Principles and Applications of Building Science
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Lecture – 07
Thermal Performance and building envelop

In this module will be looking at Thermal Performance of Building Envelop.

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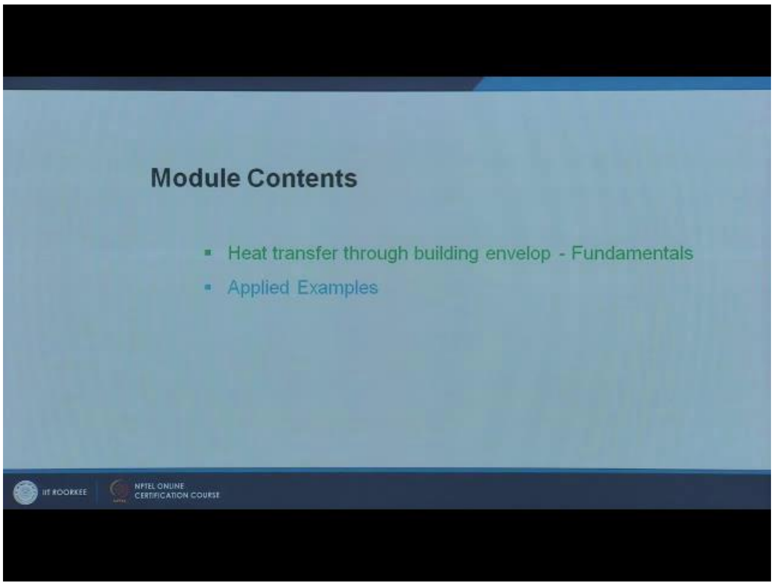

Module Contents

- Heat transfer through building envelop - Fundamentals
- Applied Examples

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NPTEL ONLINE CERTIFICATION COURSE

I will be teaching about the fundamentals of heat transfer through building envelop and I will be showing you some applied examples in which we will be looking at how these principles are applied in specific buildings.

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Heat Transfer through Building Envelop

Let us take a look at this particular image. There is a cross section of a wall; it can be any material for now we are not getting into what are the thermal and physical properties of this wall. There is cross section imagine it is 200 mm thick wall and here what you see is the time line, its starts from 12 o clock on a particular this a night, then it goes on to the 1 day cyclic 24 hours and then this is a second day

So, there is totally 48 hours covered here starting from 12 in the night goes on to 24 hours that is the second day. What we were trying to show is a heat buildup heat transfer and then heat reemission; that is how the wall is getting heat in and how it is getting heat out of the building, so this is outside and inside of the building. Let us start looking at somewhere from this point, say take about 8 a clock where you start getting imagine this is a east facing wall it can be any surface later we will look at the details. But imagine this is east facing wall, you start getting solar incidents somewhere around 637 in the morning it depends on the season as well, so imagine you get some solar incidents here then this walls starts getting heated up. What happens there is a heat buildup this you know the depth of this bars show how much of amount of heat is getting buildup.

So, there is a heat buildup here, then depending on the thermo physical properties of the wall; the wall is going to store some amount of heat and then pass some amount of heat into the room. This process takes a while that is the solar radiation needs some time to heat up the wall. Then it needs some time to pass through this particular distance say now it is 200 mm, then after while you start getting a realizing say when there is a you know initial heat buildup you do not say anything here, say if you apply heat here if you touch this surface immediately you are not going to feel anything.

After about an hour that is what we tried (Refer Time: 02:37) here, after about an hour or slightly more in this particular wall it depends again how insulate the wall is. We were going to look at this precisely in this module. After while you start getting the heat passing into the build surface that is into the room, so there is a peak here this particular peak after say 1 1 and half hour you get the peak inside the magnitude may be different that is why the colors are different. Now you are getting heat into the pumped into the build space.

So, after this heat sources is gone that is after the sun has gone to the other side of the building or after the sunset this particular wall; now there is no heat source eventually its starts minimizing the intensity of invert heat pumping. After this there is a reverse phenomena the magnitude is not the same if you look at this there is a good amount of heat gain, whereas the reverse process it is pretty less. So, what happens here there is a eventual reverse flow of heat.

Similarly, this takes a while and after this particular time the wall also losses heat to the ambient. The same phenomena if you look at any particular surface there is a heat buildup, second day there is a heat buildup, there is a heat loss, there is a heat loss and this is for the third day that is going to be a heat loss. Inside similarly during the day time later in the day there is a heat gain, and then again the second day later in the day there is a heat gain. So, this particular peak to peak this is what is of interest to any building designer.

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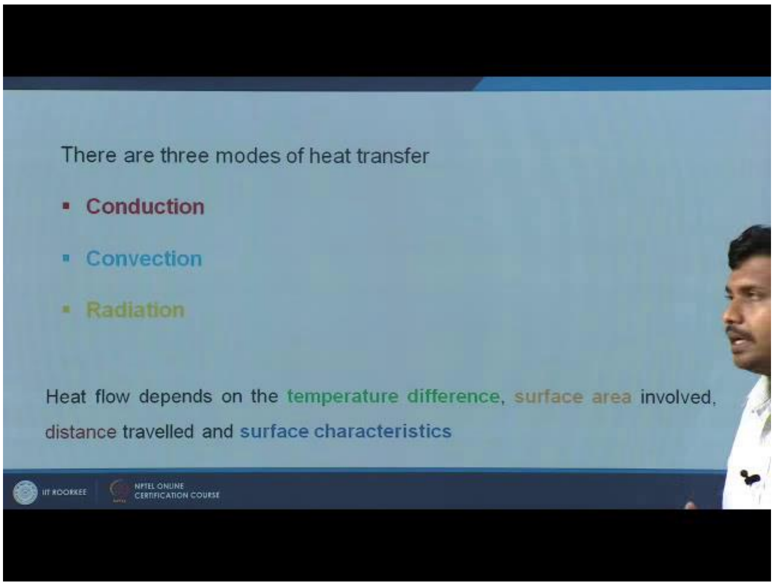

There are three modes of heat transfer

- **Conduction**
- **Convection**
- **Radiation**

Heat flow depends on the temperature difference, surface area involved, distance travelled and surface characteristics

Now, we are going to look at how these mechanisms work and what are the fundamentals behind it. Just brushing up the basics what we studied in school. There are three modes of heat transfer; conduction, convection, radiation. Heat flow depends on the temperature difference that is delta T. What happens on one side of the wall, what happens on the other side of the wall, what is ambient temperature, what is indoor temperature. Say if your air condition in your room for the same summer day the heat transfer is going different, whereas if you leave the building in a free running mode are unconditioned or naturally ventilated mode then the heat transfer is going to be different, because the delta T is different.

Then it depends on the surface area; how much wall surface or how much window surface are, what is the integrated surface area which is exposed between the two temperature differences. Outside is 45 degrees inside is a 24 degree set point temperature, so you have about roughly 21 degree difference that is the delta T. Then you have this much amount of wall area, say for example a 4 meter long 3 meter high 12 meter square of wall area, probably you have a about 10 percent window wall ratio in that. Then in that case this is an amount of wall surface which is involved in the heat exchange.

Then it depends on the distance traveled, say a thick surface or a thick wall versus a thin wall it depends on the distance traveled and then it depends on the surface characteristics, whether the surface is reflective whether it is absorptive (Refer Time: 05:40). These are few properties that are of interest towards which we will be looking more closely in this particular module.

Two bodies are in thermal equilibrium when they have same temperature; that is say you have a chamber both side it is 25 degrees then this particular wall or a particular solid is set to be or any fluid is set to be in thermal equilibrium. So, these two sides there is no heat transfer which is happening. Naturally heat flows from the hotter sides to colder side. These are basic principles which we will already know. If it has to happen from the other side you need a heat pump.

