Building Materials and Construction
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Module - 10
Lecture - 5
Walls: Functional Performances

If you recall the way beginning, we said that the various performance you know the various performances, we actually expect from building elements structural elements our not only the safety and load carrying capacity or resistance to load, but then we also need to look into some of the other functional performances. So, we looked into their resistance to load of masonry construction.

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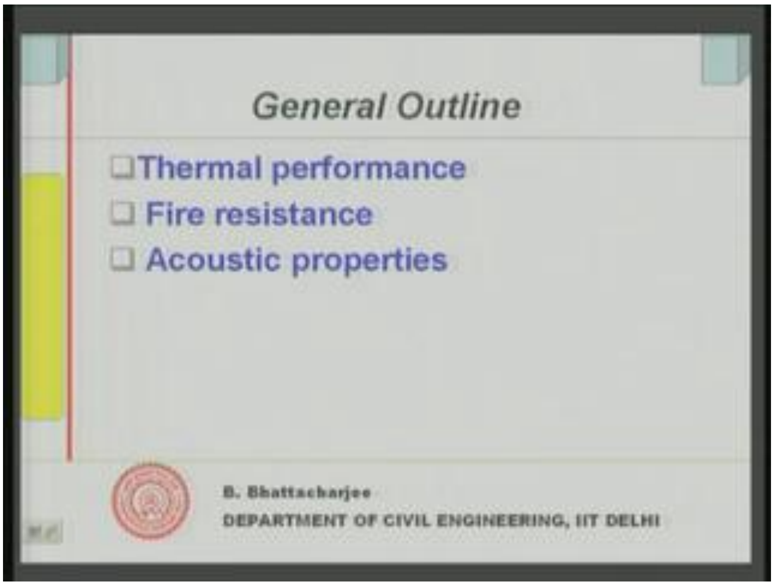

Now, we will look into the functional some of the functional performance and issues of durability. Today of course, we will look into some of the functional performances and these performances are thermal performance we will look into… We will look into fire resistance and look into acoustic properties or acoustic performance some of it we will try to deal, right.

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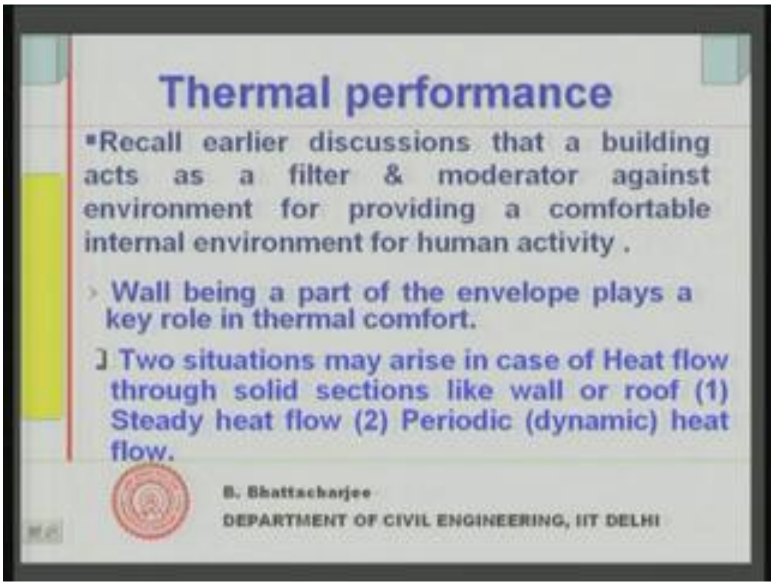

So, first let us start with thermal performance. Now, let us look into a little bit of basics of the thermal performance before. So, lets you know if you again just try to remind you that, if you look back to our earlier discussion that a building acts like a filter and the moderator against environment for providing comfortable environment internal environment for human activity; when you define right, in the beginning. if you remember the performance functional performances of building you know. So, we said that it acts like a filter and moderator against environment and provides a comfortable internal environment for human activity.

So, building must act as a moderator for comfortable you know internal environment for human activity. So, you should block whatever we do not want and allow whatever we want. For example it should stop noise coming in you should not you should stop heat coming in and filter it out, but allow the visible light to come in and so on, so forth which. We have discussed right, in the beginning. So, building must act as a filter or moderator. Now, wall being part of the envelope plays a key role in thermal comfort as well as in other comfort as well. For example acoustic comfort right. So, thermal comfort right now we are looking at. So, it plays a key role in thermal comfort.

Now, when you look at heat flow into buildings 2 situations arise, one is steady heat flow and then other is periodic heat flow, out of which periodic heat flow. In fact, is a special case of dynamic heat flow where there can be other kind of sort of heat flow etcetera, but our situation is periodic heat flow, because you know temperature variation temperature variation daily temperature variation, if I look at it is more or less periodic in nature. So, therefore, we look into 2 situations some definitions, we will talk about. Then of course, we will go into the actual details of the properties of the wall.

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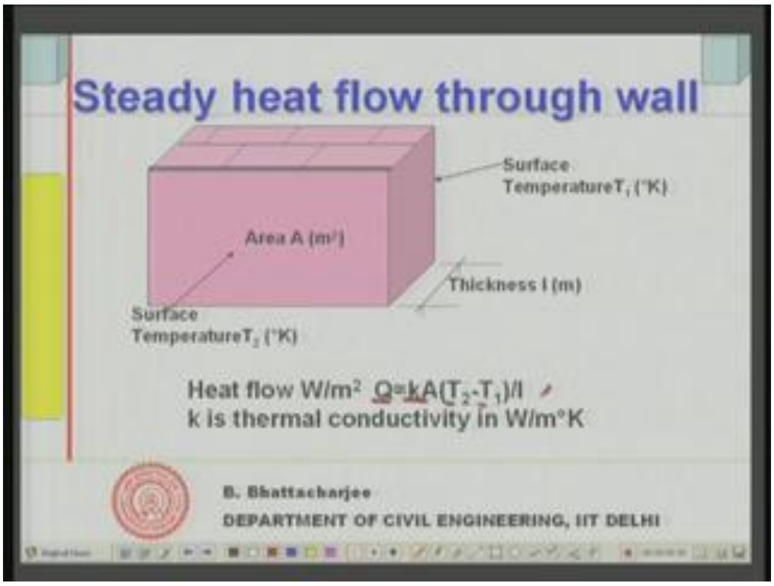

So, if you see steady heat flow through wall let us consider, it a situation where I have where I have a wall, let us say of thickness L you know, this is thickness L. This is the thickness. Then surface temperature here is T 2 and here is T 1 and this area of this wall portion of the wall, I have taken is A and heat is flowing from this direction to this because this is at some temperature and this is at some other temperature. Then from simple basic law of physics, we know that heat flow through the wall of area A would be given by Q would be given by given by you know it will be given by Q equals to k A into T 2 minus T 1 divided by I.

Q will be heat flow, in watt per meter square you know rate of heat flow through this will be given as rate of heat flow in watt per meter square will be given as k into area into T 2 minus T 1 divided by L; you know we know from basic law of heat transfer that amount of heat passing through. This area of wall is proportional to the temperature gradient that is the difference in temperature T 2 minus T 1 divided by L is the thickness. So, it is proportional to T 2 minus T 1.

The temperature difference inversely proportional to the thickness L and is also directly proportional to area A. And k is constant of proportionality, which you call as thermal conductivity and its unit is watt meter degree centigrade watt per meter degree centigrade. So, that is that is a that is the you know rate of heat flow under steady condition when T 2 and T 1 are maintained constant. Surface temperature T 2 and T 1 is maintained constant right. So, this is we can define some properties of the wall with respect to some steady flow.

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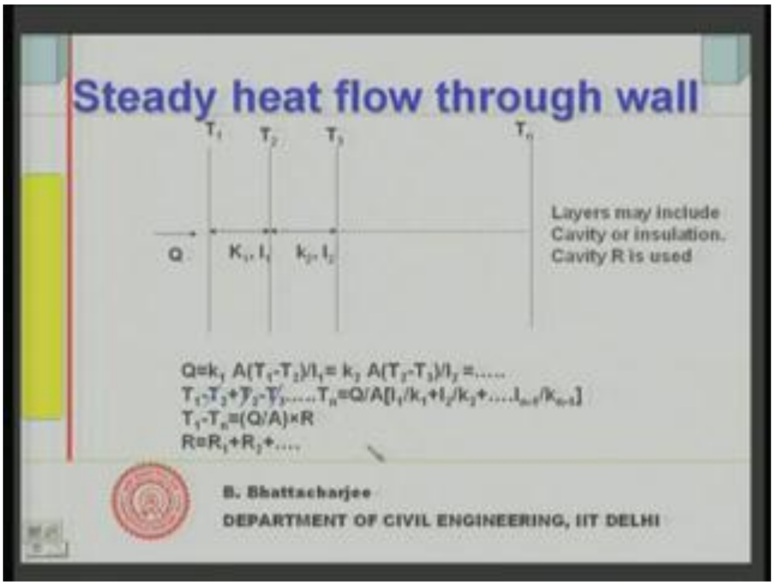

Although we know that actual heat flows in buildings is far from being steady because outside temperature is not constant and neither inside temperature is constant unless, it is maintained constant. So, either continuous supply of it or withdrawal of it. That is if you have when heating ventilation and air conditioning system in the building or air conditioning system, in the building then you can have a constant temperature within otherwise the temperature may not be remaining constant, in an unconditioned building it is not constant. So, if it is not constant and also outside temperature is not constant steady state heat flow in reality does not exist, but then we can unless we understand the steady state property or define certain properties with respect to steady state it becomes difficult to look into the periodic heat flow.

Generally the properties of the material we define some properties; we define with respect to steady heat flow and some other property, with respect to periodic heat flow.

For simple understanding although actual calculation of heat flow, into building in the context of the energy efficient building is much more complex. Several software’s are available, but at the moment, we are not looking into those situation we are simply trying to look into some properties of the wall through; which you can qualitatively understand how good my wall is or how bad my wall is.

