BUILDING ENERGY SYSTEMS AND AUDITING

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Week - 05

Lecture - 25

Lecture 25 : Thermal Comfort Indices

Welcome to the NPTEL course on Building Energy Systems and Auditing. We are in module number 5, Energy Conservation and Thermal Comfort, which we are discussing. In the last lecture of module number 5, lecture number 25, we will discuss the thermal comfort indices. In the last lecture, So, we have discussed the various components of thermal comfort, and in this particular lecture, we will discuss effective temperature, operative temperature, predicted mean vote, predicted percentage dissatisfaction, and tropical summer index.

As we understood from the last lecture, the six parameters are very much responsible or parametrically responsible for human thermal comfort. There are parameters like air temperature, mean radiant temperature, which we discussed thoroughly in the last lecture. The air speed, the velocity or the speed of the air. The humidity, that is the relative humidity, particularly in a closed condition. These four are the thermal parameters or you can say they are the environmental parameters.

The fifth and sixth are activity, which is the metabolic rate, and clothing, or the personal human parameters. So, these six parameters can be classified or treated as parametric variations by virtue of some numbers. Based on that, a composite score or index can be generated, and we will discuss today how that kind of index can be generated and how it can give us an indication of which combination is going to be comfortable or not. So, it is an old one that we discussed in the very second or third lecture, probably the psychrometric chart. In the psychrometric chart, as you know, the x-axis is the dry bulb temperature, the y-axis is the humidity ratio, and those curved lines are the relative humidity curves.

So, based on this particular psychometric chart, let us assume a boundary. That boundary will be defined with the typical two dry bulb temperatures and also two curved lines of the relative humidity. So, I am assuming this is my assumption. Let us assume that the 20° centigrade to 30° centigrade these two lines are coming under the within that temperature or in the comfort temperature also. Whereas, the 40% relative humidity which is a lower curve line and the 60% of the relative humidity is upper curve line are coming under the in between this 40 to 60% of relative humidity will be considered to be the comfort zone.

So, within this particular bounded area any combination of the any combination of the any combination of the dry bulb temperature and the relative humidity will satisfy the thermal comfort condition. Let us assume that and anything outside this particular point will not be going to be that or maybe if it is lower temperature less than 20° temperature or whatever. So, those points are not going to be considered as thermal comfort conditions or so.

Let us assume that in this respect in this respect what we can do we can go to the psychometric chart and let us suppose this is the that particular boundary 60% RH to 40% RH 20° centigrade dry bulb temperature to 30°. Now, there may be several situations inside a closed environment ah because of a lot of heat production or maybe a lot of loss of heat there will be several conditions or maybe there is a ah there is maybe some kind of the natural ventilation which is moist air or maybe there is a heavy amount of latent heat generation inside a closed air condition or so, there can be n number of situations or causes may be there which may create some kind of discomfort. So, suppose let us take the first point like this the if it is a hot and dry. The hot and dry means the temperature is more than 20 or maybe more than 30 or something like that and also it will be having very less amount of the humidity.

So, that will be lower than the 40° actually. So, I have considered two such points, one point just below that particular area. So, I have to put it up. I mean, what I have to do is I have to somehow make some physical changes or maybe some changes inside the room, like mechanical ventilation or anything that will push this particular black point inside here, then I will. I will have that kind of comfort because the condition is not at all suitable. It is very dry, and temperature-wise it may be fine, but it is dry. So, I have to increase the moisture content a little bit.

So, I have to think about humidification, not dehumidification, for this particular case. The second case, you see that the right-hand side where the dot is, the dot or the state of temperature and relative humidity, which is maybe less than 40% humidity, but the temperature is very high, maybe more than 30° or maybe 40°. So, that is also not going to be suitable for thermal comfort, so again that has to be pushed up and placed at this particular point within that particular red boundary zone, and that will be pushed in a way that is not going to be a vertical push, but a slanting push upwards. So, that means you require some kind of cooling and also some kind of evaporative cooling because it is going towards the same WBT line or parallel to the WBT line.

