Principles and Applications of Building Science

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Lecture – 15
Acoustic Quality Indicators – 1

In this module we will be talking about Acoustic Quality Indicators. There are two modules in which we will be looking at acoustic quality indicators. This module primarily covers the criteria for background noise, what all are the indicators are indices which we have to understand before. Now we said the background noise level rate in a given space.

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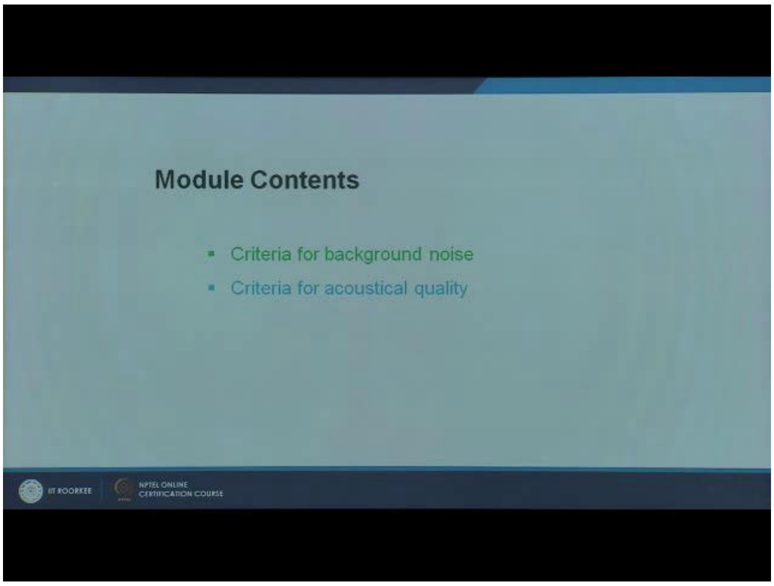

And next we will be talking about criteria for acoustic quality that is good listening how it starts. So, the second part of this will cover further more indices.

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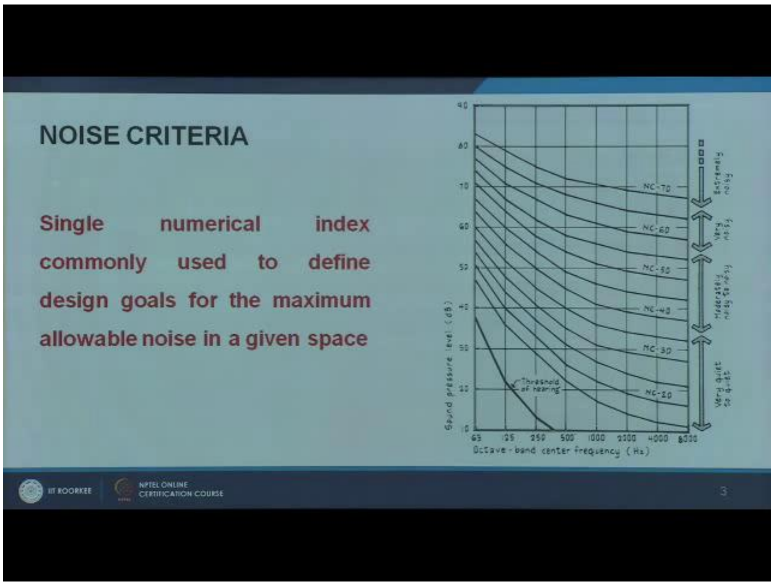

To start with the background noise levels how do you define background noise level. One of the last modules we looked at the environmental noise levels, where we talked about l equivalent and we know how these limits are defined.

In case of indoor noise levels we define in terms of basic indicator is noise criteria commonly referred as NC. Many of the standards define saying NC 30, NC 40, NC 45. A common indicator that you would find in most of the standards internationally you will find this name NC 30, 40 this things will be given. And depending upon the type of space what activity happens there and what is a acoustic quality which is required this noise criteria varies. Noise criteria are NC this is a single number index which is intended to define the design goals how much should be the allowable background noise level in a given space.

Instead of saying the overall noise level some sound pressure level are sound pressure level l equivalent should be this much this is a better indicator. This derives from this curves I will explain this first. On x axis you will have the octave band center frequency. This we looked at here this covers from 63 hertz all the way up to 8000 hertz, further low and further high frequencies are not covered here. Primary audible frequencies it starts from 63 goes to 8000 hertz. On the y axis you will find sound pressure level in decibels. There are defining contours which have been evolved.

So, if you take for example, particular noise criteria say NC 20 then you will find in the center of frequency that is 1000 hertz you will find close to 20 decibels are slightly more or less then this band. As it goes up it reduces and then as it comes down to the lower frequency this value goes up. This is more or less similar to the audibility capacity of hearing that human ear has. In lower frequency more sound pressure levels are allowed. For example, if a standard defines that you have to meet NC 40 noise criteria of 40 in a given space take it is an office space open plan office space; a noise criteria of NC 40 has to be met. Then what at you know what it means how it translates at 63 hertz you can go all the way up to 65 decibels at 63 are very low frequency. Say in mid frequency somewhere around 500, 1000 or 2000 hertz you have to be close to NC 40 that is, sorry 40 decibels and then at high frequencies it should be relatively low, say 8000 hertz NC 40 would actually mean you will have to meet somewhere around 37 or 38 decibels.

So, if you have a spectrum analyzer or a sound pressure level measuring device you will have to meet or after you design the room has to meet at 63 hertz it can go as height. It mean it can so as height 63 or 65 decibels, but at higher frequencies like a 8000 hertz it should be well below 40 decibels that is what it means. Then if you are trying to meet this then it means you have met the noise criteria which is defined. There is lower line which is threshold of hearing and noise criteria's which is close to 30 or below which means it is a very quite ambient. This is moderately noisy to noisy this is between 30 to somewhere around 50 above 50 close to 60 65 this is very noisy and above 65 this would be term extremely noisy.

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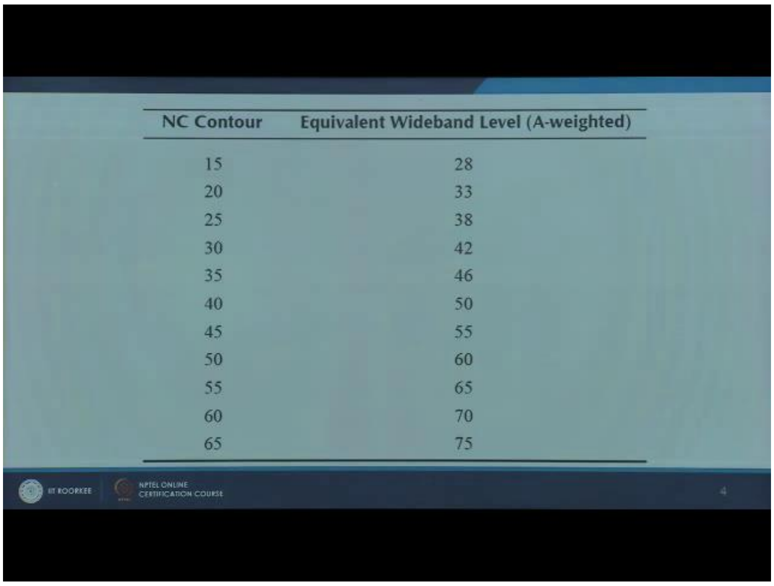

NC Contour	Equivalent Wideband Level (A-weighted)
15	28
20	33
25	38
30	42
35	46
40	50
45	55
50	60
55	65
60	70
65	75

So depending on the space, for example there is difference between a commercial area where the NC is defined versus a quite open office versus a private office and a board room the NC are the noise criteria would considerably differ. As we know sound pressure level is also you know easy to express in terms a weighted, this is also a weighted also means that you are waving it to the human ears capability of hearing. This two can be compared. For example, you take a noise contour or NC criteria contour of 40 this would be more or less equal to an equivalence sound pressure a weighted sound pressure level of 50. So, there is a relation they are also directly proportional, as this increases this also increases but still there is a considerable amount of difference. This is termed are this was found to be more or more precise in representing the background noise levels in rooms.

