Energy Efficiency, Acoustics & Daylighting in building
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Lecture - 09
Heat Flow in Buildings

So, before we go to thermal comfort related you know equations; we will look into a little bit in the heat flow path in buildings, heat flow path in buildings. But then we will go back go back little bit more related to conduction will look into so that you know it becomes it will become easier to understand the thermal comfort (Refer Time: 00:43) because the comfort equation should come. So, you look into this. Now if you look at the building, right if you look at the building, various heat flow paths.

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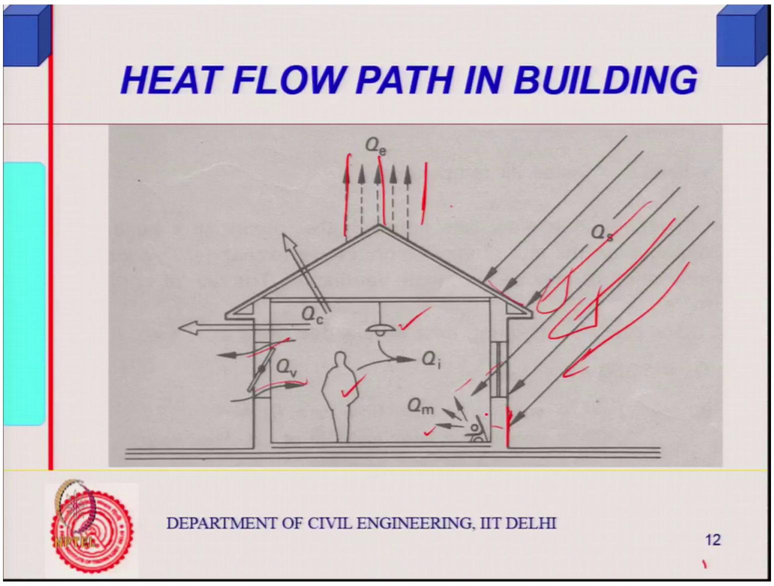

This is basically you know there would be direct sunlight can come like this. Direct sunlight can come like this.

Solar radiation direct sunsolar radiation can come like this. And if you were window, then the direct solar radiation will be received in this manner. But solar radiation can fall onto also onto opaque body is like your roof wall, etcetera. And this will heat up this surface itself, and then it will transfer by conduction. Temperature here would result in heat conduction; you know, which could be both ways coming in or going out right. So, in heat conduction heat gain can occur through the wall. Some emission radiation in a night the surfaces can radiate back to the atmosphere right.

So, conduction can be both coming in and going out, and through openings ventilation heat transfer can occur, and which can come in or get out or whichever way out. In addition to that you will have some heat generation from human bodies. Appliances heaters etcetera, etcetera, this is a situation where you have actually; you know you are cooling situation. So, you have put in a heaterif you have fan that will also generate. So, these are the you know so, you have direct solar radiation.

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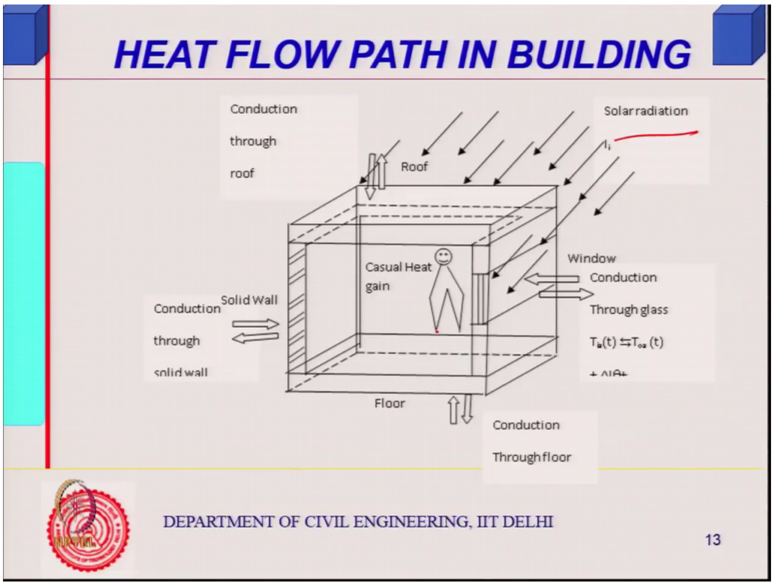

And if I make it a little bit more something like this. So, solar radiation coming like this, this is the window. So, through the window there will be little bit of conduction also, but if there is a glasses through that there will be conduction also. And some heat gain from the body human body you call it casual heat gain.

Conduction through the solid wall could go in our outside, conduction through the roof can also occur and conduction thorough the floor etcetera. So, this gives you a kind of basic idea about the modes of heat transfer. So, you have conduction. Essentially direct radiation can come in through the opening or glasses which allowed transmission of radiation. So, direct radiation can come in conduction heat transfer takes place to the opaque bodies. You know, like wall if the outside temperature is high, heat will come in if the outside temperature is low, it will go out.