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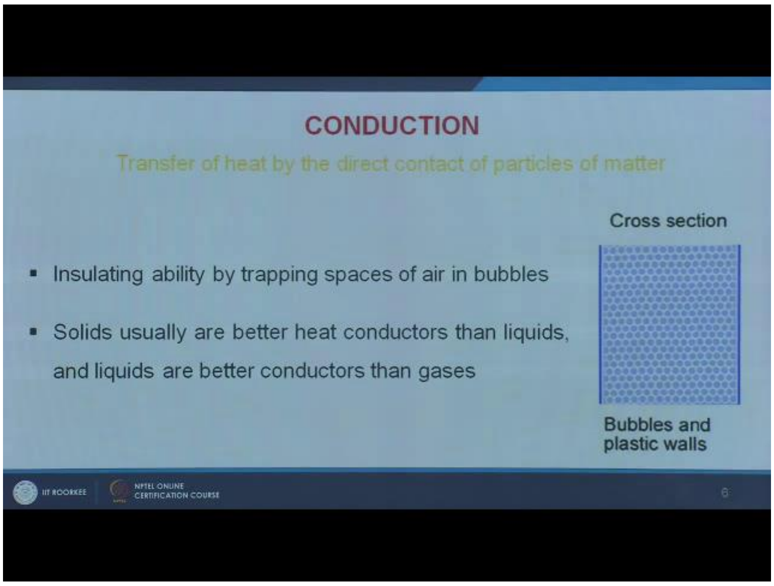

CONDUCTION

Transfer of heat by the direct contact of particles of matter

- Insulating ability by trapping spaces of air in bubbles
- Solids usually are better heat conductors than liquids, and liquids are better conductors than gases

First let us take a look at conduction. It has a transfer of heat when two particles or two bodies are directly in contact with each other. A hotter surface is in touch with the colder surface then you start realizing the conductive heat transfer. Looking into the micro structure what happens with in a body like we saw the wall case one side is getting heated up eventually there are smaller particles which are getting in touch with each other they are getting exited, and then because of that direct contact there is a heat transfer happening from one side of the other.

This particular heat transfer is the efficiency of conductive heat transfer is primarily dependent on the amount of air tabbed into this particular material. We can refer it in terms of porosity or indirectly we can refer it in terms of density that is how porous a material is. Take dense steel sheet; the material is really dense, the particles are so compactly place the density is high, porosity will be pretty minimum then the heat transfer is going to happen much faster.

On the other hand you take a like a glass wool the material like glass wool which is much; the internally the particles are much more dispersed or you take a aerated concrete foam concrete where you have lot of air bubbles which embedded into the concrete and cement paste basically. In that case the mode of heat transfer keeps changing first you know the heat will encounter a cement block then it will have an air wide.

Alternately it has to keep transferring from one medium to the other medium and there are lots of losses because of this. So, these particular air bubbles embedding them makes a lot of difference in the conductive heat transfer. Typically solids are better conductors than liquids on liquids are better conductor then gases. Typically we look at this in terms of insulated windows, again when you go far pair gases like, organ, sealed windows then. the conductive heat transfer gets further lower.

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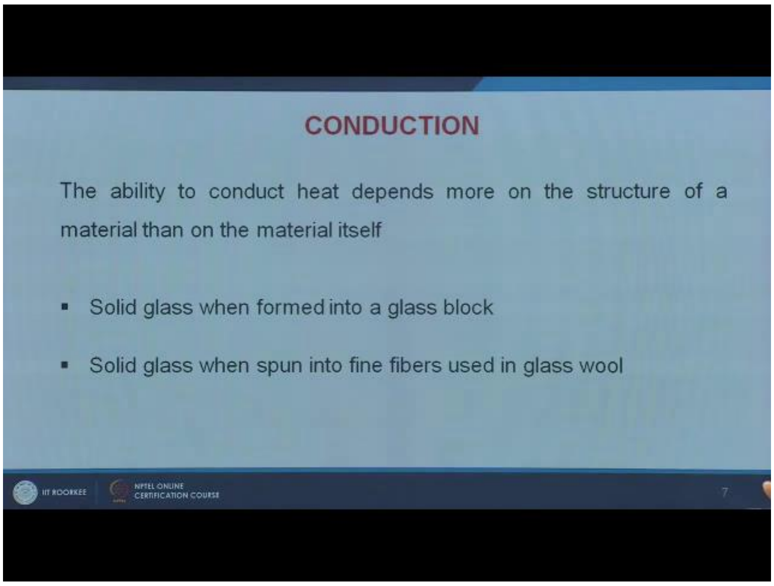


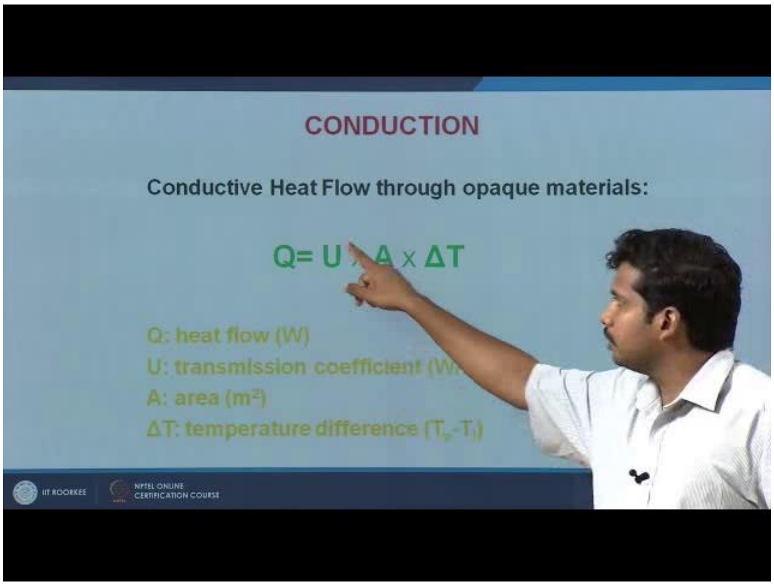
CONDUCTION

The ability to conduct heat depends more on the structure of a material than on the material itself

- Solid glass when formed into a glass block
- Solid glass when spun into fine fibers used in glass wool

Further, about conduction the conductor gate transfer depends more on the structure of the material than the material itself, like precisely when I told you what happens with the glass block the same material is used in a glass block which is commonly used for internal partitions and all that you have a glass block say 100 mm thick glass block, you have the same material, the mode of heat transfer let us take just conduction for now. The mode of heat transfer through a glass block is going to considerably more than through a fine fiber in the form of glass wool. This also has a similar material, but it is fun in the form of fibers.

So, the material remains the same, but the internal micro structure of the material more precisely is considerably the different. There are lot of air weirs built in the built of the structure itself is micro structure itself is different. So, because of this there is a considerable difference in conductive heat transfer. This is a very simple you know most commonly use the equation where for heat load cooling load determination the use this equation pretty commonly in buildings. (Refer Slide Time: 09:43)



CONDUCTION

Conductive Heat Flow through opaque materials:

$$Q = U \times A \times \Delta T$$

Q: heat flow (W)
U: transmission coefficient (W
A: area (m^2)
ΔT: temperature difference (T_e-T_i)

On one side you have Q which is the conductive heat flow through opaque materials which is equal to U, U is a transmission coefficient. We are going to look at this particular number more in detail U which is a heat transfer coefficient conductive heat transfer coefficient. Area of the surface that I was mentioning about how much area is involved in the heat transfer and the temperature difference delta T.

So, Q is in expressed in watts or you can cut it down to watts per meter square of this area component is negated. You will have a U into A into delta T. This is what actually gives you conductive heat transfer. There are two other modes of heat transfer this is primarily for how conductive heat transfer happens. So, when we talk about conductive heat transfer we have to in the process remember few terms and terminology which are in field commonly more confusing because this sound similar.