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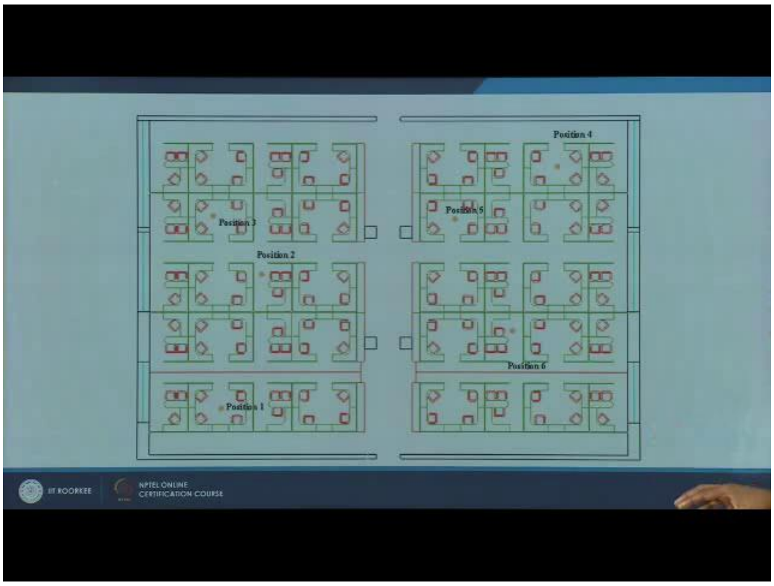

I am going to give you a specific example. This is open office a plan you know top view of open plan office we took measurement in few specific locations. In about 6 locations we measured in the acoustical quality. I am going to take this as an example further wherever we come through acoustic quality indicators in terms of offices I am going side this example. Remember this image this is a very symmetric looking open office 6 position we where measuring like, inside the work session these are cubicles say know each of this makes for work places all across we took along the (Refer Time: 06:12) plus know within close to the work spaces and few specific locations.

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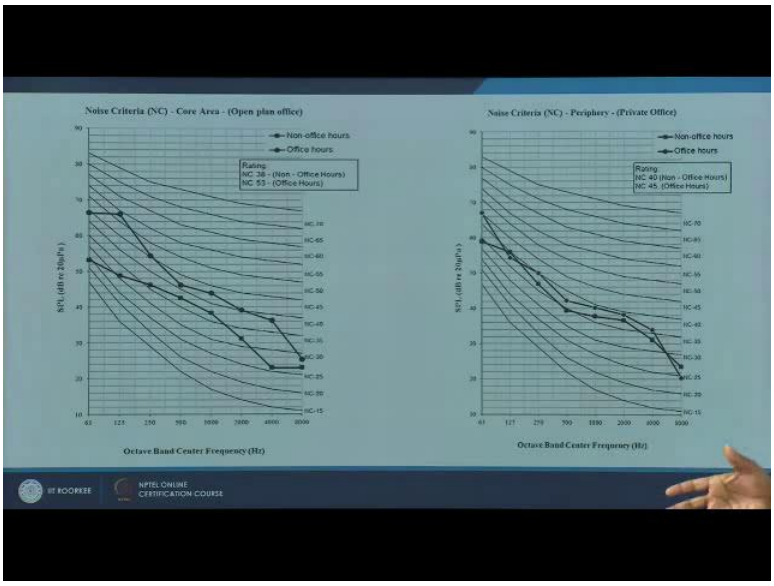

So, in a typical open office if you take the core area you will have for example, there are two times we took the measurement what you see in the background is a noise criteria the same curve that I showed you and this dark lines this represent our measured value. There are two things here this represents the non office hours, the one here before the office started or after the offices people have left. Two main things happen air conditioning system plus the computers Photostat and reprographic machines and other typical machineries are turned off, plus people talking and conversational background noises are also coming down. Due to this you find the background noise level to be low. If you estimate the noise criteria we got around 38 NC.

So, if the office standard, standard for open office says you have to meet 40 noise criteria. When people and machinery are all you know machinery turned off people are not there then we are getting somewhere close to 38 as the noise criteria. But then when you are measuring during office hours we find low frequency there is little high probably due to machinery and reprographic background noise levels. Then you also have people conversing which also increases it, we found we got around 53 noise criteria doing during office hours.

So, in our example say if we have to meet 40 nice criteria we will not be actually meeting it, we will have to go for certain kind of acoustical treatment in order to bring the noise criteria to a lower level. This is one of the private offices, this is same open office but in the periphery we had a couple of cubicles where I am sorry private cabins office cabins for senior people. We did a measurement there, but if you take private offices you found during non office hours versus office hours they were more or less closer because just it was one person occupying with minimum amount of machineries sound. It was the air conditioning sound plus just a laptop and a person sitting there.

So, more or less you know with this measurements were taken for about one hour duration, continuously they are recorded and this where estimated. So, we found more or less they were closer 40 with office hours 45. But one thing we have note that definitions for noise criteria will vary from an open office to a private office place. Here the noise criteria requirement itself would be lower; it may not be as higher as 40 or 45 a particular standard might ask you to meet noise criteria of say 35 during the office hours. Then again we might have to go for a treatment. This is one indicator of how the background noise levels are existing.

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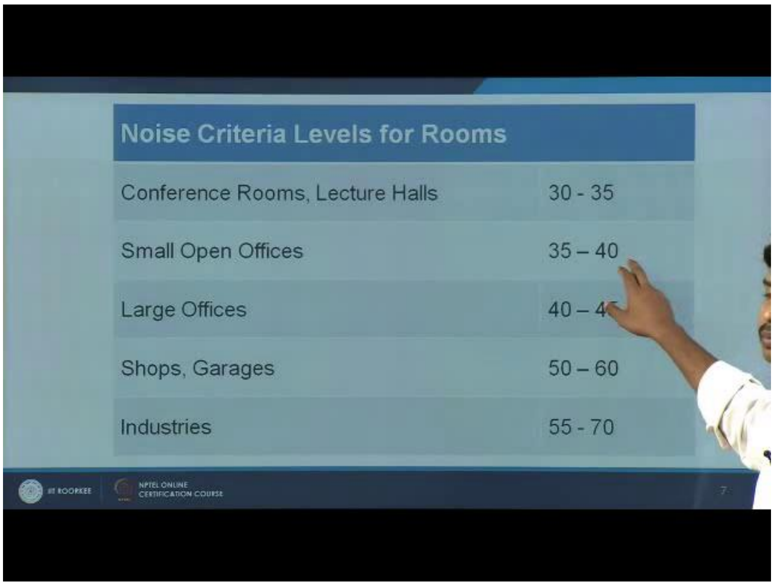

Specific standards there are different versions standards defining commonly accepted form of version. Conference rooms are rooms for lectures 30 to 35, small open offices 35 to 40 this would also include private cabins, then large offices you can go as highest 45, shops garages it would be higher and industries it can go as highest 70 NC. This is in terms of noise criteria.

There is another version of defining background noise level. If you closely look at the previous graph you had frequency is ranging from 63 hertz all the way to 8000 hertz. Typically if you want to understand what an air conditioning system causes and what it is impact on the noise level. Air conditioning system (Refer Time: 09:57) system compresses of fans, pumps, motors, air handling unit, the mixing turbulent sound plus the passage of air also causes the turbulent, the throw of it. Together there is impact or an elevation or escalation in the indoor noise level.

