuss low-energy cooling systems. In the last lecture, lecture number 9, we discussed the earth narrative, and in this lecture, we will cover two important parts of low-energy cooling systems: one is radiant cooling systems, and the other is passive downdraft evaporative cooling systems. The radiant cooling system is basically a kind of system where chilled water flows through floors or sometimes wall panels, radiating heat and cooling the inside of the building or space.

There are two types of radiant cooling: one is called the chilled slab, where pipelines are placed below the roof slab, between the roof slab and the false ceiling or suspended ceiling, and these pipelines are filled with flowing chilled water. A similar kind of chilled panel can also be provided, which is part of the wall or maybe the full wall. Chilled water passes through the valve system, and definitely, that valve must be external because it will take the maximum amount of heat gain. That particular heat gain will be nullified by this flow of water. So, the room is going to be cooled, or in other words, the cooled airflow will chill the panel, chill the slab, and from there, the radiation will take care of the total temperature drop of the particular space. In this slide, I have shown a particular chilled air system, which basically represents a slab with some pipelines. These pipelines pass through the whole surface area of the slab and are filled with flowing chilled water. The temperature may be around 8°C, 10°C, or so. By passing through, and if there is a kind of fan or a downdraft system over there.

So, a Descending air will actually be cooled, and that can come from the ceiling or sometimes it can also be implemented in the walls, so it comes from the wall. So, that is the concept of this particular type of radiant cooling system. So, by virtue of this particular process, the chilled air, when it is returned back to the plant. So, I have shown that one in red color dotted like this one; it will be a little bit hotter.

So, by virtue of the thermal exchange, it will be a little bit hotter because it is passing through a surface which is a hot surface, and the hot surface becomes cool. So, where will that particular heat go? It will go to raise the temperature of this cooled air or the chilled water. So, those are the basic principles. Now, let me understand how this particular behavior or this particular system behavior can be mathematically modeled. So, there are two things happening simultaneously.

One is the heat is going to be absorbed by this cooling system or the radiant cooling system. So, what is this radiant cooling system? It is the chilled water which is going to pass through this particular embedded mechanism of the slab or maybe below that; anyone can be implemented. So, this heat will be absorbed by this radiant cooling system. So, if it is absorbed, somebody has to lose the heat.

So, which part of the system is losing the heat? It is nothing but the room; the whole air in the room is actually going to lose the heat. So, I have represented the heat absorbed by the cooling system by capital Q, whereas the heat loss by the room is represented by capital H, and this must be equal. With a kind of efficiency mark or whatever factor, this heat balance must be equal. So, let us see how to compute this Q and how to compute this H. So, Q can be computed as A into V. What is A?

A is the area of the pipe, and V is the flow or the velocity of the water passing through this particular chilled pipe. The rho W is the density of the water, S water is the specific heat of the water, and T out and T in are the outlet temperature and the inlet temperature. As, by virtue of the heat exchange, the outlet temperature will definitely be higher. So, suppose there is a chilled panel kind of thing.

So, if you are sending some 8°C temperature, definitely this will come out with maybe 18°C temperature or so. So, this T is going to be your T out, and this is your T in. So, the difference, delta, is your 10°C or so. So, now if I see this, A is your $m^2$. I always love to do the unit balance. So, that can give me some kind of confidence that these two sides are equal, and what will be the units of the final unit.

So, V is your meter per second, this is multiplied by the rho, which is your $kg/m^3$. Into this is your J/kg/°C multiplied by this is °C. So, this is your $m^3$. So, I will do it over here itself. This is $m^3$, $m^3$ gets cancelled, kg also kg gets cancelled, °C and so it is left with joule per second, which is your watt. So, this much is your total heat gain through the system, because of this chilled water passing through and there is a temperature difference. But the next H, how should I compute H?

H can be computed, what is H? H is the heat lost by this particular air inside a particular space. So, how much is the volume of the room? Vr, the Vr is the volume of the room. And what is S air?

S air is the specific volumetric specific heat of the air. So, how much joule temperature is required to increase 1° temperature of 1 $m^3$ of the air or whatever. So, again if I do this particular unit balance, V is in your $m^3$ multiplied by this $J/m^3$. And this temperature is your °C. So, finally, I will come out with J, not J/s here. So, that is the total amount of the energy that will be taken out by the room.

