BUILDING ENERGY SYSTEMS AND AUDITING

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Week - 03

Lecture - 15

Lecture 15: Periodic Cooling Load

Welcome to the NPTEL course on Building Energy Systems and Auditing. We are in module number 3. Today is the last lecture of module number 3, lecture number 15. In the previous two lectures, we have discussed periodic heat flow and, based on the periodic temperature changes, outdoor temperature changes. And the solar radiation changes the heat gain through the envelope.

In this lecture, we will go into a little more detail about periodic heat flow, thermal time constant, and the computation or estimation of the periodic heat flow. So, periodic heat flow was initially discussed in the first module, the second lecture of the first module, where we saw that the outdoor temperature is time-variant, and we also used that particular time-variant outdoor temperature in the last two lectures to compute the total heat gain through the building envelope. So, again, if I repeat a bit, the outdoor temperature and the indoor temperature variation will be similar in kind, but there will be two distinct differences. Those distinct differences are if I see a particular periodic profile of a 24-hour profile of outdoor temperature and indoor temperature.

I have shown this in this particular graph. The black-colored curve is the outdoor temperature, and the red-colored one is the indoor temperature. So, in that, the two temperatures are alike, but there is a difference: the number one difference is there is a phase lag or a time lag. The peak in the outdoor temperature and the peak in the indoor temperature, there will be a delay.

So, this is one of the phases shifts we will see. We will see how much time lag or how much delay is going to happen, and that particular time delay or time lag, how it will be imparted in the computation of the heat gain through the building. The second distinct change we study in this particular graph is the difference in the amplitude, the peak amplitude. The outdoor max and the indoor max are not the same. So, there is a kind of damping happening because the wall element, the roof element, or maybe any fenestration element has some capacity to absorb heat.

And that heat absorption will actually lead to a change in temperature between the outdoor and indoor. And this particular phenomenon is called the decrement factor. We have discussed this in the very first or second lecture already, but we will take these two things, the time lag and the decrement factor. Today's lecture is for the computation of the periodic heat gain through the envelope. That is why I am discussing this again.

Three, four slides. We will be repeating from the first lecture, second lecture, or so. So, the decrement factor is the ratio between the indoor max temperature divided by the outdoor max temperature. So, definitely this ratio, this μ ratio, will be less than 1 because we can say from our experience or understanding that the indoor max temperature will always be less than the outdoor max temperature.

And how much is this difference? What will be the delta? What will be this delta? Delta will depend upon a lot of factors, one of which is the density, and another is the specific heat of the material of this envelope. So, how much heat can it absorb?

That means, if I say the density and also, of course, the thickness, because if the thickness is higher, it has to pass through many layers one after another, and it will take some time to get into the indoor environment. So, there is a time lag, and also if there are many layers, the thickness is high. Each layer will actually absorb a lot of heat, and that is why there will be a differential amount of Tmax, indoor max, and outdoor max. So, as and when we can see this μ is very less, that means it has a higher amount of damping capacity. So, it will be better for our application in the building.

So, we will target a high time lag and also a low μ value. So, what is the impact of this thermal mass that will actually govern this time lag and this particular decrement factor? Suppose this is the profile of the outdoor temperature, with this profile, if I say the indoor temperature is something like this dotted line. So, that means this is having a smaller amount of time lag. So, the time lag is small.

The decrement factor is also a little high because the amplitudes are almost the same, the time lag is also less, and this is also why the decrement factor is high. So, I can say that, from the logic, it has a low thermal mass. So, that means it is a kind of material which may be thin in thickness; the envelope is thin, maybe a glass piece of 6 mm or 10 mm glass. Or maybe it is a material which can conduct heat very fast and cannot store the heat. So, something like that combination may be there for this kind of phase difference and amplitude difference.

Whereas, if some other room or some other space has some other kind of wall, another kind of wall in the sense, maybe the maybe the same material with high thickness or maybe the same thickness with a high thermal mass material or so, then we will see that the indoor temperature will be much lower, the peak is much lower, and there is a phase difference. So, there is a time required to I mean, the movement or the conductance of the heat from the outside to the inside will take time, number one. And number two, the amplitude outdoors and the amplitude indoors will be much less, if you compare, it will be much less.

So, here you see the decrement factor will be low; it will be very close to 1 or something like that, and there is a time lag that is more. So, these two phenomena, based on the thermal mass and based on the overall thickness and the composition of the envelope materials and all, there will be certain changes in the phenomena of the indoor temperature or the heat gain inside a building. So, today we will see how this particular phenomenon of time lag and the decrement factor will be taken care of in our heat load computation. So, next, we will see some of the parameters of this thing, the wall thicknesses and all. So, if I see, it is a time lag as and when the thickness increases.