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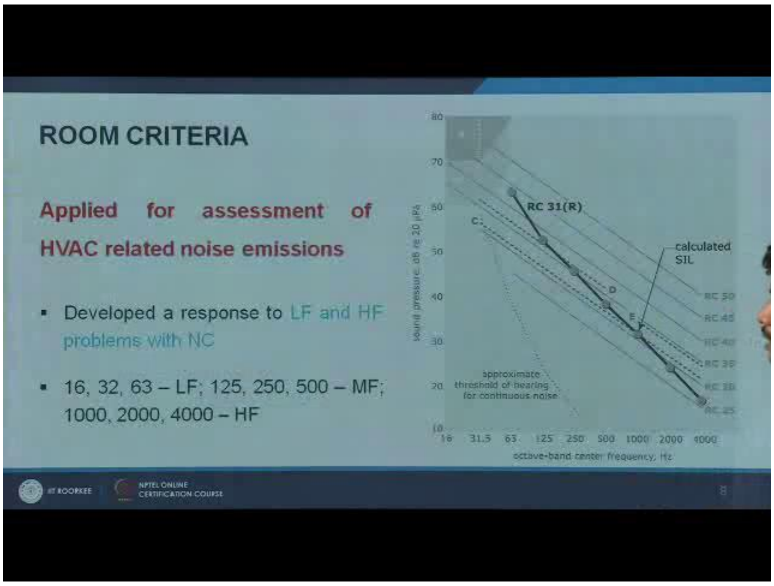

So, if you have to understand then closely you have to go beyond what frequencies are presented here. That is exactly what was done in this. This is called room criteria or commonly referred as RC. There have been many versions. The current are more commonly referred is RC mark 2. There have been many improvements in this room criteria thing. These are certain definitions are criteria which are said set by standard. So, the current one RC marks 2.

This is similar graph you have the octave frequencies octave band center frequencies in the x axis. Difference is it goes up to the maximum it goes up to the 4000 hertz, but minimum earlier it was up to 63 hertz now it is further go into up to 16 hertz. So, you are actually considering or starting to consider much lower frequencies than what noise criteria actually allowed for. It was primarily developed to consider the low frequency and mid frequency associated problems in terms of primarily relating in terms of HVAC noise emissions.

So, if you look at a air conditioning standard like ASHRAE they would ask you to (Refer Time: 11:25) to certain room criteria, because your designing the HVAC system as a mechanical engineer as a HVAC engineer. Finally, you will have to meet the room acoustic criteria; other the room criteria. There are you know 3 4 specific things which we have to note. Main as the earlier thing there are they were curves there are saying noise criteria NC 20 and NC 30 here we have room criteria starting from 25 it goes up to 50. There is threshold of hearing. One thing interesting if the frequency levels go below, say for example 63 hertz or say 16 hertz, there are not much of the frequencies which our ear can actually sense and appreciate. At this frequency when sound is emitted this will be felt as direct physical vibrations rather than audible sounds.

No very high sound pressure level or decibel levels only can be hard at for example 16 hertz, but before we start hearing it you start feeling the physical vibration. There are two zones defined here zone B and zone A, these are if you take zone B these are regions where there is a probable vibration and these are specific vibration. For example, at 16 hertz your spectrum analyzer shows that you have a sound pressure level of say 65 db it means there is a probability for vibration or at least the decks are machinery HVAC system going to cause a probable vibration. At zone A the levels are even high this would indicate that there are definitely certain vibrations which are going to result. Apart from this there are three lines; line D line C and E.

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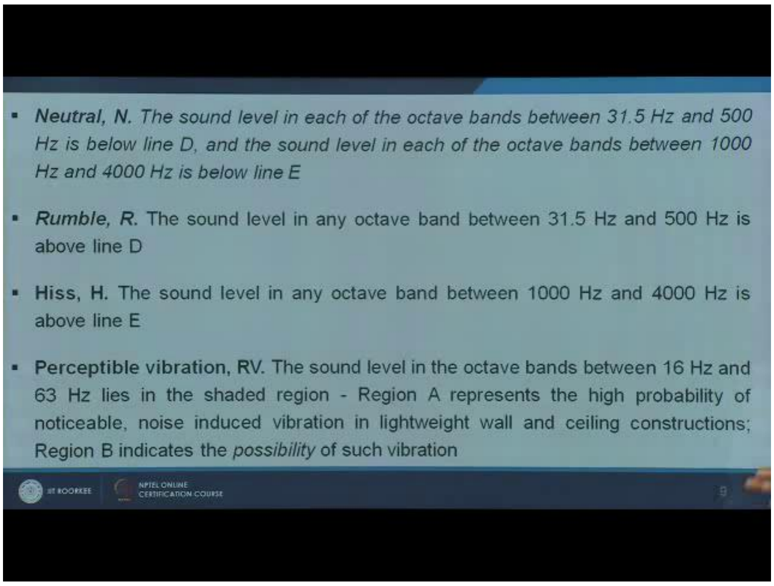

We will look at what they mean. Neutral for example, a neutral level are RC neutral means each of this octave bands, the sound pressure levels are lying below these dotted lines here. There are two important criteria; one is rumble other is hiss. Rumble is a low frequency indicator and hiss is a high frequency indicator. If your sound pressure levels say your keeping a spectrum analyzer again you are measuring it. If you are low frequency sound pressure levels are exceeding this particular line D, this dotted line D it will indicate here going to have a rumbling sound. They are actually trying to categorize the sound itself, the character of the sound itself you will experience a rumbling sound.

Whereas, if your sound pressure level spectrum analyzer measurements are going to cross line E at this frequencies are slightly higher frequencies then you will be experiencing a hissing sound. This is what actually it means. Then as I said if they cross and get into the boundary B then you will you can expect probable vibrations and when they go into zone A it means there are going to be certainly some vibrations associated. Main things where vibration occur is the h (Refer Time: 14:34) decks where the turbulent air flow causes certain vibrations.

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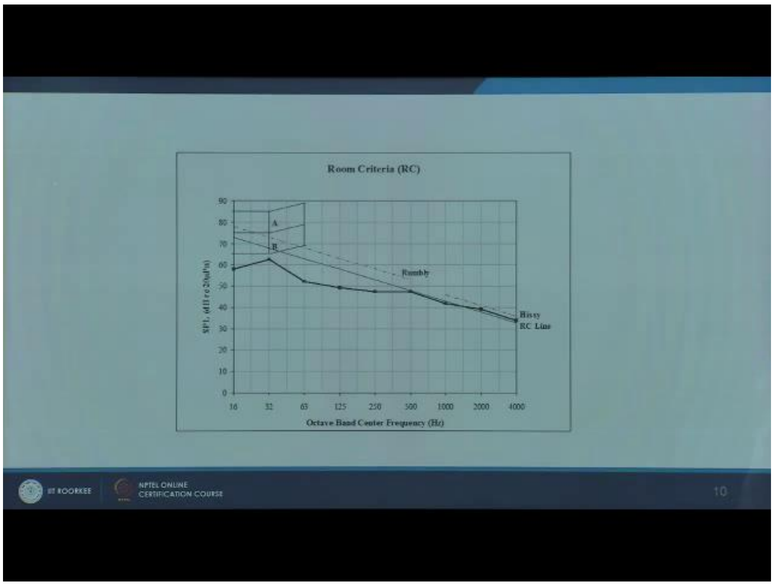

The typically example of the same office which I was taking about when we measured there was no rumbling sound, but there is a slightly hiss sound because it was trying to touch not really cross but it was trying to touch the E line. But pretty much the room a criterion was met only problem was the noise criteria was slightly above. There is a stacking difference here, if you find the room criteria to be acceptable you can infer that you do not have to really rework on the HVAC system or the design are treating the HVAC system itself. You might probably then make sure or ensure that this HVAC system does not have much of the impact on the noise level. When noise criteria are not met your main attention should be on acoustic treatment.

Whereas, if you see the room criteria is shooting up it means your main attention you have to focus on the air conditioning system there may be certain problems when I am saying you have to prioritize looking at the air conditioning system associated noise levels. So, we looked at two indicators for background noise levels. We will look at one of the important indicators for the indoor acoustic quality. A very common term it is a day to day you know this term is in day to day use reverberation time. This is one of the first indicator this is not the only indicator of acoustic quality among several indicators this is a most commonly used and one of the simple induces which you have to understand. Reverberation time, it is time required for the reflections of a direct sound to decay by 60 decibels.