So, 1 of the properties I will related to the steady heat flow and let us see what it is. Let us consider again a wall layered wall. We have seen that Q is equal to k A T 2 minus T 1 divided by L in the previous slide that expression we have seen. Now, supposing I have a layered wall, I have first layered where the temperature here is T 1 and here is T 2. Temperature here is T 1 and here it is T 2 and then T 3 etcetera up to N. So, actually there are 1 2 3 up to N minus 1 layers and every layer has got a thermal conductivity k 1 small k 1 it should be L 1 small k 2 L 2 etcetera.

So, thermal conductivities are k 1 k 2 k N minus 1 and thickness of these layers are L 1 L 2 etcetera. Then since my heat flow is steady it means that all temperatures are constant. Therefore the amount of heat coming in here must be going out from there as well. Otherwise what would have happened, if this was not constant the amount of heat coming in and minus the amount of heat going out, if it is not same that should be equals to 0 you know Q 1 Q coming in here must be equals to Q going out.

Otherwise the balance heat would have gone on rising the temperature of this layers, but that is not happening, which means; that heat coming in here must be equals to heat going out. So, in steady condition heat coming in heat entering into the wall is equals to heat going out and under such situation same amount of heat would be passing through each of these layers. So, I can write this equation which I wrote earlier that that Q 1 Q equals to, because heat flowing through each layer is same equals to k 1 into A area is same again area of all these walls are same into T 1 minus T 2 divided by L 1 k 2 A 2 T 2 minus T 3, the second layer and so on so forth.

For all the whole layers and if I continue this you know, if I further rewrite this T 1 minus T 2 rewrite an expression for T 1 minus T 2 similarly T 2 minus T 3 etcetera and add up. Then I get T 1 minus T 2 plus T 2 minus T 3 etcetera last term will be T n, will be equals to Q by A you know every time Q by A within bracket then L 1 divided by k 1 divided by since I am writing taking L 1 divided by k 1 plus L 2 divided by k 2 etcetera

L n minus 1 divided by k n minus 1, because I am writing T 1 minus T two. So, I will take the Q 1 on this side A on this side.

So, it will be Q by A k 1 divided by L 1 and so on, and sum up. So, many terms when we sum up all the temperatures T 1 minus T 2 plus T 2 minus T 3 etcetera. So, I can write this equation and you can see that all this terms of T 2 T you know all internal temperature like T 2 T 3 up to T n minus 1 all this will get cancelled, because you will have T 1 minus T 2, in the next time we T 2 minus T 3 and the next term we will have T 3 minus T 4 etcetera. So, you will have a negative term first negative term from first layer, but a positive term of this temperature T 2 from the second layer.

Therefore all such internal temperatures cancel leaving me T 1 minus T n equals to Q A into this l 1 by k 1 plus l 2 by k 2 and I write all of this equals to R. So, if I write all of them equals to R then Q T 1 minus T n can be written as Q by A into R where R stands for R 1 plus R 2 plus etcetera; you know where R 1 is equals to l 1 by k 1 and R 2 is equals to R 1 is equals to l 1 by k 1 and R 2 is equals to l 2 by k 2 etcetera. So, as you can see this is nothing, but resistance you know 1 over this is thermal conductivity or conductance; l 1 by k 1 is a kind of resistance right resistance of heat flow.

So, that is what it is. So, these are resistances of individual layer and these layers are in series, I can sum up this resistances to get the overall resistances and Q over A multiplied by the overall resistances is T 1 minus T 2 T n.

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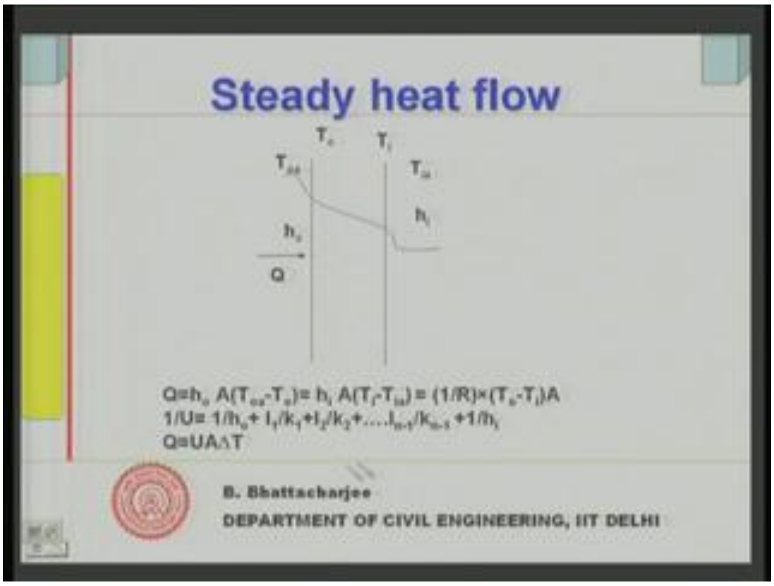

So, this is the first observation or first equation we get and from this we can define some properties, but let us look into the situation. So, far we looked into surface temperature, but actually surfaces are now exposed to never exposed directly they are always surrounded by fluids there in air. So, wall is in air roof etceteras slab they will be you know they will also be in air.

So, now air to surface heat transfer that takes place through convection and radiation. That takes place through convection and radiation. That takes for example, here from air to say t oa is the outside air temperature T o is the surface temperature T i is the inside surface temperature and T i is the outside air temperature. You know this value is T i a this value is T o a.

So, how the temperature profile will look like, there will be sudden drop here. Then of course, this if this is an homogenous wall this will be uniformly reducing to T i then again there will be a sudden drop. Now, from here air to this surface the heat transfer takes place through conduction and radiation It also depends upon velocity it also depends upon velocity of velocity of velocity of air depends upon temperature differences etcetera, but what we do is we actually express it in terms of an equivalent conductance term called surface conductance’s h o and h i.

So, these are called surface conductance’s. These are called surface conductance’s you know h i and h s are surface conductance’s and they are in their unit is in watt per meter square. Their unit is in watt per meter square. Their unit is in watt per meter square. So, these are surface conductances and their units are in watt per meter square. They represent an equivalent k over l, equivalent k over l for a surface layer. So, now I can write therefore, equivalent k over l I said. So, their resistances 1 by h which is the unit of this ones are h i is what per meter square watt per meter square you know degree centigrade.

So, they have watt they are in watt per meter square degree Kelvin and you know these values roughly for outside walls usually around 12. Order of 12 per 5 watt per meter square degree centigrade or degree Kelvin and inside is around 8 or walls. So, in anyway; so then we can consider these 2 as separate layers and you can write same expression that you have written earlier that is Q is equals to h naught since the heat flow from here and through the wall and through the outside surfaces are same I can write h naught into A T o A minus T o h i a T i a minus T o is equals to 1 by r T o minus T i into A.

You know just repeating the previous expression, because this has got a resistance of R. So, 1 by R into T o minus T i into A is equals to Q that you know from the last expression last slide expression and same thing must be equals to h i into A into T i by T a because this we have defined as watt per meter square. So, multiplied by meter square into per temperature difference and this how the expression should be. So, then I can write this whole thing by putting an equivalent term like this, I did earlier.

Supposing I did you know I sum up T o minus, I just add up find out expression for T o minus T A, I find an expression for T o minus T A, I find an expression for T o minus T A, I find an expression T o minus T a T o minus T A, I find an expression for T o a minus T o. I will get it as equals to Q divided by h naught A. Similarly, I will get an expression for T i minus T i a and if I sum it up like I did earlier and also for this, if I sum this up temperature that is sum up T o A T o A minus T A plus T A T o minus T i plus T i minus T i A. If I do this exercise I did before I will get an expression like this Q equals to u into a into delta T where delta T is nothing but T o A minus T o A minus T i A and I will get an expression of U A delta T, where U is given by 1 over U is given as this expression. I did the exactly the same exercise which I have done in the previous slide.

So, I will get U and this U is called this actually thermal transmittance or U value and in steady state you can show that Q equals U into A delta T. Now, you see U and A are the properties of the. U and A are the properties of the wall properties of the wall material delta T is of course, the temperature difference. So, these are the properties of the wall material. So, higher this value of U more will be the heat transferred for the same temperature difference and this is an important property of the wall. This is an important property of the wall U value. This is an important property of the U value less is the U value better is the insulation. Better is its thermal property.

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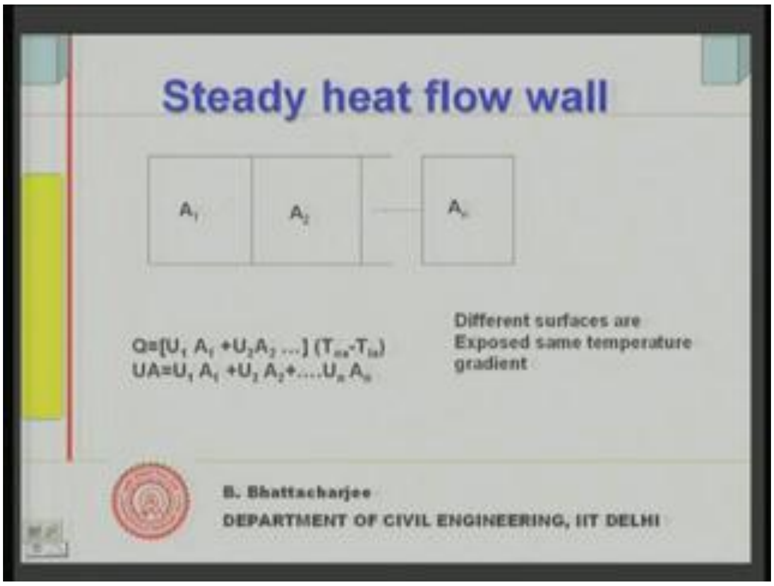

So, this is the steady state properties of the wall and 1 can determine this through various calculations using the formulas that I have given. Supposing, I have walls in parallel several walls several surfaces are there which are in parallel like A 1 A 2 up to A n then total heat flow heat flow through each of this wall and they are subjected to same temperature differential T o A minus T i A. They are subjected to same temperature differential T o A minus T i A then overall heat flow through this set of surfaces. All this surfaces which are parallel to each other will be given as U 1 A 1 plus U 2 A 2 etcetera multiplied by. So, total U of the all of the system would be overall many surfaces which are in parallel will be given as U 1 A 1 U 2 A 2 and U n A n.

