Architectural Acoustics
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Lecture – 15
Reverberation time and Intelligibility

So, we have seen the different types of absorbers in the previous lectures and we have also seen the phenomena of area effect the phenomena area effect, see deep effect and also try to see grazing attenuation. And had concluded with a number of number of statements which were actually required to be taken care while we are designing subspaces.

Now, Professor Bhattacharya has elaborated on reverberation time calculation of it, and today we will also try to see how reverberation time is qualitatively associated with the spaces we design; with which we will also try to see intelligibility that is speech intelligibility that is how much a speech is need needed to be heard and the articulation index. How these three these two things affect the human hearing?

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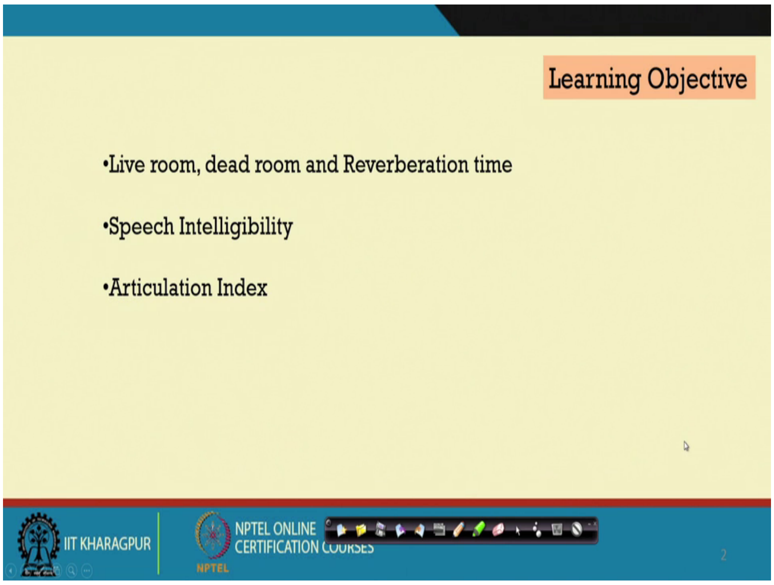

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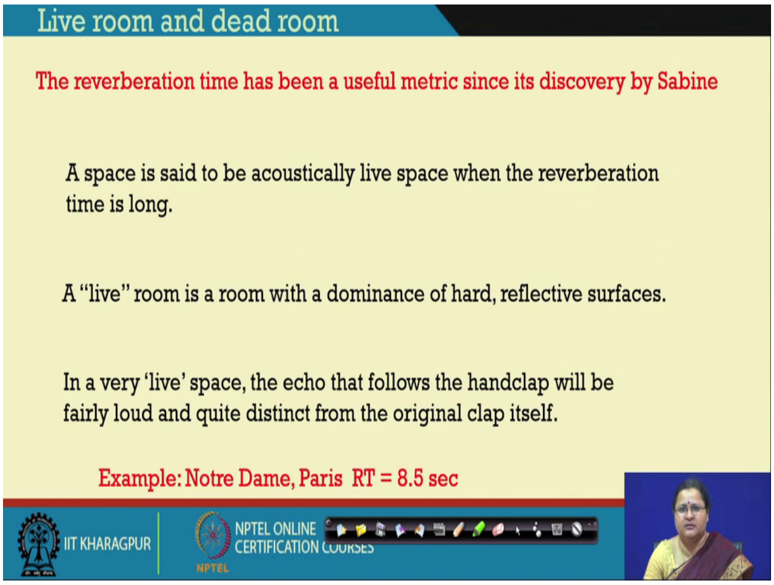

So, coming to live room and bedroom the concept when the reverberation time was found out as an useful metric after the discovery of Sabine, it was seen that areas which have longer reverberation time were very livelihoods. So, spaces which were having long reverberation times termed as live spaces and this was seen observed that when reflective surfaces are more, or rather absorptive surfaces are less the liveliness of a room is experienced.

So, in certain kinds of performances we required a live room. So, we need or we welcome reflected sound whereas, we do not require reflective sound in cases when we required to get the sound distinctly. So, a live room is characterized by reflective surfaces, hard surfaces, and more the amount of hard surface that is lesser the absorptive surface higher is the liveliness. And a very lively space and within a very lively space actually if you do a hand clapping the hand the sound that is echoed back actually is louder than the original sound in cases.

We have the Notre Dame, Paris which has which starts with had the reverberation time of 8.5 seconds that was; obviously, because of the huge volume etcetera. But it is also not desired to have such high reverberation time where nothing could be heard, everything would be echoed back and back to the receiver.