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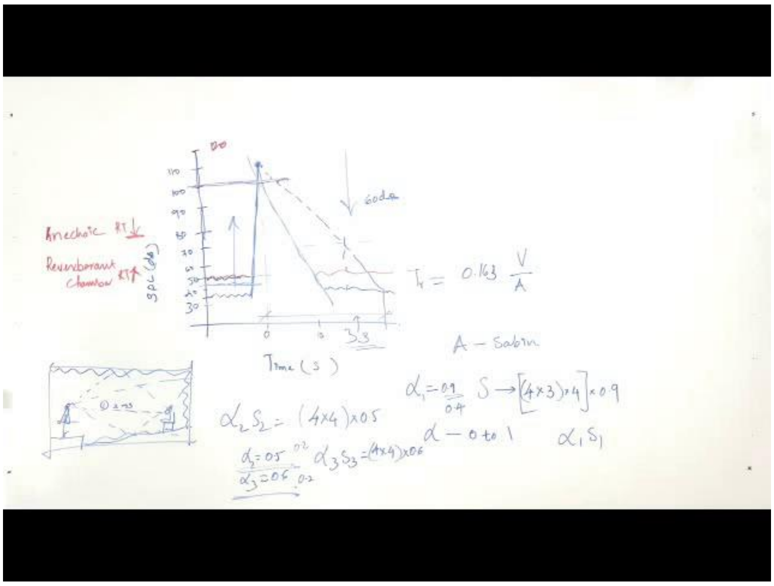

Let us look at it in this way. In x axis I am going to have the time we will talk about milliseconds because the velocity of sound 343 meter per second more specifically in room temperature indoor. Then the time within which the acoustic wave would reach you even in a very huge auditorium would be in milliseconds. You will not even experience few seconds it will be few milliseconds the sound would reach you. Let us take this as sound pressure level in terms of decibels.

So, let us say there is 30, 40, 50 I am going up to say 100 decibels, now say 110 so and. Now, there is a background noise level like we looked at say it is a you know a small lecture hall you have certain background noise level across the time. You are going to create impulsive sound, say for example you are busting a cracker what would happen. There would be a sharp sound which goes as high for example as 110 d b, then it would not decay that fast, but it would eventually be decaying there will be a slope and then it would come back after while it would come back to background noise level. Imagine if the background noise level is around 30 35 decibels then you are elevating the sound pressure level and it takes while to reach the background noise level again.

Now, here it is again continuing with the background noise level. If you mark this peak point as 00 milliseconds that is 0 seconds this is a start of the thing and this for a example it takes about a few milliseconds let us talk about seconds first we will come back to milliseconds later. Say now if you are considering this in milliseconds say imagine it is taking about 1 second to come back to this point. The slope this line is estimated and the time taken between this and this that is the reflections of direct sound. So, this point this peak direct sound, it can be a clap, it can be gun shot or it could be a cracker or any standard sound source you are elevating the background noise level and then your letting it fall the cracker is just one impulse it falling of it takes about 1 second. This is exactly what you call in terms of reverberation time it is expressed in seconds; reverberation time is expressed in seconds.

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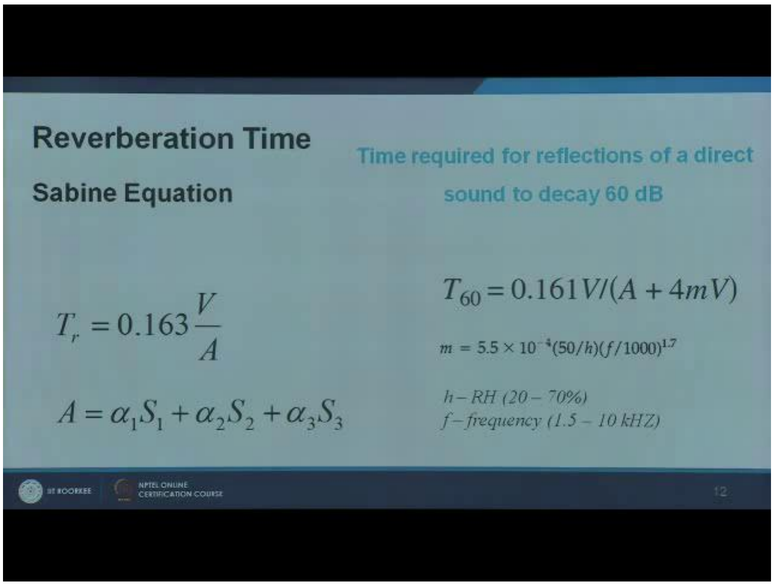

The simple formula is used here reverberation time is a factor of the room volume V is a room volume in the denominator you have a factor called A. V by A and you have 0.161 or 163 original variation t r is a reverberation time and a is a acoustic absorption it is expressed in Sabine’s. So, then name of the person who did all this physical experiments and finally he derived a relation between these parameters. A actually is a factor of S that is a surface area and alpha which is absorption coefficient.

We will look at more about absorption coefficients in one of the following sections. Alpha is absorption coefficient of a material and S is a surface area of that particular material. Say you have a room of for example 4 meter by 4 meter and the height is 3 meter, so very small room. You have wall surface plus you have a floor carpet and you have a fall shielding. So, without you know forgetting any door window anything it is a shield room so with a simple room you have three different materials; first is the wall surfaces the surface area. The wall if you have to compute reverberation time the first thing you need to do is compute the surface area of wall surfaces. So, you have four walls it is a 4 meter by 4 meter room 4 by 3 meter you have 4 walls, this will be the surface area.

The wall it does not have any observing materials surfaces. The absorption coefficient ranges from zero to one. Zero means it is perfectly observing, one is totally reflecting it is a coefficient. Say for a typical reflecting without untreated wall the reflections probably will be around say 0.85 or 0.9 there is no absorption happening with in the wall surface itself. So, let us take it as 0.9. Then what you will have you will have to multiply the whole thing by 0.9. So, this is alpha 1 S 1 this is the first surface we are considering.

The next surface would the floor surface, that would be say alpha 2 S 2 will be 4 meter by 4 meter this is a floor area into I said it is a carpeted floor let us say the absorption coefficient. I will define more about and talk more about the absorption coefficient it varies with frequency spectrum it is not a single number for all the spectrum. It varies according to frequency, but let us takes one number right now.

Let us take the carpet have an absorption coefficient of around 0.5 that is 50 percent absorbing. Then you multiply this by 0.5. The third surface we talked about alpha 3 S 3 that would be the ceiling again it is 4 meter by 4 meters. Let us take alpha 3 this was alpha 1, alpha 3 to be for instance 0.6. You have a fall ceiling not a very strongly observing fall ceiling is simply gypsum fall ceiling then you will have 0.6 here. If you take sigma you sum it up you get a number called A defined in terms of or the unit of measurement is Sabine’s, this goes to the denominator, you have the room volume in the numerator you multiply the whole thing you will get directly the reverberation time. Very simple formula here, a logical understanding goes like this.

If you have to improve the reverberation time say you have to typically longer reverberation times are longer time for decay of sound. Instead of 1 second if this where to decay all the way here, instead of this is going to take say 3 seconds total from this point to this point if it is taking 3 seconds then the reflections stay in that room. Imagine you are entering into your new house you do not have any furnishing, you do not have people staying nothing is where just an empty room. If you clap or if try and sing if you talk you will be hearing lot of reflections, there will be a ambient sound which is continuing which is not decaying out with close window, but then eventually you start occupying you put in your furniture's, you have your open windows, people around everything is observing our scattering the sound, then the reverberation eventually comes down, this exactly what we are talking about.

If it is 3 seconds there is going to be a lot of reflected sound. As I earlier said the time taken for sound from the source to reach the receiver a point receiver will be in terms of milliseconds. Initially if you remember we were talking about milliseconds here we will come back to that discussion, but this will be in milliseconds. But if you have reverberation time very long say for example 3 seconds, 4 seconds then by the time the first say you know this is a first claps say you are imagining your clapping or spelling one word by the other word. The first word reaches the persons here in a few milliseconds, then you will have the second word spell; the second word will be coming, but by the time if the first signal has not decayed down or the reverberation time is high then this would start masking the second one.

