Energy Efficiency, Acoustics & Daylighting in building
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Lecture - 19
Comfort

So, as I said, you know we started, I mean last time looking at comfort and we have several sensory mechanisms like.

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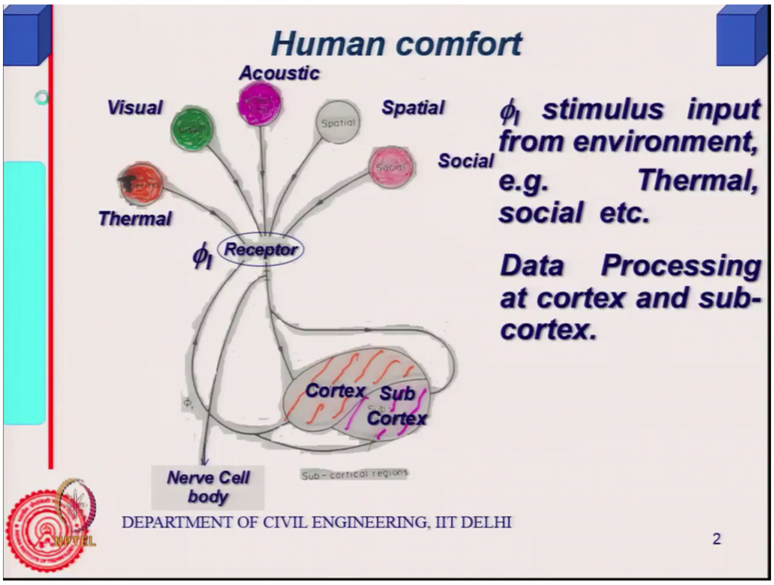

A thermal visual acoustics spatial related to space and social and. So, on and if there is a change in temperature thermal for example, sensible heat is through temperature. So, if there is a small change in temperature that is what we call as stimulus input from the environment similarly, change in the loudness level noise level right. So, that is loudness level, actually intensity of sound. So, that is again related to, it is a another kind of stimulus or a change in the lighting level.

So, these are the stimulus. So, you get signals actually right and they go their receptors are eye, ear, etcetera. There are the receptors right and then this goes to the contraction, sub contraction for processing and then it gives a signal whether you are comfortable with it or not. I mean whether you can tolerate this or whatever it is your reactions basically. So, mathematically one can talk in terms of phi eyes, which are the stimulus input from environment and this, it goes to the receptor and processing in the cortex and sub cortex.

So, these are transmitted through nerve cell right.

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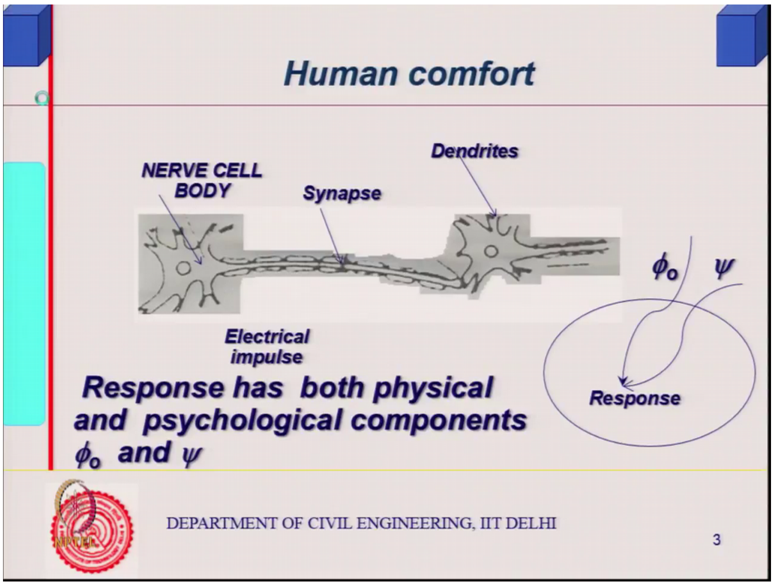

So, basically then they go to synapse and a nerve cell body to synapse and dendrites and all that, there is a physiological mechanism is essentially form of electrical impulses and responses. This is physical part of it, temperature is physical. You know physical, you can measurable things, but there are issues like adaptability, the issues like adaptability. You can adapt, you know and there is also some kind of psychological components also.