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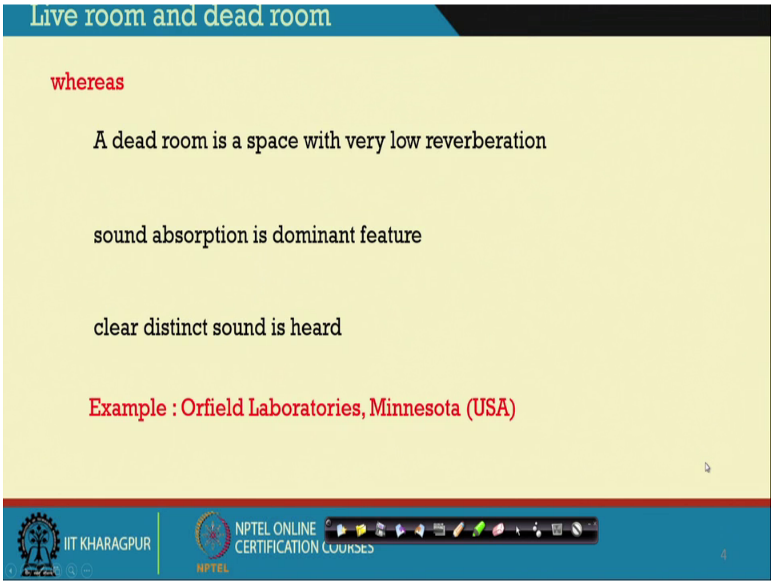

Parallelly what we told a dead room is a space where there is very low absorption and the sound absorption very low reverberation. Obviously the maximum part of the sound which is produced is to be absorbed. So, absorption is the dominant feature of a dead room, and clear distinct sound is heard. We have given the example of those the anechoic chamber or the acoustical wedges which actually characterize dead room environment. And we have the Orfield laboratories of Minnesota which is an anechoic space where the dead room feeling is understood most.

So, there even the heartbeat is not heard and for your information the heartbeat is considered to be of the order of 10 decimals. So, the pressure level of heartbeat is 10 decimals which is not even heard within that area within that room. So, and it has been told by scientist that they cannot stay within such environment for some few minutes this that is also annoying.

So, when an echo at that is a coming back of sound is not acceptable even dying down of sound immediately with no echo back, no sound coming back reflecting back to the receiver is also equally annoying.

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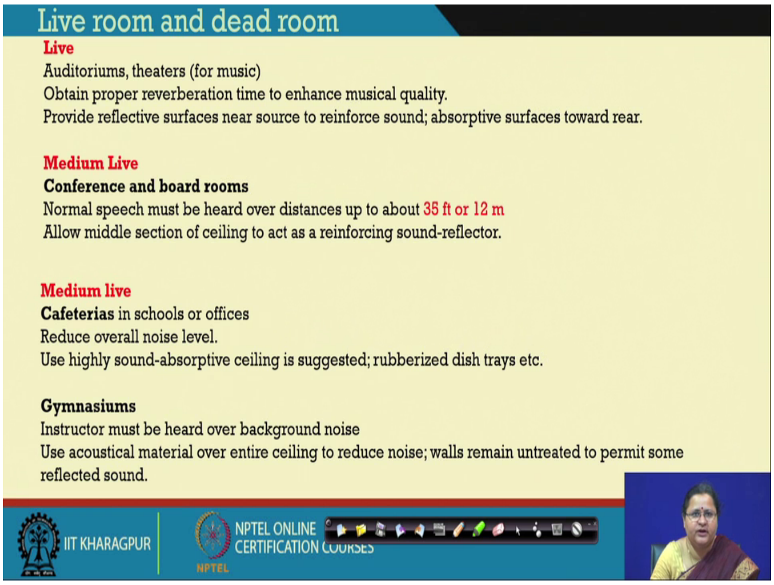

So, we will see that our rooms generally which we deal with that is the auditoriums theatres etcetera where musical performances are happening. We need live rooms and to obtain proper reverberation time we have to choose particular kind of absorbing milk materials, and particular amount of absorbing materials. So, that it reinforces the original sound and helps the environment to be qualitatively better than compared to a 100 percent live room, or a 100 percent dead room.

So, we need to treat such spaces where we require musical performance of a particular quality and coming to the medium live we have conference rooms, board rooms, and further examples of cafeterias within a school, or within an office, or the gymnasium with all come under the medium live. So, what is medium live? It is a mix and it is a it is something in between a very live room or a dead room, so if that is controlled by the reverberation time which we will come later.