The first one is the upward push, which means there is no change in DBT. So, it is a kind of humidification, no cooling or heating, sensible loss will not be there, or sensible gain will not be there, but in the second case, it is a So, it will have both: one component of the cooling, sensible cooling component, and another component of the humidification component. Let us see another two points which are in the warm and humid zone because it is warm and humid: warm because the temperature is on the higher side, and humid because the RH is also on the higher side.

So, take the first top point central one; you have to push it down if you want to manage it or if you have to provide some kind of thermal comfort. So, to push it down, you have to cross the line of 60° humidity. So, you have to reduce the humidity; you require dehumidification, but no sensible heating or cooling is required over here. Whereas, if you go to the other point, which is your sensible cooling and the dehumidification point, I mean that will be the action. So, you have to push it inclined towards down, and it requires both components, that is, the cooling also, and it also requires some kind of dehumidification.

So, and finally, maybe you have a very cold atmosphere or maybe a cold interior. And you require some kind of sensible heating just to push that particular black line, the leftmost black point, put it inside that particular red boundary zone or so. So, we understand this; we understand these two are the prime factors maybe that we can think of, that the relative humidity and the DBT are going to have a primary role. So, we can go a little back and then we can say that these two are maybe the combination of this air temperature and the humidity that will play a role. But we will see how this

this air temperature, air speed will now be going to take, and mean radiant temperature we discussed earlier. So, it has a combination of the air temperature and the air speed also with some kind of radiant heat. So, this is also going to be taken into account in further discussion. So, the first discussion we have taken into account the relative humidity and the temperature. Then we can discuss the third one.

So, the first addition is the air velocity. So, and in this particular case, if I take air velocity also into account, that is called the effective temperature. So, what is effective temperature? It is again a combined factor of these three: the dry bulb temperature, the relative humidity, and the air velocity, in such a way that it can now participate in a way that it can give a kind of a situation under these three combinations—something is higher, something is lower. So, in that particular situation, how a human body reacts to the thermal comfort scenarios or so.

So, in this particular monogram, we can see this particular monogram. If you see, it has two axes or two side axes, you may say. The left side is the db t, or you can actually take g t. So, g t is a group temperature, which mostly tends to indicate the mean radiant temperature. We are assuming here that the d B T and the globe temperature are more or less the same kind of scenario. The right-hand side scale is the W B T. So, it is your wet bulb temperature. So, even if you take this D B T, if you take the D B T plus this W B T combination. In fact, that is going to lead to the D B T and R H combination.

These two are already taken care of here. What is happening if you take the G T, the globe temperature? So, that means we can say this is R. The mean radiant temperature we are taking for this particular combination. And the other axis, there is a third axis also, or the third parameter, which is the air velocity in meters per second. Which starts from 0 or something like that, and 0.1 maybe, and 0.5, 1, 1.5 to 7, and it is from 1.5 onwards is very high velocity.

So, sometimes I may start the ceiling fan or maybe some kind of a stand fan, or maybe there is a really ample amount of natural ventilation coming in through the windows or so. Based on these three combinations, we can see where the comfort is. The comfort is given as this shaded line. This is ET. ET is the effective temperature.

ET is the effective temperature or comfort effective temperature. Now, how will I decide about it? Suppose my DBT or MRT or the globe temperature is 40. At that time, my WBT is about, suppose, 20° or so; this is the 20°. So, I will connect these two lines.

So, if I connect these two lines. So, it goes like this. So, any combination of the air speed will not give me any kind of comfort, or the effective temperature does not come under the comfort scale also. The effective temperature lies between almost 25° to 30, not 30, 20, 26, 27, 28; this is 28° or so.