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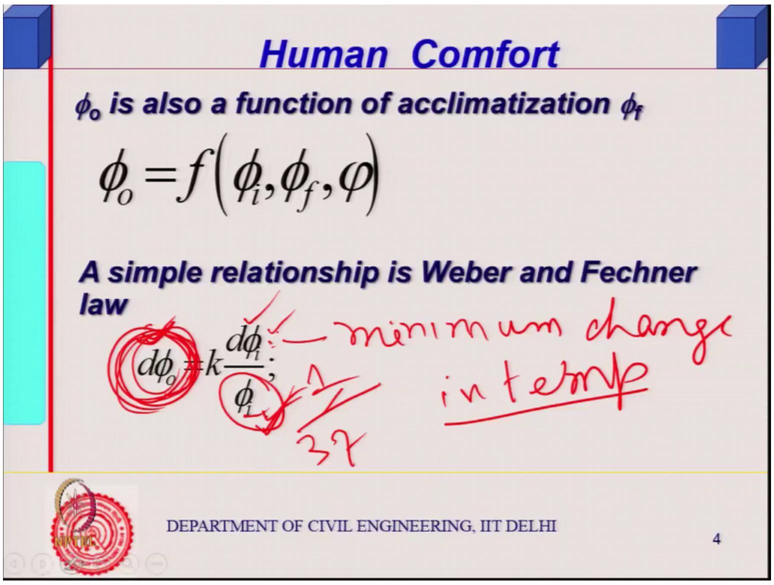

So, actually response is a function of you know response psi is a function of phi 0 and 1 can phi 0. I mean it is psychological part is psi actually and phi 0 is a response. So, it is a function of phi I, which is a stimulus phi psi is a psychological aspects. I mean it is associated with your mental feeling be of being well being or not.

So, well being you know that kind of thing plus also the environmental factors, which you can a acclimatize on. It is you know, if a person who is say born and brought up in or spend most of their life in, let us say higher temperature tropical countries. They find cold countries, slightly cold intolerable, while this is not. So, for the people who were brought up there, it is the way around when such people come to, let us say tropical scenario, they cannot tolerate higher temperature.

So, this is acclimatization and all that besides that psychological well being, that part that is also there. So, anyway simple relationship is one of that is Weber Fechner relationship, where it says that delta phi 0 is a response. So, response delta d phi 0, which is the response or the smallest response is a function you know, is a function of d phi i by phi i. So, it is proportional to d phi i. For example, the least amount of temperature difference say delta phi i as I am saying this one, let us say minimum change in temperature, minimum change in temperature that you can perceive that, that is perceptible is you know this is a minimum, I mean this if below some value of this, you will not find anything d phi i is there will be no response.

So, there is a minimum level and that is divided by phi i, you know there a supposing, there is at higher temperature, because this divided by say at 37 degree centigrade, if you perceive let us say you can find out 0.5 degree, change at 25 degree centigrade perceive, you will be requiring, you know like it is proportional to the temperature itself, less temperature change you will be able to perceive, because d phi by phi i is equals to d phi 0. So, this is the response. So, to minimum perceptible response will depend upon the actual temperature as stimuli change, change in stimuli divided by the value of or example temperature value 37 degree.

So, let us this d phi is 1 degree. So, 1 by 37 minimum d phi 0, you need is let us say some fixed value, because that is what you can, that is the response may not be in terms of temperature. It is you can perceive it. So, the temperature difference you required to perceive at higher temperature is more, because it is a ratio of phi i to d phi. Similarly, lux level or visual lux level, the lighting level which at higher lux level, you require more d phi to get same d phi 0 to find out the difference visually, we can find out the size of a object or let us say something like a glare is related to again logarithmically, related to the level of contrast and so on.

So, this is Weber Fechner’s law, in other words if you integrate it, you get it.

