Design Advisory #10: CAS-DA10-2004

How Does Room Effect Affect Room Acoustics?

Most duct runs terminate with some type of register, diffuser, or other terminal device. The amount of noise generated from the device can be significant and should be taken into account when determining the room's overall sound quality.

When selecting a terminal device, at first glance you may believe that its published noise criteria data seems too low. On further investigation you'll probably see that the performance data contains a footnote stating that a 10 dB credit (10 dB reduction in sound power level per frequency) was given for room absorption or "room effect". There's nothing improper about this practice, but the actual room geometry should be checked to see if the 10 dB adjustment is truly justified.

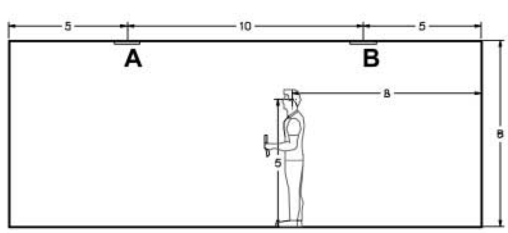
"Chapter 9, Room Acoustics" in McGill AirFlow's *Duct System Design Guide*, shows how to account for room effect and how to solve the room effect equation. It then removes the mystique surrounding noise criteria (NC) and room criteria (RC) calculations and demonstrates how to apply the resulting calculated sound pressure level values to NC and RC graphs so specified sound quality can be met. (Check the McGill AirFlow web site Tech Tools section in the near future, as we plan to have an on-line program to calculate NC, RC, and dBA levels based on user-entered input.)

To help make the "room effect" design process and product selection easier and more predictable, McGill AirFlow has developed a full line of proprietary air diffusers and outlets that can meet a wide variety of noise criteria for both commercial and industrial applications. For example, our popular Type SP Duct-D-Fuser™ has internal orifice plates and perforated metal skin to allow greater airflow distribution with minimal noise generation. Our improved flush-mount grille is used in places where rectangular taps are outfitted with a grille or register, and our Factair™ terminal outlet is an excellent choice for spot cooling or heating. There is complete acoustical and airflow data for all of these devices. Please contact your local McGill AirFlow sales engineering office or representative about your particular application for design assistance.

Sample Problem 9-1

A 14-ft x 20-ft x 8-ft room is supplied by two diffusers. The diffusers are mounted on the longitudinal centerline of the room, 5 feet from either end wall. The residual sound power level in the duct just upstream of the diffusers and the regenerated noise level of the diffusers are shown in Table 1. What will be the octave band sound levels at a height of 5 feet from the floor, on the longitudinal centerline, 8 feet from the end of the room?

Elevation View



Chapter 9 includes a step-by-step sample problem to guide you through the room effect equation.

Duct System Design Guide

$69.00 value!

McGill AirFlow's *Duct System Design Guide* is available exclusively on CD.

To request this CD, e-mail: marketing@mcgillairflow.com

Visit www.ductexpress.com!

Request a quotation through our secure site. A bill of material is forwarded to our sales staff who will respond to your request within one business day.

Over 300 products available for order online!

McGill AirFlow Corporation

2400 Fairwood Avenue
Columbus, OH 43207
614/443-5520, Fax: 614/542-2620
E-mail: mafengineering@mcgillairflow.com

©2004 McGill AirFlow Corporation

CHAPTER 9: Room Acoustics

In the previous section, we discussed the various sources of duct-borne noise and the natural attenuation mechanisms of duct systems. If the fan sound power level and the duct system size and configuration are known, one can calculate the residual sound power level at any outlet in the system. The next step is to determine the sound pressure level that this sound power will generate in the room or area that the duct is serving, and whether this is in conformance with acceptable using design criteria.

9.1 Air Terminal Noise

Since most duct runs will terminate with some type of register or diffuser, it is first necessary to calculate the generated noise caused by the air flowing across the terminal device. Acoustical and airflow data is usually obtained in accordance with ASHRAE Standard 70, *Method of Testing for Rating the Performance of Air Outlets and Inlets*. The data should present noise levels as a function of frequency and air volume or velocity. These levels should be treated as generated sound power levels and added to the residual sound power levels at the outlet, using decibel addition.

If the diffuser sound power is within 10 *dB* of the residual sound power level in the duct, it will increase the sound power level being emitted in the space. Additionally, poor flow conditions at the diffuser or register entrance can substantially increase the generated noise levels.

