Principles and Applications of Building Science
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Lecture - 04
Thermal Comfort in Built Environment – 2

In previous module, we have been looking at thermal comfort in built environment. Primarily, we talked about the basics of thermal comfort and factors influencing it. Now we will start looking at, what comfort zone is, how do we define comfort zone, how comfort zone is defined in international models, as well as Indian models. We will look at few examples. First let us take a look at how do we primarily define comfort zone, I am referring to ASHRAE, standard 55 thermal comfort, you know standard.

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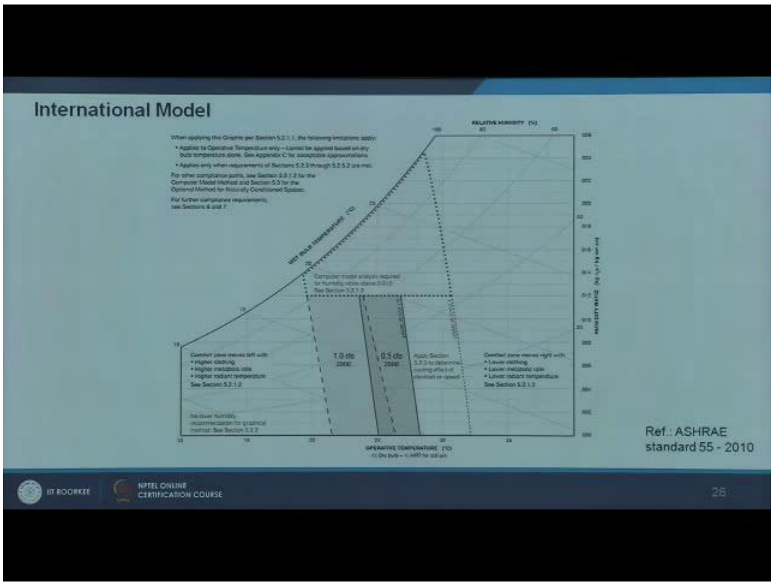

This is psychometric chart, we have been talking about psychometrics, you have, instead of, there is a one small change in psychometric chart, instead of dry bulb temperature, here we have something called operative temperature, which is equivalent to, say in still air, about less than 0.5 or say 0.2 meter per second air velocity. More or less still air, it is half of dry bulb temperature, plus half of mean radiant temperature. This is replacing the dry bulb temperature, in the actual psychometric chart. Right hand axis, you have humidity ratio, then you have these lines, relative humidity lines.

Now, comfort is defined based on, one is environmental condition, here temperatures and humiditys, apart from this, you have also have the clothing insulation and metabolic activity, the personal variables. This comfort zone actually includes this all these factors. There are 2 boxes, if you look at it closely, there is one shaded box, which says, which is ranging somewhere between, 25 degrees operative temperature. It goes more close to 27, 27 and half degrees, operative temperature, at very low humidity. At high humiditys, it is around 24 to somewhere around 26, 26 and half degrees here. When the humidity increases beyond this, the comfort zone does not ex10t, which means, you will not have thermal comfort beyond this point. This is an international scale; we will come to applicability later.

But quickly, this is the comfort zone, with 0.5 clove value. When your clothing insulation is 0.5, you have light summer wear, and then this would be your wear comfort zone. What happens when you put on slightly thicker clothes, winter clothes, or thermal wear for instance, not to at the ex10t of total, you know, blazer kind of thing. You have, say one clove value, which is not a total thermal wear, insulated thermal wear, but more or less like an office cloth, you know suits, office suits, you will have close to one clove value. Essentially what happens in the comfort zone? It is start moving towards your left side. So, instead of you know, the comfort starting from 25 degrees, it goes as low as 21 and half degrees. So, if you are tightly dressed, if your thermal insulation, clothing thermal insulation is getting higher, you will need clover ambient temperatures, for yourself to be comfortable.

So, from 0.5 clove value, the upper and lower limit have tilted, or moved towards left side. Apart from this, when you are doing higher metabolic rate activity, you are, instead of you know, sedentary activity, you are getting into more strenuous physical activity, and then your comfort zone will move towards your left. Apart from the clothing insulation then when you have a higher radiant temperature, MRTR globe temperature is getting higher, then your comfort zone, will move towards your left. On the other hand if your clothing insulation is further low, are your metabolic activity is getting further low, or the radiant temperature are lower comparatively, you have more colder surfaces around you, even when temperatures are conditions are not suitable, if these conditions prevail, your comfort zone would start moving towards your right. Not to the further ex10t, but there is a limit, within which, it can move.

Another thing you can notice this is, with an air velocity of 0.1 meter per second, and when you have air velocities of up to 1.2 meter per second, then your comfort zone shall be higher. If you take a closer look, say take a relative humidity of around 20 percentages here, somewhere close to this. Your lower limit of the actual comfort zone was around 24 and a half, 25 degrees and the upper limit was, somewhere close to 27 degrees, but this is at still air, around 0.1 meter per second, or when there is still air. When you have a higher air velocity, when your air velocities are above 1 meter per second, say 1.2 meter per second is what is given in the chart, then that the same relative humidity, the lower limit would be somewhere around 26 degrees, operative temperature and upper limit can be has high as 31 and half degrees, even with 31 and half degrees, operative temperature, you will still be within comfort zone, when you have enough air velocity. This is a kind of comfort zone, which is defined in ASHRAE.

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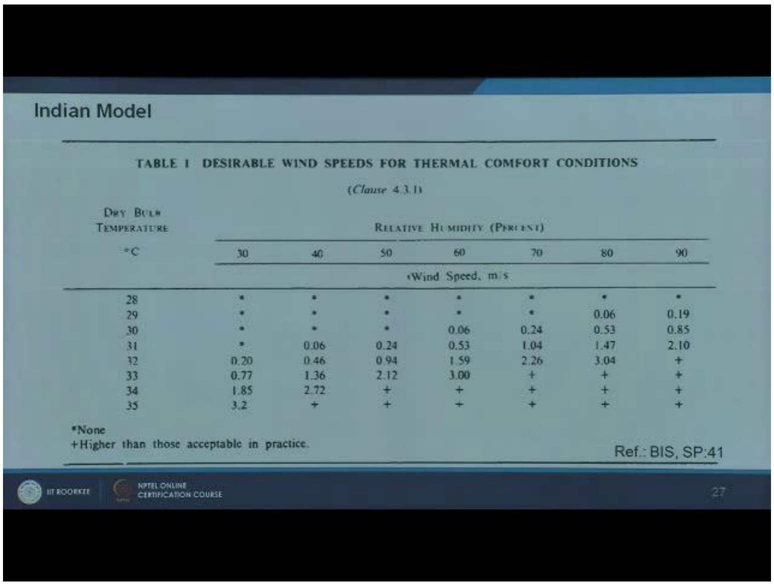

Indian Model

TABLE 1 DESIRABLE WIND SPEEDS FOR THERMAL COMFORT CONDITIONS

(*Clause* 4.3.1)

Dry Bulb Temperature °C	Relative Humidity (Percent)						
	30	40	50	60	70	80	90
	(Wind Speed, m/s)						
28	*	*	*	*	*	*	*
29	*	*	*	*	*	0.06	0.19
30	*	*	*	0.06	0.24	0.53	0.85
31	*	0.06	0.24	0.53	1.04	1.47	2.10
32	0.20	0.46	0.94	1.59	2.26	3.04	+
33	0.77	1.36	2.12	3.00	+	+	+
34	1.85	2.72	+	+	+	+	+
35	3.2	+	+	+	+	+	+

*None
+Higher than those acceptable in practice.

