



ASHRAE Chapter Meeting HVAC Noise & Vibration Control Best Practices



Industrial



Architectural



Marine



Environmental



Military



OEM



HVAC



Aviation

Presented By



Noise & Vibration Control, Inc.
610-863-6300

www.brd-nonoise.com



Why Acoustics Matter!





Topics

- ☺ Introduction to Acoustics
- ☺ Fundamental Design Questions
- ☺ Acoustic Materials





Important Acoustic Terminology

- Loudness vs. Pitch
- Tonal Content
- Decibels: Sound Power vs. Sound Pressure
- Decibel Weighting Networks

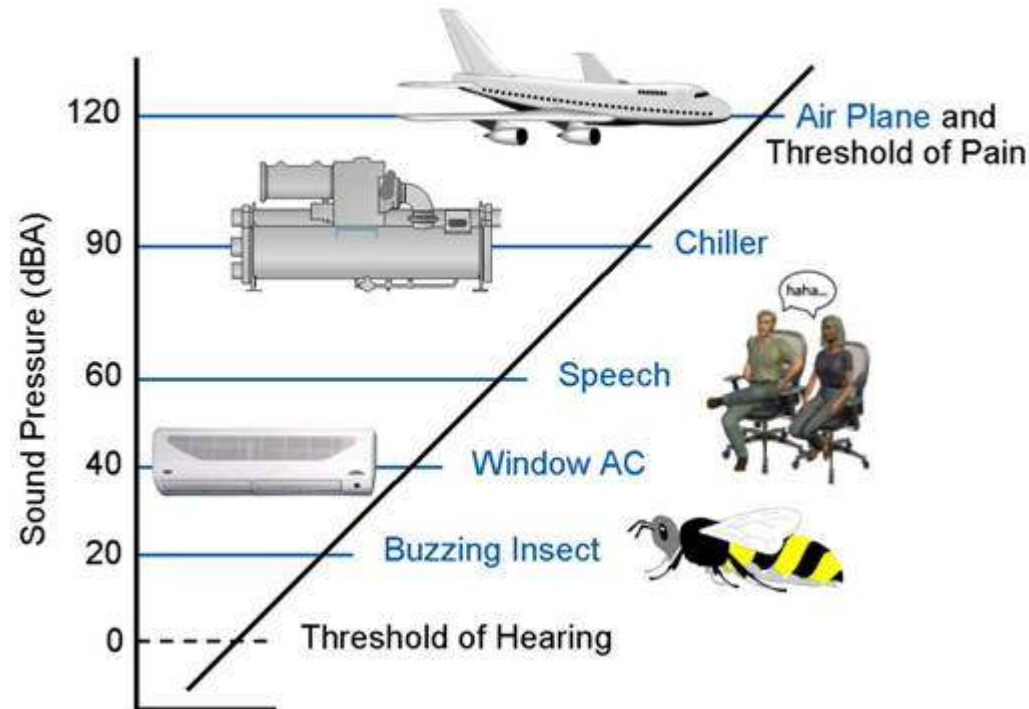


Loudness = Quantity of Sound

Pitch = Quality of Sound



What Is The Decibel Scale?



The decibel (dB) is a dimensionless unit calculated using the ratio of a measured value (p) to a reference value (ref). The values of sound pressure of most interest range from the threshold of hearing at about 20 μPa to a level of extreme danger at about 200 Pa. This range of variation translates to 7 orders of magnitude with the high level being 10,000,000 times that of the lower threshold. The use of a logarithmic scale compresses the unit of measure to a manageable range in order to simplify calculations, computations and quantitative manipulation of data.



Actual Scale versus Decibel Scale

Source	Watts	Watts – Exponential	Decibel re: 10^{12} W
Saturn Rocket	100,000,000	10^8	200
Turbojet Engine	100,000	10^5	170
Jet Aircraft at Takeoff	10,000	10^4	160
Turboprop at Takeoff	1,000	10^3	150
Prop Aircraft at Takeoff	100	10^2	140
Large Pipe Organ	10	10^1	130
Small Aircraft Engine	1	10^0	120
Blaring Radio	0.1	10^{-1}	110
Automobile at High Speed	0.001	10^{-2}	100
Voice, Shouting	0.0001	10^{-3}	90
Garbage Disposal Unit	0.00001	10^{-4}	80
Voice Conversation Level	0.000001	10^{-5}	70
Ventilation Fan	0.0000001	10^{-6}	60
Office Air Diffuser	0.00000001	10^{-7}	50
Small Electric Clock	0.000000001	10^{-8}	40
Voice, Soft Whisper	0.0000000001	10^{-9}	30
Rustling Leaves	0.00000000001	10^{-10}	20
Human Breath	0.0000000000001	10^{-11}	10
Threshold of Hearing	0.00000000000001	10^{-12}	0

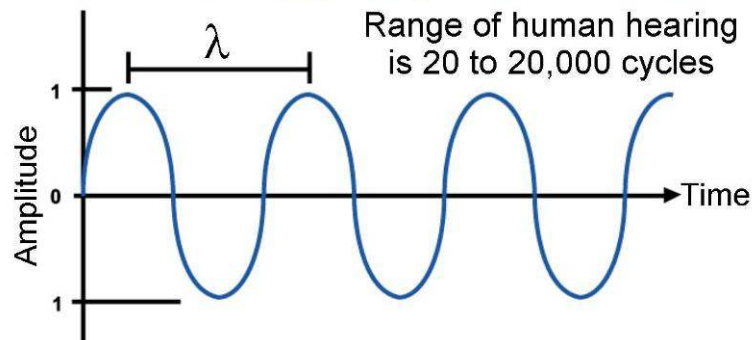


Frequency and Wavelength

$$\text{Wavelength} = \lambda = c / f$$

Where: c = Speed of Sound in Air = 1127 ft./sec.

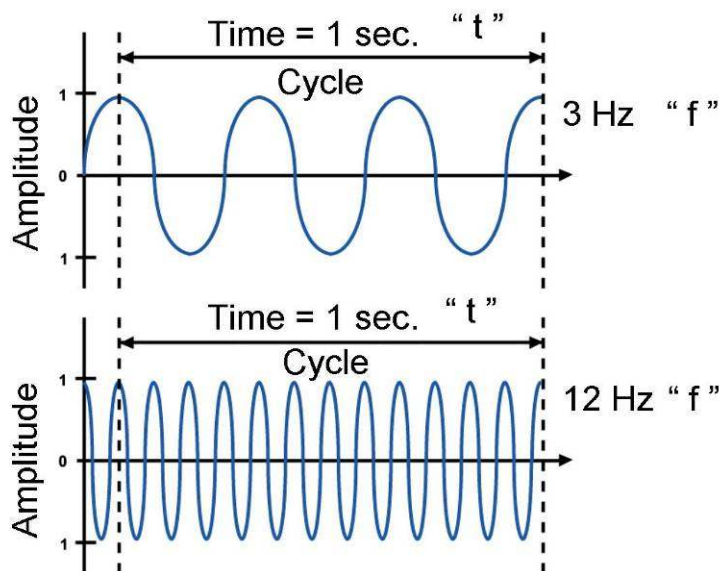
f = Frequency (Hz) (cycles per second)



Sound **wavelengths** are the linear measurement of one full cycle of displacement where the motion of air molecules is first compressed and then expanded (forming a pressure pulsation). The wavelength is determined by the ratio of the speed of sound to the frequency.