If the velocity profile is not uniform across the diffuser entrance, sound power levels may increase by as much as 12 *dB* above the manufacturer's predicted levels. This situation can often be corrected with flow straighteners. If flexible duct is used as a final connection to the terminal device, it should be run as straight as possible. Any offset greater than one fourth of the diffuser collar diameter over a length of twice the diffuser diameter will increase the noise levels by as much as 15 *dB* greater than the manufacturer's predicted levels.

9.2 ASHRAE Room Effect Equation

ASHRAE endorses a simple procedure for determining the sound pressure levels that will result from sound power emitted at the terminal of an HVAC duct. The equations are for normal rooms, which mean that there is assumed to be a certain amount of sound-absorbing surfaces and furnishings in the space. It is possible that extremely hard or soft spaces will have a slightly higher or lower sound pressure level, respectively; however, ASHRAE claims that the method will be accurate to within "2 *dB*.

Equation 9.1 is used to predict the sound pressure level at any distance (*r*) from a terminal outlet. The sound pressure level in a room is a function of frequency, room volume and the distance from the terminal outlet to a specified point in the room. The calculation must be repeated for each octave band center frequency (*f*).

$$Lp = Lw - 5\log(V) - 3\log(f) - 10\log(r) + 25dB \qquad \textbf{Equation 9.1}$$

where:

Lp = Room sound pressure level (dB re 20×10^{-5} Pascals)

Lw = Source sound power level (dB re 1×10^{-12} watts)

V = Room volume (ft^3)

f	=	Octave band center frequency (*Hz*)
r	=	Reference distance (*ft*)

For multiple terminals, the sound pressure level at the reference point is calculated for each terminal, using the appropriate *Lw* for that outlet and volume of the room. The resultant levels are then added using decibel corrections presented in **Appendix 9.10**.

Sample Problem 9-1

---

*A 14-ft H 20-ft H 8-ft-high room is supplied by two diffusers. The diffusers are mounted on the longitudinal centerline of the room, 5 feet from either end wall (10 feet between diffusers). See **Figures 9.1** and **9.2** for the plan and elevation views, respectively. The residual sound power level in the duct just upstream of the diffusers and the regenerated noise level of the diffusers are shown in **Table 9.1**. What will be the octave band sound pressure levels at a height of 5 feet from the floor, on the longitudinal centerline, 8 feet from the end of the room?*