Direct radiation which falls on to the opaque body finally, they are transferred inside by conduction again because they will heat up the surface where the wall etcetera and it will low. So, conduction, heat transfer, direct solar radiation, you have looked into ventilation heat transfer can takes place if I have openings, right? And from wall to inside again, it will be through surface coefficients or whatever it is. So, this diagram shows you the modes of heat transfer in building modes of heat transfer in a building or in a space within building as we have seen, right? And we have I can make it fairly complicated by this kind of a diagram.

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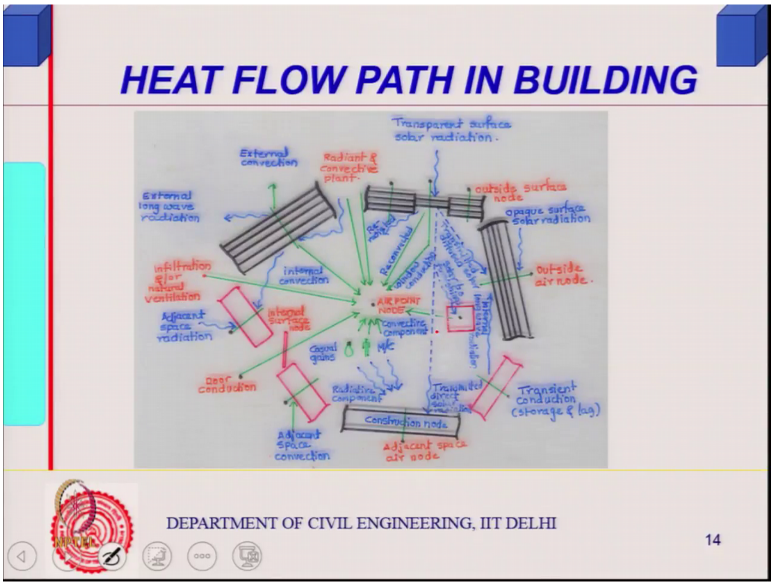

But it is simpler one is already, there will be you know like for example, this is external convection this external long wave radiation, you know I might have mention to you what is long wave radiation or short-wave radiation one day. But I will explain it again other day when I was talking about the glass properties of glass, or I was talking about you know earths heat balance. That time I was telling you that whatever heats annually comes in it goes out, but if there is if there is a carbon dioxide cover, it can actually block some of the heat going out like glass, like green house gas we are talking about or green house is we are talking about.

So, glass has this property you see the quality of radiation or characteristics of the radiation depends upon temperature of the body. Sun radiates at very high temperature; right, therefore, it radiates spectrum of radiation which includes visible ultraviolet visible etcetera, etcetera to infrared heat radiation as well, right. Because it radiates at very high temperature, while you come to terrestrial bodies, earth it radiates actually at much lower temperature to the outer cosmos which is the lower must still lower temperature in the night the earth will radiate back. Now since it is it is it is temperature is lower it can only radiate long wave radiation or it is a function of temperature, you know, it is law physics actually it is a function of temperature the lambda value.

So, it is usually long wave radiation low energy radiation that goes in. Now these radiations are you know they are not capable of getting transmitted through glass. So, glass traps the long wave radiation, but allow short wave radiation to come in, right allow short wave radiation to come in. So, building will actually radiate only long wave radiation, back building will radiate long wave radiation back. So, therefore, external convection and long wave radiations from the surface, but all radiation outwards from the building or earth will be all long wave radiations, right? So, in fact, just take we will discuss the sometime later on; that means, if I look at the absorptivity of a you know absorptivity of a surface, I should have let us say opaque surface white wall surface is absorptivity to solar radiation should be low should absorb least, right.

Absorptivity is a fraction of energy it absorbs, but it is emissivity to long wave radiation should be high. So, that it absorbs least, but in the night, it radiates out maximum. So, this character is long wave you know it all long wave. Similarly, it is shown here transparent surface solar radiation gain. So, more complicated you know this is a air node inside. So, from wall to inside there be convective heat transfer and radiative heat transfer. But what we do is we simplify many of them. So, one can make it relatively complex as this diagram shows, but we can still make it for more simpler we will see that.