So, therefore, U value you can see is an important property of the walls and it depends upon thermal conductivity of the materials in the wall if there are several layers thermal conductivity of the several layers will be there right. In this case different surfaces are exposed to same temperature and these U values of this you know U values of each individual wall you can find out. And since their areas are known overall U 1 can find out, when it is layered material, you can have various layer including cavity or insulation including cavity or insulations. Thermal conductivity of the cavity and insulations all are important and you can find out using this formula.

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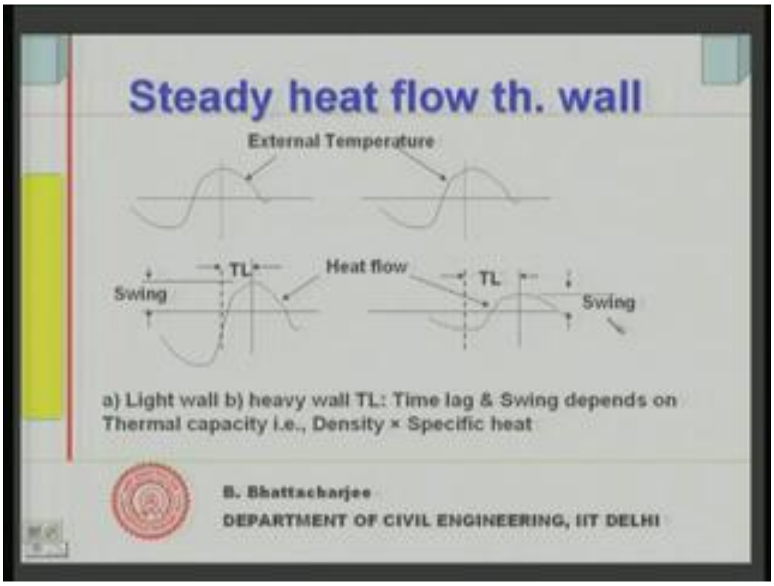

So, U value is important because U value tells us how much heat will flow through the wall how much heat will flow through the wall, right. So, now let us look at periodic heat flow through the wall. Periodic heat flow through the wall, we will look into periodic heat flow through the wall, but before that just 1 more minute.

So, if I put an insulation inside since U 1 over you know U is 1 over U is basically l 1 by k 1 right. So, U is actually proportional to thermal conductivity. If the thermal conductivity is less of any layer it will show you better insulation or less Q value. If it is cavity wall cavity resistances are known and one can put the cavity resistances in calculation and find out. So, U value is an important property of the wall and U values can be calculated and anyway more details into this is not possible for us.

So, lower thermal conductivity of the wall the bricks and the mortar and combination would ensure that I have lower U value and less heat flow into the. Now, let us look into unsteady state heat flow. You see we can look into swing heat flow swing. This is unsteady state heat flow or periodic through the wall or periodic. Actually what we are looking at is periodic heat flow you know through the wall. Now, temperatures say if this is my outside temperature they vary one can approximately this is periodic.

If today morning, I had temperature at 8 am, I have a temperature let us say: is something like 27 degree centigrade in a given place in a given tropical climate then it is expected that tomorrow 8 o'clock again we will be in same temperature of course, except for when season is changing. So, which means; that my temperature is periodic my temperature is periodic.

If it is same temperature I will see again and same temperature, I will see again and so on, so forth. In a way you can call it as periodically varying. So, f t is equals to f t plus some time period. So, after 24 hours t plus 24; normally this is what is situation in 1 can approximately assume that way. So, if you have a outside temperature periodic temperature right this is what is periodic heat flow. Let us see what happens when I have such heat flow. Now, situation would be something like this. If this is my external temperature the wall through the wall the heat flow into the building will not take place instantaneously.

For example, the peak temperature occurs around 3pm in most of the places, I mean; in tropical countries because our day is in summary days such usually 3pm 1 would possibly peak outside temperature around 3pm, because 12 noon local time is the maximum time, I am talking about local time not the Indian standard time, 12 noon local time will have a maximum radiation received over the surface. So, around 2 pm 3 pm we will have the peak temperature outside temperature. Peak outside temperature 1 would find around you know around 2 pm or 3 pm and that is the time.

Now, supposing I have a wall through the wall the peak heat flow through, the wall will not be exactly at 2pm, but it will be sometime later because wall will absorb the heat and then radiate heat part of it will radiate outside, but part will go inside. So, peak heat flow will differ. There is a time difference between the peak heat flow and this time difference we call as time lag. We call as TL which is time lag I mean; short form we call it time lag or phase lag. Then the swing inside also will be will not be same swing as outside. It will be different.

Now, consider 2 types of wall. This is the same you know 1 is a 1 is a 1 is a heavy wall 1 is a light wall. So, this 1 is a light wall. In the light 1, light wall you will find this time lag is less, because it will absorb less heat and the swing also will be relatively high, but if I have a heavy wall this is a heavy wall it will absorb a lot of heat and radiate it much later. So, for example, it might absorb the peak outside temperature somewhere around 2pm, but inside heat flow might take place somewhere around you know 6pm,8pm 10 and even something like 2am 12 hours of phase, 12 hours of time lag.

So, this these properties are important where diagonal variation is very high where in desert environment where, it is you know desert in hot dry desert sort of climate diagonal variation temperature variation between the day and night is very high, I mean; early morning 1 may feel even cold. So, in such situation if, I use a highly thermal mass large thermal mass of the wall heat flow will be differed to time when actually you need heating on the, because early morning temperature makes it we feel a little bit cold.

So, if I have sufficient time lag I use a heavy mass heat flow will be you know peak heat inside will be much later. So, I did a high thermal lag in desert sort of climate and this can be obtained from heavy wall. So, TL is time lag and swing depends on thermal capacity which is a property of density and specific heat. So, density specific heat and thickness of the wall as well. So, thermal capacity and thickness of the wall; so both specific heat and density product that is very important, I should have a heavy mass and thermal mass of the as it is called thermal capacity and thickness of the wall. You can feel it.

Thickness thick wall construction is preferable in desert climate in unconditioned building of course, in condition building also it will be useful, if it is 24 hour condition, but insulation has got a big role in energy saving and energy efficient building. So, this is what is steady, and unsteady state heat flow thermal performance right.

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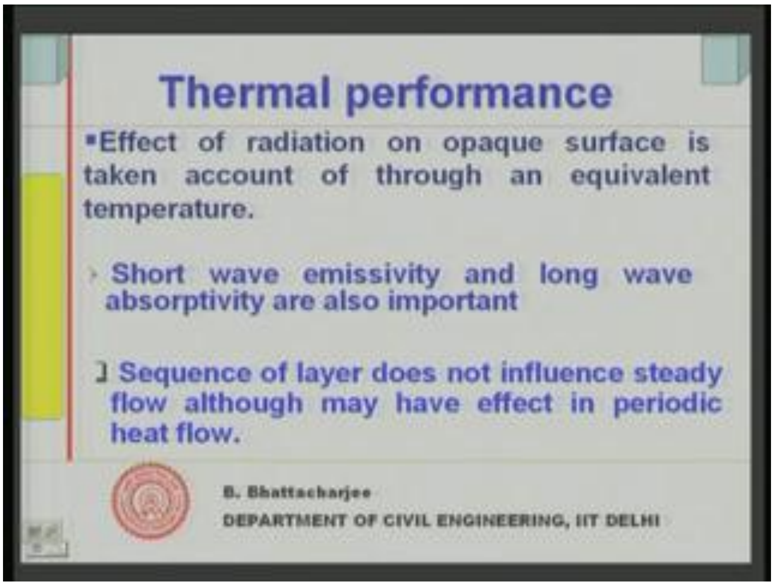

So, effect of radiation additional some other things are important effect of radiation on opaque surface walls are taken account through an equivalent temperature you know, because if a wall is exposed to radiation say south facing wall or south east and south west facing wall in northern hemisphere in country like India it receives a lot of radiation roof of course, is the maximum.

Now, these walls receive good lot of radiation. Now, this radiation outside the air temperature of course, is very much therefore. For example a north facing wall does not receive radiation except, in the early in the morning and late evening in slightly higher latitude right. Say most of the part it would not receive the direct solar radiation. Suns radiation direct sunlight will not be there on that, but the air temperature still is there. So, therefore, air temperature due to air temperature heat flow will be occurring inside, but if you look at the south facing wall especially, in winter or south west or south facing wall south east facing wall always facing wall in the afternoon.

There will be same radiation. So, air temperature plus the radiation effect is to be taken into account and this is done through something called an equivalent temperature you call it sol-air temperature. Anyway that is not our point of discussion here. We will not go into details of that, but radiation effects are also to be taken care of and the absorptivity of the surface long wave absorptivity, I mean; short wave absorptivity this is this is otheractually. This should be short wave. This should be absorptivity short wave absroptivity because it it receives it receives solar radiation short wave absorptivity and long wave emissivity.

This will be same because short wave emissivity is same as absorptivity. So, there is no problem. So, this 1's are important. This 1's are also this properties are important short wave absorptivity and long wave emissivity, they are important properties because if it is absorptivity is high it will absorb more radiation. Radiation absorption to suns radiation that if it is high white surface usually white wash surface absorbs less although it emits quite a bit of it bit in the night.