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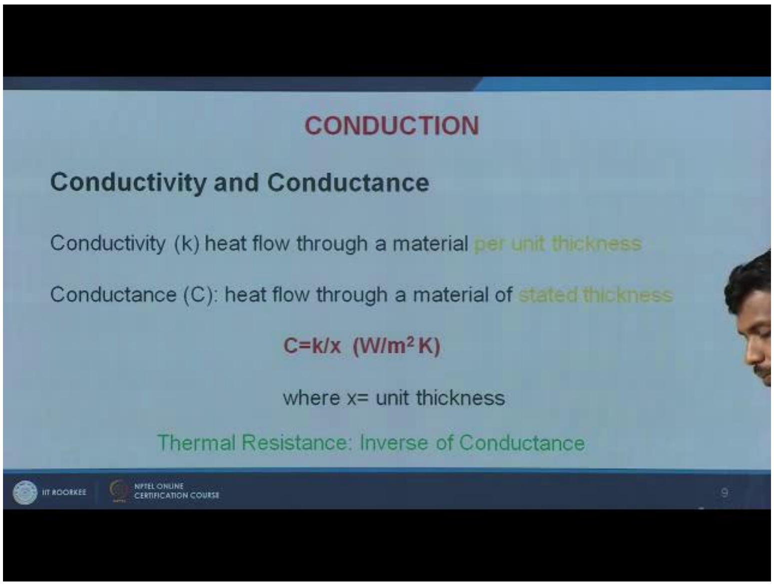

CONDUCTION

Conductivity and Conductance

Conductivity (k) heat flow through a material per unit thickness

Conductance (C): heat flow through a material of stated thickness

$C=k/x$ (W/m^2K)

where x= unit thickness

Thermal Resistance: Inverse of Conductance

Some of the commonly use parameters that is conductivity, conductance and thermal trans meters; these three parameters are quite frequently used, but they are more interchange quite often confusingly. First let us take a look at what conductivity means; it can be express commonly it is express that k, but the innocent can be anything. It is heat flow through a material per unit thickness.

So, the first thing we have to understand is conductivity is a materials property; it is a inherent materials thermal property. It is not dependent on thickness because thickness factor is negated here it is per unit thickness whatever it is, so when we say conductivity of the material is expressed in watt per meter Kelvin. It is amount of heat getting transferred from one side of the material to the other side of the material. It is commonly measured in laboratories. There are methods like hot plate apparatus, hot box apparatus these are apparatus used for ASDM codes are available.

For these testing I can tell you few examples. For example, if you want to say test the conductivity of brick. You slice the brick put them in between two plates; one is the hot plate other is the cold plate there are standards for setting these temperature dimensions and proportions, so from one side the hotter side to the colder side heat transfer happens and how much amount of heat is getting transferred through this slice of brick is measured as its conductivity or the k value as I said it is expressed in watt per meter Kelvin.

In hot box apparatus you can test larger material wall (Refer Time: 12:04). There are two chambers; one chamber is a hot chamber another is a cold chamber. So, from one chamber to the other chamber heat transfer happens. Hot box apparatus gives you more realistic estimates of heat transfer compare to hot plate, because it is more an idealistic condition. But, it is easy to test materials for say example you want to know what is the conductivity of a thin glass sheet or conductivity of a aerated concrete block then you can simply put it in a hot plate apparatus test, it you will know what is the conductive heat flow or the conductivity

The next parameter which is important is the conductance. Here, this is the heat flow through a material for a stated thickness. Now we are starting to include the cross sectional thickness of the particular material. So here this is like conductivity k by x is a unit thickness, so the unit is watt per meter square Kelvin.

So, this is where when example when somebody says conductance of a material, the first thing you should asking them is for what thickness. Conductance for a 100 mm thick brick wall 110 mm thick brick wall would be different from at 220 or 230 mm thick brick wall, because conductance is a includes a factor of thickness here. As the material gets thicker and thicker the conductance value is going to come down, because thickness is your denominator. Thermal resistance countries like US they do not refer to conductivity and conductance or the transmittance value rather they talk about r value or the resistance value it is the inverse of conductance.

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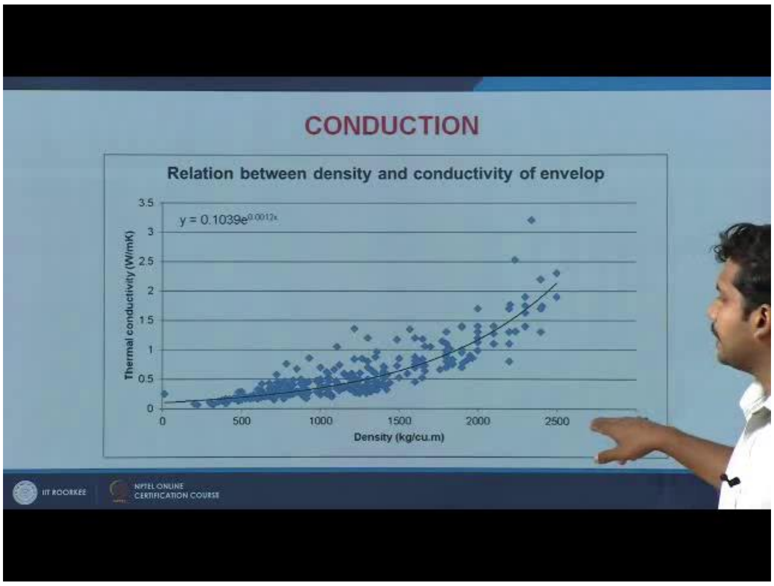

CONDUCTION

Actually this plot though I have plotted in x axis you have density of different material, these are common construction material. It starts from very low density material like glass wool insulation material and it goes as highest 25 100 thick dense concrete kind of material. I have taken different density material which are commonly used for building envelop its can be solid (Refer Time: 14:08) structural material versus insulation material from one end to the other end, here you have a thermal conductivity watt per meter Kelvin conductivity not conductance.

There is a strong relation between density of a material and conductivity of a material. As a density increases there is a proportional increase in conductivity. I would not say density is only factor determining thermal conductivity, there are other properties and it is but directly proportionate. In the most of the cases that is most of the materials there can be differences that is what I actually you see it is not like a linear relation it is a exponential relation, but typically as the density increases for most of the construction material used in building envelop the thermal conductivity is going to go up.

The next important parameter of the most commonly used parameter term is the U value. U value typically is referred as thermal transmittance, but more technically more precisely it is air to air thermal transmittance. So, you have a wall surface, if you carefully look at the cross section what are all the cross sections through which cross sectional elements through which is going to get transferred the most common thing you know take a brick wall 210 among thick brick wall with 10 mm plus around both sides. Totally it makes it 230 mm thick.

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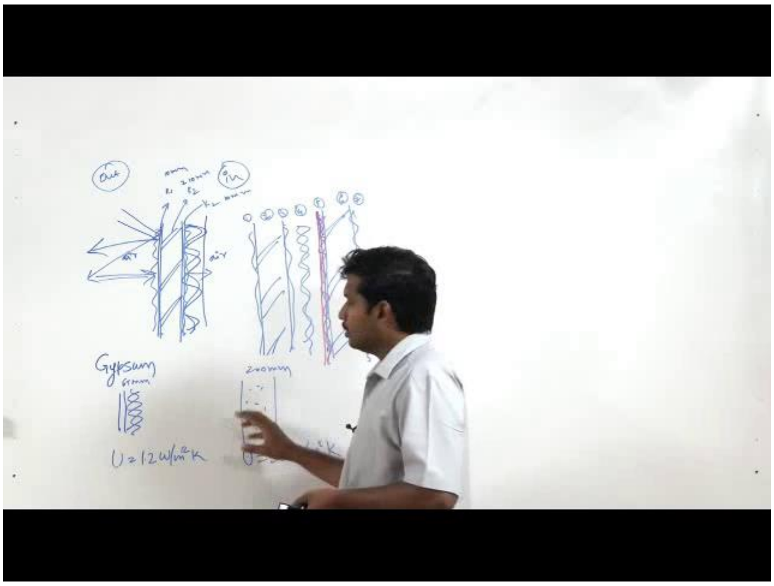

Now if you draw a cross section is going to look like this. You have a layer of pasture, then you have the brick layer, then you have the internal pasture. So, there is conductivity value for this, there is a connectivity value for this, and there is a connectivity value for this. Converse you have the thermal resistance. And the reverse you have a thermal resistance. But apart from this there are two other parameters which are here h naught and h I if you say this is outside and this is inside. Then you have a thin layer of air fill which adores to this particular surface, both outside surface as well as inside surface.

