Architectural Acoustics
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Lecture – 08
Indoor Acoustics, Reflection and Absorption

So, good morning students welcome to the NPTEL course on Architectural Acoustics. This course is the as you know it is divided into 8 week and we are in the second week, second week lecture number 8, the Indoor Acoustics and Reflection and Absorption of Sound.

This week lecture was started with Dr. Sumana Gupta and the room acoustics is initiated, in that room acoustics we came to know some principles and, some observations of sound and the behavior of the sound in the interior. Today, I will going to deal with the reflection and absorption, which are the two major phenomenon in indoor acoustics.

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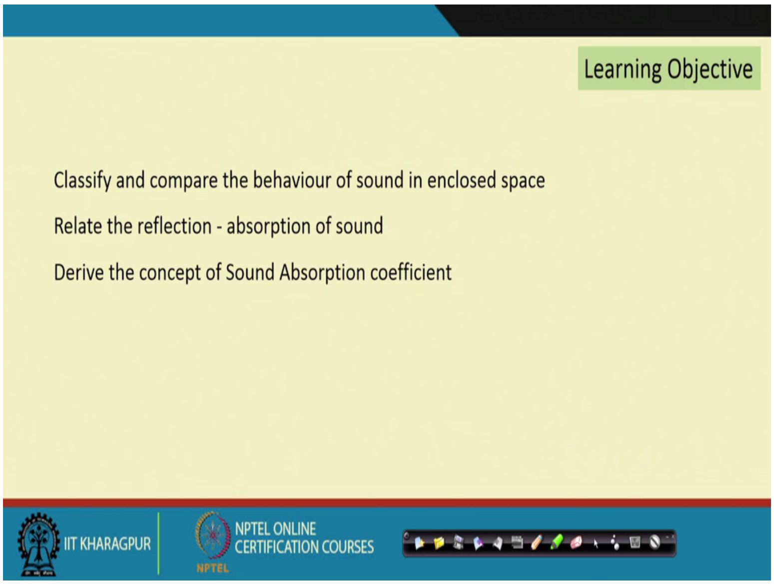

So, we have some learning objectives in that we will try to classify and the compare the behavior of the sound. How in the behavior of the sound in the enclosed space will going to behave and, what is the follow up classification of that he also going to know about the absorption and the reflection and relate that these two phenomena in a particular room acoustics domain, will derive some concept and from that concept our major goal will be the derivation, or the understanding of sound absorption coefficient.

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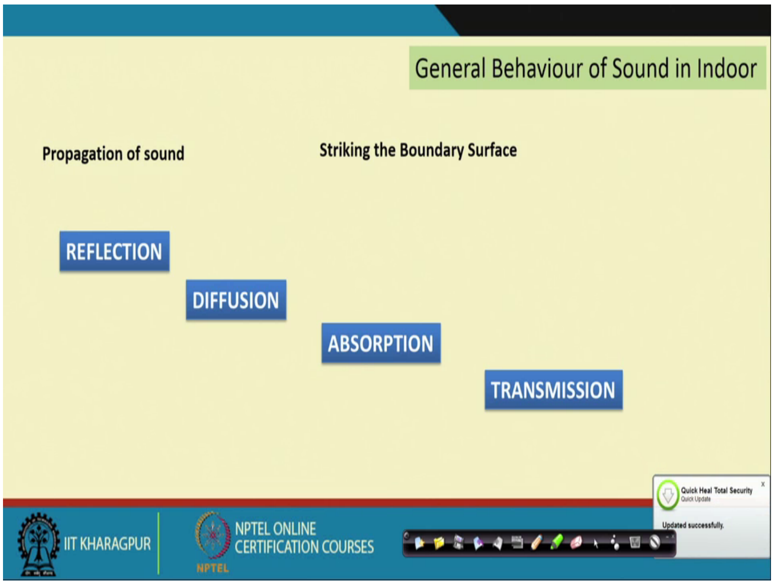

So, let us start with the some phenomena. If you see the general behavior of the acoustics, in the sound in the interior, the propagation of sound where it is strike to a boundary element, or the boundary surface because, you know that the indoor is actually the closed by six surfaces in a particular space is closed by six surfaces. So, when it is strike in some the some of the boundary surfaces there are typical phenomena occur.

The first one is reflection, the second one is called diffusion, the third one is the absorption and, the fourth one is transmission of sound. So, all those 4 phenomena are very important in the domain of the understanding of the room acoustics. So, we will discuss one after one, I know that doctor Gupta has already thought about the reflection diffusion and all, but we will just go in a brief manner and we will try to visualize the phenomena in a different way.

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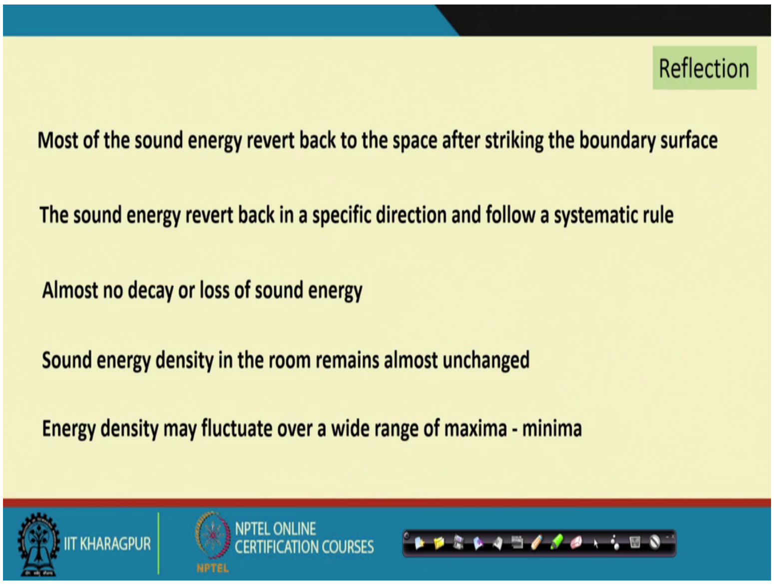

The reflection of sound is actually when a particular sound strike in a boundary surface and, it is revert back so, it will go to a particular direction and, this direction is follow some systemic rule which is a reflection law of reflection, which is very similar to the law of reflection for the optics. So, if there is reflection. So, the amount of sound energy is incident on a particular surface will reflected back, revert back so, the almost no decay will occur in the sound energy almost no decay, it will be some decay will occur, but it will be very less.

So, by these phenomena when there is a reflection and there is a regular reflection in a symmetrical or the systematic way, then the sound density the energy density in a room will be remain almost unchanged, another important thing is that the energy density will fluctuate over a wide range. So, suppose you take a particular corner of a room and, there is sound energy density, another corner there may be a some different density and this fluctuation having a wide range of minimum maximum.

As you already know if there is a concave surface, it will disperse if it is a convex surface, it will sub merge or a kind of a the converge in a particular point which is called a hotspot. So, those are the typical phenomena for the reflection.