Night long wave radiation is pretty high in case of white wash surface. So, that is absorptivity and emissivity's are important properties. Sequence layer does not influence steady flow, but it have some effect is periodic flow. So, if you put a insulation inside or outside would not matter as far as steady flow is concerned, but that will have some effect on periodic flow.

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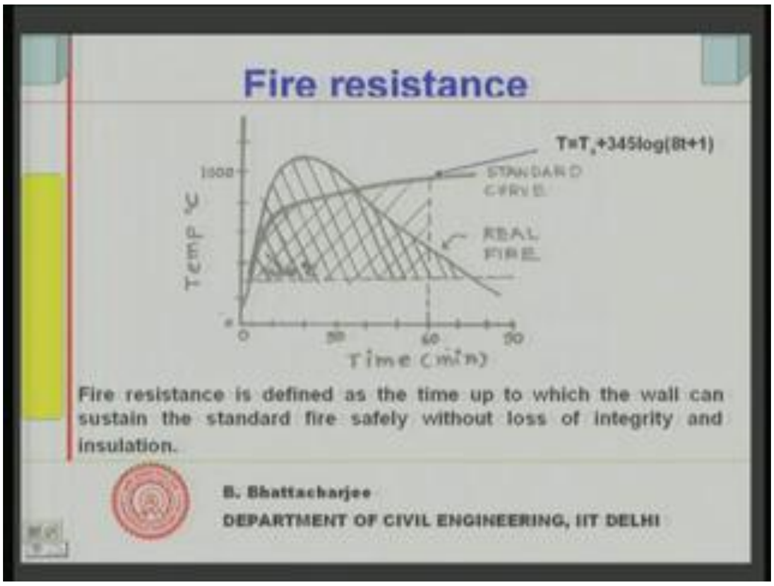

So, that is all about the thermal performances. Now, let us look at the fire resistances fire resistors. This is another perofmrance very important performance. So, let us look at fire resistance. Now, what is fire resistance? Fire resistance is defined in terms of time. Fire resistance is defined in terms of time and it is the time let me give you a formal definition. It is the time you know it is the time up to which the wall can sustain the standard fire safely without loss of integrity and insulation.

Fire resistance is defined as the time to which up to which the wall can sustain the standard fire safely without loss of integrity and insulation.

Safely means it will not collapse and it should not have loss of integrity on insulation. We will define this. Now, standard fire what is up to which some standard fire. Now, standard fire is defined by the time temperature curve. For example this is the temperature this side is the time and this is the standard fire curve. This is the standard fire curve standard fire curve of a furnace. Actually we do it through a fire test. So, fire test is done in furnaces where you generate time temperature.

Temperature versus as a function of time and it should follow this sort of a curve which is defined by this equation. Temperature should be equals to temperature of the furnace temperature should be equals to T a is the ambient temperature that is initial temperature root temperature initial furnace temperature plus 345 log of 8 T plus 1 where small t means time small t means time. T is temperature in degree centigrades. So, standard fire curve can be something like this.

Now, supposing I subject my wall to this furnace curve, then if it sustain this; that means, it remains same does not collapse or does not show excessive deformation till 60 minutes then its fire resistance, I will call it 60 minute or 1 hour. If it sustains this standard fire for 4 hours governed by this equation remains; there you know sustains does not collapse does not crack does not transmit the fire or heat to the next side, then I call it you know for 4 hours. Let us say then its fire resistance is 4 hours.

So, fire resistance is defined in terms of time which up to which the wall can sustain the standard fire safely without loss of integrity and insulation real fires really looks something like this. They are not exactly same as the standard fire, but we can define what is called equivalent fire severity, if the time temperature you know area under this curve and this curve is same. Anyway that is details we are not going into, but we have defined the fire resistance. You must understand that fire resistance its unit is in time and it is the time for which a wall or building element can sustain the standard fire. That is the basic idea something more about this.

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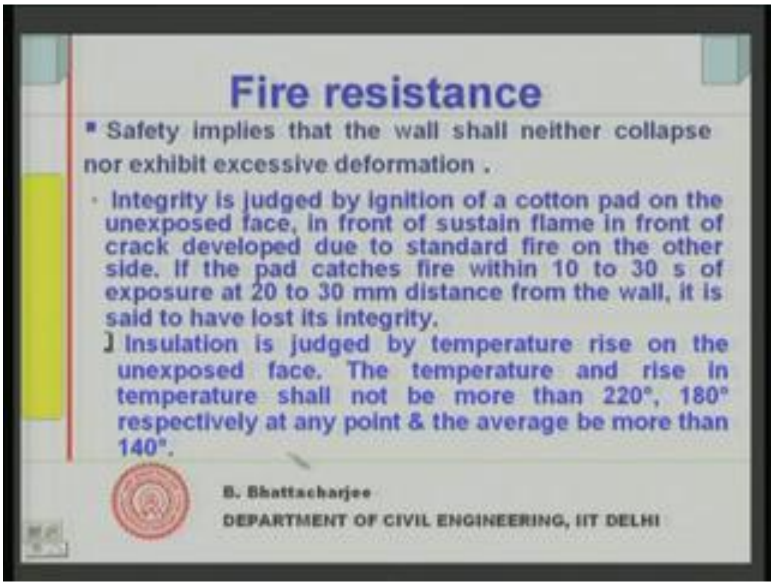

So, safety implies that wall shall neither collapse nor exhibit excessive deformation. It should not excessive deformations right, then integrity is judged by ignition of a cotton pad. Integrity is judged by ignition of a cotton pad. You know how we judge the integrity cotton pad on the unexposed face on the cotton pad on the unexposed face that is the face on which the fire is not there and in front of a flame, when you have subjected the wall to the fire in the furnace the furnace you know it might have cracked.

So, when it does the crack has formed through the crack flame has spread to the next room. So, that is what we are trying to see integrity means; it should not allow flame to spread to the next room. Now, integrity is tested by a cotton pad on the unexposed face; that means, if this side is your fire on the unexposed face you keep it here the cotton pad right and this cotton pad kept for 10 to 30 seconds and if you know between 10 to 30 seconds if it catches fire between 10 to 30 seconds if it catches fire, then we say that the wall has lost its integrity.

So, sustain flame in front of a sustain flame you put it and it should not catch fire within 10 to 30 seconds. Insulation is defined in terms of temperature rise. Insulation is defined in terms of temperature rise on the unexposed face. On the unexposed face the temperature rise in you know, in the unexposed face shall not be more than 220 degree centigrade at any point irrespective of whatever was the initial temperature. Not the temperature you know temperature should not be more than 220.

So, you measure by putting thermocouples at close spacing and at no point temperature should be more than 220 on the unexposed face and temperature rise should not be more than 180 centigrade nor the average temperature rise should be more than 1 forty degree centigrade. So, when temperature rise temperature reaches to average temperature becomes more than rise for example, if it was 25. Now, its average temperature outside you would have several measuring points the exact temperature of all the measuring points and calculate their average.

If it is more than 165 then you will you know say that the moment it reaches 165. Initially it was 25. So, temperature rise is 140 average temperature rise. If it becomes 165 that time you note down and that is the that is the fire resistance. That time is the fire resistance or any point if it becomes 205 up to 20 is supposing if the initial temperature was very high. Then that time we recall. Similarly, when, because I will keep the crack if there is a crack, I will put the pad in front of it every time you know at several time intervals the moment it catches fire, I will say that it has lost its integrity and at that time I note down.

Supposing it has happened after 3 hours then the fire resistance is 3 hours or its shows excessive deformation after 3 hours, then I will call fire resistance as 3 hours. So, fire resistance is measured in terms of time you know when tested under tested against standard fire and it is tested. Performance criteria is used for testing safety against load it should not collapse and it should show integrity should not spread the flame to the next side not should it actually transmit the heat to the next side.

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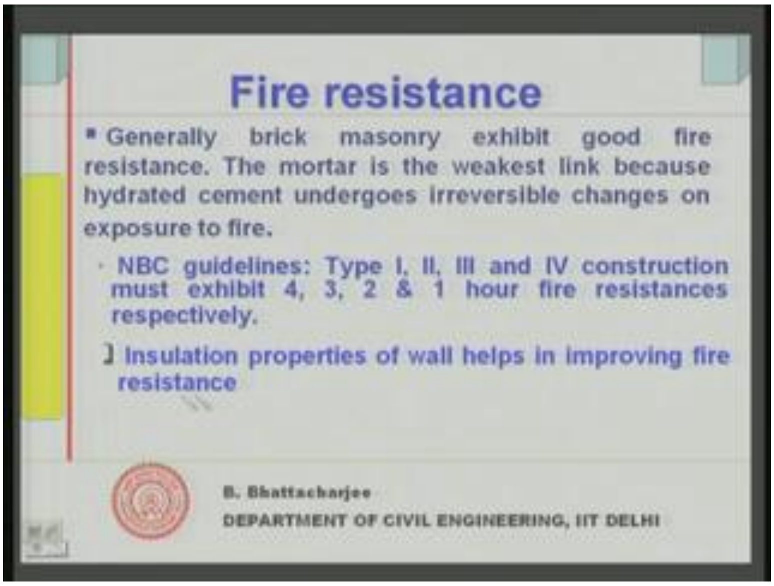

That is what insulation is generally brick masonry exhibit good fire resistance. That is one thing interesting because brick has been manufactured at high temperature. Fire temperatures are you know near to the fire temperature therefore, brick does not show any problem.

That is what we said when we were looking at unique properties mortar is generally the problem. It behaves like any cement hydrate. If there is some irreversible reaction that takes place and we mentioned it sometime in connection with the mortar. So, therefore, mortar shows some sort of a problem. Now, national building code of India it gives us guideline. National building code NBC guidelines are type 1 type 2 type 3 and type 4 construction must exhibit 4 3 2 and 1 hour of fire resistance respectively.