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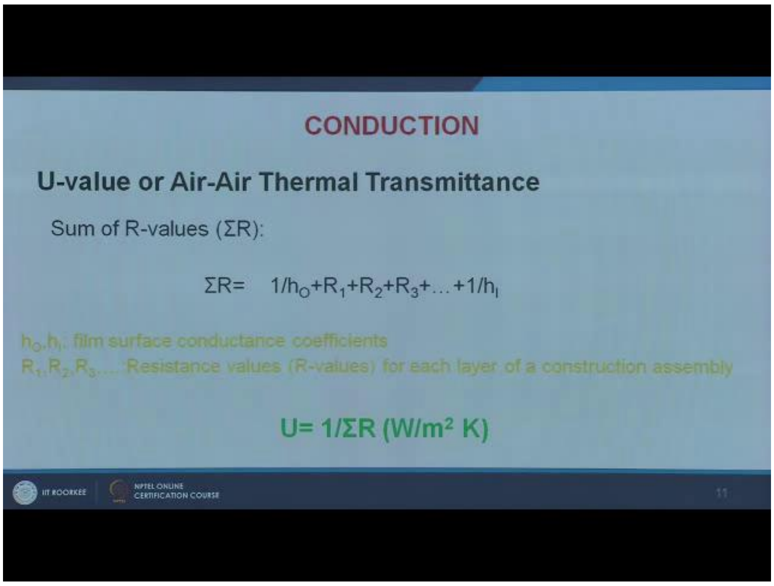

CONDUCTION

U-value or Air-Air Thermal Transmittance

Sum of R-values (ΣR):

$$\Sigma R = 1/h_O + R_1 + R_2 + R_3 + \ldots + 1/h_I$$

h_O, h_I: film surface conductance coefficients

$R_1, R_2, R_3, \ldots$: Resistance values (R-values) for each layer of a construction assembly

$$U = 1/\Sigma R \ (W/m^2\,K)$$

Actually, the resistance of this particular fill has a quite a significant impact on the total conductive heat transfer from outside to inside. This particular film coefficient also primarily depends on the surface characteristics of the wall as well as the environmental condition. We look at it more in detail. But, now to quickly understand there is k 1 which on the reverse if you include the thickness say now it is 10 mm, this is 210 mm and this is another 10 mm, this is out this is in. Together this gets you 230 mm brick wall, but apart from this you have a film coefficient out and film coefficient in. This exactly is what we are trying to look at. First we were trying to sum the r values that are the thermal resistance on total. Then we are taking a one by thermal resistance one by the sum of thermal resistance which becomes your U value or air to air thermal transmittance that is why we say now this is outside air to inside air that is overall air to air thermal transmittance is what is referred as U value.

The unit per U values watts per meter square Kelvin say must conductance take a close look at air films; you have an outdoor air film, you have an indoor air film it is determine by the surface characteristics as well as environmental condition. There are lot of reference table is as per as formulas to calculate lot of reference table is as full as formulas to calculate lot of people are conducting detail research in this field, but for a simple understanding of the subject there is a significant amount of variation in this film conductance outside as well as inside, for a rough surface versus a smooth surface, for a reflective surface or a emissive surface versus a less emissive surface.

It also depends on what is the relative humidity outside, it also depends on, how much air velocity, how much velocity of air is (Refer Time: 18:14) in this particular surface. Their film coefficient is going to be different when it is windy versus when it is a (Refer Time: 18:22). There is a considerable amount of difference here.

Another important factor we have to understand; though for simple building calculations are even some of the simulations we typically take a constant U value for a particular wall. Say the take the same case of 230 mm brick wall we often take U value something between 2.1 to 2.3 watts per meter square Kelvin. And this is a single value which is used for calculation through the year, but what happens with respect to the surface finished, with respect to the change in ambient temperature, ambient humidity, and ambient air velocity.

Then one needs to understand that the U value is not constant, but is it dynamic although the year. It varies from hour to hour, it varies from day to days season to season, but for total building calculations are load calculation say heating cooling load the impact of this film coefficient on the changing U value because of these ambient as well as surface characteristics is say about 4 to 5 percent; are still it is being research roughly about 4 to 5 percent which is not a heavy impact compare to the other contributors. For example, I want to introduce c insulation here the effect of this versus the effect of insulation is considerably different. Insulation has very high impact compare to the change in film coefficient.

So, often it is ignored, but still as a scientific number this has good amount of significance in the calculation of U value.

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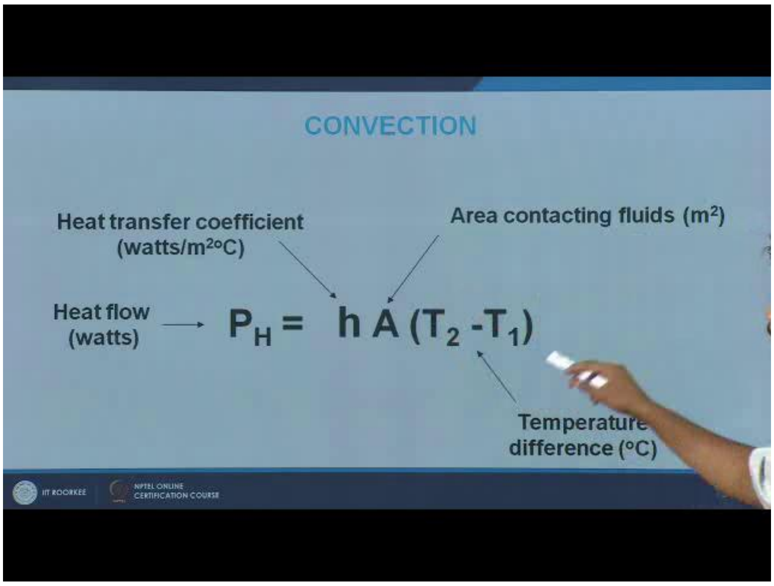

CONVECTION

Heat transfer coefficient (watts/m^{2}°C)

Area contacting fluids (m^2)

Heat flow (watts) → $P_H = h A (T_2 - T_1)$

Temperature difference (°C)

Then about convection, we often know, we always talk about air velocity and how it improves comfort. Convective heat transfer you have a simple formula again, you have H which is a convective heat transfer coefficient, then again A area contacting fluids it can be window or it can be say for example mechanical heat transfer it can be the fluid by itself then it is a temperature difference that is delta T this would give you the total amount of; there we referred it as Q here we calling P whatever the number it is a total heat transfer through convection.