8°. This line is the 28° line or so. So, it is not coming comfortably. Suppose, maybe, let us say this is maybe 12° or so, 13 or 13°. This is 13° DVT. Then probably, with the same combination, I am passing through this particular dark color zone, which is a comfort zone, but this comfort zone will not be suitable for all the combinations of the wind velocity or the air velocity. Its comfort with these two combinations of WBT and the wet bulb temperature, the comfort comes on 0.1 to 0.2. So, this is all of these four lines. These four lines are 0.1 to

2.0 meters per second, the wind velocities or so on. In between that, there can be comfort, but it is relatively looking like the temperature, which is about 22° to 26° or so, 22° to 26° or so. That kind of temperature can be maintained. But this passing through lines passes through almost about 20 to 21°. Something like that, which will look like it is not 20, sorry, it will be around 25° temperature. Even if it is the driver temperature and is much higher, 40°, but because of the air velocity and because of the humidity present in that particular

So, in that particular air, the effective temperature will be around 25°. So, these two are now combined with the air velocity, air velocity, and that leads to the effective temperature, effective temperature. So, that is one of the criteria. And we can go to the operative temperature next. The operative temperature is another way to look into the S-ray and other types of indexes, as actually taken into the operative temperature in nature.

This is also, you see, it is the MRT. DBT and the, and your velocity, that V, V stands for the air velocity, these three things are now here taken care of. So, here it is, the three things: MRT, DBT, and the air velocity. are taken into account, and this is the typical formula for that, and where the air speed is very, very low, mostly it is a stagnant kind of scenario, 0.1m/s or something like that or below that, then this bracketed term will be, or the under-root term will be going to be 0 or very, very, very small, and then it can be redefined. It cannot come directly from this particular equation, but it is redefined as the operative temperature is MRT plus DBT. This is not BDT, sorry, this is a mistake, this is DBT.

$$L = M - W - \left(3.96 \cdot 10^{-8} \cdot f_{cl} \cdot \left((T_{cl} + 273)^4 - (T_{mr} + 273)^4\right) + (f_{cl} \cdot h_c \cdot (T_{cl} - T_{ai}) + C1 + C2)\right)$$

by 2, and this MRT plus DBT by 2 is almost, most of the time, we have taken this as the operative temperature. So, what is the operative temperature? It is a simple, kind of a composite index of the temperature, which, like effective temperature, where the MRT and DBT and the velocity of the air are taken into account, then the combination of these three can give a certain temperature which is not equal to MRT, which is not equal to DBT, which is not equal to WBT, which is a new combination as operative temperature, which you may say that which human may feel as our brain may map that kind of temperature as an operative one. So, this is the thermal comfort scaling which is superimposed in the psychrometric chart given by the ASHRAE 55 2013.

So, this is a very interesting kind of a chart because it superimposes the zones of the thermal comfort, number 1. And number 2, it superimposes various zones of thermal comfort based on the Clo values. It has actually the 0.1 Clo zone, see this is the first boundary, not 0.1, 1.0 Clo zones as normal kind of clothes, and there are little less 0.5 Clo zones. And, these two are basically two closures. So, if you have a little bit of heavy garment also, then the first shaded area, the first shaded area

The comfort zone will be operated, maybe from 22° to 26° or so in the DBT, sorry, not DBT, operative temperature. See, there is another change in the x-axis; it is not the DBT, it is the operative temperature mentioned in °C, half of the dry bulb plus half of the MRT for still air, yes, in the case of still air. Now, if this is 0.5, a little bit more temperature, 25° to almost 27° or something like that, it is 0.5 flow; it is a kind of comfort, but you see there is, in that particular little darker zone, it is written 0.1m/s air speed is required to maintain that particular comfort. The first one, you do not record any kind of air velocity; maybe you do not need any kind of natural ventilation, you may not need any kind of ceiling fan or any kind of fan; it is normal. The third zone determines the very lower amount of clothing with a very low metabolic rate.

And a very low kind of mean temperature, but you need a higher amount of speed, 1.2 meters per second. So, as you go sliding from the left to the right, you require more air speed and you require less clothing values also. So, there are two main and one sub-zone, so three zones maybe you can say, and then this has been devised as one of the basic fundamental requirements of thermal comfort from the ASHRAE 55. This is another one, operative temperature of ASHRAE; they have also given it like that. The mean monthly outdoor temperature is in there.

This is also very, very, very important and very crucial, the composite index; you may actually think of it if you go for any kind of audit; we will discuss it in the next class, next chapter, or maybe the next to next one. So, in the case of the energy audit or so, if somebody is asking for a little bit of comfort, you can actually see whether the comfort is required or not based on this particular chart. So, the monthly mean outdoor temperature is on the y-axis, of course, the x-axis and the upper axis are the same, which is only° Celsius and° Fahrenheit. And the indoor operative temperature is on the y-axis. So, operative temperature we can take in a still air kind of scenario with half of DBT and half of the MRT.