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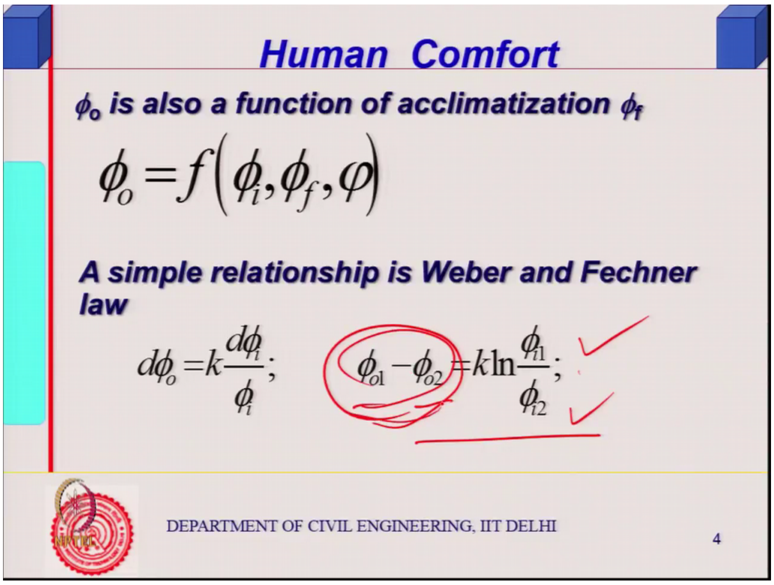

Phi 0 minus phi 0 phi 0 1 minus phi 0 2, let us say this is perceivable, this you can sense it is a function of log of phi i to 1 or phi to you know, it is a function of logarithmically related change, in logarithmic changes the stimuli inputs are logarithmically related to our perception right. So, if we change the, let us say light level, lighting level. So, log of some for function, let us say sum log of sum, let us say lux level, I mean since, I have not defined, I am not, it is difficult for me to, at the moment tell you.

So, log of lighting level, let me say which was there and you have now increased it. So, log of the second value, log of the increased value minus the log of the first value is related to the kind of perception, whether it is, there is a change or not, I mean you may not be able to perceive, if this difference is too small, that is a perception level. There is a minimum difference required for which you will be able to distinguish that; there is a change in the lighting level. Now, that is related to log of the initial lighting minus log of the final lighting level that is what I am saying.

Similarly, you may not be able to sense that there is a temperature change, if the environment temperate change, it is related to log of the initial temperature minus log of the.

Student: (Refer Time: 08:10).

Changed Temperature.

So, it is related logarithmically all right. Similarly, intensity of sound, you know decibel as we shall see it is logarithmically related intensity of sound, which is related to loudness is logarithmically related. So, some of these things are logarithmically related and thus this law says that is logarithmically related right. So, this law say that, it is logarithmically related.

Now, we can look into thermal comfort, we will come to visual comfort and acoustic comfort, you know noise related comfort whenever it comes at the moment.

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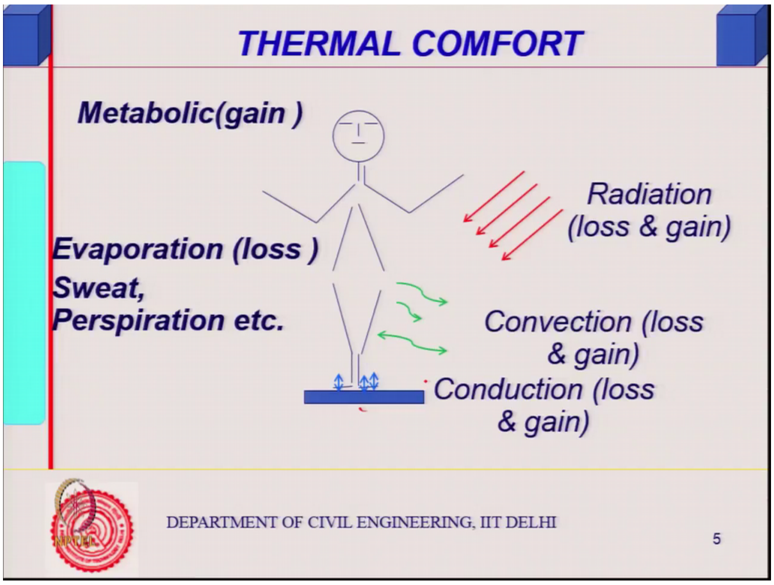

Now, since we are looking at the thermal aspects. So, we will now look into thermal comfort. Now, if I look at thermal comfort, this is a human body, let us say and I might have radiation coming from outside, if all my surfaces are quite warm or some appliances are there which are hot, they would actually, there we will heat, you know they will be transmitting heat by radiation, also I can lose heat by radiation, if the surfaces are cold.