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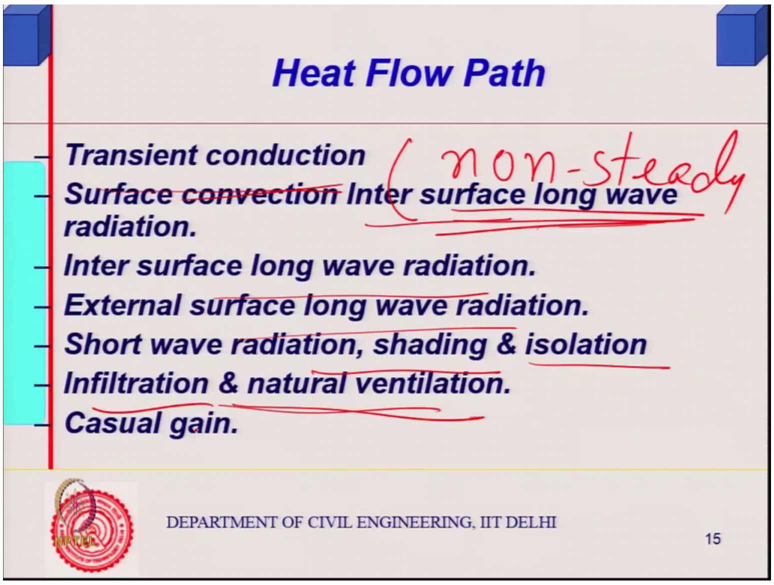

So, if I write the heat conduction into the building is transient conduction, because temperature outside is wearing transient is what? Non-steady state, what is I think I may not have define. This steady state is temperature remaining constant; which will never be the case over a short range you might approximate it in certain climate the temperature outside remains constant.

But reality it will never be. So, temperature will have some kind of variation and therefore, it is not it is non-steady transient or dynamic is also used synonymouslys with non-steady, but transit you know it can non-steady state also can be of varieties of kind or transient can be of varieties of kind for example, you can have sudden increase, right. And then come there transitory or periodic and so on.

So, anyway so, this is conduction through opaque bodies. Surface convection and inter surface convection from surface to inside, then inter surface long wave radiation or long wave radiation between 2 surfaces. External surface long wave radiation going out you know, the diagram that was there that it today all of them, short wave radiation coming inside the building through the glasses. If I have a shading, they can actually block that and insolation actually, it is anyway infiltration and natural ventilation.

So, air movement can air hot air from outside can bring in heat or if I have hot air going outside from inside to the room it will take out the heat. Cool air coming in winter cool air coming from outside makes it cool, right. And if cool like basically room is maintained warm therefore, cool air you do not want it to come in winter. But summer you would like if the outside air is cool you like it to come.

So, these are related to natural ventilation, and infiltration I said was unwanted you know forcefully entering. So, if you have leakages at the window door construction defects which allows air movement to takes place that is what we call at infiltration casual gain from human body appliances etcetera, etcetera that is what we call as casual gain.

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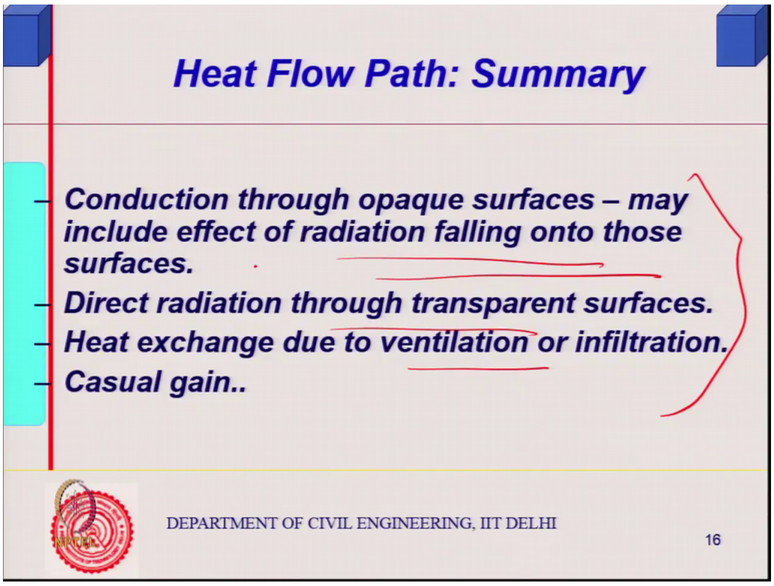

So, if I summarize them, conduction through opaque surfaces may include effect of radiation falling onto those surfaces. Because opaque surface will get heated up, and direct radiation through transparent surfaces, glasses, transparent surfaces. And heat exchange due to ventilation or infiltration casual gain. So, this all this diagrams are for complicated. Finally, I might summarize them into this 4 for our purpose.

So, basically conduction through opaque bodies wall ceiling roof whatever there, and if radiation is falling onto those opaque body finally, they it will be transferred inside through conduction only. And then direct radiation through glasses heat exchange due to ventilation and infiltration if there is a air flow through leakages; that will bring in heat or take out heat or whatever it is, and casual heat gain from human bodies appliances etcetera, etcetera.

So, when you we can model them simplified form, you know you trying to keep it simple as much as possible for amenable to hand calculation. Computational program can be very robust depending upon what one is doing there are softwares available, as I mentioned, but to understand this these are the summarize these are the mechanisms of heat transfer.

