

# NOISE CONTROL IN MECHANICAL SYSTEMS

Prof. Sneha Singh

Department of Mechanical and Industrial Engineering

IIT Roorkee

Week:6

Lecture:029

Lecture 029: Noise criteria

The slide features a blue header and footer. At the top left is the IIT Roorkee logo. In the center is the Swayam logo with the text 'FREE ONLINE EDUCATION' and 'swayam'. To the right is the NPTEL logo with the text 'NPTEL ONLINE CERTIFICATION COURSE'. The main title 'Noise Control in Mechanical Systems' is in a large, bold, dark blue font. Below it, 'Lecture 29' and 'Noise Criteria' are in a smaller, bold, blue font. The presenter's name 'Dr. Sneha Singh' and department 'Mechanical and Industrial Engineering Department' are listed below. At the bottom, there is a photograph of the IIT Roorkee main building, a large white classical-style structure with a central dome and columns. A small number '1' is in the bottom right corner.

Hello and welcome to this course on noise control and mechanical systems. In today's lecture, we will discuss noise criteria. I am Professor Sneha Singh from IIT Roorkee. We have started with the discussion on the various principles of noise control engineering. And based on that, various kinds of noise control strategies.

Basically, the source, path, receiver model for noise control and the various methods within that have been discussed. In today's lecture, we will discuss controlling noise in the environment as a noise control engineer, as well as noise indoors. Today's lecture is mostly focused on noise indoors. For example, as a noise control engineer, you're given the task of controlling noise indoors.

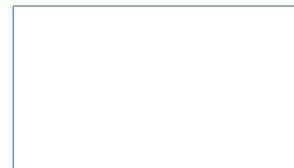
## Summary of previous lecture

Source - path - receiver Model.  
Noise path



## Outline

- Criteria for acoustics of Indoor spaces
  - ✓ - Noise Criterion (NC) curves
  - ✓ - Noise Rating (NR) curves
  - ✓ - Room Criterion (RC) curves
  - ✓ - Balanced Noise Criterion (NCB) curves



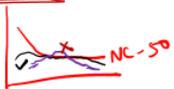
There should be some reference on how you determine the desired noise level in a particular space, especially as a designer or architect designing various buildings and indoor spaces where noise control and acoustics become integral. Some standards should exist based on which these spaces can be designed. That is why we have various criteria for the acoustics of indoor spaces, specified in terms of the noise criterion curve, noise

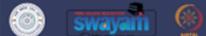
rating curve, room criterion curve, and balanced noise criterion curves, which we are studying today. We also call them the NC curves, NR Curves, RC curves and the NCB curves. These are some standard curves which represent, these are the plots or graphs of decibels versus frequency in, one-third octave usually, and these standard graphs say that, this is for this particular kind of space. This could be the typical, decibel versus, or the one-third octave spectrum variation in the various indoor spaces.

### Noise Criterion Curves (NC Curves)

- **NC curves:** are family of standard curves of dB versus <sup>1/3 Octave</sup> frequency, which show the ideal upper noise limit of a particular indoor environment.
- Developed after extensive interviews with people in offices, public spaces and industrial spaces. Major concern was: interference of noise with speech communication and other listening tasks (radio, music, TV, etc).
- The noise spectrum of a space is measured and plotted against the family of NC curves.

*home indoor environment has NC 50 Recommended.*



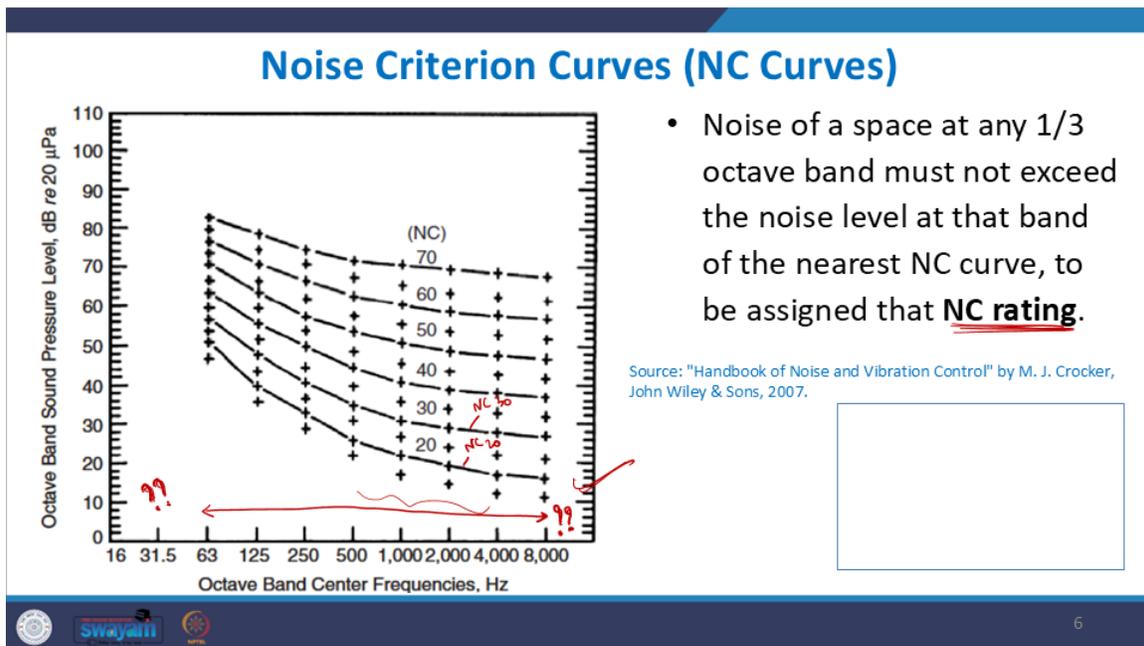

5

Let us see the very first, that is the NC curves or the noise criterion curves. They are a family of standard curves dB versus, one-third octave frequency in Hz, and this shows what should be the ideal upper noise limit of a particular indoor environment. Suppose, you say that, some indoor environment has an NC value of 50. That means that there is a family of curves in this, so let us say this is the curve belonging to NC 50, which means that for that particular space its one-third octave spectrum should be such that it should nowhere exceed this NC 50 curve like that. That is how the definition is that for a particular environment, whatever is the recommended NC value, and you have a standard contour that belongs to that NC value, that nowhere the one-third octave spectrum of that particular indoor environment should exceed that level. This would be correct. If, suppose, you had a one-third octave spectrum something like this of the indoor environment.