So, it depends upon the temperature difference. So, radiation heat loss similarly, convection loss as well as gain, if the air temperature is high then I will have some heat gain, body will gain heat from the surrounding. So, body gains heat or loses heat to the surrounding, both by radiation as well as by convection right and then conduction loss also can occurred through something like; you know your body is in contact solid, with any solid like I am standing somewhere. So, conduction also loss and gain take place. Now, in addition to this there is metabolic gain as I said whenever you are doing activities you know your heart never stops sudden, body parts never stop working.

So, it is working, heart is pumping, all the time blood circulation is going on all the time. So, you are generating, because all you know, all the energy that we gain through our biochemical process from the food etcetera, it goes in our locomotion movement of the, you know blood circulation all those kind of things. Now, everything is not converted into work, it cannot be some of it will be lost as heat to the surrounding, you know that is what we know that all energy cannot be converted thermodynamics tells us that there will be you know, system cannot be a 100 percent efficient. So, lot of it is lost by as heat and that depends upon the amount of or nature of the work, that you are doing if were, if your blood circulation increase, loss of heat becomes more. So, that is metabolic heat gain to the body.

Now, this heat is actually absorbed by the body finally, it has to lose to the outside environment, otherwise body temperature go on increasing. So, metabolic heat is always a gain, it is always a gain metabolic, heat gain and it depends upon your activity. There can be loss by evaporation from the skin, there can be loss by evaporation from the skin, because evaporation is always a loss, the body has got a mechanism. What it does is, when temperature you know body is not able to dissipate heat by convection, conduction and radiation to the surrounding, because it is warm. Then what it would do? It will start actually, first increasing the blood circulation at the skin. So, that temperature of the skin increases and it will, if it is higher than the surrounding then it can now lose some of this heat.

Is if the skin temperature is higher than the surrounding. So, more blood circulation, skin temperature increases and it can then lose some, but supposing this also does not work, because temperature outside is quite high, you know air temperature, just outside the body is quite high then what it does? It actually starts generating moisture at the skin surface loosing moisture from the body and this will evaporate. So, it is a kind of adiabatic cooling, because when it evaporates it is takes the latent heat of evaporation from the body itself or skin itself. So, that is evaporation is always a loss besides that, through our respiration process, hot gases will be you know exalted out from the body. So, some loss can also occur moisture loss as well as both latent and sensible heat loss can be there, through respiration process.

So, perspiration sweat etcetera all these process can lead to loss, but there are some gain also I think, I have not mentioned it here, there are some gain also in winter for example, surrounding temperature is very low then body starts losing heat rapidly and in the inner body temperature, particularly temperature of the brain, if it goes down then things it may not be functioning, you know system may not be working. So, you start feeling a kind of discomfort when the temperature outside is very cool, because body is losing heat anyway can clothes, etcetera. These are very much there besides that body as good is on own mechanism, what it does? It starts generating heat more.

Now, what does it do by shivering mechanism? So, shivering mechanism is one by which it generate more heat. So, that even if the heat is lost something is being supplied to the body, if you are doing anyway some exercise or something that to generate heat, but shiver you know. So, shivering mechanism is gain of heat, sweating mechanism is

Student: Loss of heat.

Full loss of heat right.

So, that is what it is.

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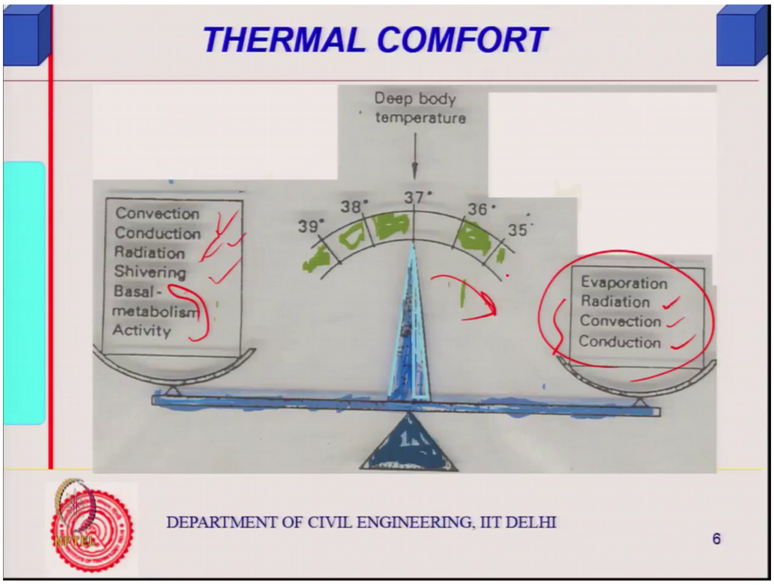

