BUILDING ENERGY SYSTEMS AND AUDITING

Dr. Shankar Pratim Bhattacharya

Department of Architecture and Regional Planning

IIT Kharagpur

Week - 03

Lecture - 12

Lecture 12: Cooling Degree Days Method

Welcome to the NPTEL course on Building Energy Systems and Auditing. Module 3 is going on, and this module is basically on building heat load estimation. In lecture number 12, we will discuss the cooling degree days method. So, in this method, in this particular discussion, we will cover the cooling degree days, the concept of cooling degree days, and we will discuss stepwise and give a demonstration on how, through cooling degree days, the building cooling load can be estimated.

Now, first of all, we need to know what cooling degree days and heating° days are. So, you know, this particular outdoor temperature of a particular area always follows a kind of periodicity in nature. So, it increases and then, after some time, it decreases, and it creates a similar pattern if you take a portion of 3, 4, 5, or 6 days. But maybe there is a slight difference after some changes in the weather conditions and also during the change of season from summer to autumn and from autumn to winter.

There will be slight changes, and gradually that particular periodicity will change, but the amplitude will change; there may be a high peak that will go down or whatever. Again, if you take a particular patch of maybe 15 days to 1 month or maybe 7 to 18 days or something like that, it will remain almost the same if there is no sudden change in weather. So, in this particular behavioral pattern of the outdoor temperature, we can think of a mean temperature and a base temperature, and based on that, we can calculate the total heating load. We may not go into deep detail of each hour's outdoor temperature or maybe the daily peak and daily changes after some 6 hours or so.

So, only a diurnal temperature difference we can think of, and then we can find out what the average temperature difference is and if there is some kind of base temperature. We can see the deviation, and we can think of that, I mean, we can assume that the particular shift, that particular distance between the mean and the base temperature, is the cooling or heating requirement; that much°, that much °C, is my heating requirement also. So, in this kind of periodicity where it is available. So, we can actually get some weather data or the kind of temperature data, at least for any city, maybe a monthly average or maybe a daily average something like that, and we can actually go to a calculation mode to see that per month how much is the degree days, how much are these deviations also. So, to explain that particular thing, let us take one day's temperature data. Suppose this is the particular day's temperature data; it is night. At 12, it was midnight, it was 18°, and then gradually it is increasing and finally, it is increasing to 36° at around 3 pm in the afternoon time, again it is decreasing to 18° at night. So, the periodicity, the behavior, or the change and ups and downs of this temperature profile will be like this, this blue color dot joining the dotted points or so. Now I may think of a baseline, something like what is base temperature or the baseline?

I want to keep the room at 20°C temperature; that is my base temperature for a particular room. I want to keep the room at 20°C temperature. In this way, I may say that This is the difference between this base temperature and the outdoor temperature. So, at midnight, the base temperature is, I want to keep it at 20°, but the outdoor temperature is 18°.

So, it is –(2). So, I do not need any kind of cooling, I do not want to switch on the air conditioner at that particular time because I am already at 20°, which is a comfortable temperature for me, and the outdoor temperature is 18°C. So, those minus values are in blue color. So, I do not need any kind of heating or, sorry, any kind of cooling requirement at those times, maybe from night 12 to almost morning 6 o'clock, I do not need any kind of cooling. But at morning 7, I need 1° of cooling, and at 8 o'clock in the morning, I need 2° of cooling because the outdoor temperature is 22° at 8 o'clock in the morning, and my base temperature is 20°.

Of course, I have, or this particular method has assumed that it is a very quick and steady-state flow, but it is only because You know, there is a wall we have discussed in the very first lecture; there is a decrement factor, and there is a time lag. We will discuss this in this lecture, not in this lecture, but in the subsequent lecture of this module itself, at the end. That is how this decrement factor will take place or will affect it, but here, at present, for the cooling days, let us assume that it is an instantaneous steady-state flow. So, that way, you see the maximum demand is almost 16° at around 15 hours, that means 3 pm or so.

So, that means I may say that this particular area, which is above the base temperature, requires cooling. This particular required cooling, and that much temperature has to be brought down to the base temperature. So, I think at 7 o'clock in the morning, 1° of temperature has to be brought down, and at 8 o'clock, 2° of temperature has to be brought down. Similarly, at 12 noon, almost 11° of temperature has to be brought down, like that, we have to bring it down. So, the total summation of the brought-down temperature has to be the sum of this particular hill-like portion above the base temperature of 20°, that portion.