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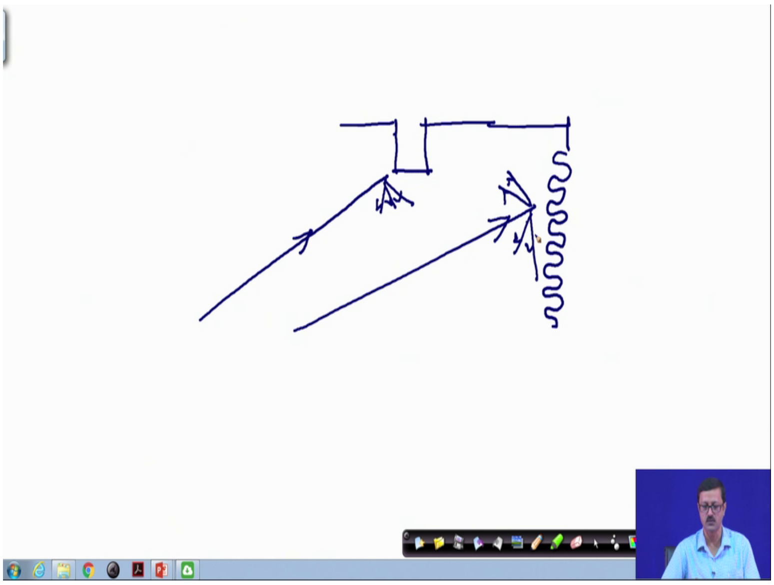

Now, for the diffusion it will happened, if suppose if there is a being that projected out, or may be in a wall there are some kind of the curtains. So, in this case suppose I take a energy or sound path, when the sound is incident on this beam there will be some kind of diffraction. So, there will be the it will obey the reflection of sound the law of reflection of sound, but by virtue of the change of order of the dimension, or may be a there are heavy poles it will going to diffract.

So, if there is any such phenomena, or any such the boundary conditions are of different geometrical shape, it may the regular reflection may lead to a homogenous diffusion.

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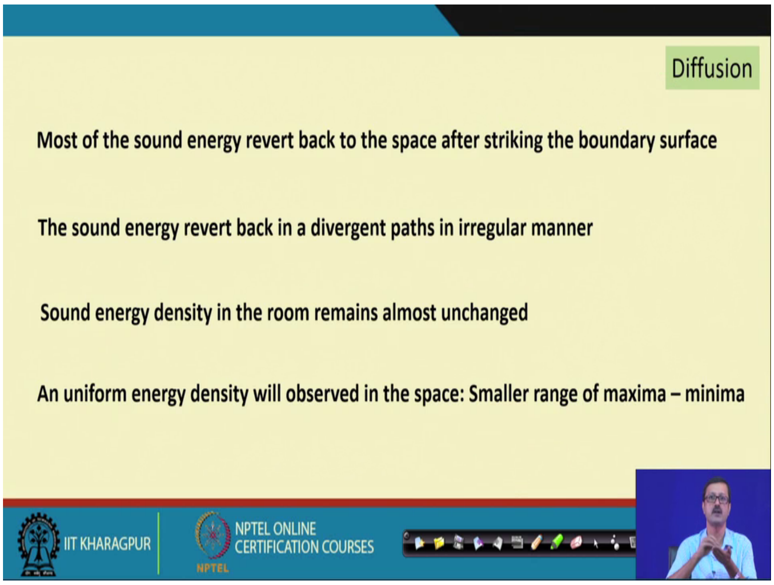

So, let us go to the next slide. So, the diffusion is in case of the diffusion most of the sound is revert back, after striking the surface which is very regular like the reflection, but it will be a diffracted back or the revert back in a divergent path in a irregular manner, which is the one of the significant difference between the reflection and diffraction.

The sound energy density of the room will remain unchanged because, there is almost no loss it is reflection like reflection only, but uniform sound density will be absorbed and, the maxima minima in the various point on the of the building, or the space will now will be a smaller range. So, you will get a almost uniform sound level all over the room.

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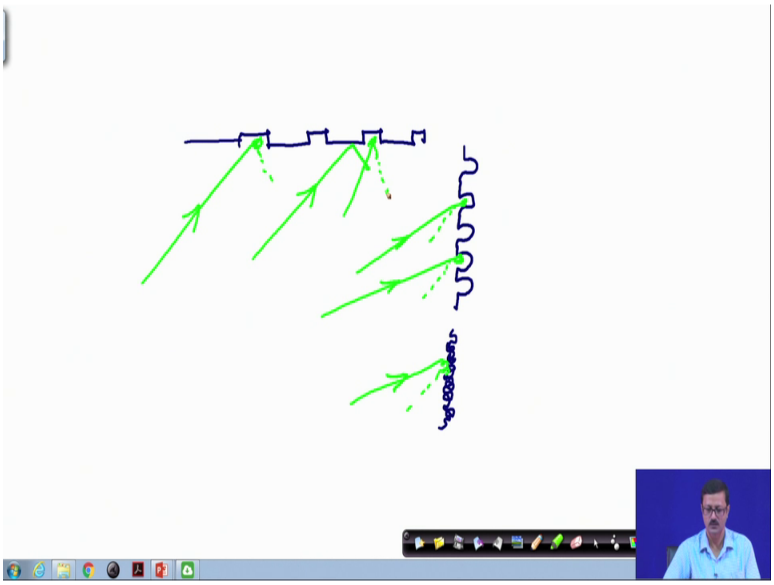

The next one is absorption the absorption criteria is again a very interesting criteria and here by virtue of some kind of surface boundary conditions, or maybe there is some and the ceiling there are some kind of the regular cavities, or maybe there are some very fibrous material. So, depending upon these particular surface conditions, the sound energy will interact, there may be a reflection, but in some of the because of the dimension of this particular recess it will be interact.

And due to that the revert back of the sound path, or the sound energy will not going to happen, or there may be a very minimum amount of energy will revert back or reflected back. So, this is a typical phenomena of the absorption of the material of absorption of the sound in interior and, again let us go back to the power point presentation.

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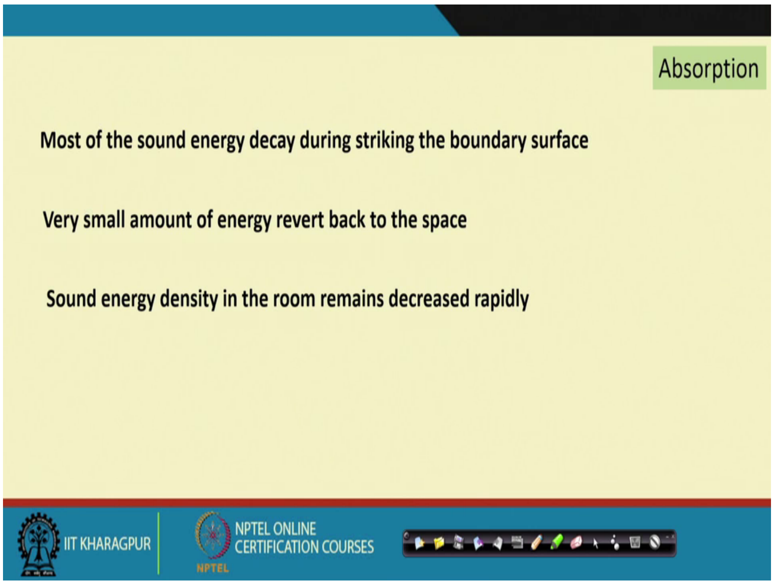

So, the most of the sound energy decay during the after the striking off the boundary surface, because of some kind of physics behind it, or some kind of the frictional loss or some kind of the mechanical loss, the very small amount of energy will revert back to the space, I have just now it is discuss that one and, the sound energy density of the room will be rapidly decrease because, nothing has to become again into the space.

So, most of the sound energy, which was fallen upon a particular surface that will going to absorbed by the surface. So, there will be no such the reflection back of the energy.