Ref.: BIS, SP:41

We will look at more models quickly. Coming to our Indian model, this is not a graphic representation, but they have nicely presented 2 tables, I am referring to, there of Indian standard, sp 41 special publications. This is hand book of functional efficiency in buildings. This is a very old standard, which has been in use, 2 nice tables have been presented here, similar looking tables, but only differences this is, a set of conditions for comfort, thermal comfort, and the next table is, conditions for, acceptably warm conditions. It does not have to be really comfortable, but it can also be acceptably warm, warm, but still again accept it, then, the conditions slightly differ. First let us like, take a look at this first table; here you have dry bulb temperatures, starting from 28 to 38 degrees.

On this, along the row, you have relative humidity stating, starting from 30 percentage going all the way up to 90 percentage, and what these numbers represent? They represent the required amount of air velocities. Say for instance, your air temperature is 30 degrees, your relative humidity is somewhere around 60 percentage, it says 0.06 which means; you may not need much of air movement to be comfortable. Even with at 30 degrees and 60 percent of relative humidity, with still air, you can still be comfortable. This, tests were done for Indian subject, so the derivation hold good for most of warm humid compositor hard dry bulb regions of India. 30 degrees, 60 percent relative humidity, you will still be comfortable without air movement.

Now, if the relative humidity increases to 80 percentage. Same temperature, 30 degrees humidity, increases to 80 percentage, you will need 0.5 meter per second air velocity, in order to be comfortable. Looking back our at our measurement, we will, we know we said, with a well cross ventilated residential space, you will expect around 0.4 to 0.5 meter per second air velocity, which means, temperature is 30 you know, degrees up to 80 percent humidity, you will still be comfortable, and marginally you will be comfortable even at 90 percent relative humidity. But as the temperature increases, take a case of say 32 degrees here, when it is 50 percent humid, you will already need 1 meter per second air velocity, and as you go up say 80 percentage, you will almost need a very strong wind, or 3 meter per second air velocity.

When it further increases, this means, you cannot attain comfort. Take a case of 35 degree temperature, 30 percent humidity you will need 3 meter per second air velocity to be comfortable, but beyond that, even a slide increase in relative humidity, you cannot attain comfort. Similar table, the same you will find dry bulb, this, along this column, and relative humidity along this row, but the numbers changes considerably, and the ex10t also increases. The earlier table, we had up to 35 degrees, here we have another degree added up, and this is acceptably warm condition. What they say, 30 degrees, 60 percent relative humidity, they say it is acceptable.

It does not need any air velocity; this does not arise at all. Even 33 degrees, 40 percent relative humidity, without much of air movement, you can still be comfortably warm. There is the term called acceptably warm, which means, it is, you can accept it 35 degrees, 40 percent humidity, you will need around 1, 1.5 meter per second air velocity. Typically, with the ceiling fan, or a pedestal fan, table fan, you will be able to much closer, around the vicinity of the throw, you will be able to get around, 1, 2, sometimes 1.5 meter per second air velocity.

If you really close to of pedestal fan, you will be able to manage 1.5 meter per second, air velocities typically example which we worked out, an interesting case is we know that these boundary conditions are existing, how do we really report? Say you want to measure for your own class room, or for your house, and you have to report that whether temperature humidity air velocity is ok or not? Have minimum climatology lab will have, sensors for temperature, relative humidity as well as anemometer, with these quick handy things you can do simple experiments, and you can reported this way.

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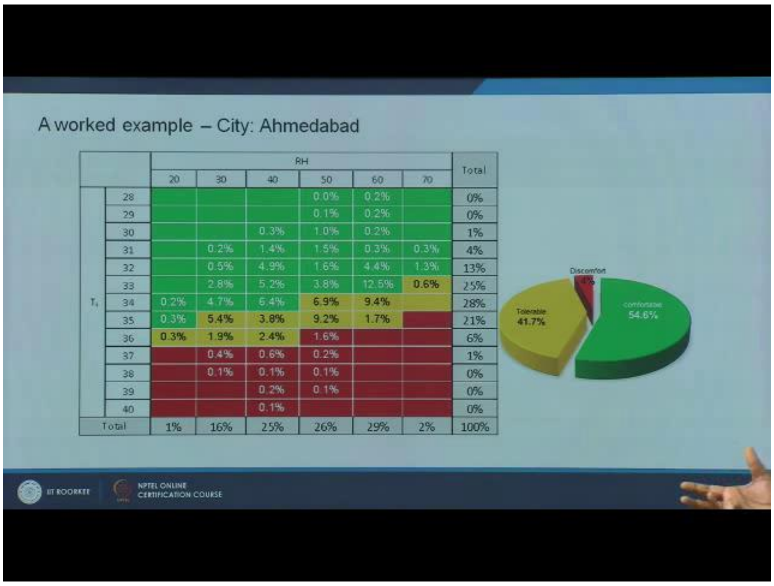

		RH						Total
		20	30	40	50	60	70	
T_i	28				0.0%	0.2%		0%
	29				0.1%	0.2%		0%
	30			0.3%	1.0%	0.2%		1%
	31		0.2%	1.4%	1.5%	0.3%	0.3%	4%
	32		0.5%	4.9%	1.6%	4.4%	1.3%	13%
	33		2.8%	5.2%	3.8%	12.5%	0.6%	25%
	34	0.2%	4.7%	6.4%	6.9%	9.4%		28%
	35	0.3%	5.4%	3.8%	9.2%	1.7%		21%
	36	0.3%	1.9%	2.4%	1.6%			6%
	37		0.4%	0.6%	0.2%			1%
	38		0.1%	0.1%	0.1%			0%
	39			0.2%	0.1%			0%
	40			0.1%				0%
Total		1%	16%	25%	26%	29%	2%	100%

As per, you know, you can say as per national building code, whether comfort conditions are acceptably warm condition are existing or not. A simple way of reporting, here what we have done, we have taken the similar condition, indoor temperature, this we call crust of statistics. Simple analysis, temperatures here, relative humidity here, and this percentage represent, how much percentage of data, falls within these combinations. Say we did not measure anything, with 31 degrees and 20 percent humidity, where as, we had about 1.5 percent of data, falling in 31 degree and 1 and half, know, 50 percent relative humidity. 34 degrees, 50 percent relative humidity, we had about 7 percentage a data.

