BUILDING ENERGY SYSTEMS AND AUDITING

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Week - 05

Lecture - 24

Lecture 24 : Thermal Comfort Parameters

Welcome to the NPTEL course on Building Energy Systems and Auditing. In module number 5, where we are now discussing energy conservation and thermal comfort, this is the first lecture on thermal comfort, and this is lecture number 24. So, in this lecture, we will see the concept of body heat. The human body heat and the heat balance, the thermal comfort parameters mainly, and we will also see one of the very important concepts of MRT or the mean radiant temperature. So, in the introduction to thermal comfort, we always talk about thermal comfort in our day-to-day life, and in the scientific communities, we also talk about thermal comfort. How thermal comfort is defined is very important. So, it says that it is the condition of the mind. which actually expresses satisfaction with a particular thermal environment. It is the mind, and also in ASHRAE 55 2004, it is stated similarly as ISO 7730 has stated: it is the condition of the mind that expresses satisfaction with the thermal environment, and it is assessed by subjective evaluation.

This is very important; it is a subjective evaluation. A particular thermal environment which I may feel comfortable in, you may not feel comfortable in. It depends upon a lot of parameters, a lot of other types of factors like ethnicity, clothing, the environment, the way we have been brought up since our childhood, and all. So, there are a lot of subjective parameters there. So, both codes state that it is a condition of the mind.

So, it has to be some kind of satisfaction with the mind. So, definitely the parameters have to be evaluated by some kind of subjective evaluation. So, let us see today in this particular lecture, lecture number 24, what are the various parameters. In lecture number 25, we will see the indices, what are the thermal comfort indices. So, this is the very well-defined and well-defined equation that actually states the heat balance equation of a human body.

So, it is stated that on the left-hand side, there are so many parameters starting with a positive parameter of m. So, there are some kinds of gains; when there is a positive, there is a gain; if there is a negative part, there is a loss. So, what are the gains? There is an M; M is always going to be a gain. So, M cannot be negative, which is metabolism.

$$M \pm Cd \pm Cv \pm Rd - Ev = \Delta S$$

So, it is human body metabolism that will produce some kind of heat; sometimes it produces a high amount of heat, sometimes it may not. So, if we are very active in our actions and all, suppose we are running, we are playing some games or so. So, or maybe we are working with some kind of gymnasium exercise or something like that, the metabolism will be high, but if we are lazier, we are sleeping, we are sitting down on a balcony. So, definitely the metabolism will be ah, much, much less, but this cannot be negative.

The next three parameters, Cd, Cv, and Rd, are nothing but conduction, convection, and radiation. They are sometimes positive and sometimes negative. So, conduction is the contact temperature difference or, due to the temperature difference, the contact temperature difference between my body and the back of my chair. There may be a temperature difference. So, there is conduction of heat, which will flow from one part to the other. So, there may be a chance of a negative value. So, there may be conduction losses if my backrest is cool enough and the temperature is less than my body temperature. I will lose some kind of heat.

The second one is convection. Convection occurs if there is air that is warmer than or if there is air that is less than the skin temperature or cooler than the skin temperature. So, convection will take place between these two. So, there may be a plus or minus Cv also. Then there is radiation. So, radiation from the sun, maybe if you say it is about outdoor thermal comfort, say directly under the sun or maybe under the sky or any kind of radiating body if you are very close to the window.

Which actually radiates a lot of heat if you are very close to the ceiling, which is exposed to the outside and is very hot or even in the night, it is very cold. So, there is a situation where the human body may lose heat or it may gain some kind of heat. That is why the Cd or the radiation part is also plus or minus, which is because of the sky temperature or the window temperature. Suppose it is snowfall outside, and if it is, I am going to lose some kind of heat. Suppose it is the month of May or June, with hot scorching heat outside, then I am going to gain some kind of heat. That is why it is plus or minus in that particular equation.

