BUILDING ENERGY SYSTEMS AND AUDITING

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Week - 03

Lecture - 13

Lecture 13: Cooling Load Calculation-I

Welcome to the NPTEL course on Building Energy Systems and Auditing. In module number 3, we are discussing building heat load estimation. In the third lecture, we will see the cooling load calculation part 1. And, also in the next lecture, we will do part 2. So, in this lecture, we will demonstrate stepwise how to calculate and estimate the building cooling load if there is a variation in outdoor temperature.

If we remember correctly, in the last lecture number 11, we calculated the cooling load based on a particular outdoor temperature and based on a particular thermal solar radiation. The thermal heat gain through conductive and radiative ways was calculated for a specific outdoor temperature and solar radiation. This process will be the computation process, and the estimation process will follow the same flowchart or flow diagram that we discussed in the last class.

So, in that, there are three steps actually. In the first step, we will calculate the solar air temperature by virtue of the first equation. The second and third equations will give us the conductive and radiative heat gain. Radiative heat gain will be applicable for windows, any transparent surfaces, and opaque surfaces. Also, for windows, we have to calculate the conductive and radiative heat gain. Now, the only difference we will discuss in this lecture, compared to lecture number 11 and this lecture number 13, is that the outdoor temperature (To) and the solar radiation (I) will vary.

This is going to vary for each hour because, as we understand, it is climatic data, and the outdoor temperature is not constant throughout the day. The solar radiation is also not constant throughout the day. The solar radiation is not constant and uniform in the various parts of the wall, which means the wall on the eastern side. The wall on the western side or maybe the southern side will definitely have solar radiation in a non-uniform way or at a particular time. So, we have discussed that earlier.

So, this fluctuation of solar radiation and outdoor temperature has to be taken into account if we want to calculate or estimate the total heat gain of a building, not for one hour, but for the whole day scenario, the whole working day scenario. Because a particular building, if it is an office building or any kind of institutional building, it may operate during the daytime, maybe from morning 10 to evening 5 or something like that. So, during that period of time, there is a fluctuation in these two environmental parameters: the outdoor temperature and the value of solar radiation. So, what will be the total heat gain?

From morning 10 to evening 5. And what is the peak heat gain? So, from the peak, we have to estimate the total amount of cooling load required, and we have to estimate the total capacity of the air conditioning unit also, from the beginning, from 10 to 5 or whatever this particular period of time. So, we have to see how much the total heat gain is, and that total heat gain Will be equivalent to the cooling load.

That much cooling is required in our tropical country like India. So that will give a kind of estimation that that much amount of energy is required to cool down the particular environment, that is, the indoor environment. And if now the building is some other type of building, maybe a mall. So, it may work from the morning 10 to the late night, maybe around 12 in the night or midnight or so. Or maybe it is a hospital, then it is throughout the day.

So, like that, we have to see how, what is the total span of the working time, and based on that, the outdoor temperature and the solar radiation we need to take. Of course, the solar radiation may go to 0 after the sunset or so, so that part only the outdoor temperature will be calculated, but during the daytime, both parameters will come into the picture. So, with a small or simple problem, we will start understanding this, and also, we will see some internal load, how to calculate that one. So, suppose I have taken a a small building room or maybe a comp that I have mentioned as a computer lab which is in the south, you know, this is the southwest corner of a building, and other two sides are not exposed to the outdoor, and also the east is also not exposed to the outdoor, okay? So, these two are not exposed, so only the heat gain will be

possible from the south and the west and also from the roof. So, I have mentioned that it is a 7m x 5m room computer lab with a 4m of height. So, the facade area I can easily calculate: the southern facade area is your 7 x 4, 28 m^2, whereas the western facade area is 5 x 4, 20 m^2. This is the facade area, and based on the 15% of the WWR, window to wall ratio of both sides, we can actually calculate how much is the total solid wall area. And 15% of this 28 and 20 will be the window area of the southern part and the western part. And this is a ground story or some story that it is a roof is also going to be open to the atmosphere or open to outside. So, this is a third facade which is also there, which is a roof, which is your almost 35 m^2, 7 x 5 is a 35 m^2 roof is also exposed.

So, I have to estimate the cooling load for 10 hours, 10 working hours of the particular computer lab, and average some monthly climatic data of some month is given for the month of June, suppose is given. Like this is the average data, so what I have is data given as time series data from morning 9 to evening 6, the temperature, outdoor temperature. It starts from 26° and again goes as high as maybe 38° at 2 o'clock, and then it again comes down. Even we have given the solar radiation on the southern side, the western side, and the roof. If you see, the roof is almost exposed to some amount of solar radiation.