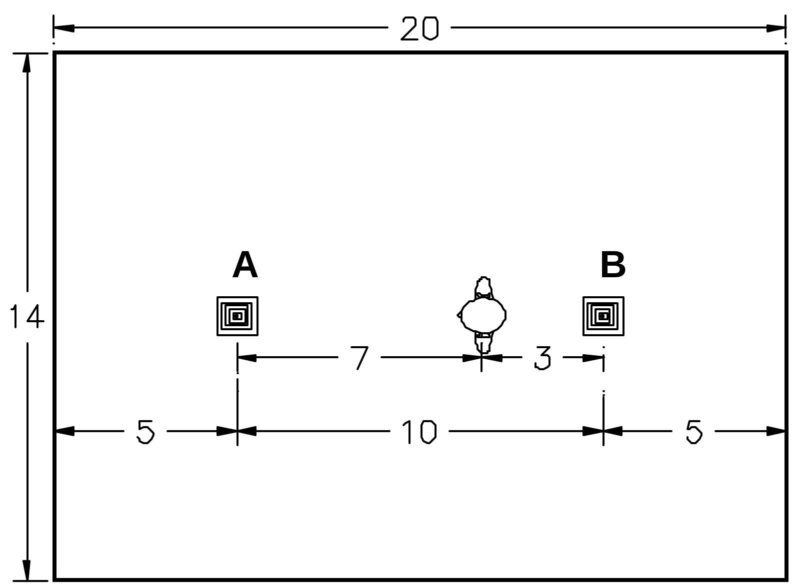


Figure 9.1
Plan View of Room for Sample Problem 9-1

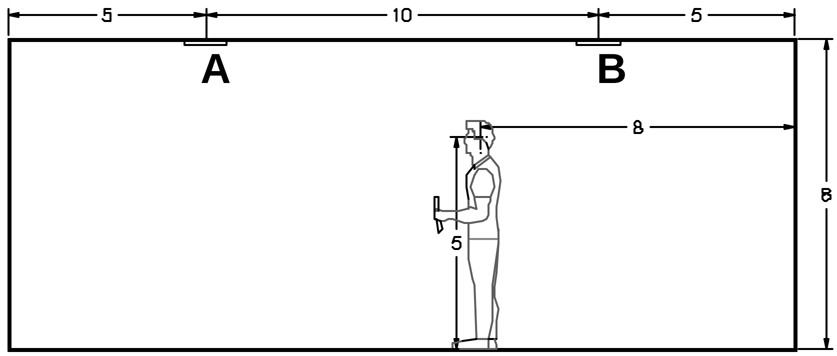


Figure 9.2
Elevation View of Room for Sample Problem 9-1

Table 9.1
Sample Problem 9-1 Noise Levels

Frequency (*Hz*)	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
Residual Duct *Lw*	35	38	46	31	46	41	33	26
Diffuser *Lw*	33	35	36	36	35	33	27	18

Answer: The sound pressure from each terminal is calculated, using **Equation 9.1**, and added together. The terminal closest to the reference location is *A* and the other is *B*.

The reference location is a point 5 *feet* above the floor (3 *feet* below the ceiling) and, in plan view, located midway between the long walls, 3 *feet* from one terminal and 7 *feet* from the other. The reference distance from either terminal can be calculated from simple geometry:

$$r(A) = \sqrt{3^2 + 3^2} = 4.2 \quad feet$$

$$r(B) = \sqrt{3^2 + 7^2} = 7.6 \quad feet$$

The distance term [*10 log(r)*] is: Terminal [A]: 10 log (4.2) = 6.2 = 6 *dB*
Terminal [B]: 10 log (7.6) = 8.8 = 9 *dB*

The room volume is 14 H 20 H 8 = 2,240 ft^3, therefore, The volume term [*5 log(V)*] is 5 log (2,240) = 16.7 = 17 *dB*

To determine the overall source sound power entering the room, it is necessary to add (decibel addition) the residual duct sound power level and the generated sound power level of the terminal devices. The resultant sound power level from each terminal is then adjusted by the factors in **Equation 9.1** to determine the sound pressure level at the reference location.

First, calculate the sound pressure level resulting from the noise exiting Terminal A. This step is summarized in **Table 9.2**.

Table 9.2
Sound Pressure Levels Due To Noise From Terminal A

Description	Data (dB)							
	Frequency (Hz)							
	63	125	250	500	1000	2000	4000	8000
Residual Duct *Lw*	35	38	46	31	46	41	33	26
Diffuser *Lw*	33	35	36	36	35	33	27	18
Resultant *Lw*	37	40	46	37	46	42	34	27
Room Effect:								
-*5 log (V)*	-17	-17	-17	-17	-17	-17	-17	-17
-*3 log (f)*	-5	-6	-7	-8	-9	-10	-11	-12
-*10 log (r)*	-6	-6	-6	-6	-6	-6	-6	-6
+25 *dB*	+25	+25	+25	+25	+25	+25	+25	+25
Lp due to A (use **Equation 9.1**)	34	36	41	31	39	34	25	17

Next, calculate the sound pressure level resulting from the noise exiting Terminal B. This step is summarized in **Table 9.3**.

Table 9.3
Sound Pressure Levels Due To Noise From Terminal B

Description	Data (dB)							
	Frequency (Hz)							
	63	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
Residual Duct *Lw*	35	38	46	31	46	41	33	26
Diffuser *Lw*	33	35	36	36	35	33	27	18
Resultant *Lw*	37	40	46	37	46	42	34	27
Room Effect:								
-5 log (V)	-17	-17	-17	-17	-17	-17	-17	-17
-3 log (f)	-5	-6	-7	-8	-9	-10	-11	-12
-10 log (r)	-9	-9	-9	-9	-9	-9	-9	-9
+25 *dB*	+25	+25	+25	+25	+25	+25	+25	+25
Lp due to B (use **Equation 9.1**)	31	33	38	28	36	31	22	14

The resultant sound pressure at the reference point, due to the sound power level from both terminals, is the logarithmic sum of the two levels, *Lp* (resultant). (See **Table 7.3** for decibel addition rules). The result is summarized in **Table 9.4**.

Table 9.4
Sound Pressure Levels Due To Noise From Terminals A and B

Description	Data (dB)							
	Frequency (Hz)							
	63	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
Lp due to **A**	34	36	41	31	39	34	25	17
Lp due to **B**	31	33	38	28	36	31	22	14
Lp Resultant	**36**	**38**	**43**	**33**	**41**	**36**	**27**	**19**

9.3 Design Criteria

Now that we are able to calculate fan sound power, duct attenuations, generated diffuser noise, and convert sound power level to a sound pressure level in a room, we must determine whether the sound pressure level is suitable for the noise criteria in the space. For this purpose, various criteria have been introduced in an attempt to relate a spectrum of noise to various occupancy situations.