But lastly, it is Ev, which is always a loss, which is the evaporation. So, because of the moisture and the sweat in our body, we will always evaporate. Always evaporating means it is actually the body's mechanism that creates some kind of sweat, and as and where sweat is created, it will evaporate, and as and where it is evaporated. So, I am going to lose some kind of body. Heat, and that heat is latent heat. So, it is always going to be negative, and then because of the sweat, I am not going to gain anything.

So, it is always going to lose some kind of. So, all these things, if you add and if you subtract and all. So, there may be a lot of permutations and combinations possible, and a lot of scenarios can be possible. So, that is equal to the right-hand side with ΔS, some kind of the balance heat of the human body or so. Now, see, this ΔS will fix up your body condition or the mind sometimes, and from that point of view, we can say yes, we are comfortable, thermally comfortable, or no, we may not, or maybe we can say it is neutral, we are not so comfortable, or it is not so kind of bothering me.

So, let us see how that particular thing will take care in the next slide. So, Δ is the change of heat storage, so that we understand. Our body temperature is almost about 36, 37° centigrade, around 37°C. So, there are some losses always going to be happening, and there are some gains on the other side. So, based on that, if it is thermally balanced, if I say, then it is this ΔS equal to 0, and I can keep my body temperature exactly at 37° centigrade, and probably I will feel very neutral.

I will feel very neutral, meaning I am not comfortable, of course. Neutral is also a type of comfort where I am not going to feel any cold, nor am I going to feel any kind of hot atmosphere or so. This environmental parameter, how is that going to relate to these four things in my equation? Metabolism is not at all directly related to any kind of the This environmental parameter is the body parameter, the body's biological parameter mostly. And evaporation is actually directly or indirectly linked with the DBT, air velocity, and the RH. So, if these are changing, the evaporation rate and everything will change.

Radiation between the two bodies is going to be a thermal conductivity and all those, so that there is a temperature difference. And this temperature difference is, yes, sometimes an environmental parameter. Just now, I told you if there is snowfall outside and there is glazing, there is a window, and you are very close to the window, there is a kind of change in radiations also. The convection, yes, there is the air velocity. Maybe you are in a room that does not have any kind of air conditioner. It has a natural airflow. So, based on that, the temperature of the outside DBT will play a role.

There are some human psychological parameters also. Yes, metabolism is, of course, a human psychological—sorry, not psychological, I am sorry—it is a human physical parameter. So, it depends upon the surface area of any human being, the weight of a person, it depends upon the sex, and it depends upon the age of a person also. The evaporation is also, yes, sometimes a physical parameter, its ability to produce some kind of sweat, your surface area uncovered with clothing, the surface area covered with clothing, those. Similarly, the clothing and your surface areas also come into the picture in terms of your convections and the radiation. So, now if you see, there is a balanced kind of scenario in this particular graph. On the x-axis is the temperature, high or low, based on our body temperature, and at the top, I have written down this particular human body equation, the heat storage equation.

And on the x-axis, the right-hand side is the clothing, and the left-hand side is the metabolic rate. So, now the body temperature will feel 37° centigrade, which is the normal body temperature when this ΔS is equal to 0. So, your loss and your gains are almost equal, and there is no ΔS. But if there is a hot condition, that means the room is hot. So, there is much more positive, and there is a less amount of negative.

So, this ΔS has a positive value. Now, it is how much positive it may be; a small positive value is something you can accommodate. If it is a little bit more, you can still accommodate it. And if it is finally very high, and if it is more than that, your body temperature will change, right? Because ΔS being positive means your body temperature will now increase from 37 to 37.5, 38, like that. And if the body temperature is more than or almost equal to 41°, that means almost 4° above the 37.7°, which is like a very high fever kind of thing. And if this is so, you are in trouble; you will be really in trouble, and you may go into a kind of shock. Or maybe a kind of trauma, or that may sometimes be known as a heat stroke, that kind of scenario. And in medicine or in our clinical community, they call that hyperthermia.