There are other issues related to the definition of this type 1 type 2 type 3 and type 2 construction, but important issues are there fire resistances 4 hours 3 hours 2 hours 1 hour etcetera. Insulation property of wall helps in improving the fire resistance. We will see that how it does.

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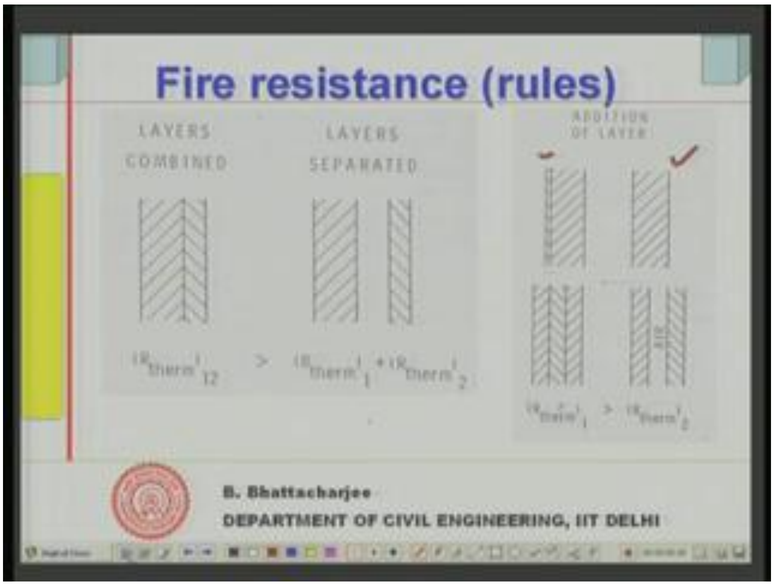

Let us see some of those issues some rules. For example if you have 2 layers right. So, R stands for fire resistance as well as thermal resistance 2 layers. They are when you combine them they are separate. So, fire resistance of this one will be higher than fire resistance of individual walls.

This is 1 rule. So, a thin wall will; obviously, will show you lower. Now, if you add another layer. For example if I add a layer here if I add a layer here you know this was the original I add another layer plaster or even something. Some insulation I mean something then this will have a higher fire resistance than this. Its thermal resistance is also more. So, fire resistance automatically will become more because you see fire walls also requires heat transfer from the fire side. Fire side of the wall to inside and deteriorate the material.

If the heat is not transferred there will be no deterioration or sometime in the surface of course, burning of frame spread can be there, but otherwise it is the heat transfer which is important and this heat transfer of course, temperature is increasing. So, properties will change with the temperature. So, heat transfer again is an important issue there right. Now supposing I have 2 layers 2 of these materials; you know and I join them up, I add you know this was the situation and I add an insulation here and some material here. So, this will have better thermal resistances. This will have better thermal resistances and fire resistances are related to his right.

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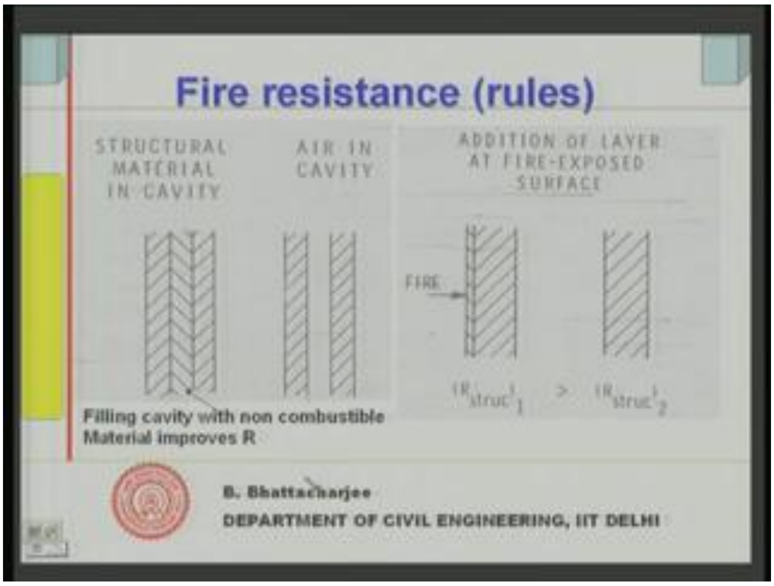

Let us say let us see some more rules. Structural material if you put in cavity then filling cavity with non combustible material. This should be non combustible that will improve R. So, it was a cavity earlier. Now, you have put in some non combustible material and this can improve the fire resistance. This can improve the fire resistance.

Addition of layer towards the fire exposed surface. Insulation layer if you put it. So, this of the structure and material would be better than this. So, you know thermal if you add an insulation layer to the fire side it would improve the fire resistances right. So, this was the original and now is this and this is divided by this.

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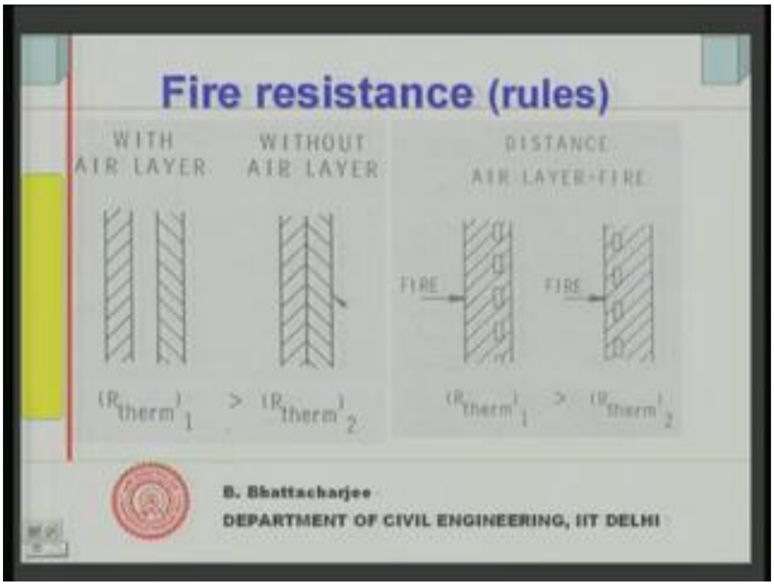

So, it improves actually. Now, supposing I have air layer cavity and I have no layer I mean earlier case we said that we have air layer, but I put an non combustible material. That is better, but even if I do not have a non combustible material.

If this lower said layers; were joint and now I put a cavity it increases my fire resistance. It increases my fire resistance. So, these are some rules related to the fire resistance. Supposing I have cavities inside or hollows inside and I put it distance from the fire is important.

If it is close to the distance close to this distance this resistance is lower, but if I increase this distance, if it is on the other side of the fire side you can say of the fire on the non unexposed side of the fire it is seen that it shows a better fire resistances. It shows better fire resistances.

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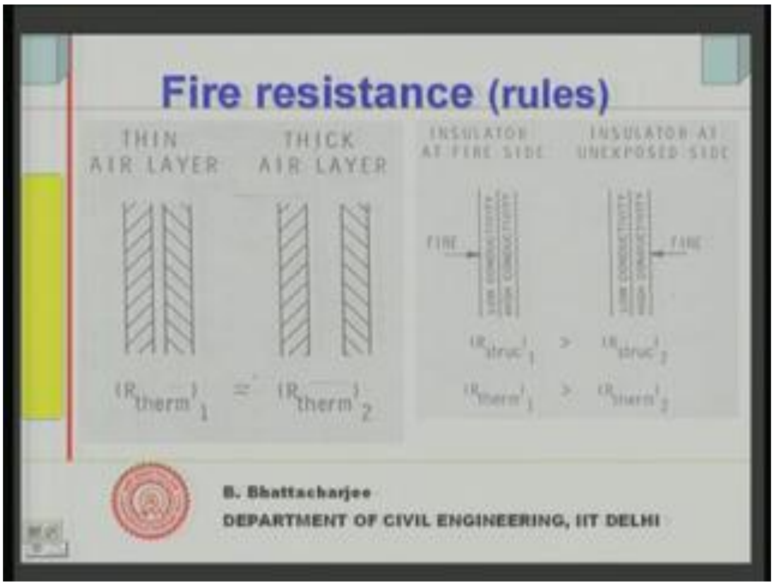

Similarly, well if I have the thickness of the cavity does not have much effect on the fire resistance you know thickness of the cavity does not have much effect on the fire resistance.

So, if you have thin layer of the cavity or thick layer does not make much of a difference. Thermal conductivity in materials plays a big role because as I said the fire also means if it is to insulation property directly is related is related to the thermal conductivity right now cracking etcetera is also related to the temperature because temperature might cracking. If the temperature inside has to rise heat has to be transferred from the fire side to the other side, and this would occur this would depend upon the thermal conductivity and thermal conductivity here as a function of temperature. Also the specific heat and heat capacity will also play a role.

So, thermal conductivity on the low thermal conductivity on the fire side low thermal conductivity on the fire side you see, that this will have a better you know fire resistance then this 1 low conductivity, I mean; the fire on the other side the high conductivity side.

If the fire is on the low conductivity side, this will have better resistance thermal resistance and I mean; better fire resistance compared to the compared to the fire on the high conductivity side and 1 would rather recall here the fire resistance of slab is or RCC members RCC wall. If it is there you know RCC wall or slab anything is a function of the cover, because it is the cover which provides you insulation to the reinforcement bar.

So, whenever you have reinforced concrete element there the cover is very important from the fire point of view. So, thermal conductivity low conductivity material steel itself is high conductivity you know compared to let us say concrete or brick or similar sort of thing also you remember moisture.