Wavelength (ft)

$$= \text{Speed of Sound (fps)} / \text{Frequency (Hz)}$$

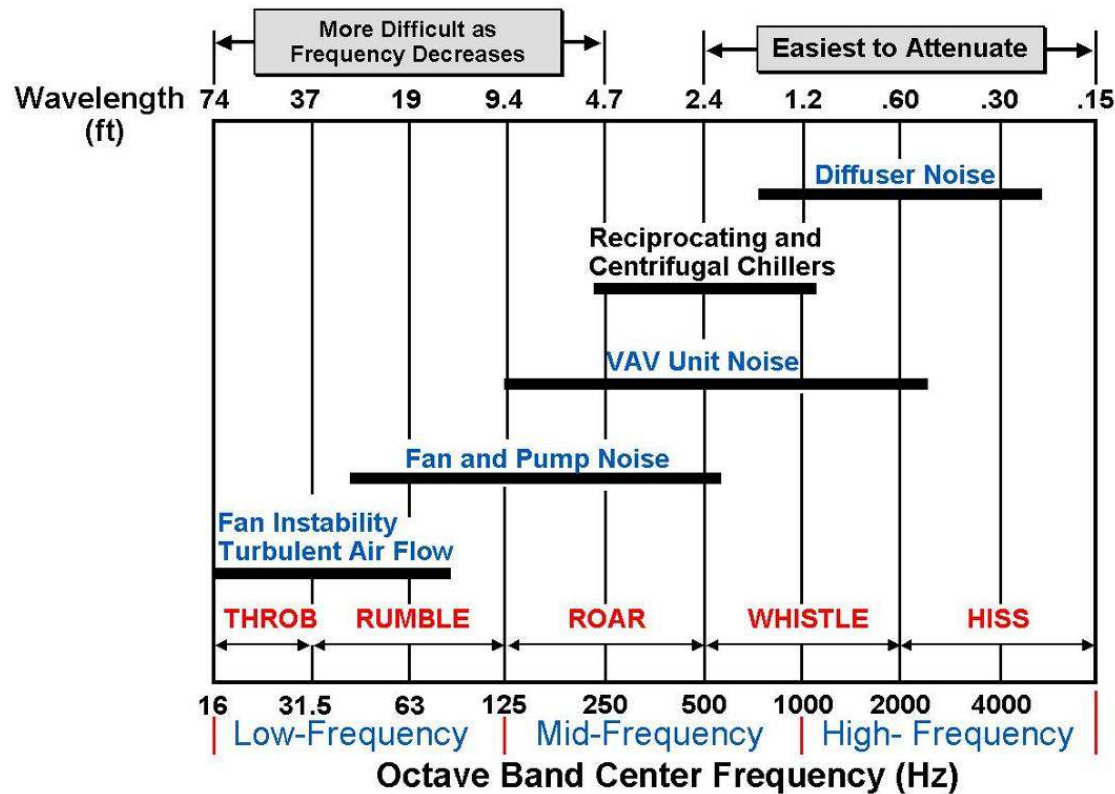
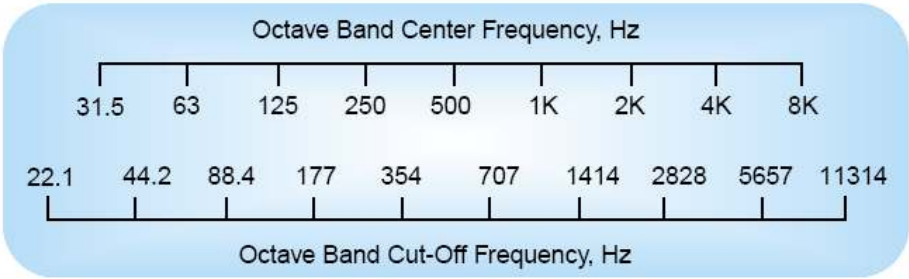


The rate at which these pulsations occur is called the **frequency** and is described in cycles per second (1 cycle per second equals 1 Hz). Each cycle is one complete expansion and compression.



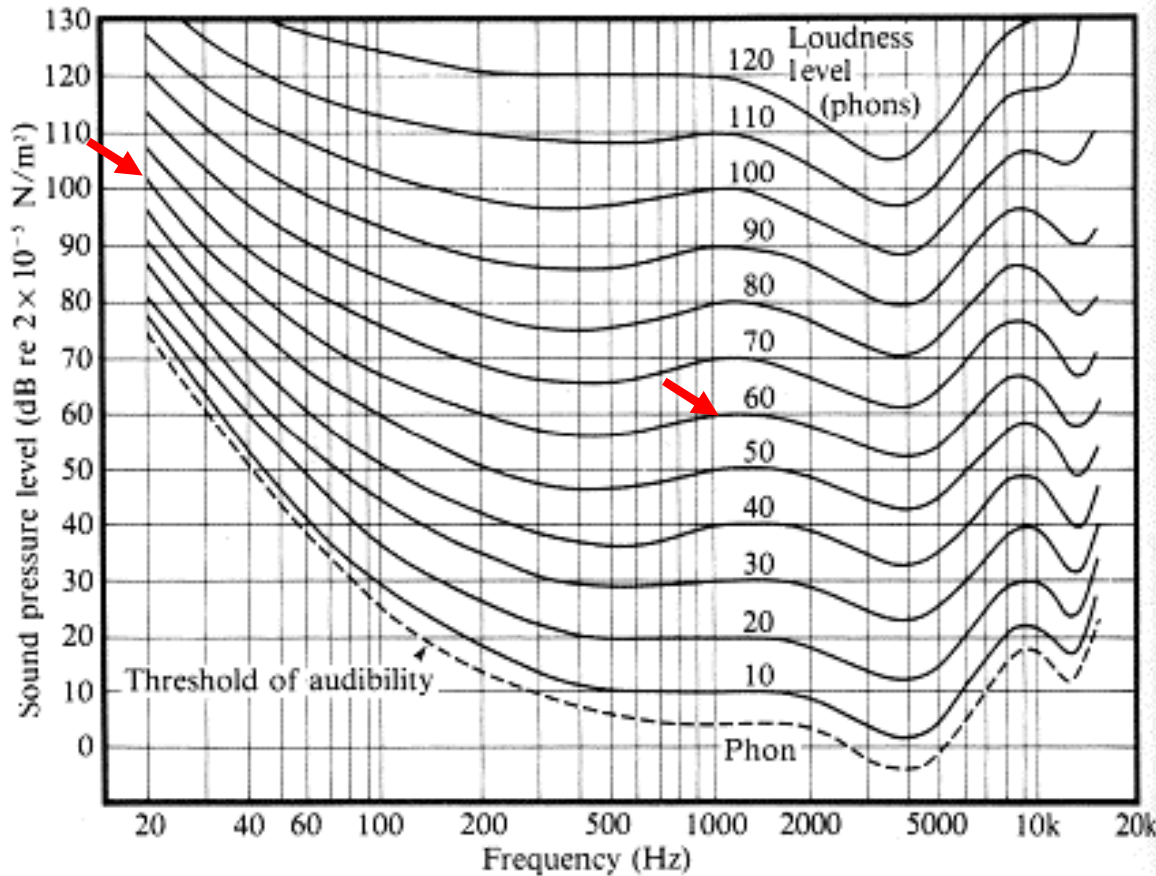
What Are Octave Bands?