So, at that time, what we do actually, if you see, is we want to increase the heat loss; we want to try to be more negative. So, we sweat because it will be evaporative cooling, then the EV will be more. We try to remove our clothes because that will increase our body surface exposure to the atmosphere, or we can go for a very light amount of clothing. So, we turn the fan on, which will be our habit because we want to increase the airflow that will evaporate the sweat from my body. So, that will again result in some kind of loss.

So, we increase the body surface area, and we want to spread out. We can lie in the bed or somewhere there. So, we want to increase the body surface area as much as possible, which will actually decrease heat loss by evaporation or convection and all. So, we also try to decrease heat production. Heat production comes from the metabolic rate. So, we want to decrease that. So, we will stop eating. If you eat, it will start generating a lot of heat.

We will stop eating, decrease any activities, and not go for any kind of exercise or something like that. So, you see, the body has light clothing, and we will have a low metabolic rate. We can sleep, lay down, or something like that. In other words, if you go back to the other type of scenario when the condition is very cold, and your ΔS is negative. So, if this ΔS is negative, it will decrease your body temperature from 37 to lower, and if it is less than 35°, you are again in trouble.

So, it will go to hypothermia, which is called hypothermia, and it may lead to some kind of attack. So, a cold attack or something like that. In this scenario, we have to decrease heat loss. We do not want to lose any heat. So, what we will do is, number one, our body will not sweat. Number two, we will apply heavy clothing so that we do not lose any heat from our body. So, we will have winter clothing, shelter from the wind, and not allow any kind of

The fan movement or so, we will shelter from the wind and we will reduce the body area by folding arms and legs. So, we will not spread out; we will reduce our body surface area. On the other side, we will try to increase heat production. So, we have to increase the metabolic rate. So, there are two or three ways: we will shiver, do some more work, and that will produce some kind of heat.

We may eat something, maybe hot milk, which will increase my metabolic rate. Or we will do some activity, shivering, or some activity like running or something like that, which can produce some kind of heat. So, that way, these two things will be balanced with each other. So, from this perspective, we can see the thermal comfort parameters depend upon So many environmental parameters, mainly these four environmental parameters: the air temperature, we all know DBT.

The mean radiant temperature (MRT) we will discuss now, air speed, and the humidity. Whereas, there are some Personal factors also. The first two personal factors are very important: the activity, which is the metabolic rate, and the clothing. Clothing, you know, the amount of clothing and all these things also play a role in your heat balance condition and also lead to thermal comfort. Other than these two, activities and clothing, you can map. But other than that, the state of your health, the adaptive or the optimization, then the body type, whether you are thin or fat, your age, gender, genetic or ethnic group. You are coming from which kind of climatic area, or from childhood, you are growing in which climatic area. Those parameters are also going to affect, but those parameters cannot be mathematically modeled.

Your mood and your attitude, your intense drive or enthusiasm, body rhythms like the rhythm cycle, your diet, your social situations, whether you are relaxed, or where you are in fear, So, you know you are in a stressed mental condition; those also come into play. Also, you have to consider your standard of living, which also comes into play sometimes, whether you are rich or whatever. Those parameters from 3 to 13 cannot be mapped properly because that is why it has been told that it is a subjective parameter. Your thermal comfort is a subjective parameter. So, but let us try to create some kind of indices. So, from that point of view, we have to consider those 6 parameters: 4 thermal parameters and

the human parameter. So, the first human parameter is the metabolic activity. So, metabolic activities are measured in units called 'met,' and one met is almost equal to 58.2W/m², OK? So, this is the chart of the met, which comes from the ASHRAE 55 table. So, different activities have some kind of different met values.

Suppose you are sleeping; it is 0.7. Whether you are standing and relaxing, it is 1.2. Suppose you are doing some kind of shovel work; it is almost 4, 4.8. Heavy work is more. Suppose somebody is sleeping; in this particular figure, it is 0.8 met. Somebody is playing badminton or maybe table tennis; it is formatted. So, based on that, the clothing insulation now depends upon our clothing, depending upon our different types of clothing, so it changes its value.