Now, you see there will be an equilibrium condition. So, somebody is passing through and taking out some kind of heat, and somebody is losing the heat. At a certain time after this, there will be a steady state. Initially, there will be a very high amount of energy loss, and then gradually it will reduce down, and there will come a time which I call the steady state time or whatever will be reached after t seconds in such a way that the total loss will be equal to the total gain or whatever, and then thereafter there will be no change.

If there is no certain change in the temperature or so. So, if you change the temperature of the inlet water, definitely things will change or whatever, but otherwise, it will remain constant. Suppose that constant equilibrium state or the steady state will take T seconds after you start any kind of flow or so. So, this Q into T, Q was in joules per second multiplied by some seconds with some factor of eta because there is definitely some kind of loss or so, there is some kind of efficiency factor. So, that I must be equal to H.

Then this H is in joules. So, both sides, the right-hand side and the left-hand side, the units will balance. So, finally, my equation, the mathematical modeling equation, the mathematical modeling of the radiant cooling will be Q into capital T into eta, the efficiency factor, must be equal to the heat that is going to be lost by the particular space. And H and Q can be computed by virtue of these two equations. So, again, let us solve a small problem.

So, data has been given that for a radiant cooling system, the velocity of the pipe through the pipe is 0.3 m/s. The diameter of the pipe is 75 mm. So, definitely, I can find out the

A, and this is the V, which is already there. I know the inlet temperature and the outlet temperature are 12° and 22°C. In the previous case, we discussed that as 8° and 18°, something like that. We know the room dimensions, we know the initial temperature of the room is 40°, and that will definitely be cooled down because it has to lose some kind of heat by virtue of the system.

The capital T is this, capital T is this, 10-minute time is the capital T. The efficiency is 50%, and the work done by this cooling is 45°. So, what I have to find out is what will be the final room temperature after steady state. So, definitely, that temperature will be much less than 40°, but I have to find out what should be the temperature, and also I have to find out the COP, the coefficient of performance. So, I have found out this particular Q by virtue of that equation that we have discussed.

This is my area; I found out the area. V is already given; rho and S are known, the specific heat and the density of water, inlet temperature, and the outlet temperature. So, if I give everything over here, I got 55.5 kW, joules per second. Or kilojoules per second is the total Q, or the heat flow that will be taken away from the room to the pipe's water. Similarly, I have to find out now H. So, the equation is this equation where I know the room volume is 1000 $m^3$. The specific volumetric specific heat of air I know.

I know the initial temperature, but I do not know the final temperature. So, that will be the unknown in this equation. So, I put the V, I put the S of the air, I put this to the temperature, and finally, it has to be something like 1250 x (40 – T). If you remember, this heat H that comes out from the room will come in joule or kilojoule or megajoule, whatever it may be, but the Q is in the form of watt, kilowatt, or something like that. So, I have to multiply by time.

So, that time is also given to me as 10 minutes, which is equal to 600 seconds, and 50% is the efficiency. So, I will go back to the third formula where Q is 55.5. This Q is 55.5, T is 600 seconds, eta, that is the efficiency factor, is 0.5, and the total H is there, and my only unknown is T. So, by solving, I got T is 26.68°, which is far below those 40°. Now, I know that this particular system works well. So, that means if I run the system with this 12° temperature and whatever the flow velocities and whatever the cross-section diameter of the pipe, it is definitely going to help me, and my temperature will be going down from 40° to 27° or something like that, but whether it is beneficial.

So, I have to check with the COP, the coefficient of performance; it has to be more than one; otherwise, I do not want to employ this system because I have to work. I have to have some kind of work, and that work should give me some kind of benefit. So, the COP I have found out is the Q, which is your 55.5, whereas 45 kilowatts is your total expenditure by virtue of running that I have mentioned over here. The 45 kilowatts is the work done for the cooling. So, that is your W.

So, by virtue of some kind of cooling arrangement, we have to cool the water or so. So, you may use some portion of evaporative cooling, then maybe some other type of cooling, and then some kind of refrigeration cycle it has to be passed through. So, a total of 45 watts is going to be your total amount of energy expenditure by running this cooling system. And you have to use pumps also, and your total heat loss is about, if I go back a little bit, 55.5 kilowatts. That is the total heat you are getting taken out from the room.

