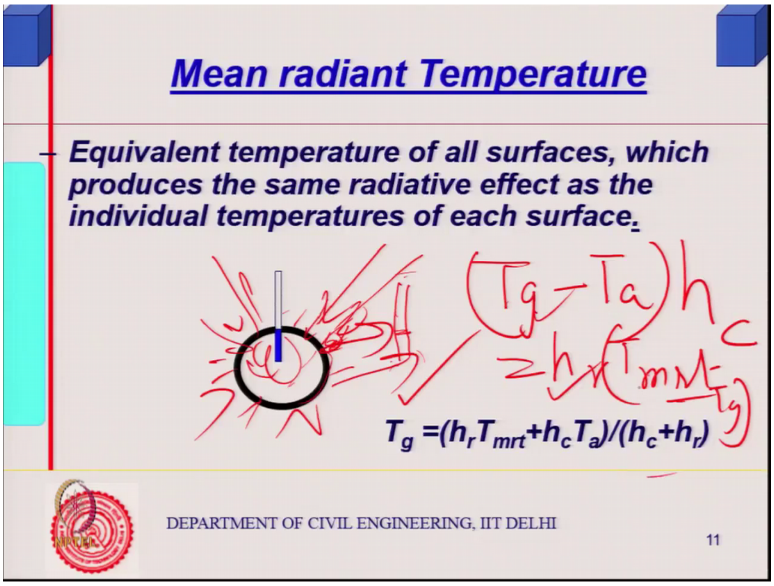
Energy Efficiency, Acoustics & Daylighting in building
Prof. B. Bhattacharjee
Department of Civil Engineering
Indian Institute of Technology, Delhi

Lecture - 20
Comfort

So, to account for the radiation; what we do is; as I said you know the surfaces by comfort condition also it depend upon the surface temperature because the surfaces will radiate heat. Now, this is taken care of in terms of something called mean radian temperature.

(Refer Slide Time: 00:39)



So, it is equivalent temperature of the surfaces which will have same radiative heat transfer effect onto the body, same as a individual surfaces temperature. What I mean is; every surface will have different temperatures in the room; some wall will have one temperature, another wall will have another temperature. And maybe ceiling will have another temperature; they will have different temperatures in the room all surfaces.

If I have a single temperature to represents you know some kind of; I will not call it weighted average, some sort of a single temperature of all the surfaces. It will produce a radiation heat effect that should be same as that is existing with different temperatures of the surfaces.

So, different temperatures of the surfaces it will produce some radiative heat transfer effect. I assume a single temperature of all the surface that should produce the same affect. So, this is the temperature we should find out well; we do measure do not measure it directly, but measure it through a device called globe thermometer. So, it is nothing but you have a globe black end globe; like a black end sphere and put the thermometer inside.

That means you have a thermometer, put it in a black end globe. Now, why black end? Then it will absorb all the radiation; it will absorb all the radiation. And then its temperature will increase because this temperature will be more than the surrounding thermometer temperature. Suppose, I have a thermometer, just another thermometer by the side of it there is another thermometer, small thermometer here. And we will find that this is somewhat less, this is somewhat higher. Because this air here will warm up receiving all the radiation that is falling onto this globe from the surfaces that is all around.

So, the globe thermometer temperature will be somewhat higher than the DBT in the room, Drive Bulb Temperature in the room. Because it will take care of the radiation that is coming in; this is black end surface all the radiation that is coming in. Now, if the surfaces are almost same temperature; as the air temperature then this temperature will be nearly same.

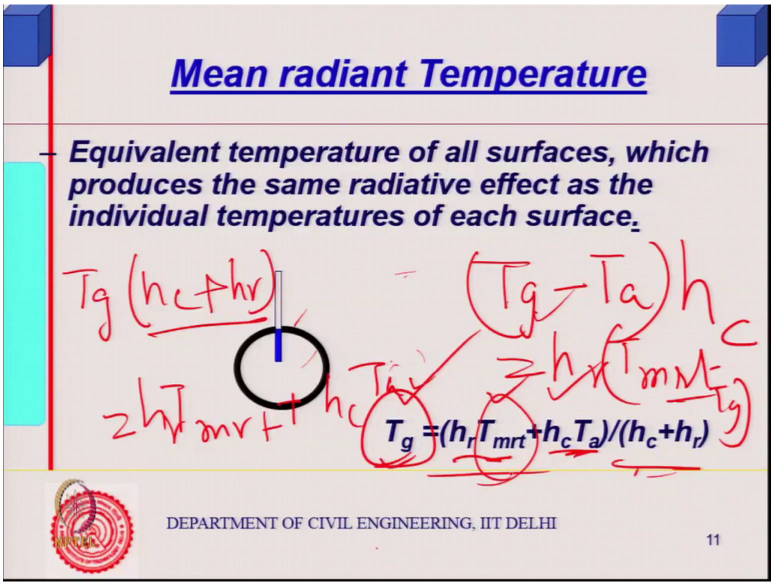
So, T g this is called globe thermometer temperature T g is this term, now once its temperature rises or temperature here is more as indicated by this thermometer; this will start dissipating that heat, assuming that all air surfaces temperature remaining constant. A steady state will be reached after I put that globe thermometer; temperature of this one will rise and then stop it will remain there.