Standardized octave bands are groups of frequencies named by the center frequency where the upper limit is always twice the lower limit of the range. Test data for performance of acoustical materials is standardized for easy comparison at the center frequencies. Equipment noise levels and measurement devices (dB meters) also follow the preferred octave bands.





A 1K Hz tone at 60 dB would require a 102 dB tone at 20 Hz to sound as loud to the human ear.



dB	Actual SPL Reduction	Perceived Volume Reduction
3 dB	50.00%	18.77%
6 dB	75.00%	34.02%
9 dB	87.50%	46.41%
12 dB	93.75%	56.47%
15 dB	96.88%	64.64%
18 dB	98.44%	71.28%
21 dB	99.22%	76.67%
24 dB	99.61%	81.05%
27 dB	99.80%	84.61%
30 dB	99.90%	87.50%
33 dB	99.95%	89.85%
36 dB	99.98%	91.75%
39 dB	99.99%	93.30%
42 dB	99.99%	94.56%
45 dB	100.00%	95.58%
48 dB	100.00%	96.41%
51 dB	100.00%	97.08%
54 dB	100.00%	97.63%
57 dB	100.00%	98.08%
60 dB	100.00%	98.44%
63 dB	100.00%	98.73%
66 dB	100.00%	98.97%
69 dB	100.00%	99.16%
72 dB	100.00%	99.32%
75 dB	100.00%	99.45%
78 dB	100.00%	99.55%
81 dB	100.00%	99.64%



Calculation Tools

Decibel Addition:

$$10 \log (10^{\text{dB}/10} + 10^{\text{dB}/10} + \dots)$$

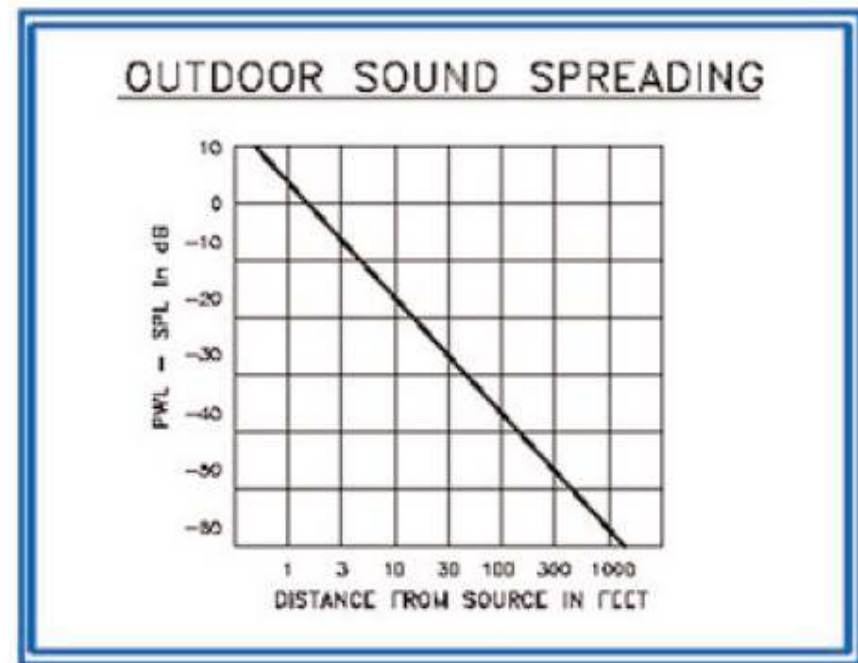
$$\begin{aligned} \text{For example, } 87 \text{ dB} + 87 \text{ dB} \\ &= 10 \log (10^{87/10} + 10^{87/10}) \\ &= 10 \log (10^{8.7} + 10^{8.7}) \\ &= 10 \log (1.00237 \times 10^9) \\ &= 10 (9.00103) = 90 \text{ dB} \end{aligned}$$

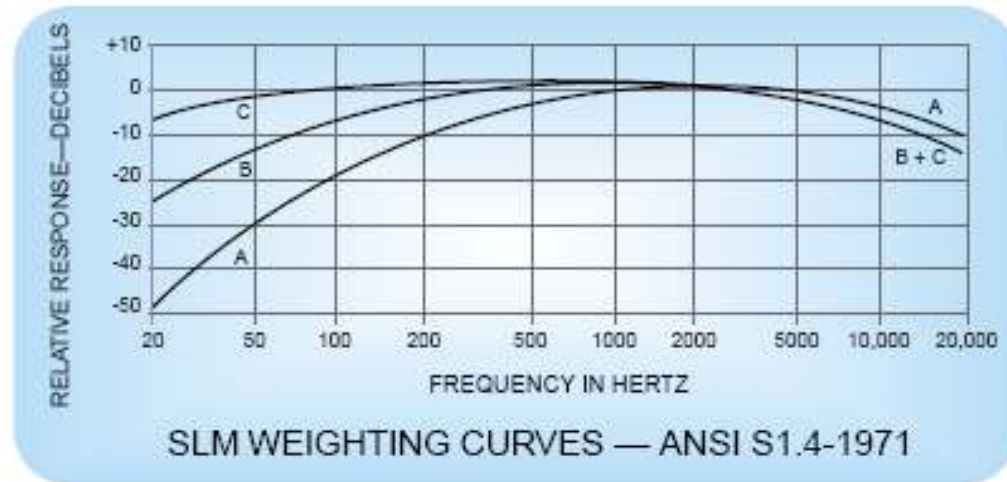
Difference between two decibel values	Amount added to higher value
0 or 1	3
2 or 3	2
4 to 9	1
10 or more	0

Sound Power to Sound Pressure:

$$\text{dB} = L_w - ((20 \text{ Log dist in ft}) - 2.4)$$

$$\begin{aligned} \text{For example, at } 30' \\ \text{dB} &= L_w - ((20 \text{ Log } 30) - 2.4) \\ &= L_w - ((20 * 1.477) - 2.4) \\ &= L_w - (29.5 - 2.4) = L_w - 27.1 \end{aligned}$$





	Octave Band Center Frequency, Hz								
	31.5	63	125	250	500	1000	2000	4000	8000
A-weighting	-39	-26	-16	-9	-3	0	+1	+1	-1

A-weighting network is designed to approximate the human hearing response.