So, if you have light clothing, just nothing but a bermuda or something like that, in a thin scenario, it is 0.15, and if it is very heavy winter clothing, it may go up to 1.3, 1.4 also sometimes. So, based on that, it has been changed. Next is the mean radiant temperature also. Mean radiant temperature is conceptually it actually inside a room, inside an interior room, all the surfaces, and also all the equipment and all the furniture will radiate heat in some form.

And based on that, an imaginary room has been conceptualized, which can be treated as the same as the actual room if there is the same amount of radiation heat exchange from the surfaces. So, based on this particular phenomenon, we can say this particular surface from the various objects in the surface, there may be a wall, there may be a ceiling, there may be some light, there may be some kind of room heater. So, each and all sub-surfaces, even there may be some kind of table or chair, which sometimes have some kind of heat-generating source. So, from those sources, the heat flux or the radiation goes towards the center or maybe the other side, or you may say that a particular heat flux is flowing from the higher temperature to the lower temperature zone. So, in an imaginary way, we can think in the center or maybe any point in my particular room, suppose in this classroom, I am sitting in one of the corners.

So, if I want to feel what the mean radiant temperature will be. So, at this particular point, I need to see how much exposed area, three-dimensional exposed area, I have from the different parts of the radiating bodies, and those radiating bodies may be a wall, ceiling, or maybe some kind of equipment or maybe some kind of furniture. So, based on this particular concept, a blending formula can be used to find out. There are various formulas to find out, but this is one of the easy ways to find out the

The radiant temperature, mean radiant temperature, where it has been stated that Tg is the globe thermometer temperature. So, the globe thermometer is actually used to find out the mean radiant temperature, but not directly. You have to use the globe thermometer temperature and use this equation, where Tg is the globe thermometer temperature, Va is the air velocity, and Ta is the dry bulb temperature of the particular thing. So, why the globe thermometer? The globe thermometer is the normal thermometer

kept within the black-colored globe. So, it actually appears to be, or it has to be assumed to be, a black body, and it will collect all the heat from the three-dimensional surfaces. So, definitely, it has a little bit higher temperature with respect to the ambient air temperature, which we call actually as dbt. So, based on this, you see there is a difference, Tg minus Ta. Always, the globe thermometer temperature will be a little bit higher, maybe 0.01° to 0.5°. Sometimes, if it is on the topmost floor and your ceiling is exposed to the outside temperature, hot temperature, or so, then maybe it is 2 to 3° changes that can also be noticed. So, this within-bracket term is going to be positive always, and under root v, the velocity, so it will be a little bit less. So, by virtue of that, this Tr, that is the mean radiant temperature, will be slightly above the globe temperature also. If there is no air velocity, theoretically, you can say it is equal to the globe temperature; otherwise, it will be a little bit more. Globe temperature also from the globe temperature.

So, how can we find out? One way to find out this mean gradient temperature is directly with the globe thermometer, but if we know the partition wall, the exterior wall, and the ceiling temperature, then theoretically in two dimensions or you may say it is kind of approximately we can calculate. So, I have shown a figure in it, it is a cross-section of a room, and my point of interest is this. This is my point of interest, and from the point of interest, I have subdivided the area in the two-dimensional plane for all the objects

Those are having different types of temperatures, and assuming that the floor is 28°, not assuming, maybe the floor is 28°, the ceiling is 48°, the partition wall is 26°, like that, the window is 52°, very hot. And based on my position, the angle which comes from two dimensions from the window is 20°, and the wall ceiling is supposed to be 90°, the floor is also 90°, and the partition wall is 120°. So, the sum of all those angles must be equal to 360°. So, it is approximate why I have not taken into account the three-dimensional angle, number one, that should be. And also, I have not taken the other two sides of the wall because that gives me a three-dimensional character.