9.3.1 NC Rating Method

In the past, the most commonly accepted criteria were the noise criteria (*NC*) curves, which were introduced in 1957. These curves are shown in **Figure 9.3**.

Note that all NC curves slope downward, left to right, indicating that the allowable sound pressure levels are higher in the lower frequencies. This is consistent with the auditory sensitivity of the human ear (see **Section 7.5**).

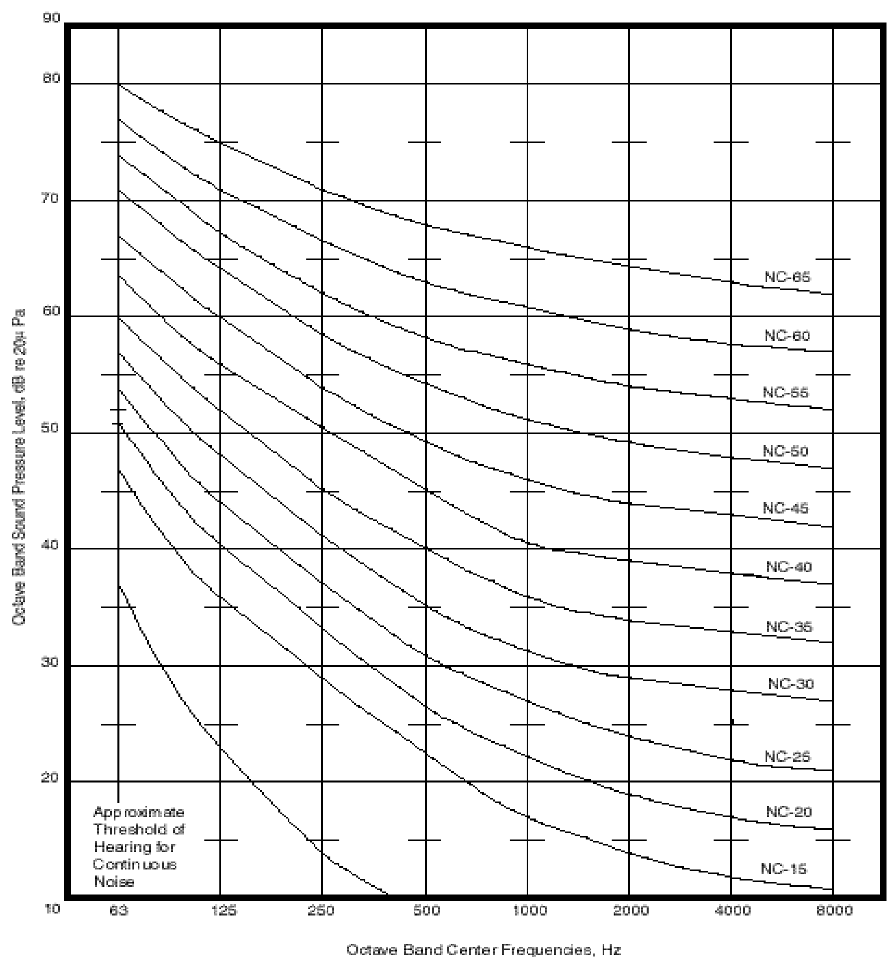


Figure 9.3
Noise Criteria Curves
(reprinted by permission of ASHRAE)

When determining the noise criteria of a space, the actual sound pressure levels are plotted over the standard curves. The *NC* rating of a particular noise source is generally taken as the value of the lowest *NC* curve that is closest to the highest point of the actual noise spectrum. *NC* ratings should always be in increments of 5, though interpolation between curves is often done. Usage of *NC* curves often results in an unbalanced noise spectrum since the highest sound pressure dictates the *NC* rating, and no requirement is specified for the relationship between nearby frequencies.

As an example of how to use the *NC* rating method, the calculated sound pressure levels of the office background noise from **Sample Problem 9-1** is plotted in **Figure 9.4**. The lowest *NC* curve that is closest to the highest noise spectrum sound level is at 1,000 *Hz*. At that point the spectrum touches the *NC-40* curve. Therefore, the room would have an *NC-40* rating.