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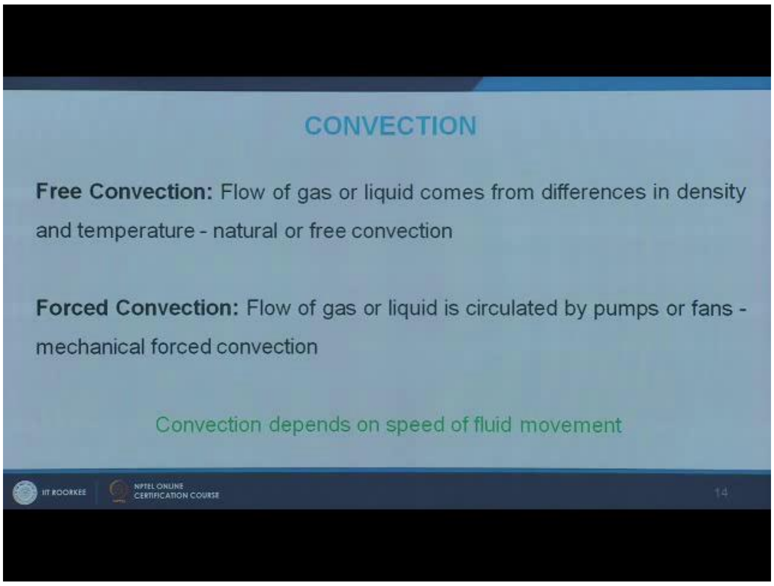

CONVECTION

Free Convection: Flow of gas or liquid comes from differences in density and temperature - natural or free convection

Forced Convection: Flow of gas or liquid is circulated by pumps or fans - mechanical forced convection

Convection depends on speed of fluid movement

Two types of convections are there; free convection, when the transfer of heat occurs or the moment of flow of gas are liquid occurs because of density and temperature difference the other is forced convection, where you have a mechanical system or a pump which is forcing the convective heat exchange. This is typically happening in air conditioning system where you have a mechanical system where you have a mechanical system forcing the heat transfer or forcing the flow of fluid on subsequently the heat transfer. This for example can be referred to the stack effect where the hot air raises up on the cold air settles down. This is a natural phenomena because of density and temperature difference of the air.

The convection efficiency depends on the speed of fluid moment. Simple example the more breezy the air you get more comfortable pretty fast compared to stain layer. Say you have an air velocity of 0.5 meter per second versus air velocity of 1.5 meter per second, so the comfort level considerably improves.

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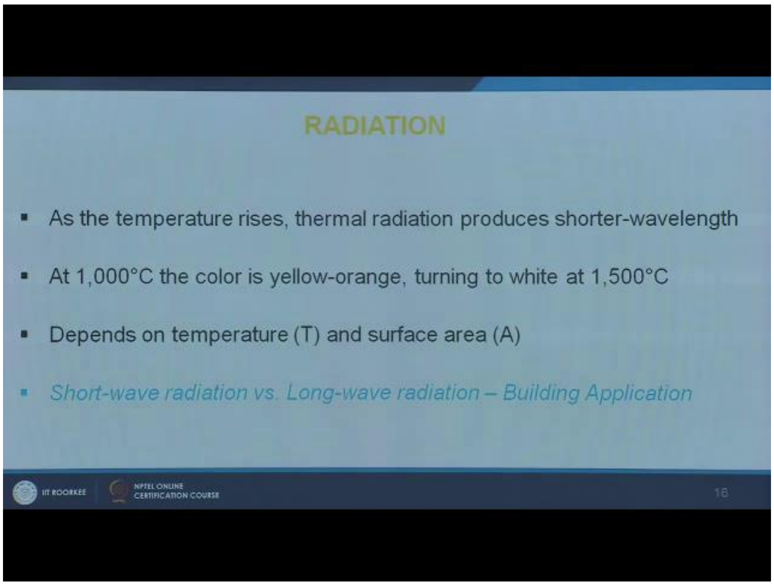

RADIATION

- As the temperature rises, thermal radiation produces shorter-wavelength
- At 1,000°C the color is yellow-orange, turning to white at 1,500°C
- Depends on temperature (T) and surface area (A)
- *Short-wave radiation vs. Long-wave radiation – Building Application*

The next mode of heat transfer is a radiate heat transfer, it is electromagnetic waves through which the heat is getting transferred it does not need a medium. Typically we know we get direct solar radiation it passes through the space without any medium. Thermal radiation is a electromagnet wave which includes light, some of the radiations we are able to see we call visible spectrum. We have ultra violet we have infrared short wave or long wave infrared and the thermal radiation varies with a respect to that temperature of the emitting surface, the higher the temperature of the object the more thermal radiation and it gives off.

As the temperature rises the thermal radiation produces more short wave length radiation. For example, typically the 1000 degree centigrade the color of light will be yellow orange and it would to turn white as the emitting surface increases in temperature. You should remember the heat transfer depends on the temperature of the emitting surface and the surface area which is receiving it. There are two types as we said, we are interested as per building applications; it is short wave of infrared and long wave infrared. Ultra violet the ozone layer is more or less observing the ultra violet radiation. As per buildings infrared is important, short wave as well as long wave radiations are important. The direct solar radiation which is impinging in a surface is short wave radiation a buildings surface observe it. And then while storing after storing it start reemitting it.

Once the reemit; the reemit in the form of long wave radiation, this is typically we refer in the form of glass houses are the green house effect in buildings. So, you have a glazed window, the glasses transparent in to short wave radiation it let us in short wave radiation. The internal surfaces get heated up and they reemit long wave radiation. Now the glasses more insulating towards long wave radiation, it does not allow the long wave radiation to go out. Because of this reason the indoor environments get heated up, this long wave radiations are trapped inside the room. Because of this you have warmer or hotter indoor environment.

So, typically use of glass is not or else simple glass without treatment non treated glasses are not advisable in the hotter region is mainly because they trap the reemitted long wave radiation.

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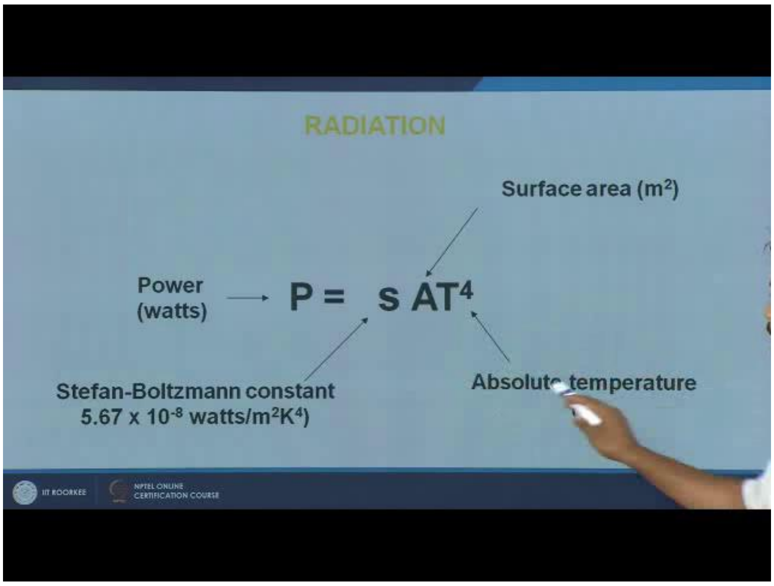

RADIATION

Surface area (m^2)

Power (watts) → $P = s\,AT^4$

Stefan-Boltzmann constant 5.67×10^{-8} watts/m^2K^4)

Absolute temperature

Radiate heat transfer can be calculated, you need a Stefan Boltzmann constant then the surface area and the absolute temperature of the emitting surface.

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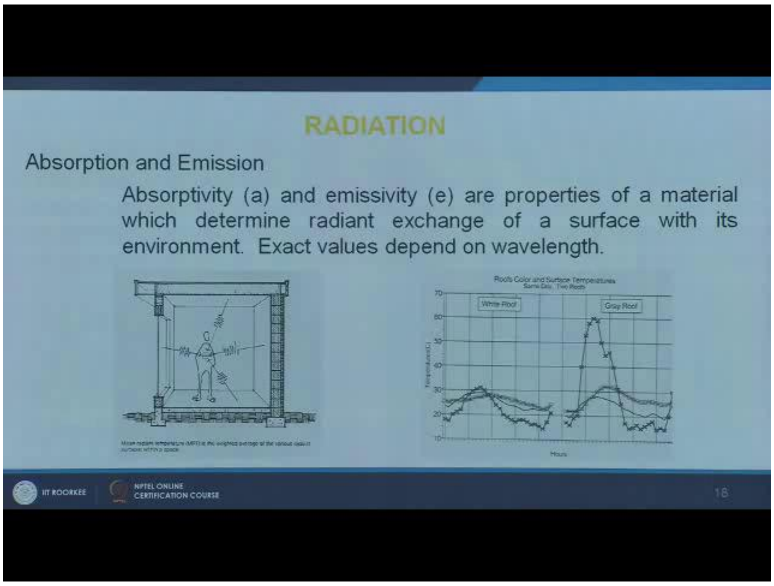

RADIATION

Absorption and Emission

Absorptivity (a) and emissivity (e) are properties of a material which determine radiant exchange of a surface with its environment. Exact values depend on wavelength.

