BUILDING ENERGY SYSTEMS AND AUDITING

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Week - 03

Lecture - 14

Lecture 14: Cooling Load Calculation-II

Welcome to the NPTEL course on Building Energy Systems and Auditing. So, in Module 3, we are discussing building heat load estimation. In this fourth lecture of Module 3, the cooling load calculation part 2 will be discussed. In the previous discussion in the 13th lecture, we discussed how to take care of the periodic heat flow. How the variation of the two climatic data of a particular area, the outdoor temperature and the solar radiation of some different surfaces, can be taken into account.

So, today we will see this periodic variation, but also how this periodic variation can be normalized with the average data. So, we will look into that. We will see how this variation is actually going to play a role in total during a particular period. So, you see, particularly in any place, this variation in temperature is periodic. Even the variation in solar radiation is periodic.

Periodic means, if you take a certain time, maybe 12 hours or 24 hours for a particular day, it is not constant. It changes; it increases, then decreases, then increases again, something like that. But this periodic means this particular change will keep repeating, maybe the next day or the second half of the period or whatever. So, that is going to be a periodic function, but exactly that periodic function may not be because all periodic functions, if you see simple harmonic motion or so, will be either a sine function or maybe a cosine function. But this change of temperature, this change of solar radiation for any kind of surfaces, is periodic. Today, what we see are fluctuations. Next day, tomorrow, we will see more or less the same fluctuations, but that is not going to be purely a sine or cosine function.

That is number one, but that is not going to hamper our discussion, and that much of mathematical modeling may not be required for our calculations or so. If we see that a periodic function is applicable for a day, what is the change of the periodic function the next day? It will be very, very minute. You may say that there is a change in the periodic function from the summer month to the winter month. Yes, there is a change because of the angle of the solar altitude or the azimuth angle that is going to change.

The total solar hours will change. So, based on that, there is a change. But if you take, for example, today, maybe the first of January, and the second of January, there is not much change. Even if there is, we may say there is no change. If there is some kind of fluctuation or atmospheric changes in that particular locality, there may be a change, definitely.

But if you take the last 50 years of data for January 1 and January 2 in a particular location. And if you see that the fluctuations are more or less the same. So, similarly, we can say that a particular set of data for a particular time period, maybe one month or so, will remain almost the same, and then it will gradually shift to a little bit hotter, maybe in the month of February. So, over a time period of data, we may say things are almost the same, and that will ease our computation, and that will apply to a large amount of data calculation, like for annual calculations, right? So, let us go to a brief discussion about these particular changes.

So, suppose I have 3 timelines, maybe 10 am, 11 am, and 12 am in the morning. If you just go outside, there are three different temperatures. The temperature is increasing from 20, 24, and 27° in these particular three times. There is a 4° change from 10 to 11. There is another 3° change from 11 to 12, right?

There may be a change in the I value. I think this is the radiation. The radiation at 10 may be 50 W/m^2. The radiation at 11 is 120, which is high, and again, it may be low at 80 at 12, maybe on the eastern side or maybe the northern side. So, based on these two values, the blue dot and the yellow dot,

we have three different values of the solar air temperature, different values of the temperature difference, so at the end, we have different values of the conductive and the radiative heat gain. So, we have seen in the last lecture or last discussion, yes, we have computed for all the 10 hours. All the 10 hours, this solar air temperature, the temperature difference ΔT, and also the conductive and the radiative heat gain. Let us do the same for these particular 3 hours and let us do these things for some other types of hours, maybe 12 hours, maybe 24 hours for a day. So, there will be some kind of periodic changes or so based on these 3 data points that will change. This is the nature of the supposed temperature variation or any kind of maybe the solar radiation variation also for a particular given period of time.

See, this is periodic. The next day, if you superimpose the temperature data, it will be more or less the same, and the next day, more or less the same, and then gradually it will change if the season changes or whatever. So, a particular snapshot, let us say, this is the variation. So, if I can find out the mean of the variation, I may say that this is the mean line. That means, if I have the mean of those data up to 12 hours data, 24 hours data, this dotted line is the mean line. Now, this periodicity, the periodic form, why this mean, where is the mean?