Similarly, if you have look at this, about 28 percent of the data was, around 34 degree, if you look at this way, around 29, 30 percent of the data had 60 percent relative humidity. With this, if you make a chart, simple chart, again this has a constant air velocity. We had a ceiling fan running, which means the air velocity is around 0.8 to 1 meter per second, roughly, say around 0.8 meter per second, with that air velocity, these are the temperature in humidity combination. Which means, out of the whole thing, 54 percent, 54.6 percent was comfortable, this whole area 41.7 percent was tolerable, tolerably warm, then you have 4 percent which is uncomfortable.

So, this is how a simple example of, how to consolidate your comfort reporting, using simple instrumentation, and day today measurements. What is the other considerations apart from you know this 6 things which we talked about? Important factor is something called draught. Imagine it is a very cold day.

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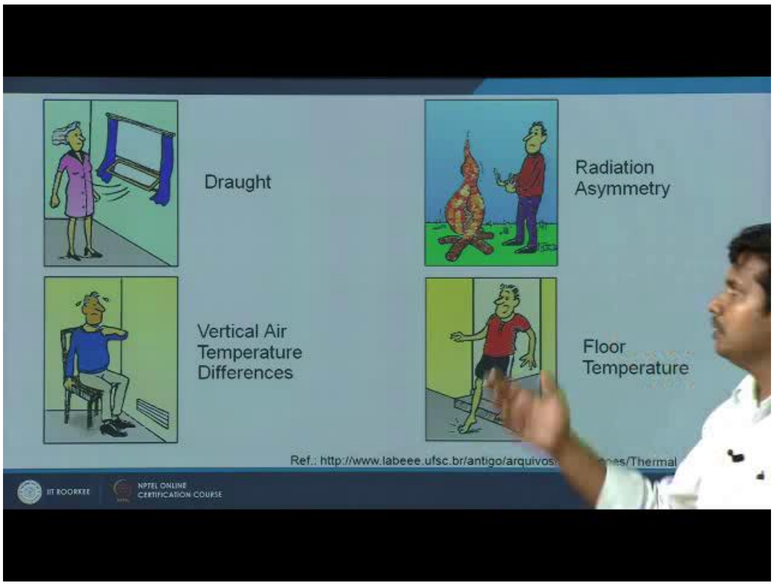

You have chill breeze coming through your window, then you feel the chill, sometimes outdoor conditions we call it wind chill. You call it draught in the indoor, cold air. Then you have vertical temperatures difference, you are sitting next to a heater, or an air conditioner. Then the temperature difference between the foot as well as the head level considerably varies. So, a vertical temperature difference, I am going to show you a few you know, numbers, where you can actually determine what is the percentage of discomfort as well. Apart from this you have something called radiant asymmetry. I showed you a sensor using with we can measure radiant asymmetry you are sitting in the center of the room. One side, you have a hot surface, say glass large glassed window, where you have direct solar radiation.

So, this particular surface is hot, you have radiant heat gain from one surface. The other surface is really cold. So, you have heat losses happening, radiant heat losses happening to the other surface. Then, you have, you are starting to experience something called Radiant Thermal Asymmetry. This can also happen in the vertical plane, you are on the top most floor of a building, your roof starts radiating lot of heat, and your floor is not that hot. So, there is a kind of radiant asymmetry, which is existing. Or you have under floor air conditioning system, you get, you know the chill surfaces in the bottom, plus the ceiling is emitting, the roof is emitting lot of heat, you have radiant asymmetry along the vertical axis. Then you have floor temperature differences.

This is primarily due to conductive heat flow; this also has a measure concern in terms of comfort, apart from these 6 parameters which we were talking about earlier. Taken closer look at radiant asymmetry, like I said, on a colder day, you are sitting next to a wind. One side is really cold, these window surface temperatures are getting as close to single digit number; say 4 to 5 degrees you get in the window surface the indoor surfaces, indoor environment is heated.

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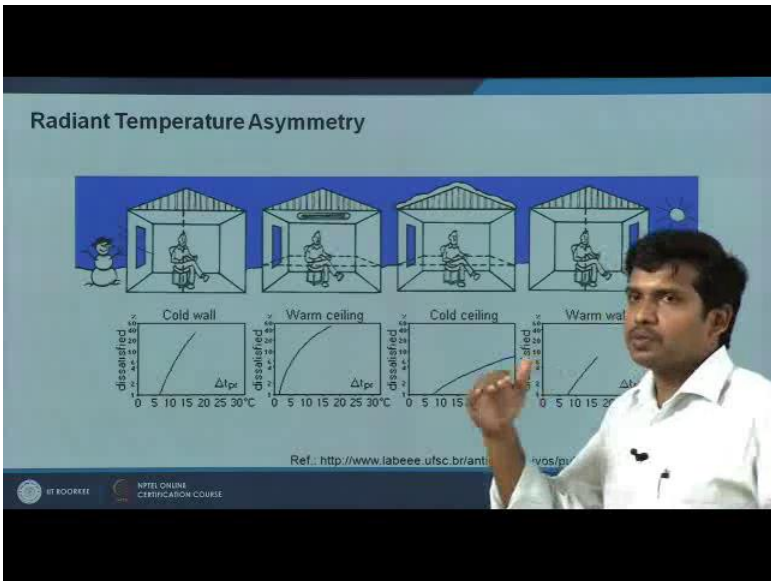

So, more or less, the surface temperatures are revolving around 20, 21 degrees. So, you clearly get around 15 to 18 degrees temperature difference, between this surface and this surface. So, when you do the same mean radiant temperature calculation, which I have talking to about, then the emission from this surface versus the absorption towards this surface is going to be considerably different. These standards, where I am referring to, ISO 7730, gives you a simple graphic indicator of, what is the delta T that is the temperature difference between one side to the other side, and with the increase of this, how much will be the increase in percentage of people, who are going to be dissatisfied. It varies from person to person.

So, typically we express in terms of percentage of people, who are dissatisfied with it. So, the dissatisfaction goes up, as this temperature differences increases. This also varies for a warm ceiling, the same example I was talking to about, an exposed roof case, versus a cold floor surface, the vertical difference, or a cold ceiling, say when you have snow on the roof surface, your surface is going to be cold on top. The floor is heated now. This difference, this is also considerably different from one, warm ceiling is different from that of the cold ceiling, cold wall is different from that of the warm wall, the percentage of the dissatisfied, and the pattern of variation is also going to vary. Then the vertical temperature difference is I am going to shortly show you some examples of what we actually measured. Vertical temperature difference, occurs both in air-conditioned, as well as unair-conditioned, non air-conditioned or so called free running spaces.