Now, at that point of time whatever heat is being received must be dissipated out to the surrounding. So, it receives heat by radiation anticipate that heat out to the surrounding by convection and if the air temperature is lot convection and radiation both. So, that we take care of in terms of h c which is the surface conductance of this particular one. So, it actually transmit this heat to; so, equation will be T g minus T a into h c; that is the loss. T g is higher and that must be equals to whatever I am receiving; so, h r let us say; hr into

T m; mean radiant temperature the constant, temperature minus T g that is what I will be receiving?

So, mean median temperature is the constant temperature of all the surfaces that minus T g into h r; radiative heat transfer coefficient and that is; so, from this it follows. One can actually derive this expression, I am not sure whether I have derived it. So, this let me remove now this explanation is over this is the kind of equation that is there.

(Refer Slide Time: 05:27)

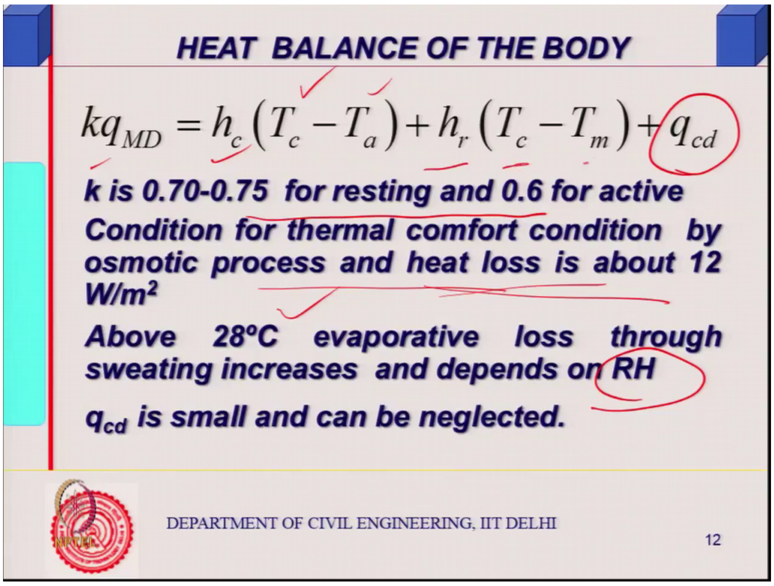


So, T g you know h T g; so it would be T g; T g from this one hc and this side also minus T g; so, if I bring it here h c; h hr must be equals to T m r t; hr plus h c; T a divided by h c hr gives me the T g. So, this is measurable; T g is measurable T m r t is not measurable; this is I assumed temperature of all the surfaces. So, if I measure globe thermometer temperature T m r t is taken care of.

I can actually; this is conceptual more conceptual, but T g can be measured, T a is measured. So, what we do is; if you want to take the radiation effect into account, then instead of using T a; I use T g. Suppose, there is surfaces are very warm surfaces are quite hot compared to the air then instead of taking T a, I take T g that will take account of the radiation that is falling onto the body also.

So, thermal comfort is related to T g; so if I take T g then I have also taken into account to the radiation as well as air temperature itself. So, now my comfort condition depends on T g, relative humidity and you know T a itself would be definitely there. But T a is already taken care of in T g; so, T g relative humidity air velocity; type of clothing, acclimatization, adaptation etcetera etcetera.

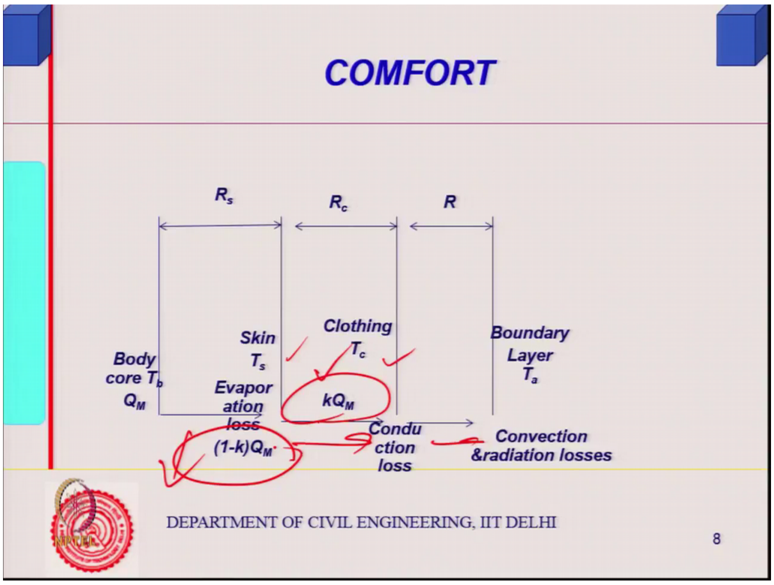
(Refer Slide Time: 07:16)



So, you know this is what I said; this is a Fangus law; which was there. So, k M D t; h c t c minus T a h r t c minus T m plus q c d. So, k is 0.75; that means, 25 percent 1 minus k that goes out straightaway, h c is the conductance of the h cloth to the air. So, T c you know that convection part the last part; then hr is T c minus T m plus qc d. So, this is the conduction loss this is radiation loss actually; so for resting and points.