We have two important terms here; one is the absorption other is the emission. You know often you get to see a term called absorptivity, it is expressed as a or alpha commonly people say the absorptivity of the material or if you want to calculate or you want to simulate there is always of parameter or a space where you need to enter the absorptivity of the material. And there is also another term emissivity; you commonly hear term emissivity, low emissive glasses (Refer Time: 24:30) glasses.

This is a emissive property, these are the two properties which determined the radiant exchange of a surface with its environment. It depends on the wave length of the radiation as well. Say you know white roof versus grey roof or a painted surface versus a unpainted surface, a black color painted surface versus a white painted surface, a mats finished surface versus a reflective surface.

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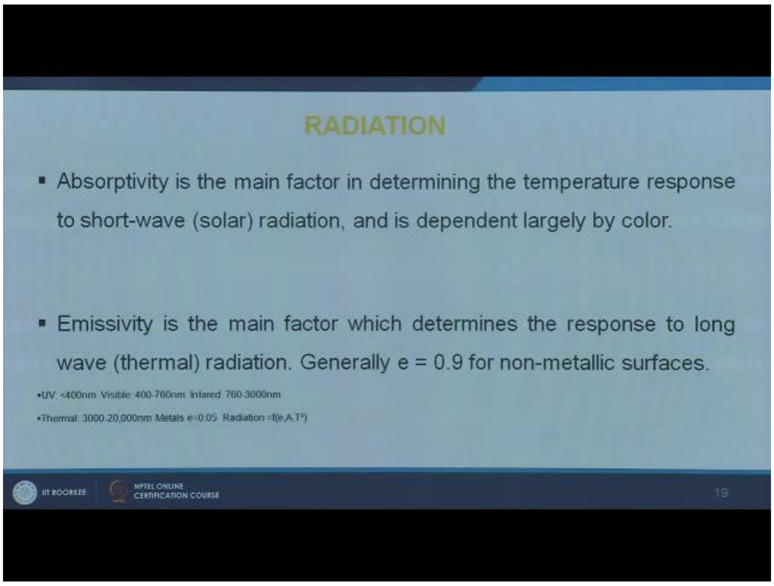

RADIATION

- Absorptivity is the main factor in determining the temperature response to short-wave (solar) radiation, and is dependent largely by color.
- Emissivity is the main factor which determines the response to long wave (thermal) radiation. Generally e = 0.9 for non-metallic surfaces.

•UV: <400nm Visible: 400-760nm Infared: 760-3000nm

•Thermal: 3000-20,000nm Metals e=0.05 Radiation =f(e,A,T^4)

So, absorptivity is the main factor which determines the temperature response in the short wave radiation, and it is dependent largely on the color. This is where we talk about a white painted surface versus a dark color painted surface. We say it as a absorb lot of solar radiation.

The next important properties is emissivity, is determines the long wave or the thermal radiation exchange. So, that is where the effect of low emissive or (Refer Time: 25:19) coatings come into application.

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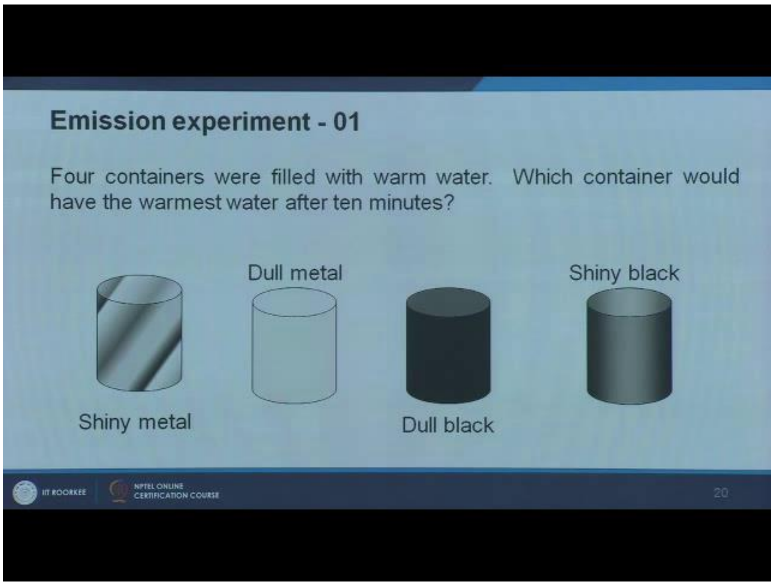

Emission experiment - 01

Four containers were filled with warm water. Which container would have the warmest water after ten minutes?

Let us take a look at quick a small experiment that we can imagine. Let us you know I have termed it a emission experiment, imagine there are 4 containers; one is the shiny metal container it can be like a aluminum or a (Refer Time: 25:37) shiny metal container. Then this is a dull metal container, it is not shiny. Third is a dull black container and the forth is a shiny black container. Imagine you are filling warm water similar temperature water in all these 4 containers, say take a 10 to 15 minutes times.

Now which of these surface which of these containers will still have slightly warmer water and which will have cooler water? If we able to understand this in a small scale then we will be able to have a better clarity and what happens in the buildings.

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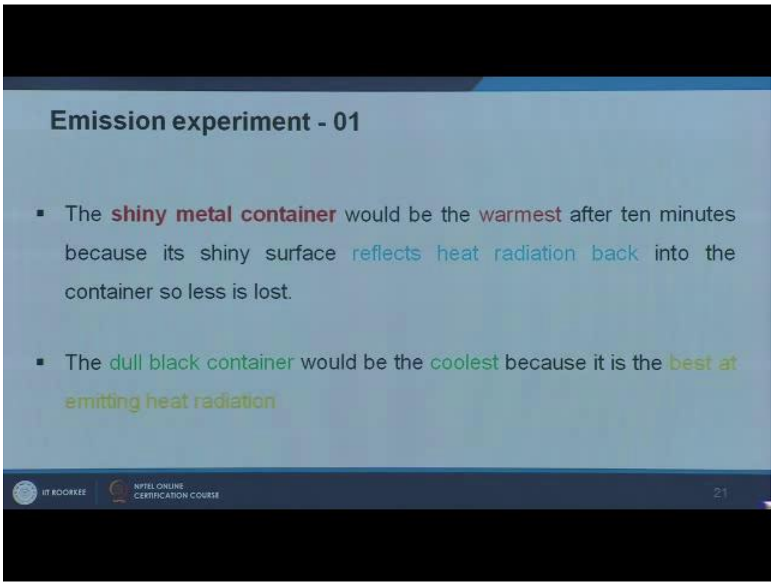

Emission experiment - 01

- The **shiny metal container** would be the warmest after ten minutes because its shiny surface reflects heat radiation back into the container so less is lost.
- The dull black container would be the coolest because it is the best at emitting heat radiation

The shiny metal container would have the warmest water after 10 minutes comparatively among the 4 containers, because the shiny surface reflects like the heat radiation back into the containers, so not much of heat loss happens. Whereas, the dull black container would be the coolest because it is based in emitting heat radiation. We have the black body radiator. So, it emits the lot of heat in that reason for that reason this shiny metal contain, water in this container retains more heat compared to the other one.

Similarly, you keep in the same part that is the same vessel you have warm water, but you are placing it equidistant from a heater. Say it is a radiant heater you are placing these container next to a heater at similar distances. Now, which will have warmest water after 10 minutes?

