Architectural Acoustics
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Lecture – 10
Application of Reverberation Time

Good morning, welcome to the NPTEL course on Architectural Acoustics, this is the last lecture of the second week and this is on the Application of Reverberation Time. So, this lecture will end our the second week and this whole module of the room acoustics.

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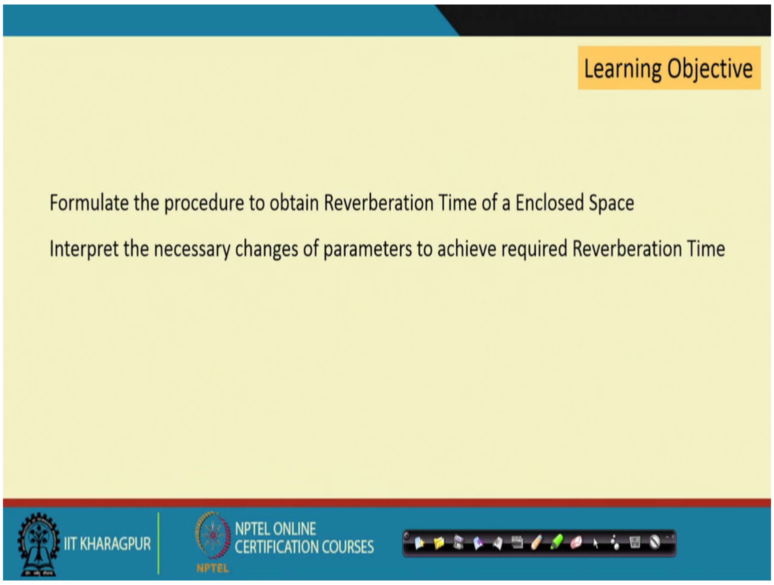

So, in this lecture we will try to do some the application oriented the version of the reverberation time.

If you remember in the very first two lecture, we know we are discussed about the various fundamentals of the room acoustics by doctor Gupta and, then the following two lectures, I have discussed with your sound absorption coefficient first and, then the reverberation time and concept of the reverberation time.

So, today my goal will be or the objective will be will formulate some procedure to obtain the reverberation time for any enclosed space. So, we will go very step by step way, how to formulate one after one and finally, the aim is to get the RT and, also we will going to interpret the necessary changes of the parameter to achieve this required the reverberation time.

So, what will be the significant change? So, if you know the this formulation this step by step formulation, then in suppose in the second step what can be changed to get the some effect on the last and, that kind of the interpret this particular the formulation of the necessary changes in the parameter we need to know.

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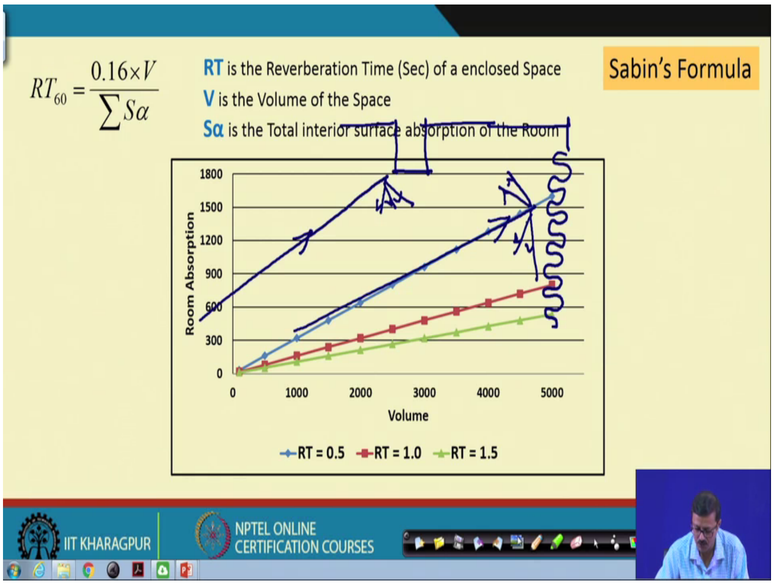

So, here let us again go back to the Sabine's equation, which is given as you know that RT is equal to 0.16 V by S alpha, I have put a summation sign because, it is summation of the S alpha the sum of the various surfaces and it is product of the it is the absorption coefficient.

Now, let us draw a graph this graph is based on the volume and the total room absorption, but total room absorption is S alpha the this submission S alpha and, if you see in this particular this equation, or may I may go to a blank page in the blank page.

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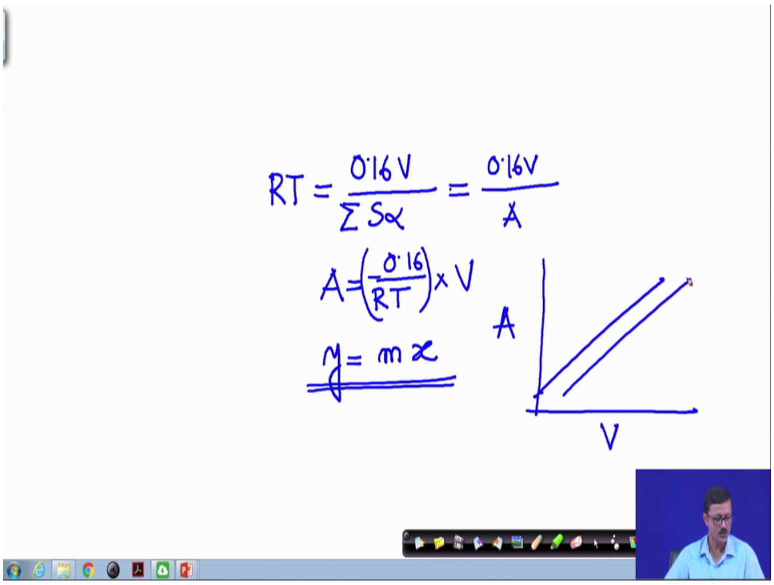

So, it is the RT, RT is equal to 0.16 V S alpha which is summation. So, this is the total absorption. So, I write capital A and this is 0.16 V.

So, if I say this as the A is equal to now 0.16 times RT multiplied by V. So, this is give you a kind of a equation which is a equation of linear equation, where A can be replaced a represented by x, this is some slope of the equation and this is x y equal to m x kind of thing..

So, I will get a straight line equation as I know from this particular way, this is will going to be so, I will if I plot this A in the x and sorry A in the y and, this V in the x, I must get some line like this, and various lines because of the various combinations of the RT. So, I got those lines I got those lines over here and, those lines are actually your this green line is actually for the RT is equal to 1.5 and, this blue lines are RT equal to 0.5 the red is for 1.