And if we look into the purpose in a conference room or in a board room people are to be heard across the table from one point to the other. So, we have to understand what is the function happening with in that room and considering that a certain amount of absorber have to be provided in certain locations. So, we will go into some of the special spaces we design, but it is not possible to cover all.

So, in a conference or a board room normal speech must be heard over distances and whereas, in cafeteria or within a school or an office we have to reduce the overall noise level. So, noise is created by the utensils, movements; people talking inside. So, rubberized; rubberized items for the dishes etcetera are advisable along with which the internal environment also should be having such absorption which will lead to middle, medium, or reverberation time.

Coming to the gymnasium; obviously, the cafeteria size and the gymnasium size are not same. So, the volume also is very important because RT within the formula we have a component of volume. So, when the volume is higher the absorptive materials are to be put in higher amount to get the same reverberation time.

So, the in case of the gymnasium we have the entire ceiling. Because the sources are scattered, various activities go on within a gymnasium and sometimes a instructor needs to be heard from different points. So, the instructor can move from point to point giving his instructions to the people within the gymnasium, and that leads to how the absorbing materials are to be prepositioned.

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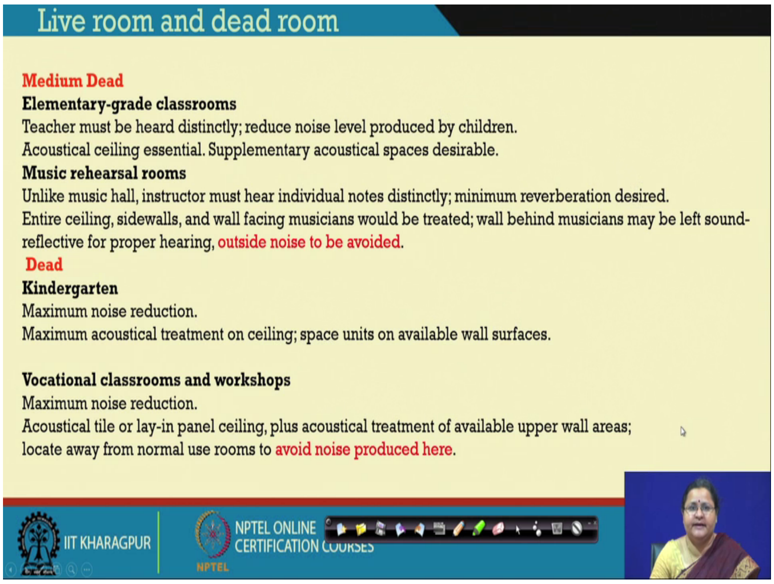

Coming to some medium dead rooms we see we often as architects would be designing schools, which would which would have a primary section a kindergarten section, or secondary section and you have to understand the teacher has to be heard and the students are also to be heard by the teachers.

So, in that case a medium dead room is required. So, that amongst the students whatever small nose is been generated is not creating disturbance of reaching the sound to the teacher and it should be distinctly heard that is also important. In music rehearsal rooms also a similar kind of environment is required that is not totally dead, but almost dead where the outs where the practicing persons are to be heard by the music by the music instructor whereas, the music instructor needs to be hard to the people who are taking the lessons.

Similarly, if you come to dead room kindergarten schools there is a lot of noise created by the little children. So, you are training them at that level. So, the teachers are training them not to make noise, but at the same time they are creating such noise. So, you need dead kind of environment. So, that the noise gets dissolved in small short times.

So, that in that case the reverberation time targeted should be quiet low coming to vocational classrooms and workshops where trainings hands on trainings are given they are also a lot of noise can be generated and to keep that keeping that in mind a dead kind of environment is suggested.

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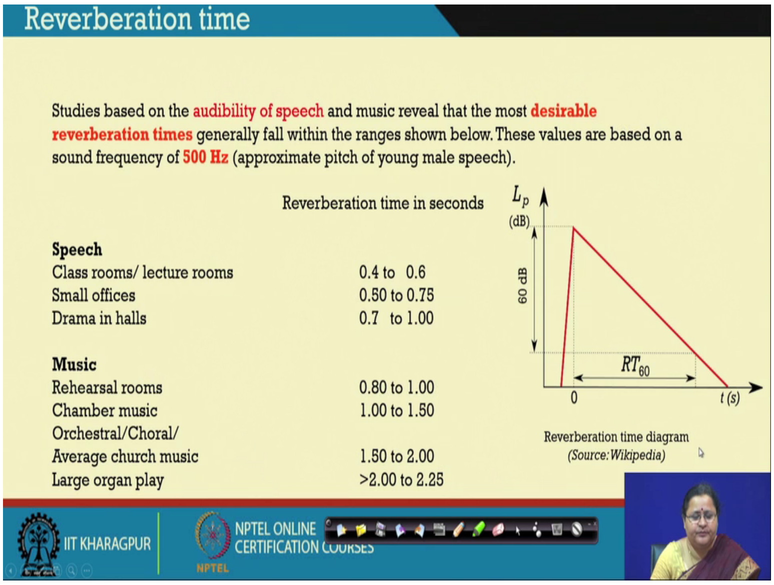

