Energy Efficiency, Acoustics and Daylighting in building
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Lecture – 10
Heat Flow in Buildings (contd.)

So, we are looking you know we will continue from where we stopped in the last class. So, what we are looking at was u value for wall sin no in layered wall with each layer in series.

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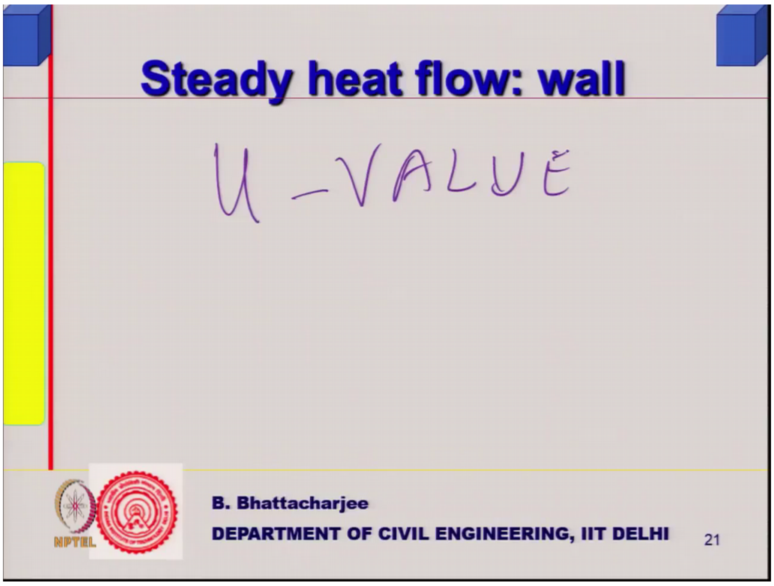

Now, let us look at layers in parallel layers in parallel; so, steady heat flow through wall and let us look at walls in parallel.

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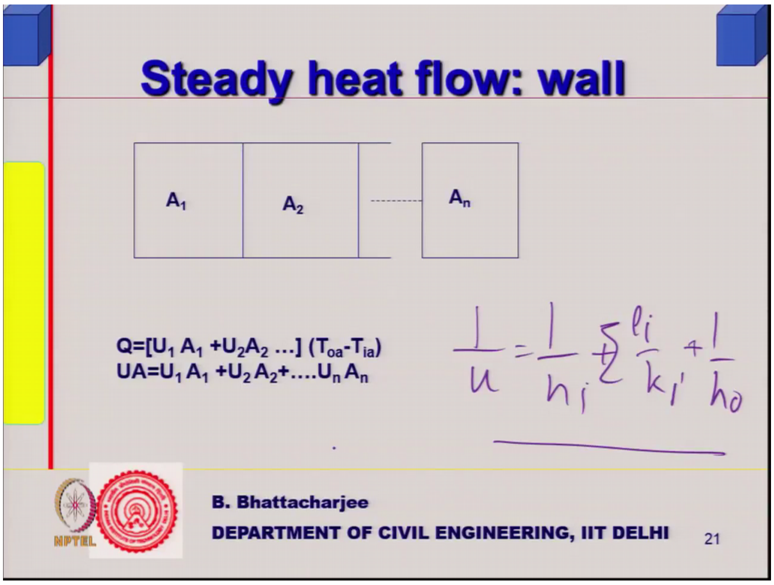

Suppose for example, if we will consider a room; it will have wall with window and another wall. So, if I consider six surfaces temperature; let us say outside is constant and inside is constant; temperature across the wall inside is constant outside is also constant. So, temperature across the wall is constant temperature gradient is same.

So, analogous to electrical circuits you know the potential across resistances are same, then it is basically parallel. So, in such situation the heat flow Q would be given by U 1 A 1; as you can see U 1 A 1; U 2 A 2 etcetera etcetera and all of them and this is a constant temperature difference across the wall, so you know. So, it can be written like this U A is equals to equivalent; U A is equals to U 1; A 1, U 2; A 2 etcetera etcetera U n, A n.

So, once walls are in or surfaces are in or you know the construction sections are in parallel, then it will be U 1; A 1. And we have seen earlier that 1 by u is equals to 1 by h i plus l; 1 by k 1 remember that you know sigma l i by k i and plus 1 by this is what we saw in the last class previous class, this is what we derived.