Note that curve is similar but opposite the equal loudness contours.



What is the overall dBA level?

Octave Band	Center Frequency	Unweighted Sound Pressure (dB)	A-weighting factor (dB)	A-weighted Sound Pressure (dBA)	Decibel Addition	Overall Resultant Level
1	63	94	-26	68	72	91 dBA
2	125	86	-16	70	86	
3	250	85	-9	76	86	
4	500	89	-3	86	89	
5	1,000	89	0	89	89	
6	2,000	77	1	78	89	
7	4,000	75	1	76	79	
8	8,000	76	0	76	79	

Difference between two decibel values	Amount added to higher value
0 or 1	3
2 or 3	2
4 to 9	1
10 or more	0



Why is it important to know dB versus dBA?

	63	125	250	500	1k	2k	4k	8k	Total dBA
A-scale	-26	-16	-9	-3	0	1	1	-1	
dB	111	103	98	92	85	79	69	62	94
dBA	85	87	89	89	85	80	70	61	94



What is Sound Pressure?

Decibels of sound pressure (L_p) have a universally accepted reference pressure of 2.0×10^{-5} Pascals (Pa).

$$L_p = 20 \log_{10} \left[\frac{\text{Root Mean Square (RMS) Sound Pressure}}{2.0 \times 10^{-5} \text{ Pa (Reference Pressure)}} \right]$$

What Is Sound Power?

Decibels of sound power (L_w) have a universally accepted reference value of 10^{-12} watts (1 picowatt).

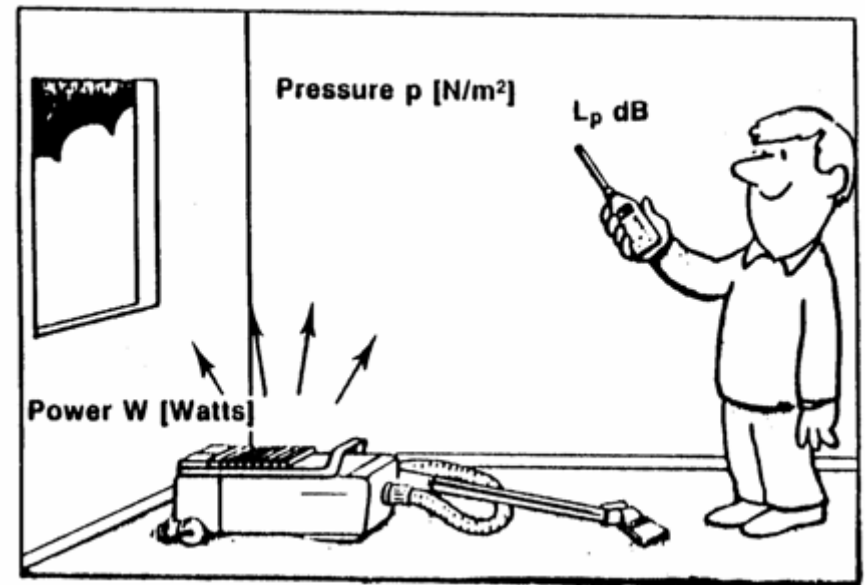
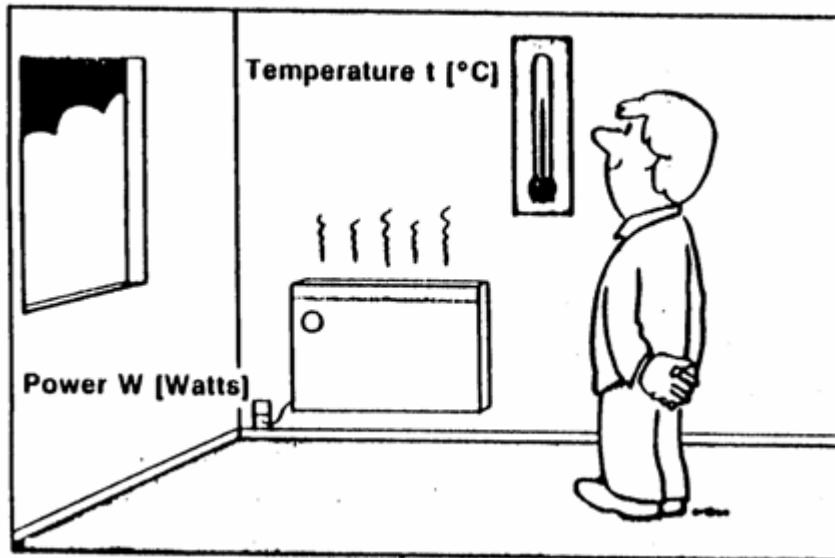
$$L_w = 10 \log_{10} \left[\frac{\text{Watts Sound Power}}{10^{-12} \text{ Watts (Reference Value)}} \right]$$



PWL vs. SPL

Power vs. Pressure

Cause vs. Effect

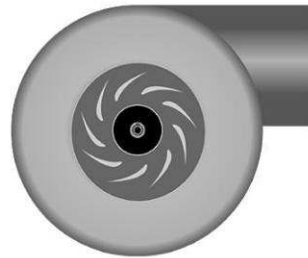




Typical Sound Pressure Levels	Sound Pressure Pa	Sound Pressure Level dB	Subjective Reaction
Military Jet Takeoff @ 100 ft	200.0	140	Extreme Danger
Artillery Fire @ 10 ft	63.2	130	
Passenger Ramp at Airport	20.0	120	Threshold of Pain
Loud Rock Band	6.3	110	Threshold of Discomfort
Platform of Subway Station	2.0	100	
Large Diesel Engine @ 130 ft	0.6	90	Very Loud
Computer Printout Room	0.2	80	
Freight Train @ 100 ft	0.06	70	
Conversation Speech @ 3 ft	0.02	60	
Window Air Conditioner	0.006	50	Moderate
Quit Residential Area	0.002	40	
Whisper @ 6 ft	0.0006	30	
Buzzing Insect @ 3 ft	0.0002	20	
Threshold of Good Hearing	0.00006	10	Faint
Threshold of Youthful Hearing	0.00002	0	Threshold of Hearing