So, coming to the reverberation time if we see that studies have been made through experiments on the audibility of the speech, how much one is heard or needed to be heard. How long it is needed to be heard? For music it is reveal that all the most desirable reverberation time, for music it is different, for speech it is different.

And the most desirable reverberation time falls within the range which has been presented below presented in the list and these are all for 500 hertz sound frequency which is produced by young male speech. So, here you can see what was discussed in the previous slide that classrooms and lecture rooms have a reverberation time of say 0.4 to 0.6.

Small offices also will have no reverberation times from 0.5 to 0.75 for hall drama in halls which is where also speech is the purpose, it is kept low little more than that of the classroom or the small offices but little higher. So, that it creates a live environment for music actually you see the change.

For different types of music it varies from 1.5 to more than 2 to create such high reverberation time the purpose is to create the lively create the overlaps between the syllables; between the syllables which are spelt out or thrown by the source sound, and that needs to overlap with the next sound which is generated.

So, that creates a blender or mix of the sound and that is why the targeted RT within the within the musical performance spaces are to be kept higher. So, here you seen in the small graph which is taken from the Wikipedia you see the drop of sound pressure level from it is original level by 60 decibels the time taken is defined as the RT.

It is also said that the sound pressure level reduced by 1 million to 1 million at of it is actual sound pressure level is also defined as the reverberation time. So, the sound pressure level is important and it is and the time which it takes to get reduced to 1 millionth of it is original string is also important.

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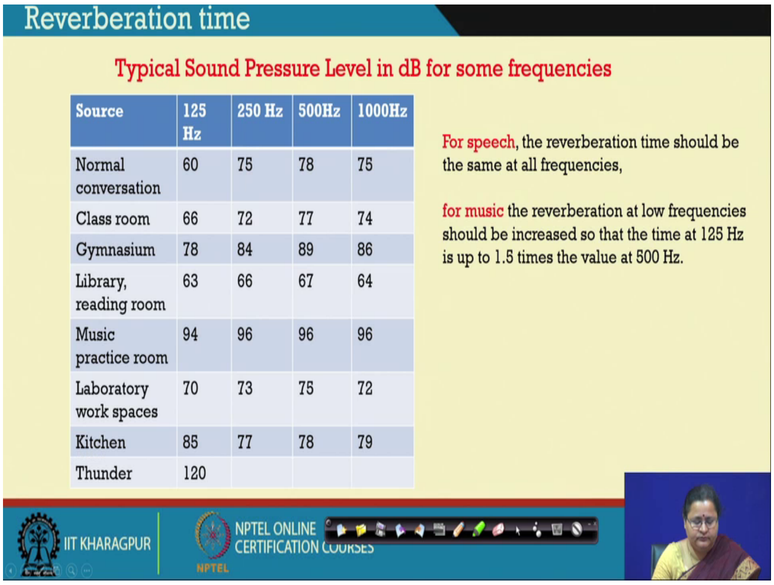

Here are the typical sound pressure level in decibels for some frequencies 125, 250, 500, 1000. And here you see normal conversation which can happen between 2 persons of 125 hertz is just 60. So, then it is 75, 78 and 75. So, you can see that sound pressure level is not same for all frequencies and for speech the reverberation time can be taken same for all frequencies.

Whereas for the musical performance; you can considered the reverberation time as 1.5 times for the lower end, but the actual RT which is required for beyond 500 hertz. So, this if you keep this in mind you can create spaces with a better quality sound and here I have given you an example of a thunder which all of you have experienced it is of 125 hertz and has a decibel level or a sound pressure level of 120. And I as I was talking of kitchen we get lot of sound from kitchen that is also of 85 decibels when it is of 125 hertz.

So, those are actually creating and anions while you listen such sound when it comes when an utensil drops from your hand in a kitchen. So, we have to be careful while we design and keep these reverberation time keep the sound pressure levels in mind while we are taking care of the reverberation time.