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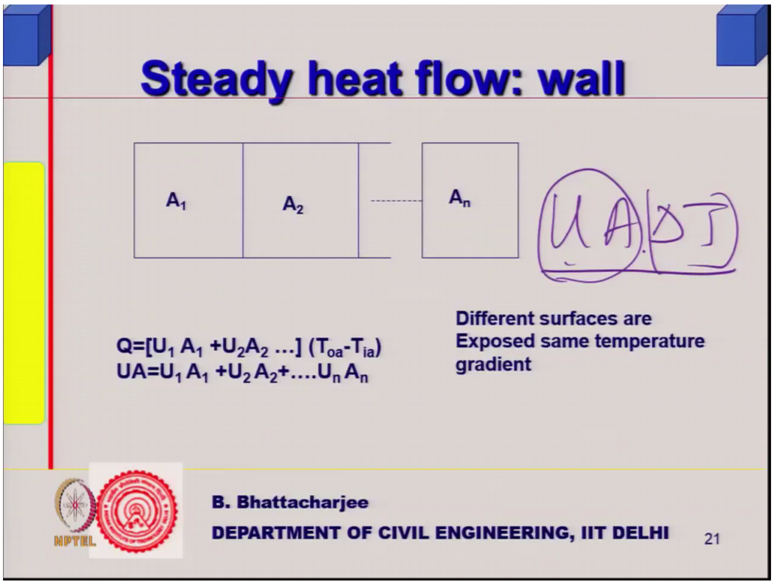

So, the heat flow through a wall or roof or a section; simply it will be given simply by U A delta T equivalent U A, you can say if it is in series then you for the series layered wall. And if many of them are in parallel and temperature difference across them is same you know you can write it like this; so that is what it is. So, different surfaces are exposed to same temperature gradient, this is a scenario; if they are exposed to different temperature gradient, then that was the formula 1 over U etcetera etcetera; which I just showed you one here.

Maybe we can go back and recollect the whole thing; if you remember you know you just recollect the whole thing.

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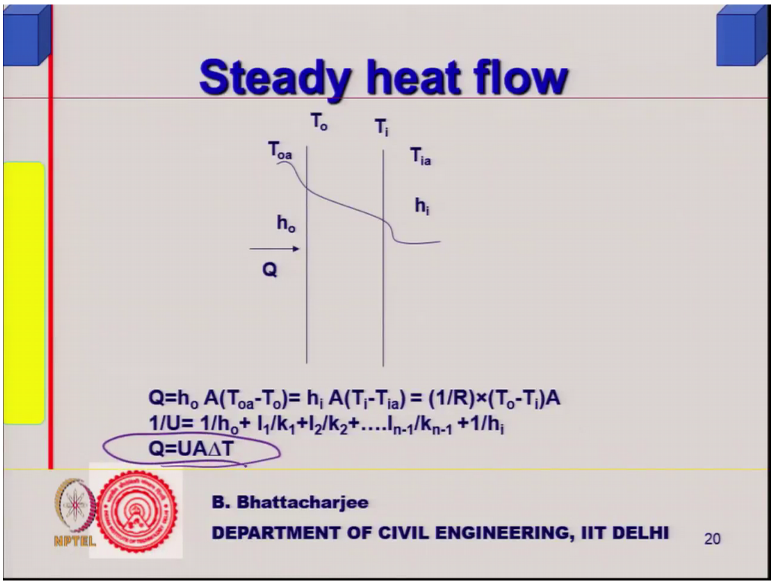

So, this is what it was and we derived this and we are saying that you know for Q is equal to U A delta T that is what it is. So, if you know that is what we derived earlier.

So, let us progress from here, but; however, external temperature is never steady, it is not constant particularly in tropical climates as we have seen. For example, we have seen hot dry desert climate; it is periodic you know it has annually periodic. But diurnally also; periodic daily also, it is periodic and diurnal fluctuation can be very large in hot dry desert climate.

That means, minimum to maximum temperature in a day can be significantly large, but its periodic; it varies periodic, it varies repeats itself after 24 hours and it so happens that you know like most of the human activity is also in a way periodic; you come to the class every day at 8'o clock because we adjust our life according to the 24 hourly periodicity.

So, but external temperature natures; external temperature is periodic even in warm humid climate. It would be periodic diurnal temperature variation may not be; so much compared to let us say hot dry dessert climate. But between the seasons it is; if there could be you know the; its periodic, but the amplitude might reduce with time.

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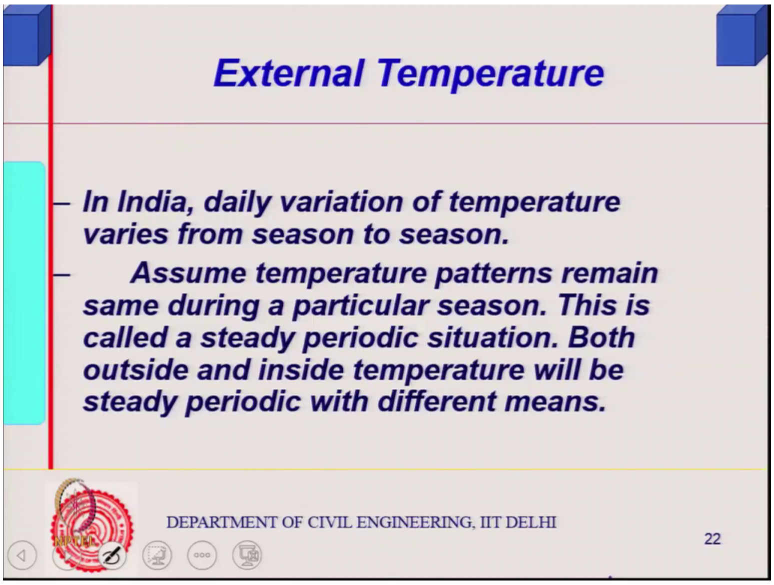