So, as the RT value is changes the line and slope of is also going to change and, as the RT value is decreasing the slope is increasing, that is one of the major observation from this particular graph.

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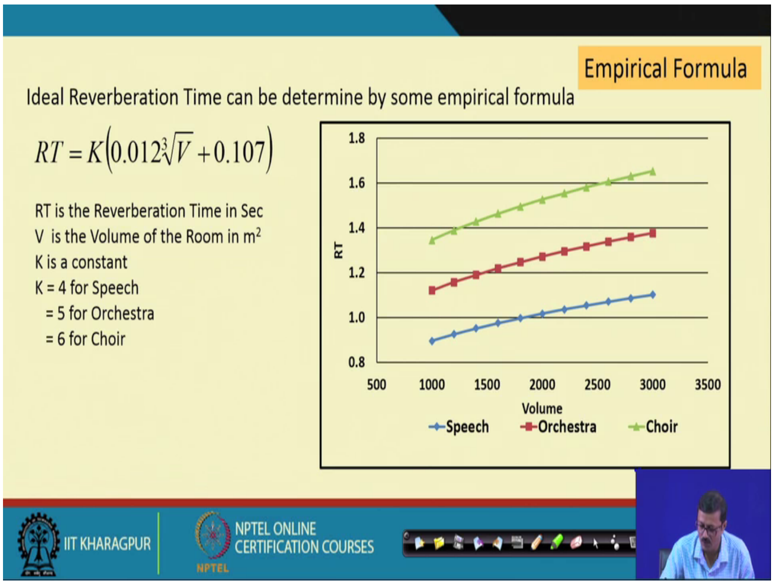

Next let us go to the another empirical formula, where the RT can be calculated by virtue of some volume. So, after this Sabine's equation lot of physicist actually go into calculate the RT and, this RT value is not going to be fixed for same, I mean different type of performance will be required different type of RT.

So, various physicist actually work in this area now and, some of them has some come up with a some formula the some kind of the empirical formula. So, this is one of the empirical formula, where RT can be projected by this. And here the V is the volume of the room and K is a constant and, this K is based on different type of performance. So, suppose if it is a speech just like this particular the lecture room is for speech. So, this case four, suppose it is a orchestra where there are some instruments some singing and all it is 5.

Suppose if it is a choir kind of a thing where is a group song in a kind of a thing then it is 6. So, again by virtue of this V and RT values, the RT is kept in the y axis and the V is volume in the x axis. Again you can plot for different volume what should be the proposed RT value. So, we can see the green one which is for choir, which is higher and the speech, which is blue which is lower.

So, for the speech you required some low value of RT for a music you require little more.

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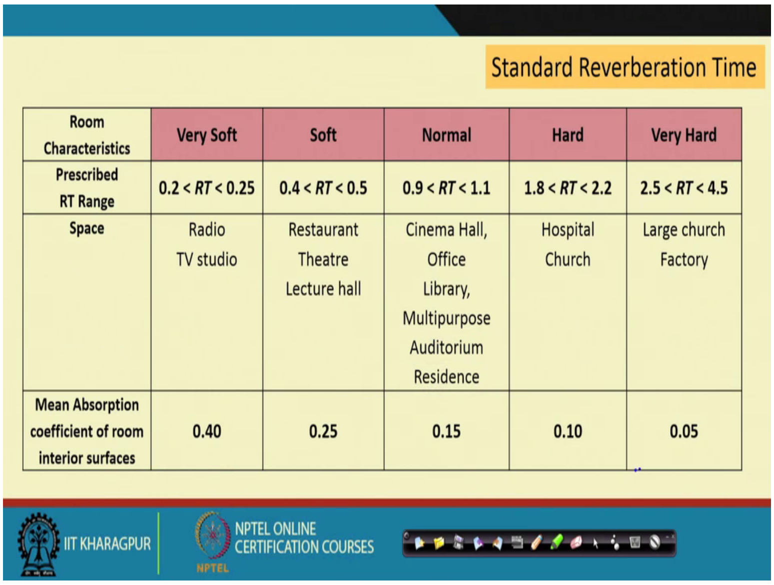

Room Characteristics	Very Soft	Soft	Normal	Hard	Very Hard
Prescribed RT Range	$0.2 < RT < 0.25$	$0.4 < RT < 0.5$	$0.9 < RT < 1.1$	$1.8 < RT < 2.2$	$2.5 < RT < 4.5$
Space	Radio TV studio	Restaurant Theatre Lecture hall	Cinema Hall, Office Library, Multipurpose Auditorium Residence	Hospital Church	Large church Factory
Mean Absorption coefficient of room interior surfaces	0.40	0.25	0.15	0.10	0.05

So, let us go to a kind of a band where, we can see the what are the different standard reverberation time for different space, or different performance. So, there are 5 such classification room characters classification very soft soft where the RT is very very low.

See the RT when it is 0.2 to 0.25 second it is actually required for the recording studio the TV studio for the radio, or any kind of broadcasting cases. Suppose any television broadcasting where there is a speech, any commentary box for any sports arena, you required very low RT value 0.2 to 0.25 second. And the mean absorption is almost 0.4. So, you have to put lot of absorber and that 0.4 as to be achieved.

The soft is 0.4 to 0.5 the RT value will between 0.4 to 0.5 it is for the theater, where there is again there is a speech there is lecture hall, just like this is the speech restaurants and all. The most cases are normal cases, which is 0.9 to almost 1.1, where it is cinema hall, the office building, the library, the multipurpose auditorium residence etcetera are in normal category, where the mean absorption coefficient is almost about 0.15.

The hard where the reverberation time is little more, who is 0.1 0.8 to 2 is charge and the hospitals. And very large is the factory and the charges 2.5 and 4.5, you see the charge and the religious place you always required the very high RT value. So, perhaps we have already learned the classical architecture and the history of architecture, if you go to the history of architecture lecture and the books, you see the all the church in the European church and very high in volume and also it is having very hard surfaces.

The church required very high RT not only church, any short of religious song and religious deliberations, it is actually demand high RT value, it may be a bell of church, it may be some singing in the temple, it may be some kind of a beating of drums in the for the monastery Buddhist monastery, or maybe it is the azan in the Islamic the mosque and all. So, you required all there is prolong version of the sound, which demand high amount of the reverberation time.

In other sense when it is a speech which is recording studio, or maybe theatre or lecture hall in this particular domain, you require a very very discrete and concrete and very split of sound, that should not be any prolong kind of a case, then there will be kind of the hearing problem and, the intigilability problem and the kind of the confusion will create in time of hearing.