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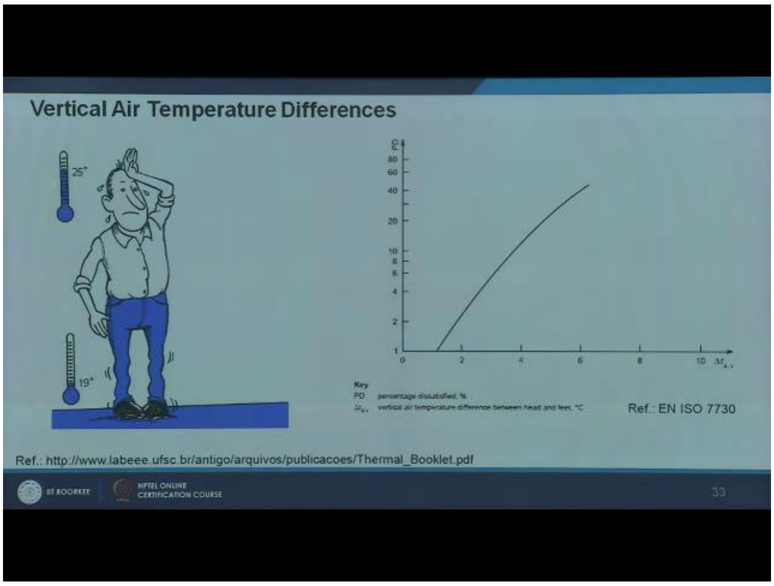

As the vertical temperature difference increases, then your percentage PD, percentage of dissatisfied - increases. It is you know not so linear, but still, it increases with the, it is directly proportional, as this increases, this will also increases. Typically in air condition spaces, cold air settles down, the warm air rises up. So, naturally you will have a vertical temperature stratification or difference.

So, you can easily find about 3 and half to 4 degree vertical temperature difference, but it depends on the, you know, floor to ceiling height, how much height it is, say if it 3 meters, the difference might be slightly lower, but if you are talking about 5 meter or 6 meter tall, you know, space then the vertical temperature difference is going to be considerably different. But even in the case of naturally ventilated space, here we took measurement in our naturally ventilated building.

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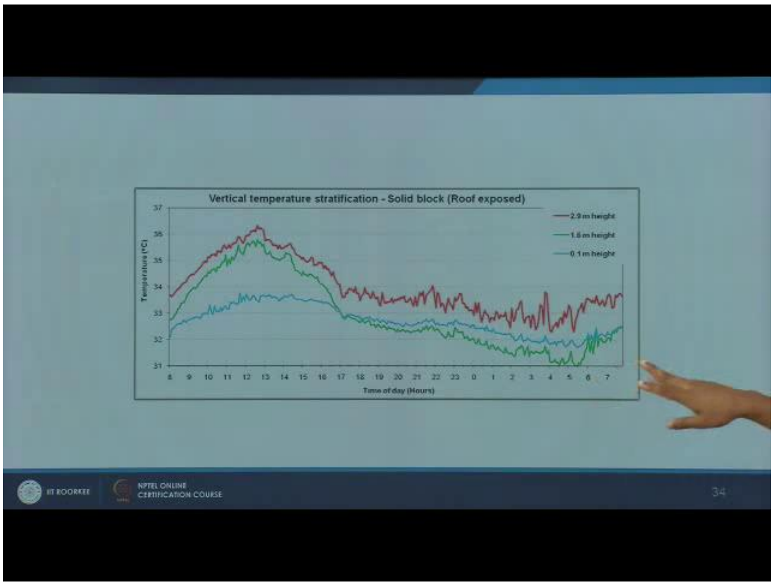

This is again hot and humid climate. We took measurements at 3 different heights, 0.1 meter height, which correspondence to the foot level of a standing person, 1.6 meter height, this is somewhere in the center of the room, or which correspondence to your face, or head level. 2.9 meter height, which much close to the ceiling, the roof is exposed. So, what kind of difference you find here? The maximum difference is 33.5 to 36.5, which is about 3 degrees difference, the peak level, but eventually it comes down.

Even when it is low, the minimum difference you get is also around one and half degrees.

So, vertical temperature difference considerably varies, but one thing, you know, need to note here, these 2 lines, this blue and green line, that is, the foot level and the 1.6 meter, that is the head level, this is considerably difference, different, but at one point they converse, and then in this particular level 1.6 meter drops down below the 0.1 meter line here. This is the temperature at the floor level; this is the temperature at the head level. This was interesting because, what we noted as the connective mechanism sets up, the heat is dissipated, this is also lying in the window plane, and it is cross ventilated.

So, the temperature eventually drops down, that is not much of difference, around point 5 degrees, but still, it is drops down while the floor level temperature, more or less was still and it was revolving around 33 degrees, even after that it does not no fall much below 32 degrees. You know it also depends, slightly on the material used. The earlier was, you know, solid cement block, this is like a low density block, it can be an aerated concrete, or a hallow wall, you know cavity wall system. Even there, you will find the vertical temperature difference, it will considerably be different from one material to other, the magnitude may be different, but the pattern of variation remains the same. We were talking about other phenomenon, the draught. External environment we call it wind chill, there are different indices. The commonly used is, wind chill index.

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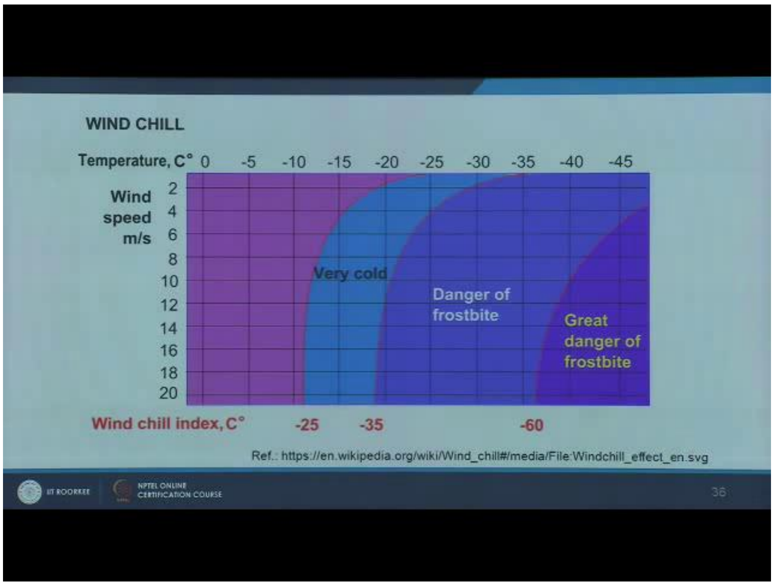

What this tells you? Below freezing point, as a temperature goes further and further, and if the wind velocities are increasing, the same amount of temperature, the same 20 degrees, which you pursue at 2 meter per second air velocity, versus the same 20 degree you face a 20 meter per second air velocity, you will start feeling very cold. There is a danger of frostbite, and there is a real danger of casualties because of frostbite. On the other hand, with respect to hotter environments, you have the heat stress. There are indices like heat stress index, wet bulb globe temperature WBGT. Now, these are heat stress indices, which combine air temperature, as well as humidity. As the temperature increases, and as the humidity also goes up, the amount of heat stress increases, the WBGT or heat stress index might go up. There are different indicators; this is just to give you a simple example.