So, one can think in terms of this temperature variation varying from season to season. And during a season, we can assume the temperature remains same during a season given season temperature pattern remains same. That is yesterday's 8 AM temperature would be used likely to be same as today's 8 A M temperature and so on so forth; so, it is periodic.

So, this is basically a steady periodic situation; in a season it is periodic we call it steady periodic situation. Because period you know its amplitude is not changing every day, its pattern is same. So, both outside and inside temperature because whatever comes in whatever heat comes in during the day time, during the night; it will be dissipated out of the room.

So, therefore internally air temperature also will remain steady periodic; that means, its peak or amplitude will remain same right. Because it is not storing any heat only during the seasonal change of one season to another season, there would be storage or something. So, in a given season both inside temperature is same and outside temperature fluctuation is also similar.

But during the change of season; let us say winter to the summer, it is going transition period you know summer heat comes it was cool, then it starts to every you know envelope and everything building component everything starts absorbing some heat because its temperature gradually rises.

So, we are not looking at that situation; we are look at steady periodic situation in a given season.

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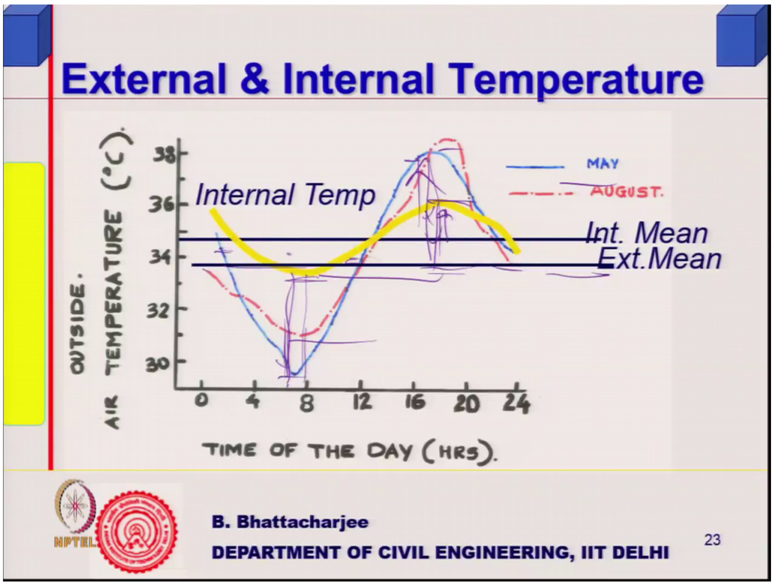

So, we can model this; so external temperature typically you know measured temperature. Let us say in one of the buildings are in our campus somewhere around 1985; one of the rooms; inside a room and outside the room. So, just outside the room we measured; one of my friend and course recess scholar at that time; so May and August temperature patterns are something like this.

So, you can see the periodicity; this temperature will be somewhat similar, this temperature; this temperature blue temperature during the month of May was something similar; he measured two times and the diurnal variation during August is this much; in May was something of this kind. So, it is a real time measurement temperature; time of the day it is showing, so, it is somewhat periodic.

So, we assume it to be steady periodic and if you look at the internal temperature which of course, is not measured, but here measured temperature it was something like this generally with a difference between this peak here and peak here; some difference between the peak getting shifted. And you can understand physically why does it shift? Because outside maximum temperature you were talking of temperature, we have not taken account of the radiation part of it and all those things temperature; inside temperature and outside temperature whatever it is.

Now, what will happen? The material, the construction will absorb some heat; then it will transmit that heat inside. So, there is a time delay what you call time lag or phase difference, as you call in electrical technology; something of that kind you know there is a phase difference there is a phase out of phase by some time; so we call it time lag.

So, that is it, so external mean is somewhat like this and internal mean is somewhat above. So, if you see the mean external for example, 25 degree centigrade, 45 degree centigrade are the peak temperatures. Let us say minimum and the peak temperature outside; 25 and 45, may be somewhat higher if it is receiving radiation and all that. So, what is the mean? 45 plus 25 making it 70, so 35 is the mean.