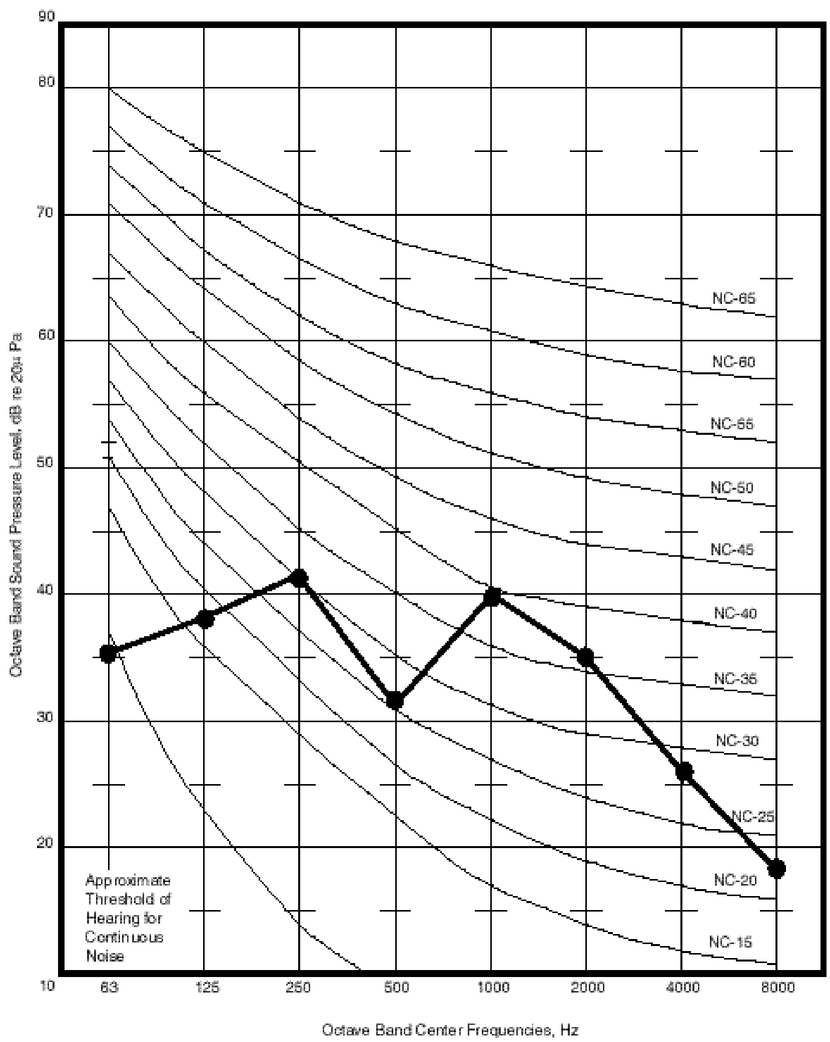


Figure 9.4
NC Rating Determination for Office Background Noise

The *NC* curves are actually plots of allowable sound pressures as a function of frequency. See **Table 9.5** for the sound pressure data that make up each *NC* curve. **Table 9.5** may be used in place of plotting measured sound pressure data on an *NC* curve. A determination can be made of the room *NC* rating using **Table 9.5** by finding the lowest NC criterion that has all of its sound pressure levels greater than the spectrum data, beginning with the NC-15 and working up the table.

Table 9.5
Sound Pressure Level Data for *NC* curves

***NC* Criterion**	**Sound Pressure Data Point on Curve (dB)**							
	Frequency (Hz)							
	63	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
NC-65	80	75	71	68	66	64	63	62
NC -60	77	71	67	63	61	59	58	57
NC -55	74	67	62	58	56	54	53	52
NC -50	71	64	58	54	51	49	48	47
NC -45	67	60	54	49	46	44	43	42
NC -40	64	56	50	45	41	39	38	37
NC -35	60	52	45	40	36	34	33	32
NC -30	57	48	41	35	31	29	28	27
NC -25	54	44	37	31	27	24	22	21
NC -20	51	40	33	26	22	19	17	16
NC -15	47	36	29	22	17	14	12	11

Sample Problem 9-2

The following sound pressure levels were recorded by a sound level meter in a classroom.

63	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
58	53	53	44	40	36	37	25

*Using **Table 9.5**, what NC criterion does the room meet?*

Answer: Determine NC criterion for each data point.