Imagine in a hall you are sitting here the person is talking here talking from this place you are seated in this area, you also have the reflection from floor ceiling more clear picture of it. See you are sitting in a place that is the podium you are seated here there is a direct sound coming here, say imagine you have a 6 milliseconds then there will be a reflected component. There will be many reflections each surface will reflect and there will sound reaching you if this sound does not get observed or decayed down within say for example, 0.8 second or 1 second, then they will start interfering with the second signals.

So, this is signal one. When the signal two starts coming in they flow each other in milliseconds like, I am talking I spelling each word within a few millisecond gap there is no much of time delay, so they will start masking each other. We will look at it more in detail, but this is so critical if you start introducing an absorptive layer here. If you start introducing absorptive layer all around then these sounds the longer will reflections are eventually getting absorbed. Movement they are getting absorbed then the masking effect eventually comes down, this is exactly what we are trying to do.

So, in the context if you are wanting to reduce the reverberation time that is where we are talking about say imagine the original reverberation time was 3 seconds you want to bring it down to 1 second. There are different methods to do it common method which industry you know any you know kind of material seller would tell you is to go for an increased absorption coefficient. Instead of using a 0.5 absorption coefficient we had our alpha 2 as 0.5, alpha 3 as 0.6, instead of 0.5 he would advise you to go for 0.2 or instead of 0.6 he will say go for 0.2 or 0.3 and he will say treat your wall surfaces so instead of 0.9 this can be made easily to 0.4.

With all this conditions you are increasing the number in the denominator that is the total Sabine's will go up with this the reverberation time can be brought down, this is one method. But there are other methods you can vary the surface area instead of treating the whole wall whole ceiling whole floor area you can pick and choose you can increase or decrease the surface area in which you are creating. There is a third method you can look around now volume. If you think 3 meter or 3 and half meters height is not required in your case then you can reduce it to say, imagine you are reducing a 3.5 meter room to a 3 meter. You are actually reducing the volume here, if the volume reduces reverberation time will go down, if you take large auditorium, cathedrals, safer houses they are huge in volume. The reverberation time will go as highest to 0.5 seconds, whereas small lectures halls, small rooms you will you know the best designed hall would have reverberation time of somewhere about say classroom would have a reverberation time excepted around 0.8 to 1 second. Less than 0.8 you will have a better audibility.

We will look at audibility more in detail, but simply speaking this is a relation between the volume surface area of absorption and the absorption of the material. Three things you know you can determine the reverberation time. It also is a factor of frequency as I said it varies with respect to the frequency and not also it varies with respect to the relative humidity, but in common calculations we do not get too much into detail but this is yes in fact this is accountable you cannot simply ignore it. But still for a simpler understanding in this module you can go with around 0.163 or 0.1361 V by A, Ais in Sabine's acoustic absorption which is a factor of the absorption coefficient and the respective surface area.

There is a term called t 60 which is 60 decibel, the sound has to decay by 60 decibels. In this case you have a sound pressure level of 110 db is a maximum, from 110 db the sound pressure level has to decay down by 60 decibel it should come down the total decay should be 60 d b, this has here increased it has to drop by 60 db the time taken for drop by 60 db is actually what you measure as reverberation time.

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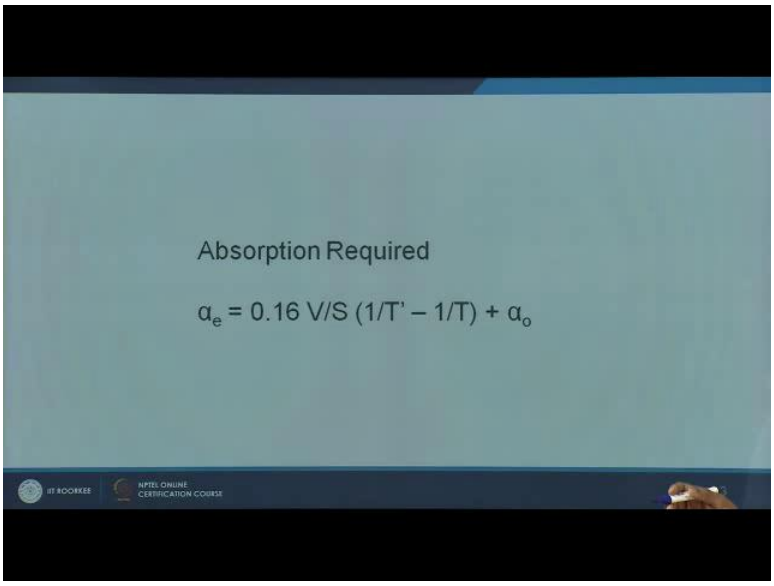

A simple reworking of the formula you can actually find out what is excepted absorption. So, if you have the required absorption and the actual absorption you can find no sorry the expected reverberation time and the actual reverberation time, you can find what is expected absorption, this is a typical field problem. You already have a room in which you have to add absorption material, how much amount of absorbing materials you will add substituted there is a existing absorption alpha naught, you have the reverberation time the existing and the reverberation time which you intended to achieve. So you have a reverberation time of 2 seconds or 3 seconds you would like to bring it to 1 second, substitute it you have current alpha that is a existing absorption you will able to find what is a expected sound absorption coefficient which is required.

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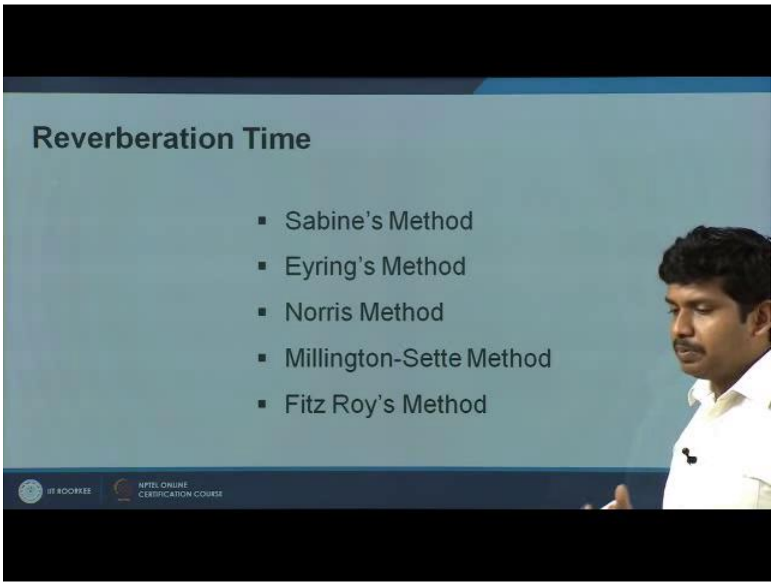

There are different methods of determining reverberation time we looked at the Sabine's formula. Apart from this there are four other commonly used things they again vary based on applications Eyring's Method, Norris Method, Millington-Sette Method, Fitz Roy's equation these things are also applied for detailed acoustic calculations specific hall types specific absorption types Sabine's model cannot be extrapolated. So, you will need a detailed working. They also have certain principles like you know imagine reflection methods certain things are assumed here I am not going to get into details of these models right now, we will stick to the Sabine's method.