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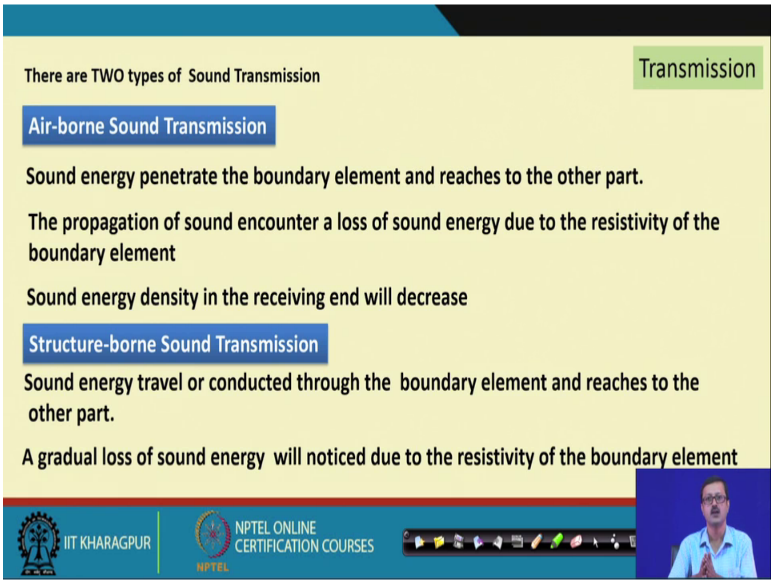

The fourth what we have discussed as a part of the behavior of the sound in interior is a transmission. And, there are two type of transmission one is called the airborne sound transmission and, one called the structure bond sound transmission.

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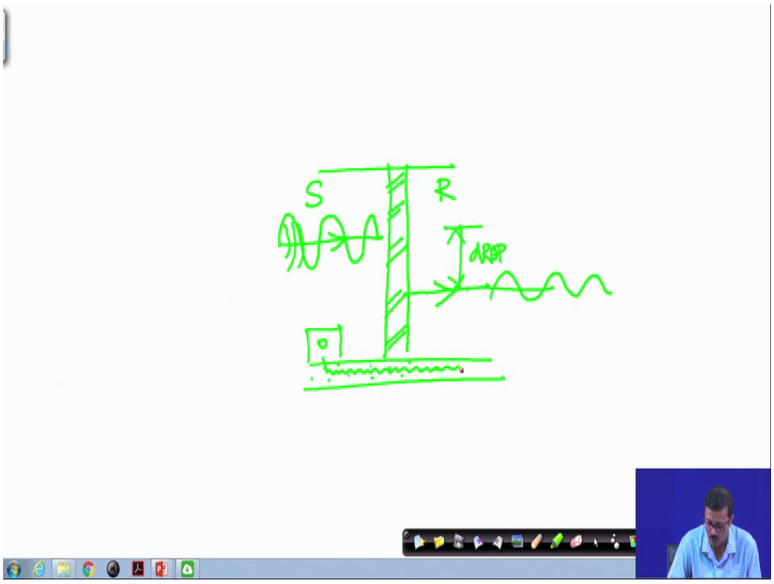

Suppose this is a particular wall, brick wall or may be any wall of any such material and, this is a resource room and, this is a receiving room and, there is a sound which was a high level sound incident on this particular partition wall between this two room and, when will see if you see the propagation of the sound and, when it travels by transmission by between this particular wall, which is the partition wall the sound level will going to drop.

And the propagation of sound or the amplitude of the sound will be little low. And this is the airborne sound transmission, very similarly there may be a structure borne some transmission because, may be this is a concrete slab and, there is some kind of a machine, or some object, which create some kind of vibration and sound. And the sound will travel through this particular surface itself and, propagate and enter into the other receiving, or more than other room and, this is called the structural borne sound transmission.

So, in structure borne sound transmission and the airborne sound transmission has to very different approach, I mean when we actually deal with the stoppage of that particular transmission sound and, we will discuss in the later part of our discussion. And the structure borne sound so, in case of the airborne sound the sound energy penetrate from the boundary element and, it will reaches to the other part of the thing and, it will be created by some kind of a vibration or some kind of the resonating effect.

Where as in the structure borne sound, sound will travel through the material itself the envelope material of the building, or the building or the room itself and, it will where, it will propagate there will be gradual loss of the sound energy and, it will propagate from one point to the other point. And the how much the loss will be occur it will be depend upon the what is the resistivity of the material again the sound path.

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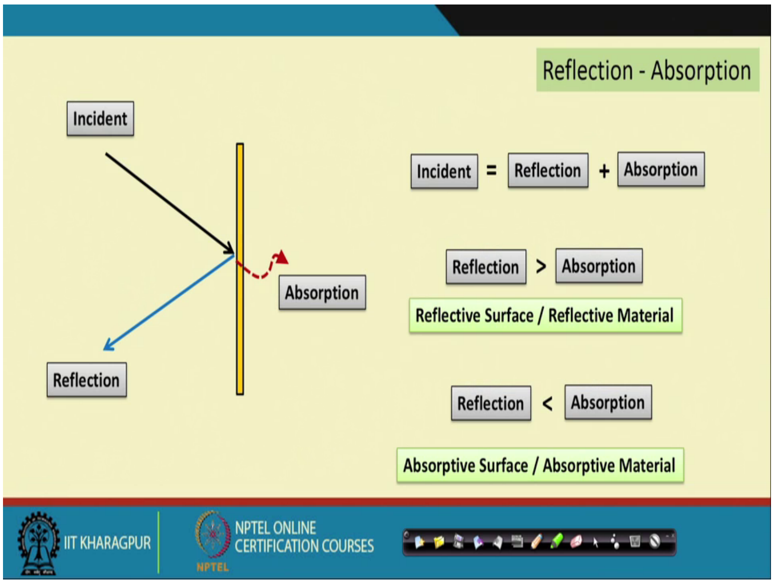

So, let us go to the next phase of my presentation, where I will now discuss the reflection and absorption. Suppose in a this yellow stick is a supposed a surface and, there is the incident sound ray, or the sound energy is fall upon that particular surface, there will be a reflection and there will be some absorption.

So, I can say that the incident energy, or incident amount of energy must be equal to the reflection energy and plus the absorption energy and, there will be some two or three cases, one case is suppose the both are same. So, it is a non reflective or non absorptive kind of a surface. And, when the reflection is much much higher than the absorption I say it is absorbed reflective surface. And, when the reflection is much much less with respect to the absorption then it is a absorptive surface.

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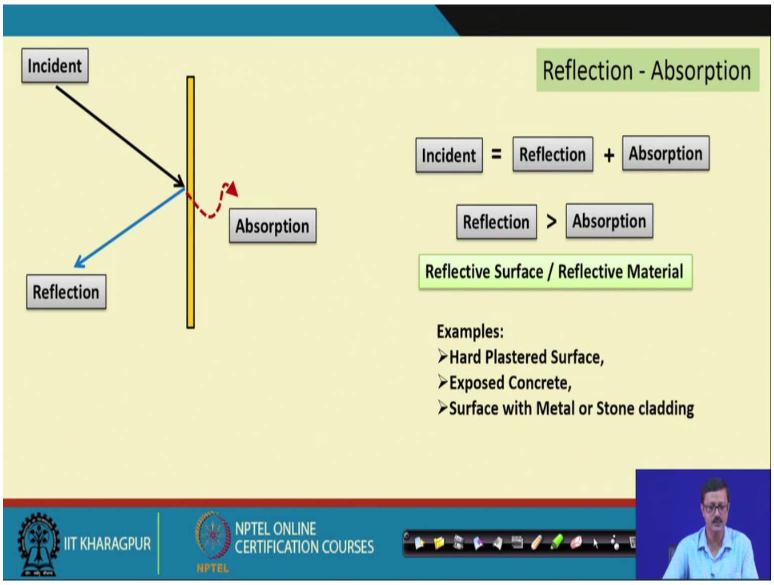

So, in this figure what we have shown is that is reflective surface and, the absorption part is quite less with respect to the reflection part. And the surfaces which is very popularly known for a very actively participate in the reflection is the hard plastered surface, exposed concrete surface metal surfaces, or stone cladding those kind of the very hard surface.