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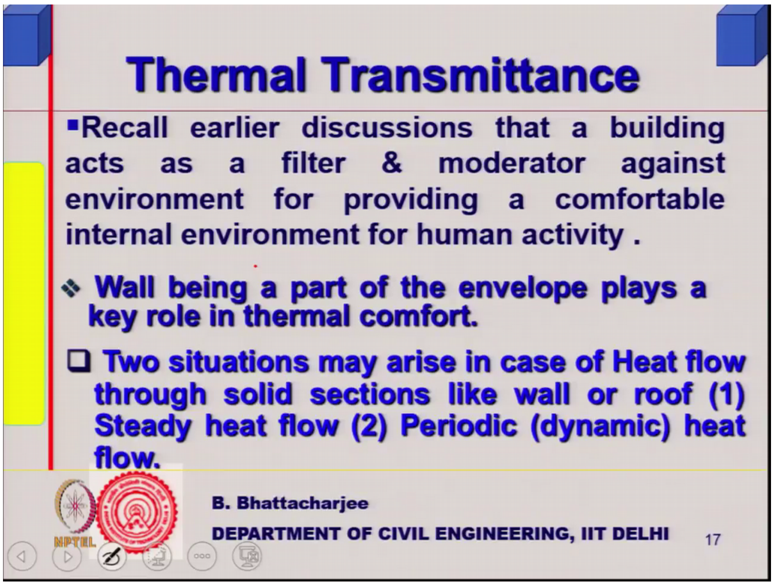

So, we define something called thermal transmittance, right. Well we said that building is supposed to act as a filter. Sometime, I think I mean the beginning, I mentioned that it tell us good thing to come in; it is a moderator do not allow bad thing to come in; that means, it will block the summer heat allow you know, winter heat to come in. Summer block the summer in, but light at light required light all the time for internal.

So, wall being a part of envelope plays a key role. So, wall and it is roof get play very key role actually as you know, because envelope part of the envelope right. So, they are you know they are the major moderators; which envelope is a major moderators. So, wall is one of the main thing. So, we look into some of those wall. Now this as I said that heat flow conduction heat transfer here is transient or dynamic. Now situation here is actually when you have looking at dynamic situation. We can do one thing we will discuss this in details later on.

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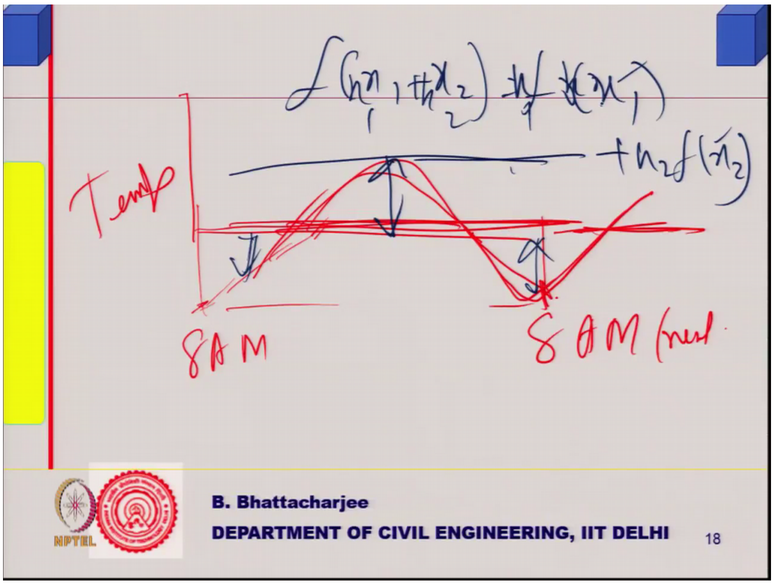

Supposing this is 8 AM today and 8 AM next day. And let me say, I have some temperature this axis is temperature, right. So, what you will find is if I have a temperature, let us say some temperature let say something like 37 or 25-degree 25 degree somewhere here. Then it will go on increasing and possibly next day also it will be somewhat similar. And again, it will be you know somewhat; sorry, it might be something like this similar. Some sort of you will might find something of this kind.

Usually temperature is periodic. 24 hourly periodic because it is related to suns rotation I am just talking of external temperature. So, when I am talking of dynamic here, I am looking at a situation of periodic heat flow. I am looking at the situation of periodic heat flow, right? When I am looking of dynamic in case of heat transfer from surrounding to the building I am looking at a this situation. That is what is been stated here. So, periodic here it is dynamic heat flow dynamic heat flow is periodic actually because I can assume that 24 hourly period and everything will be periodic as long as my season is same.

Over a period of time, over a given season even in composite monsoon climate which has got 3 different seasons, you might assume that it is by and large periodic for certain period of time. So, that is how it is. So, let us look at this first this part, but steady heat flow is important, why? Because I can find out the mean of this heat flow and today's mean and tomorrows mean will be same. Outside mean will be same. So, I can assume that that remains constant mean remains constant.