But the southern side has some started radiation getting radiation from the sun from 11 to almost about 17, that is 5 o'clock, whereas the western side is getting radiation from 1 pm to 6 pm or so, and the values are given in W/m^2, and all the material data is also mentioned in the top table, so U-value is mentioned, I have mentioned the SHGC of the window. I have mentioned the surface absorption and the surface conductance. Those two data will be required for your solar air computation, and the indoor set point temperature is kept constant at 24°. So, basically, my aim is to keep that computer lab at 24°C throughout these 10 hours from 9 to 6. But there is a variation in the outdoor temperature and the solar radiation on all three sides, exposed sides.

And how these changes are going to happen in the calculation of the load, that cooling load. So, each row, each row I have to calculate the conductive heat gain and also. So, for each row, I have to actually calculate this Q equal to Au ΔT. And also, the Q equal to A SHGC into I for each row, for each row I have to calculate, and the ΔT calculation will be tricky because every time I will have this TSA minus TN. This ΔT and the TSA is going to fluctuate.

TSA is going to fluctuate because your I value is fluctuating, and the temperature value is fluctuating, and that also fluctuates in the 3D for inside. So, I have to use Excel for computation manually; it may not be that possible. So, this is the heat gain. So, I have made a table, of course, this table was cropped from an Excel chart. I will show you the Excel chart.

So, the outdoor temperature and those are the 3 or 4 data which are required to find out the solar air temperature. So, each time, each morning, suppose 9, that outdoor temperature is 26°. Whereas, your I, that is the I value, is 0. So, this will then be equal to 0. So, that means this will go to cancel, and this TAC will be equal to TOA, is it not?

Similarly, the next hour also it will be 28°, will remain 28° because this is 0, because this is 0 at 6 o'clock, it is also going to be 28°, but from 11 to 17 hours there is a value, there is a changing value of this I, and based on that, there is a slight change or that is noticed in the solar air temperature by virtue of this formula. So, the second case, what I will do, I have taken this as 50 multiplied by, I mean, I am talking about the 11 hour, 11 am, so it is 50 isn't it, and these two are equal, I mean, these two are constant for this is 0.6 is the absorption, and this is 18, and the corresponding outdoor temperature is 32 plus, so this, so that gives me equal to almost 33.66° C. So, like that, by virtue of the Excel computation, I found all the solar air temperature, and then I have the indoor temperature constant, and I can find out the ΔT. So, here you see I have found out the conductive heat gain for the southern side. So, these three data are now the second layer required.

So, the ΔT I got by virtue of this minus this for each row. I know the area; I know the U value. I know the SHGC value, so based on these four, I can find out the conductive and the radiation heat gain, and I can add them up to get the total heat gain. So that means the total heat gain on the southern side is also increasing, and at its peak, it is almost about 1183 watts. At about 2 PM, and then again it is decreasing. So, like that, I have to recalculate the same thing for the east, I'm sorry, the west, and the roof. So, this is for the south. I have calculated, I think, the hourly heat gains also, and then I have calculated for each part of the facade.

So, let me go to the Excel. So, in this Excel, see what is mentioned over here in Table Number 1 is the building geometry. So, I have to give the building geometry data, that means what is the length of the north facade, what is the height of the north facade, like that. So, as the north and the east facade are not exposed, they are not getting any heat. So, I have put the value 0, 0, and WWR is also 0.

So, the southern facade is 7m, as we see, and the length and the width are 5, and the height is 4, and 15% is the WWR. The roof is also 7 and 5, the height is not height, but the width, and the other part, the length 7, 5 is the 35. So, and I have here, I have to put this green table as your input table. And whatever you will get here, it is in the other part. So, the U values and the SHGC absorption coefficient and the surface conductance are mentioned over here, and outdoor temperature series data. I north and the I east are 0.

So, there is no question of it because it is not exposed. The south and the west things are there, the I value of the roof. So, total kilowatt-hour per hour is mentioned over here after calculation. So, in this particular Excel, for each sheet, I have calculated, and the final calculation is this, and then I have taken that into the in this particular chart.

So, total the kilowatt, how much is the kilowatt calculation is there, and total cooling load kilowatt-hour is also mentioned, 31.83, by virtue of adding all those. The peak load is 5.98 kilowatts, which is at 2 p.m. So that means you have to purchase, if you want to purchase any kind of air conditioner for this room, you have to purchase based on that. So peak tier is 1.71. So, by virtue of dividing this 5.9 or 6 by 3.5.