Tonal Noise

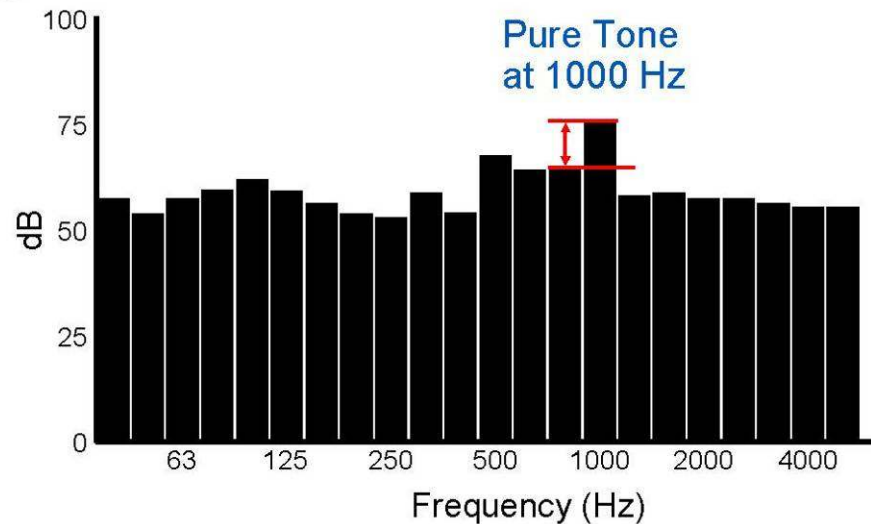


rpm required 850

Number of blades: 64

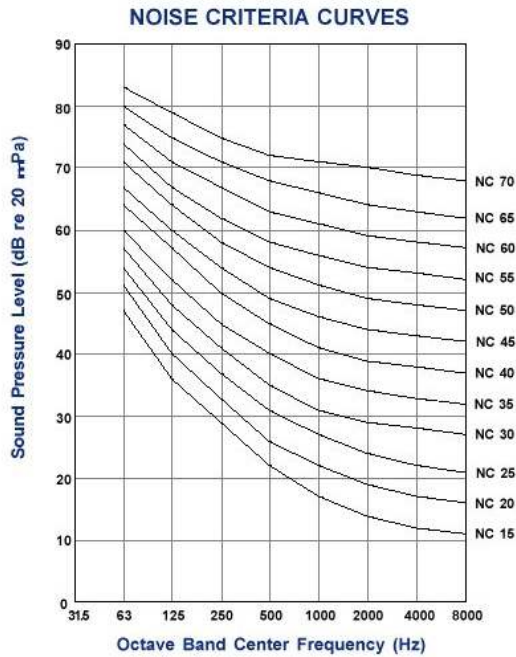
$$f_B = \# \text{ BLADES} * \text{rpm} * \frac{1 \text{min}}{60 \text{sec}}$$

$$f_B = 64 * 850 * \frac{1}{60} = 906 \text{ Hz}$$



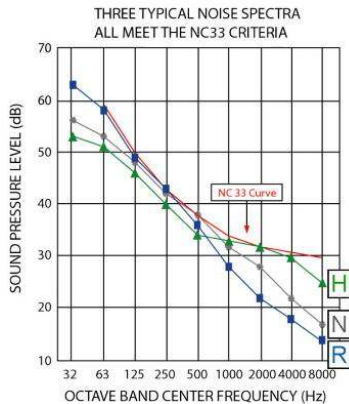
Sioux Falls, SD Municipal Code defines tone as:

“any sound which can be distinctly heard as a single pitch or set of single pitches.... and shall exist of the one-third octave band sound pressure level in the band when the tone exceeds the arithmetic average of the sound levels of the two contiguous one-third octave bands by **five dB for frequencies of 500 Hz and above**, **eight dB for frequencies between 160-400 Hz**, and by **15 dB for frequencies less than or equal to 125 Hz.**”



Recommended NC levels for various room uses

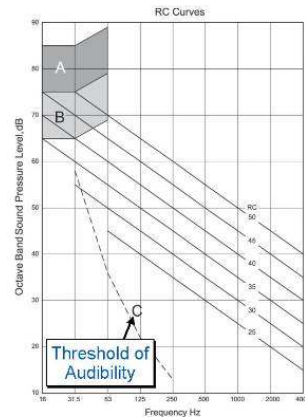
Broadcast studios (distant microphone pickup used)	10	Office buildings:	
Concert halls, opera houses, and recital halls (listening to faint musical sounds)	15-18	Offices	
Small auditoriums	25-30	executive	25-35
Large auditoriums, large drama theatres, and large churches (for very good speech articulation)	20-25	small, private	35-40
TV and broadcast studios (close microphone pickup only)	15-20	larger, with conference tables	30-35
Legitimate theatres	20-25	Conference rooms	
Private residences:		large	25-30
Bedrooms	25-30	small	30-35
Apartments	30-40	General secretarial areas	40-45
Family rooms and living rooms	30-40	Open-plan areas	35-40
Schools:		Business machines/computers	40-45
Lecture and classrooms		Public circulation	40-50
with areas less than 70 sq. m.	35-40	Hospitals and clinics:	
with areas greater than 70 sq. m.	30-35	Private rooms	25-30
Open-plan classrooms	35-40	Wards	30-35
Hotels/motels:		Operating rooms	25-35
Individual rooms or suites	30-35	Laboratories	35-45
Meeting/banquet rooms	25-35	Corridors	35-45
Service support areas	40-50	Public areas	40-45
Churches, small	30-35	Movie theatres	30-40
		Courtrooms	30-35
		Libraries	35-40
		Restaurants	40-45



H = Hissy

N = Neutral

R = Rumbly



Region A:

High probability that noise induced vibration levels in light wall and ceiling structures will be noticeable. Rattling of lightweight light fixtures, doors and windows should be anticipated.

Region B:

Moderate probability that noise-induced vibration will be noticeable in lightweight light fixtures, doors and windows.

- OSHA, MSHA, etc.
- Company policy
- Bldg criteria for human comfort
- Local ordinance:

generalcode.com
municode.com
noisepollution.org
amlegal.com

Outdoor Objective Criteria State, City, Township Ordinances

meter which has a uniform ('flat') response over the band of frequencies measured.

'Stationary emergency signaling device' means any device, excluding those attached to motor vehicles, used to alert local persons engaged in local emergency operations. These include, but are not limited to, fire-fighters, first aid squad members, and law enforcement officers, whether paid or volunteer.

7:29-1.2 Industrial, commercial, public service, or community service facilities

[32 N.J.R. 2230, 06/19/2000]

(a) No person shall cause, suffer, allow, or permit sound from any industrial, commercial, public service or community service facility that, when measured at any residential property line of any affected person, is in excess of any of the following:

1. From 7:00 A.M. to 10:00 P.M.:

- i. Continuous airborne sound which has a sound level in excess of 65 dBA; or
- ii. Continuous airborne sound which has an octave band sound pressure level in decibels which exceeds the values listed below in one or more octave bands:

Octave Band Center Frequency (Hz)	Octave Band Sound Pressure Level (dB)
315	55
63	62
125	74
250	67
500	62
1000	60
2000	57
4000	55
8000	53

cc.

iii. Impulsive sound in air which has a peak sound pressure level in excess of 80 decibels.