Now, this is outside mean. Now inside mean also living constant. Because whatever you know sometime it will be observing heat and sometime it will be giving above the heat, right? Otherwise it is temperature will go on building up that is not have that cannot happen; because outside condition is by and large same periodicity is maintained. If I assume that they are all periodic say, similar you know what you call steady periodic situation steady periodic situation. Steady periodic means it is periodic, but remains steady. Now that would be over a season by and large it will remain steady periodic.

During the transition from one season to another of course, there would be changes even internal temperature would change. So, coming back to this, this might be my outside mean inside mean could be somewhere else. Somewhere else well for the time being let me put it might be somewhat higher let us say what higher or lower. That we will see later, but that will also remain constant today tomorrow it will remain constant. Because there also it is periodic inside also will be periodic I am not talking of condition building, unconditioned building because it will receive some heat and give you a some heat.

So, inside condition also would be periodic you know and that is why common day experience also sometime in the day room is very warm and sometime in the night it is not. So, warm you know. So, there is a change and it is periodic again 24 hour periodic we can assume. So, if I deal only with the mean, and deal with this fluctuation separately, this fluctuation from the mean separately some fluctuation will be plus some will be.

Student: Minus.

Minus, right? And some of their effect together, then I can get the overall effect, right? I can super impose a effect of the means. And effect of the variation from the mean separately and add them up. You can add them up as long as your feminized or equations are all linear. A linear in a linear system, f x plus 1 x 2 is equals to or you know k x 1 k 1 x 1 k x 2 is equals to f of.

Student: K x 1.

K x 1 plus.

Student: K.

K 2.

Student: F x.

F x 2. Independently you can sum them up these are constants. And you get the same. Thing you can understand that you know many, many of the structural engineering scenario you do that p 1 force effect of force p 1, you can add the effect of force p 2 supposing you want to find out you know various effects like deformation related to a force sum you can sum it up as long as the system is linear, right? But if your modulus of elasticity is varying with you know it is not linear stress strain diagram, then you cannot do this there will be problem.

Because you cannot at this effects. So, as long as linear I can do this, and we assume here heat transfer situation is linear heat transfer situation. So, therefore, there is no problem we can sum up. We it is very simple algebra nothing like this supposing I have got k 1 you know.

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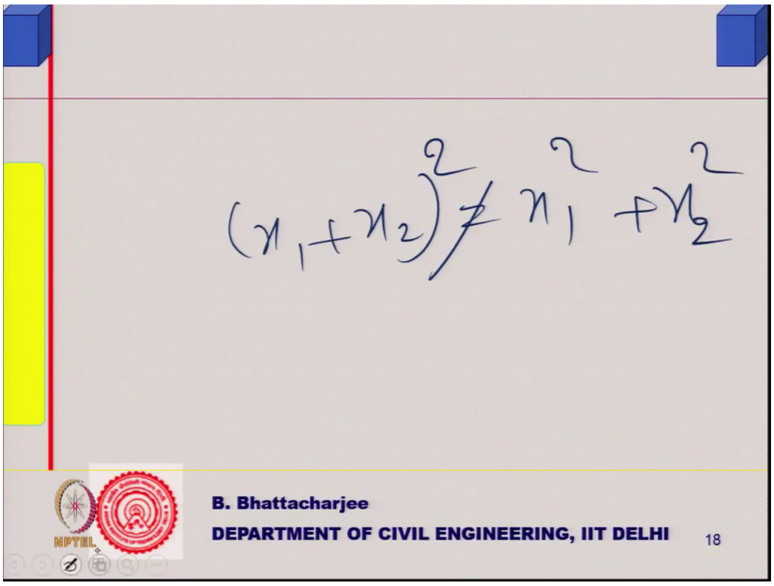

It is a function of k 1 x or, but if it is x square x 1 square plus x 1 plus x 2 square x 2 square is not equals to x 1 square plus.

Student: X 2.

X 2 square now is whereas, if it is linear then x 1. So, that is basically that is that is idea. You can see that we separate out the steady part and.

Student: Non-steady.

Non-steady part let us look at the steady part, right now that is why I was just telling you all that. So, let us come to the steady part now and define that transmittance that I was just mentioning.