At some levels, although for most of the ranges, the one-third octave is below, but at least in one particular region, it is above the specified value. This is not an acceptable indoor

acoustical environment, whereas this black curve becomes an acceptable indoor acoustics environment if, suppose, this is the recommended value. This is the recommended one.

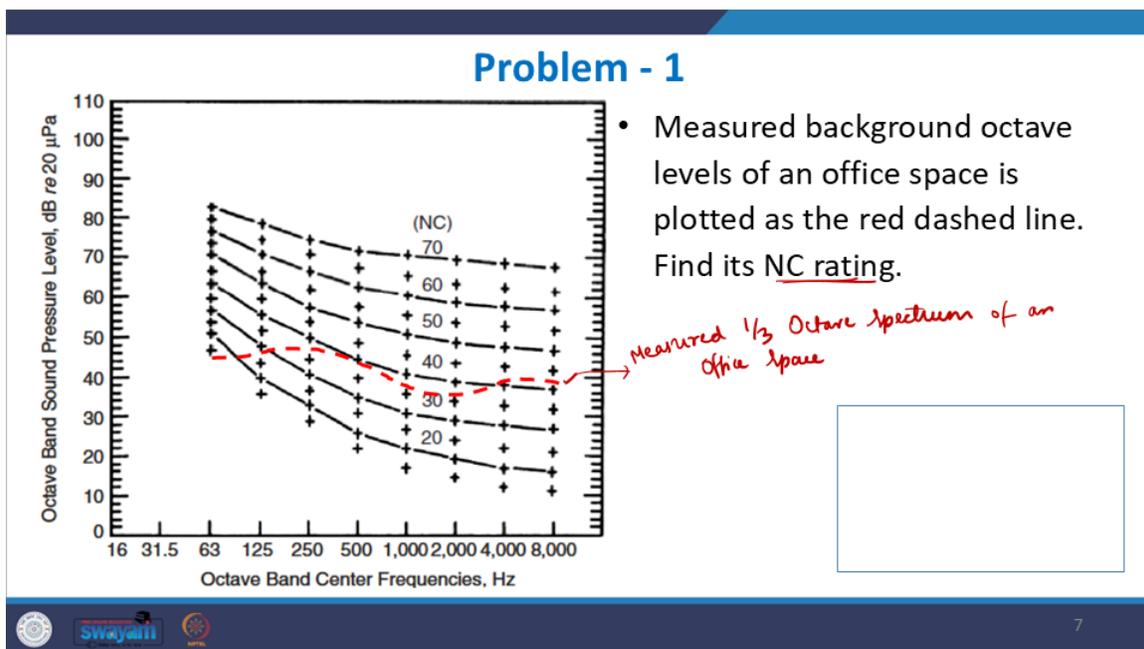
How have they been derived? Usually, in the past, a lot of research has been conducted, extensive interviews and listening studies have been done with people who are residing in these various kinds of indoor spaces such as, offices, public spaces, industrial spaces, and so on. The major concern that was found is that within the indoor space, the acoustics should be such that, or the noise level should be such that it does not interfere with the tasks that involve listening. For example, it should not interfere with any kind of speech communication. It should not interfere with other listening tasks like, watching television, radio, listening to news, music etc., And all that was a major concern. There were obviously other concerns as well. And the noise spectrum is then measured. What happens, suppose you have to find the NC value, you want to find that, this is a particular space. What is its NC value? Then what do you do? You first measure the noise spectrum of that particular environment or indoor environment or space, and you plot it in the one-third octave spectrum and you compare it with the family of the standard NC curves.



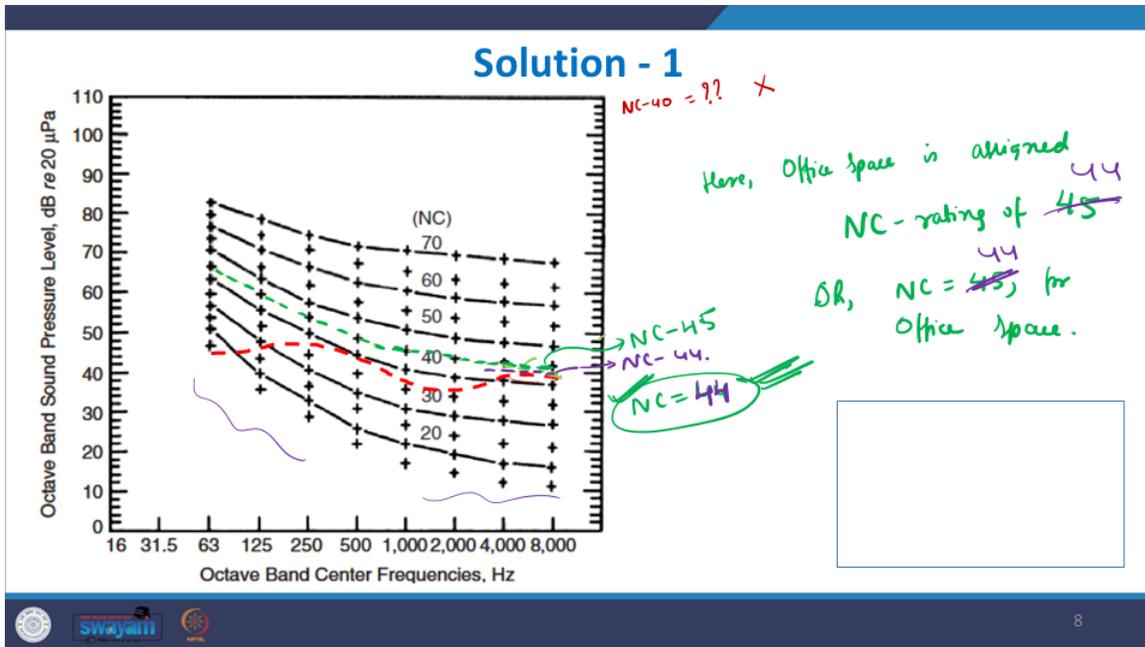
This is how the standard NC curves look like. This corresponds to an NC of 20, this one corresponds to an NC of 30, and so on. What it shows from the curve you can overall see is that, because our hearing is more sensitive beyond 500 Hz and so on. They are the one-third spectrum. Ideally, this should be the shape of the spectrum within that acoustical

environment. In these sensitive zones, the dB level should be lower, whereas in the lower frequency zone where human ear sensitivity is very low, even higher decibel values have been allowed in these curves, and you can notice that these curves are only devised for this frequency region from 63 Hz to 80 Hz, and here there was no value, and here also no value. It was one of the earlier curves, and hence this was the frequency region of interest within which these standard NC curves were defined.