So, this is k is 0.70 to 0.75 for resting and 0.6 for active condition, for thermal comfort condition by osmotic process and heat losses about 12 watt per meter square. Because various kind of this value; how much is lost from the body before passing through the clothing and skin. Because, if you remember that model that we did earlier.

(Refer Slide Time: 08:35)



So, some portion of heat goes away straightaway; this is passing through the clothing and this same one has to pass through the boundary layer. And my temperature here is clothing temperatures is T c; this is the skin temperature; k Q M has to pass through there. So, this k would depend upon how much is being lost? How much is being lost from the body?

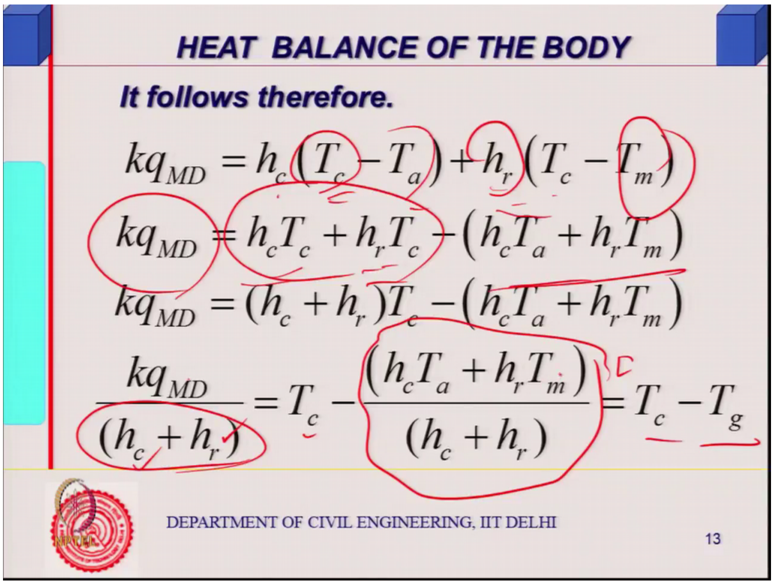
So, by various mechanism and that we are saying that it could be something like; T c was the clothing, T a is the outside, h c is that one and k is depends upon what it depending upon? Your type of activity; some process heat losses about 12 to 12 meter square is a condition for thermal comfort condition by osmotic process in a loss can be there, it is about 12 watt per meter square or so.

Whatever it is; the values are not again not very important. Above 28 degree centigrade evaporative loss through sweating increases and depends on relative humidity. Well all we are trying to see is the factors which will affect, so below 28 degree centigrade sweating does not occur really. If it is above 28 then loss through and it will then depend upon relative humidity; q c d is conduction loss; like I am standing on the floor.

So, loss to the floor; if I am touching something; now the contact area is; so, small conduction heat loss and the air temperature difference may not be too large. So, I can actually q c d can be neglected.

Now, radiation again takes place from T c; I mean like T c was clothing to the mean radiant temperature T m is actually mean radian; I did not write full m r t. So, this is the radiative heat transfer mean radiant and this is T c to air and this is the surface conductance.

(Refer Slide Time: 10:48)



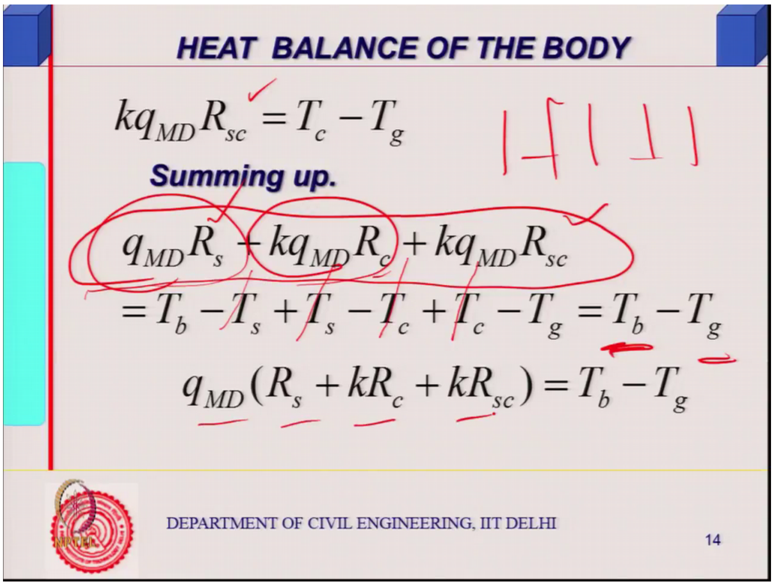
So, this is neglected therefore, what we are seeing is q m d; q k m d is T c minus T a hr T c minus T m. So, important issue is this and this and this etcetera etcetera and I can write it something like this minus h c; I can just h c, T c I can separate out h r; T c radiative this I can separate out and h c; T a etcetera.

So, this is; this minus this is a; the heat transfer; the loss of heat is given by this formulae; I mean this sort of formula. And T c can be taken common a little bit of algebra and I can write it is q m d divided by h c plus h r. This is the radiative heat transfer coefficient and convective heat transfer coefficient will be given as T c minus T g.

Because T g was remember; this was T g all that we are trying to show here is that T g is an important factor; if mean radian temperature is high. If this is same as T a; this value will become h c; T a, h r, Ta; so, this will become simply T a.