So, you can see that deep body temperature is somewhere close to 37, 37.4 etcetera right and if you, your temperature actually reduces down, you know, I mean or it can reduce it down by evaporation, convection, conduction and radiation and heat gain can occur by convection, conduction, radiation, shivering and basals metabolic activity, the metabolic activity. So, these are the, this is cause gain, these are causes loss. So, these three are common in both the places, shivering for it causes gain and this causes.

So, finally, body should maintain something like 37.4 degree centigrade, which is deep body temperature.

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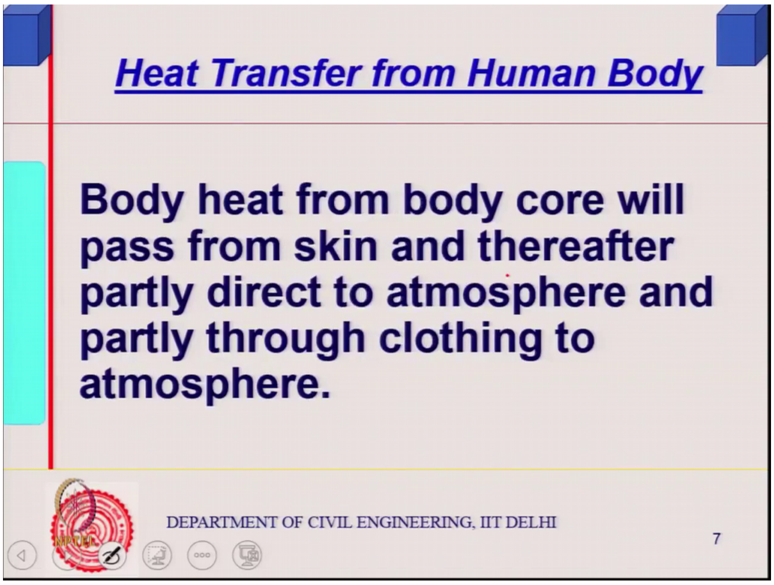

So, the body heat, you know body heat, from body core will pass from the skin you know. So, it should, it actually maintain that temperature. So, what happens is when I am looking at warm temperature outside warm or you know, this is a temperature, is higher. So, body heat from the body core would come to the skin, pass from skin, if it is exposed or through the clothes right, directly to atmosphere or partly through the clothing to the atmosphere.

So, you know through the clothing some heat, will be passing some whichever part of the body is exposed it, will lose heat directly to the atmosphere. So, we can actually model it, we can model it.

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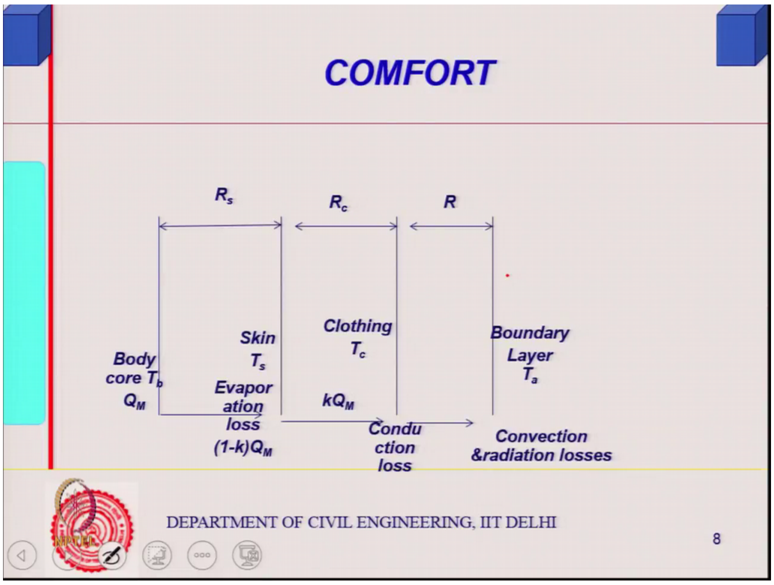