Suppose you now have the one-third octave spectrum of any indoor environment; you plot it against this particular graph. And see whatever what is the closest NC curve which is just above or equal at all points to that particular octave spectrum, and that will give you the NC rating of that particular environment. To illustrate further, let us have a look at a problem and we define the NC rating for an environment.



Let us say we have these NC curves, and this red dashed line indicates the measured one-third octave spectrum. This is the measured one-third octave spectrum of the particular environment of interest, which is here the office space, and we want to give an NC rating to it and say what is the NC rating of this environment, of this office environment. We have plotted the one-third octave spectrum of this particular space against the standard NC curves, and we want to see which is the closest NC curve where at no point the measured octave levels exceed that NC curve. Let us see, for example, let us solve it. We start with NC 40 and see whether this is true.



What you see is that at most of the points, the measured octave spectrum is below the NC 40 curve; it is only within this small region that it is just above it. You cannot say it is an NC 40 environment because at all points, the measured octave spectrum of the environment has to be lower than the corresponding value of that NC curve in that particular octave spectrum. So, retaining the shape, if we draw the various, NC curves, so we will see that just here as well, we will have some NC curve, this is the curve between 40 and 50; this is an NC 45 curve. We have drawn that between 40 and 50; we have that NC 45 curve which follows the same pattern as the rest of the NC curve and passes at 1000 Hz from 45 decibels. You join all the plus points here. To get that NC curve. This becomes your NC 45 curve. You see that at NC 40, only for a few values, the octave spectrum of the measured environment is greater than the corresponding NC 40 curve. NC is not 40 for this environment. just above it is the NC 45 curve, It is the curve which is higher or equal to the octave levels and closest to it. We cannot say it is NC 50 or NC 60; they are all above it, but they are not the closest. The nearest highest curve is another way to put it. the nearest highest NC curve becomes its NC rating. Here the office space is assigned an NC rating of 45, or simply you can say NC is equal to 45 for the office space.

Then let us see the next curve, which is the noise rating curve. just like you have the noise criterion NC curves. Which is a standard family of curves that say, this is the typical variation that should be there between the typical graph of dB versus the frequency for people to have the best experience or the best acoustics within an indoor space.



## Noise Rating Curves (NR Curves)

- **NR curves:** are family of standard curves of dB versus frequency, which show the ideal upper noise limit of a particular indoor environment.
- Originally produced to develop a procedure to determine whether noise from factories heard in adjacent apartments and houses is acceptable. Unlike NC curves, there are corrections for time of day, intermittency, audible pure tones, fraction of time the noise is heard, and type of neighborhood.
- The noise spectrum of a space is measured and plotted against the family of NR curves.

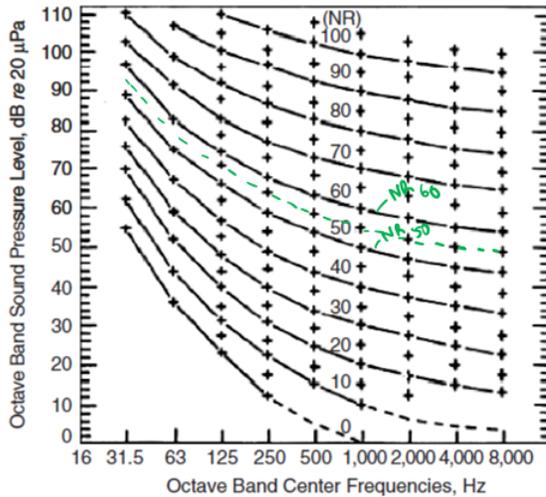
*Some indoor space is recommended to not exceed NR 55*



You also have the NR curve, which is again in similar lines. This is because these two are both doing the same job. Both of these curves have exactly the same mechanism, and what it means is exactly the same, but their shapes and patterns are different. They have been devised by two separate forms of experiments and scientists. The NR curves were developed again using a lot of studies done with factory workers and also with people residing near the factories in adjacent apartments and houses to find what kind of noise level they find acceptable.

What is the difference between the NR and the NC curve? In the NR curve, there are also corrections for the time of day the measurement is taken because, the NC curve just assumes that at night and during the day, you have the same recommended pattern of noise level. But in the NR curve, they do the corrections with respect to the time of day, the intermittency, the duration of the noise, whether it is a pure tone, and all those things, various other factors are taken into account to devise a new set of curves. And what you do, suppose you want to assign the NR rating to an environment, what you do, suppose you say again that, some indoor space has been recommended to not exceed NR, let's say 55. What it means is that whatever is the one-third octave level in that environment, nowhere should it exceed the value of the graph of the NR 55. This shows the various NR curves. nowhere, if suppose this is 50, this is the NR 50 curve, this is the NR 60 curve, so here we will have an NR 55 curve. whatever is, the measured one-third octave band of that space. Nowhere should it ever sort of intersect or go above the NR 55 curve at any point.

## Noise Rating Curves (NR Curves)



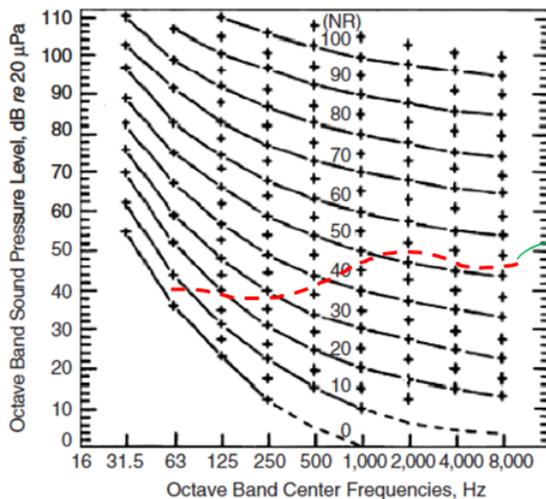
- Noise of a space at any 1/3 octave band must not exceed the noise level at that band of the nearest NR curve, to be assigned that **NR rating**.