Now, what can we do? We can further rectify it in such a way that we can actually pick up the minimum temperature and the maximum temperature of the day. That means, the T minimum and the T maximum of that particular day. T minimum is 12°, and T maximum is 36°. So, I can find out the daily mean temperature, which is half of the T maximum and the T minimum because for weather data, it is easy to get the T maximum and T minimum.

Many websites give you this information, and sometimes newspapers do too. There are many sources where, for any city, you can find out the T maximum and the T minimum for a day or maybe for that particular month or whatever. So, in this case, my daily mean temperature, T mean, is 24°: (36 + 12) / 2. And my base temperature So, this is the T min, and my base temperature is 20°. So, the base temperature is this: T, this is the base temperature, which is 20°. T is, you know, periodicity. T base is fixed, and T min is also fixed. Based on these two, 12 and 36, this 24 has been computed.

The difference of 4° between the T mean and the T base, 20 and this 24, is going to be significant for our CDD, which is cooling degree days. So, in total, how much is the summation of the T mean and T base? It is 4 multiplied by 24 because there are 24 hours and there is a 4° difference for this particular T mean and T base. So, the sum of the T min and T base is 96°. So, that means I can say this hump is almost like 96°C, this hump.

So, you require 96°C of cooling for your day if you take all the highest numbers or so. Of course, it is not exact because there is again an approximation of T min and T base, which is very close to 96°. So, this way I can understand that from the weather data, I can actually convert that to per day how much° of temperature I need to go for cooling, and if I know the OHGC or the overall heat gain coefficient. So, I can actually multiply that and find out the daily cooling load or whatever it may be. This blue portion, this 4°, is the drop, and the summation of that is your 96° total for that particular drop.

So, what happened is that this particular hump above the T mean, I am sorry, above the T base, which is 20°, T base is now neutralized, and we now think of it as constant for the whole day, and that is actually your cooling day of 2° or so for your base temperature of 20°. I am sorry, this has to be 4°, and we have discussed that; this is a typographical error. So, I will rectify this; it will be 4°, and with 24 hours, it is 96° or so. So, this 4° is an average, I may say, for the whole day

is the total° of my cooling requirement. Now, suppose this is the temperature data of Delhi. So, I have just picked up the minimum and maximum temperatures from January to December. So, I picked up the data for January, March, and May. You see, in January, Delhi has a maximum of 20° and a minimum of 8°; this is 20° maximum in January.

The maximum temperature is 20°, and the minimum temperature is 7.7, which is 8°. I kept it at 8°. So, the mean temperature is 14°. (20 + 8) / 2 is (28 / 2), which is 14. I kept the base temperature as 20°. So, 20° is my indoor base temperature, and I want to keep it that way. So, it is negative in Delhi in the month of January, which means in the month of January, I will not need any kind of cooling. So, any negative value I will not take. I will take only the positive values because that is my cooling demand. Negative values mean I do not need any kind of cooling; it is already cold.

In March, what is the temperature? T max in March is here. T max is 15. I am sorry, this is for the night. So, the minimum temperature is 15.2. So, 15, I think I kept it at 15, and the maximum is 29. So, it is 30. So, the mean temperature is 22.5.

So, there is a 2.5° difference between the mean temperature and the base temperature, which means 2.5° per day. And I am actually calculating for the month. So, how many days does March have? March has 31 days. So, 31 x 2.5 is the amount of cooling load required in degree for the month of March.

In the month of May, it is almost 40°, and the minimum is 25°. So, 32.5° is the mean, and 20 is my base. So, 12.5° is the per for the whole month of May is the cooling demand. So, I have to multiply by the number of days; May has 30 days.

So, 30 into 12.5. So, now how can I further rectify these cooling degree days? So, CDD is negative for the month of January. So, no cooling is required; fine. The average daily CDD is 2.5° for the month of March, okay.

So, if the building is running all 30 days and 24 hours per day, suppose it is a hospital building where every 24 hours you need cooling. So, 2.5° per day, 30 days in a month, and 24 hours. So, almost about all the three, if you multiply, 1800° of cooling is required for the whole month for that particular building for that particular space. If the building is running 24 hours, 24 days only.