But if it is an unconditioned building and inside temperature fluctuation might start from around 33; might go to about you know depending upon what kind of room it is, maybe 34 even and 39 or 40; it might be inside, if it is a light weight or whatever it is depending upon the situation. So, the inside means tends to be somewhat slightly higher than the outside mean, inside mean tends to be somewhat higher.

However outside inside peak is much lower and you know this amplitude difference; amplitude is much lower and this is almost shown as a sinusoidal or cosinusoidal sort of function. But actually they are not; they are periodic, not necessarily a pure sin pure tone sort of pure sin or pure cosine function; so that is how actually outside and inside temperature vary.

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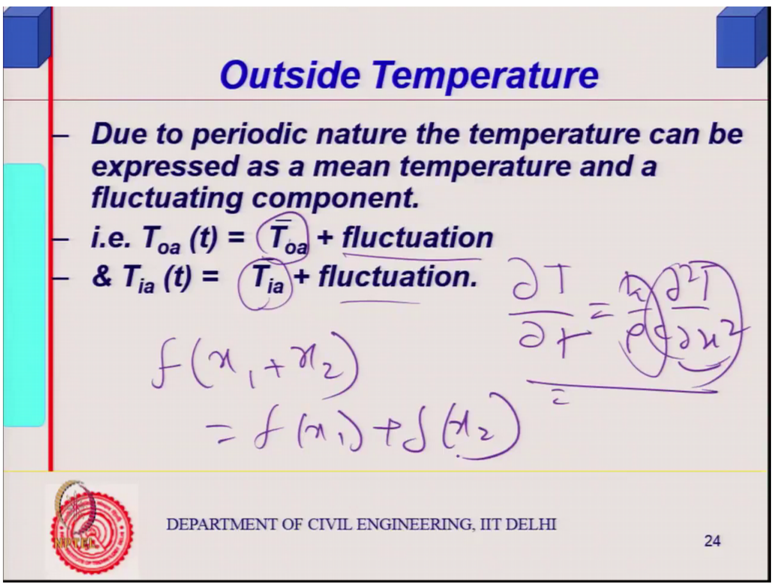

So, what we have observed that during steady periodic time; temperature can be expressed as a sum of the mean plus some fluctuation above it; which will be plus or minus and outside temperature also expressed in terms of some constant mean and plus and minus fluctuation.

So, we can actually mean temperature and a fluctuating component; that means, outside temperature if I call it T o a; t as a function of time, this is a constant value which is the mean T o a bar is a mean; plus the fluctuation, you know that is what we have seen; let me repeat that is what we have seen. I have a mean plus some fluctuation; I have a mean minus or plus or minus fluctuation.

Similarly inside mean plus or minus fluctuation; so both the inside and outside mean I can express some fluctuation which would be plus or minus depending upon the scenario, depending upon the situation. Similarly, internal one I can express in the same manner T i a plus and minus fluctuation and you see this is remaining constant.

So, I can find the effect of this two constant temperature and find out separately the effect of this fluctuation and sum it up. Because my system is linear; linearity principle is superposition principle is valid, when your system is linear. Material property is not varying with the field variables; that is your temperature in this case, material properties are not varying with the temperature; we assume they are constant.

Because if you remember your equation, it was something like this k over rho c; one dimensional heat transfer equation; which we derived some day earlier. And if this naught function or k over rho c we call it; alpha thermal diffusivity or I think that is the notation I might have used.

So, whatever the notation I have used; does not matter at this moment; we will use them again appropriately. So, if it is naught function of the field variable temperature; then it is a linear problem because there is no product involved. If it is functional; so, that will material non-linearity; which is the case when temperature variation is very large. Also you have linearized the boundary condition like radiation boundary, which was T to the power 4 and we have linearized it.

So, there is a linear equation as long as this material properties are not function of temperature then you can superimpose. You can superimpose the effect of the mean over the effect of fluctuation and sum it up. If you know; it is something like as you can understand, if it is you know four f x plus x is equals to f of x 1 plus f of x 2 that is superposition principle; you do use it in structural engineering as well.

Effect of a given force; deflection due to a given force plus deflection due to another force, you can sum it up if modulus of elasticity you know its linear elastic material. So, that is something analogous to this, but non-linear; so we are assuming this linear and therefore, we can superimpose this.