2. From 10:00 P.M. to 7:00 A.M.:

- i. Continuous airborne sound which has a sound level in excess of 50 dBA; or
- ii. Continuous airborne sound which has an octave band sound pressure level in decibels which exceeds the value listed below in one or more octave bands:

Octave Band Center Frequency (Hz)	Octave Band Sound Pressure Level (dB)
315	65
63	71
125	61
250	53
500	46
1000	45
2000	42
4000	40
8000	36

cc.

iii. Impulsive sound in air which has a peak sound pressure level in excess of 80 decibels and such impulse sound shall not be repeated more than four times in any hour. Impulsive sound which repeats more than four times in any hour shall not exceed 50 dBA.

(b) No person shall cause, suffer, allow, or permit sound from any industrial, commercial, public service or community service facility that, when measured at the property line of any other industrial, commercial, public service or community service facility of any affected person, is in excess of any of the following:

- 1. Continuous airborne sound which has a sound level in excess of 65 dBA; or
- 2. Continuous airborne sound which has an octave band sound pressure level in decibels which exceeds the values listed below in one or more octave bands:

Octave Band Center Frequency (Hz)	Octave Band Sound Pressure Level (dB)
315	55
63	62
125	74
250	67
500	62
1000	60
2000	57
4000	55
8000	53

cc.

3. Impulsive sound in air which has a peak sound pressure level in excess of 80 decibels.

7:29-1.3 Stationary emergency signaling devices

(a) Testing of only the electromechanical functioning of a stationary emergency signaling device shall occur at the same time each day that a test is performed, but not before 8:00 A.M. or after 8:00 P.M. Any such testing shall only use the minimum cycle test time. Except as provided for in (b) below, such test time shall not exceed ten seconds.