Suppose that in some office building, there are 6 days of holidays and 8 hours per day because it is a kind of office building. So, your total multiplication of 2.5, 24 is the number of days, and 8 is the number of hours per day. So, a total of about 460° of cooling is required for the month of March for some other building, which is operating 24 days and 8 hours per day, right? So, similarly, if I take now the month of May, the month of May your

CDD is 12.5°, but it is the average, of course, for the month, but what I can assume is that for the month of March, 22.5° is the average difference between my T mean and the T base. I have kept my T base as 20° because of that. Now, if I keep the T base as 22°, this will now be 2° less. So, maybe 10.5° or so. So, similarly, if I have 30 days of 28 hours.

So, you see, for the month of May, you need to have 9000° of cooling load requirement because the month of May is much hotter than the month of March. For the second type of building, 24 days with 8 hours, you multiply 12.5, 24, and 8. So, 2400 hours or °C will be the cooling requirement. So, now we can really understand that because of the change of the month, due to the change of the maximum temperature and minimum temperature, my T mean is going to change, and my base temperature, if I fix it. And then, if it is not negative, if it is positive, this difference between the T mean and the T base means that I require some kind of cooling, that much° of cooling is required for that particular month.

And now, for that particular month, how many working days are there? How many hours of work per day? If I multiply that, I can actually estimate how much °C will be the total cooling required for that building for that particular month. And now, if I multiply by the overall heat gain coefficient, which is the multiplication of the envelope area corresponding to the U value, I can directly find out how much my cooling requirement is in kilowatt-hours or so. So, here is the formula I have already discussed. Here, there is a plus sign. The plus sign means I will always take the positive value because I will not take the negative sign. Why should I take the negative sign?

If this T mean minus T base is negative, then no cooling is required, as we have seen in the Delhi case in the month of January. So, finally, this overall heat gain coefficient will be multiplied by the CDD with 24. For whatever the number of days or hours, and whatever it is, we have to divide this by 1000 to convert it from watts to kilowatts or whatever that way. So, now, let us see this discussion on this particular building. I have kept and drawn the two floor plans of a building. The ground floor and the first floor, the green hatched portions are the air-conditioned areas.

So, I do not need any kind of air conditioning cooling load calculation for those areas. So, only these areas have to be calculated. So, the WWR for the north and south facets is 20%, and the WWR for the east and west facets is 15%. So, there are a little fewer window in the west and east, and the U values are given too. So, first of all, what we have to do is find out each facet area and also the roof area.

So, now suppose if I want to find out the area of the north, so this wall is on the And also, on the first floor, this wall is in the north. So, this wall area will be 10 meters multiplied by the height of the floor, which is taken as 4 meters. 10 x 4 = 40. And this is also north; this north is 15 meters x 4 meters, which equals 60. So, 60 + 40 = 100, which will be your north area.

So, like that, I can calculate the south area, you can calculate the east area and the west area, and also the roof area. The roof area will be the roof of only the first floor—I am sorry, only the first floor—this area, and maybe some remaining portion of this particular area can also be taken. So, the roof area is also these three patches of the first floor—I am not, I should take this one. Will be the—I have to take the first floor. So, it is 15 x 4 = 60, plus this is 15 x 4, this one, and this is 8 x 4, 32, so that means 92 will be the roof area.

So, I have calculated, and this is the particular city where the T max and T min have been given for all the months. And I have assumed a base temperature of 22°C, which will help me to find out the CDD, and 20 days a month, 8 hours working day. So, we will take that afterward; let me first find out how to calculate the areas and all. So, this is the—if you see the area, the north facade area, I have just told you it is 100, then the east facade is this, and the east facade is this. So, this is 4 into 4—please remember the height is 4 meters; the floor height is 4 meters.

So, 4 into 4 again, this I cannot take because this is some area which is having some kind of space. So, this will not be exposed to the wall; it is exposed to the outside. So, east is your 32, 16 plus 16 equals 32, 15%. So, I can find out the total wall area and the window area; this is the wall area and the window area. Similarly, the south is having these 2; these 2 are your 32, this is your 32 because 4, 8, 4s are, and this is also 32.