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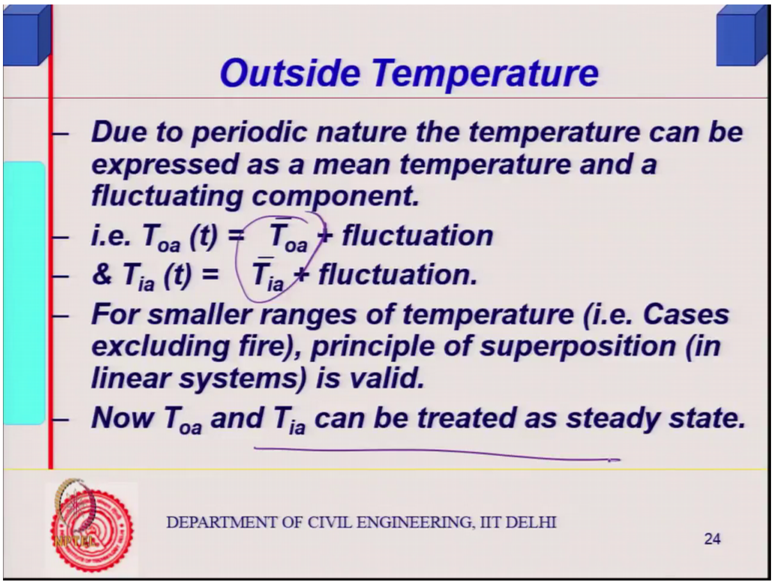

So, for smaller ranges of temperature; cases excluding fire principle of superposition is valid and therefore, we can sum up the effect of the two. And this can be, if this is a constant not function of time at all, we can treat that as steady state. So, find out the steady state heat flow and find out the fluctuation heat flow due to fluctuations; sum it up you will get the total heat flow or we can manipulate this; how we do it, we will see that, so that is it actually.

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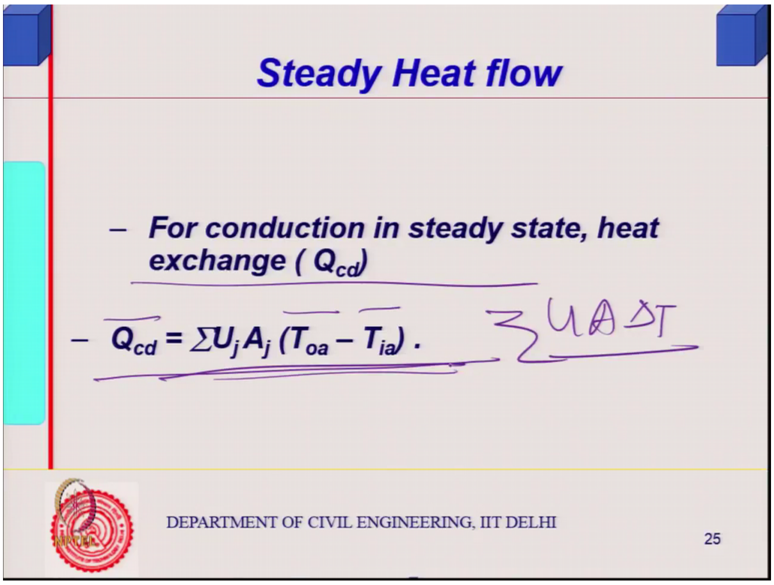

So, for conduction steady state, heat exchange Q c d therefore, I can come back to my formula. We said that conduction heat; mean we can look into mean heat flows so, T o a bar minus T i a bar; Q c d this is; I can conduction heat flow. Steady state heat flow, we have said it is U A into delta T steady state; that is what we have seen just few minutes before and previous lecture.

That in case of steady heat flow it is Q A delta T and you have number of walls you sum it up for this and that is what you get. So, U A; A i because walls and roof and ceiling and everything, all the sections put together, you can sum it up. So, that is the conduction steady state conduction heat flow.

And now we can look into steady state; heat flow by other mode; convection, but that is your ventilation convection here is not really exactly the; is the circulation of air; ventilation or infiltration.

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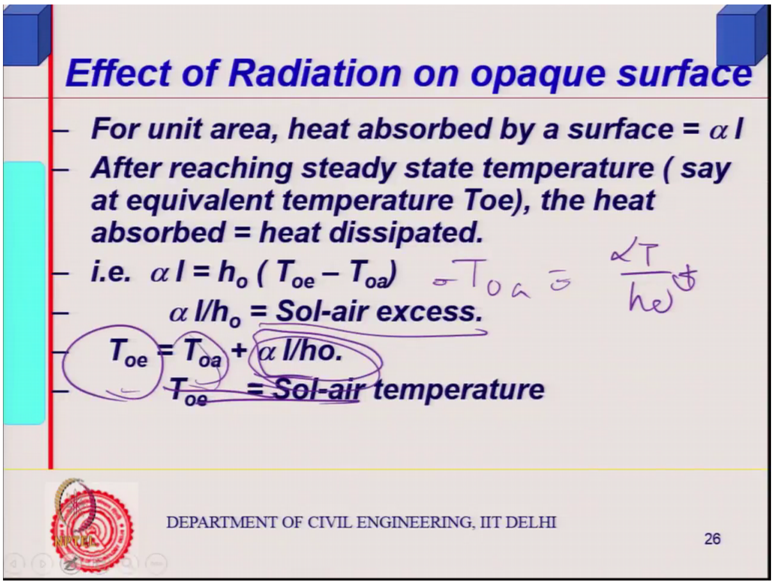

And radiation when it comes to an opaque body; then what we do is because I said if you remember the modes of heat transfer we looked into; there are conduction because of temperature; if outside temperature and inside temperature difference and radiation falling on opaque bodies, like rooftop.