Source: "Handbook of Noise and Vibration Control" by M. J. Crocker, John Wiley & Sons, 2007.



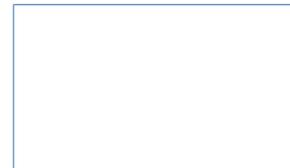
That is what it means that it should not exceed NR 55. And similarly, just like you have the NC rating, you have the NR rating. What it means is that you find the one-third octave spectrum of that environment, you plot it against the family of the NR curves, and see which is the closest highest curve where, at no point the one-third octave spectrum of the environment is exceeding the corresponding value of that NR curve. Just like how we did for the NC curve.

## Problem - 2



- Measured background octave levels of an office space is plotted as the red dashed line. Find its NR rating.

*Measured 1/3 octave level of an Office space*

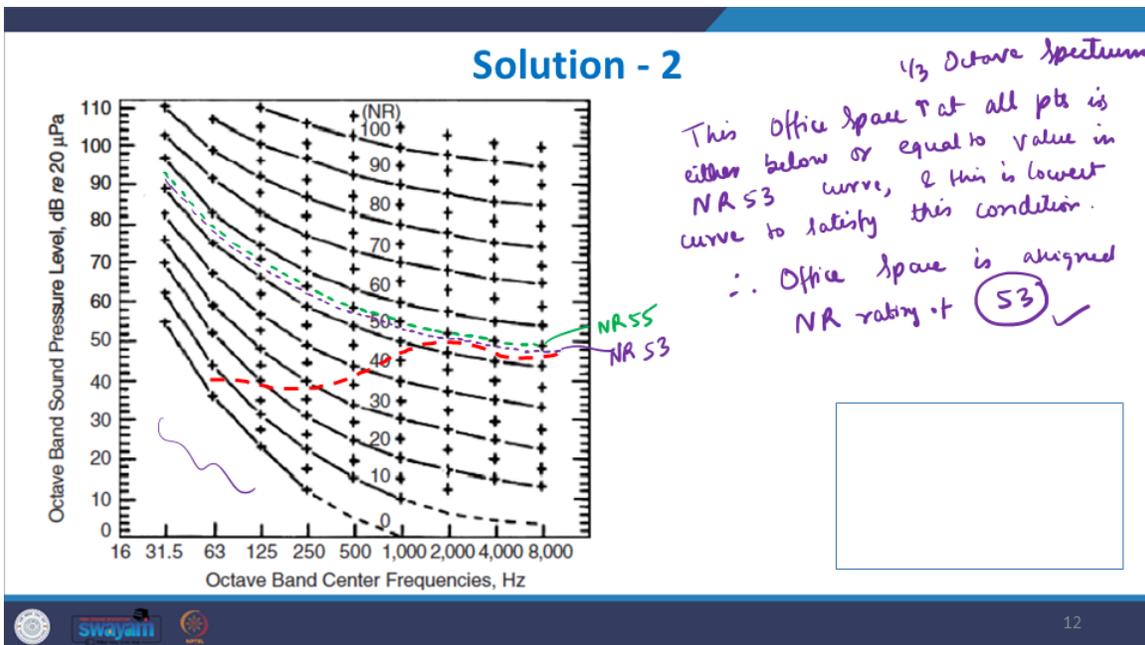


let us again see an example, we are given, the background octave noise level of a particular space, a different kind of graph, so this is the measured one-third octave levels of a space, which is an office space, an indoor space, is given. You have to find what would be its NR rating. So again, by the same logic, if you see this is NC50. In most of the cases, it is below, NC50, but at some values, it is exceeding NC50. But in all the cases, this curve is below the NC55 curve.

This is NR55, in all the values, and I am taking, these in the steps of 5 dB. at all the places, it is, exceeding or it is closest to the NR55 curve. should we assign it an NR55?

Now, let us have a look at the previous example. What happened was that it was just approaching NR45, and I had assigned it a value of NR45. It could also have been very well assigned as NC equals to 44 or something like that as well, which is the closest value. In the same way, if you have to be more precise, you can say instead of 45, instead of taking the steps of 5, let us say we assign it NC equals to 44, that is the point where this is the NC equals to 44 curve, the NC is 44 curve. I think it would be better to assign it a value of 44.

Which is the closest where it is exactly the highest level is just touching the NC 44 curve. So here we get the NC as 44.



In the same way here as well, although NC 55 is above it, but there should be some curve which is just touching it tangentially to it. So let us find that curve. So over here, I think

again it should be NC 54 or 53. Some value like that. So, these divisions are 5, so it is almost, one-third of the division, so 5 by 3, so close to NC 53, I would say. You can make an educated guess even if you are not given a family of environments. You can find out which is the nearest curve where it is either below or just touching that curve. So, we find that it is just touching at the NR 53 curve, this is the NR 53 curve. So here, this office space at all points is the office, this office space one-third octave spectrum at all points is either below or equal to, the values in the NR 53 curve, and this is the lowest curve to satisfy this condition because then all the further curves above it will also satisfy this condition. So, the lowest curve to satisfy this condition. The office space is assigned an NR rating of 53. The lowest curve where this condition gets satisfied, where the measured one-third octave spectrum is either less than or just equal to the values in that curve like that. So you can find out, you can make an educated guess, and so on.

### Room Criterion Curves (RC Curves)

- The RC curves were originally developed by Blazier based on extensive hearing studies in indoor spaces with HVAC noise.
- The noise spectrum of a space is plotted against the family of RC curves.
- Unlike NC curves, more stringent criterion is adopted in frequencies < 30 Hz and > 2000 Hz.
- More preferable for indoor spaces with dominant HVAC noise.
- The RC rating number of a space is arithmetic average of the octave band levels at 500, 1000, & 2000 Hz.