If T m is equals to T a; mean radian temperature is same because the surface temperature is same as the; so, if this is T a then this term will be simply become T a; T g will become equals to T a.

(Refer Slide Time: 12:20)

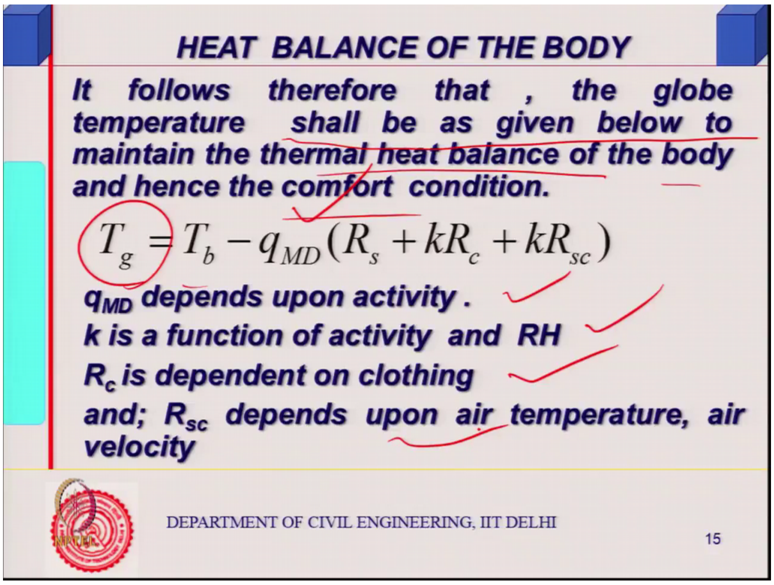


So, k M D is equals to T c minus T g and summing up you know resistance and all that if I put it; again this is the same sum total of the all the fluxes multiplied by the resistance is at body temperature minus T g. So, it is not really layers in series that model we are applying q M D is what is generated part of it; passes through the body rest all goes out; this is the R S was the first resistance up to the skin.

This is the resistance of the clothing; this is the resistance from the; I mean cold clothing to the surrounding atmosphere. And that must be equal body temperature minus T g; the surrounding temperature is if the air temperature and surface temperatures are different and therefore, all cancel out and all that that is fine.

So, q M D is equals to R S k you know; so can now see what are the factors which govern the thermal comfort?

(Refer Slide Time: 13:24)

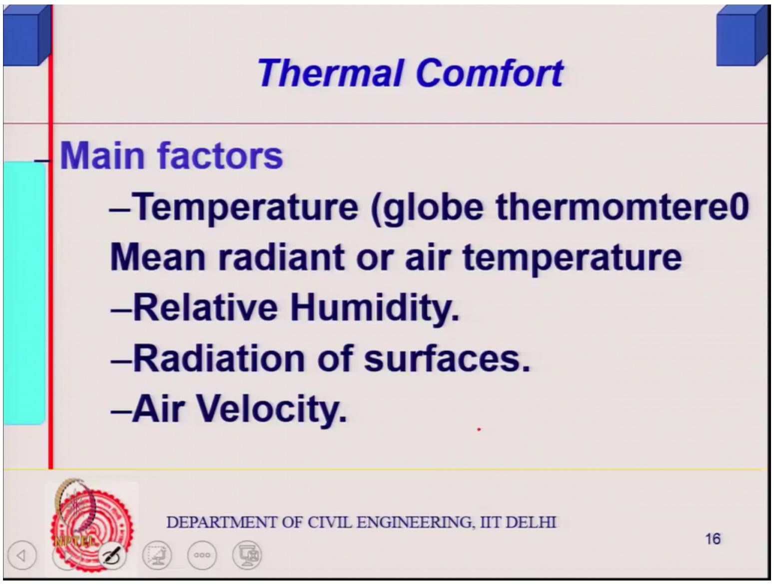


So, it follows therefore, that globe temperature shall be given below, maintain the thermal heat balance of the body and hence the comfort condition; so, T g is important. So, T g is important that is what all we are saying q M D depends upon activity. How much you have generated? k is a function of activity and relative humidity because evaporation loss is taken care of in 1 minus k; R C is dependent on clothing, R S C depends upon air temperature and air velocity. R S C is from the clothing to the surrounding clothing to the surrounding. So, thermal comfort depends upon your activity relative humidity how much it can be lost by evaporation clothing?

Student: Air velocity.

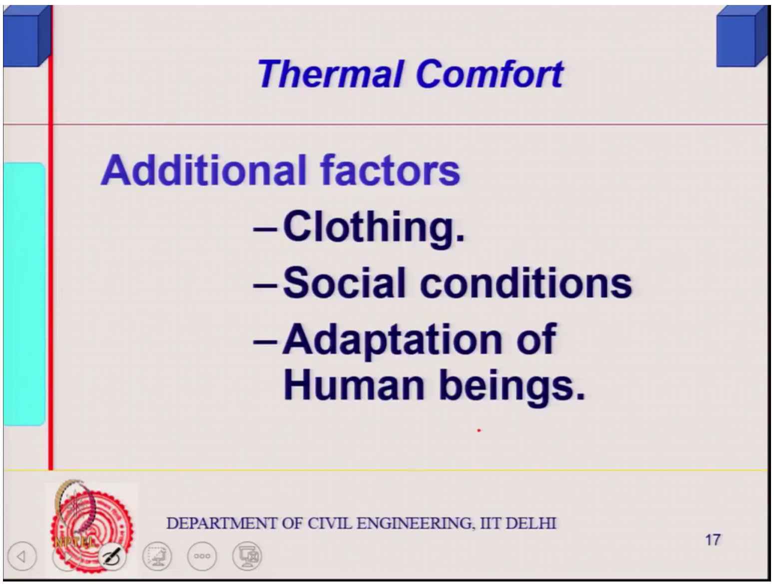
Air velocity of course, is there and R S C depends upon air temperature and air velocity. So, these are the factors you have seen.