So, it is almost about 3 times 32, which is 96. 96, yeah, 96m², and then the WWR and all these things are there. So, from that, I can find out the wall and this area, and finally, the west is also the same; the west is this one, and this one is the west, similar to the east. So, that is 32, and finally, the roof area is this chunk of the roof, which is 60, and this chunk of the roof is 32. So, 92.

So, like that, I have broadly taken all the area. I have 4 sides, and I have a roof also. So, I have taken all the area and put it there in the Excel chart. I have another Excel chart for this. So, I will go to the Excel chart.

So, this is that Excel. So, the façade one now I have kept 10 façades. Maybe you can have different types of façades, maybe not only 4 sides. So, you may have 10 façades also. So, from here I can give the areas like the north is 100, the east is 32, and this is 96.

So, let me first give this is 100, this is east is 32, this where this is 96 I think, and this is again 32, and your roof is your 96, probably the roof is your 92, sorry, 92, roof is your 92. and WWR for the roof is 0 because there is no window, and this the façade this is 20 and 15. So, this is your 20% is the façade 3, sorry, 20% is façade 3, and this is 15% and 15%. So, and this is the U value of the wall, U value of the window. So, you will get and this is your T max and T min, base temperature is 22°, working days of 20°, 8 hours of working days are that particular thing, and this is your per month the what is your heat load calculated that is estimated in this through this Excel chart.

So, here again, let me go back to the slide. So, here you see. this overall heat gain coefficient which is equal to your sorry. So, that is equal to your summation of A into U. So, that means summation of A and the U. So, for windows and for there are different U values, the different U values for the window, different U values for the wall. So, if you just AU of the wall is this much, AU all the windows are this much, and if you add up 3992, 3992 is your OHGC.

Now, here you see I have calculated the mean temperature and the base temperature. So, January's mean is 20, the base is 22, CDD is 0, actually it is minus 2. So, no heating is required. So, 0. Even February it is 20 to 22, 0. Even December it is 20.5 and 22, it is 0 because it is negative. So, I may say that in the month of March, only 2° of heating are required per day.

Average per day. So, the month of March has 20 days or whatever. Of course, the month of March has 31 days, but the working days I am keeping as 20. So, 20 into 2° means 40° per day, and there are 8 hours. So, there are 8 into that. So, 8, the 40 into 8.

So, the 320° is the total cooling requirement of the month of March. So, this will be your 2 into 20 days into 8 hours. So, almost 320° for the month of March, just like we have seen in the earlier example of Delhi. Similarly, for the month of maybe June, it is 11°. See, 11 into 20 into 8. So, something like that, some big value, some big value will come, and then that has to be added.

Here, I have done that one. So, this is the CDD that I have got from here from 0 0 2 7 11 11 11 0 0 2 7 11 11. This is the CDD per month, and this is for 20 days. So, just multiply 20 by 2; 7 by 20 equals 140; 11 by 20 equals 220. This is your OHGC. Multiply that with the working hours, 8. So, the total kilowatt-hour will be my total requirement.

Now, let me see the balance of the unit balance because I always love to see the unit balance. OHGC is what? It is A into U. So, them^2 into W/m^2°C , OK. So, this is gone. So, the Overall heat gain coefficient has a unit of W/°C . Now, this is the rest of all. CDD is °C multiplied by this 20, the number of days, and the number of hours. So, the number of days, 20, gives a kind of °C because that 20 day is 2°.

So, your total is 40°. So, this is actually going to be some°, and this is days, this is hours. So, what I am doing over here is, if I write here, this is OHGC. I am multiplying it with CDD per month and multiplying by hours. So, OHGC is your W/°C multiplied by the °C into hours.

So, that means I am finally getting watt into hour, and I am converting that to kilowatt-hour, which is the unit of energy. So, I have got, and then if I sum it up. So, finally, I got 40,878 Wh. This is in watt-hour. This is in watt-hour. This is in watt-hour, and so I can find out that one. I think I have to divide that by 1,000. So, it is watt-hour, or maybe kilowatt-hour. I have to. It is kWh.

Kilowatt-hour, and then I can check that one. That total amount of 40,878 kilowatt-hour is the total requirement of the cooling load for that building annually, the annual cooling load requirement. If you remember the last class, what we did, what last lecture what we did, we actually calculated for a particular solar radiation and temperature for a particular time, for that particular hour or whatever. And now it is whole sol for a year, but of course, it is approximate. It gives you only the conductive kind of treatment. It is not taking care of your radiation heat because SHGCA is missing, solar air temperature is missing, and no data of the solar radiation is there.