Researching Outdoor Objective Criteria

www.generalcode.com

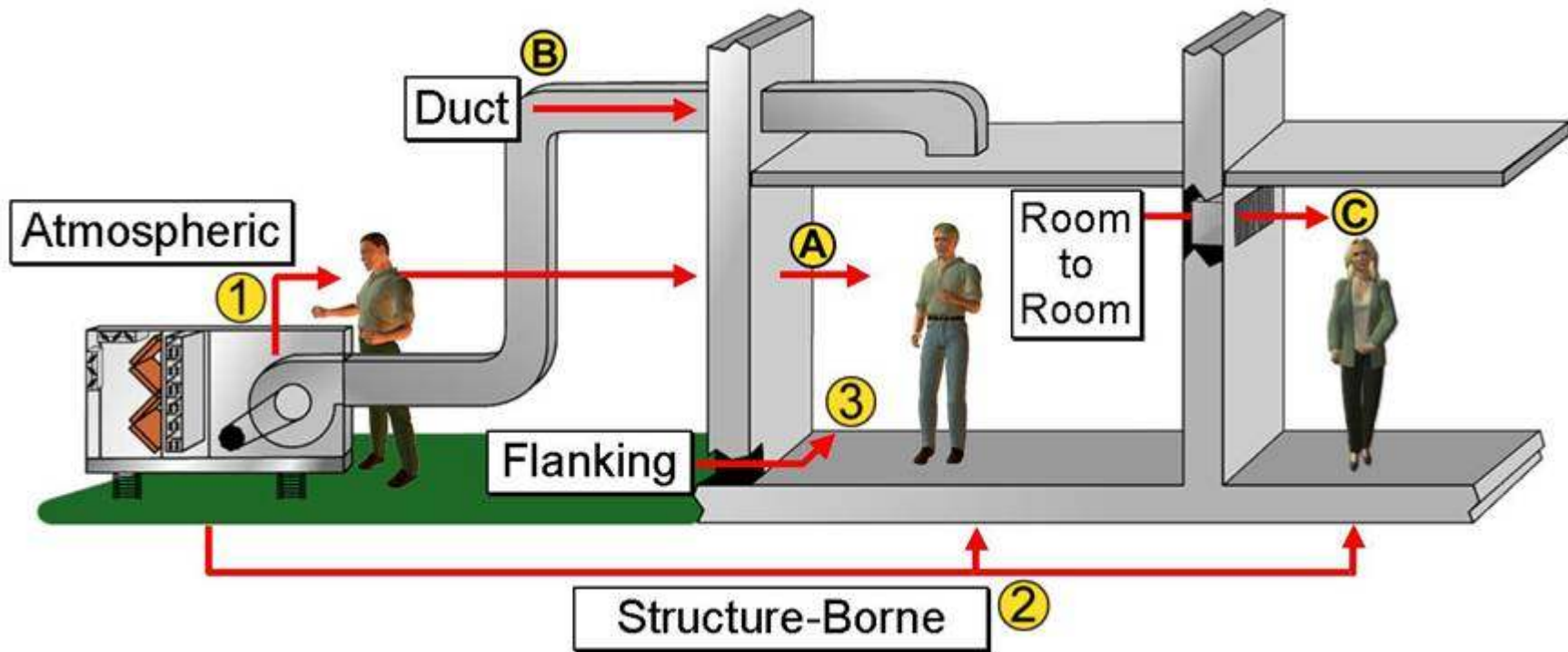
www.municode.com

www.noisepollution.org

www.amlegal.com



System Problems Require System Solutions

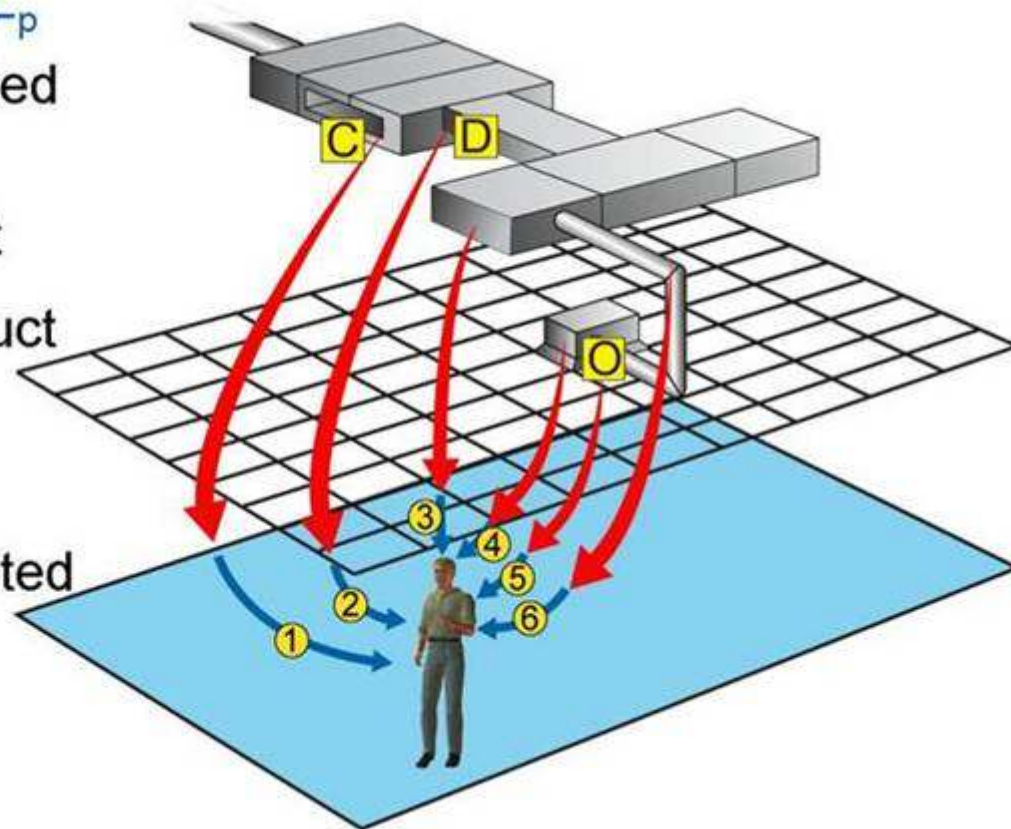




System Problems Require System Solutions

Sound Pressure L_p

- ① Casing Radiated and Inlet
- ② Duct Breakout
- ③ Distribution Duct Breakout
- ④ Discharge
- ⑤ Outlet Generated Sound
- ⑥ Flex Duct Breakout





1. Where are we now?

Freq (Hz)	63	125	250	500	1K	2K	4K	8K	A
Lw	90	98	99	97	94	92	85	81	100
Loss_{100'}	-37	-37	-37	-37	-37	-37	-37	-37	-37
Lp	53	61	62	60	57	55	48	44	63

(Sound Levels 270 ton Air Cooled Chiller)

2. Where do we need to be?

TABLE OF ZONING DISTRICT NOISE STANDARDS

Maximum Allowable Octave Band Sound Pressure Levels

Octave Band Center Frequency of Measurement (Hz)	Residential		Residential / Industrial		Business	Industrial
	Daytime	All Other Times	Daytime	All Other Times	Anytime	Anytime
31.5	76	68	79	72	79	83
63	75	67	78	71	78	82
125	69	61	73	65	73	77
250	62	52	68	57	68	73
500	56	46	62	51	62	67
1000	50	40	56	45	56	61
2000	45	33	51	39	51	57
4000	40	28	47	34	47	53
8000	38	26	44	32	44	50
Single Number Equivalent	60 dBA	50 dBA	65 dBA	55 dBA	65 dBA	70 dBA



3. How much noise reduction is required?

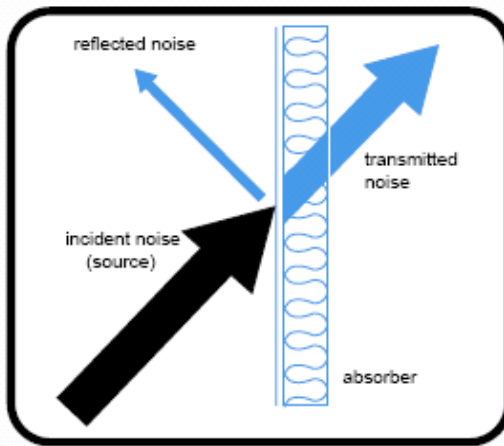
Freq (Hz)	63	125	250	500	1K	2K	4K	8K	A
Chiller	53	61	62	60	57	55	48	44	63
Ordinance	67	61	52	46	40	33	28	26	50
Needed Attenuation	--	--	10	14	17	22	20	18	13

4. What needs to be done to achieve compliance?

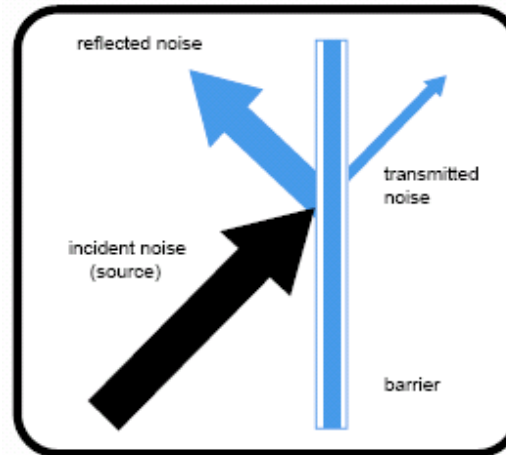




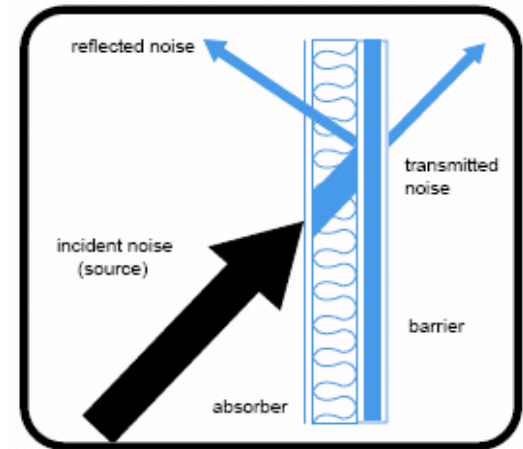
ABSORBERS



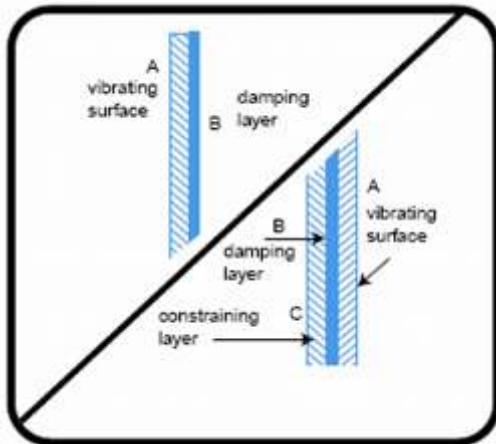
BARRIERS



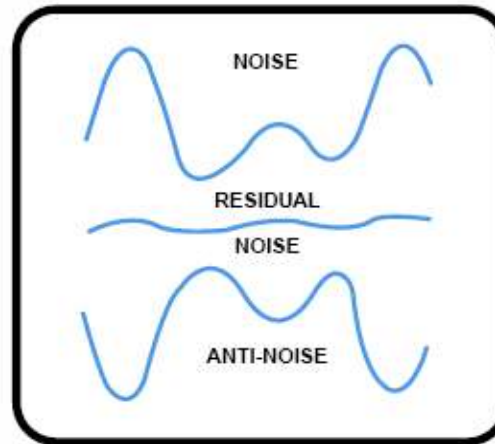
COMPOSITES



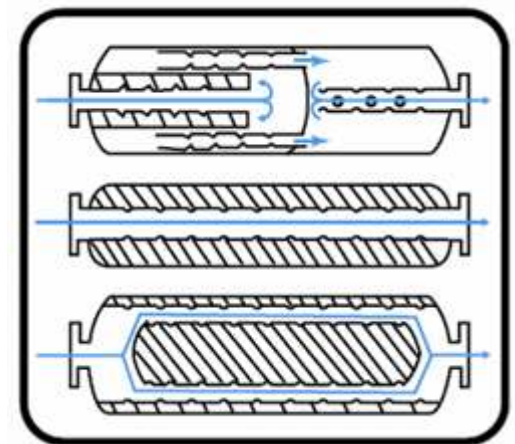
DAMPING



ELECTRONIC



FLOW CONTROL





Air-Cooled Chillers

Covers



Discharge Stacks



Silenced Discharge Stacks



Wall Treatments



Barriers



Enclosures





Water-Cooled Chillers

Covers



Soft Enclosures



Hard Enclosures



Rooftop Units

Covers



Acoustic Curbs



Discharge Stacks and Acoustic Screens





**Have a
noise-free
day!**



A Specification Should Provide “Just the Right Prescription”