(Refer Slide Time: 14:17)



So, therefore, main factors again summing up globe temperature mean radiant temperatures etcetera taken care of in the globe thermometer temperature, relativity humidity radiation of surfaces, which is again taken care of in globe thermometer temperature and air velocity. So, these are the factors which governs your thermal comfort.

(Refer Slide Time: 14:37)



Now, how do I take care? I can actually say each one of them; clothing is equals to 1.5 clo, air velocity is so much; I can define that your thermal comfort in a room would depend upon air temperature or the surface temperature or mean radiant temperature. So, ranges of those I can define and say this is the comfortable range; depending upon your type of clothing, depending upon also the air velocity.

So, all these four, five factors each; I can give a range, but that will become too cumbersome. What we can do is; we can combine all of them into a single index. So, these are called comfort indices, we will use one or two comfort index. So, comfort index actually combines effect of the radiation coming from surfaces; that is globe thermometer temperature.

Also the air temperature, relative humidity air velocity and might vary from clothing to clothing. Additional factors which are not quantifiable easily adaptation of human being, there are some people who were trying to do research on this line and have been done also; number of them are doing in India too, but what I find is they go on you know survey, talk to people, whether you are comfortable in this condition or not that kind of question and survey done.

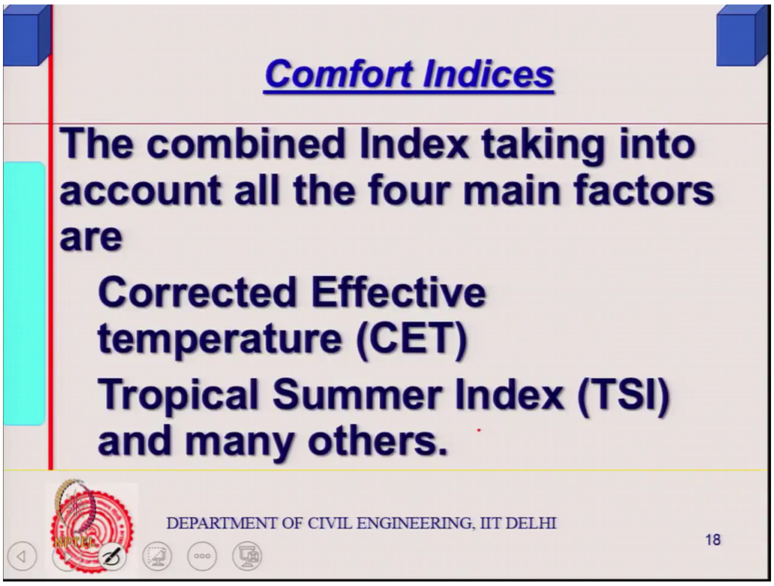
But regression and scientific basis; I am not very much convinced; because you find that you know it is so much of variation and statistical the researchers some of them which I have seen; I not very convinced of course, it depends upon adaptation. But how do I quantify it? That still remains a question; it is still you know; how do we generalize and quantify that is a area of research actually.

So, adaptation of human being is very important; you do adapt yourself, but up to certain limit. You cannot put in something like 45 degrees centigrade temperature a person, you put into 45 degree centigrade and you say that the person will adapt itself himself or herself to a comfortable situation. That is not possible; there is a upper limit beyond which it will not work. So, that is what it is; clothing I have already said, social conditions.

So, you have if you see that Indian there is something called the Indian index which was developed long back; largely in this part of the country Roorkee CBRI They did some work and I think space d work of Agra University somewhere; they did some work, peoples were subjected to put into a certain environment, asked whether they are comfortable or not. So, from that some index have been developed; that gives you a comfortable range, but gives you a tolerable range also comfortable range beyond that tolerable range. And adaptation might come in someday; more understanding newer maths coming in how to take care of all those; you see this management science; they use lot of what you call logistic regression.

For example, we normally in science and engineering conventional we have been using regression where x is quantified, y is also quantified. But suppose y is a qualitative variable good, bad you know linguistic variable; in that case there are other kind of regressions. So, which are coming through and someday we might have better answers to adaptability, but at the moment these are addition factors not easily quantifiable clothing is, but social conditions and adaptation of human being; these are not easily quantifiable at the moment.

