ACOUSTICS BASICS FOR HVAC&R DESIGNERS

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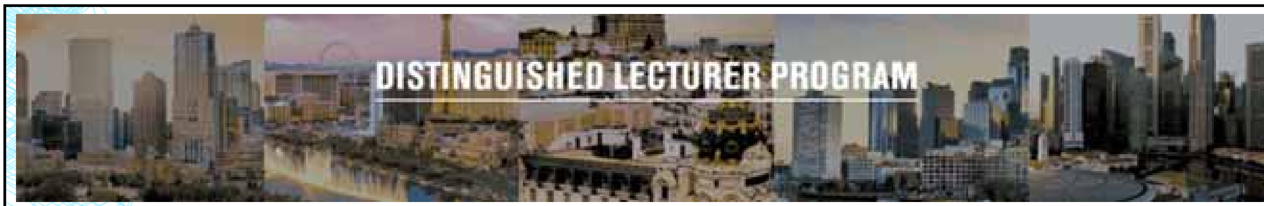

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- Chapter Student Activities
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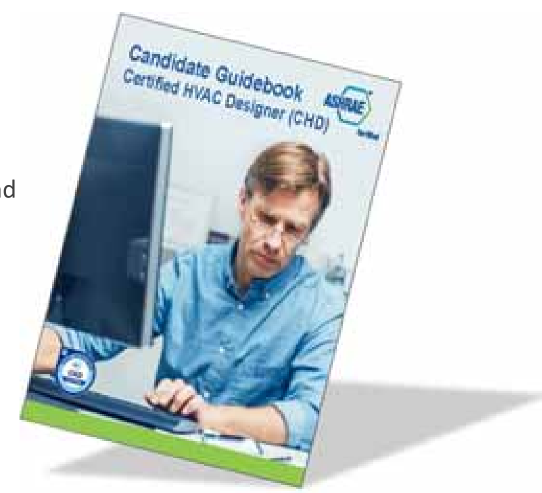
CERTIFIED HVAC DESIGNER (CHD)

For those industry professional who are:

1. Developing HVAC plans for permit and construction
2. Determining building/project HVAC requirements
3. Selecting HVAC equipment and systems to meet building/project requirements



LEARNING OBJECTIVES

1. What is sound is and how the ear and brain interpret sound?
2. What are sound criteria and how are they used in design?
3. How is sound measured?
4. How do we design for a sound level?
5. How is sound and vibration related?

INTENT OF HVAC&R ACOUSTIC DESIGN

- To Develop HVAC Systems that produce noise levels that are judged to be non-objectionable to the majority of occupants.
- This does not mean that they must be too quiet since HVAC noise is many times desirable to mask other objectionable noise.
- At an appropriate level to mask other noises yet low enough not to interfere with speech or other activities in the space.
- Absence of perceptible tones, or level variance in time.
- Of a neutral spectra approximated by NC or RC curves.
- ***What is objectionable is very subjective!***

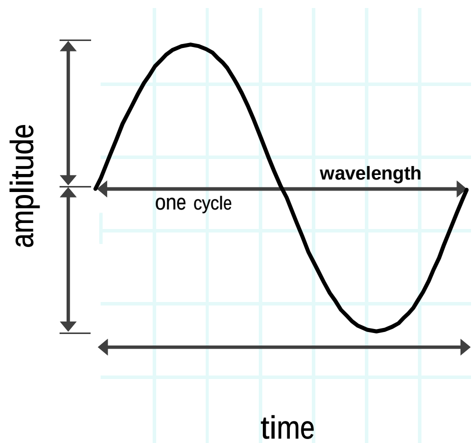
WHAT IS SOUND AND HOW WE HEAR

SOUND & NOISE

Sound ***- The oscillatory motion of air molecules that causes the eardrum to move***

Noise ***- Sound that causes a psychological reaction, usually negative.***

WHAT IS SOUND?