Now that causes heating of the rooftop itself and that is then transmitted inside by conduction process; so let us look at this one. Now if i is the intensity of radiation, absorptivity of the surface is alpha, absorptivity is a ratio of heat absorbed divided by heat incident. That is what we defined earlier, we talked about this sometime earlier emissivity, absorptivity and all; so this is the amount of heat that would be coming in; that amount of heat that would be absorbed by the surface.

Suppose it reaches a steady value; you know it is a constant steady i; it is not fluctuating, I mean which is our assumption because suns position will change, radiation will change. But if I take the mean radiation, mean would not change; mean diurnal because yesterday's, today's; everyday mean will remain same; that is what I am saying I separate the mean and the fluctuating component.

So, if I consider the mean; the mean will remain same because in a steady periodic situation. So, if I take mean and assume that my intensity of radiation is constant, so constant radiation is coming in; this will be absorbed by the surface. And it will attain a steady condition; that means, its temperature will effective temperature around the surface will also attain a constant value.

So, after reaching a steady temperature say equivalent temperature T o e; we call it T o e T outside environmental temperature. The heat absorbed must be equal to heat dissipated, you see it must be receiving that heat; part of it, it will be dissipating out; rest of all will cause its increase in temperature. Because when its temperature increases, temperature of the surface increases because the radiation coming in; it will start dissipating to the or heat will be transferred by convection and radiation or surface conductance to the surrounding air; because surrounding air is at lower temperature.

Surface is getting an equivalent temperature which is higher that is because it is receiving radiation. So, once its temperature increases; it will start dissipating this heat to the surrounding environmental which temperature is lower. So, we take that equivalent temperature of this surface as T o e and alpha I must be equals to this is what is coming in; must be equals to what is going out. The going out is T o e minus T o a, where this is the surface temperature; environmental equivalent temperature minus outside air temperature; h o is the surface conductance.

It will receive the direct radiation multiplied by the absorptivity and it will radiate or transmit back to the surrounding air, which is at lower temperature; T o e, T o a. So, T o e minus T o a; into surface conductance because we said that the surface transmits heat to the surrounding air by that. So, equivalent surface conductance we have taken; linearizing the radiation and convection heat flow (Refer Time: 19:16) free convection, so this is what it is.

In other words, the T o e can be expressed like this; T o e is T o a plus some additional term. T o e can be expressed like T o a minus some additional term; T o a because from this simple a algebra T o a. So, equivalent temperature is somewhat higher and by this amount compared to the outside air temperature and this we call as sol air excess; excess temperature over the air temperature, so we call it sol air; sol air radiation; so, sol air excess and this temperature we call it sol air temperature.

So, this we call as sol air temperature; this we call as sol air temperature, this we call as sol air temperature and this we call as you know this is sol air excess this is sol air excess.

So, now I can take this temperature and then what will be the heat transfer inside? It will be if the inside temperature is T i a and this is steady value; let us say it is all steady, you know I have taken I bar mean temperature this is mean everything is mean; then how much will be the heat transfer heat transfer inside under steady condition? When steady radiation is falling onto the surface? This equivalent temperature of the surface outside I can take it, minus the inside temperature into U into A; that is what it is.

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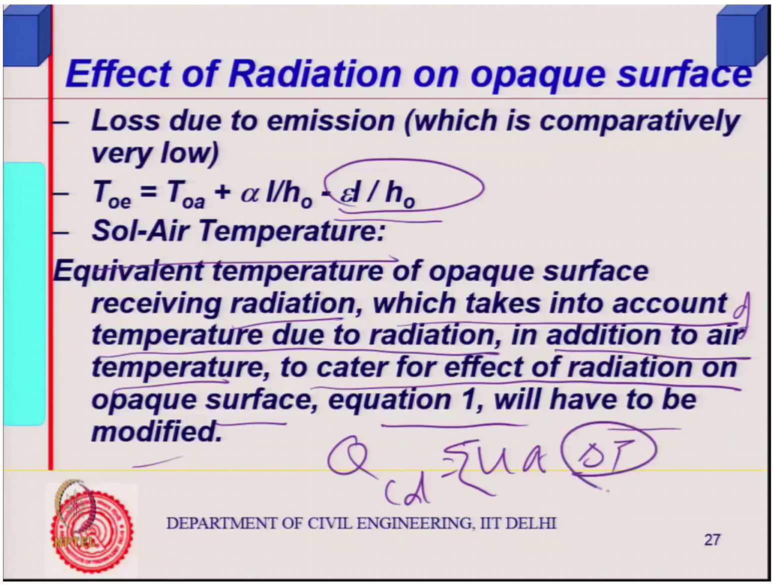

So, I do and if there is some loss; long wave radiation loss, then a more general equation is of this kind. Sol air temperature; suppose the surface is heat it is radiating back to outer cosmos which is as much lesser, but this amount is very small. In night; it is the only one. So, night surface loses it, but daytime; the amount of it received is much higher and this component would be relatively small.