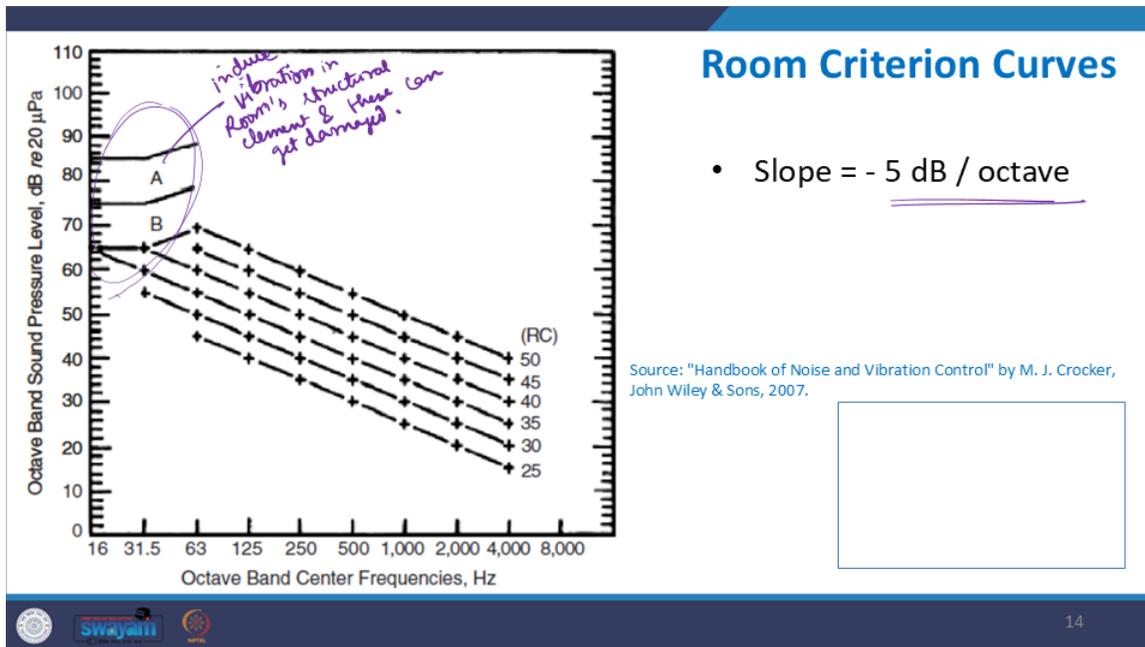
13

The third criterion, the third indoor criterion curves are called the room criterion curves. These were developed by the scientist Blazier. He had done a lot of hearing studies in the indoor spaces, especially the indoor spaces where the HVAC machineries were installed.

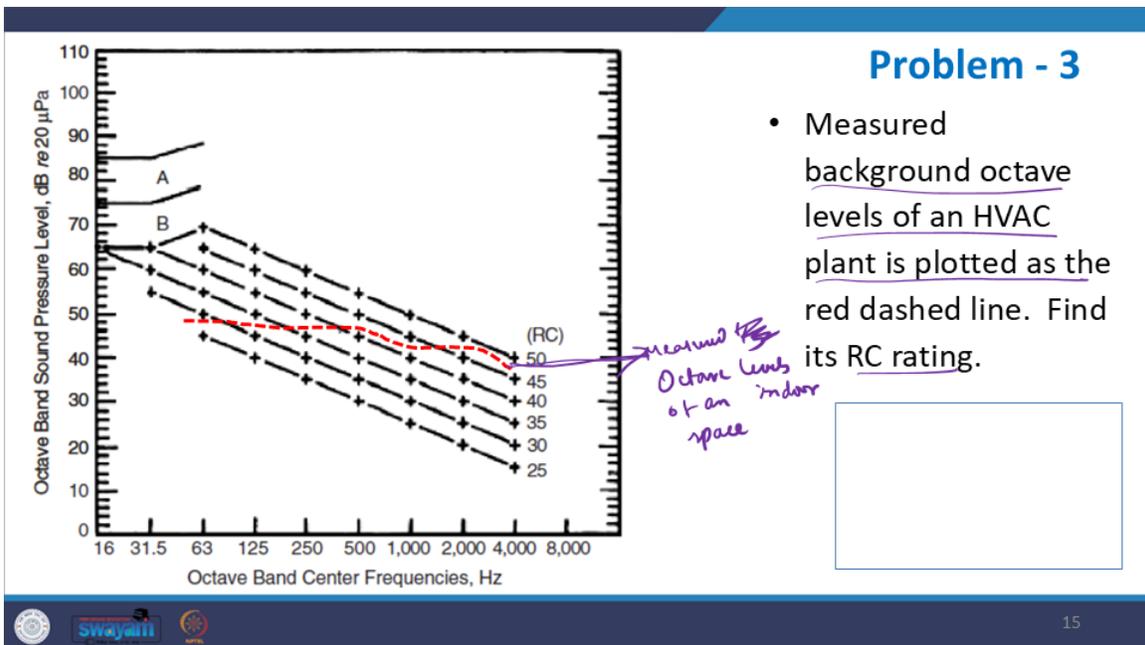
It is very specific to an HVAC kind of environment. they devised a set of curves, and any environment which is an indoor environment with HVAC as one of the major dominant noise sources present in the environment must satisfy or their value should be very close to the standard RC curves. What happens is that in the NC curves, what we saw was that it is one of the most traditional and earliest of the room criterion curves, the earliest of the indoor criterion curves, and here there was nothing, beyond 63 Hz and nothing beyond 8000 Hz. in very low and high frequency ranges, this curve was not defined.

In the RC curves, they handle this situation. they also define it for the values which are smaller than 30 Hz, and here what they have adopted is a more stringent criterion for this because in the previous curves, what is observed is that you have a very lenient criteria on the low frequencies because the human ear is not sensitive to these low frequencies, so we are saying that even a much higher decibel level would be okay. They are very lenient on these low frequency regions. Allowed dB levels are much higher compared to what should be there in these mid frequency regions, so they are very lenient. In the RC curve, they adopt that we should also have more stringent criteria in these frequency ranges because even at very low frequency ranges, what happens is that it is an indoor environment, so there could be a lot of structural elements within that indoor environment, the walls, roofs, roof panels, as well as the various inside panels and structural elements. at low frequencies, because mostly these structural elements have their fundamental vibration frequency which is usually at a lower frequency range, so suppose sound is there at these low frequency ranges, even if the ear is not very sensitive, this can lead to the vibration of the structural elements within the room. And because of that, the room becomes susceptible to structural damage. It is again even at lower frequencies, having a very high level is not desirable because it will induce the vibration of the structural elements and essentially the damage and the wear and tear of the elements in the room. Hence, these stringent criteria are there, and here any space is assigned an RC rating not by the logic of what we were using for NC and NR curves, but rather what we do is we plot the 1/3 octave spectrum of that environment and see what is the arithmetic average of the measured 1/3 octave spectrum at 500, 1000, and 2000 Hz, and that average becomes its RC rating.