How do we delete it; assuming conduction heat transfer through the body or equivalent conduction deep body temperature. So, this is your body core temperature, there is a Qm right and then skin temperature is Ts then clothing Tc and then boundary layer, because skin is in contact with air. So, we will have a surface conductance kind of effect boundary layer. So, one can think in terms of resistances from body core to the skin, from skin to the clothing and from clothing through the, you know or clothing on skin to the boundary layer.

So, one can write like this resistances think in terms of equivalent conductance and therefore, something similar to you know transmittance. We can conceive something like this.

Student: Sir, what is boundary layer?

Sorry.

Student: Boundary layer.

Because the skin is in contact with the air so that would be by convectional radiation like wall surface to the surrounding. We took ho hi something similar.

So, this is the boundary, you know this is a, this is I mean, it is a very thin layer. We cannot define this in absolute length unit, because it is not fixed. So, it depends, you know it is a very thin layer, but temperature of the air is always higher than the surface temperature, solid surface temperature. So, that we have taken it in terms of equivalent convection, radiance equivalent conductance, the radiation and convection, we have taken in terms of equivalent conductance.

So, we are talking of that resistance 1 by ho or 1 by hi 1 by ho or 1 by hi right. I mean the thickness here shown is, it is a schematic diagram. So, that is why thicknesses are not really. So, supposing Qm is the heat generated right. There will be some evaporation loss and lesser the fraction is k km is the loss by evaporation right, because you know like as I said through your respiratory system also, you lose some heat and right from the skin, you are losing some heat does,

Then k Qm is what passes. So, loss is 1 minus k Qm sorry. k is k k Qm is what passes through this clothing and some portion goes through the skin and evaporation loss and all that 1 minus k. So, conduction loss, then the boundary layer loss. So, convection and radiation losses as I said boundary layer will have convection and radiation losses and therefore, this is how you can conceive it, model it in that manner. So, values of metabolic heat dissipated.

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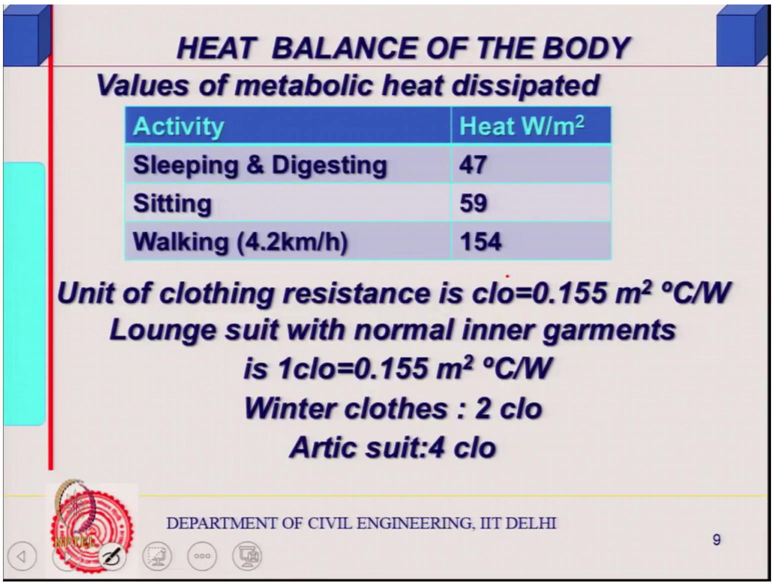

Let us say activity typically, given is this will come to that model some. This is you know Fanger's equation, because you can simply write steady state equation Qm passing through that and sum up 1 by r. So, Q will be equals to all resistances 1 by all resistance or something similar to your u value into delta t temperature difference right.