So, that is your benefit. So, this is your benefit, this is your expenditure, which is slightly above 1. So, we may decide whether we can go with this system or not, or sometimes we may want to reduce this 45 to a little bit less. So, we can get a better value of the COP. 1.23 is definitely acceptable.

But, we may not go with it because it is not that high of a value. The earlier exercise in the last class, whatever we saw in the last lecture, was almost like 6. Anything around 3 is very much appreciated. So, next, we will discuss the passive downdraft evaporative cooling system. This is a purely evaporative cooling system.

And in this particular system is used for a long time. In some of the desert areas, if you go to some of the areas like the Arabian countries or so, this particular system is used widely. So, the system is something like if I want to see, this is a kind of cooling tower. And this system is also called a PDEC, the passive downdraft because it is a downdraft from top to bottom. I will take the air in and I have to cool it. So, here you see in the top part of this kind of shaft, it is a shaft kind of thing, there are some baffle valves and there are some outlets or the punctures.

So, those punctures actually take care of the hot outside air in, I have shown in red color arrows. And this ruffled wall will try to channelize that towards below. Please remember that the hot air is lighter. So, it always wants to go upward in direction. So, this baffle wall will be such a way has to be designed and there will be some kind of mechanism of some kind of a pump, downdraft pump fan, not pump will be there.

So, that will actually take that particular hot air into that particular shaft. The next level, this is the entry level, the next level you see there are some kinds of the wall and some kind of the systems has to be adopted where the water sprinkler systems have to be there. So, water will sprinkle from top to bottom or probably from bottom to top and bottom something like that and that will provide such a way that whenever the air flows towards the down it should pass through this wet water wall or the surfaces. So, there may be some kind of a Hanukum kind of surfaces which is always going to be wet by some kind of a

The water sprinkler, and through that water, this honeycomb kind of surface, air is actually passing through. The movement of the air is guided through those particular holes and pores, and it will go down. Maybe there is another fan below which again drops that air a bit. So, if you imagine that this very slowly, this hot air is passing through this particular honeycomb kind of structure, which is wet by water, it will take care of the moisture from the wet wall or the honeycomb structure, and it will cool down by virtue of evaporative cooling. And by virtue of this particular evaporative cooling system, whenever it comes to the third layer, again, there are some kind of baffle valves that will deliver this cooled air or the air after evaporative treatment to the different levels or so. You see now the blue color arrows, which means cool air, which was hot in the first layer, now it is cool through the second layer, and now it is channelized to the different levels, upper floors, and lower floors or so. So, this is the total mechanism, and maybe in the end, you can have some kind of pit where you can actually get some water because some water is definitely going to fall down, and you have to collect that and again recycle it to the top.

Of course, the water temperature will be a little high, and you have to again make it a little bit cooler. So, by this draft, the downdraft passive downdraft evaporative cooling system, it can only be applicable where the evaporative system is applicable, that means in climatic zones like hot and dry climates, particularly in desert climates, it will be very, very good to provide, and it will be very efficient in those kinds of desert climates. You will get a very high value of COP over there, and you will get very cool air, and that will definitely help the indoors. So, again, let us see from the mathematical modeling because simple mathematical modeling is always important because you need to see whether, I say, Adam, we have seen the last one. The COP value is something like 1.23, which is more than 1, but not so good with respect to the our whole sole expenditure or so. So, we have to see how much is actually our benefit, how much I can cool down. There, I am going to cool down from 40° to 26°, which is good enough, but the COP value may not be that good. So, I have to see here also what mathematical modeling I can propose for this particular PDEC system. So, again, we have to see the two parts: somebody is losing some kind of heat, and something is

So, this heat loss or heat lost and the heat gain should be in proper balance with each other. So, how much heat will be lost by the air is written in this equation. So, HL is the Q of air, where Q is the flow rate, how many $m^3/s$ of air are coming from this particular inlet level. And the S air is your volumetric specific heat, Ti and To are your inlet temperature and outlet temperature. But here, the inlet temperature will be higher than the outlet temperature because, by virtue of this process, it will lose some heat.

So, that is why Ti minus To is written. Now, this particular heat loss by the air should actually be absorbed by someone, and it is actually absorbed by the water. So, the heat absorbed Ha by the water is nothing but the Ea, where Ea is the rate of evaporation multiplied by the latent heat of absorption, which is how much is absorbed. Rate of Evaporation. The rate is how much per second, how much rate it is evaporated.