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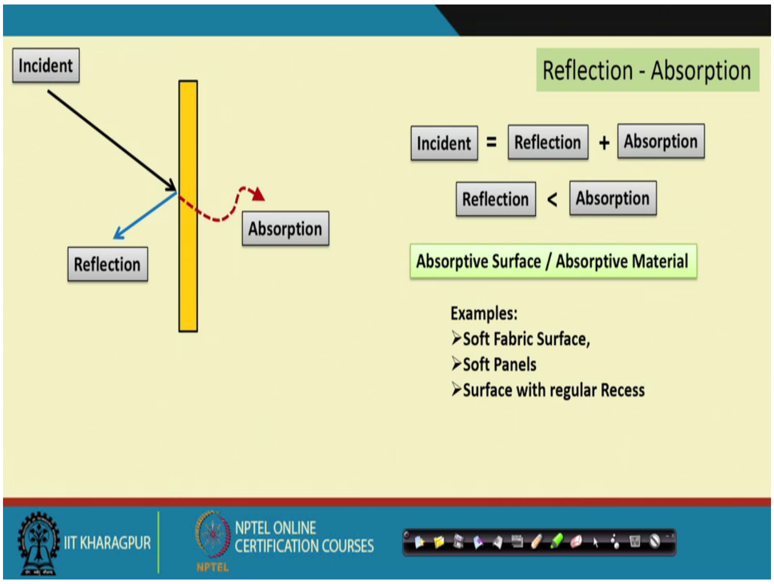

In other hand the absorption is where the amount of reflection is less and the amount of absorption is more by, virtue of some the nature of the surface material. And I have shown here in this particular figure you see, the blue line which is a reflection line is quite smaller with respect to the dotted red line, which is absorption. And absorptive surfaces are quite soft surfaces with respect to reflective, it is soft fabric, soft panels, surfaces with various irregular regular resources both all are act as a absorptive surface. And they have different further classification also.

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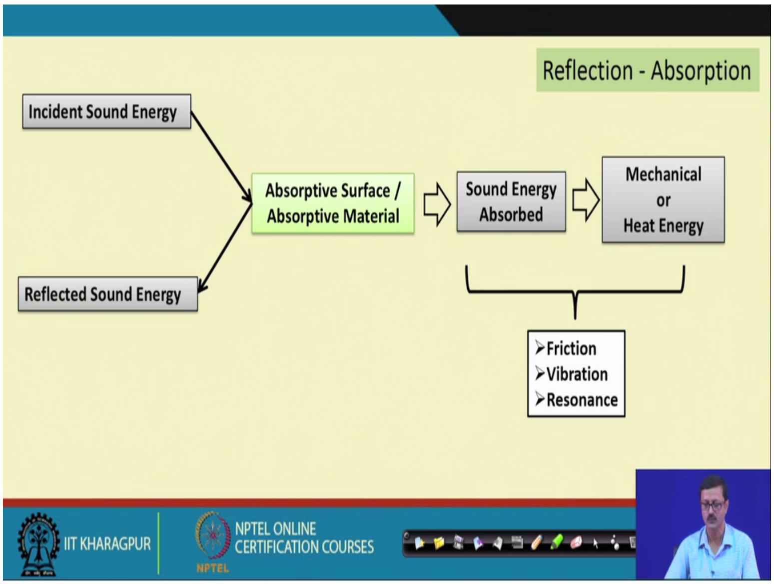

So, in general the absorptive surface material or the absorptive material, can act like I mean the way it actually handle the absorbed the energy is finally, translate it to the mechanical, or the heat energy, which energy is actually sound energy is absorbed which is going to the translated, or the transform to a mechanical, or heat energy. And by how it will actually transform the heat, or mechanical energy from that point of view there are three classification of the sound absorptive material one called fictional absorbers one is called vibrating absorbers one another is called resonating kind of absorber.

So, in the next week Doctor Sumana Gupta will tell you in detail what is the various significant difference between them and, how and where to adopt this particular absorber for better sound environment.

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Now, let us when we talk about this absorber, let us find out some coefficient, or some physical quantity or parameter from where I can actually measure and actually compare between two absorber.

So, that is why a non dimensional quantity called absorption coefficient of popularly as a sound absorption coefficient is taught of equalizer. Sound absorption coefficient is part of the sound absorption coefficient is defined as the ratio of amount of sound energy, that is incident on a particular surface and the amount of sound energy that is going to absorb by a particular server. So, actually it is absorption by the incident energy.

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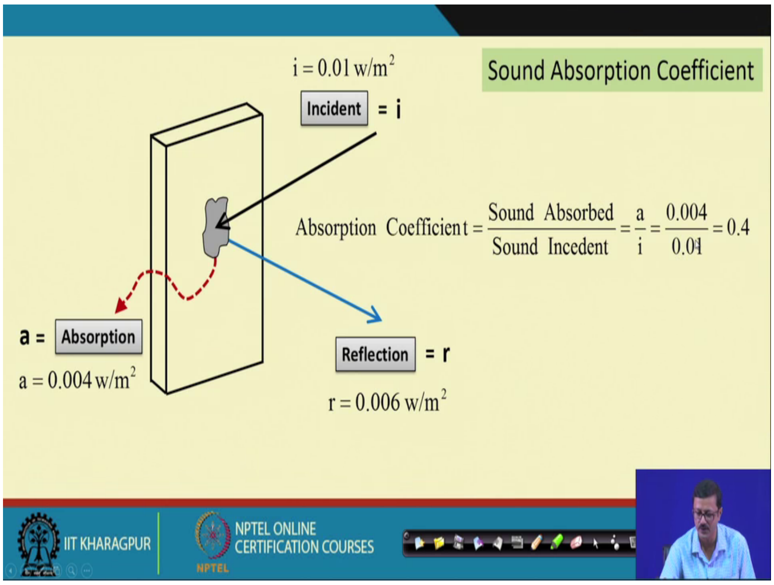

So, as I know the incident energy is equal to the, this equal to the reflection plus the absorption. So, definitely this is absorption will be quite little less with respect to the incident. So, the value of the absorption coefficient will lie between not more than one, I mean lie between 0 to 1 that fluctuate between the 0 to 1.

So, suppose this a panel in this particular slide you see and, there is a incident energy of I, which fall upon a particular area suppose the unit area of one meter square. And there is reflection which is r over here and, there is absorption of a. So, by definition the absorption coefficient is a by i and, this coefficient is going to suppose if I get some kind of the sound intensity. Suppose the initial incident intensity is 0.1 watt per meter square and, after reflection a very fewer amount of 0.006 watt per meter square is reflected back to the room.

So, 0.004 watt per meter square is absorbed. So, I can say the absorption coefficient of this particular panel is 0.4, because a by i is 0.004 by 0.001.