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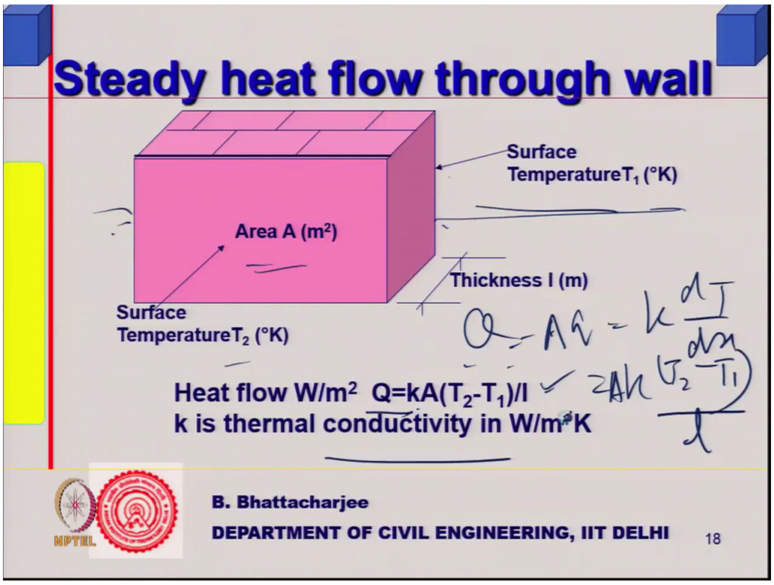

So, steady heat flow through a wall, let us look into. So, I have a surface let us say surface temperature is T 2 here, and that side it is T 1. And these sides are all insulated. These sides are all insulated like a brick work or very large you know this side is very large infinite such compared to this thickness. So, that we can assume the heat transfer is occurring only in one direction. We not very close to the edge of the wall.

So, we can assume heat transfer is only one dimension. This area meter square this surface temperature is T 1, this side is T 2, and from l heat flow then would be total heat flow would be given by heat flow per unit area or small q. Which was k T 2 minus T 1 by l remember we said q is equals to k d T d x. And I can write it as k T 2 minus T 1 divided by l if l is a thickness. So, that is what I am doing. Multiplying by the area will be capital Q. So, capital q will be capital q heat quantity of heat flow watt per meter square rate of heat flow is k a T 2 minus T 1 divided by l. K is a thermal conductivity, right? This degree is not there watt meter k. I think is now written in degree, it does not matter.

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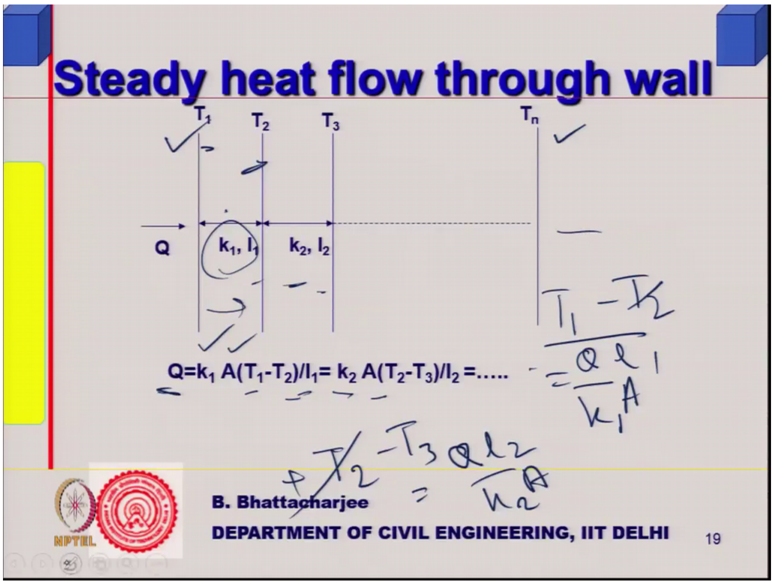

Now, suppose you have a layered situation. Supposing have a layered situation, then heat and now I temperatures are all constant, because I said that I am looking at the steady scenario right steady scenario. So, let say I have one layer whose conductivity is k 1 thickness is l 1. Second layer conductivity is k 2 thickness is l 2 and so on, T n heat coming here is q heat going out also should be q, because it is steady state. So, heat passing through each one of them is same. So, q will be equals to k 1, this k 1 into a into T 1 minus T 2 T 1 minus T 2 divided by l 1. And this heat is coming to the next layer. So, I can write for the next layer k 2 a area is same etcetera, etcetera and I can do this for all.

And then I just separate out T 1 minus T 2 you know, I can write T 1 minus T 2 will be equals to q by k 1 A. Similarly, I can write you know and where is l gone l will be together here right l will be here only l 1. Similarly, T 2 minus T 3 will be written as q l 2 by k 2 into A, right? And T 3 minus I can go on writing like this corresponding one. And if I sum up this T 1 T 2 T 1 minus T 2 plus T 2 minus T 3 etcetera, etcetera. What we will find? That this 2 will out T 3 will also cancel out I will be only left with T 1 and T n. And this algebra I am just doing this I am just doing this algebra now.