So, long wave radiation losses are less in the daytime; night it is high, but we are not interested in night; this quantity is generally of the order of around 100 watt per meter square or something of that kind. So, we can neglect it actually and but general more general equation will be of this kind. So equivalent temperature; so this sol air temperature we define like this.

Equivalent temperature of opaque surface receiving radiation, which takes into account of temperature due to radiation in addition to air temperature; to cater for effect of radiation on opaque surface equation 1 will have to be modified etcetera etcetera; which is the equation 1. Equation 1 was U a; c d; Q c d is equals to U a sigma U a; this equation which I have given delta T.

So, now delta T will get modified if you want to take into account of radiation because some surfaces will receive radiation; some other surfaces may not. So, I have to separate two parts and corresponding, i going from 1 to n and maybe j going from 1 to m, where m surfaces are receiving radiation, n surfaces are not receiving radiation; so, in my temperature differences could be different.

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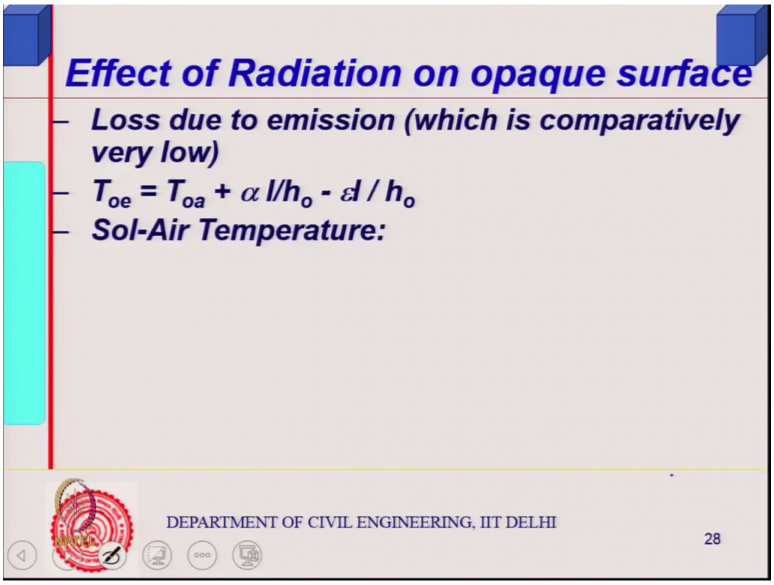

So, that is it; that is how we take effect of radiation loss due to which is comparatively very low as I said and therefore, we neglect this part. So, that is what is basically how we take care of sol radiation and we take care of radiation and radiation falling on to the surfaces.

So, we will look at the convection part a little bit later on; let us look at how do you handle the unsteady state part? How do you handle the unsteady flow through that wall? Then we will come back to convection. So, convection or ventilation heat transfer which is simple, but unsteady flow through the wall is somewhat little bit involved because now I am looking at a dynamic situation or not steady situations.

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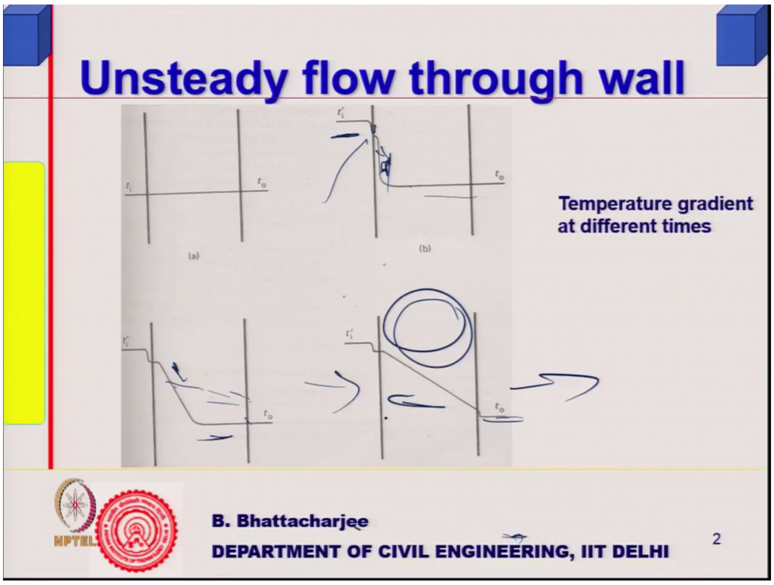

Now suppose, I consider a wall initially at constant temperature then suddenly I increase the temperature to T i. So, initially the outside air temperature I have just increased to T i. So, first it will heat up the surface and temperature pattern will remain like this.