63	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
NC-35	NC-40	**NC-45**	NC-40	NC-40	NC-40	NC-40	NC-30

From the table, we see that the NC rating is dictated by the data in the 250 Hz band. The answer is **NC-45**.

9.3.2. RC Rating Method

Although the *NC* rating method is still widely used, the room criteria (*RC*) rating method is preferred and is often required in acoustical specifications because it reveals tonal components that go unaccounted for in the *NC* rating method. The *RC* rating method also accounts for the acoustical energy produced in the low frequencies (16 and 31.5 *Hz*), which may result in perceptible vibration of building components. **Figure 9.5** is a plot of the family of *RC* curves.

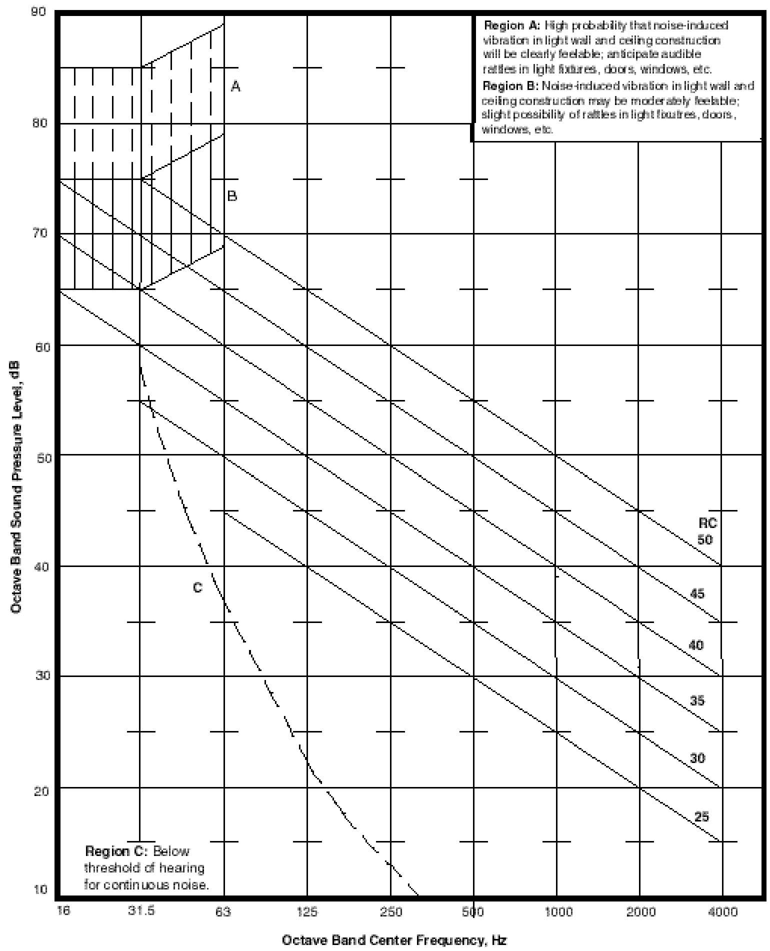


Figure 9.5
Room Criteria Curves

RC rating procedures are more involved than the *NC* rating, but they are fairly simple to follow. The following procedure is used to obtain RC ratings.

RC Rating Method Procedure

1. Plot the sound pressure level data on the *RC* curve.

2. Calculate the arithmetic average of the sound pressure level data in the 500, 1000, and 2000 *Hz* frequencies. Round to nearest dB. This is the numerical RC rating.

3. Draw a line with a slope of -5 *dB* in the frequency range of 31.5 to 4,000 *Hz*, passing through 1,000 *Hz* at the value calculated in step 2. This is the reference curve.

4. For the frequency range from 31.5 to 500 *Hz*, draw a line 5 *dB* above and parallel to the reference curve. Draw a second line 3 *dB* above and parallel to the reference curve, extending from 1,000 to 4,000 *Hz*. The range between the reference curve and the 5 dB and 3 dB curves represents the maximum permitted deviation of the noise spectrum to receive a neutral rating.

5. Determine the quality of the sound by observing how the shape of the spectrum deviates from the boundary limits based on the results of step 4. That is, note the relevant sound quality descriptor from **Table 9.6**.