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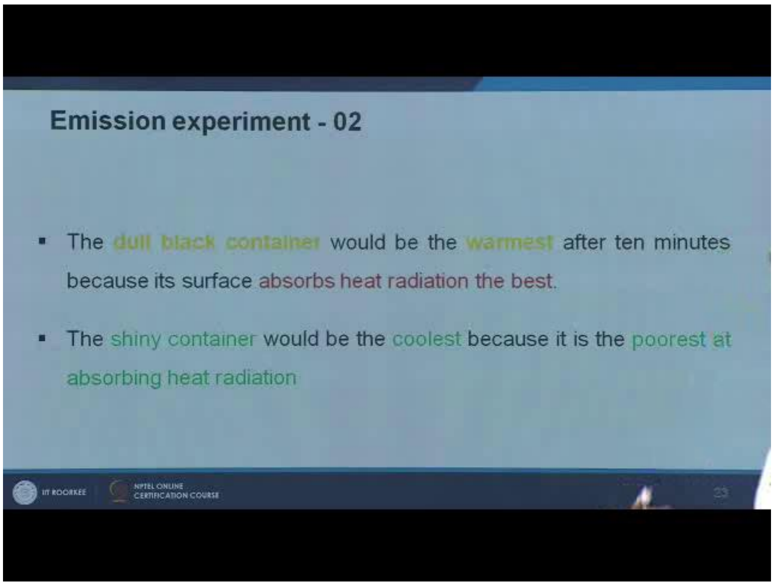

Emission experiment - 02

- The dull black container would be the warmest after ten minutes because its surface absorbs heat radiation the best.
- The shiny container would be the coolest because it is the poorest at absorbing heat radiation

Now it is a other way round the dull black container would be the warmest, because it is also a absorption you know it is a black body observer. It observes of radiant heat because of this the water gets warmer or at least it is able to maintain its temperature. Whereas the shiny container would be the coolest because it reflects most part of the heat it is poorest in absorbing heat radiation. The similar phenomena happen in a large scale in actual buildings.

Typically connecting whatever we have studied so far conductive convective and radiative mechanism.

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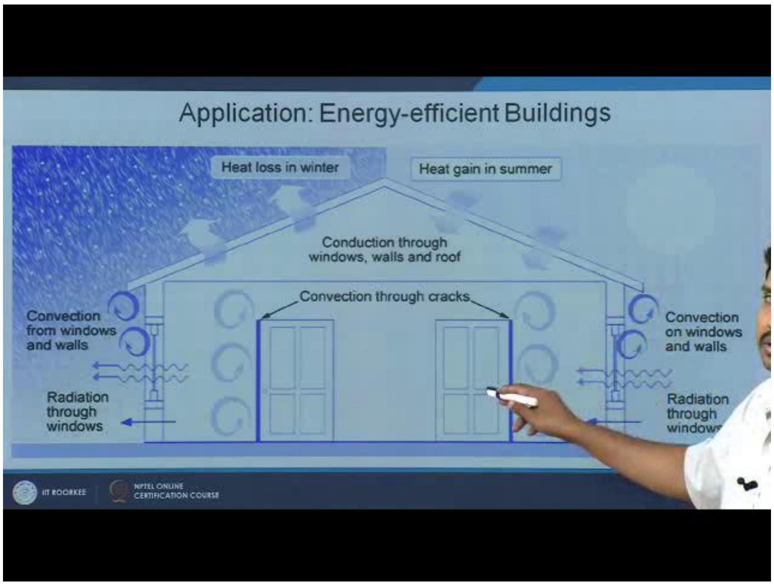

Application: Energy-efficient Buildings

What happens through the wall simple conduction phenomena that will looked at first it can happened through wall, it can happen through window, it can happen through roof or through the ground there can be conduction. Then the next thing is convection, where it can happen through open window or it can happen through mechanical system or it can happen through cracks in the doors and windows.

The third is radiation, the ambient is hotter that is a lot of short wave radiation is going to enter through the glass or glaze surfaces. Then indoor is getting heated up find a green house effect. Alternately the wall is also getting exposed to direct solar radiation it gets heated up and then you will find the wall reemitting in to the inside. This is also part of radiative heat transfer. Similarly, the opposite phenomena happen in winter.

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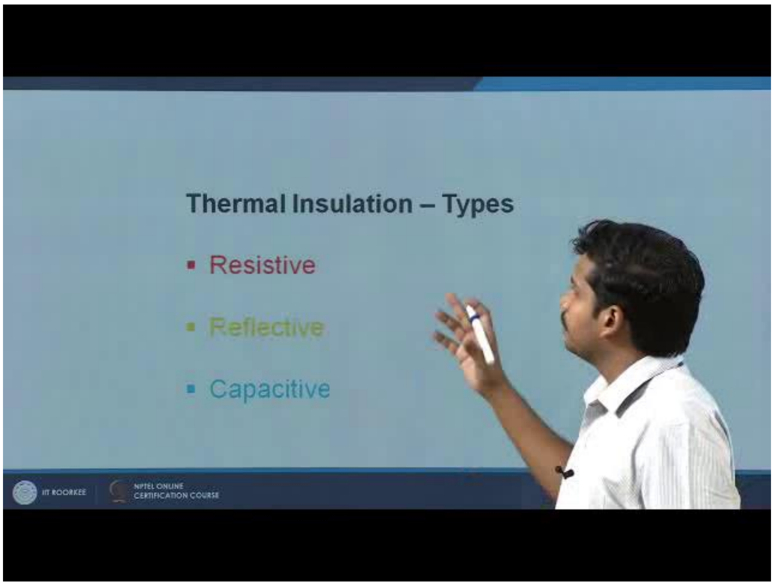

Thermal Insulation – Types

- Resistive
- Reflective
- Capacitive

Now looking at the types of thermal insulation, so the whole interest for us in studding these heat transfer in building envelop is to provide a better thermal envelop which can resist heat during summers and it can enhance heat transfer through during winter. It can gain more heat in winter and it can resist more heat during summer. The most common type of thermal insulation which is used or which is often refereed one and half in the field is a resistive insulation.

So, you have a always a companies selling products, they say this product has very low U value or the resistance value pretty high, r value of this much. We often talk about resistive insulation, here the primary mode of heat transfer which it attacks the conductive heat transfer. So, this is the first thing because of the thermal resistance there is inertia in heat transfer, so this particular wall has a U value. Now I am going to insulate this wall, then the conductive transfer is going to minimize. So, this is the type of resistive insulation.

The second type of insulation is reflective insulation. Imagine you have a reflective coating here which is going to reflect back the direct solar radiation. In this case the mode of the first shield you know becomes the first shield, alternately you have a wall, you have the second wall it is a double layer wall. Simple what happens now you have a air film you have a air film there is a third thing here. So, this is layer 1, layer 2, 3, 4, 5, 6 and 7. So, the heat transfers through seven different layers. Now let us introduce a thermal insulation here, this becomes resistive insulation. Next thing is for example, if I am painting this surface with the reflective coating. So, if I am able to say this particular membrane is going to be a reflective code I am introducing reflective thermal insulation.

The third or most rarely used insulation type is a capacitive insulation traditional. Architecture India especially has been relying on capacitive insulation. You see materials like you know granite, thick walls, massive (Refer Time: 31:13) walls being used in buildings. They were kind of capacitive insulation; they were taking advantage of the materials thermal capacity and its density in storing heat. They were using massive walls because the wall get heated up it stores a lot heat inside before transmitting it to indoor and evenings when the diagonal you know the range there were diagonal heat range is much larger temperature range, the night time temperature is pretty low. Before it gets transferred inside it is re-radiator outside.