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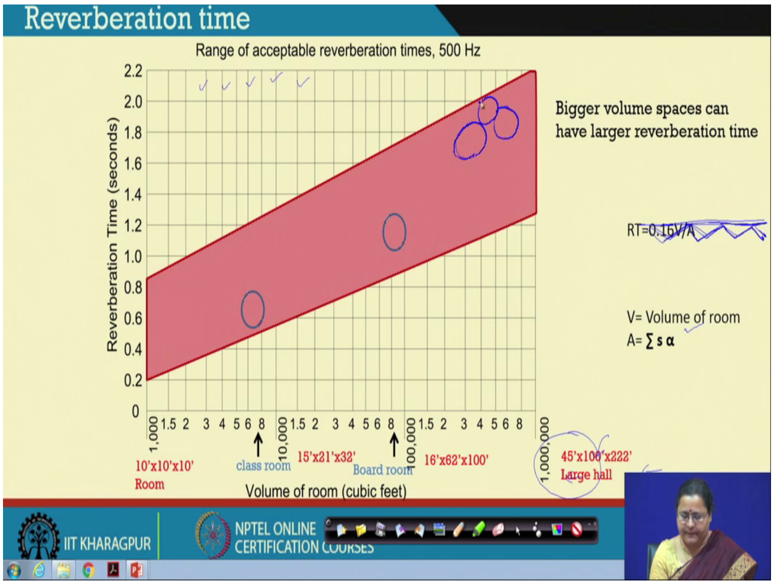

So, let us see how we can think of the reverberation time within our spaces. Say of different volumes we see a 1000 is the starting which is 1000 square feet is the starting volume which can be a 10 feet by 10 feet by 10 feet room. We have the next volume as 10000 square feet which could be a 15 feet, 21 feet by 32 feet room and then a 1 lakh square feet volume room. It could be 16 feet, 62 feet, and 100 feet. These I have worked out for you so that you can perceive these spaces and then large halls say 45 feet that is almost 15 meters high 100 feet, and 222 feet so, that is a large hall.

And let us see how the reverberation time is required to be found out. So, this is the reverberation time is plotted on the y axis and the volume of the room is plotted on the x axis. So, we start with a volume of 1000 cubic feet that is a room of 10 feet by 10 feet by 10 feet, and then we move further up to 10 lakh square feet which is of the order of a very large hall.

If we try to find out where a classroom should be located in this in this area we have this particular graph showing the reverberation time which the lower part is the dead room to medium dead room. The middleman is medium room, and the upper part is for the live room, so we had seen that classroom should be on the area of the reverberation time of 0.4 to 0.6.

So, if we have a classroom of 8000 square if we have a classroom of 8000 cubic feet volume our reverberation time is expected to be in the marked area. Similarly for a board room which will be of the order of 80000 square feet cubic feet area, even see the reverberation time will be in the medium dead area which is shown by the circle in the bed.

So, you can actually locate what kind of reverberation time you require and it will vary with the volume of the space which you are designing. So, reverberation time you have to keep in mind at the same time you have to keep in mind the volume of the space. So, for that for that you will get different quality of the space.

So, the middle lower band shows the to medium dead, the middle portion is the medium room and the upper portion is the live room. So, for auditoriums you will target for bigger auditoriums you will target some spaces over here, so some places over here. So, you can now understand how to make use of this graph.

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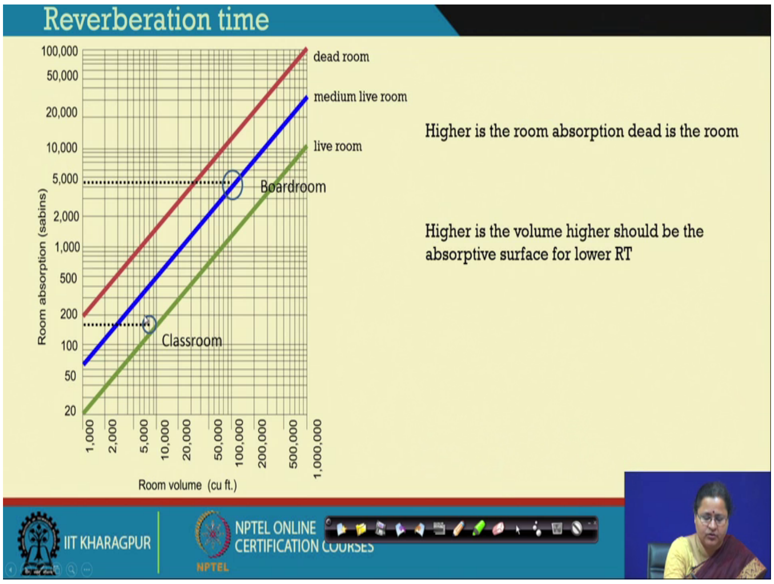

Now, along with this we also need to know with what kind of volume and to get what quality of room considering the reverberation time. What is the amount of absorption that is required? So, you see higher is the room absorption deader is the room that dead is the room that has been already experience through calculation of RT, and higher is the volume higher should be the absorptive surface.