Definitely, the time lag will also increase because it will take more time to actually penetrate the high thickness one. So, the left-hand side graph is actually showing a kind of straight line, a positive straight line, where thickness increases, wall thickness increases, roof thickness increases, and we see the time lag increases. So, we see our traditional buildings are mostly of that kind of nature. Probably that is because we go for the load-bearing kind of structure. So, the ground floor, first floor, those areas, the room sizes, the wall sizes are high, and also it will give you a high kind of time lag.

The second graph, I mean to say, the left-hand side, right-hand side graphs are taken from this Introduction to Architectural Science book. And you see it is the same pattern: the thickness increases on the x-axis, and the time lag increases on the y-axis. So, it is a positive kind of graph, but it also deviates because of the density. See, there are three densities: one is less than 1200 kg/m^3. And some others are 1800 to 2400, which is kind of concrete or so.

So, the central line you may say is brick, the other line may be kind of perforated things or so. So, there is a variation in the time lag. Similarly, we can also see the decrement factor and the wall thickness, the variation, but it is reverse. If the thickness increases, the decrement factor decreases. It is a negative kind of graph, but it is not mostly a straight-line graph.

It is a kind of the non-linear kind of graph, but the impact is negative. The increase of the thickness impact is negative, or the impact is going to be reduced. So, that means if the thickness is high, the wall can store more heat. So, it will not pass the heat, so much energy, to the inside of the room. So, that is why the inside room temperature will not shoot up and go close to the outdoor temperature.

So, there will be a considerable amount of peak temperature difference between the outdoor and the indoor, and that is why the decrement factor is less. And, in this particular right-hand side graph, there are 3 lines again. So, if it is insulated, suppose the same wall, same thickness wall, suppose if I take the 2000 thickness wall. So, for the if I take these 3 points because these 3 points lie on the 200 mm thickness. So, what happens?

What is the first lower one? The lower one is the external insulation. If I give the insulation externally, it will be better. It will be better that the decrement factor is 0.2. But if I give the internal insulation, then it comes about 0.3 or something, a little more than 0.3 or so.

Internal insulation is always better to give external insulation. If I want to give external insulation, the same thickness and same material can be provided externally. Initially, it can stop the heat propagation or the heat conduction internally. For still better, the decrement factor will be a little bit high. But in uninsulated cases, if I am not interested in any insulation, it has its own decrement factor, which may be 0.45 or something like that. So, that means if I have a choice, should I insulate a roof on the top? The surface exposed to the outside top surface, or should I go for the bottom surface? So, it is always better to go for the top surfaces also.

So, next, we will see the thermal time constant calculation. So, this is one of the parameters which was devised and given in the SP 41 or Bureau of Indian Standard Code. It is the ratio between the heat stored Q divided by the U factor, the U value. And it is actually governed by this equation, where L is the thickness, K is the thermal conductivity. The ρ is the density of the material, C is the specific heat of the material, and fo is the outdoor or outside surface conductivity.

So, this particular equation holds good when it is a single leaf or a homogeneous wall. So, row clustering is nothing, just a brick wall or maybe a concrete wall, shear wall kind of thing externally. So, here, if I see this particular L is going to be in meters, I am just first computing this product of L, ρ, and C. So, if I say that L, ρ, and C, the unit will be in meters, and this is the density in kg/m^3. Specific heat is in J/kg°C. So, that means this kg and this kg get canceled, and this is going to be m^2. So, this is J/m^2°C, whereas this bracketed term will be maybe L by K. So, L / K is also going to be the same as L / Fo.

Which will be, this is meter and this is watt per meter° C, this value of the K, this is the K value I am taking and this is the L value. So, this is going to be my m^2°CW. So, if I now multiply these two, this one and this one, these two if I multiply. So, this is J/m^2 °C multiplied by m^2 °C/W.

So, this cancels watt is nothing but joule per second. So, these joules cancel and second goes up. So, it is in second. So, it is a time unit. So, how much time it can store some kind of the heat, something like that, it can give you a kind of idea.

So, if I have a series of surfaces. So, practically we have this kind of scenarios, a series of surfaces, then we can actually use this equation, a little bit modified from this, the first layer, the outside layer, the first layer. So, that means, this is the L1 layer. So, all are L1. This is the second layer equation and this is the third layer.

So, like that, I can go for the fourth layer also. The third layer equation only has the change that the last part in the bracketed term is by 1 by 2. So, half of the term and the rest all are the same, will be the same. So, we will see one, and these are the values that I have taken from the book, and I will see some of the cases.