This mean will be exactly at the center point of all the data, where the amount of the higher data and the amount of the lower data from the mean almost will be equal or should be equal because that is why that line is called the mean. So, there will be some observations or fluctuations above the mean, and there will be some observations below the mean. And because this is the mean line, we may say that the sum of the mean deviation above the mean deviation and the sum of the below mean deviation has to be equal, and that is why this is called the mean line, is it not?

So, the amount of the above mean deviation, that means these are the green up arrows, plus if I add up and the downward red arrows which are below the mean, plus that means the sum of those the green will be equal to the red because that is why this particular mean line has been developed. I mean, by all the data and adding all the data divided by the amount of data. So, the mean is developed based on that. So, if I see this mean calculation, if I only calculate based on this mean value.

I am not going to do 12 times or this 10 times or maybe 24 times periodic computation of all the data; instead, I will just take the mean. So, can I get the same effect? Let us see. Let us see whether I can get the same effect or not. So, this is called the periodicity of the mean.

So, I have taken a simple area, I mean a particular window I have taken, of an area of 10 m^2. The U-value of the window is 4, SHGC is 0.6, the absorption values are 0.5, and the conductance values of the surfaces are 20. And the first point I have written is that the heat gain through the given window is computed based on the conduction and the radiation over these 5 hours. This serial number 1, 2, 3, 4, 5, the output temperatures are 20, 25, 30, 35, and 30. I have taken some random numbers and also I have taken the solar radiation for those 5 hours as 0, 50, 75, 175, just some random numbers. And I have $10m^2$ of the window area, and those are the property values.

So, I want to use the solar air temperature, calculate the solar air temperature for those 5 hours, calculate the conductive gain for those 5 hours and radiative gain for those 5 hours, and add up and see what the effect is, and let us see what the effect is for the mean wave. So, here I have, just like in our lecture number 13, I have calculated the solar air temperature by this particular formula and using this data, and I got the variations right, and I also have the indoor temperature. I think I mentioned over here that I have mentioned that this indoor temperature has to be, I mean, I am assuming it is 18°; I keep it at 18° and I got the ΔT for all the 5 hours.

I got the A, the area of this portal windows 10, U value is 4, SHGC is 0.6. So, the conductive heat gain from this equation area multiplied by the U x ΔT based on the solar, solar temperature and the T indoor set point temperature. I also calculated the radiative heat gain from the area of the window, the SHGC of the window and the corresponding I value of those 5 hours. So, you see the first hour it is 0 conductive heat gain.

Why? Because the radiation I value is 0. The first hour as I value is 0, the temperature outside temperature becomes the solar rate temperature because this I value is 0 in that case, right. So, I have calculated. After this calculation, what I did is that I have added up those values, those 5 hours values and this is the, I think I have mentioned over here, no, sorry.

I have added up these values, total conduction value is 2300, sorry. What is this 2300? Total heat gain conduction, total heat gain through conduction, 2300 watt. And this yellow box indicates the average heat gain throughout these 5 hours. So, that is this is average, this is total.

So, how did I get the average to total? This 460 x 5 hours. It gives me that gives me 2300. Similarly, the radiation average is 360, the average is 360. This is your average, which is your 360 watts x 5, gives me the total, which is 1800 watts. Right, so this is the average and this is the total. Similarly, I have also found out how much is the average temperature, solar temp, sorry, the outdoor temperature, 28°. What is the average solar radiation? 60.

28° is the average temperature. The average solar radiation is 60, not 300, 60. Average solar air radiation is 60. Total is 300. Total is 300 for these 5 hours. 60 into 5.

So, this is 60 into 5 is equal to your 300. Average solar air temperature is 29.5. And average ΔT is your 11.5. So, based on this 5-hour calculation, I found the average or mean value in the yellow boxes, and the total values are in the green box. Now, see if I use this average outdoor temperature, the average solar radiation.

Could I get the average TSA? Should I get the average ΔT? Should I get the average? Heat gain: should I get the average heat gain through radiation and conduction? So, if I use 28 and 30 instead of all five, should I get 29.5? Should I get 11.5? Should I get 460 and 360? And after I get 460 and 360, I can just multiply by 5 and get the total. That is my ultimate aim. So, let us see. Here is the same fundamental, and then see. I have to first find out this average solar air temperature based on the average values of the outdoor temperature and the average value of the solar radiation.

So, these values are, you see, the 28. Why 28? This is your 28 average values. See, if you go back, this is 28, and this is 60. Please remember these two values.