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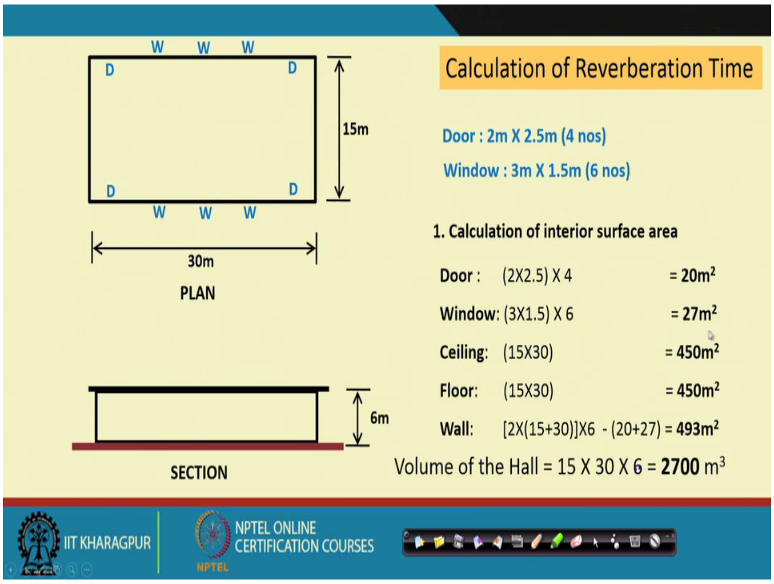

So, let us next stage let us try to calculate the how the reverberation time can be calculate what are the steps what are the formulations. So, I have drawn a plan of a hall of 30 meter by 15 meter and, the height of the hall is 6 meter which is given in the section and this hall is having 4 doors of 2 meter by 2.5 meter and 3 meter by 1.5 meter 6 windows which is plotted in this plan in blue colour.

So, first what will do in the very first step, we first find out the what is the interior area. So, we calculate the door area is 20 and the window area as 27, the ceiling is 30 by 15 is 450 floor is also 450 and wall area, I calculate the perimeter and I multiply the perimeter by height 6 and I deduct from that 20 plus 17, because that is the window and door in is in the part of the wall.

So, 493 is the total wall area total wall area, and the volume of the hall is 15 into 30 into 6 which is equal to 2700, 2700 meter cube. So, first you calculate the all the surface area, then go to the next and try for the next data that is given for this particular.

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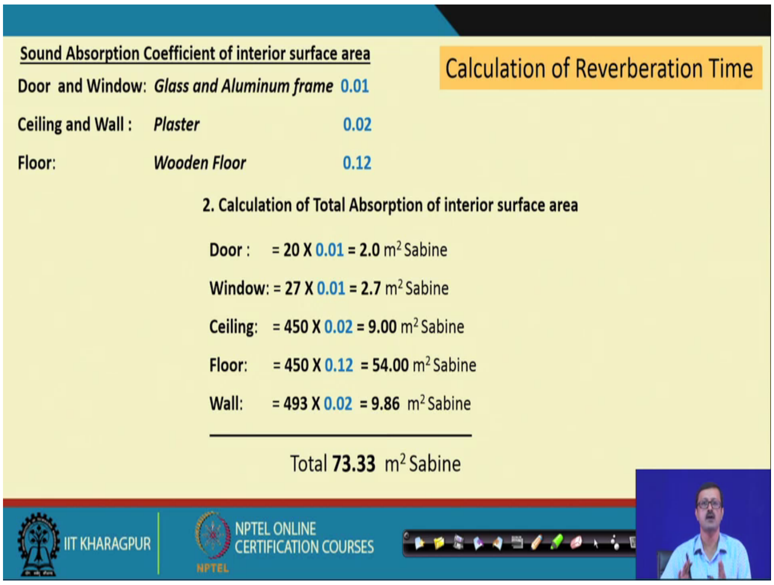

So, what the next set of data. So, next set of data is given as the door and window as glass and aluminum, which is having alpha value of 0.01, because this is very very reflective the ceiling and wall is also very reflective as 0.02, it is plaster and the floor is wooden floor is 0.12. So, if you see all the three materials what I have given as a part of the problem are most reflective material.

The alpha value is very small very close to 0 for the first one 0.12 for the floor. So, I am expecting I am expecting a very high RT value for this for this room, then I start calculating the next stage, where I multiply this alpha value with the corresponding area and, I am finding the total absorption of that corresponding area by meter square 7.

So, I have multiplied everything, ceiling is 0.02 and the floor is 0.12, again wall is 0.02 because both are plaster. So, and I add all this 5 and, then I got a total absorption is 73.33 meter square 7. So, my second the stage, or the formulation is over so, now, I know what is the sum S sum S sum of S alpha I also know the V so, I can calculate the RT now.

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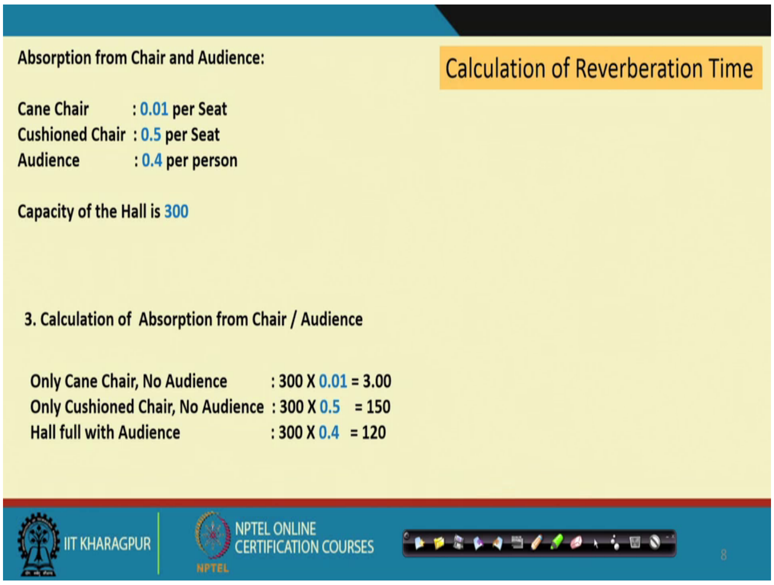

But let us go to further some character of the room. Suppose this hall is having a capacity of 300, 300 people can sit and listen something over there and, there are two options, suppose there is a cane chair or may be a cushioned chair like this like this cushioned chair. And there is a audience also so, I have given the per seat, what is the absorption cushioned chair is 0.5 cane chair is 0.01 and audience is 0.4. And by virtue of the clothing and all these things, but the hair and all you have the kind of the absorption for human being also.