6. Assign the spectrum a complete *RC* rating; using the value determined in step 2 and the descriptor in step 5.

Table 9.6
Sound Quality Descriptors for RC Rating Procedure

Sound Quality	**Descriptor**	**Description**
Neutral Spectrum	(N)	Sound pressure level data falls within the 5 dB and 3 dB curves and reference curves established in step 4
Rumbly Spectrum	(R)	Sound pressure level data exceeds the boundary established between the 5 dB and 3 dB curves and reference curve (31.5 to 500 *Hz*)
Hissy Spectrum	(H)	Sound pressure level data exceeds the boundary established between the 5 dB and 3 dB curves and reference curve (1,000 to 4,000 *Hz*)
Tonal Spectrum	(T)	A prominent sound pressure level data point in any octave band exceeds the boundaries established between the 5 dB and 3 dB curves and reference curve by more than 3 *dB*
Acoustically Induced Perceptible Vibration	(RV)	Sound pressure level data occurs in cross-hatched region of *RC* curve

Just like the *NC* curves, *RC* curves are actually plots of sound pressure levels. See **Table 9.7** for the sound pressure data that make up each *RC* curve.

Table 9.7
Sound Pressure Level Data for *RC* curves

***RC* Criteria**	**Sound Pressure Data Point on Curve (dB)**								
	Frequency (Hz)								
	16	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**
RC -50	!	!	70	65	60	55	50	45	40
RC -45	!	!	65	60	55	50	45	40	35
RC -40	!	!	60	55	50	45	40	35	30
RC -35	!	60	55	50	45	40	35	30	25
RC -30	60	55	50	45	40	35	30	25	20
RC -25	55	50	45	40	35	30	25	20	15

1. Shaded areas represent noise that is below the threshold for hearing for continuous noise exposure.
2. ! symbol indicates a serious vibration condition may exist if sound pressure level is more than 65 dB.

Sample Problem 9-3

Consider the sound pressure level data calculated in Sample Problem 9-1. What is the RC rating?

Answer: Follow the steps outlined in the previous section.

Step 1: The data is plotted on the RC graph in **Figure 9.6**.

Step 2: Average of the sound pressure levels in the 500, 1000 and 200 Hz bands is (33+41+36)/3, or 37. RC rating is 37. Now we need to determine the sound quality descriptor.

Step 3: The –5 dB slope reference curve is shown as a solid line in **Figure 9.6**. The line is located between the RC-35 and RC-40 curves.

Step 4: The two limit curves are shown as dashed lines parallel to the solid reference line from Step 3.

Step 5: Since sound pressure levels in the 1000 and 2000 octave bands exceed the limit (dashed lines) established for sound pressure levels between 1000 and 4000 Hz, the sound quality descriptor is (H) for hissy.

Step 6: The complete RC rating is **RC-37(H)**.

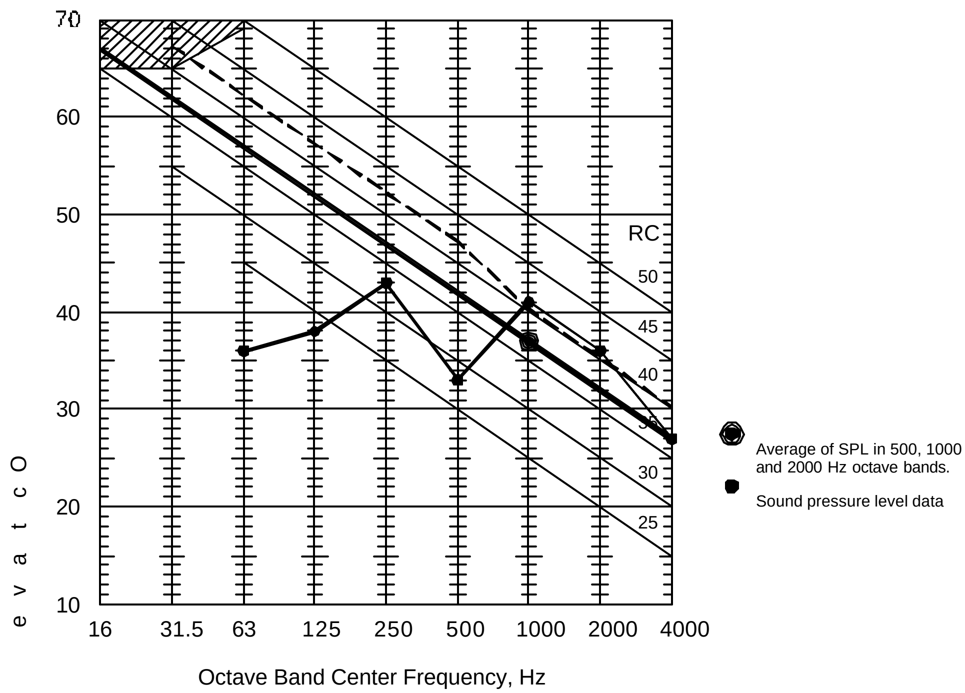


Figure 9.6
Plot of sound pressure level data for Sample Problem 9-2

9.3.3 Criteria Design Guidelines

The allowable *RC/NC*-curve for a space is generally chosen by the building's owner or architect; however, **Table 9.8** provides design guidelines for achieving acceptable RC neutral, or RC(N), background sound based on room function.