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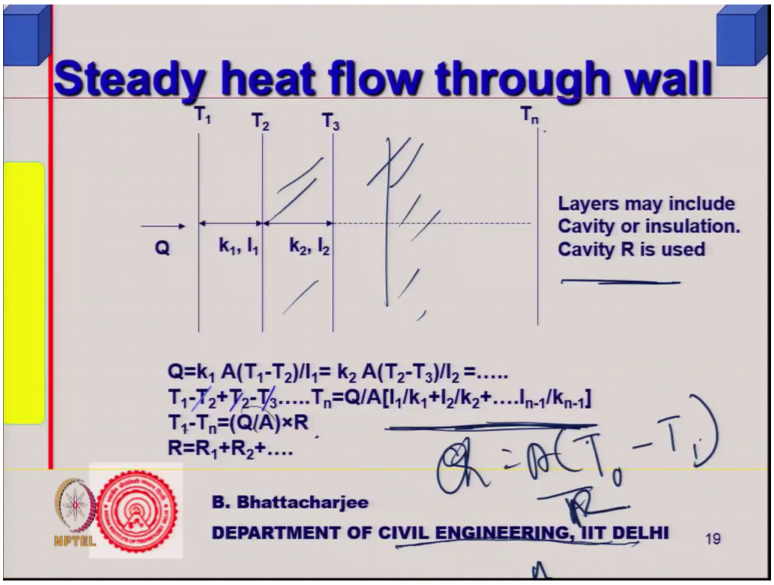

So, T 1 minus T 2 plus T 2 minus T 3 etcetera, etcetera will be Q by A will be common because Q by A everywhere Q by k. So, I will have I will be left with l 1 by k 1 plus l 2 by k 2 etcetera, etcetera. This right I will be left with this. So, this term when I have layers in series layers in series, in if you look at electrical analogy when resistances are in series you adapt the resistance and resistance is nothing but you know resistivity and resistance. Resistance is rho l over ayou know resistivity is rho. Resistance is rho resistivity multiplied by l by you know a in electrical.

Here also similar analogy you can look into l 1 by k 1 into A if I take it that is must basically nothing but the resistance of this unit. I am summing up the resistances actually when they are in series. I am summing up the resistances, all right? So, this actually will cancel out and I will be left with T 1 minus T n,that is nothing but the potential difference or voltage difference. So, T 1 minus T a is nothing but q by A into r. So, we are calling this as r of this system l 1 by k 1 plus l 2 by k 2 etcetera, etcetera. And r is equals to sum of r 1 r 2 r 3 r c that is it, right.

So, when layers are in series I will have something like this. Layers may include cavity supposing I have a air graph here you know these are all solid air graph here. So, all I good to do is at the cavity resistance just at the cavity resistance you know or insulation. So, then cavity resistance must be known. And this values are given I mean people have found out because the internally there will be convective or redditive heat transfer. But then depending upon of course, the thickness if the thickness is very small generally, below 3-millimeter circulation cannot occur. So, in pours really convection do not occur always finds pours convection do not occur.

Even radiation between pour should be very small, because the distance has small temperature difference may not be large. So, but in walls I will have actually if I have 5-centimeter 50 mm gap. I will have some resistance you know some heat transfer, right. And equivalent resistance one can find out these values are given in code like s p 40's bur of Indian standard special publication s p 41. It gives you values of resistances and conductances of many of the material in a gross manner, but is quite useful for our purpose unless you are looking into more details.

So far you know values of conductivity resistivity conductivity surface conductance etcetera they are given in many books, but standards they are also given. For example, in Indian standard special publication s p 41 and s p 32 they give you. S p 41 is for you know non-industrial buildings. This is, this you know this is special, I think I have given it in reference. So, you can look into s p 41 you such the IS Indian standard court site. Indian standard site you will find it. So, they give you those values.

So, resistances of cavities are available there, right. But there is one more thing remaining.

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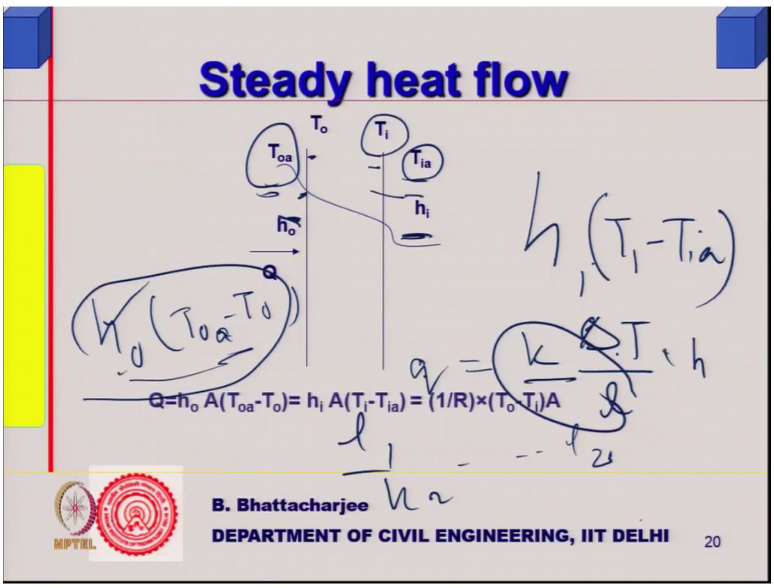