Suppose this is summer cloth. So, it having a absorption coefficient less, suppose it is in winter if I having a jacket, or maybe some kind of a woolen, my for the audience absorption per audience absorption is also will be very very high. So, what happened is that now I go for the third calculation for the absorption for the chair and all. So, only cane chair if I use, then it is this much because per chair is 0.01 and, there are 300 chair only cushioned chair, or no audiences is if it is there, then is 150 and if the audience is full I mean there is a full audience, then the 300 audience per audiences is 0.4 this is 120.

So, either it is a full house or maybe a it is empty or maybe it is half full so, some conditions will be there and, based on that I can take the permutation combination and, then I can again find out some amount of absorption.

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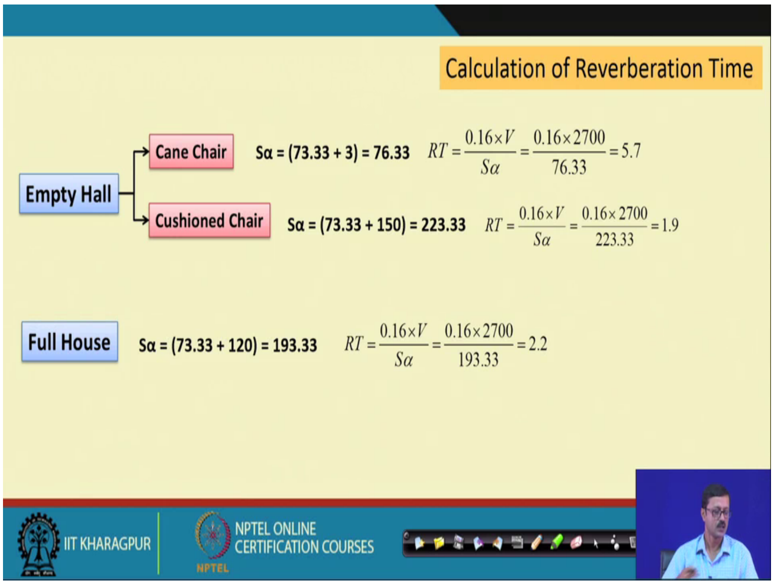

So, what happened in case of there is a empty hall. So, if there is a hall is empty there is no audience and, I have only cane chair which is very very very reflective in nature and there is no absorption at all. So, the total S alpha value will be 73.33 plus 3 why 73.33 that that comes from the absorption of the surfaces and, why this is 3 if you go to the previous slide, if it is cane chair no audience it is 3.

So, total absorption is 76.33 and the RT value by virtue of your volume and 76.33 and 0.16 is 5.7, I predicted that I told that if there are less amount of absorption and there are so, much of reflective surface, I am going to get a the high reverberation time and I am getting that and this hall is empty hall no audience. Now, let us see if I replace the chair, cane chair by cushioned chair. So, 73.33 will remain same, but 150 comes from comes from this cane chair and no audience case.

So, this two gives me 223.33 as the S alpha and finally, this will be my RT value 1.9 drop down 5.7 to 1.9 it is improve. Now, let us see if it is full house this full of people. So, all chairs are full of peoples. So, the audience is now going to absorb, then this is 120 is for the full audience and 73.33 is give me 193 and the corresponding RT value is 2.2.

So, you see if there is a empty hall, or maybe a full house, or if it is a cane chair, or some other type of chairs, it is also impart a physically the RT value of a room.

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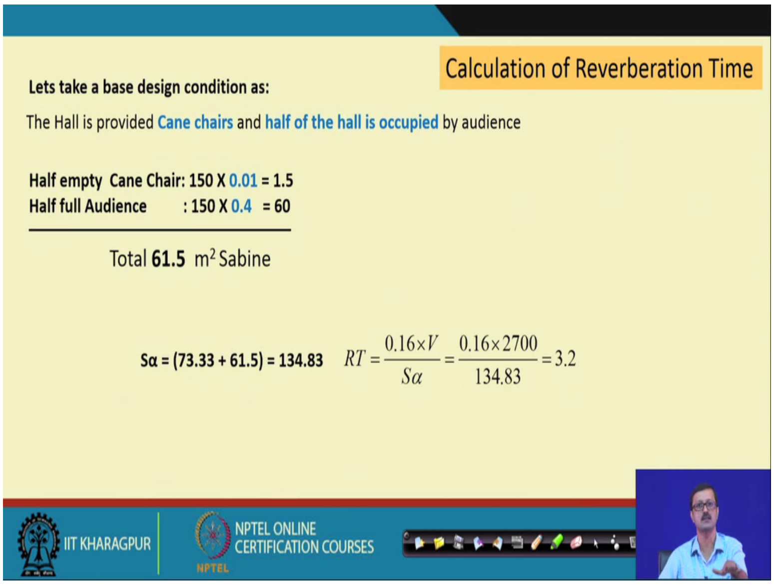

Now, let us take a design based case, I am going to design this particular room for a base case, where I have going to use the cane chair and, the half the hall is occupied so; that means, the half the hall will be occupied and rest half is cane chair and, this will be my best design condition and for that I want to set up a particular the design the RT value.

So, for that I recalculate the what will be the empty chair conditions 150 empty chair with 1.5 absorption and, the 150 people will 0.4 equal to 60 is the meter square Sabine. So, total is 61.5 and, for that condition this 73.33 remain same surface I have not changed. So, finally, 134.83 and it is gives me 3.2 reverberation time and please remember this 3.2 is my base I want to improve it improve it means, reverberation time improvement means, you have to reduce the reverberation time 3.2 is too much supposes this hall is for speech we require almost 0.6 or so, if it is for music or so, 1 second or 1.2 second like that.

So, 3.2 is something like a charge. So, this cannot be actually take in so, I have to improve the other surfaces.