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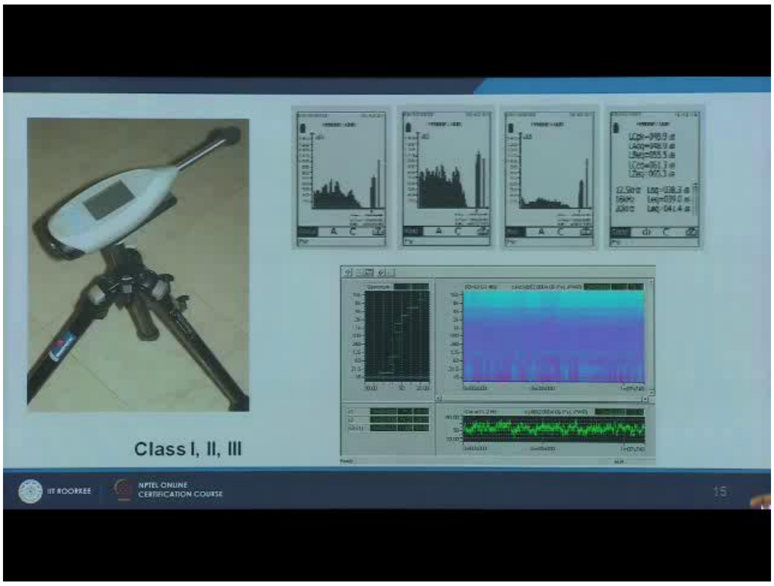

At a typical sound spectrum analyzer there are different classes. Class III very simple you will only get a sound pressure level SPL; you will not get the frequency spectrum. Class II you might get frequencies spectrum some of the manufactures do it. Class I is for long term recording you can also have statistical parameters reflected with it, you also get apart from the basic A weighted, C weighted or linear levels you will also get a signal recording function where you can record for; say specific duration 8 hours, 12 hours or for even longer duration it will be recording that capability is there. Then it will also record in terms of different frequencies. It can record single octave, third octave you know as the class goes up the complexity of the spectrum analyzer increases. Basic sound level meter of class III to a detail spectrum analyzer of class I.

Let us talk about a practical problem now. We talked about a quite ambient you are trying to measure background noise level of an auditorium; here we talked about a background noise of 30 or 35 decibel. In an auditorium a background noise level with air conditioning system typically will range somewhere between 40 and 45 decibel. There will be certain disturbances you cannot have a very quite if the auditorium is getting larger you will have an air conditioning system running it is hardly you know possible to get something below 45 decibel. So, your actual background noise level is here.

Then when you say the peak level there will also be certain masking here, so it is a good idea or a good practice to live a 5 decibel threshold here and another 5 decibel threshold here. So, now already we are in 50 decibel the maximum we have come down to say 100 or 103 decibels living certain un-relations on the top, because you cannot perfectly reach 110 it may slightly vary so assume you are in 100 decibel minimum possible. Again this was a background, in our case the auditoriums case this background and after the decay it is going to come down to this point this is a peak level which we are assuming. How much is the decibels left 50 decibels we have. But if you have to determine RT 60 that is 60 db decay you are not able to get 60 db drop here, which means the sound source which we were using should actually go to 120 db or 115 db so that you get enough (Refer Time: 34:32) for a physical field measurement. In practical measurement this is highly difficult like measuring directly RT 60 either you will need a very quite ambient or a very high decibel impulsive source with which this will be possible.

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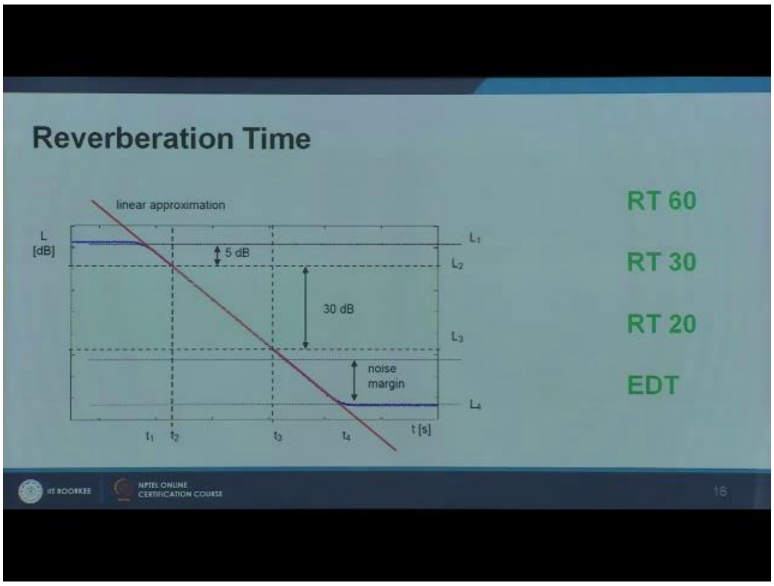

So, for a common use a better indicator is instead of reverberation time 60 it is reverberation time 30 that is the decay of sound by 30 decibels is taken. Most of the sound level meters are almost all the spectrum analyzer sound meters will have RT 30 as a function, you will not find reverberation time 60. One more you have to note RT 30 does not mean it is half of RT 60 it is interpolated value where the slope is primarily considered. It is not that this would be a RT 60 then you take half of it is RT 30 is going to just half RT 60 it is not like that.

It is an interpolated value you are actually counting the slope or the decay this particular slope is taken, as I said you have level one that is a peak level you leave a (Refer Time: 35:36) 5 decibel, you count 30 db decay, then another (Refer Time: 35:42) plus you keep a noise margin here. The background noise level for instance if it varies fluctuates between this you have t 1 it stack start actually from t 2 because you are living a (Refer Time: 35:52) for specific undulations. It also has certain functions in terms of acoustic defects will talk about it. You have t 3, this is your threshold then you live the noise margin. This is a better prediction rather than counting a very huge slope and then calculating it. So, RT 30 is most commonly used indicator measurable directly in the field apart from laboratory conditions where RT 60 is quite possible, it is not that it is not possible but RT is 30 is more practical for field application.

You also have RT 20 for a short measurement you have something called EDT; early decay time which is also important to count lateral reflections. Lateral reflections are something which comes to you like from side walls from the initial ceiling reflectors or the floor planes. We will look at EDT and the reflections in a short while. But you should know that there are different types of reverberation time RT 60 that is decay of sound pressure level by 60 db RT 30 which is 30 db decay t 20 which is 20 db decay. And early decay time corresponds to a 15 decibel decay are lower, it is a early reflection corresponding to early reflection and its decay most commonly used as I said is RT 30.

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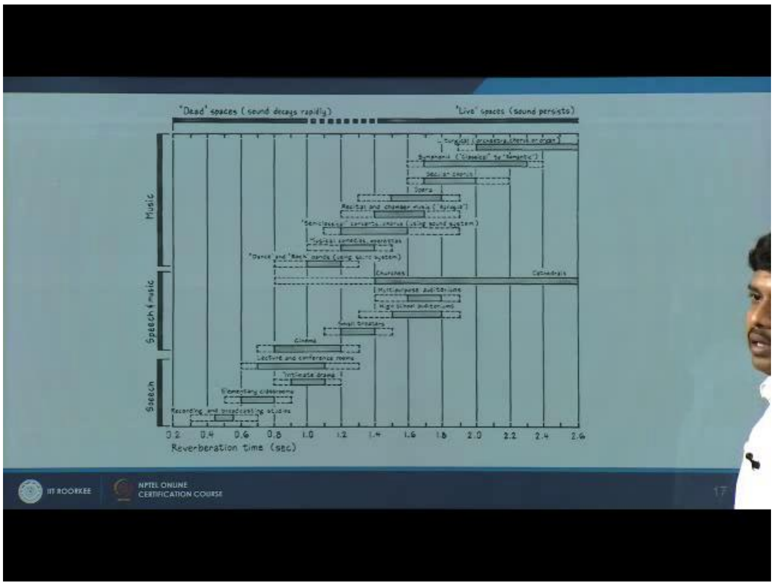

These are certain common reverberation times which are specified. If you look at one end recording or a broadcasting studio a small recording studio the theater kind of recording theater. Most commonly found in radio stations and your broadcasting typically TV or radio broadcasting stations they are highly absorptive typically small rooms where reverberation time as low as 0.4 0.3 is expected. Typically classrooms you can expect as I said somewhere between 0.5 0.6 it can go to 0.8 0.9 sometimes you will find 1 second, it is not bad somewhere around 0.8 is advisable.

As you go for example, lecture and conference room, instead of small classrooms you go to lecture rooms or conference room slightly larger one then you can go up to 1.2 1.3 seconds. As it goes to (Refer Time: 35:05) you will find as highest 2.6. Similarly, for symphonic kind of orchestras it depends on what kind of play is performed. If you look at it symphonic for classical to romantic then the reverberation time is different, orchestra chorus and organ when organ pipes are used you will need fairly high reverberation time. You also see in cathedrals you also have organ pipes tires performed you will essentially need a high reverberation time to appreciate the music better. Dance and rock bands again lower RTs sufficient.