This shows the RC rating, here more stringent criteria are available here rather than the curve going very exponentially in the higher direction, we have flat curves because even these conditions are not desirable because this can induce vibration, although we may not hear these sounds very loudly, but vibrations can be induced in the room's structural elements, and these can get damaged.

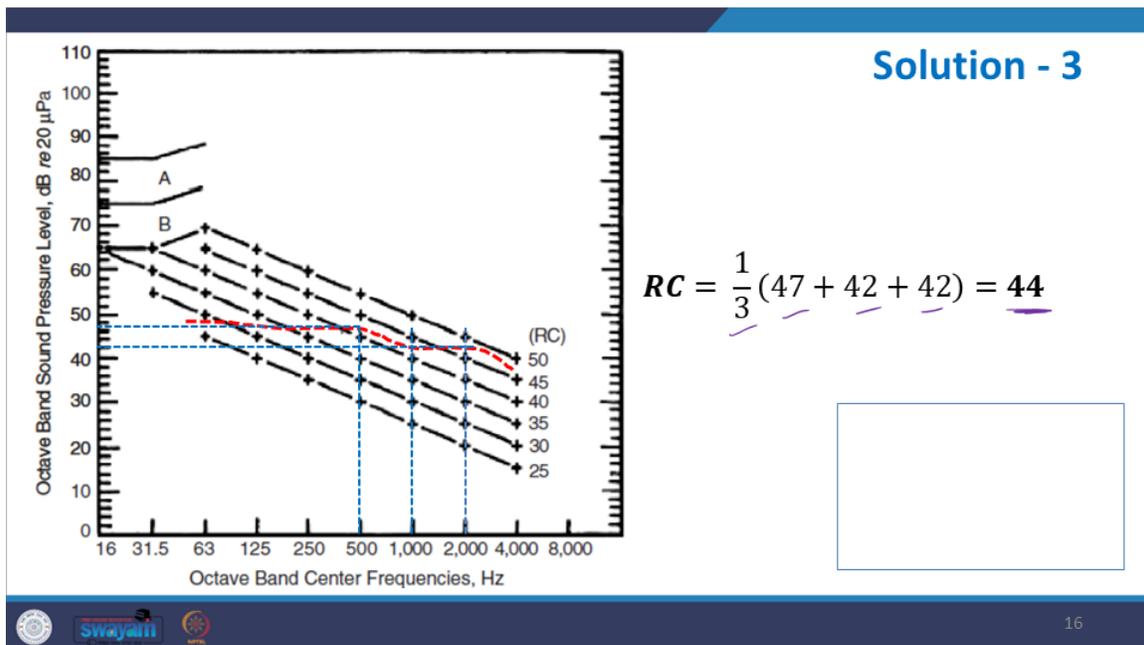


Even that is not desirable from the vibration point of view, and hence, it is flatter and downward compared to the previous curves. We have the downward values. And for this curve, the typical slope is 5 dB per octave. We are observing a flatter curve here.



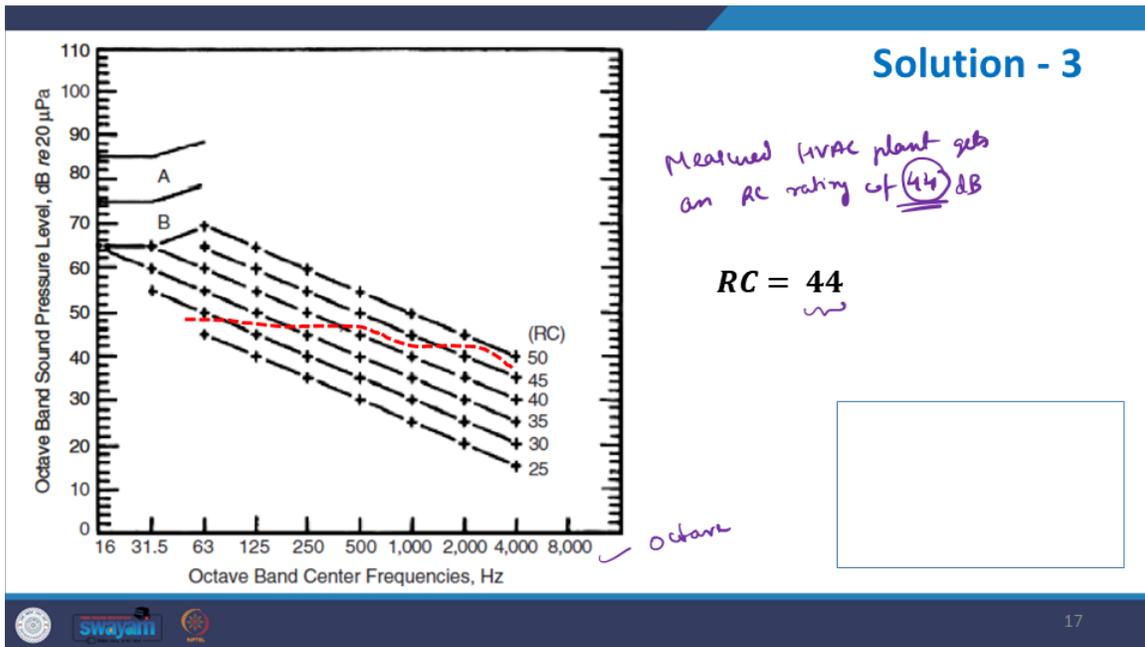
Let us say, for example, this is the RC curve and the background octave levels of an HVAC plant. The RC curves were usually designed for HVAC machinery, and although they are

applicable for other indoor spaces as well, they work best when the noise source is some kind of HVAC machinery. We have measured the background octave levels in an HVAC plant, and that is plotted as this line. This is the measured one-third octave levels of an indoor space. You have to find out what its RC rating is. Here you do not see what the nearest curve is. here, if you go by that logic the nearest RC curve is 50, where it is just above or equal by that logic, the RC should be 50, but that is not the logic used in the case of RC rating. The RC rating is simply whatever your measured octave levels are; you do the arithmetic average. In the 500, 1000, and 2000 Hz range.