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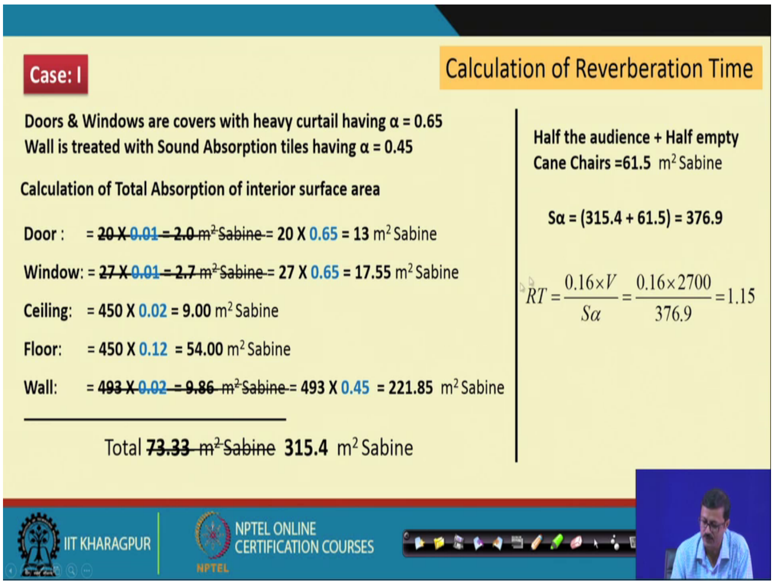

So, I have first case as I will do some covering, I will cover the door and window by heavy curtains having alpha value 0.65. And the wall be treated with the absorption some absorptive tiles having alpha point. So, I have taken this two decision, I will treat the wall and I will treat the door and window by virtue of some the curtains.

But the ceiling and floor I will not going to treat, that will be as usual as earlier. So, if I do that I have taken the same the calculation table from the previous. So, door is now a new way we have to calculated, the 20 will remain as 20 the area has not going to changed, but instead of this wooden door or the glass door and the glass window, now there is a curtain. So, 0.65 comes from here and this is got cancelled.

So, the 2 2 meter square Sabine which was earlier is now, 13 it is improved, 2.7 for the window is no improve to 17.55 by virtue of induction of this two curtains ceiling and floor, I told I have not I will not going to treat. So, this 2 remain same 9 and 54, but wall is now going to change, what was earlier the earlier was it is the plaster 0.2. Now, I have treated with that the wall, with a sound absorptive tiles 0.45. So, this 4 9 3 the total area of the wall was multiplied with 0.45 and 9.86 is improve to or increase to 221.85.

So, totals Sabine total amount of Sabine are the meter square Sabine at the total amount of absorption of the room was 73.33. Now, it is 315.5 so definitely I am expecting a low version of the or the low RT so, let us see how much is RT. So, cane chairs and half audience give me 61.5 and, this 315.4 from the surfaces total is 376.9 you see earlier it was 3.2 and this is 1.15, much more controlled was achieved.

But if it is in for speech if it is for music, for some kind of musical performance 1.15 or if this hall is for some movie or the cinema it is ok, but if it is for speech for any kind of lecture room, it is not still now is not suitable it is too high we have to come down to point 6.7.

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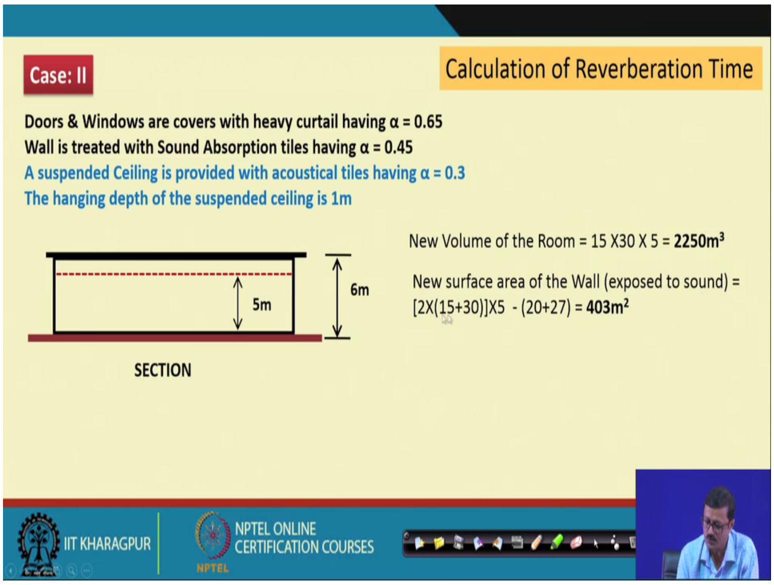

So, I have a case 2 also so, in case 2 what I did I remain this two as it is curtains in the door and window, sound absorb absorptive styles in the this wall 0.45, what I did here is that, I created a suspended ceiling with some tiles of alpha value 0.3 and, I hang this particular ceiling at a depth of 1 meter.

So, why what I did I did a new surface, I put a the suspension ceiling at a depth of a 1 meter from the structural ceilings of it, and that gives me 2 benefit 1 is I also treated that particular surface with the acoustical tiles of 0.3. So, my the surface which was clustered was hidden now and, the absorption coefficient is also increased and, the second one is by virtue of lower down the ceiling I decrease the volume of the room also.

Now, you see in the volume of the room has to be calculated as height 5 meter not 6 meter because, 1 meter is actually taken by the suspension ceiling. So, let us recalculate the volume 15 into 30 into 5, which was 2700 earlier now it is 2250 and the reflect new surface of the wall, also will decrease because, the one meter band in the roof, which was now hidden by the suspended ceiling has to taken out from my calculation.

So, now the perimeter is multiplied with 5 instead of 6 6 was earlier. Now, it is 5 because this portion is exposed to the sound and 20 plus 27 is the door and window was detected. So, now, new the area of the wall is 403. So, based on this new to volume of the wall, volume of the room and the surface of the wall let proceed for the calculation.

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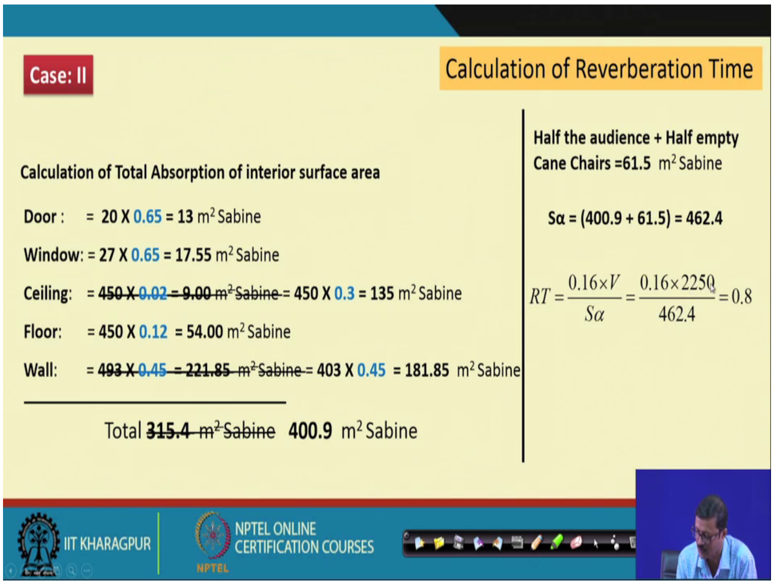

Door and window remain same 0.65 multiplication ceiling is now different because, now this 0.02, which was clustered which gives me 9 meter square Sabine is now 0.3. So, 450 into 0.3 that is 135 Sabine, I have not treated the floor. So, it is remain as at as it is 54, but there is a again change in the wall, there is no change in the acoustical coefficient of the tiles which is 0.45, but there is a decrease in the surface area of the tiles which was 493, now it is 403 almost 90 meter square of the reduction in the area.