We will see that also will come in the later. We will, of course, see. So, but if you want to see some kind of a comparative study of two different buildings in the same locality or maybe the same building in different localities just to change of the CDT. So, we can have a kind of an idea that what could have been my annual cooling load, what could have been my total amount of the cooling load requirement, or my expenditure for electricity for running the AC, the air conditioner, and all these things in a building. So, that is why if I again go back to the very first figure, I have not taken all the

Proportion of the building, the white portion I have not taken, the white portion, the surface area of the white portion I have not included in my calculation. Because by virtue of the architectural drawing, I know the ground floor has 3 patches, and in the first floor, these 2 patches will be air-conditioned. The rest of the white areas are non-air-conditioned areas, which means maybe some storeroom, some canteen, maybe something like that, some toilets, maybe some staircase or something like that. So, and the central blue patch is the corridor. So, I only take care of the air-conditioned area.

And not only the air-conditioned area, I have taken care of the air-conditioned surface area of the air-conditioned area, and then I have calculated. So, based on this calculation, I have just demonstrated that one to you. So, first, you have to give the facet area of different facets. I have kept 10 facet areas. And maybe your building is too large, or maybe some kind of the there is not always square or rectangular shape; there will be typical shapes. So, you may have different different areas.

So, you may have required 10 areas. You may then give the monthly maximum and minimum temperature of the location. You can generate it or get it from some kind of the I have mentioned one website here. If you can go to this particular slide, this www.degreedays.net. So, you can check that one. You can get directly the cooling load and all. So, and then the base temperature and the working hours per day, etcetera, if you can feed this thing will be ready.

So, this is what we have shown to you, and so, if I again, let me before finish, if I go back to the Excel chart. So, you see this is the case we have discussed; you are all getting this 3992 as an OHGC. Now, what is the total amount of cooling degree days? The annual cooling energy demand is 40,878 kilowatt-hours, and the peak monthly demand is 7,025 kilowatt-hours, which is for these 3 months because, in these 3 months, you see, the temperature or the T max and T min are such that the average temperatures are the same. Now, if I change the base temperature, suppose I am not comfortable with 22°, I am comfortable with 18°; that particular building or that area, I am not going to change that particular 18°.

You check this value; the peak is 7,000. And the annual is 40,000; if you make it change, it is now changing; it is 9,500 as the peak instead of 40,000; now it is 69,000 as the peak. Only a change of how much? 2°? The last one is 20, I think, not 22; there is a 4°C change. So, a 4°C change results in a change of that much. So, if you think of that, I am comfortable with 24°, 2°. So, instead of 40, it will be less than 40; now it is 30, almost a 10,000 kilowatt-hour decrease.

A 10,000 kilowatt-hour decrease means, if you take 7 rupees per kilowatt-hour as electricity charges, almost a 70,000-rupee decrease in your annual electricity bill. And you see now we are getting 3 months as 0, and November also 0. November, December, January, and February months, you do not require any kind of cooling because those are your increases in the base temperature. So, 22°, let us keep 22°, and your monthly days, if you increase, or maybe your working days instead of 8, if you just go for 10, it is increasing from 40 to 51. So, and now if you just change the facet area, suppose you want more facet area to be air-conditioned, more area instead of this white patch area, you are going to more area; suppose it is 120 or so, it is changing; it may be some other facet area is 130 or so.

It is increasing. So, by virtue of any change in the facet area, by virtue of any change in the number of working hours or number of days, if you change it to, suppose it is a fully the 30-day building like a hospital and a 24-hour building like a hospital. So, you see it is 183,000 coming up, the demand, annual demand, almost 140,000 is the demand. So, it is an interactive chart I have prepared for you, I will share it in our forum

and for you, and let me finish the lecture. So, this is some of the references, and whatever we have discussed is that the heating or cooling degree days is the amount of heating required or cooling required on average throughout a month or throughout the time period, maybe in a day. That is first calculated based on the mean temperature and the fixed base temperature, and based on that, with the overall heat gain coefficient, the heat load is mapped or calculated. Thank you very much.