So, this is the average value TOA bar, and this is I bar, which is 60. And I got exactly 29.5 as the average solar air temperature. You see, the average solar air temperature is 29.5. So, if I now find out the conductive heat gain, the area is 10, 4 is my U value, the average TSA is 29.5, and my indoor set point temperature is 18°. By calculating, I got exactly 460. What is 460? It is the average heat gain through conduction.

And if I multiply that by 5, I can get 2300 watts. Why 5? Because this average is based on 5 hours. Similarly, if I find out the radiation, the 10 is the area. 0.6 is the SHGC, 60 is the average I value, this is the average I value, and I get exactly 360, which is this, and if I multiply that by 5, I will get 1800, which is the total heat gain through the radiation.

So, that means instead of doing this whole process, I can actually, if I know this data, actually, if I can calculate this average data, I will get the same result for the day for 5 hours. And if it is going to apply, if I apply it for 12 hours, if I apply it for 24 hours, or if I apply it for 1 month, it will be the same. Because the periodicity is such that, as we have seen, the total amount of positives and the total amount of negatives are exactly equal, some of those are exactly equal.

So, if I want to see what is the total day load, total weekly load, total monthly load, or annual load. I can exactly go with the average annual temperature and the radiation, average month-wise radiation and temperature, and all those kinds of things. So, no need to go for the whole calculation that we did in the past lecture or so. The past lecture was definitely required to know how things are going to happen, but here we want to try to take a shortcut path.

But that shortcut should not give me inaccurate results. So, definitely, I am getting an accurate result for a particular day, particular month, or whatever. And annually, I will not take the average, maybe. Only what I can do is take the average solar radiation, maybe for the summer month or some other month, or maybe the average solar radiation and the temperature data for each month or so, and that will give me a tentatively very accurate kind of result for annual heat load or cooling load calculations or so. So, as we have discussed, multiplying by 5 will give the actual result or so.

So, we are very happy that now we can actually use some less amount of data and try to find out the actual impact annually also. So, here I have taken just a hexagonal kind of space, and the same U value, SHGC, and surface absorption I have taken. The building height is 6 meters, and the north, east, west, and south walls are of 12m in length. So, that means the 12m areas can be calculated, and the northeast, southeast, southwest, and northwest walls are of 10m in length because it is an octagonal shape. So, there are 8 directions.

So, those will also take some changes in the radiation, and all those things will be taken care of. So, that is the 10m length. So, the facade area can be calculated. Assuming all the walls will have 15% of the WWR, the indoor set point temperature is 24°, and suppose the building is located in Delhi, which is at 28.7° north latitude, and the building works for, this is very important, 20 days a month and 8 hours a day, and what I want to see is I want to actually project and estimate the annual load. So, what do I need?

I at least need the monthly average temperature, number one, and the monthly average solar radiation of all nine sides. Why nine sides? There are eight octagonal sides and a horizontal roof. So, for all nine sides of the facade, if I know the solar radiation data average per month, there are 12 such data for each side and 12 such average monthly temperatures. So, based on that, I can calculate the monthly

requirement of the monthly cooling load and ADAPT, and then finally the annual cooling load. So, again, I have used the Excel sheet. So, this particular data I am going to use. It is the NBC data; NBC part 2, volume 2 has given this data. So, it is for 9, 13, 17-, 21-, 25-, and 29°s north latitude in our country and all nine facets data are mentioned for the summer month and the winter month. So, Delhi will be in and around 29°. Calcutta will be in and around 21° north. So, your city locations will be very close to, I mean, you have to take the closest north on the data of that particular. So, if I see Delhi,

Suppose, Delhi South wall. Delhi South wall will actually receive in the summer, I think, yeah, first line is the summer, 1350 W/m^2day. So, that means, if I assume that 12 hours is the duration of the sun duration also. So, 1350 by 12 W/m^2h will be this particular.

The winter month will receive more in Delhi. See this is the winter of Delhi which is 4981 by 12. Watts per meter because I am assuming this is my assumption that 12 hours is the total radiation from something like that, I mean it may not be exactly 12 hours it also fluctuates in the summer month and the winter month, but let us assume this as 12 hours. So, these are the data I have taken this is the first 21° north is for Kolkata. And this is for Delhi.