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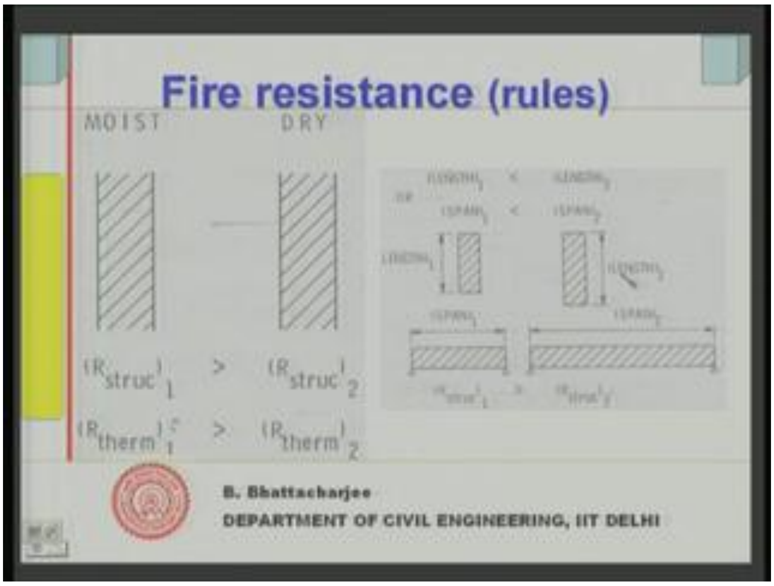

Moisture higher moisture content results in higher conductivity. We mentioned earlier, higher thermal conductivity. Therefore heat will be more transferred when it is moist. So, you find that this 1 which is moist you know moist moist, but 1 more thing as far as fire is concerned heat conductivity is all right, but moisture can absorb a lot of heat initially.

So, it might provide you a higher better you know better fire resistances better fire resistances, what about length. Length of the wall or height of the wall span of the wall or slab, if it is less the better is the resistance fire resistance you know better is the fire resistance better is the fire resistance. If span is a length is more it will be less.

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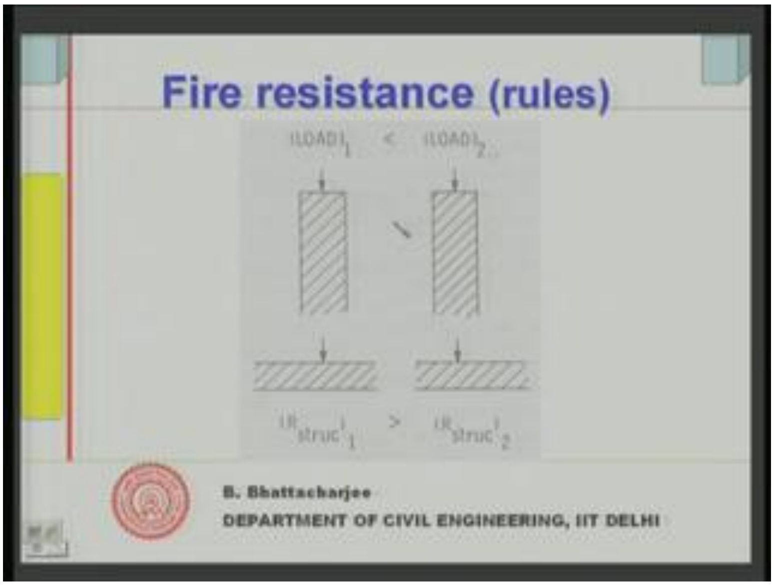

Similarly, load has similar effect. Higher load means lower fire resistance higher load means; lower fire resistance you know lower load means; load 1 is less than load 2 then this will have better fire resistance.

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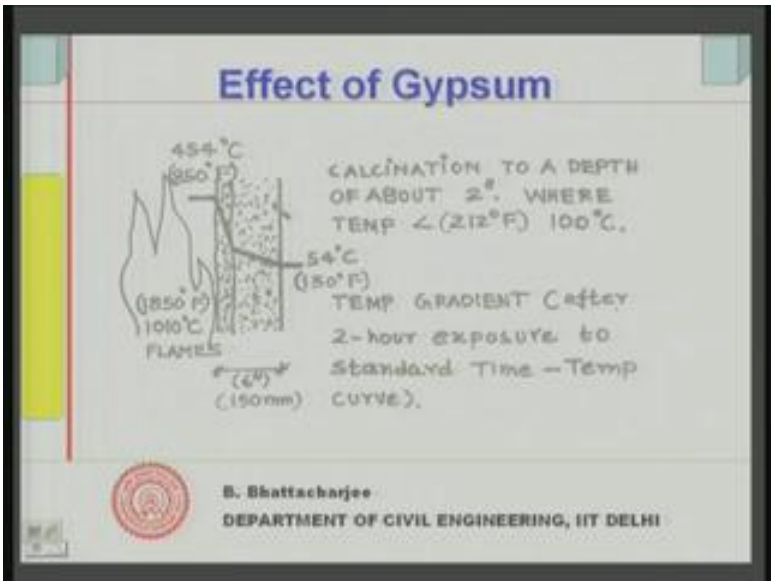

Similarly, in case of slab also or beam collection of member. So, any member you can see that if you have less load then it is better fire resistance. Now, gypsum has got a specific property. It is used quite often for fire resistance you know fire protection purposes. It is calcinations of gypsum. This is this is actually gypsum means; with water crystallization calcinations. So, this when you heat it up calcinations takes place and this results in a sudden drop in temperature you know across this layer of the gypsum about 1000 degree centigrade flames.

Let us say and it actually acts like an insulatioin very strong insulation. So, temperature gradient after 2 hours of exposure to standard curve temperature you see that here, it is actually 454 degree centigrade and here it is 54 degree centigrade with gypsum. If it is not gypsum it would have been 454 and this would been much higher. So, gypsum is a good fire resisting material. Let us see fire resistance of hollow bricks and solid bricks as well.

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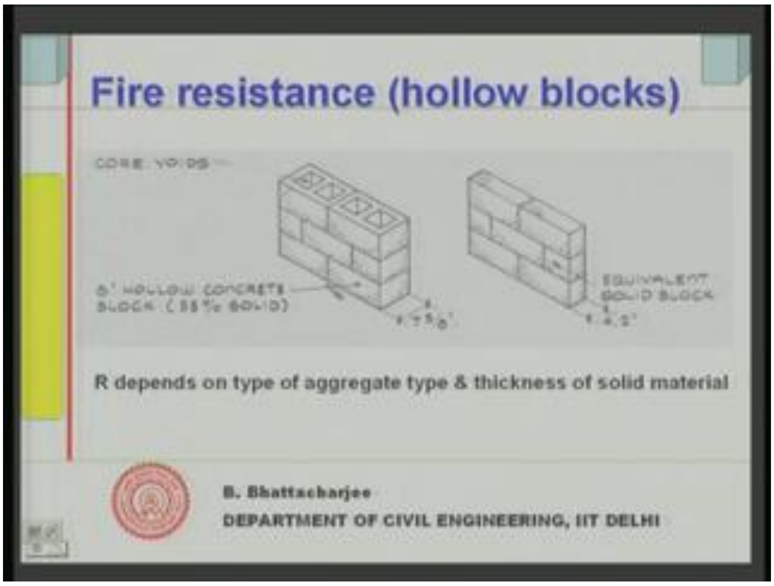

Hollow bricks fire resistance is something like this you know if this is hollow bricks the fire resistance will depend upon the amount of the solid material. The basic idea is heat transfer takes place through the solid and does not take place through the core that is the hollow portion. That is why air cavity also does a better job you know. So, you have this is in suppose you have cores or holes here and this is the solid the fire resistance will depend upon the type of aggregate, because the conductivity depends upon type of aggregate and thickness of the solid.

Supposing this has got fifty five percent of solid and forty five percent hollow you know thickness would be then multiplied by simply 155 you know it will be it would be given as seven point five by eighteen should become 4.2 inch 55 percent solid. So, accordingly

1 can find out equivalent solid block. So, the fire resistance of such hollow core walls depends upon the solid portion and also the type of aggregate. Let us see this.

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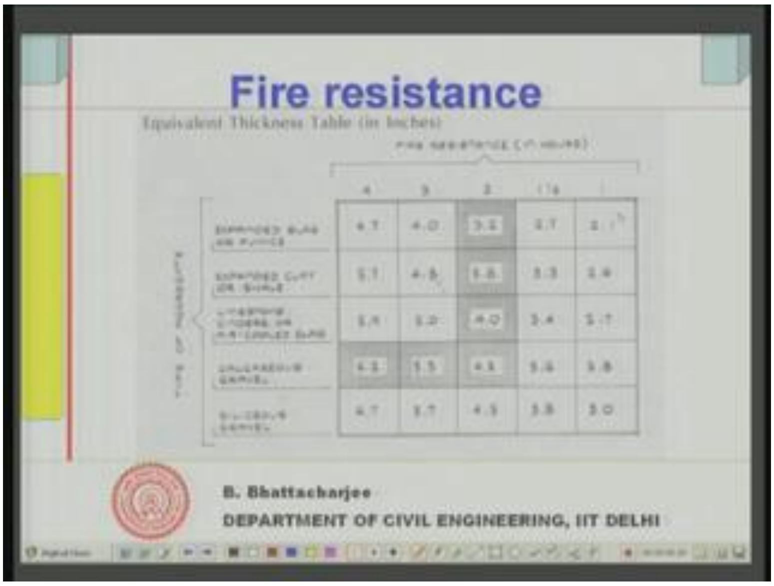

For example if I look at this table. If I look at this table equivalent you know equivalent thickness is given. Equivalent thickness which will give you 4 3 2 1 and a half and 1 hour of fire resistance in hours is given.

So, you can decide about this equivalent thickness is given through which you can find out how much is the total area of the core hollow core wall or concrete hollow core concrete blocks, because solid it depends upon the solid portion right. It depends upon the solid portion. So, if solid portion is 0.5 thickness of the hollow core you can find out simply divide it this by 0.5. Now, it is given for example, if you have expanded slab or just light weight aggregate actually. So, when you have light weight aggregate system aggregate the fire resistance for 4 hours then its equivalent thickness should be 4.7. If it is 4 then it is 3 hours it is 30.22, etcetera.