And this band, which ranges from about 10° to almost 34° centigrade, can be taken as the 90% accepted case or the 80% accepted case or something like that. So, the University of Berkeley has provided one of the thermal comfort scales. We will see that one, or you can actually visit their website. It is this, and you can check the different kinds of parametric variations and then find out what the comfort scenarios are. The last one is the predicted thermal comfort where PMV and PPD have been defined. PMV, the predicted mean vote, this particular Fanger is one of the scientists in this area and a stalwart in his research, which is very fundamental and very early research. He has devised a PMV, Fanger's thermal equations, the predicted mean vote. He has selected a lot of people and did a lot of experiments on them.

And created a kind of equation which gives a PMV as an exponential kind of equation of these particular values where M stands for the metabolic rate and two constants and the exponential multiplied by the thermal load. And against that, he also found out how people behave or how people find that particular scenario with a certain amount of PMV, the predicted mean vote. That is, how much percentage is dissatisfied. So, that PPD, which is called PPD, is also a function or it is linked with the PMV and it is exponentially linked with 100 minus 95 exponential of this PMV. So, it is an exponential graph, and then he has devised these two.

$$TSI = 0.308 \times t_w + 0.745 \times t_g - 2.06\sqrt{V + 0.841}$$

So, what we have to do is first find out the PMV. So, PMV, as we discussed, this is the the big equation, the thermal load. In fact, this L, this thermal load, is nothing but this L. This is your L. This L is your this one. This is your L, a big one, and this big one, big equations, actually take care of your metabolic rate M, W, the rate of mechanical work. FCL is the ratio of body surface area while clothing is on to a or clothing is off. These two scenarios or maybe whatever how much is the surface body surface area. TCL, clothing clothes temperature. What is the temperature of the clothes?

TMR is the mean radiant temperature, TAI is the DBT of the air, HC is the convective heat transfer coefficient of the air, and C1 and C2 are the two coefficients which depend upon the metabolic rate, work, the DBT, and the vapor pressure. So, it is a complex scenario of complex equations also based on that PMV can be calculated, and that is a number, and this number can be given with this particular equation to get the PPD. So, suppose this PMV, this number, will actually lie either between minus 3 to plus 3; this is the range between these two numbers, minus 3 to plus 3. Now, this equation is such that it is an exponential equation, and it is generated in such a way that this PMV will lie between minus 3 to plus 3, and what is meant by plus 3 or near plus 3 is that it is very hot. So, the combinations of metabolic rate, the Clo values, and all these things are such that they give you almost like 2.7, 2.8, 2.9, which is a very hot scenario; plus 2 means it is a warm scenario, plus 1 is a slightly warm scenario, and 0 is neutral.

Similarly, if it is minus 1, it is slightly cool; minus 2 is cool, and minus 3 is cold. So, based on that, it is a dipping kind of curve, and suppose you are neutral, that means 0; your PMV value, based on your metabolic rate, your clothing, your DBT, MRT, everything is almost 0. So, you are here, so that means, at least, what is the PPD? PPD is almost about 5% or so, which means the 5% is the percentage of dissatisfaction. So, only out of the 100 people, 5% may still believe

that this neutral thing is not so good; I mean, it is not so neutral, or they are not satisfied. Similarly, if you take a very high value, maybe it is 2.9 or something here, which is very hot. So, then if you see what the PPD value is, it is almost 95%. So, that means 95% will be dissatisfied, whereas 5% may still be satisfied that yes, this is not so much, not so. So, it is not going to be always 100%.

So, it is going to be neutral, and there is 5% who are dissatisfied, and in the case of almost close to 3, maybe 5% are satisfied. So, something like that will also move. So, it is a very interesting curve, and this curve has been rectified or modified over the years after a lot of research and down the timeline. With different types of scenarios, but this is one of the baselines we can consider before we go to the next website, and then we will see the Berkeley Center for the Built Environment's thermal comfort tool. So, that website address has been given.