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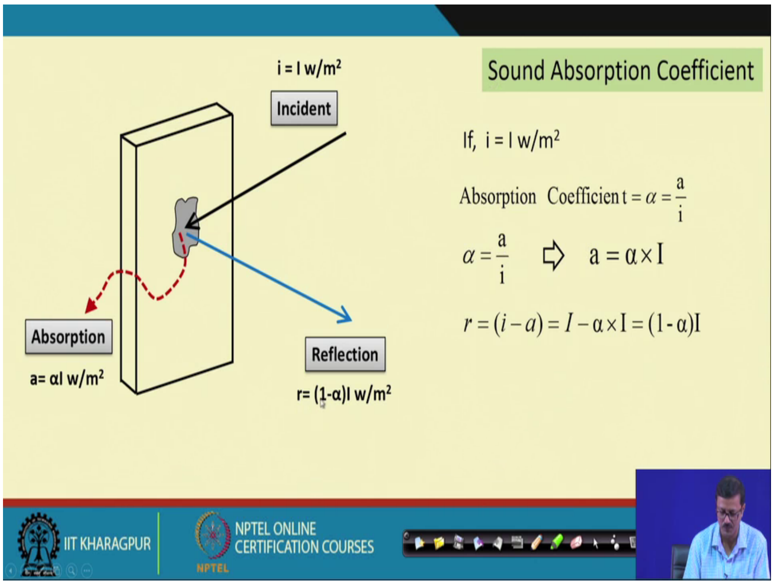

So, suppose now there I can write the like, you I watt per meter square this is just from the last slide, if I say that the initial incident energy is i watt per meter square the particular intensity and, after reflection let us have this reflection coefficient as alpha.

So, alpha equal to a by i, so then the a is equal to i alpha times i. So, that much is absorbed alpha times i. So, what is remain with me in the room after the reflection is i minus alpha times I, because alpha times I is actually absorbed. So, this much amount of left with me in the after the reflection. So, the reflection will be one minus alpha whole into i.

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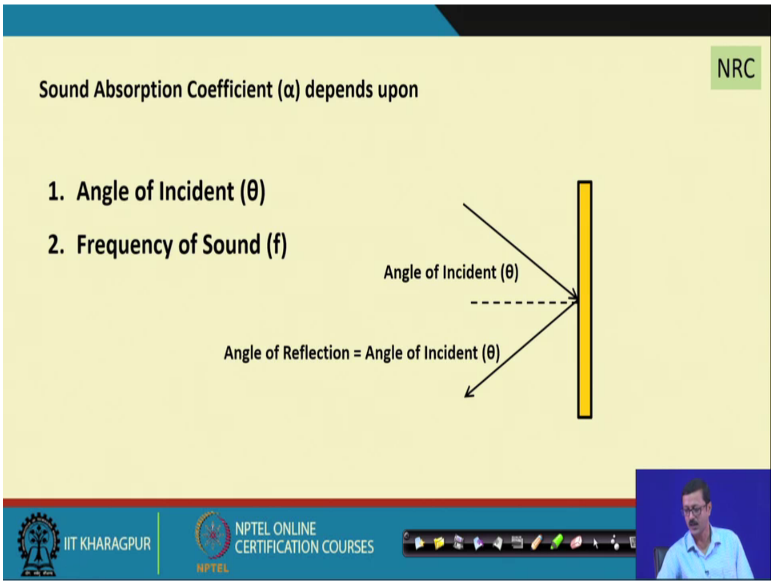

Now, this alpha the value of alpha, or maybe the absorption coefficient alpha is depend upon two quantity or two phenomena, or two parameter the 1 is angle of incidence and another one is the frequency. So, as I have already told you that this particular angle of incident will be equal to the angle of reflection. So, this reflection law of the optics will follow also in the sound.

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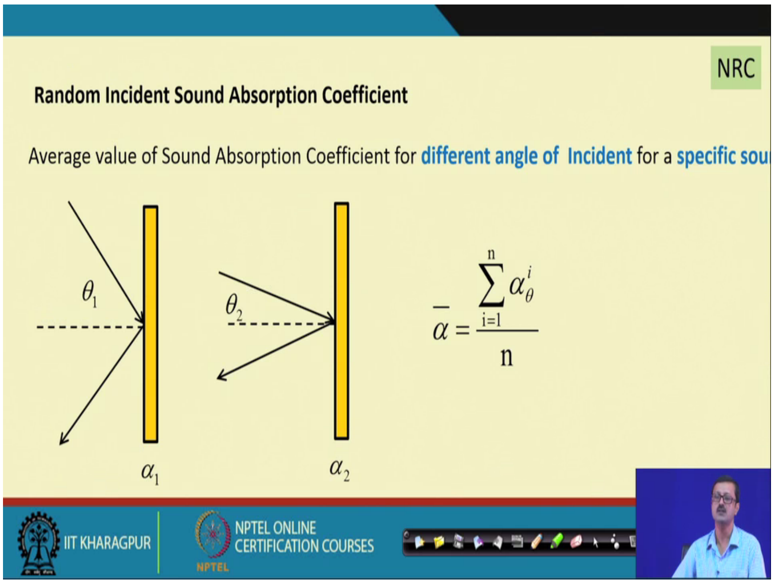

So, we will get different amount of alpha values for different amount I mean angle of reflection.

Suppose if I test a particular panel with theta 1 angle, I may get a alpha 1 for that so, the absorption versus the incident is this ratio is alpha 1. Now, suppose in the second test I change the value of the angle of incident to alpha 2, alpha 2 is less than suppose alpha 1, or may be more than alpha 1 also I am sorry the less than theta 1 or the less than more than theta 2, then suppose in case of the second I am getting a absorption coefficient of alpha 2.

So, I have to take a particular value I cannot actually go for only alpha 1, or maybe a specific value so, I need a average. So, I will do this particular experiment for so, many times and maybe n times and I will add up and then finally, find out the, what is the average. And this average is known as depicted as alpha bar and, it is known as the random incident sound absorption coefficient because, it is based on the first parameter that is the angle of incidence the alpha values. So, I am taking the average of that particular alpha and the random average has been taken.

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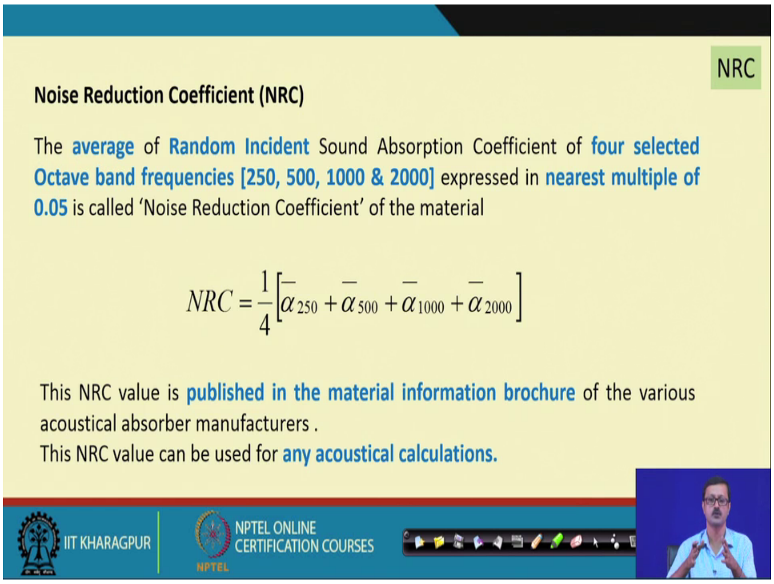

Now, second is consideration is it is also depend upon frequency. So, if I change the frequency from someone maybe one octave to the other octave, the value of alpha will also going to change. So, how can I handle that one? So, we bring another kind of a coefficient called the noise reduction coefficient, which is a the again a average kind of a thing from the alpha, or the sound absorption coefficient. So, what we do they were here is that, this average random coefficient or the random incident absorption coefficient, which is alpha bar is calculated for four selected octave band frequencies 250, 500, 1000 and 2000 hertz, because this middle band of the frequency 250 500 1000 and 200 is the most used frequency in our normal environment for any kind of speech music and all.