So, we will come to that, but typically just to tell you what is a metabolic heat, dissipated values are sleeping and digesting. Let us say 47 sitting, 59 walking, at 4.0 kilo meter per hour, will be of the order 1 5 4 and there be many more. Now, clothes are important. So, units of clothing resistance of clo 1 clo it is called 1 clo resistance of the, because that resistance of that cloth is important. You know this textile engineers, apparel design, this is whole subject. In fact,. So, there like cotton clothes, you know little bit digression cotton clothes are very good in the sense that they are allowed for us, allow lot of air movement, when polyester or synthetic ones came, pure synthetic is very uncomfortable in warm humid climate, because the losses, you know losses, evaporation losses are relatively less.

So, then the, then came the mixed terrycot. You know tera linen and cotton mix. So, they two things, you need the polyester or similar sort of things in that, you are gone you will have Criss like you press then once that remains, will cotton the pres goes away. So, there they you know, the technology developed. So, as I coming back to it, they to use this very much apparel design and you imagine if this is to be done from arm forces people or people in upper Himalayas or something of that kind you know. So, this is a rather complete science behind it, but 1 clo is point 1.55 meter square degree centigrade per watt resistance cloth in a resistance of clothing, we define and. So, we call it 1 clo 2 clo etcetera.

So, unit of clothing resistance is 1 clo must be related to the summer clothing in Europe, UK, you know this must have come from somewhere, from there only. So, some are light summer dress which is; obviously, will have a coat also in European scenario or not like this in Indian scenario or tropical scenarios, it will be in fact, bare foot and things like that, you know even bare bodied part of it, like a villager of good old days, working, ploughing, you know in a field. So, the comfort level even exposed open field, it could be, because they are working high. You know working metabolic heat generation could be quite high.

Anyway coming back to this, unit of clothing resistance is clo 1 clo and it is 0.155 meter square. So, a lounge suit with normal inner garments is 1 clo that is what I saying, you know lounge suit that is a summer. So, that how this unit came right, winter clothes could be 2 clo and Arctic suits, Antarctica and Arctica, Arctic suits, you know fully covered, it is 4 clo. So, you can get some idea.

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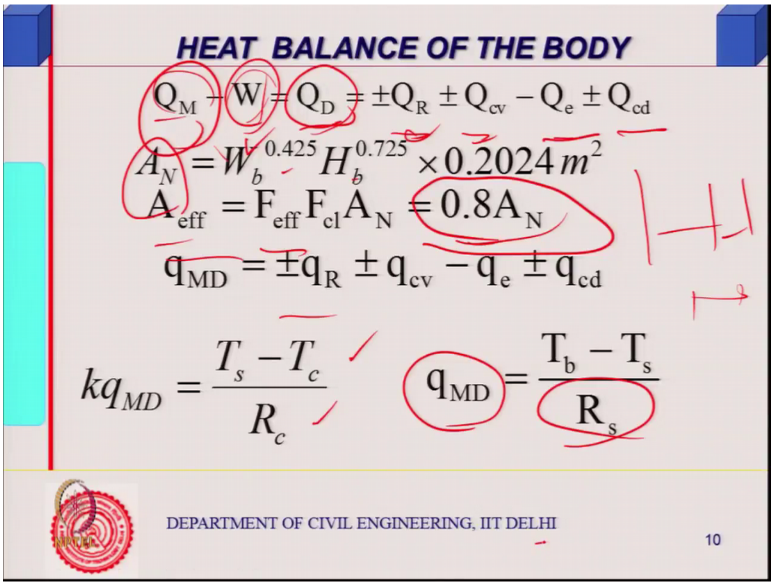

So, heat balance of the body then Qm is a metabolic heat generated and this is the metabolic heat generated minus some losses is equals to the Q D that is to be dissipated and that is to all those mechanisms, some evaporation, some conduction, and radiation convection, and all that right.

This is radiation that can be plus minus, because you know in general equation. It is general form, we are writing, it could be plus or minus, but finally, net has to be balance has to be there to maintain the inner body temperature. Conduction is plus minus evaporation is minus convection and radiation and all that. So, area of the normal body is taken like this, you know it is height is Hb and w is the weight body, weight w is the body weight, normal body weight is taken as Wb and there is an empirical equation you know.