Now, siliceous gravel you see the gravel siliceous material transmit much more heat than this sort of aggregate light weight aggregate. So, heavy weight aggregate I mean not heavy normal weight aggregate to transmit more heat. So, siliceous you know calcareous gravel or limestone etcetera it is hindered these all are somewhat if you go towards this side these are light weight and this is the you know they have more conductive. So, these 1's are more conductive.

Quartzite is the maximum you know quartz conjuncts the very high compared to minerals all other minerals. So, quartz it is it shows you higher possibly higher you know require more thickness, you would need more thickness whereas, they are less thickness towards the same amount of fire resistance because this conducts. So, you need longer thickness and this table gives you the fire resistances of hollow I mean; not from fire resistances hollow block masonry construction.

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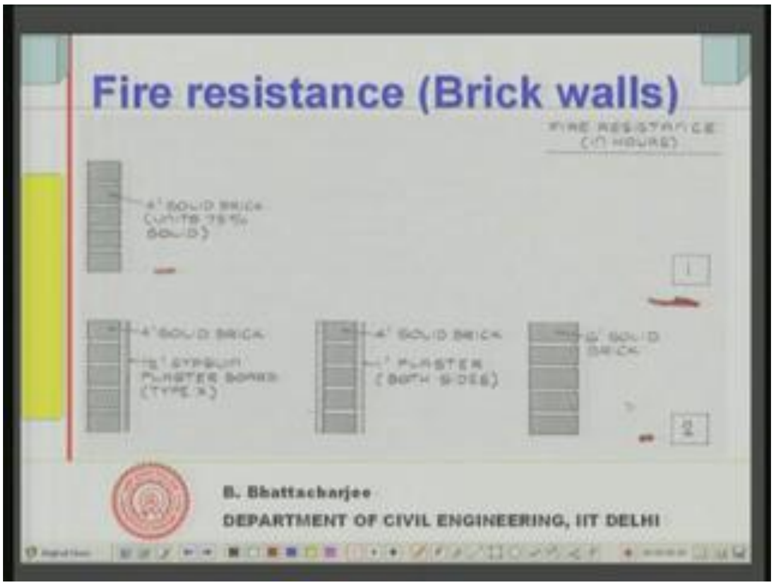

Let us see the fire resistance of brick you see this 1 what is given here is a 4 inch solid brick 75 percent solid right 4 inch solid brick solid bricks actually. It will have 1 hour of fire resistance. If I add half inch gypsum, because we have seen gypsum increase the fire property and adding a layer always improves the fire property. That is what we have seen in basic principle. So, when we add 4 inch solid wall same 4 inch wall add 1 and a half inch gypsum plaster board here right or 4 inch solid 1 inch plaster on both sides just increase the thickness by plaster another layer or you use six inch brick. All of this will give you 2 hours of fire 2 hours of fire rating as it is called or 2 hours of 2 hours 2 hours of fire resistance.

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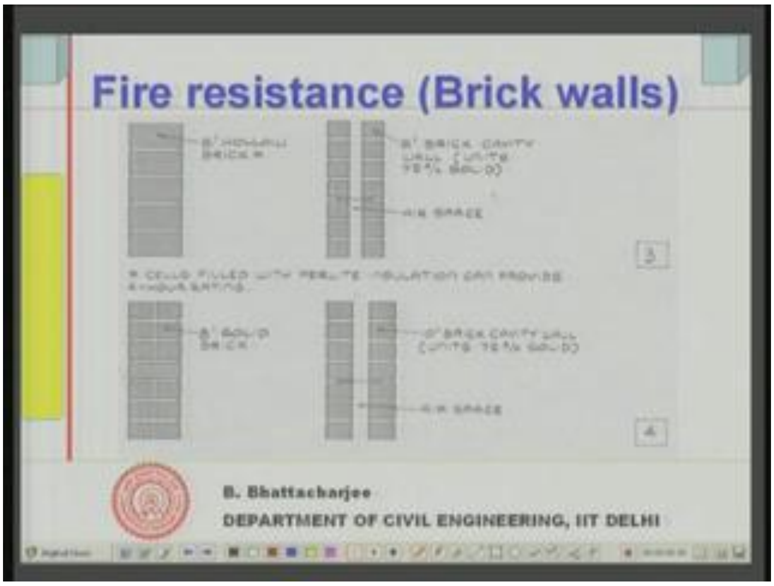

Let us see what happens if I use instead of 4 inch half brick wall you know we were talking. So, far of the half brick wall, now if you have 1 inch brick wall 1 inch thick wall like in this case, it is nearly 8 inch hollow brick. Of course, this is being talked about 8 inch hollow brick 8 inch hollow brick right and 8 inch brick with cavity wall 75 percent air space is given 75 percent solid air space is given. Then this can give you about 3 hours of 3 hours of fire rating or fire resistance.

Now, in free space cavity if you use perlite insulation this can provide 4 hours. So, in this 1 instead of using you know you know this 1 this portion instead of using just air supposing you put an insulation material insulating material you know, we said that non combustible material between the air cavity increases the fire resistance. So, this can give you 4 hours the principle that we talked about. Now, here is the example of principle that is being used. So, if you use if you put some sort of perlite which is an insulating material right perlite that can improve it to 4 hours.

So, here you put this will improve right. Now, brick solid brick this was actually hollow brick. This was hollow brick 8 inch hollow bricks right and in if you put perlite in the hollows then it will increase. Similarly, air cavity 75 percent solid and air cavity is there 8 inch total solid portion. So, 75 percent solid that can be, supposing I have got 8 inch solid brick then this will give 4 hours of right; 4 hours of fire rating and same brick when

I made it 10 inch brick cavity right 10 inch brick cavity 75 percent solid air space is inside and I get 4.

Typically, 9 inch brick wall which is very common in our 9 inch sort of brick; which is quite common in some parts of the country northern part of the country or even 20 centimeter thick brick wall. If it is a modular brick you know sizes are in centimeters they are solid brick wall is likely to give you about 4 hours of fire rating. They are likely to provide you about 4 hours of fire rating. So, this is the discussion on fire resistances. Let us look at another property the last property that we were looking at today.

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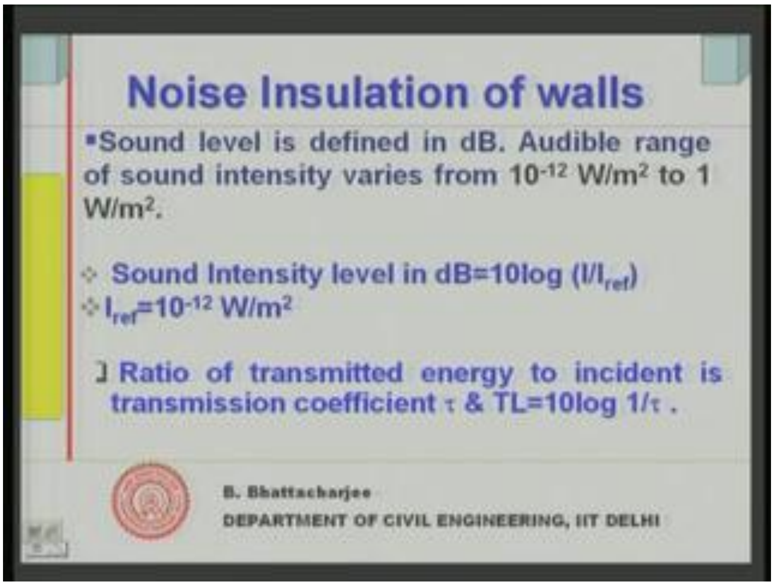

Noise insulation of walls; the wall must serve as a purpose of noise insulation, could be partition walls. Now, first let us define something how do we define noise. You see when it comes to noise sound level without going to details because this itself, can be a real full course large subject. So, we give you few definition and then look into insulation, what how we define insulation. Sound level it is defined in decibel dB sound level you define in dB and we know that audible range of sound intensity the least you can hear what is called threshold of audibility to what is called threshold of pain right.

The least level it depends upon how much energy is impinging on the ear how much energy is impinging on the ear. There is a minimum level of energy, because we know sound is nothing, but it is sound energy is nothing, but longitudinal vibrations of the ear particles. That is what happens because you generate a kind of vibration in the ear. It can travel through any media any way because mechanical waves can travel through solids, but finally, it is the molecular vibration of molecule about the mean position of equilibrium in the longitudinal direction and this vibration or these relative motions which continues and when it hits into the ear human ear we hear that sound. That energy we will hear.

So, it is actually wave longitudinal wave traveling in the ear. Now, there is a minimum level of the energy is associated with this wave. Intensity is the rate of energy per unite area watt per meter square in case of sound intensity, we define in terms of watt per meter square. The sound energy rate of transmission of sound energy you know rate at which it is impinging on to the ear in 1 meter square per meter square. So, that is what intensity is. We define the intensity in this manner and there is a minimum level below which you won not hear.

Because, when it is low energy sound you will not ear will not simply resist it. After all it is the vibration of the ear drum and through certain bones it get transmitted to the brain. So, therefore, it should be able to create that sort of vibration the diaphragm vibration in the ear drum. That minimum is called threshold of audibility and that value is 10 to the power of minus 12 watt per meter square, but there is a very high value about which it will actually cause damage permanent damage to the ear or pain.

That we call as threshold of pain and that is 1 watt per meter square. Actually audible range of intensity is from 10 to the power minus 12 watt per meter square to 1 watt per meter square. Now, this you can see is a very large range you know lower most to the higher most is 10 to the power 1. So, when you are dealing with such situations you do not deal with simple linear scale, but you deal with logarithmic scale. There are other reasons of course, to choose logarithmic scale here.

So, sound level intensity sound intensity level, because we define sound pressure level as well where you know is after all the pressure of the wave. After all this changes wave is nothing, but change of pressure above the atmospheric pressure. So, there is an increase in pressure plus increase in minus increase, because this is wave. So, pressure variation is there plus minus pressure variation and that pressure we express in root mean square terms, that all details, we are not interested right now.