So, I got almost 181.85, which was earlier 221. So, now, my new total absorption of the room is 400 almost 401 409 meter square Sabine, if you add this all now let us calculate and, if you calculate with the same half full audience and the cane chair this is 61.5 plus 400.9 462 and, if you divide that and use that one for your calculations and please remember the volume is also changed, it is not 2700, it is 2250 now and now your reverberation time is 0.8.

So, which was 3.2 in the base case untreated case, which was now one point was 1.15 in the case one now it is 0.8.

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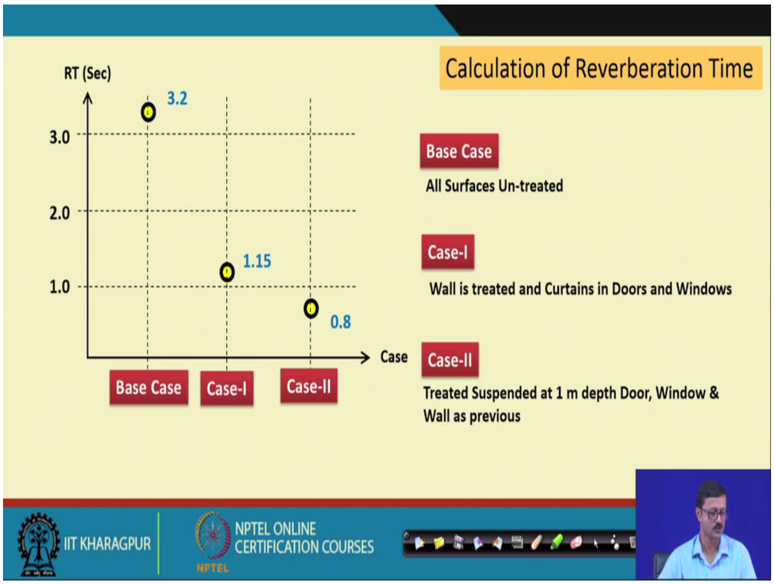

So, let us draw a graph for that the case one base case was 3.2 very high, all surface untreated what happened next the case two, wall is treated and curtains and all these things are given in the base case in the doors and, the windows and wall is treated 1.15 and finally, in the case 2, it is 1 meter drop of suspension ceiling and wall and this things are as previous treated suspension ceiling, it is 0.8 probably we can adopt that for a lecture room or so.

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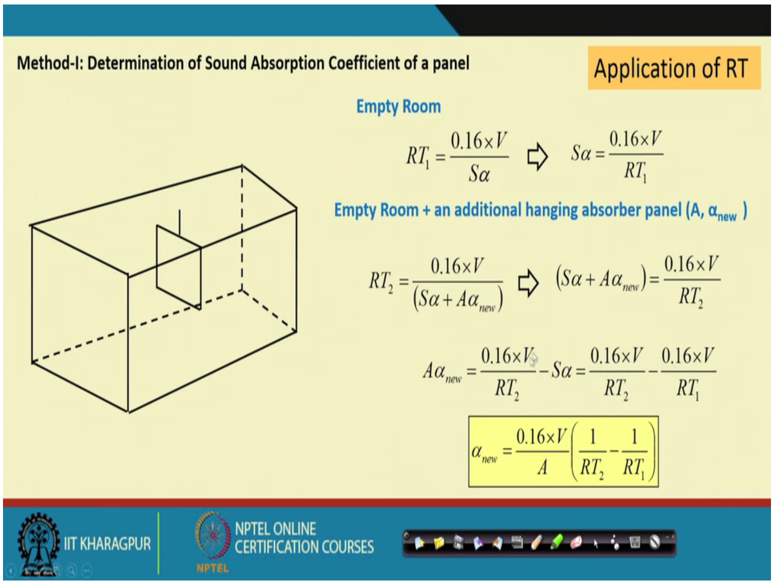

So, there are how to determine this application of the RT from that point of view how to determine the sound absorption coefficient of the panel. Suppose, I want to test a panel and, I want to find out what is the alpha value of the panel is so, how to test it so, by with this equations and all. So, suppose I have a room and this room is empty and this empty rooms gives me RT 1, this is the first condition. So, I can find out the a alpha by virtue of just change this particular rearrange this particular equation.

Now, what I did I put a additional acoustical tiles, additional panel in the that, that particular panel I am going to test. So, the RT value will going to change because, there is a new edition of material the A is the new the area of the material and, alpha new I am interested in how to find out what is the alpha of this particular panel. So, again I rearrange this equation in this.

Now, I replace this S alpha here and I can easily find out the equation the from this equation, I am what I am I did is that this is S alpha S alpha I have replaced here. And then I can rearrange the equation and the alpha new of this particular panel can be found out, if I know the RT 1 and RT 2, if I know the volume of the room and, if I know the area of the this new panel, I do not need any else, or anything else I do not need the alpha of the room walls and, all the surface areas and all I can have some other methods.