(Refer Slide Time: 18:28)



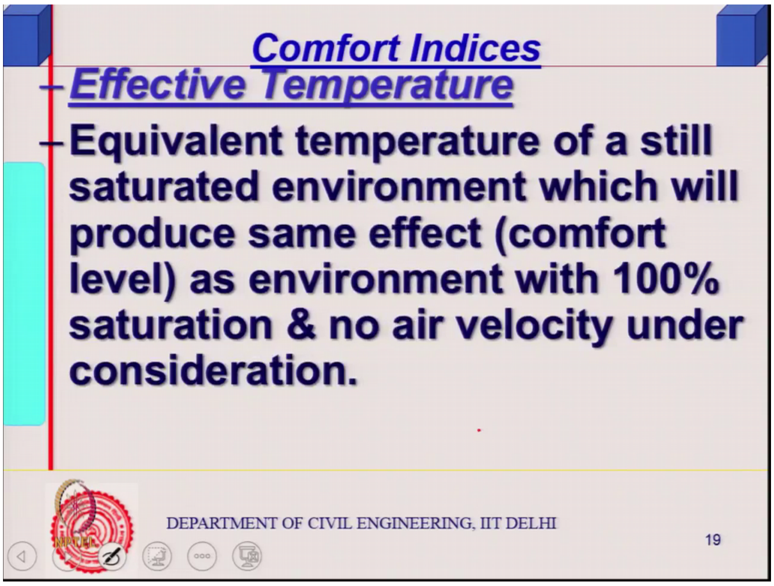
So, as I said you combine all these factors into account and that is we call as?

Student: (Refer Time: 18:35).

Comfort indexes; I mean comfort index, so that take account of this four main factors corrected effective temperature is one such index, tropical summer index is another index. And you will have many four hours, sweat rate etcetera etcetera; there are a number of them developed at different part of the world CET; I think initially developed in UK and then Singapore and all this and some of them are adopted. And we will discuss about that and tropical summer index was developed in India, as I said doing on Indian subject some experiments; so, we will discuss these to two of them.

Besides that; tropical summer index is in form of an equation. So, in form of an equation and therefore, you can easily adapt it; you can easily adopt it in any excel spreadsheet or something like that kind; CET is in form of nomogram unless you convert it into an empirical equation, you cannot use them easily.

(Refer Slide Time: 19:40)

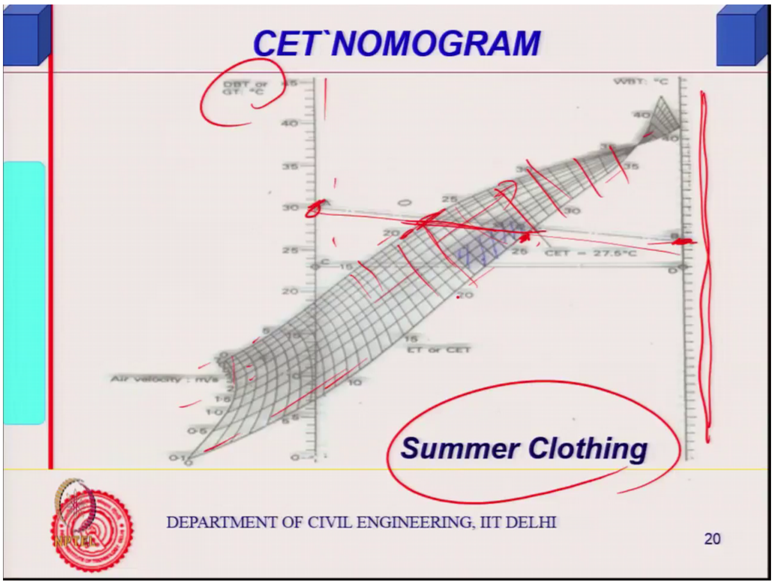


So, effective temperature; this is how the effective temperature is defined. It is the equivalent temperature of still saturated environment which will produce same effect as environment with 100 percent saturation. And no air velocity under consideration the point is; it is like this I mean let me explain the statements does not make it very clear.

It is the temperature of a 100 percent saturated environment with no air movement, which the healthy subjects will say is as comfortable as the environment under consideration. For example, you are put in a room; healthy subjects between 20 to 60 years or whatever it is; put in a room and you rate in some manner, your comfort some rating number maybe. Then you are subjected to another environment which is 100 percent relative humidity. And go on changing the temperature and say you tell me when you are equally comfortable as that.

So, this one would be the effective temperature; at 100 percent saturation, the temperature which will give you the same condition as the environment with different relative humidity and different temperature that we call as effective temperature; this was not taking care of mean radiant temperature and air velocity.

(Refer Slide Time: 21:18)



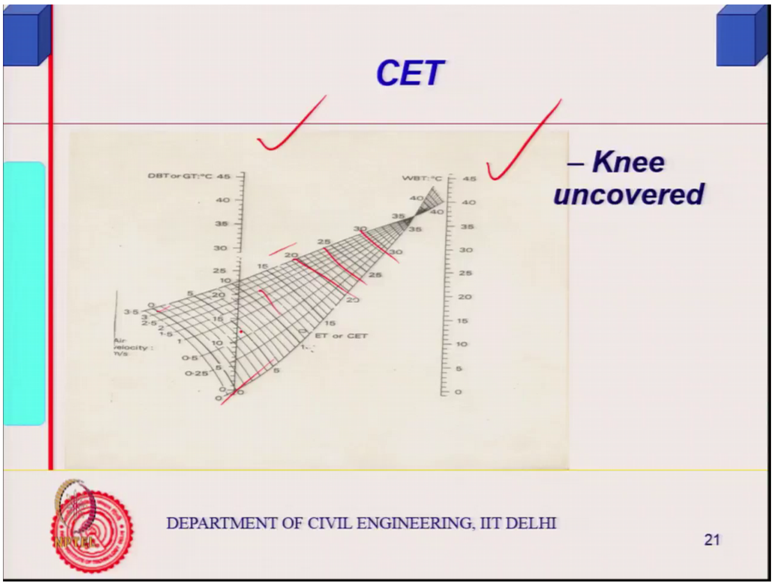
So, then came corrected effective temperature; now this value of this one is 20 to 27 degree in India. Then came corrected effective temperature, which would take care of the air velocity and also the mean radiant temperature that is globe thermometer temperature. So, this is given in form of a nomogram; nomogram in this one you have, this lines are for air velocities.