So, we can, but you can express in what is called pressure level. Let us leave the sound intensity level for our purpose and need not go into the details anymore and sound intensity level is defined in dB as given as 10 log I over I reference. So, what you are doing whatever intensity. Let us say point 1 watt per meter square divided by a reference intensity. This will be a ratio. Take log of that and multiply it by 10. So, reference is taken as reference is taken as 10 to the power minus 12 watt per meter square. That is threshold of audibility.

So, supposing I have here for example, if it is threshold of pain it will be 1 divided by 10 to the power minus 12 threshold of pain will be 1 divided by 10 to the power of minus 12 which is equals to simply 10 to the power 10 to the power 12 and if you take log of that log of 10 to the power 12 is simply 12 multiplied by 10 will be 120.

So, 1 20dB corresponds to threshold of pain and if it is I reference is taken as 10 to the power minus 12 watt meter square and threshold of audibility will be simply 1 So, 0. So, you see the audible range of sound intensity varies from 0 to 120dB, that is how you measure express the sound intensity level. Let us come to transmission loss the property of wall; 1 major properties of the wall is that it should provide us insulation that means; if I have noise on 1 side it should not get transmitted to other side and that property, which measure you call is sound transmission loss right or sound transmission characteristics as transmission loss could be a good idea.

Now, ratio of transmitted energy to incident energy is called transmission coefficient term and transmission loss can be defined as 10 log 1 over tau. Ratio of energy transmitted to incident upon a wall you call it as transmission coefficient and transmission loss is defined as 10 log 1 over tau and this is a measure of insulation quality and this is a measure of insulation quality.

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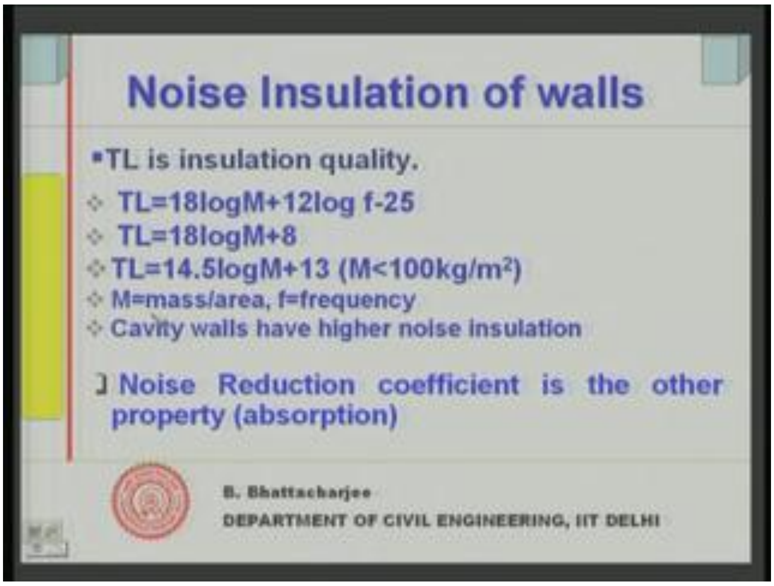

So, this must be high. This must be high and you know this is a measure of insulation quality and this must be high, and this is given through this formula empirical formula is called mass law 18 log M plus 12 log f minus 25 or a simplified formula independent of all average for all frequencies is given like this. 18 log M plus 8 M plus another is given. 14 log M plus 13.

These are actually empirically determined, but actual values may vary even still slightly more. This is called mass law which we encounter in the normal frequencies that we come across where M is the mass per unit area of the wall. F is the frequency. So, when for various frequencies transmission loss, I can find out from this formula and for all the frequencies average value, I can find out when mass is greater than mass per unit area is greater than hundred kg per meter square.

So, this is valid for mass greater than hundred kg per meter square. This is valid for mass per unit area mass density of the wall hundred kg less than hundred kg per meter square using this formula 1 can find out the transmission loss. Cavity walls have higher noise insulation you know double layer walls have higher noise insulation that the formula becomes different if it is not same and the much higher. So, 2 layer multiple layered wall has got higher noise insulation. Anyway noise reduction this is the major property and we see that the code gives us some of the values.

We will just quickly look into this. Noise reduction is another parameter you know another property and this is related to absorption of sound by the wall. You can put various absorbers right. For example in this room there can be absorbers. So, that noise any you know noise can be absorbed right. So, absorption is the energy absorbed divided by energy incident. Incidentally absorption of an open window is 1 because it absorbs I mean allows everything to pass through. So, anyway so this is noise reduction coefficient NRC is the average absorption coefficient at certain important frequencies. This is other property of the wall. So, these are the properties of the wall.

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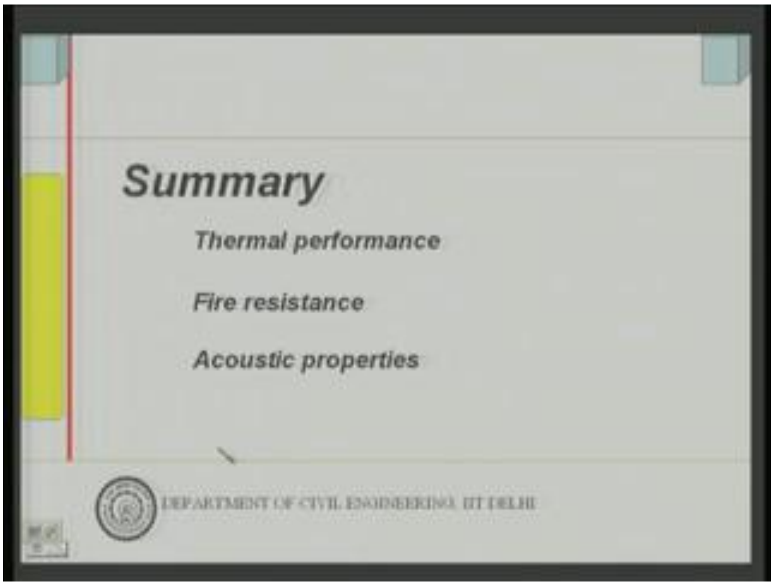

These are the properties of the wall. These are the properties of the wall. There are some values codal values available some codal values, this codal code gives us some values of the noise reduction coefficient.

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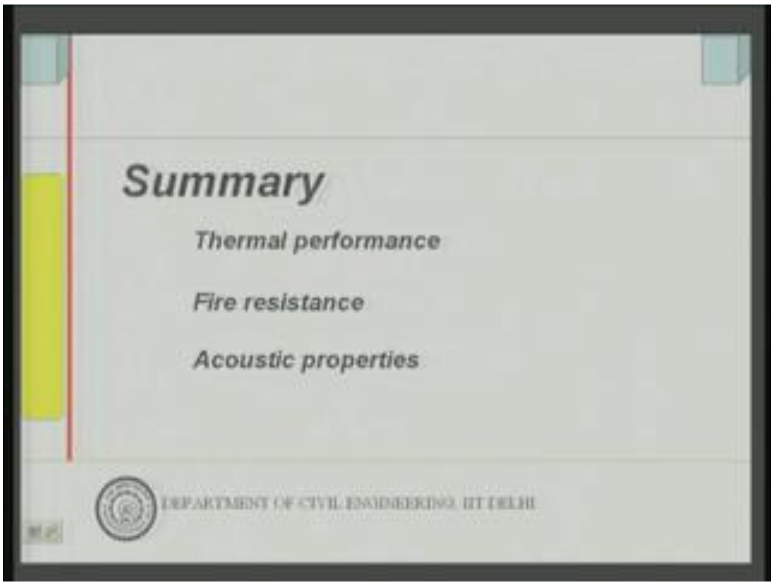

Noise reduction coefficient and these values are close to the values that have been given in the close to the values that has been given by this formula. We will try to look into some of those values, in the next class. Now let us summarize. We have defined thermal I mean; discussed about the thermal performance of walls and brick masonry in particular. We tried to define what the properties are although I did not give you some values, but we understand what those properties are. Then, we tried to look into the fire resistance properties of walls, and then we gave some reference to the solid walls and hollow walls and then lastly, we looked through the acoustic properties and I think this is the same values are just I have.

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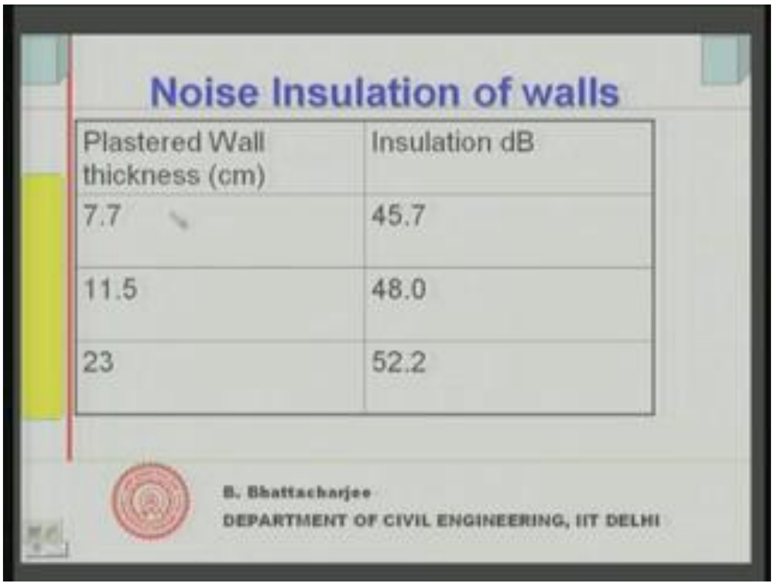

These are for plastered wall. This is from the code. These values are from the code. For example for 7.7 centimeter thick wall insulation is decibel; 45.7 decibel and so on. So, these values are there we might look into them again, in the next class.

Thank you. So, that is finishes our discussion.