So, from the south, I am getting almost 10.28 kilowatt-hour. So that is nothing but the summation of all the south heat gain throughout these 10 hours. The west is getting 7.11, the roof is highest, 14.45. So that is shown in this bar chart.

And the percentage of heat gain from the south, north, and the, sorry, south, the west, and the roof are also mentioned. Now, suppose if I have some facade area, suppose I have the eastern facade area also, maybe this is again 5 meters and this is maybe 4 meters, same height, and this is also supposing 15% or something. And there is some heat gain because I have to, there is some temperature. So, if I give some morning data, suppose it is 50 and then it is 120 maybe. And then maybe at 11 it is again 100 and then maybe it is 75 maybe or 75 or something.

So, see you have got some value, some value in the there is a bar in the east. So, you will get certainly some values. So, they are all the values are going to change, those values are also going to change. So, suppose you have some, you give some better window, I mean maybe you have a two-layer of the glasses or so, so it becomes three maybe instead of 5.3 or something, see things will going to change. Things will be going to change if you give some value of the north, maybe it is 7 meters by 4 meters with 15% of the wwr and north may also have some gain, maybe 50 and this is maybe 100 and then again 50 maybe in this part, so you will see some of the variations or something like that, okay, so and your things are changing, your things are changing the

So, what does it mean? This kilowatt-hour loading 41.07. So, let me go back to the PowerPoint presentation. So, the PowerPoint presentation shows the earlier one. So, the north facade is 0 and I am sorry.

The north facade is 0 because it is not exposed. East is also 0. It is not exposed. So there is no question of any heat gain from the eastern side and the northern side. But there is some heat that will come for this whole 10 hours.

This is in kilowatt-hour. And the total heat gain is 31 points. So, I can say that this is the total day demand. This 31.83 kWh is the total day demand, which means 31.83 kilowatt-hour is the total electricity bill that will come for this particular room for a particular day in June, that particular month, for one day only, for one day only. To run some kind of air conditioning system or to run some kind of cooling system because the total cooling load is 31.83. Whereas the peak load is 5.98, the peak load, you see, the peak load is 5.98 at 12.

The peak load is changing, or the load is changing, and the peak load is almost like 6 at 2 o'clock. That means I have to have an air conditioner that can give me at least 6 kilowatt-hour or 1.7 tons capacity air conditioner for this particular room. Otherwise, at two o'clock, when my load is that particular hour, my load is 5.98 or 6, I will not have that much of a cooling effect. Suppose I have purchased only one ton, one ton, or 1.5 ton, so 1.5 ton or one ton will be very well taken care of in these two hours or whatever other hours, but at two o'clock, my demand is 1.7. But my machine is 1.5. So that will not be going to cool that much.

That means your 24-degree set point temperature. We cannot maintain it at 2 o'clock or so. So that will be a little bit high. Maybe 26°, 27°. Because your total demand is almost 1.7, but your machine can only give an output of 1.5.

Of course, there are a lot of other things also, like the efficiency of the machine or whatever, but let us assume the efficiency is 100 percent. In that case also, 1.5 The tonnage of this air conditioning unit will not provide you the most efficient cooling if you set your temperature at 24°, right. So, we have to purchase accordingly to that peak, but if I install 1.7, 1.7 is not possible; maybe if I install 2 tons. It will effectively work well.

I can get a 24° temperature at peak time, that is 2 o'clock also. And when it is maybe morning 10 or morning 11, when the load is required less, then it can also work. The total amount of air exchange and everything will be less. So, the total power consumption for that particular hour will be 1.26 kilowatt-hours, the next hour it will be 2.61 kilowatt-hours or something like that. So, on that particular day when the outdoor temperature was given for the month of June, and these I value are given.

So, for that particular day in this particular computer lab, it will actually consume 31.83 kilowatt-hours. See, there is a little difference between these two peak loads. I am calculating in kilowatts, not in kilowatt-hours. Because that is the demand for that particular hour. Now, I am multiplying 10 times 1 hour. The 1 hour is because I have 10 hours of data, 10 hours of the working schedule of the particular office, building, computer lab, or so. I am adding those for 10 hours, and then I am getting almost 31.83 kilowatt-hours as the total energy requirement of this particular computer lab for that given day.

Now, for June, I have to multiply by 30 because June may have some holidays. So, maybe there are 20 working days. I have to multiply by 20 for those working days or so. So, that will be the total amount of the energy requirement or cooling load required for the month of June, right? So, I may say that this 31.83 multiplied by some 20 days. So, that will be for June.