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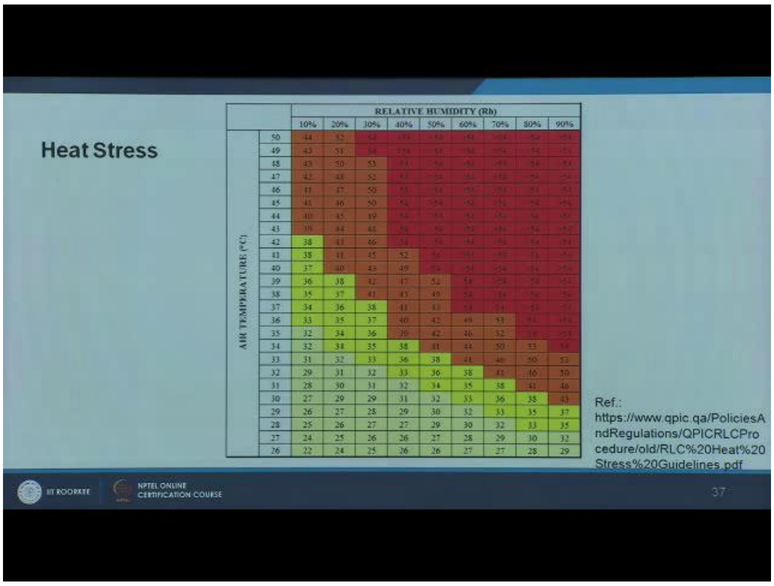

Let us quickly take a look at 2, 3 comfort models, and how they work around. I have plus presented list of comfort models, not an exhaustive list, but a few commonly referred models, starting from wet bulb temperature, it goes on to tropical summer index.

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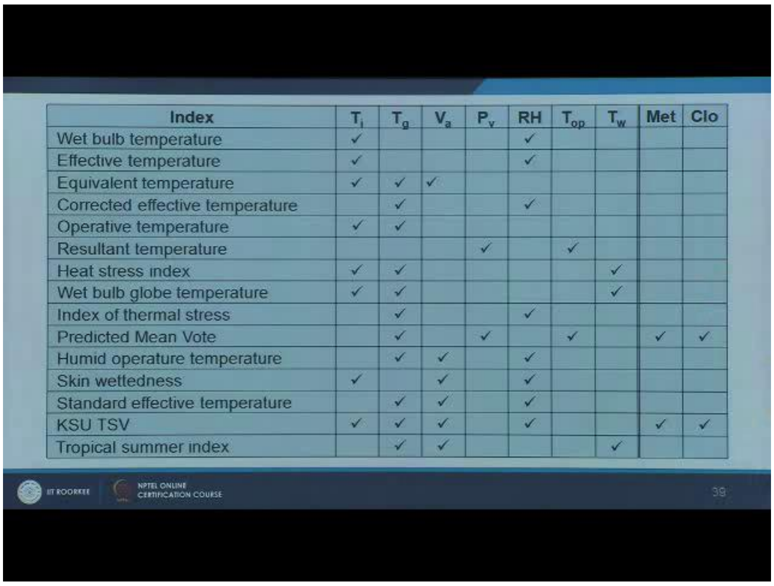

Index	T_i	T_g	V_a	P_v	RH	T_{op}	T_w	Met	Clo
Wet bulb temperature	✓				✓				
Effective temperature	✓				✓				
Equivalent temperature	✓	✓	✓						
Corrected effective temperature		✓			✓				
Operative temperature	✓	✓							
Resultant temperature				✓		✓			
Heat stress index	✓	✓					✓		
Wet bulb globe temperature	✓	✓					✓		
Index of thermal stress		✓			✓				
Predicted Mean Vote		✓		✓		✓		✓	✓
Humid operature temperature		✓	✓		✓				
Skin wettedness	✓		✓		✓				
Standard effective temperature		✓	✓		✓				
KSU TSV	✓	✓	✓		✓			✓	✓
Tropical summer index		✓	✓				✓		

This is one of the indexes developed in India. These are different environmental and personal variables. Ti is dry bulb temperature, globe temperature, air velocity, this is vapor pressure, relative humidity, and this is operative temperature. Then you have metabolic activity, and the clothing insulation. Two personal variables, just to give you an idea about, what are the parameters, these indices actually take into consideration. If you take index like a wet bulb temperature, it takes air temperature as well as relative humidity into consideration, you take an index like heat stress index, and it takes indoor dry bulb temperature, globe temperature as well as WTW, wet bulb temperature into account.

Then you have something like predicted mean vote. We look at it shortly. This is a comfort model, this takes into account, globe temperature, vapor pressure, operative temperature, as well as 2 personal variables, which is, metabolic activity and clothing insulation. To take the Indian index, this is KSU, Kennesaw State University. TSV Thermal Sensation Vote, these are different indicators. You will also find effective temperature, standard and corrected effective temperatures here.

Tropical summer index again includes globe temperature, air velocity. It includes wet bulb temperature, which is further a factor of air temperature and relative humidity, or vapor pressure, but it does not include metabolic and clothing insulation. Now personal variables are associated, but environmental parameters are taken into consideration.

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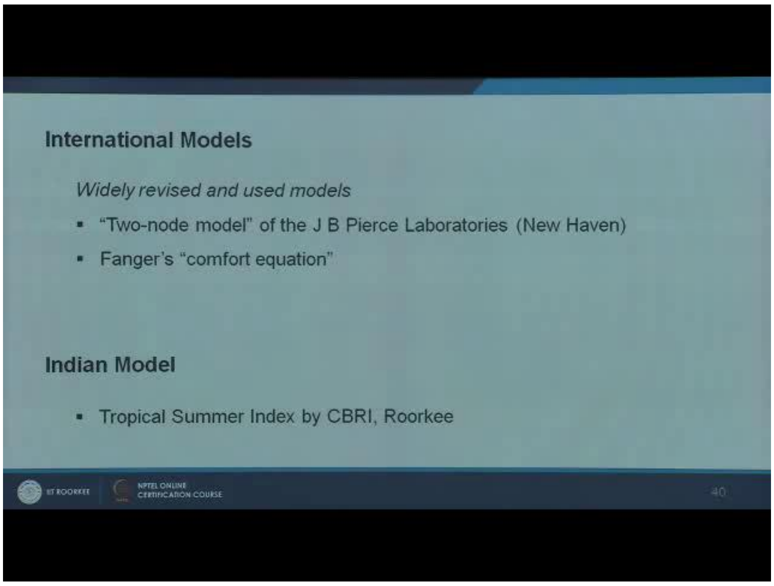

Among the international models, there are lot of international models, among them, 2 commonly used or most often revised and re visited models include, the two-node model commonly called as two-node model, which is developed by the Pierce Laboratory, JB Pierce Laboratory. And next is the Fangers comfort equation. Apart from this, you also have models like Munich energy model. There are lots of models, but apart from these, these are 2 most commonly used models. And of course, the Indian model developed in CBRI, Roorkee, and way back in the 80s, 70s and 80s, this is the tropical summer index. We will look at 2 of these models more closely.

First is the two-node model, the Pierce is two-node model. This works on the metabolic heat exchange or, the thermal equilibrium between the body and the environment. This takes two-nodes, first is the core body temperature, then is the surface temperature, and then the ambiance.