The RC rating of this particular measured space should be, let us find out what its one-third octave values are at 500, 1000, and 2000 Hz. At 500, we have close to 47 dB. At 1000 and 2000 Hz, these are similar values, which are close to 42 decibels. We do an arithmetic average of its value at these three points. Whatever the measured one-third octave spectrum is, find out the average values in the 500, 1000, and 2000 Hz range, and that becomes your RC rating. This particular measured HVAC plant gets an RC rating of 44 dB or simply 44. You do not even need to mention dB; it is automatically taken as dB.

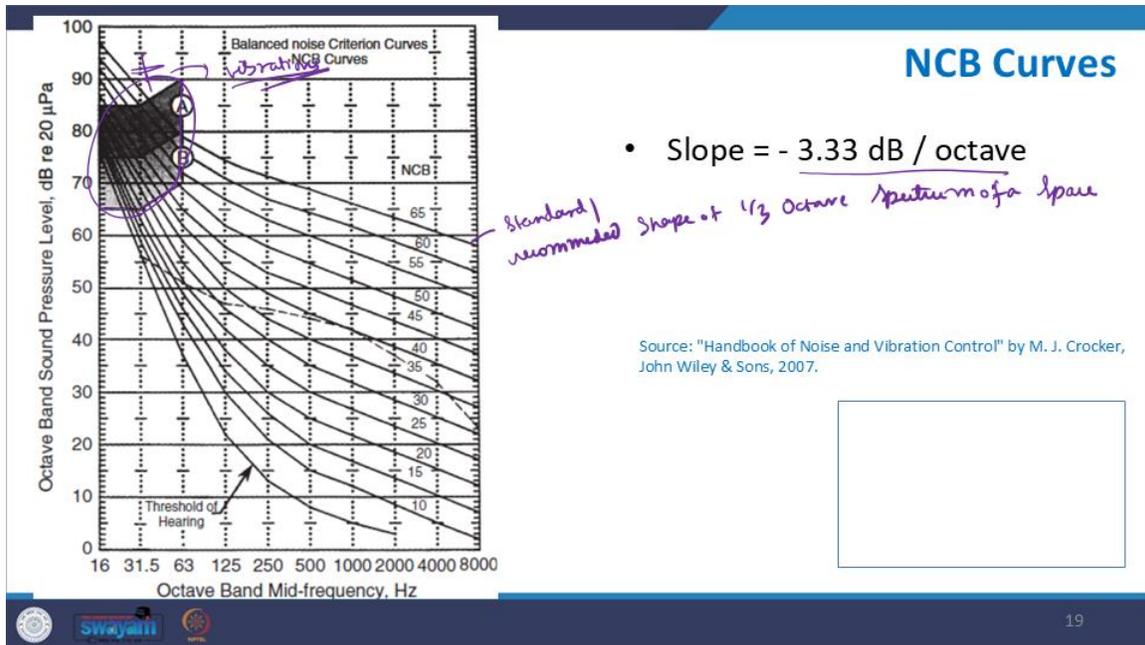
The last kind of curves you will be studying is the balanced noise criterion curves. They were an improvement on the already existing noise criterion curves. Here what happened is that again, similar to the noise criterion curves, but now what they did was that they sort of incorporated more stringent criteria in these lower frequency ranges, and they lowered



### Balanced Noise Criterion Curves (NCB Curves)

- In 1989, Beranek modified the NC curves to include the 16- and 31.5-Hz octave bands and changed the slope of the curves so that it is now -3.33 dB/octave between 500 and 8000 Hz.
- Findings from RC curves were also incorporated.
- The NCB rating number of a space is the arithmetic average of the octave band levels with mid-frequencies of 500, 1000, 2000, and 4000 Hz.

the slope of decrease in the decibel levels per octave. Instead of having a curve like this, they had a curve more like a flatter curve compared to that, so some kind of balancing was done to get the new balanced noise criterion curves, which is one of the latest curves, and the NCB rating of any environment is simply, again, just like in the RC rating, you do not need to know what is the NCB standard NCB curves of an environment; you simply measure the one-third octave levels. And find out what is the average value in the, what is the arithmetic average of its one-third octave value at 500, 1000, 2000, and 4000 Hz, and you will get the NCB rating.



This is the typical NCB curve which shows, the standard or average. Simply the recommended, so these are just recommended patterns; that doesn't mean that the indoor space will actually have that kind of pattern. This is just recommended because this has been found to be giving the best kind of experience to people indoors, that the pattern should be the shape should be like this, that per increase in the octave, it is reducing by 3.33 decibels. So that is just a recommended shape of one-third octave spectrum of a space. It is just recommended that you will get the best acoustics if your one-third octave spectrum is supposed to follow this kind of a shape, but it need not do so in reality, but this is just something that is recommended where it gives the best results, and again, most and in these regions have been flagged, which means that, although acoustically it is fine, it is dangerous because vibrations again happen, which hamper the various elements within the rift. This is a danger zone. Let us see, this is a family of, the NCB curves and the octave levels of an HVAC installed within a large room. And, the noise levels in that large room are measured, and this is the one-third octave.

Over here we represented the octave levels, ok. I think even in this one we had the octave levels, not the one-third octave levels. This is something which I would like to rectify. These are measured octave levels, ok, ok. In the same way, everywhere this is measured in the octave spectrum, not one-third octave spectrum. this is the octave spectrum. All the curves are measured in octaves, not in one-third octaves. Everywhere it should be octave levels.

They are measured in the octave levels.

### Problem - 4

- Measured octave levels of HVAC installed in a large room is plotted as red dashed line. Find its NCB rating.

Measured ~~to~~ Octave Levels of an Indoor space.