Because if v is high on the equation of 0.16 v by a; if v is high; obviously, the absorptive surfaces will be more in will be more to get the same RT. So, if we see that around 200 room absorption in Sabine is required for 1000 cubic feet of a room to get it as a dead room. And for a getting a medium live room you will see around 50 to 60 Sabine of absorption is required for a medium live room.

And for a live room you practically require 20 Sabine's of absorption for a small 10 by 10 by 10 room which can be actually achieved by the hard surfaces which is present within the which is present within the space, which is creating the space that is the wall spaces around us. So, when we are planning for a classroom which we had seen just in the earlier slide you see that around 8 for around 8000 cubic feet of volume, you will require around 170 Sabine's of absorption.

So, this gives a this graph with the previous one gives you a clue of how much of sound absorption is required for designing a classroom having a capacity of 8000 cubic feet, having a volume of 8000 cubic feet and with that actually you can plan your room absorption. So, you have to arrange for sum 170, 175 Sabine's of absorption and you have your walls ceiling etcetera available for you to get covered by absorbers.

So, now when you are planning a classroom from the basic design principles you will have to leave windows, doors, movement, areas for chairs etcetera. You have the ceiling you know the teacher position and based on all these things you can actually plan your 170 Sabine of absorption, how to put it and where to put it how to organize it within the space.

Similarly, for the boardroom which we discussed which was around 8000, 8, 80000 square feet. So, cubic feet you see you require around 5000 Sabine of absorption. So, you have to in this in the case of a board room you will have to plan for that accordingly. So, you have your 80000 cubic feet of volume where you have where you know the wall boundary surfaces, their area and where you can actually or appropriately put in these absorbers which will generate 5000 around 5 5000 Sabine's of absorption.

So, this chart these two charts actually help you to find out the amount of room absorption required to achieve medium live room, or a medium dead room to a towards a dead room, or what is the value when you require a live room? Sorry in that in the case of classroom it should have been got it is to be from the top. So, I will correct it in the slide.

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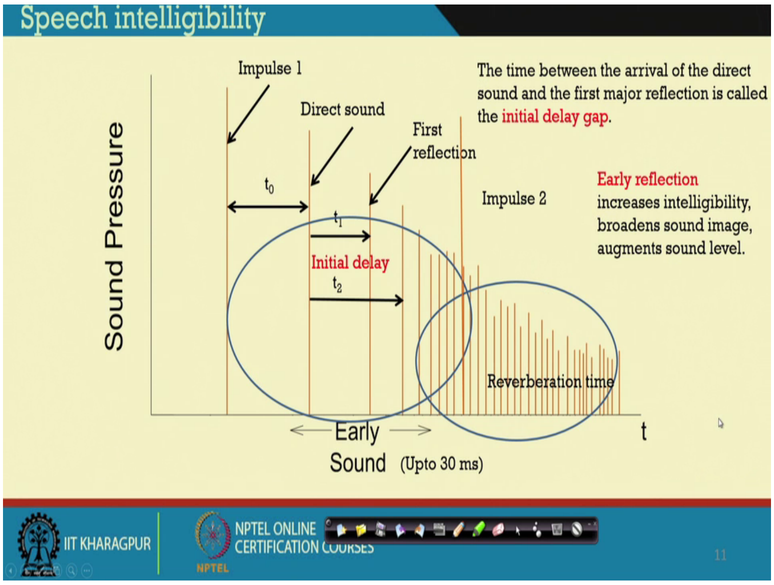

So, now coming to the speech intelligibility, now we have the sound we have discuss the sound pressure level we have talked of the reverberation time you know by this time what is reverberation and we have understood how with volume the reverberation time is changing. What is live room? What is dead room? What is medium live? And what we desire.

So, when an impulse is created that is when a sound is produced and then stopped what happens it goes and hits the receivers here. So, that is the direct sound, and after a short span of time the first reflection reaches the person. Again and after sometime another sound that is the second reflection reaches, then the third reflection, then the fourth reflection, and n number of reflections take place, this is what this picture is showing.

And what you see here that in the first part that is up to 30 milliseconds is called the early sound which is actually helping you in getting the sound; or the impulse correctly. And west is the reverberation time which actually remains within the room and where the sound is taking some time to get to get die down.