So, suppose there is a brickwork of 190 mm brickwork having some 10 mm plaster on both sides. So, I have noted down the L, K, ρ, and C values for the plaster. And I calculated the L ρ c and L by k values of that. And similarly, I have found out the big values. You see the thickness changes, the k value changes, all these things are changes.

And these are the values for the L, ρ, C and all. So, then I have computed this. So, in the first case, this 0.05 is nothing but the 1 upon f naught. So, that is constant for all the bracketed terms.

So, these are that value and point. The first one is 0.5 times this L by K. In the second case, it is 0.5 times this L by K, and in the third case, it is 0.5 times L by K. The second term is L1 by K1, and the third term is L1 by K1 and L2 by K2. So, this is actually L3 by K3. Sorry, this is L2 by K2, this is L1 by K1, and these are the three multiplications of what I am getting from the earlier slides: 1, 3, 8, 4, 3, and sorry. 13843 and 304304 are directly taken in this way: 304304 in the central case and 13843 for the terminating 2 case.

And then I found out that the calculated and computed 16.6 hours is the thermal time constant. So, similarly, I have discussed a few more. So, I have calculated the 250-brick wall. I found it is 19.5. It is a homogeneous case.

So, I have used the first equation. And I have taken some other values from the last problem. I have taken some other values of this coefficient or this parameter because there may be some changes for different types of bricks, which may give you different values of density or those thermal constants or so. So, here, if I take a smaller thickness, half thick, I have to see what is going to be the change. I will definitely logically say that the thermal time constant will be less, less than 19.5 hours, and I have computed it.

Only the change is the thickness, the L value. The rest, the ρ and C, will be the same because it is the same material, and I got 6 hours. And so, the thin wall will never protect that much; the thick wall will protect that much. Half of the thickness almost increases three times, more than three times the thermal lag or whatever. But it is not the thermal lag; it is the thermal time constant that is going to be storing the heat and sending the heat, how much the U value versus storing the heat.

So, I have computed for a 125 mm thickness concrete wall. So, the value is 7.11 hours. I have even computed for a 6 mm glass. Can you guess how much this will be? It will be very, very less because it is only 6 mm, and yes, it is less; it is only 10.8 minutes, the thermal time constant.

It can actually store, and that divided by U is almost about 10.11 minutes or so. Right, so you see, it depends upon a lot of things, mostly the thickness, and mostly it depends upon the density and the specific heat. So now, let us see another very interesting case. In the first case, I have kept the outside concrete 75 mm and inside 250 brickworks. In this case, the concrete values are like this: L, ρ, C, and L by K, and the brick values are like this. And if I now compute, I got 27.42 hours, a very high, very high value. But let us see, let us see, is this particular thermal time constant, what will be the change if I just change the orientation?

So, if I just put the concrete inside and the brick outside. It may sometimes look like it will be the same. It is not. Some difference will be there. The earlier one was 27 hours.

And this same calculation, if I do with that, the change in the 2 by L by K values or so, I found it is 37.97 hours, much higher, much higher values in that case. So, if I put the concrete inside and the brick outside, something like that. So, this is the scenario now. Let us see in the final that the periodic heat flow estimation. So, in that estimation, there are two components. One component is the average heat flow through a full cycle. So, the full cycle is the temperature changes from the morning to evening or evening to night. So, if I take the mean temperature. So, from that mean temperature, I found out what is the deviation. So, basically, this we did in the last couple of lectures back in the case of the CDD method or so, and I found that particular deviation from the mean temperature of the overall 24 hours with the indoor set point temperature, and then I multiply with the temperature.

A and the U values of the thermal envelope or the building envelope. So, that is one of the steady-state scenarios. Why steady-state scenario? So, I am assuming that a mean and playing with the indoor set point temperature where indoor set point temperature Ti is going to be constant. I will keep that constant for a controlled environment or so.

So, that is what the steady state for all 24 hours is. The same way, I am assuming it is flowing, but there is a second component also. In the second component, I am using two things: one is the thermal lag and I have a little typological error there. There should be a mu. I will correct it and send it to you. So, there is a thermal lag of some 5 hours, and there is a determinant factor of mu. So, that has to be taken into account, and then this T φ is nothing but your if I go to and now if this 2 Q1 and Q2 has to be added, and this is a time-dependent calculation.

After Φ hours, the temperature is supposed to be TΦ, and that TΦ is the sole air temperature of the outdoor surface and how much it is deviated from the mean that I have to compute. So, the first part and the second part are now added together to compute, and that will go on to compute my total heat gain through the envelope by virtue of the diurnal or maybe a kind of change of temperature. So, A and U, you know what those are. Tm is the mean temperature. So, I have to take all the outdoor temperatures for 24 hours and calculate the mean. Ti is the set point temperature indoor, which is constant.