20

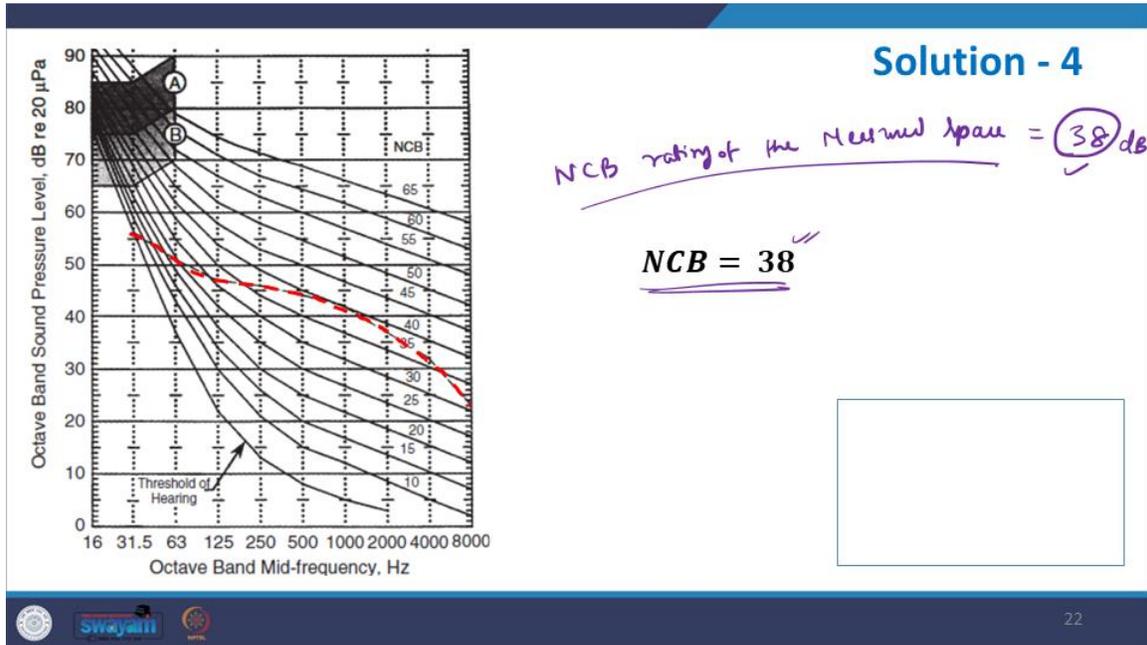
Now let us see our problem at hand. This is, the measured NCB, the measured octave levels of an indoor environment. And you have to find its NCB rating. again, you do not need to bother with what looks like how and where it is touching the NCB curves.

### Solution - 4

$$NCB = \frac{1}{4} (44 + 41 + 37 + 31) = 38$$

21

Which is the curve that is just below or just above? Nothing like that. Simply find out what are the octave levels in the 500 Hz, 1000 Hz, 2000 and 4000 Hz range and do their arithmetic average. At 500 it is having a decibel level of close to, I think it is 44 dB. At 1000, it is having a decibel level close to 41. And at 2000, it is having a decibel level close to 37. And at 4000, this is having close to, 31.



These values you find out, do their arithmetic average, and you get the NCB rating of this environment. This becomes the NCB rating of the measured space. It is simply 38. You can write decibels or you can just omit decibels. Both of them mean the same.

Type of Space	Recommended NCB rating	$L_{A,eq}$	Recommended values of NCB curves for indoor spaces
Broadcast and recording studios	10	18	
Concert halls, opera houses and recital halls	10 - 15	18 - 23	
Large auditoriums, large drama theatres and large churches	< 20	28	
Small auditoriums, small theatres, music rehearsal rooms, large meeting and conference rooms	< 30	38	
Bedrooms, sleeping quarters, hospitals, residences, apartments, hotels, motels, etc.	25 - 40	38 - 48	

I would like to close this lecture with a quick discussion and a table that gives you, some of the recommended NCB ratings, acousticians recommend that they should be the typical NCB rating of an environment. For example, you have broadcast or recording studios there, because you are recording, sensitive sounds, in the recording, you want to ensure that, you have the least noise. A very high signal-to-noise ratio and hence you need the lowest, NCB rating of 10 in various concert halls, opera houses, and recital halls. In the absence of any listener or in the absence of any additional source just within that space, the recommended NCB rating is 10 to 15 for the large auditoriums. If it is a smaller room, then you need a lower rating; for a larger room, you can still get away with a slightly higher rating.

In these large spaces, you have Less than 20. Then smaller auditoriums, theatres, musical rooms, meetings, and conference rooms. This is the recommended NCB rating. Then the bedrooms, living quarters, hospitals, residences, apartments, hotels, and motels.

Type of Space	Recommended NCB rating	$L_{A,eq}$	Recommended values of NCB curves for indoor spaces
Private or semiprivate offices, small conference rooms, classrooms, and libraries	<u>30 - 40</u>	38 - 48	
Living rooms and drawing rooms in dwellings	<u>30 - 40</u> <i>- In absence of any source within the space</i>	38 - 48	
Large offices, reception areas, retail shops and stores, cafeterias and restaurants	<u>35 - 45</u>	43 - 53	
Lobbies, laboratory work spaces, drafting and engineering rooms, general secretarial areas ✓	<u>40 - 50</u>	48 - 58	

Followed by that. You have these private or semi-private offices. I am going from the lowest to the highest recommended NCB ratings. In these office spaces, conference rooms, classrooms, and the libraries, you can have a typically 30 to 40 dB as the NCB rating. Then for the living rooms and the drawing rooms in the various houses and buildings, you can have again 30 to 40.

These NCB ratings are, in absence any source, which means that if there is no source, obviously somebody starts talking, it will not be 30 to 40. Just in the absence of any source within that space, in the absence of any source within the space, this should be the recommended rating. this is like the lowest possible background environment or the background noise level. Then, for larger offices, reception areas, retail shops and stores, cafeterias and restaurants, the recommended NCB rating or the minimum noise level should be closer to 35 to 45. Then, lobbies, lavatories, workspaces, engineering rooms, general sectorial areas, slightly higher, 40 to 50 NCB ratings have been recommended.

Type of Space	Recommended NCB rating	$L_{A,eq}$	Recommended values of NCB curves for indoor spaces
Large maintenance shops, industrial plant control, rooms, office and computer equipment rooms, kitchens and laundries	45 - 55	53 - 63	
Shops, garages, etc. (just for acceptable speech & telephone communication)	50 - 60	58 - 68	
For work spaces where speech or telephone communication is not required	55 - 70	63 - 78	

Then, we have larger maintenance shops, industrial plant control rooms, offices. And the computer equipment rooms, kitchens, and the laundry areas where, in general, typically you have louder things going on. In the absence of any direct activity going on in that space, the typical NCB rating could be 45 to 55. Then, in the shops, garages, etc., 50 to 60. Workspaces, where speech and telephone communication are not required, you can have slightly higher and so on.

Thank you for listening.

**Thank You**