So, the first part the first sound which is coming after the direct sound is the first reflection, and the gap in time is called the initial delay gap. And then comes the second sound for the impulse 2. If this impulse 2 is happening after the early sound then the first impulse is heard, but with the impulse 2 you see that the reverberation reverberated sound of impulse 1 is still persisting within the same, within the same time. So, that actually was not required for the impulse 2 that is creating noise for the signal which has been released by the impulse 2.

So, when the impulse 2 is happening a part of the reverberated sound of the impulse 1 is still remaining within the hole, within the space. So, that can actually lead to a lesser amount of sound reaching the receiver for the impulse 2, and if it is if the impulse 2 is not of enough sound pressure level to combat this noise, combat this these reflected sound of the impulse 1, then impulse 2 would not be heard clearly.

So, it is very important that this reverberation this impulse 2 should be having a high sound pressure level and the noise level that is the reverberation reverberated sound should have a lesser sound pressure level compared to the impulse 2 for a better intelligibility. So, this is what is explained through this picture and this early reflection of impulse 1 is helping the increased intelligibility of the impulse 1.

Similarly, the early reflection of impulse 2 will help in better intelligibility of impulse 2, but this noise will this noise of impulse 1 of the revenant sound of the impulse 1 will create a noise for the or the disturbance for the impulse 2. So, from this we can say that the percentage that is the amount of sound that is received from the impulse one by the ear makes helps the person to determine what was spoken.

And from there he actually understands what was told? If it is said that around 90 percent is heard then it is highly intelligent highly intelligible the speech intelligibility is high. It is said that at least 60 percent of the sound should enter into the ear. So that human being can actually understand what was the words spelt.

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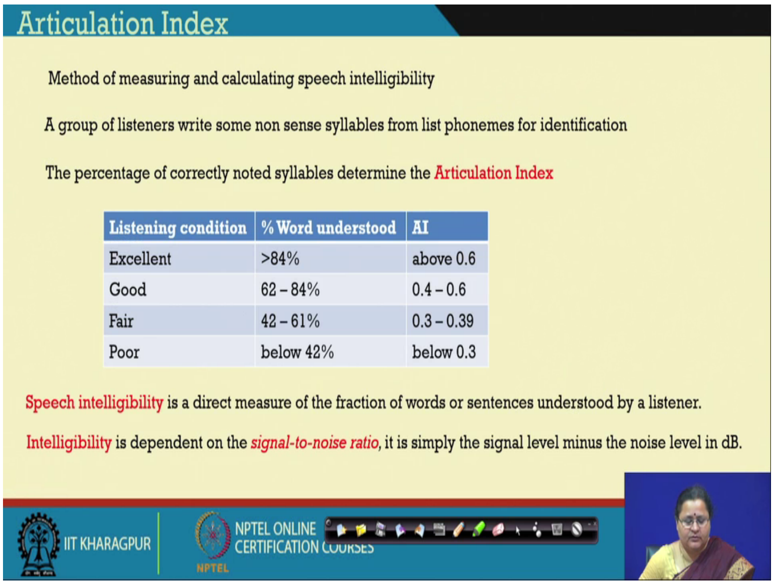

So this kind of experiment is done when syllables are actually spoken to the audience and the audience are ask to write down some nonsense words are spoken by the source. And whatever is heard is written down when the next word or the next is pulses thrown, and these are to be noted down and what the person is actually hearing is then scrutinized. So, it may be with words, it maybe rhyming words, it may be sentences.

So, the subjects are noting down the sound what they are hearing and it may not be 100 percent correct and that helps in determining the articulation index. So, the method of calculating the speech in intelligibility is called the articulation index. Say a group of listeners write some nonsense syllables which is listed from the phonemes for identification say like sat, sat, sac, sas, sap all these are told and the audience is may be missing the last part.

So, he is trying to figure out what could be what could have been told and he is writing if he is writing 100 correct; that means, the space is highly intelligible. But if he is not getting the whole part of it is left out say sa is written may be sap is not heard p is not heard he may be thinking it was sat. So, he will right sat. So, he may hear write sat several times.

So, from that what is the percentage of correctness the articulation index is calculated out? So, the percentage which is correctly noted is determining the articulation index and here is a list for that we say if more than 84 percent is heard it is excellent, if it is between 60 above 60 to 84 we say it is good and then fair for between 42 to 61 that is not much heard and poor when it is below 42. And the articulation index is given as 0.6 for which is the highest and then between 0.4 to 0.6 as you see in the list and further down it is for fair and poor.