And for summer clothing, this is summer clothing like 1 clo scenarios it is like this, this is DBT or g t; this line DBT or g t this is a wet bulb temperature. Now what does wet bulb temperature represents? Relative humidity difference between DBT and so if your WBT is in this line; so you know the value; so suppose this is your value and DBT is this is the value; you join them and you know the air velocity. Let us say air velocity is 0, then your CET is this much; CET scales are given 0, 5, 25, 30 etcetera, etcetera, etcetera.

So, it is a given form of a nomo nomogram; if you know the drive bulb temperature; you know the wet bulb temperature. Then you can calculate out the; I mean you can find out the CET depending upon air velocity. For higher air velocity, these value is lower; along this direction your, CET is increasing; along with directions.

So, for higher the air velocity this is like this is 2 meter per second, 3 etcetera etcetera; higher the air velocity this moves along this direction. In other words, your CET will reduce it air velocity because more loss can take place from the body. So, CET moves with higher the air velocity; CET lines are like this these are the CET like this 10 degree, 20 degree etcetera etcetera.

(Refer Slide Time: 23:10)

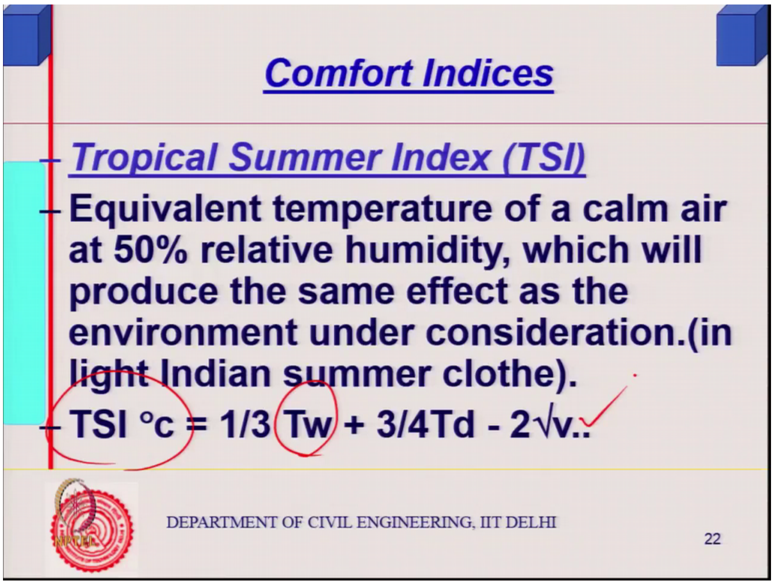


This is for summer clothing; I will come back to this and this is for knee uncovered you know the Indian type of; I mean tropical type of dresses where up to knee is uncovered. Like somebody work in the field as you have seen you know that kind of dresses. So, this is another nomogram of the same thing; same thing drive bulb temperature or globe thermometer temperature, wet bulb temperature, air velocity 3.5 air and these are the CET values.

So, CET values you can find out from such a nomogram; you can actually formulate them in form of equation and I am sure if you search literature you will find an equation giving these values as well. Because these days fitting curves are not very difficult; you can always fit in; so, this is what is CET.

So, CET is that equivalent temperature of an environment having 100 percent relative humidity no air velocity, which will produce the same thermal comfort effect as my environment under considerations.

(Refer Slide Time: 24:17)



That is CET and you find out through nomogram; compared to this; this is tropical summer index is more you know it is simpler. Simpler in the sense that it is in form of an equation; so, it is actually equivalent temperature of a calm air at 50 percent relative humidity. The 100 percent relative humidity is reduced down to 50 percent relative humidity and then put in a Indian dress because it was done in India, research was done in CBRI largely.

So, this will produce you know dress is not the summer clothing; 101 clo and which will produce same effect; why did they take 50 percent? Because relative humidity in tropical climate is usually lower. In Europe or let us say northern hemisphere United States or Canada; top of it US top part of it you will have most of the time humidity is very high. In fact, it is drier inside the room than outside; outside most to the time relative humidity is generally much higher because I mean winter anyway the snow.

Then even summer like some of the northern latitude, you do not see the sun most of the time. I am not talking of the arctic region Scandinavian area or those ones, but even place like Scotland or the line along that line, summer you do not see much of the sun while southern Europe of course, you do see. So, relative humidity is pretty high outside it is most of the time moist; inside since you maintain it is less, but normally air situation.

So, therefore, they decided to put 50 percent because; in Indian scenario you know like tropical climates; somewhere let us say hot dry, desert climate; you will have relative humid 10 to 40 percent. Only in some places like coastal areas and warm humid climate; it goes to in summer time I mean rainy season it goes to 90 percent or so.