And I have also taken down the Kolkata and the Delhi monthly average temperature and I use this particular data. So, I know the north facade data for facet area is 72 m^2. Northeast and those four walls are of 60 m^2 and the roof area calculated from this particular geometrical shape as 506 m^2. Of course, the roof is very high compared to the other wall. U value SHGC values are constant for all the facet.

I mean for roof, wall, and all this facade, the indoor temperature is 24. Working days per month is not 24; it will be 20, I think. Yeah, it will be 20 days. So, this is a typological error. This would be 20, and this will be the working hours per day, which is 8. So, I have calculated this thing in the Excel chart. This is that Excel chart. So, in that Excel chart, you have length and height, just like the earlier one, the length and height, and WW are for all the nine facets. So, you just keep on changing your building as different, different. You may have some area, some facet missing, maybe. Maybe it is your square building, and you have only the northeast, southeastern also. Do not put anything in the north, east, and west. And those facades, give the wall data, material data, Table 2. If you can fill all this, the green one is what you are actually filling there. You have to fill, and this is also, of course, partially white. So, I must give this as also as green. I am sorry; this has to be green.

So, now you give the the data of that particular latitude of north, from your NBC, north, northeast, south, southeast, summer month, and the winter month. I have assumed here 4 winter months and 8 summer months. The four winter months are November, December, January, and February, and the rest all are calculated in this particular Excel chart as the summer months. This is the outdoor temperature. This is the Delhi data. This has to be 20.

I have to change it to 20. This is the working hours, and based on that, you see your value changes or what is this first? The charge per month in the X-axis, the Y-axis is the building load, kWh. So, for the month of January, 3040 kWh will be the total load, cooling load. And this is only the envelope heat gain, not the internal heat gain.

So, it is increasing and may be highest at this particular point of the month of May in Delhi, and then gradually going down. So, this is the heat gain through different walls with different facades and all, and this is the roof, which is actually very high because your roof area is also very high compared to those of 72 and 60 or something, and that was 500 something, 509. Definitely, it will be very high. The roof is exposed too. But all other surfaces are almost very similar.

The north is very less compared to the other eight. The east is high. The west is also very high in Delhi. So, we have to really take care of the east and west in Delhi. Of course, the roof is always going to be exposed.

So, now if you change this data for some other cities, you have to change this data. So, from the NBC, you take the nearest north latitude and put those values, and for your city, you just check and give the monthly average temperature data. You can change the working days; suppose yes, it is a hospital building. So, let us assume the working days are 30 in Delhi, and some are 24 hours, as it is a hospital. So, see, it is changing.

It is changing. It's a, it's a no, no change or like that. Any change, suppose you want to give some treatment in the window. The last slide also you have seen, so some changes will occur in the window data. You want to give some kind of insulation in the roof, so instead of three, now you are maybe getting 1.25 or something. You see, there will be some change. 1.25 or something will be some kind of change, but probably this change is not occurring here. Maybe some, I will check and I will see that there should be a kind of, maybe some mistake has been done. So, this particular thing will go to change as per the change of data. Sir, let us go back to the PowerPoint presentation again. So, based on this, I have calculated and

peak hourly load and those final outputs I have calculated. I have this graph I have already shown, but only I have to check that this roof is not changing based on the U value. So, I have to check that one, maybe there is some error. I have also calculated for Calcutta based on the Calcutta data or the nearest Calcutta data for 21° north. And the peak loads and everything has been calculated.

Similarly, with this change of the solar radiation data and the monthly temperature data for Calcutta. So, I have also computed this one, and I have compared the data of Calcutta and Delhi. You see, Delhi is the blue one, and Calcutta is the orange one. Delhi, the winter is really, I mean, the temperature, outdoor temperature is a little less compared to Calcutta. So, as you see, you require a bit more heat loading in the first three months till March. April, both are the same.

But from April onwards, Delhi is picking up, and May, June, July, August, September is Delhi slightly high, but those 3-4 months of Delhi are really high. October both are the same again, but November and December, Delhi is less compared to that. So, it perfectly goes the way it actually should be, and based on this NBC data and the temperature data I have calculated. So, this particular lecture takes you to the cooling load calculation.

We have seen the mean is going well, mean temperature variation for a month, and the output temperature data for average temperature data is going well, and this particular computation is based on the conductive and the radiative heat gain. Thank you very much.