So, the speech intelligibility is the direct measure of the fraction of the word, or sentence understood by a listener. So, if we keep in mind the this graph you will understand what is meant by speech and intelligibility? So, the overlap of the impulse 1 while overlap of the impulse 2 with the impulse 1, remaining portion of the sound of impulse 1 that is the creating the noise with the for the impulse 2 is leading to a lesser intelligibility, and that is what is actually found out through the intelligibility the articulation index.

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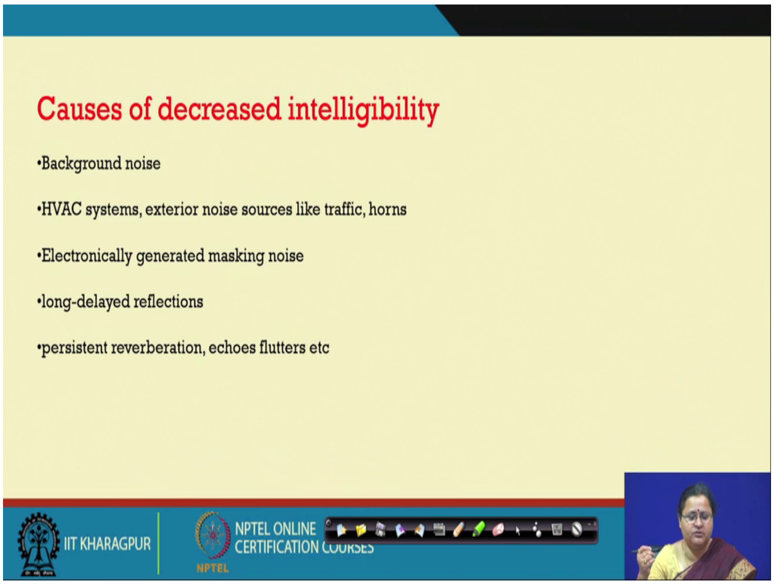

So, causes of intelligibility causes of decreased intelligibility should not be only for the impulse 1, but it could be because of any other background noise. Say a fan is moving, say HVAC system is creating some sound, some electronic music is being played which is a continuous noise in the system, or some long delayed reflections are happening that is coming back. And that is also creating decreased intelligibility or what I told or explain the persistent reverberation of the previous sounds, or some echoes or flutter echoes can cause some decrease such decreased intelligibility.

So, you have understood the with reference to reverberation time the live room, dead room, and medium live room or the medium dead rooms and the range within which the reverberation should reverberation time should live with varying volume. And the amount of absorption required in the different cases that can be understood through the graphs. Then you understood what are speech intelligibility, and the articulation index, and how it has to be calculated, what is noise within a system.

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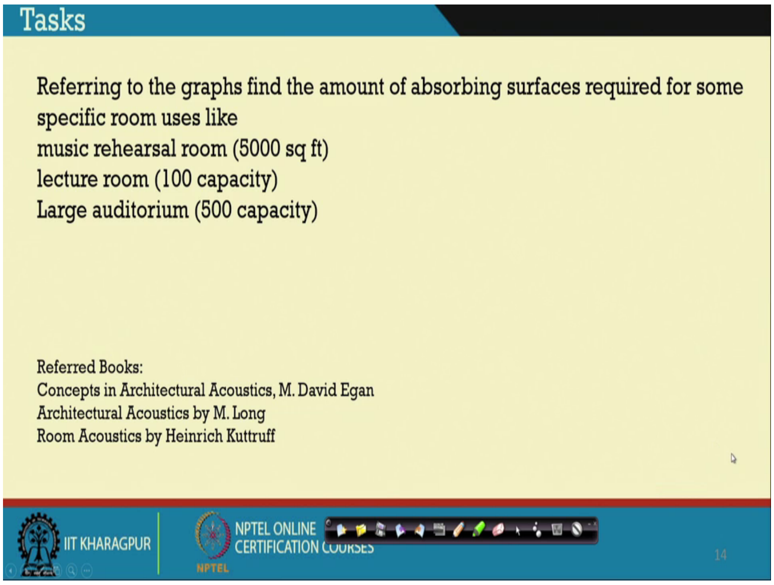

And here is some small task for you referring to the graphs you can find the amount of absorbing surface is required for some specific rooms like a music rehearsal room, or for a lecture room, and for a for a lecture room of 100 capacity or for a large and auditorium for 500 capacity.

You can work out how much area would be required for a lecture room considering as you all are would be architects. You and almost beyond 3rd year, 4th year, 3rd year level through your design classes you must have some idea of the area. And consider some volume and try to find out what should be the absorb absorbing area required for such particular spaces. Here are the list of referred books which you can actually refer and also increase your knowledge base.