So, how much water is now evaporated? The water was in a liquid state, and after one second, how much water from the liquid became vapor. So, that is the rate of evaporation. And by virtue of multiplying with the latent heat, which is 2260 kilojoules per kg of water, if I multiply that, I can find out that this much amount of heat is actually absorbed by the water, and that water becomes a vapor percentage or that particular amount becomes vapor. So, this Ea first we need to find out, sorry not Ea, Er, where Er is the rate of evaporation. The rate of evaporation is

Can be found out by the difference between these two ratios, HRo and HRi, the humidity ratio of the inlet and the outside humidity ratio of the outlet and the inlet. O stands for outlet and the R. So, there is a here at least at this particular point is the outlet HRo and at this point maybe it is your HR inlet. So, there is a difference. So, humidity ratio has a I am just writing this wrong this will be HR inlet this is HR outlet. So, definitely this will be high, this will be very high, this will be low.

So, from this high to low the difference of the humidity ratio multiplied by the Q of air that is the flow of the air and multiply by rho of air or so density of air or so. So, by virtue of this I can find out what is the evaporative rate and I can use that with the latent heat and I can equate that one. So, again a small numerical problem at the last we can solve.

So, in a passive downdraft evaporative cooling system, I have the following data: the cross-section area of the inlet is 0.5 $m^2$ and the velocity of the air is 0.25 meter per second. So, I can find out this q air by virtue of that.

And, then I also know the temperature of outdoor air is 38°, humidity ratio in the outdoor air is 6 and humidity ratio at the indoor air is 14 grams of water per kg. So, find out the outflow temperature. So, I have used this equation. So, I know that this is the rate of the air flow by multiplying this the the velocity and the cross-section area.

Cross-section area is 0.5 $m^2$, and velocity is 0.25 meter per second. So, again, let me write down this: Q is nothing, but Q of air is nothing, but your area multiplied by the velocity, right? This is. So, that gives me 0.125 $m^3/s$. So, that is there multiplied by the Sv. Sv is your 1250 $J/m^3$.

So, again, let me do the unit balance. This is $m^3/s$. I got, and then I multiplied with the specific volumetric specific heat, $J/m^3°C$, and this delta T is in °C. So, very similarly, I got the value of joule per second, which is what. So, that much, what? But here, this term is still yet to be found out, that is, how much is your treated air temperature. I have taken the air from the inlet as 38°. What will be after this passive cooling? How much is the temperature? I have to find out. So, now, let us look at the other part of it: heat absorbed.

I know the humidity ratio in and out. I think it was something, sorry, see, it was 6 grams to 14 grams per kg. So, this is (6 – 14)/1000. So, that is the kg. That becomes the kg from grams to kg, multiplied with the inlet airflow, that is 0.125, and this is the 1.225, which is the density of the air. That means 1.225 into 10 to the power minus 3. This much is your kg of water per second, the evaporative rate, right? So, because this is your change of evaporation, that much water changes, that much particular water from 14 to 6, is the change of the water content, moisture content of the air, and this moisture content of the air is applicable on a flow of.

1.125 $m^3/s$ with some density. So, that means, this much $1.225 \times 10^{-3}$ kg of water per second is evaporated out. So, that is your ER. So, $1.225 \times 10^{-3} \times 2260$ is the latent heat of the air, and what is this 1000 is actually going to be transferred from kg to kJ to J, and so that is this much of watt is your total amount of the heat absorbed by the air by virtue of the evaporative cooling.

So, I have both the things ready, HL and HA, just equating that I can get the T. The outlet is 20.3°, which was 38° in the beginning on the inlet side, 38° to 20.3°C or so. So, these are some of the examples of low-energy cooling systems in India. There are some books on it. So, you can visit those books and know more about these particular systems.

So, what we understand is that, in conclusion, we must say that radiant cooling systems and passive downdraft evaporative cooling systems are two very efficient methods of low-energy cooling systems, but definitely, we have to look into where should I go, should I adopt this particular thing, what is the COP value, and all. So, the radiant cooling systems work based on the sensible heat loss or gain, sometimes if you send some kind of hot water, whereas the PDEC system is purely an evaporative cooling system. Thank you very much.