So, this is the present scenario; you see these are all the parameters we have: an operative temperature of 25° centigrade. So, we have the next one: air speed, relative humidity at 50%, metabolic rate, and flow value. So, 1, 2, 3, 4, 5; of course, this operative temperature takes care of the DBT and MRT. So, there are 6 factors, and this is the point at present. So, suppose if I increase the met value, that means I am

or maybe if I increase the clove value instead of 0.61, suppose here we go for a very high clove value. So, I am still here, but the comfort zone is somewhere here, this blue one. So, this is I may feel warm, I may feel very warm, okay. So, let us go back to it being 0.6 or something. So, 0.6 or something over here.

Now, if I increase the metabolic rate So, I may still be neutral; if I go a little bit more, I may be slightly warm; if I go a little bit more, I may be slightly warm or very warm or something like that. It will go. So, let us go back to the perfectly warm scenario 1. And now, suppose the operative temperature is going to be high; if it is high, then I have to reduce the matte, then it is fine, then it is neutral. So, I have to slip or I have to lie down, or if I want to go for 1, then I have to reduce the claw value, then I have to remove the claws, then I may be a little bit neutral or so.

So, like that, you can have those kinds of changes, and you can see the other changes of the scenario. This is a very interactive kind of curve to understand the thermal comfort and how the met value, clo value, and the humidity. Suppose I have increased further to 30°, and also it is a warm and humid climate, almost you know, 84°. So, it is very slightly warm scenario, and if I increase the met value at that time.

So, I am doing some kind of a lot of exercise or so, then you are going further beyond or so in that scenario. If you increase the flow value, it will be warm or something like that. So, we are doing just the reverse. So, what do we have to do? We have to reduce this value; no, 0 may not be the good value. So, but your mat activity has to be very, very.

So, then probably you are slightly warm in this kind of scenario. Here, what can we do? We can increase the air speed. So, if you increase the air speed, you can be neutral. So, it is humid.

So, you have to increase the air speed. So, it will be neutral. If you increase the air speed too much, So, you will feel slightly cooler, and again, if you decrease the temperature too much, you will be cold. It will be very, very cold. A 16° temperature with 1.7 air speed will be very, very cold. So, that way, we can think this can be a very interactive kind of curve.

So, let us go back to the PPT, and then this is also the Indian model. So, in the SP 41, they have given the dry bulb temperature, relative humidity, and the wind speed. What will be the wind speed scenario? Based on that, those are the comfort scenarios, and those plus signs are the acceptance for the not those acceptable in practice. Higher than that, and the star dot points are not possible. So, there is another kind of scenario given in our SP 41, which is called the tropical summer index, which is also applicable in our country. So, the formula is this: Tw is the wet bulb temperature, Tg is the globe thermometer temperature, and V is the air speed.

So, we have in this particular tropical summer index, we have taken the RH, we have taken the globe temperature which is close to the DBT and also the speed of air. So, those temperatures have been taken into account and this particular TSI can be computed. So, if you know the globe temperature and all those kinds of the DBT, wet bulb temperature, and the velocity, you can calculate that one and go to the next slide or in that particular SP 41, there is a graph and a hatched portion in the graph. It gives you the comfort zone and it has a boundary. The boundary, what it is written over here, TSI value between 25, sorry, TSI value between 25 to

to 30° with an optimum condition of 27.5°, that is the optimum condition for the TSI, that is the tropical summer index. If it is above 30, that means, 30 to 34, it is hot warmth; if it is more than 34, that means, more than 34, more than this 34. So, this is 34, it is very hot or above the whereas it is 25 to 30. So, if it is 19 to 25, it is on the lower side, cold, but if it is below 19°, it is too cold.

So, if it is below 19, then it is too cold. So, these are the other way, another Indian way. Indian way in the sense, this is generated by the SP generated by Indian scientists and given in the SP 34 for our tropical climatic condition. So, that also can be taken into account; we will see how that can be implemented in the further lectures when we go for the energy audit or maybe the energy retrofit.

So, what we have discussed is that here are the thermal comfort parameters PMB, PBB and some other indices. Thank you very much.