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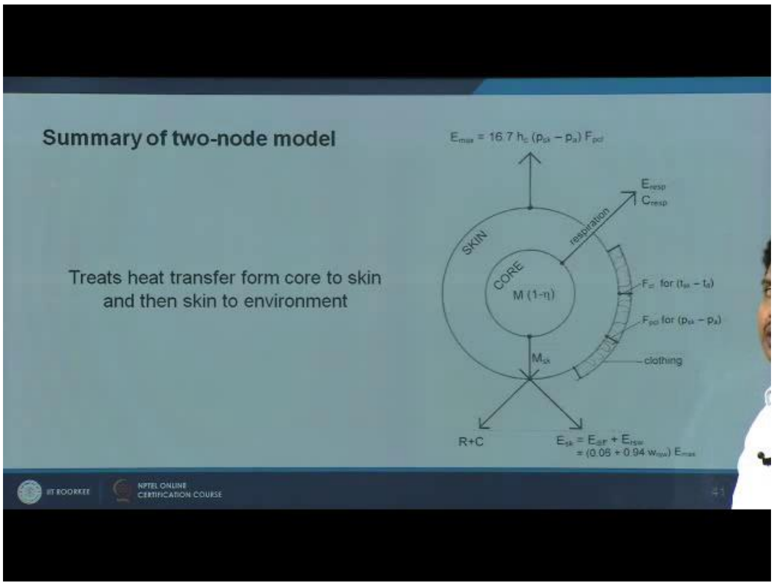

So, this actually calculates how much is the heat exchanged, between the core body and the skin. And then, how much is exchanged, effective exchange, between the skin and the ambient condition. It can be indoor or outdoor condition. So, effectively it summarizes, it also include the effect of clothing, and the metabolic activity, because you are taking about the metabolic heat generation. So, it is typically a heat transfer model, where thermal equilibrium is obtained. You call it is thermal, it is not actually thermal comfort, but it is thermal equilibrium, that is what this model tries to derive.

The next commonly used model or most, you know, familiar model rather is, the Fangers PMB model. Fanger is a scientist who developed this model. This is predicted mean vote. So, as the name says, it is a kind of predictive index. The basic theory behind or the philosophy behind it is, you know, he pulled on more than hundred people; he pulled them in a laboratory. He varied the environmental parameters, 4 environmental parameters, temperature humidity, air velocity, and radiation, as well as, 2 personal variables, metabolic activity. He made them 2 different activities, plus, he asked them to vary the clothing insulation. With these variations, parametrically, he determined what is the comfort vote, for each of these set of conditions.

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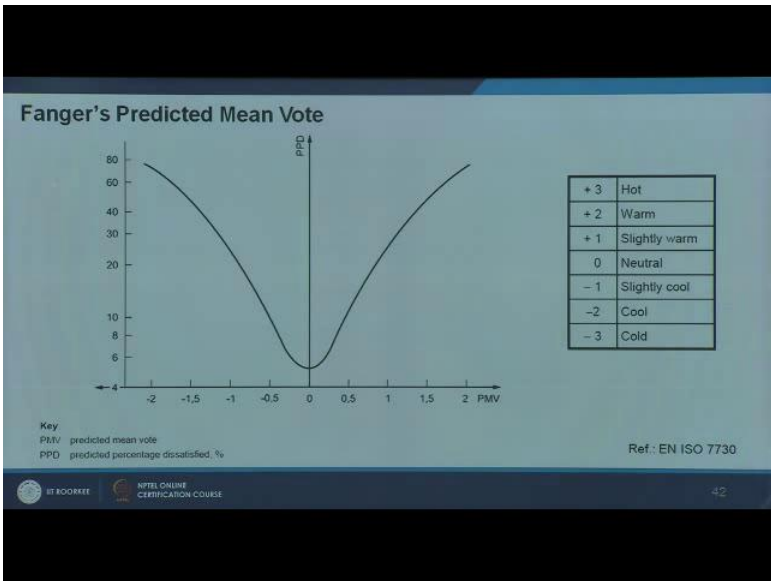

So, based on this, he also determined another indicator called, predicted percentage dissatisfied. At certain kind of environmental condition, and personal variable combinations, how many percentage of, you know how much percentage of people are really feeling uncomfortable? So, this is the inverse bell shape curve. It has it, is a double likert scale, it is start from 0, which is neutral, on others, you know, one side, right hand side, it has slightly warm, which is plus one, indicated as number plus one, warm, and hot.

On the other side it goes to minus 1, minus 2 and minus 3. This is cold. Some cases, if you are doing in extreme condition, say if you are evaluating PMV in India, it may go to minus 3.5, minus 4, because we are dealing with hotter conditions. We will look at it, but typically the actual scale given is, plus 3 to minus 3, both ISO 7730 thermal comfort standard as well as Ashrae 55 standard, refer to Fangers model. There has been lot of modification to Fangers model as well, but primarily, this is inverse bell shape curve. What we need to note, when there is 0? Which means, thermal neutrality, we talked about thermal equilibrium and neutrality.

When there is thermal neutrality, this is at it is minimum. That is percentage of people dissatisfied, it is at the minimum, but still it is around 5 percentage, which indicates even with ideal condition, when all the environmental variables as well as personal variables are more or less amicable, still there will be about 5 percentage of people, say 5 out of hundred, would still be feeling uncomfortable. Leaving them aside, this particular curve will increase. If your predicted mean vote increases, say from 0 to 1, 1 to 2, or 2 to 3. There will be an increase at around 2, the percentage of people dissatisfied will be 80 percentages, and further it will go up.

And similarly on the negative side, that is on the colder side also, but one quick thing, note we have to take, we will look more about it in the adoptive, you know, comfort section the further following module. But one quick thing, you have to observe here, is, as stated, these are results based on standard, static laboratory conditions. There are set of environmental variables which are preset and people are responding to these environmental variables. They were not allowed to get adjusted or acclimatized to these things.

They were not adjusted, you know; allow adjusting their clothing insulation, nor adjusting their movement, or any kind of parameter, temperature, humidity, radiation, nothing. They were they did not have any personalized controls available. So, there is a lot of debate going on about, whether the Fangers Pierce model really applies to the field or not. There has been lot of investigations which say, that it needs a correction, with which can applied to the field. Some of the authors also site that, you know, this is far beyond field application. This is more lab oriented index, but all said and done, this is a parametric equation, or rather an empirical equation, which based on which the PMV is derived. It has variables from metabolic activity, it has variables like, the clothing, you know, surface factor of clothing, radiant temperature is there then heat transfer coefficient, air temperature is available.