Tφ is the outdoor solar air temperature after 5 hours. What is φ? Time lag. Suppose the material is having 2 hours or 3 hours of φ. So, I have to take for 2 o'clock the earlier 2-hour or 3-hour earlier the solar air temperature.

So, that is the Tφ. I have to calculate for each hour, and I have to segregate that one after how many hours or so. μ is the decrement factor, and φ is the time lag. So, suppose this is the series data, time series data of temperature from 12 to 12, and I am interested to compute, and these are the values I have given. I have given $10m^2$of the area, 3.5 is the U value, and the daily mean temperature.

So, the mean temperature of this I have computed T min as 24° centigrade, and the indoor temperature I kept at 20°. I have assumed that the material has a 0.4 decrement factor and a 3-hour time lag. So, I want to, I am interested to find out what will be the heat flow at 14 hours, at 2 o'clock in the afternoon. So, I have to put everything over here in this equation.

So, I have to go back. I have to go back 3 hours and note down what will be the TSA at that particular 3 hours back from this particular point. We have to go back. So, that is 32.5°. So, that will be my TΦ.

And then I have to put everything. So, 10 is the area. 3.5 is my U value. What are 24 and 20? This is the T mean temperature from all the data, 24.

The indoor set point temperature I have kept as 20°. 0.4 is the mu, that is your decrement factor, and 32.3 is the time lag solar air temperature 3 hours below because I assume that my material is giving me a 3-hour time lag. So, it is 32. So, I am not taking the exact 39 for this. I am taking 3 hours back and finding out the solar air temperature of that 3 hours back, 32.3.

Minus 24 is my, so this is my Tφ. Tφ I should say at behind, so it will be around 11 hours. And this is again T min. So, that gives me this is already I have written over here. So, by computation I got 256 watts.

By this computation, I got 256 watts. So, that much heat will actually be propagated over a period of 14 hours or so. That means the first part of the equation, A x U x Tm and T - TI, is a steady state. Overall period of my temperature variations also. The second part is the lag stage or the decrement factor, which changes every hour because every hour, if you go to the 15 hours, you have to take the 3 hours earlier solar air temperature like that.

So, I have again, suppose I have computed for for this particular thing, and suppose I have to compute it for 17 hours same. So, 17 hours if I see that means evening afternoon 5 o'clock. So, I have to go 3 hours back and I have to take the 2 o'clock solar air temperature, which is 39°. So, just like that, 3 hours phase lag temperature I have to take to put it over there.

Only change will be in this particular equation will be instead of 32 point something was there, 32.3, instead of that here only change will be in this 39, and the heat gain is 350, but which was 256 over there, so more heat will be conducted at five o'clock with respect to two o'clock, but probably yes, the solar air temperature at two o'clock is much higher than the five o'clock. Because it is an effect of 3 hours behind that heat will be conducted through the wall or something like that. So, it is, you know, it is going to depend upon the point this μ factor. If the μ factor is low, so this second part will be low, and if there is a high amount of Tφ, so it will be the peak will be shifted much more. So, we will see.

So, I have computed this. For the same values that we have just seen, with this, I have computed for 6 hours. 0.4 is the decrement factor, and all are $10m^2$ in area. 3.5 is the U value, Tmean is 24.125°, and the indoor temperature is kept at 20°. So, this is the variation. The blue line indicates the outdoor temperature, which is in the To in this axis, and this in this axis is the Q, so that is in watts, right? So, you see there is a shift. The highest peak temperature is at 15, the solar air temperature, but there is a shift of 1, 2, 3, 4, 5 hours almost, and the peak is also going to be over there, or 350 or something like that. So, I did it for two combinations. One combination is the last combination, which is 0.4 as the df, which is the purple color curve, and six hours is the Tl, the time lag. The second one, which is the dark green color, where I have used a df of 0.8, so it is a thinner material, maybe 0.8. And 3 hours of time lag.

So, if you see that. See, the purple color has much more damping. Same wall, same U value, same A. So, there is much more damping. It was almost the highest one, almost like 350 or something. Here, it is 600.

Okay. There is also a small-time lag because it is 3 hours. And this is high. Okay. So, like that, we can compute.

So, what we have seen over here is that we studied or discussed the thermal time lag constant, which actually shows the heat capacity versus the E value of the material, and also, we have computed or discussed the periodic heat gain through a wall element or any element due to the time lag and the decrement factor. Thank you very much.