After some time temperature here will increase, but still it will remain like this. And further if I wait for 5-6 hours or maybe 10 hours in a wall, then you will find that there is a temperature gradient existing; and here of course, outside temperature whatever it is. Why? Some heat is stored by this element here; it stores submit its own temperature increases.

Temperature is a measure of sensible heat, so you can sense this and as the heat gain has occurred the wall has actually gained some heat; its temperature will increase. Now heat flow from this point to this point would depend upon the temperature gradient existing there. Similarly, temperature gradient you know mean temperature gradient existing here so; obviously, this point is at lower temperature and heat flow will occur in this manner.

So, as we have seen from Fourier law that whenever your heat transfer is occurring; you know constantly I am supplying heat here because I have raised this temperature. So, I must be supplying some heat to keep this temperature constant. Now this heat would be transferred to the other side and we know that for flow of heat we need a temperature gradient.

So, this temperature difference must exist and here this temperature is to outside; so, after sometime it will become steady. What I am trying to say is; that this element, the wall element or construction element stores the heat because its own temperature has increased, so it stores the heat. Now if this is changing suddenly I reduce it down again then some heat flow reverse direction to T 2 docker.

So, the stored heat it will dissipate; so, heat storage comes into play whenever I am looking at dynamic situation; non steady state situation, unsteady state flow. While in steady flow; what temperature remains constant. So, whatever heat came in must have gone out; that is what we assume that whatever comes in must go out.

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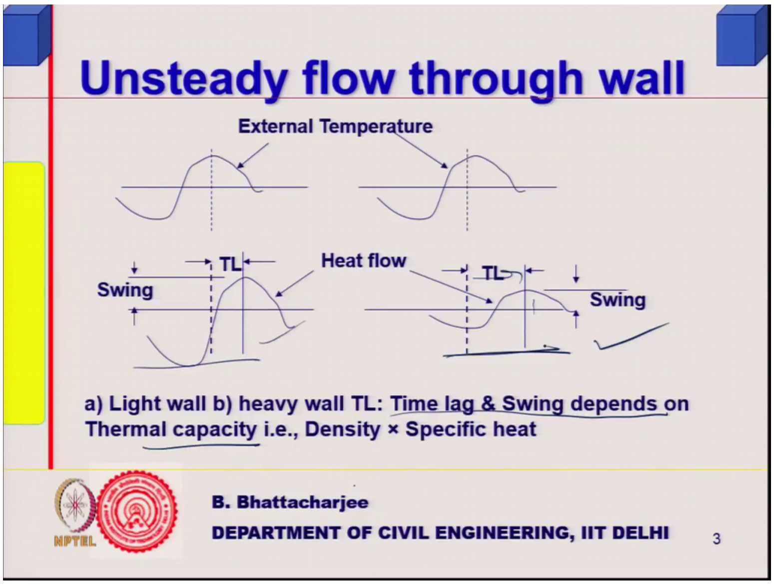

So, Q is constant in and out here it is not same and we derived that conduction equation earlier if you recollect. So, follow it up from here in our case of course, the temperature is periodic and you have something like this you know that is what we have seen temperature is periodic.

So, external temperature and we said that there is a shift time delay peak gets delayed. And even this fluctuation is somewhat lower; temperature or heat flow outside external temperature internal heat flow that there is a swing there is a swing about the mean. And this time delay or the amount of swing depends upon the construction of the wall. Now this is for a you know; both these cases, so this is for a light wall, this is for a heavy wall.

Why? Heavy wall will store lot of heat before it starts dissipating to the other side. You know, if I have a thick wall whole of it has to be heated; before it starts dissipating to the other side. So, the time difference would be more; not only that it also will have, you know it will transmit also less.

So, the swing is relatively more; so this is for heavy wall and this is for light wall. Time lag and swing depends on thermal capacity, thick wall and if rho c it can store more. Now what is specific heat? It is the amount of heat that will be stored in per unit mass of the body for 1 degree temperature rise. And volumetric heat capacity is basically rho into c.

So, rho c; that is what we have seen k over rho c, that is volumetric heat capacity that is the amount of heat that will be stored in unit volume of the material. So, heat storage is related to thermal capacity that is what we are saying, so density into specific heat thermal capacity. So, that is physical explanation of; why there is a difference? Now let us see; how we numerically model it? So, we will numerically model it, now any question if you have will look into this.