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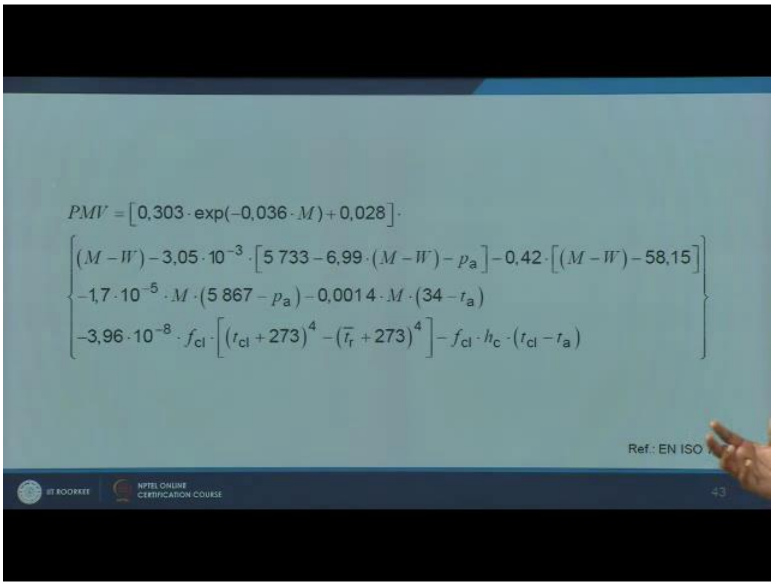

So, doing this, it is an exponential empirical equation, based on which, you will be able to predict PMV. Moment you know PMV. Similar for fashion (Refer Time: 25:20) you can also determine PPD. It is a kind of extended heat balance equation, in which, both environmental as well as personal variables are taken into account, even with corrections, you know, we have found that some of the field studies, through field studies, this model applies well and it is more or less, the balanced kind of an approach to predicted environmental conditions.

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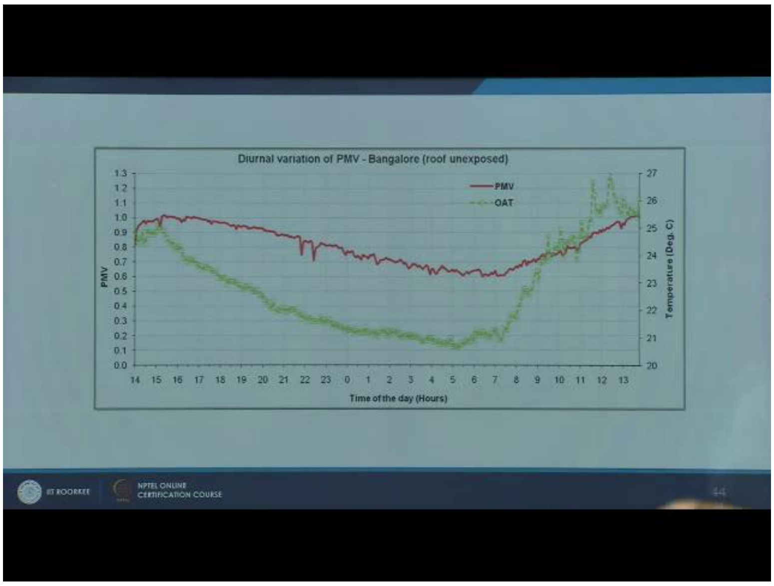

Some of the measurements for your reference, I am not getting into details much of what this is. This is outdoor air temperature, and this is PMV, the left hand y axis is PMV, this is air temperature taken in Bangalore.

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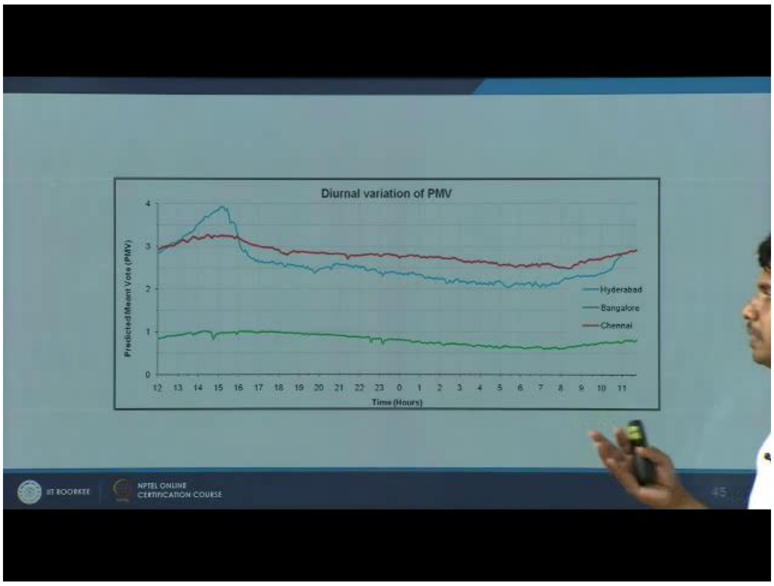

How it varies during summer, summer in Bangalore PMV varies around 1. This is in the case of Hyderabad, as well as Chennai. It goes as I said, it can go up to, you know, 3 point, 54 sometimes, it depends primarily on temperature, humiditys. As such, this is developed for European subjects. So, the applicability in Indian contest it is not directly, but you have to apply some weightage factors, you have to do field validations, before applying this parameter.

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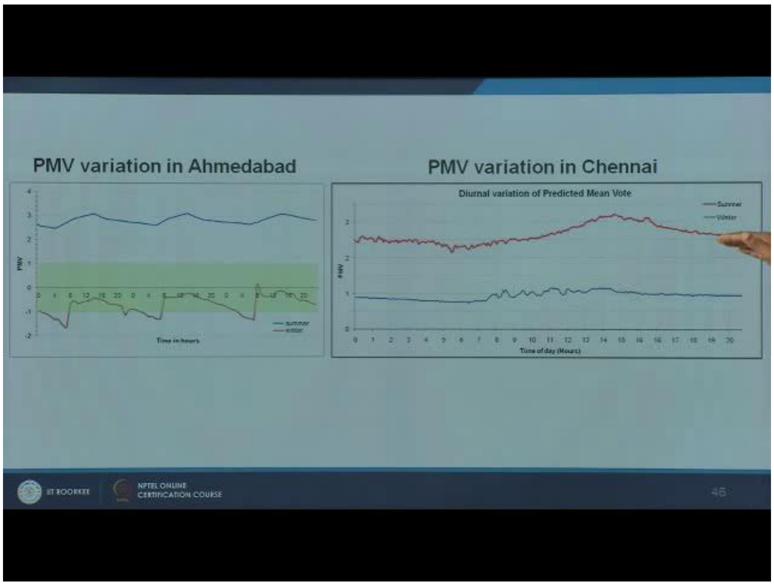

In case of Ahmadabad, hot and dry climate, during summer, this is a comfort band minus one to plus one typically, if we say, just 20 percent of people dissatisfied, it is permissible. During winter, it goes below, that is, touches minus 1.5, but summer, it goes around 3, 3.5 whereas, place like humid region, like you know, warm and humid climate like Chennai, during summer it touches around 1 close to 1.5, but in summer, it goes beyond 3. It touches sometime around 3.5, 3.8 do not mean it is unbearably hot. People can still accept it, but as I said, this model will really need validation for application, in actual field conditions. As such, you can also find differences in terms of building exposure. PMV will show certain difference, because MRT or radiant temperature is part of the PMV equation.