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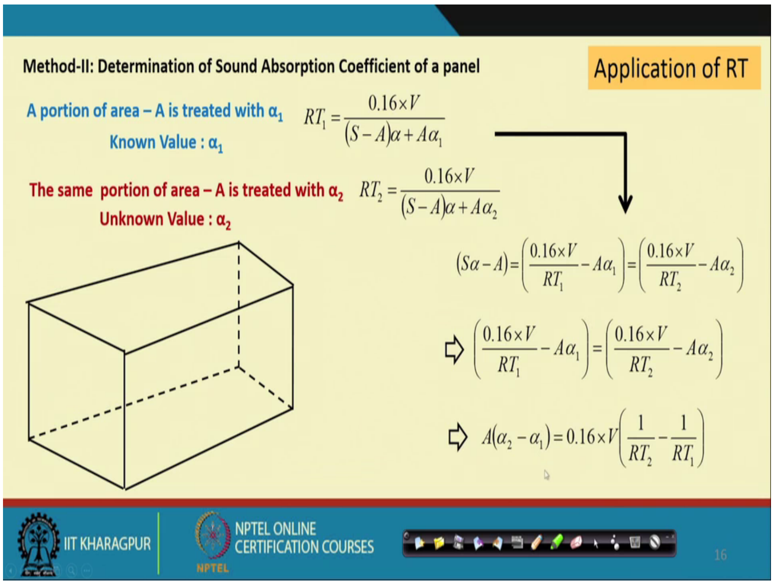

Suppose I know that one material which is I have drawn here is a blue and, this particular value is alpha one of this particular material is known to me. Suppose, I know this material what is the value is known to me and, I found out the RT by this situation, this is a total S that is the total surface area minus A into alpha plus A into alpha 1, because I assume that the rest of the area is having the alpha. So, the rest of the area multiplied in the alpha and, this blue area which is the a is alpha 1.

So, this keeps me the total absorption and this RT, next I replace this by a another material, another same area by another panel the red in color and, this alpha two of this new material is unknown to me. So, I can rewrite this equation by RT 2 I will get some different RT and this is alpha 2. Now, just rearrange this equation because, the S alpha S alpha minus A is common for this one S alpha minus A and, then you can rearrange and finally, you can calculate the alpha you can calculate the alpha 2 from this equation by this rearranging this things.

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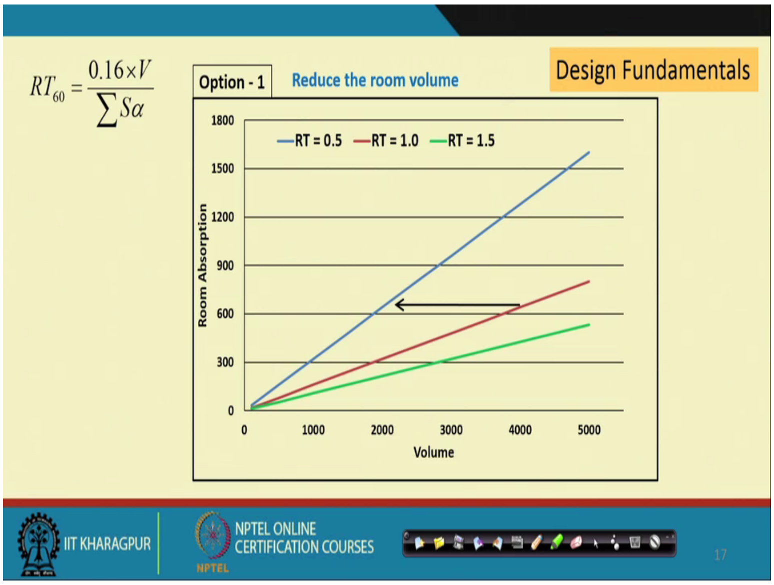

Now, there are way to handle this particular scenario, am I understanding is that I being a designer being a acoustical designer, I have to provide some RT, or some design RT for a particular room and, when I got a particular room or a hall, it is all reflective surface plastered surface and all reflective surface. So, I have to render it with some different material and finally, I have to propose the material and finally, I have to give some kind of the RT I mean achieve some RT value.

So, if you remember this graph I have drawn in the very first slide today. And these are the absorptions room absorption total room absorption which is S alpha and in x axis is the volume. So, this green line indicate or may be there is red line indicate the RT value is 1 and, this blue line indicate the RT value is 0.5.

Suppose I am I am targeting a 0.5, I am targeting to achieve 0.5 and my present value of RT of this room suppose 1. So, I have to reduce the RT value how to reduce from this, particular graph I can go from red to green blue by virtue of a horizontal shift and, if I go with this is my option 1, I have to reduce the volume see I have to reduce the volume from 4000 to 2000.

Another interesting point you see if I want to go from green to red same see the difference is 0.5 second, I have to go smaller, I have to go smaller, but if I want to go from one second to 0.5 second same the difference is again same I have to go higher. So, where you go towards the lower part of the reverberation time you have to give more effort more rendering more absorption.

But in this option one is reduce reduction of the volume from this to this, is sometimes not possible why it is not possible, because the volume of the room and the dimension of the room is basically comes from the occupancy the rows, number of rows, the size and the leg space and the chair and, the table and lot of other furniture details and the prime factor is some kind of a circulations and, thus there are some the occupancy requirement and all.

So, sometimes and also the other dimension the aspect ratios of the hall also. So, sometimes or probably many times it is not possible to reduce the volume and achieve that. So, the option one is not practical.

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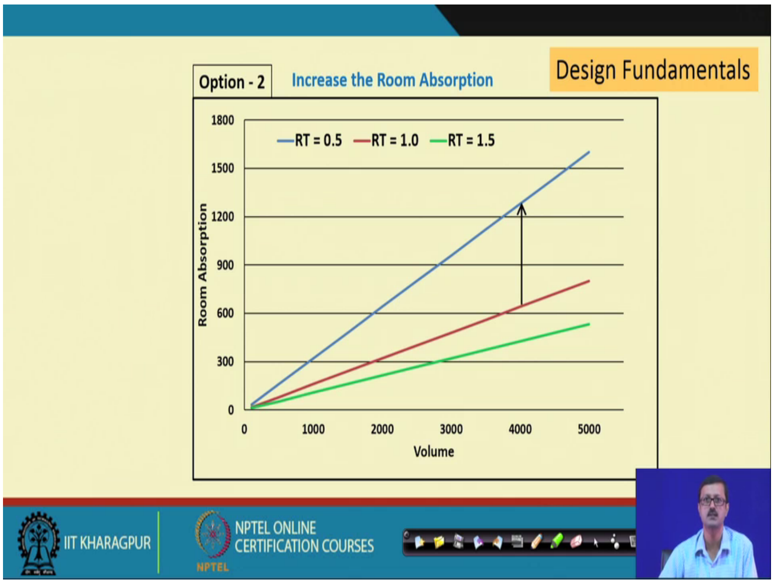

So, how to touch this blue line, from red line, the another way if you go vertical. So, if you go vertical also from this 4000 in rather decreasing the volume, you can also touch, but what is this you have to increase the room absorbent. So, from here it is almost 620 or something like that or may be 652 almost 12000 plus.

So, how to increase the room absorbent and, what is room absorbent S alphas, you cannot change S mostly, or what you can do is that you can increase the value of alpha, what how can you increase the value of alpha, we can some kind of a acoustical tiles of course, if you do that it is required money because, you have to render it with some different acoustical material, it required cost and so, you have to be careful also I mean how much is actually going to achieved or so.