And we will take the average of that. So, I have written down that one fourth of those four, random alpha values. And it will be actually express nearest multiple of 0.05 and this is called the noise reduction coefficient of any absorbed panel. And that is the end of it because this particular NRC value is actually published in the material information brochure. So, if you purchase any material and, if you want to note what is actually it will behave as the absorber, you must read the NRC value of that.

So, if you see the NRC value is little high or very high or very low. So, we can see it is a good absorber or not so, good absorber or reflector. So, and this NRC value will be actually taken for any kind of calculation, we may say in our in our discussion or sometimes in our right up that it is sound absorption coefficient, but actually it is mean the NRC value of the panel on the surface.

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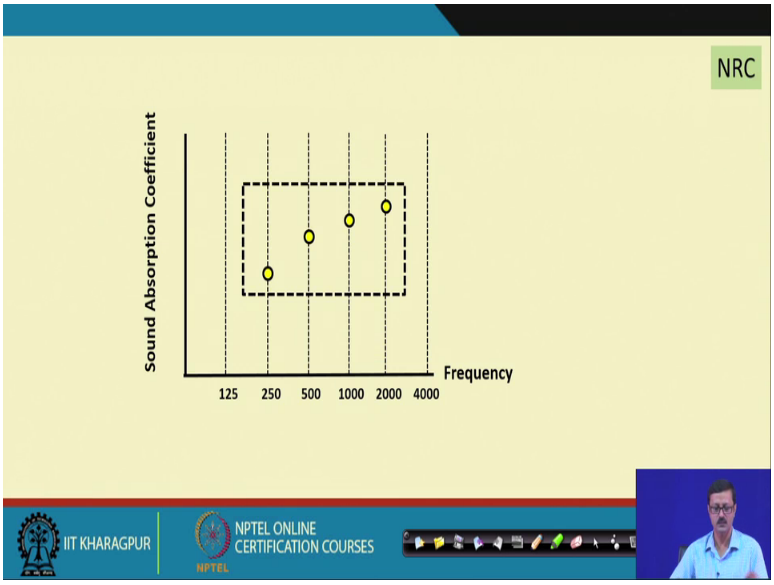

So, there are this kind of 4 band has taken and, we can plot the this four different frequencies sorry different sound absorption coefficient, with respect to the this 4 middle band of the frequency octave band frequency and, we can get the average value of that one fourth of some of those and can say that that is the NRC value of the material.

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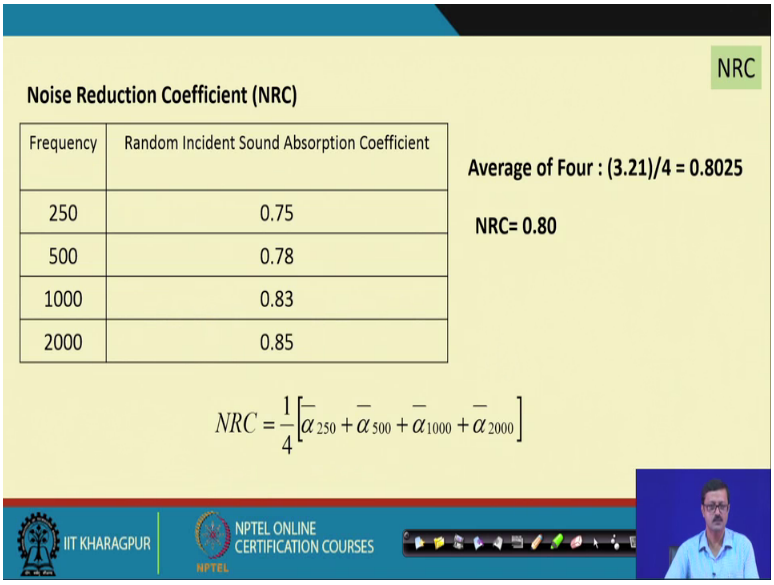

Now, let us a small example I have just put an some values 250 for that is 0.75 78, or 500 0.83 is for the 1000 and 0.85. So, the average of this four is actually you see this is 0.8025. So, by definition you have to round up by 0.05 so, the NRC value will be 0.08.

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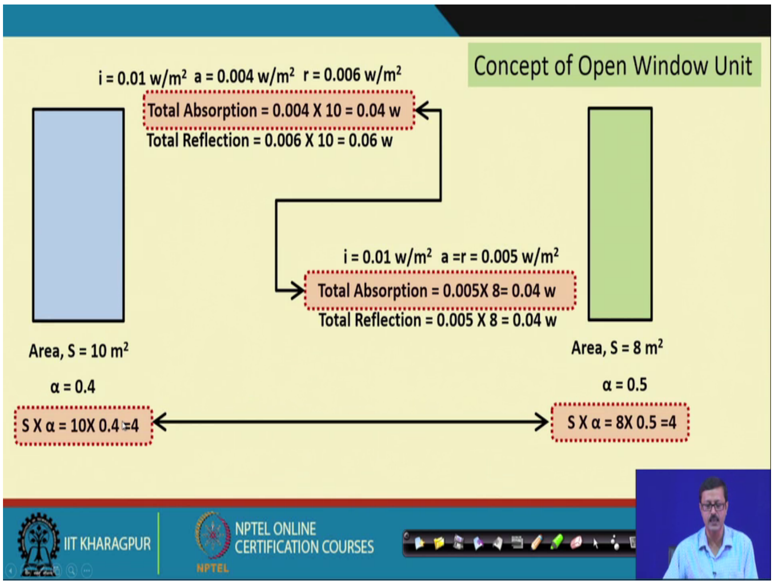

Now, the concept of this particular absorption and, how it will be actually relate to a certain other in unit for of absorption or so, as we remember or we have already discuss thus the value of alpha that is this coefficient is unit less. So, suppose I have a area of a panel which is having 10 meter square of area and, this 10 meter square of area is having the alpha value of 0.4. So, I can say that a if I the incident energies in density is 0.1 watt per meter square it will reflect back almost 0.004 and I am sorry, you reflect back 0.006 and absorb 0.004.

So, the total absorption is 0.004 watt per meter square into 10; that means, 0.04 watt. So, the total reflection for this particular surface is 0.06 watt or so, very similarly I take another surfaces which is 8 meter square of area and, it is alpha value is 0.5 and very similarly I can say that the absorption of this area is 0.005 into 8 which is area so, 0.04.

So, this 0.04 this particular wattage or the amount of amount of the energy that is absorbed can also be found out by multiplying, this 8 into 0.5 by S alpha. So, this 0.4 sorry 4 and this is S alpha for this is also going to be 4. So, I can say that this 0.04 and, this is also a 0.04 the total absorption for both the cases are almost equal and, these two are going to have the equal equivalency of 4 as S into alpha.

So, we can say from this particular slide, or you can actually deduct or the conclude that I can actually multiply the area and the alpha value of that particular surface. And I can actually say this much amount of proportional amount of energy can be absorbed.