So, this particular capacitive insulation was valuably used in our traditional architecture. But modern architecture we mostly relay and resistive insulation, you have some insulation material you can put it inside the wall outsider and center of the wall. Some cases reflective insulation is starting to the use now this is also effective, but capacity insulation say when you use a material like concrete. Typically people look at concrete as not so useful material because they think U value was of concrete is high. Say imagine concrete wall of 200 mm thick are 230 mm thick brick 230 mm has a U value of 2.1 watts per meter square Kelvin, whereas similar thickness 230 mm concrete wall whatever U value of around 3.5 or 3.6 watts per meter square Kelvin.

So, naturally if you do conductive heat transfer calculation, concrete wall will give you more heat load or cooling load because it is transmitting lot of heat inside. But what one needs to realize there is a lot of difference between the insulated wall say for example, imagine you have a gypsum wall which is a thin sheet plus glass wool insulation 50 mm you can manage the U value of something close to 1 or 1.2 watts per meter square Kelvin. Compare this is was the concrete wall 230 mm which has U value of 3.5. Now I am talking about two different things; first is a gypsum wall, one is a gypsum panel and then you have insulation imagine the U value is 1.2 watts per meter square Kelvin. Then I have a concrete wall, this will be about 36 mm, the concrete wall is to 100 mm, here the U value is 3.5 watts per meter square Kelvin.

Now, this U value is more or less three times of the gypsum wall. Advantage is if you calculate conductive heat transfer this is really advantage is if it is air condition if it is (Refer Time: 33:55) the whole thing works really in a good way. But if you talking about a naturally ventilated space what happens a part from this conductive mode there is also a capacitive insulation or the thermal capacity of this particular wall is high compare to when insulated gypsum wall panel. In this sense this particular material or any massive material is able to store a lot of heat one then reemitted back to the outside compare to what a thin insulated wall can do.

So, the third mode of heat transfer or a capacity mode of heat transfer is really valuable. This is exactly what we were doing in our traditional building. We are going to look at these types more in detail along with some indices which are really use for us.

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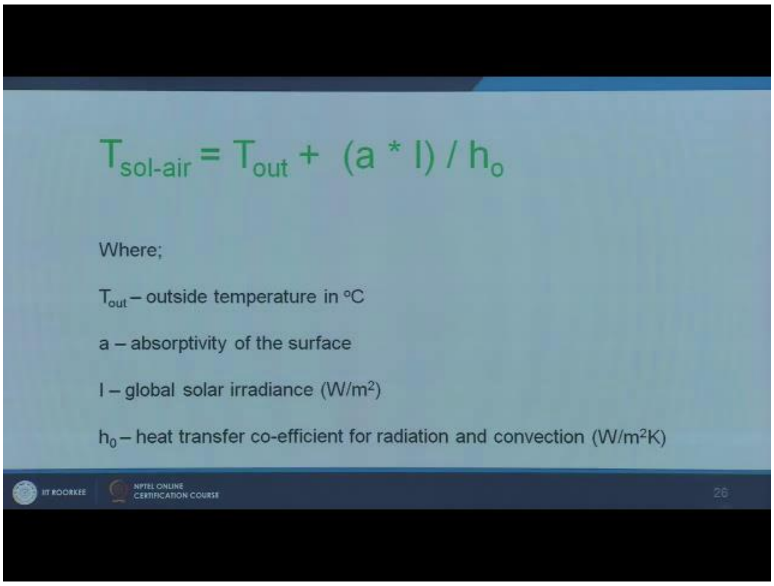

$$T_{sol\text{-}air} = T_{out} + (a * I) / h_o$$

Where;

T_{out} – outside temperature in °C

a – absorptivity of the surface

I – global solar irradiance (W/m^2)

h_0 – heat transfer co-efficient for radiation and convection (W/m^{2}K)

Before going into the next section one important thing we should understand while we discus about heat transfer through building envelop is a concept of sol-air temperature.

We did discuss about sol-air temperature in one of the previous module, this is a very valuable indicator. When we talk about delta T, you know what happens to the temperature here outside temperature outside versus temperature inside we were talking about T o and T i, but what is more important is what happens on the surface, what happens in this particular surface, what is a surface outside temperature and what is a TSI, what is the inside surface temperature.

These two parameters are crucially important. The ambient temperature say in summers in a hot drive climate may go up to 45 degree centigrade. But what happens there is a concept calls sol-air temperature where you have to add the effect of ambient air temperature along with the incident solar radiation which is following in a surface. Naturally when sun falls the solar radiation short wave radiation falls in a surface it also enough through radiative heat gain it also increases the surface temperature.

So, the surface gets pretty hot, when ambient temperature is 45 degrees on a say typically a grey or white colors surfaced all even the surface temperature in a east or south facing wall during summer is bound to go up has highest 55 to 58 degree centigrade. It considerably varies based on the surface property as well as the solar radiants and third is the heat transfer coefficients. This particular equation is really important. There is a factor of outside air temperature T out plus you have absorptivity of the surface.

So, here is where you a white color surface versus reflect you know that dark color surface. Then the global solar irradiance watts per meter square, the amount of solar radiation; as the amount of solar radiation goes up the sol-air temperature is going to go up. At dark color surface then the sol-air temperature is going to go up. The light color surface the absorptivity is less, so the sol-air temperature is going to come down. Then you have heat transfer coefficient for radiation and convection on the outside surface. So, as this going to increase sol-air temperature is going to come down. This has a slight effect marginally lower effect. This is a particularly important thing we are going to look at this further more in the next modules.

One quick information I wanted to give you as the sol-air temperature increases the discomfort hours, we talked about degree discomfort hours; the discomfort hours drastically goes up even with the different U value, the U value van be lower or higher but as the sol-air temperature increases that is the surface temperature here is going to up that is delta T is increasing the discomfort is going to considerably increase.

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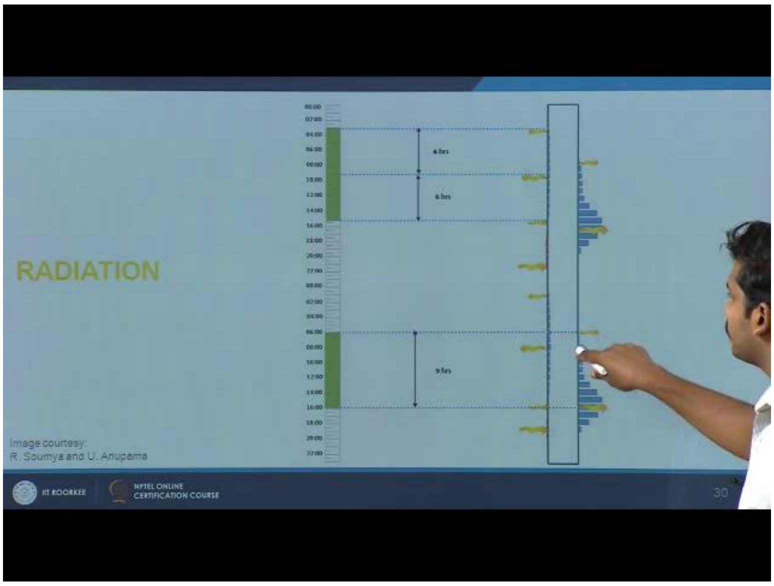

RADIATION

Image courtesy:
R. Soumya and U. Anupama

Looking back at what we were seeing in the first slide; imagine a material with a high thermal transmittance and low thermal transmittance the heat built up considerably varies because of which the heat transmitted indoor varies along with that the time taken for heat transfer also varies. We look at this further more in detail.

This is how connective heat transfer happens, the same wall with the closed window, the same wall with open window. How much amount of heat is gained or lost because of cross ventilation. This is about radiative heat transfer. The time taken for radiative heat transfer also considerably varies; there is sol-air temperature. Apart from this; this is going reemit into the building and then it is going to absorb and reemit it outside the building. So, three modes of heat transfer and how it is used in buildings.

To quickly wrap up we looked at the fundamentals of heat transfer through building envelop and we looked at few applied examples for a better understanding of heat transfer.

Thank you.