If you look at this side, these particular things are for speech. For speech performance you will require slightly lower reverberation time some where 1.2 1.3 are lesser not more than that both speech and music. If you are designing multipurpose hall it may vary somewhere from as such you cannot get very small because the auditorium if you take the volume is very high naturally the reverberation time will be higher, then you will expect somewhere between 1.4 1.5 it can go further higher also. It depends on what type of speech and music, music performance or instruments are used. Then specifically if you are music, music theaters, orchestras, opera houses you will essentially find reverberation times somewhere ranging from 0.8 or 1 second all the way to 2.5 3 seconds.

Another thing is spaces with low reverberation time like say 0.2 0.4 0.5 seconds are termed as dead spaces, where the sound decay very rapidly. Whereas those with higher reverberation time or (Refer Time: 39:45) live spaces. One important thing you have to notice before you practice in the field you should be aware that not always lower reverberation times are good. You term it as very dry space or you know very dry sound, you always need certain amount of reverberation time zero is not possible unless it is a very controlled space, somewhere around 0.8 to 1 second is appreciable even for speech performance. Whereas, when you have instrumentation playing depends if it is a violin or string instrument versus a percussion instrument depending on the type or a wind instrument depending on instrument type and sound it produces the frequencies spectrum will produces sound you will require a different type of reverberation time.

So, do not try to make this space to much absorptive, do not put too much of insulation material, do not put too much of absorption material specifically so that the room becomes to dead. You have to have a live room to appreciate speech music whatever this level have to have continuity when you especially have music performance. Even for speech in order to re enforce the original sound this signal versus the re enforce reflected sound initial reflections we call or early reflection you need certain amount of reverberation in order to avoid difficult in speaking for the speaker and an appreciation of listening for the listener side. So, certain amount of reverberation time is needed not too high not too low.

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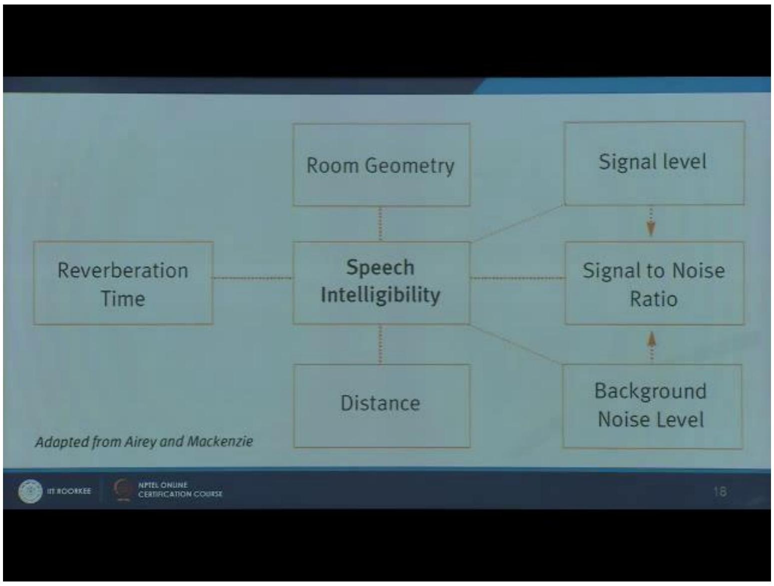

It depends on various factors. It depends on the speech intelligibility primarily affected by reverberation time. The speech becomes intelligible or less intelligible depends on the room geometry as we talked about, it depends on the source to listener distance, it depends on a signal level, how loud I am talking or how quite I am talking. Then you term something call signal to noise ratio. Signal is what I am emitting if I am talking, noise is something which is reflected re reflected and the background noise level together you call signal by noise. When the noise is getting higher than the signal the intelligibility will drastically come down and the background is very high or the reflections are too high the noise level that is a denominator is going to go up. So, signal the noise ratio will come down, which means I have to exact myself to be louder or you will not have required intelligibility, then it depends of course on the background noise level.

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	RT = 0.0 seconds		RT = 0.4 seconds		RT = 1.2 seconds	
Signal/ Noise Ratio	Normal Hearing	Hearing Impaired	Normal Hearing	Hearing Impaired	Normal Hearing	Hearing Impaired
Quiet	94.5%	83.0%	92.5%	74.0%	76.5%	45.0%
+12 dB	89.2%	70.0%	82.8%	60.2%	68.8%	41.2%
+6 dB	79.7%	59.5%	71.3%	47.7%	54.2%	27.0%
0 dB	60.2%	39.0%	47.7%	27.8%	29.7%	11.2%

A quick example; two things are to be noted here you take a specific reverberation time say let us take a reverberation time of 0.4 seconds, two things are there normal hearing and hearing impaired people. There are two columns here, this percentage indicate how much percentage people can understand the signal. If I am lecturing how much percentage of my communication is understood. When the signal noise ratio is quiet that is almost the signal is very strong, 92 and half percent can be understood for a normal hearing capacity person. As the your signal to noise ratio reduces 0 db means noise is almost equal to the signal only 47 percent or less than 50 percent can be understood. For hearing impaired people it is further more only 25 percent of what you talk would be understood close to 25 to 30 percent only could be understood. It also depends on the reverberation time.

Let us take say 12 db signal to noise ratio that is signal is strong, but still you have little amount of noise. For a normal person hearing you have around 90 percent when reverberation time is very low, when the reverberation time is around 0.4 it reduces to 82 to 83 percent goes all the way down to close to 69 percentage when reverberation time increases. As this increases further this listening or understanding ability will eventually drop down, from 89 it come to 83 and further down to 69 percentages here. So, it is depending upon the reverberation time as well as the signal to noise ratio.

When I say 0 reverberation time there are specific spaces in laboratory called anechoic chambers and anechoic chambers. These are chambers where the reverberation time is much close to 0. I will show you few pictures when we talk about acoustic material. You know directly opposite thing for this is a reverberant chamber here RT is almost low, here RT is really high the reflections it is more of (Refer Time: 44:43) reflective metal surfaces so reverberation time is really high in reverberant chamber. These are typical laboratory settings commonly used for material testing or testing the noise level from sound sources.

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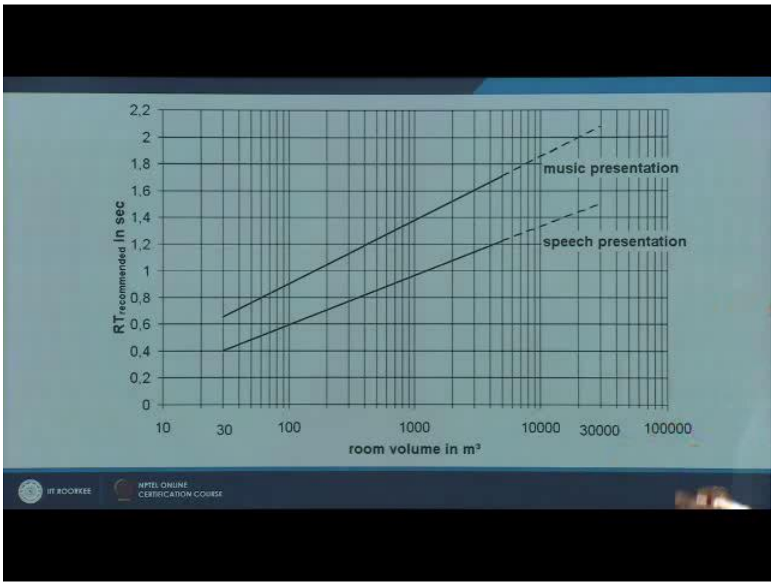

I have put few dependencies of reverberation time for example RT as a room volume increases in meter cube here, the reverberation time recommended increases. As you are hall bigger and bigger the reverberation time for say this is for speech and this for music the reverberation time. For example, a 100 meter cube hall for speech you will require an RT of 0.6, if it for music you will have 0.9. Whereas, a 10000 meter cube hall a large hall the data line indicates it may not be very much suitable for speech presentation, if you take slightly say around 5000 you know allowed or permitted to go up to an RT f 1 or 1.2 meter per sorry seconds. If it is a music performance you can go as highest 1.6 or higher. It depends on the room volume it also depends on the frequency, ideally this particular calculation which I told you in the absorption here is where the absorption coefficient in frequencies come into picture RT varies from frequency to frequency.