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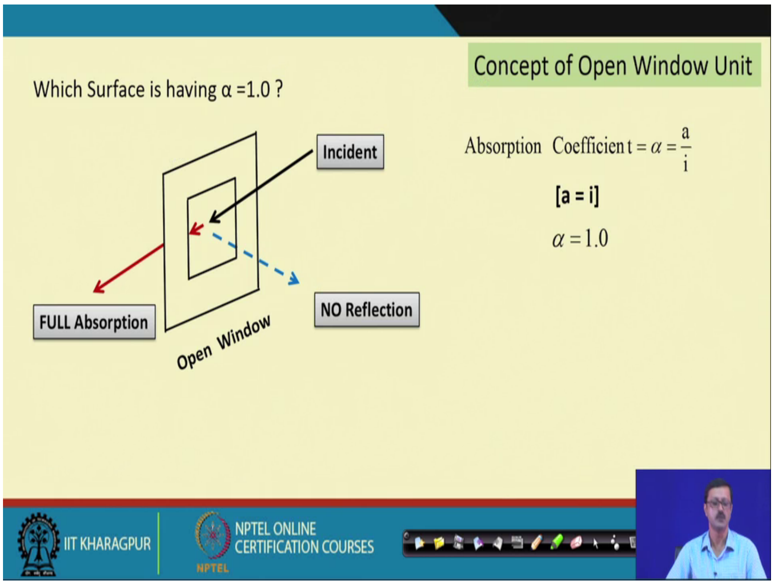

So, now let us see that is there is any such material, which is having alpha value of 1 and what does it mean alpha value of 1 means, it is almost everything is absorbed nothing is going to reflected back.

See a open window is something like that because, in open window if there is some incident energy, almost all the energy is actually absorbed the full absorption is going to happen and there will be no reflection and, by virtue of that the alpha value is going to be 1 because a and i will be remain will be equal.

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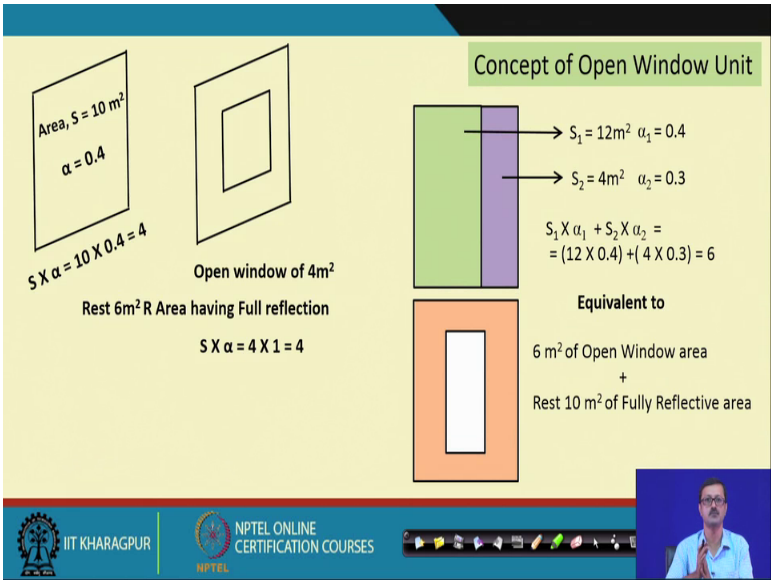

So, suppose I have a again a panel of 10 meter square and alpha value of that panel is 0.4. So, the S alpha product is 4. So, I can say that it is equivalent to a open window which is having a 4 meter square of the area, because this 4 meter square of the area which is having the alpha value of 1, because it is open window it is give me the same S alpha product.

Of course, I have to assume that the rest of the area or the rest of the panel is fully reflective. So, everything is going back so, very similarly suppose there are two such panel one is green panel, which is having the S 1 the surface 1 is 12 meter square and alpha is 0.4. So, that an another is suppose S 2, which is a purple color little smaller in area 4 meter square alpha 2 of that is 0.3. So, the some of both the S alpha product is 6.

So, I can say very well from the earlier concept, this 6 is going to be like a 6 meter square of the open window area, rest 10 meter square of the area, which is the other part of the this particular wall is fully reflective. So, what I mean to say from this slide is that, this S alpha product is related to a open window. So, it is equivalent to how much proportional area of the open window I am just comparing that.

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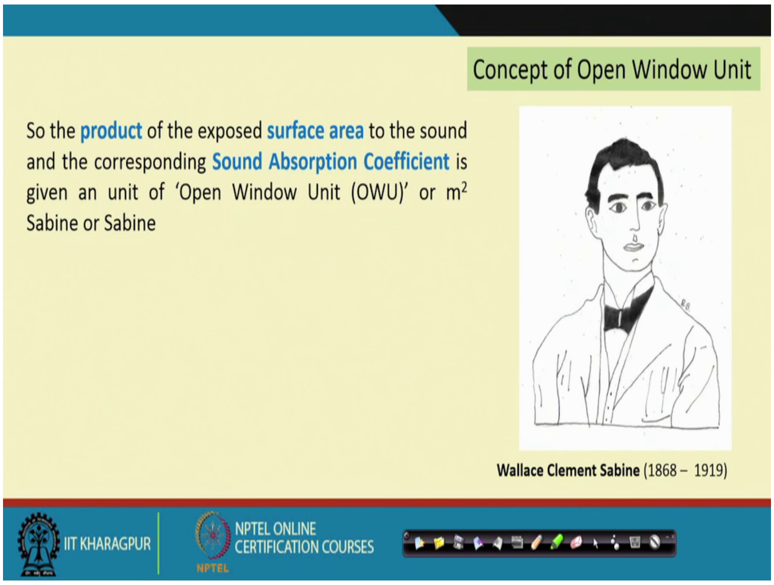

And this particular open window concept came to in a in a way and, it is actually initially it was called as open window unit OWU, or meter square Sabine meter square Sabine, because the physicist the American physicist WC Sabine, he has contributed a lot in the area of the revolution and this particular acoustical physics, for that to (Refer Time: 28:32) and for he his particular acknowledge for his particular work. This absorption coefficient multiply by the corresponding area is called as meter square Sabine.

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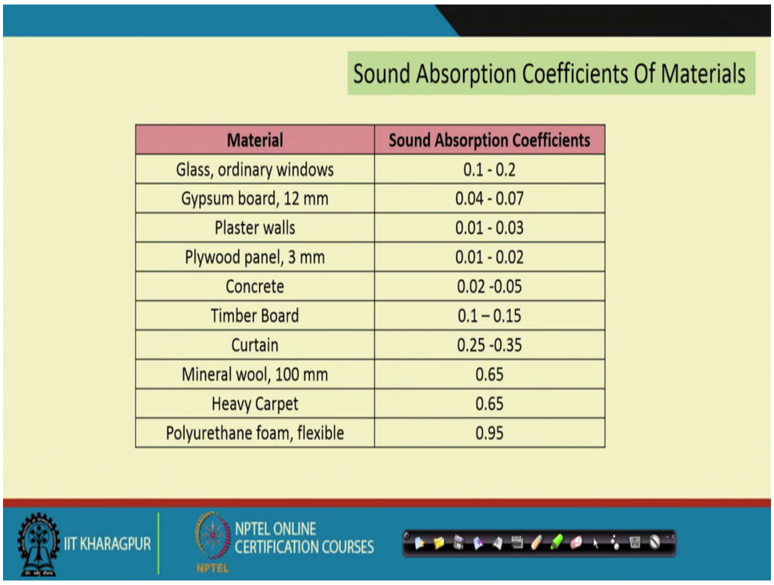

Material	Sound Absorption Coefficients
Glass, ordinary windows	0.1 - 0.2
Gypsum board, 12 mm	0.04 - 0.07
Plaster walls	0.01 - 0.03
Plywood panel, 3 mm	0.01 - 0.02
Concrete	0.02 -0.05
Timber Board	0.1 – 0.15
Curtain	0.25 -0.35
Mineral wool, 100 mm	0.65
Heavy Carpet	0.65
Polyurethane foam, flexible	0.95

So, there are some list of material which I have taken from someone book, which is I have given in the reference also. So, and the absorption coefficient of those materials are listed down, you see the materials which is the first second third row fourth row are of very solid material solid in the sense of very hard material. And maybe a polished kind of a surface glass, gypsum board and the plaster wall, plywood panel and you see the absorption coefficient is very very low.