Table 9.8
Design Guidelines for HVAC-Related Background Sound in Rooms

Environment	RC(N)[a,b] Criterion	Environment	RC(N)[a,b] Criterion
Residences, Apartments, Condominiums:	25-35	**Laboratories (w/fume-hoods)**	
		Testing/research, minimal Speech communication:	45-55
		Research, extensive telephone use, speech communication:	40-50
		Group teaching:	35-45
Hotels/Motels		**Church, Mosque, Synagogue**	
Individual rooms or suites:	25-35	General assembly:	25-35
Meeting/banquet rooms:	25-35	With critical music programs:[c]	
Corridors, lobbies:	35-45		
Service/support areas:	35-45		
Office Buildings		**Schools**[e]	
Executive and private offices:	25-35	Classrooms up to 750 ft^2:	40 (max)
Conference rooms:	25-35	Classrooms over 750 ft^2:	35 (max)
Tele-conference rooms:	25 (max)	Large lecture rooms, without speech amplification:	35 (max)
Open-plan offices:	30-40		
Corridors and lobbies:	40-45		
Hospitals and Clinics		**Libraries:**	30-40
Private rooms:	25-35		
Wards:	30-40		
Operating rooms:	25-35		
Corridors & public areas:	30-40		
Performing Arts Spaces		**Courtrooms**	
Drama theaters:	25 (max)	Unamplified speech:	25-35
Concert and recital halls:[c]		Amplified speech:	30-40
Music teaching studios:	25 (max)		
Music practice rooms:	35 (max)		
Indoor Stadiums, Gymnasiums			
Gymnasiums and natatoriums:[d]	40-50		
Large seating-capacity spaces with speech amplification:[d]	45-55		

NOTES:

a: The values and ranges are based on judgment and experience, not on quantitative evaluations of human reactions. They represent general limits of acceptability for typical building occupancies. Higher or lower values may be appropriate and should be based on a careful analysis of economics, space usage, and user needs.

b: When the quality of sound in the space is important, specify criteria in terms of RC(N). If the quality of the sound in the space is of secondary concern, the criteria may be specified in terms of NC or NCB levels of similar magnitude.

c: An experienced acoustical consultant should be retained for guidance on acoustically critical spaces (below RC 30) and for all performing arts spaces .

d: RC or NC criteria for these spaces need only be selected for the desired speech and hearing conditions.

e: There is evidence that HVAC-related sound criteria for schools, such as those listed in this Table, are too high and impede the learning process for children in the primary grades whose vocabulary is limited, or whose 1st language is not English. Some educators and others believe that the HVAC-related background sound should not exceed RC 25 (N).

(reprinted by permission of ASHRAE)

9.3.4 Other Criteria

The *NCB* and *RC Mark II* are two other noise rating methods for specifying noise criteria, but they have yet to achieve the acceptance of the *RC* or *NC* methods due to their complexity. You can learn more about these methods in **Appendix. A.9.2**.

9.4 Spectrum Shape

Regardless of whether the *RC* or *NC* rating method is used, it is important to have a balanced noise spectrum. A complete acoustical analysis of the HVAC system will allow the designer to control the noise spectrum so that it closely approximates the shape of the *RC* or *NC* curve. HVAC systems without balanced noise spectrums are likely to have poor sound quality and can cost a building owner money by making it difficult to find occupants for noisy areas of the building. For example, a slight humming noise may cause a loss in productivity even though the over-all sound pressure levels are within a specified NC criterion. This is why it is important to use the RC or other rating method that considers spectrum shape.

If there is a problem with spectrum shape, sometimes noise is added to the environment to provide a more balanced noise spectrum. This is called noise-masking, and can consist of a discretely located sound system, providing broad-band sound to the environment. This method can also be very effective at masking private conversations in an open office environment. Usually, this is an inconvenient and expensive solution. It is always better to evaluate potential noise problems during the design stage before they become cost problems.