So, the surface area of the body through which heat will be lost, it is related to the body mass, you know weight and height weight and height right and then there is some 2 0 2 4 meter square, that is it, but effective would be related to cloth also. So, some factor for clothing and some factor you know area of the clothing etcetera, finally, it is 0.8 N is taken approximately. This is the, we do not, you know like just some sort of a kind of an empirical values right exactly, is not really required, because it will vary so much from person to person or you know globally, if you try to see, it will be very highly varying. So, we take it roughly as 0.18 0.8, and through which heat has to be dissipated.

So, q MD is equal to q. You know this is per unit area, I can now divide by per unit area. So, Q D if I divide it by the area, the heat that is to be dissipated right. This is to be dissipated, is given by this expression per unit area. If I divide by 0.8 N then I get the per unit area. So, this q MD should be equals to Tb minus Ts; what was Tb body temperature minus skin temperature body temperature minus skin to. So, total this is the work actually, this is the metabolic heat generated, some of it goes into the work in the body finally, this is to be dissipated out of the body right and this is divided by this area, because flux I am finding out and flux is proportional to temperature, different difference divided by resistance right.

So, resistance for the skin noq q MD is what has to go out, it comes to the skin, this much then I should multiple by a factor 1 minus k. So, k MD is Ts minus Tc divided by Rc, if I recollect the diagram that I had a, you know resistance of the skin first, then resistance of the clothing then resistance of the you know surface boundary layer. So, q MD must be equals to kq MD k is the factor, which goes in and 1 minus k goes out from the skin itself, directly from the skin itself 1 minus k is going out by evaporation as well as you know. So, through the cloth, this must be dissipated, k MD you know, it must be dissipated.

So, that is finally, has to be disappointed and one might actually model this, but such modeling do not help us, much really only except that understanding, the heat dissipation occurs through skin cloth and clothing is important. So, from this what we are understanding is I mean there are details of this (Refer Time:25:3) equations, but that is it is just simply this equivalent q k, k MD is equals to Ts minus Tc by Rc and that is must be also equals to Tc minus Ta of divided by resistance of that boundary layer. So, but it gives us understanding. What understanding does it give this exercise, the algebraic exercise that I have done? Clothing is important; your comfort condition depends upon clothing.

It depends upon amount of radiation, you can receive. Now, where do you get the radiation from? All the surfaces; supposing I have got a light or something and it is quite warm, you know light some kind of lamp or something or some sort of you know this is light together with some sort of (Refer Time: 26:25) and fitting, you know this kind of these are the fitting light, fitting. This may not be as warm as it is, it used to be, because good old days. Now, you use all those leds and much less actually heat generation there. So, most of it is light converted into light.

but supposing, I have a heater or something of that kind that would dissipate, that would transmit heat and surfaces in summer, those who stayed here, let us say in Delhi or in northern India in summer, in an unconditioned room, you go and touch the wall, you will find that it is very hot, if you touch the ceiling directly, it is suppose, one concrete ceiling, it is there. You will find roof, you know you will find it is very hot; that means, those walls and surfaces will be radiating heat to your body.

Air temperature could be lower, but radiation effect could be there. I am just saying or air temperature both can be higher. So, that for radiation effect has also to be taken into account, this is what two things, we have understood from all these exercise, clothing is important, radiation is important and; obviously, air temperature important. Now, one more thing is important, what is it? Because your body get cooled by evaporation loss heat by evaporation therefore, relative humidity the capacity of the air to absorb moisture that is also important.

So, what you found out besides clothing radiation that is your surface temperatures, relative humidity air temperature, these are the important thing. Now, there can be losses by convection and evaporation and it could be by forced convection, because you remember we talked about free.

Student: And forced.

And forced.

Force is relative to a velocity

Student: (Refer Time: 28:10).

Of the air.

Therefore, radiation of the surfaces, air temperature, relative humidity and air velocity, these are important factors for thermal comfort, because heat can be dissipated through the body, like that. Clothing is important and adaptability, because if you remember Weber Fechner’s law, we are looking at we said there is a psychological as well as, psychological as well as.

Student: (Refer Time: 28:41).

You know your social aspect is, there aspect you know adaptability is there. So, these are the other factors which goes in, you know defining some sort of thermal comfort or quantifying thermal comfort in some relative terms. So, we will just look it into it and how many to, of two types.