So, there is this is the option two the increase of the room absorbent also give you reduce your particular RT there is a third option also.

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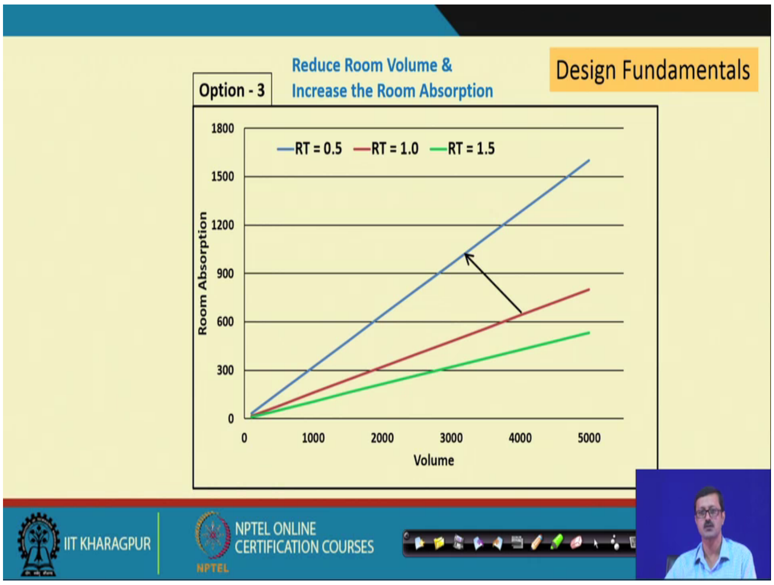

You can touch this particular blue line from the red line by going angular, what is that mean going angular means, actually I am increasing the room absorption and parallelly I am decreasing the room volume. So, if you decrease the room volume and increase the adsorption, which was my last case by creating a false ceiling I decrease the volume and, I render the surface with the room absorbent this two also going to help me.

So, again if I go back there are 3 options to achieve a particular design RT, either you reduce the volume which always not going to possible, you increase the room absorption, which is a bit costly of course, but mostly we do like that, or sometimes we can increase the volume we reduce the volume and increase the room absorbent, which may be come into a most practical scenario. So, you are almost are may be at the end of our lecture number 10.

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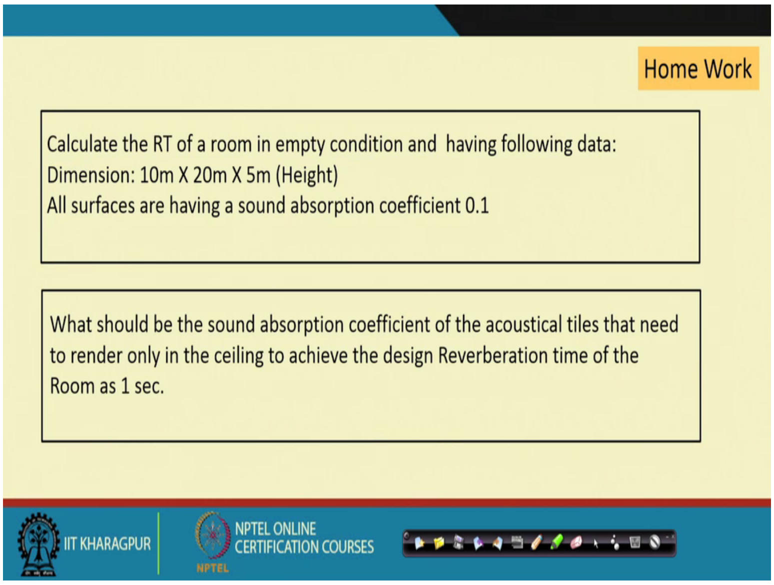

So, as usual we have some kind of homework for you. So, I have given a just a single problem, the calculate the reverberation time of a room, which is empty condition there is no furniture no the audience for the following data, the dimensions I have given. And the all surfaces having a the sound absorption coefficient is 0.1. So, again you can expect a very high reverberation time for as a answer.

So, I have further the same problem is further extended like, what should be the sound absorption coefficient of that need to be provided only in the ceiling to get the reverberation time one seconds. So, definitely in the first problem I will get reverberation time more than 1 second and so, I want to make it 1 second. So, then only I am going to treat the ceiling surface only the ceiling surface. So, what will be the alpha value of that that particular tiles, I need to place in the ceiling that I that that is that is my question. So, at the end I hope you have learned about the room acoustics.

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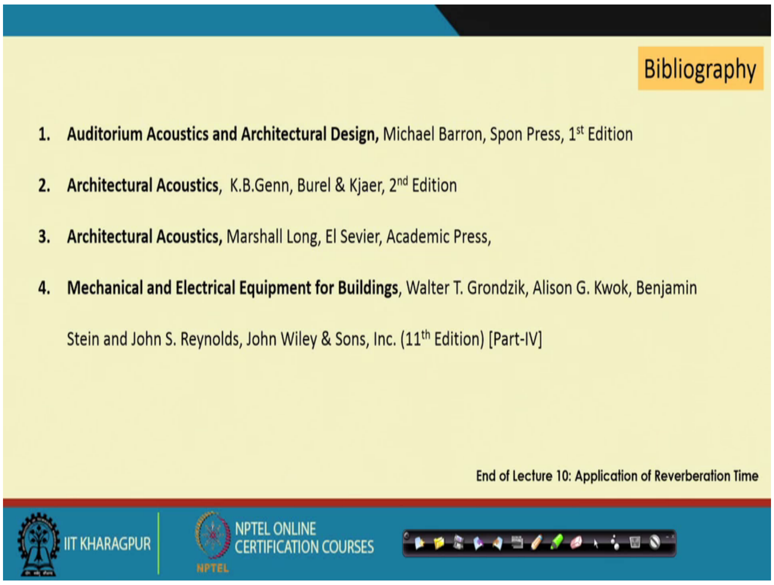

And understand the basic principles of the room acoustics in the first two lecture, third lectures, you understand probably the way we handle the reflections and the absorptions and, we define the reflection coefficient the sound reflection coefficient of any panel, or kind of material.

And finally, in the last two lecture we discuss the concept of the reverberation, reverberation time and, methodology or the formulation how we can actually calculate the reverberation time and we design for reverberation for a particular room. So, the next week we will start the acoustical material various type of acoustical material and Doctor Sumana Gupta will deliver her lecture on that.

Thank you very much.