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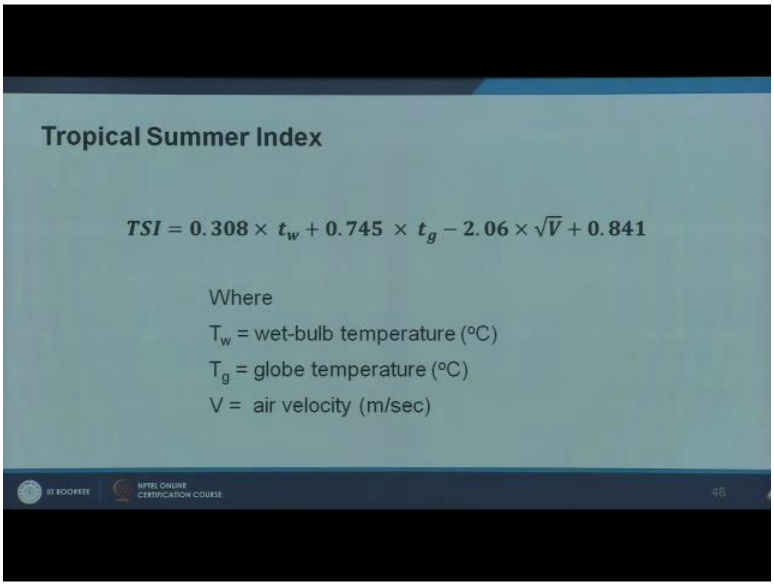

So, the effect of orientation will have an impact of PMV. Finally, the tropical summer index or, which is the index which is developed in the Indian context, with Indian subjects. The tests were, more or less like in the PMV model. Again you know, people were asked to choose, which conditions environmental conditions they are comfortable with. Based on this, an index or the boundary limits of comfort was actually tuned. These experiments were done around 1980s, 75 to 80 these experiments were done, but this does not include personal variables, like PMV, which excludes metabolic activity, and clothing insulation, but it takes into account, wet bulb temperature, globe temperature and air velocity.

So, if you closely look at the equation, globe temperature as a maximum weightage, this as 0.75 of globe temperature, which means, an increase of globe temperature will have the maximum impact on tropical summer index, whereas, an increase of wet bulb temperature, say humidity goes up high, wet bulb temperature is affected. It has about 0.31, which means around 30 percent or less impact, this will have compare to globe temperature, the impact of wet bulb temperature is lesser. But both of these things will result in increase of tropical summer index, while air velocity is in negative. If you want to improve thermal comfort, you provide more air velocity. Say simple, enhancing cross ventilation, or turning on a ceiling fan, or a pedestal fan, you improve or increase the air velocity, because of which you are able to reduce tropical summer index. Say take an air velocity of one meter per second, you will reduce the tropical summer index almost by 2, 2 degrees.

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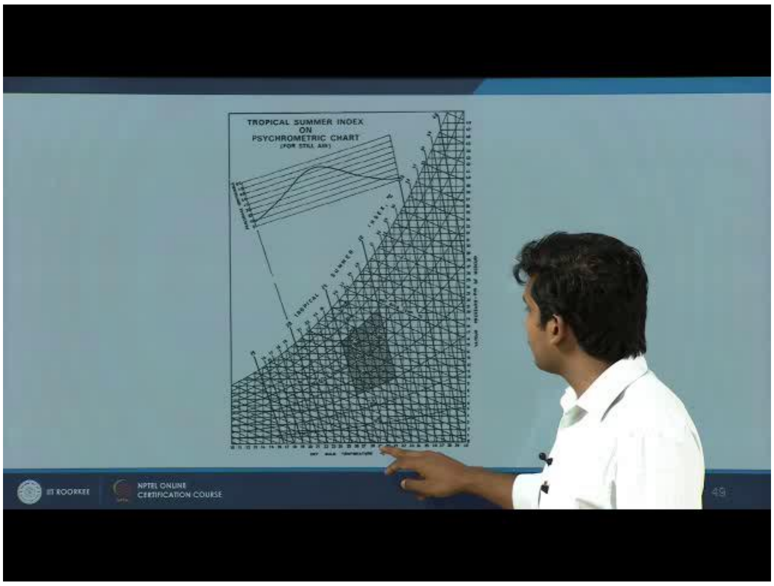

On the psychometric chart, same this is a tribal temperature, vapor pressure, relative humidity lines are there. Tropical index, you know tropical summer index has, the boundary of comfort drawn somewhere here. So, below 20, below 30 percent relative humidity, it is not comfortable, and above 70 percent relative humidity, it is not comfortable. If you take a closer look at it, it starts somewhere from 28 degrees, 30 percent relative humidity, 27 degrees, and then on the further end, when the humiditys are also high, it tilts towards the left. You can be comfortable up to 70 percent humidity and around 29 degrees temperature. When the humiditys are lower, say 30 percent humidity, you can be comfortable up to 31 degrees. Like we saw in Fangers index, there we had percentage people dissatisfied, here it is percentage people comfortable, it is a bell shaped curve, as a tropical summer index drops, that is, you know, it goes towards the lower temperature side, the numbers of people feeling comfortable, drops down.

Similarly, when the temperature goes up, the number of people feeling comfortable also drops down. So, typically we define comfort in this way. Again if you have to really improve on this index, you have to include the effect of air, you know, metabolic activity and clothing insulation. The effect of cross ventilation, like I said, it can easily bring down to 2, 2 and half degrees, in terms of tropical summer index.

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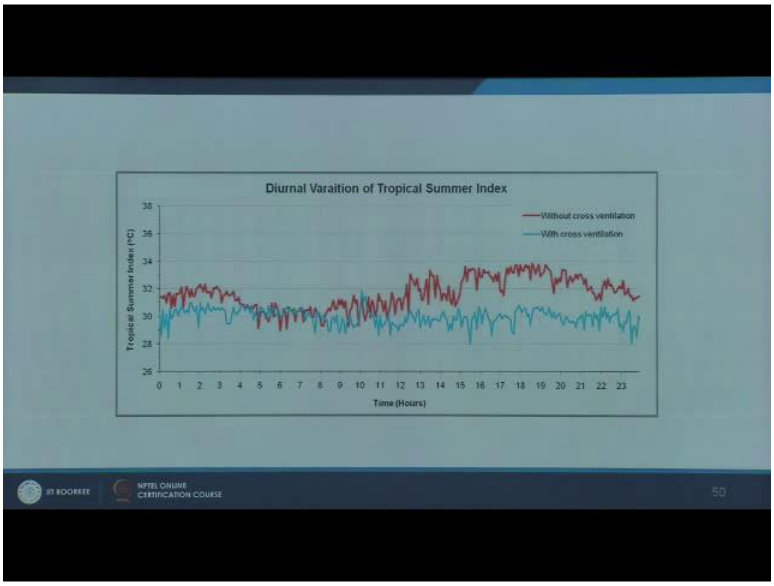

So, we will close this session here, to get a recap, we looked at the comfort zone, how comfort zone is defined in international models, we looked at the Ashrae comfort zone, then we looked at how Indian standard defines comfort zone, then we also looked at certain comfort models. Primarily, we looked at the Pierces two-node model and Fangers comfort model. Apart from which, we also looked at the tropical summer index, which is in, the applicable more in the Indian context.

Thank you.