As I said, surface is never solid surface is always contact to the fluid. So, if outside air temperature is T o a and surface temperature is T o. Inside surface temperature is T i of a wall, and inside air temperature is T i a then there will be heat transfer occurring from this also because there is a temperature difference. The heat transfer will be occurring from and heat transfer will occur from this to this as well, right? Now this heat transfer is both by convection and radiation both free and force convection, and that h we talked about it is related to that h.

So, this heat transfer can be written as this h i you know, h I have written into T I minus T i a. Similarly, here it will be h o T o a minus you know T o, air temperature minus surface temperature; where T o is the surface temperature of the wall, T I is the insides (Refer Time: 26:45) I mean, I am writing deliberately inside and outside. So, that we get familiar with what actually it is if you know. So, this this is h.

Now, what is this? This is the we call it surface conductance or coefficient of surface heat transfer surface heat transfer coefficient, and it is unit is watt per meter square. As we have seen already discussed this earlier. So now, if I want to find out the resistances of this one, you know it will be simply 1 over h o. Resistance of this fine layer l layer, it will be simply 1 over h o, because this is watt per meter square and temperature difference because you remember q is equals to you know q was equals to how much was it k delta T temperature difference you know delta T let me write divided by l. So, l over k is a resistance l 1 over k 1 l 2 over k 2 etcetera they were the resistances.

Now, here q is a function of h into delta t. So, 1 by h is a resistance. H is a surface conductance, 1 by h is a surface resistance. Resistance you know surface resistance. And this is been you know by linearizing heat transfer and all that that we have done, right?

So, when I take that into account and try to find out the Q, again then I will have h a T o minus you know this term also I should take into account, and h i this same heat is passing through this. So, I have to take account of that also. So, I will have this must be q must be equals to 1 by r T o minus T I. This we already we have done last slide we did that you know. So, q is equals to simply q by a into r, T o you know likes. So, q will be equals to Q capital Q is equals to.

Student: (Refer Time: 28:43).

T 1, or T o in our case it will be T o minus.

Student: (Refer Time: 28:51).

T i into a by r right a by r sorry a by r. So, that is how it is. So, I am writing the same thing here, I am writing the same thing here, 1 by r into a T o minus T I. And that must be equals to whatever is going out here and whatever, right.

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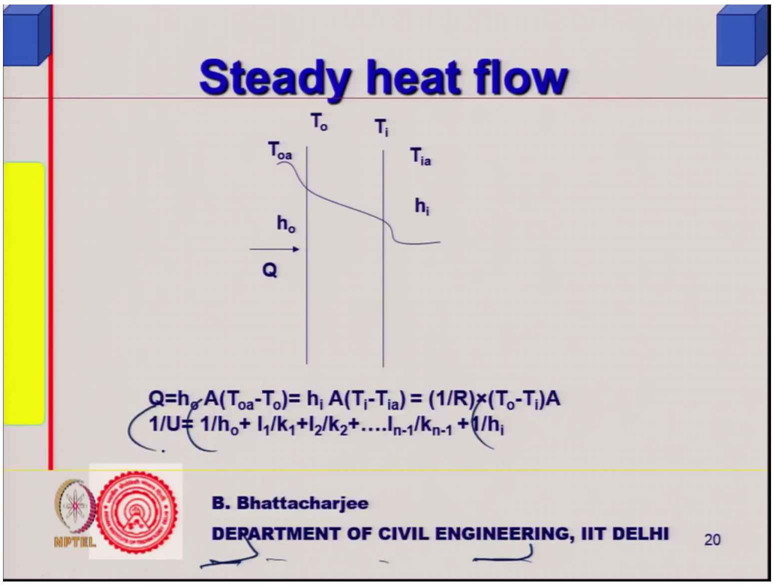

So, if I combine this like I did previously, yeah if I combine this I will write it previously, I will get 1 by h o plus l 1 k 1 etcetera, etcetera plus 1 by h i, right? Because equivalent resistance is this and equivalent resistance is this, for the surface layers and this, I call as 1 by u. And this u is called u value that is a matter of transmittance of the wall. That is a measure of transmittance of the wall, right? That is a measure of transmittance of the wall.

So, I think they are weird. So, we defined u and heat transfer steady heat transfer through the steady heat transfer through the wall will be given as u into a into delta T; where delta T is air temperature outside minus air temperature inside. Or air temperature inside minus air temperature outside. So, air to air temperature difference is delta T r into u A, because that is what is known to be me surface temperature would not be known to me; that is how we define u.