So, it is all actors the reflective material reflecting surface whereas, if you go down starting from the last I mean in the last 4 rows, if you see the curtains then the mineral wool, then the heavy carpet and polyurethane foam, all are having the values are the higher range values. So, those can be act as a those can be act as a sound absorptive surface for our, this thing.

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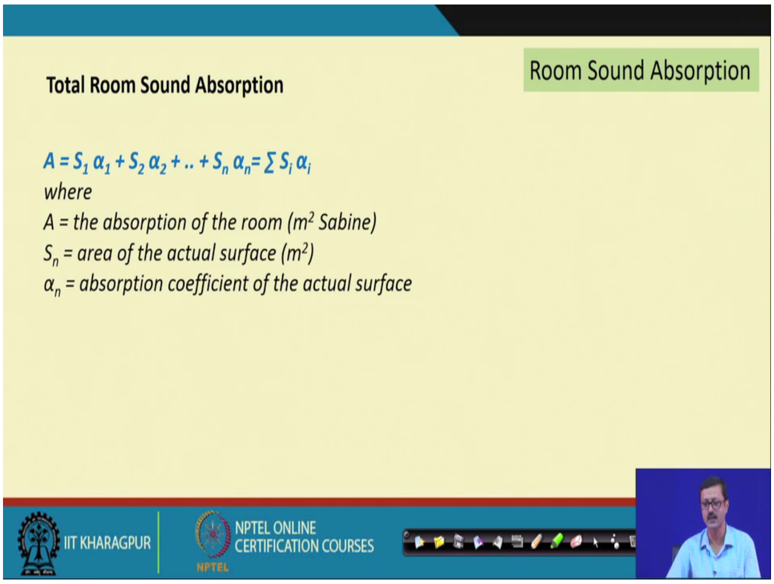

So, we have further more there are two such mathematical equations we can may think of so, this room total room absorption suppose we have in a room 6 surfaces 4 wall, one ceiling and one floor. And all the wall ceiling and floor of different acoustical materials, floor maybe having carpet the false ceiling may have some kind of acoustical treatment in the top.

So, alpha 1, alpha 2, alpha 3 corresponding S 1, S 2, S 3. So, the total room absorption in meter square Sabine will be the product of the S n alphas.

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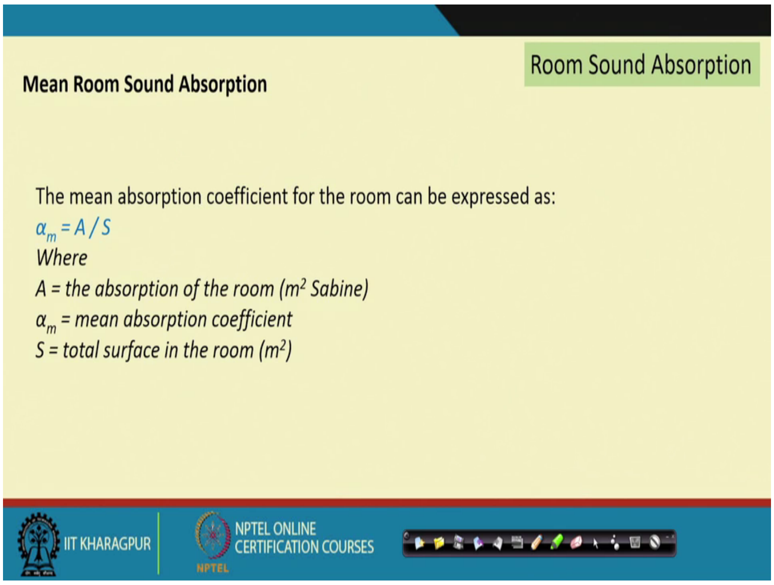

And if I that product that product is called as suppose the total absorption a capital A and, if I divide that capital A by the total amount of the surface area available to me interior area, then this will be the mean, mean sound absorption of the particular area.

So, that can be sometimes useful for our calculation further, when you talk about the reverberation and reverberation time. So, let us take some homework for today. So, first homework is that it is not some mathematical.

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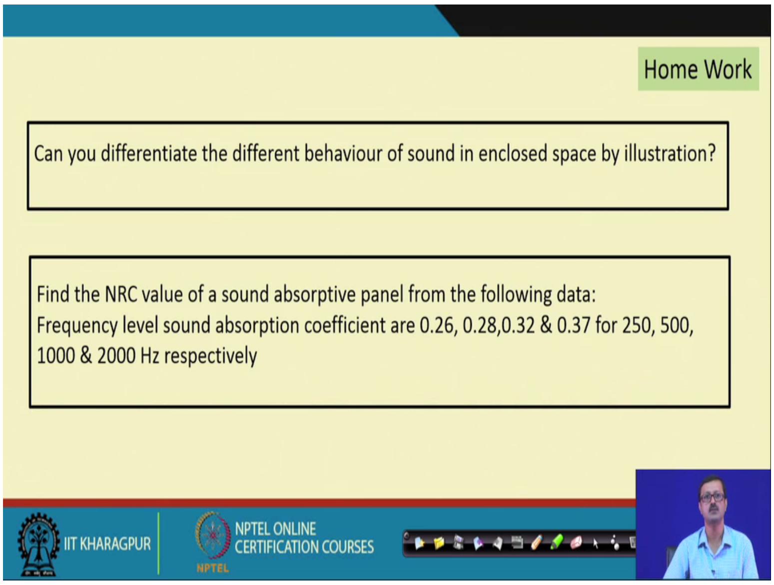

but it can you can just think of can you differentiate between the various behavior of the sound, in the enclosed space with illustration do some need you need to draw some sketches for that and, second one probably I have given 4 frequencies and, corresponding to that I have given 4 absorption coefficient of course, this is the absorption coefficient are of your the random incident angle point of view.

So, can you find out the NRC value the noise reduction coefficient value of the absorptive panel.

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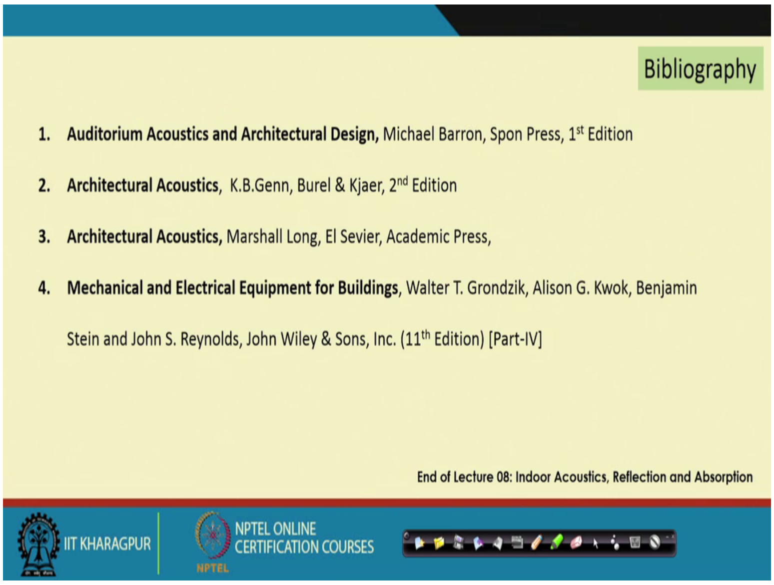

So, that is the end of this lecture number 8. And those are the books those are the some of the notebooks, which is we can go through for your further understanding and, move for the next chapter.

Thank you very much.