So, the temperatures are listed down, and the angles are also listed down. What we have to do is multiply the temperature and the angle. So, these multiplications of each surface are there, and with respect to its angle, it is multiplied and has been summed up. Summed up, and the summation is 12600, which is the total, and that is divided by the whole angle, which is 360°. So, that means it can give me around 35°, the mean radiant temperature.

Again, this particular way of calculation is, I must say, a secondary way of calculation, just to give you a kind of broad idea of the mean radiant temperature. This has been devised, but this has been without, if you do not have those sensitive instruments. Like globe temperature or so, you may devise it like this, but it will be a little bit approximate in the calculation from the point of view. It is better to go with a globe thermometer, and from the globe thermometer, even the globe thermometer temperature in a very static kind of wind condition, even that particular globe thermometer can be read as an MRT in the absence of other parameters or so. So, this particular angle multiplied by the aperture angle multiplied by the object temperature, summing up and divided by the whole angle, which is 360, can give you MRT values also.

So, sometimes there is a radiant asymmetry. The radiant asymmetry means, suppose you are situated in a certain position in a room, and the two parts of the room may be the top and bottom or may be the left side and the right side, having two different extreme temperature differences. Maybe there is a window which is actually radiating heat. When it is 52° or something like that. Whereas, the other side is the partition wall or some other window which is exposed to another room, which may be your air-conditioned room, and that window may be around 18° or so.

So, how close you are to the 18° window or how close you may be to the 50° window. Based on that, there is a radiant asymmetry; you know, your back side may feel like this. So, cold, and maybe the front side may not be that much because it comes under the thrust of the radiant heat. So, that is a kind of asymmetry. The asymmetry is calculated, and the comfort, the percentage of the dissatisfied.

Again, it is a subjective criterion placed on the y-axis, and this is the radiant temperature asymmetry placed on the x-axis. The lower part is in Celsius, and the upper part is in Fahrenheit. So, there may be a warm ceiling, a cool wall, a cool ceiling, or a warm wall. So, there are various scenarios. So, this radiant asymmetry can also be calculated like this. So, I have calculated the radiant asymmetry.

So, the ceiling temperature is 60, whereas the floor temperature is 20, a very asymmetrical scenario. The wall temperatures are 30-30. So, I have distributed the angles with 60° on the wall and 120° for the ceiling, and I have calculated the MRT above that point, the black dot. So, as the black dot is my point of interest, the above temperature MRT will be high because it is exposed to 120° with a ceiling of 60° temperature. So, that gives you almost 50° in temperature. The MRT above, whereas the MRT below will be less because it is 120° exposed to the floor, which is at a lower temperature of only 20°. This 20° temperature actually creates an issue. All other parameters are the same, the wall and all are the same, 180-180.

So, this is going to be 23. So, there is asymmetry between 50 and 23.3. So, there is a 26, 27° asymmetry between the above and below. So, let us see what happens if it is 26°. So, let us see what happened if it is 26°.

So, I draw a line from 26°, and if it is a warm ceiling. So, I may say that it is very much because of the discomfort, as this may lead to a situation where more than 80% of people will be uncomfortable. So, something like that is the radiant asymmetry. This radiant asymmetry is also going to bother a person. I mean, if the radiant, suppose I say, because of the 10° radiant asymmetry. So, and if it is due to the warm ceiling, just like in my case, I can say that around 10 to 20, or 18% of people will be dissatisfied with that.

In my case, it is 26°. So, many more people will be dissatisfied, almost about 95% of the people will be dissatisfied with that. So, that is the radiant asymmetry. So, what we discussed today is the thermal comfort of a human body. We understand the body temperature balance equation. We also understand that it depends upon

some environmental parameters like air temperature, relative humidity, air speed, and the mean radiant temperature. We have thoroughly discussed parameters like the mean radiant temperature. There are two more responsible parameters also there, which are the metabolic rate and the clothing insulation. So, in the next lecture, we will go into the thermal comfort indices. Thank you very much.