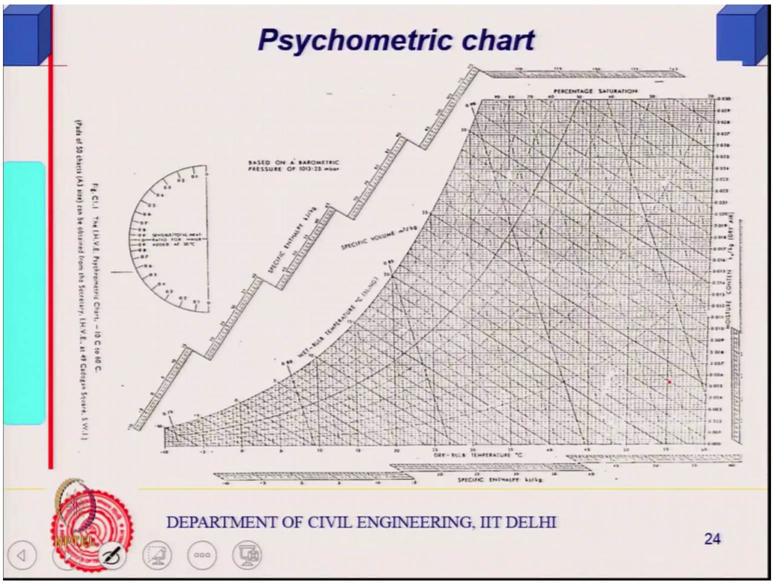
So, they decided to keep it at 50 percent relative humidity and same otherwise it is same and then they fitted an empirical equation. So, empirical equation the simplified form is something like this; you know TSI tropical summer index, actually it was 0.33; I mean point three T w; wet bulb temperature. So, this is your wet bulb temperature this value was 0.74 something.

So, they actually fitted you know from the response of the subjects actually they found out this TSI value. Put the people to an environment asked them to rate the comfort, put them in 50 percent relative humidity calm air asked them to rate the response when the response is same the temperature of that 50 percent; go on changing the temperature of that controlled environment when they say the comfort is same you note that temperature that becomes TSI.

Now, you get TSI for large number of people fit that to velocity inside that actual room not the control room drive bulb temperature of the control room and wet bulb temperature of the control room. So, equation was a little bit more elaborated slightly v minus 2 or some such thing under root, but this is simplified form is, this which is easy to remember one third its 0.3 or something this was 0.74 or some such things; slightly different, approximately can be written; after all it is an empirical equation one third T w three fourth T drive bulb temperature. So, this is wet bulb temperature, this is drive bulb temperature, this is the air velocity; these are 2 root v; this is what that TSI is

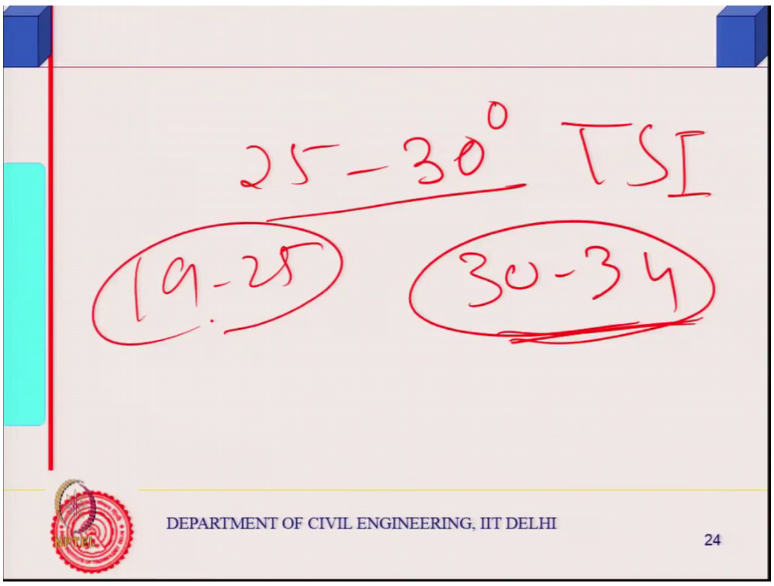
So, it is easily adaptable to any small calculator calculations and the comfortable ranges are this is what it is; light summer, Indian summer clothe that is why I said.

(Refer Slide Time: 28:09)



So, comfortable ranges are something like I will come to psychometric chart; they actually put it in the psychometric chart, but comfortable ranges are something like 25 to 30. So, comfortable range of TSI is 25 to 30, but they also say that 19 to 25 is tolerable. So, 25 to 30 is comfortable TSI this is comfortable, but 19 to 25 is tolerable and 30 to 34 is also tolerable. I mean naturally conditioned not conditioned building, naturally ventilated building you cannot maintain this temperature it is not very easy to maintain this.

(Refer Slide Time: 28:55)



So, but you can maintain possibly internal air temperature to this; otherwise this tolerable you know many people in this country may not be able to afford air conditioner and things like that. So, therefore, 30 to 34 is considered to be comfortable; tolerable and this 19 to 25 is also considered to be tolerable. And what they have done is; they have put it in psychometric chart, we will just have a quick gap and then come back again.