- Accountability
- Cost Control
- Predictable Performance
- Review of subjective and objective noise criteria



Common Specification Strategies





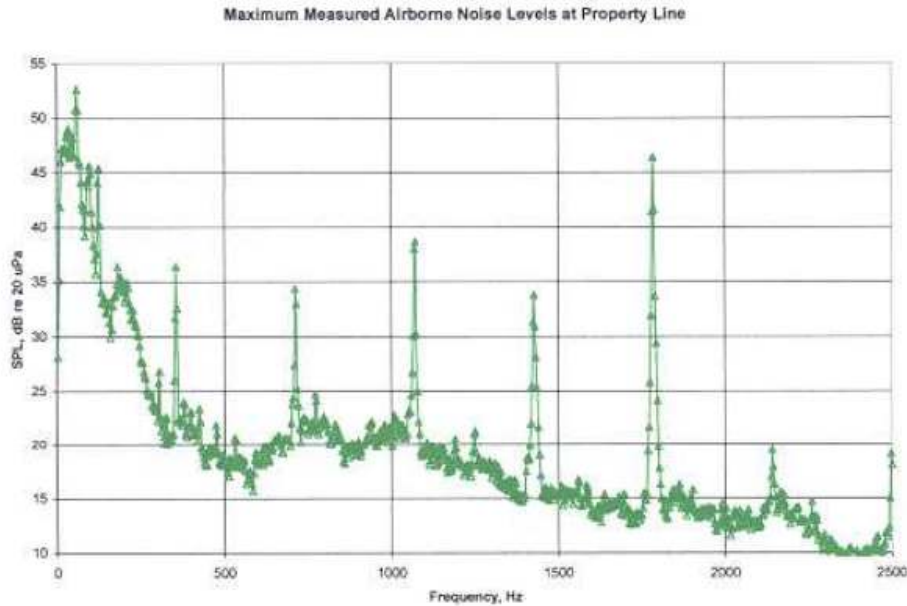
Common Spec Strategies on Noise Sensitive Projects

- Specify sound data for lowest rated model as equipment basis of design
- Specify all available OEM equipment low noise options
- Specify an equipment model that is not tonal
- Specify the same treatment used on the last noise sensitive project
- Retain an acoustical consultant to write the specification
- Specify base equipment and address any noise problems at start-up

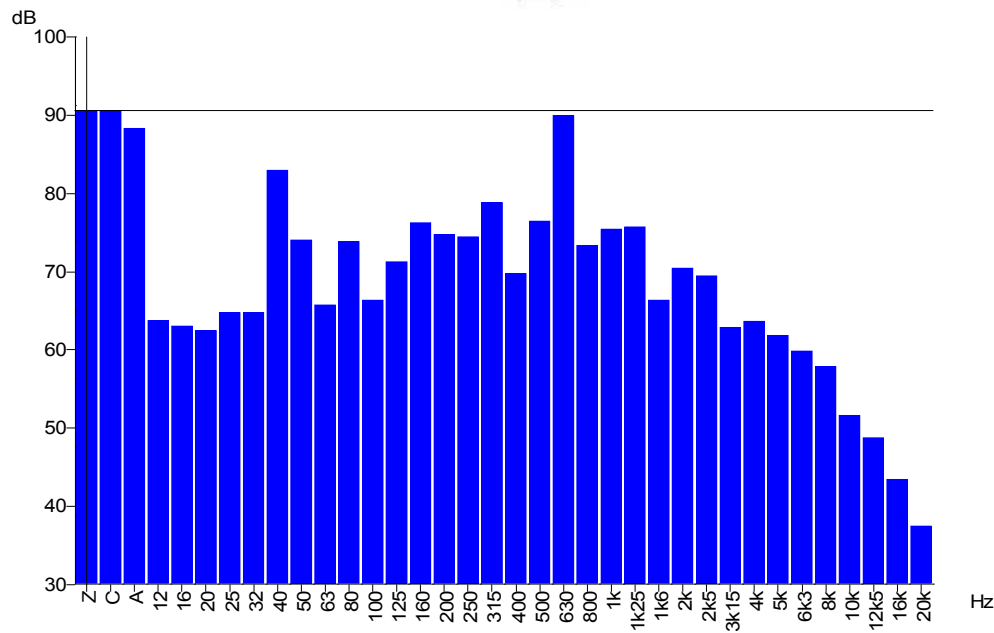


Common Specification Strategies:

- ❖ Specify an equipment model that is not tonal



Screw Chiller Sound Pressure Levels



Scroll Chiller Sound Pressure Levels

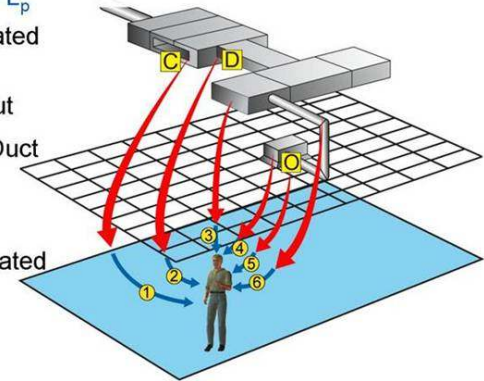


Best Practices Acoustic Design

- Answer 4 design questions
 1. Where are we now?
 2. Where do we need to be?
 3. What needs to be done to get there?
 4. How much will that cost?
- Use 3-5 dBA safety factor
- Cursory review on every project, in depth review when warranted
- Assess site ambient noise levels
- Evaluate airborne and structure-borne transmission
- System problems require system solutions

Sound Pressure L_p

- ① Casing Radiated and Inlet
- ② Duct Breakout
- ③ Distribution Duct Breakout
- ④ Discharge
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Best Practices Specifications

- Job specific combined design/performance specs preferred over generic performance specs
- Evaluate project specific objective and subjective criteria
 - Indoor criteria: NC, RC, NCB, RC Mark II
 - Outdoor criteria: Zoning and ordinance criteria
- Place in Division 15/23 with equipment
- Specify single source for system acoustic performance
- Specify turnkey where installation critical
- Require submission for approval as “or equal” 10 days before bid date



**Have a
noise-free
day!**