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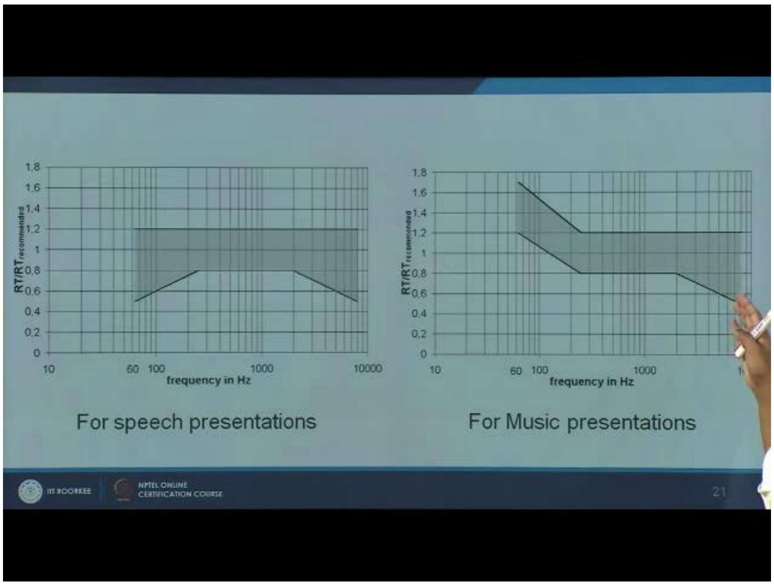

So, the allowable reverberation time also varies for speech and for music with different frequencies. You may require a lower RT in certain frequency. For example the RT permitted may be lower for high frequencies are higher in low frequency, mid frequency more or less is taken as a center or the balancing point.

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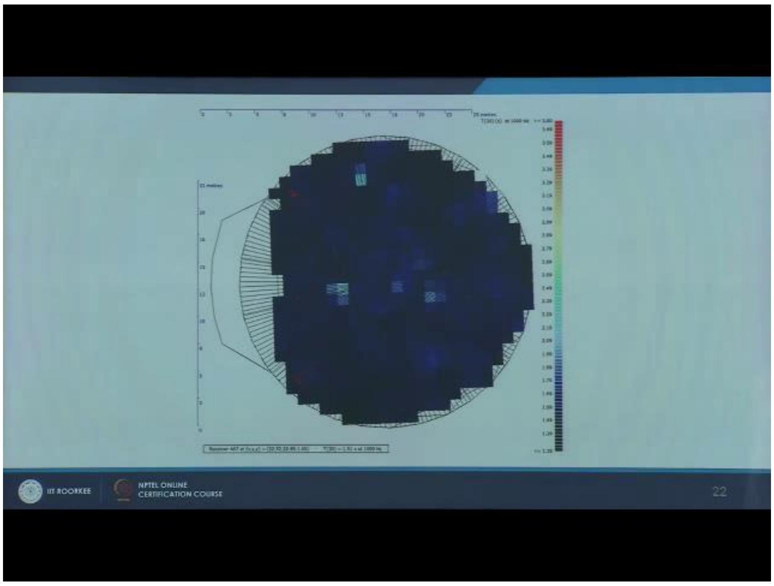

One simple example we had a circular hall where the reverberation time where estimated, I am intending to tell you here that it is also function of this space or location where you are sitting or standing in a particular room. This is a circular room what you see in terms of gradation is a reverberation time 330 here this is a 1000 hertz it varies somewhere from 1.2 or 1 second at specific points close center you are finding reverberation time of round 2 or say 1.8 (Refer Time: 46:27) up to 2.2 seconds we found.

So, it is also function of the location for larger halls, for the location in which you are seated. You may not observe special variation in small classrooms, but of you are located in a very huge auditorium. From a position here in one end to the center to a further seat behind are this position close to the state you will find a reverberation time difference if you are experiencing the sound pressure.

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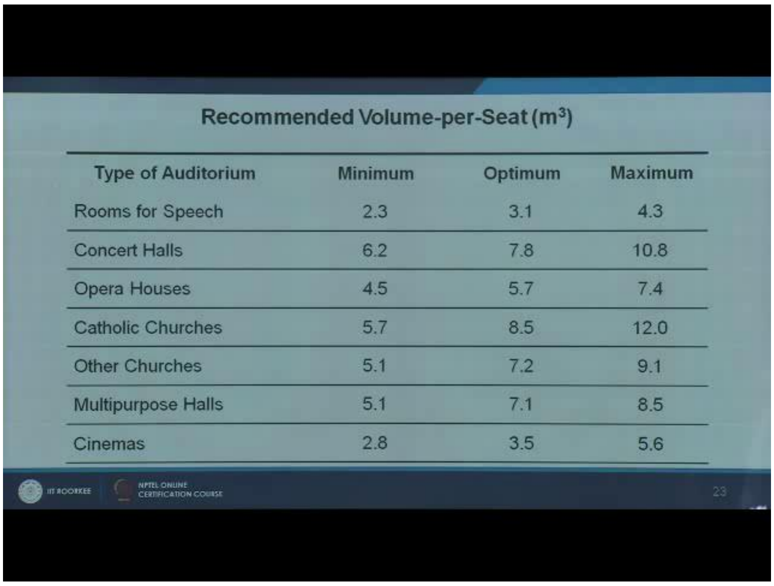

Recommended Volume-per-Seat (m^3)

Type of Auditorium	Minimum	Optimum	Maximum
Rooms for Speech	2.3	3.1	4.3
Concert Halls	6.2	7.8	10.8
Opera Houses	4.5	5.7	7.4
Catholic Churches	5.7	8.5	12.0
Other Churches	5.1	7.2	9.1
Multipurpose Halls	5.1	7.1	8.5
Cinemas	2.8	3.5	5.6

Recommended volume per seat for different spaces, if you see rooms for speech the number are lesser allowable you know it is a simple thumb rule. If you have per seat how much volume you can give that is how huge the room can be. And the other side of it goes all the way to churches or concert halls where the volume per seat is very high. As I said it is a factor the instruments used the type of performance done there it determines seat and the volume, how much volume you allow.

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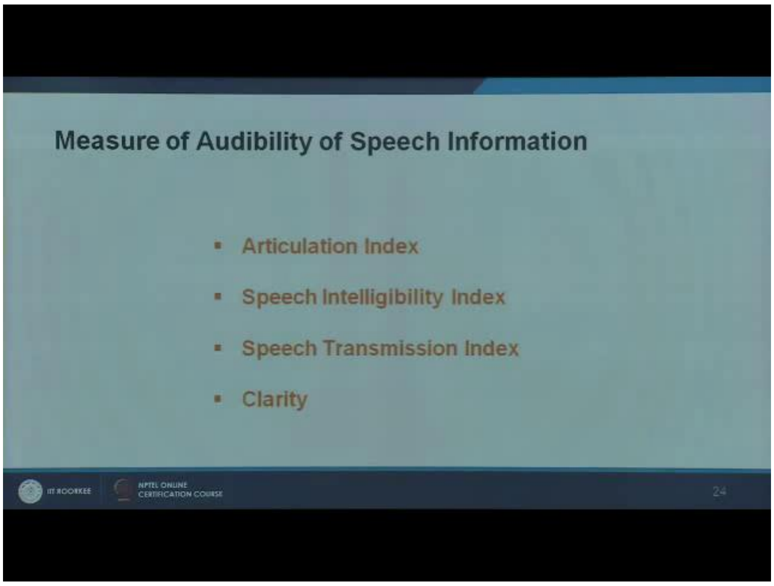

There are indicators for acoustical quality; articulation index is there, you have speech intelligibility index, speech transmission index, and clarity. We will look at these things in the following module.

Thank you.