Similarly, if I know the average temperature and the solar radiation for the months of July, August, September, and all the 12 months, I can recalculate this thing for all 12 times and find out what the demand is for each and every month, and I can calculate what the annual demand of the total load is or so. So, based on this way, we can actually calculate, but this is a simple calculation for a month, a day, a day of a particular month. So, in fact, I can repeat it if I have the data for each and every individual day. I can repeat it 365 times and find out the overall annual demand, but it is too laborious. So, it is better to have the monthly data. So, 11 or 12 times, I have to repeat this particular calculation, add up, and then find out what the total effect is annually.

So, next one, if I see this particular two graphs. So, this is the graph when I have shown the south wall, the outdoor temperature, this is the solar air temperature, this is the solar air temperature for the wall and windows, and this is for the roof. So, you see this is the temperature, outdoor temperature, outdoor temperature is the blue line, window solar air temperature is the orange line, this is the window which is higher, and the wall temperature is the green line. So, that means if you take the ΔT, so if you take the ΔT as ΔT as T outdoor temperature minus indoor temperature, or if you take ΔT as T SA - T in, there will be a change.

There will be a change because there is a fluctuation. So, it is better if I take this one because that will give me the exact kind of scenario because solar air temperature is the surface temperature outside of any envelope surface. Similarly, if you see in the case of the roof, it is also high, I mean this is high, I mean if you take some of this in your computation, the data which is shown in the blue line, which is the outside temperature data, your total capacity and everything will be less, total consumption will show estimation will be less, but actually, it will be high because it will be actually governed by the solar air temperature. So, next, what we will do is we will see some of the internal heat gain.

So, because of the people, because of the lights and the illumination features and all, and also depending upon the equipment, there are some kinds of loads that will be estimated. So, we can say the equipment loads are the electrical plug loads and the process loads. So, these are the tables from the Quainsberger book, I can see this is some of the activity of the human being, based on that, some of the how much watt is the load that can be estimated. So, if you are sleeping, it is almost like 70 watts, if you are somebody sitting and doing moderate work like some kind of computer and some kind of office activity. So, this is 130 to 160 watts.

So, that particular data can be used for any kind of internal heat gain. Similarly, the equipment or the light will radiate some kind of heat. So, in the case of, suppose, the fluorescent bulb, 90% of the heat will be released, and 10% of the heat will be actually used for the light. Similarly, the fluorescent is 80 percent.

So, like that, and also for the equipment, what can we do? The equipment will have some kind of power. Suppose some computers have 100 watts, some machines may have 200 watts, 500 watts, whatever. So, we can estimate the efficiency as epsilon. So, 1 minus epsilon part of the wattage will be actually converted to heat, we can assume that because epsilon times W will be the actual power consumption to run the machine; the excess will be assumed as heat.

So, based on this, I have recalculated what the internal gain of this particular computer lab will be. I have estimated or assumed that there will be 15 computers. There will be 20 CFL lamps of 40 watts, which have a heat output of 60 percent. There is a computer with an efficiency of 60 percent. I am sorry, the CFL's heat output is 80 percent. The computer has an efficiency of 60 percent.

There are 15 computers and 15 occupants, which will give you 130 watts as sensible heat. So, we can directly take that there are computers of So, 200 x (1 - 0.9) will be the per-computer heat output. There are 15 computers like that, CFL is 20 numbers, and this is the wattage, and 0.8 is the amount of heat that will be gained. So, in total, I can add up and say that almost 2.9 kW will be the heat gain due to this particular internal gain, and there are 10 hours.

So, that means multiplied by 10, 29 kWh will be the total heat gain for this particular room due to the internal load. So, I have now this been by the old value. So, I can now add up those 29 and 2.9 to get the new peak value and the new total estimated value for the day. So, the total energy for cooling is just 31 points. This will be for the envelope gain plus 29. So, that is 60.83 kilowatt-hours has to be my total heat gain or cooling load required for the whole day based on the envelope gain 31.83 plus 29 is my internal gain. The peak load for the cooling is which was 5.98 + 2.9 per hour that we have calculated. So, it will actually be going to be 8.88.

So, that means you require 2.5 tiers of capacity. So, what we did was we separately calculated the internal load based on the equipment, based on the number of people or number of occupants. And the amount or the number of equipment, and we added for each hour because that will be running for each hour. We can assume that, and then we can actually see what is the change in the peak load, what is the change in the total load, and based on that, we can estimate our total cooling capacity, total purchase of the energy, and that is for this particular lecture. So, what we have seen is that we have calculated the cooling load based on the variation of the outdoor temperature and the solar radiation, and also, we have discussed the internal loading. Thank you very much.