- Audible emissions resulting from vibration of molecules within an elastic medium

$$\text{frequency, Hz} = \frac{\text{cycles}}{\text{seconds}}$$

$$\text{wavelength} = \frac{\text{speed of sound}}{\text{frequency}}$$

- **All** sound levels are expressed in dB or decibels

$$dB = 10 \bullet \log_{10}\left[\frac{\text{Measure}}{\text{Reference}}\right]$$

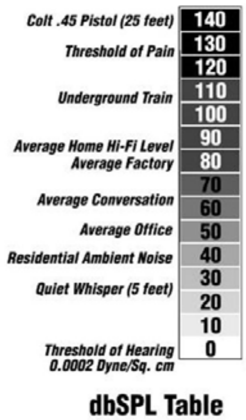
- Decibels are 10 times the logarithmic ratio to a reference value

SOUND POWER VS. SOUND INTENSITY VS. SOUND PRESSURE

- There are 3 basic measures of acoustics:
  - **Sound Pressure** referenced to 10^{-12} Pascal
  - **Sound Power** referenced to 10^{-12} Watts
  - **Sound Intensity** referenced to 10^{-12} Watts/Meter^2

All are expressed in dB (Logarithms)

SOUND PRESSURE (L_P) – OCCUPIED SPACES



- Sound Pressure is what you hear and what a microphone measures
- Sound Pressure is <u>dependent</u> on position and the surrounding environment
- Sound Criteria (RC, NC, dBA) are always given in sound pressure

SOUND POWER (L_W) EQUIPMENT RATINGS

- Sound Power is the measure of how much sound is generated at the source
- Sound Power is <u>not dependent</u> on position or the surrounding environment
- Sound Power is <u>always</u> greater than Sound Pressure and would be approximately equal to the Sound Pressure at the center of a point source sound generator

SOUND INTENSITY (L_i)

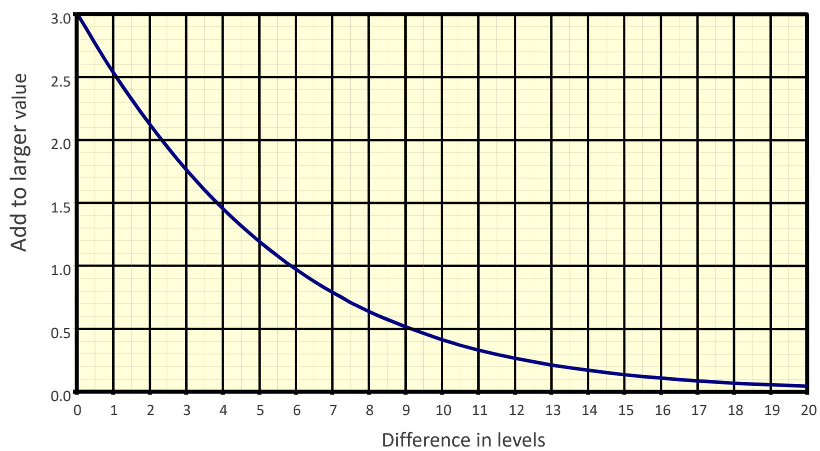
- Sound Intensity is a measure of sound flow or flux (dB Watts/m^2)
- Sound Intensity has both amplitude and direction
- For plane waves the Sound Intensity amplitude equals the sound pressure

COMBINING MULTIPLE SOUND LEVELS

$$\mathrm{dB}_{\mathrm{Added}} = 10 \bullet \log_{10}\left[10^{\left(\frac{dB_1}{10}\right)} + 10^{\left(\frac{dB_2}{10}\right)} \ldots 10^{\left(\frac{dB_N}{10}\right)}\right]$$

- If the levels are the same or within 1dB then it add 3dB
- If the levels are within 2 to 4dB then add 2dB to the larger level
- if the levels are within 5 to 9dB add 1dB to the larger level
- if the level is 10 dB or more different, it will not have a significant effect.

LOGARITHMIC ADDITION



FREQUENCY

The rate at which something vibrates back-and-forth – air, sheet metal, cast-iron, drywall, concrete, eardrums, etc.

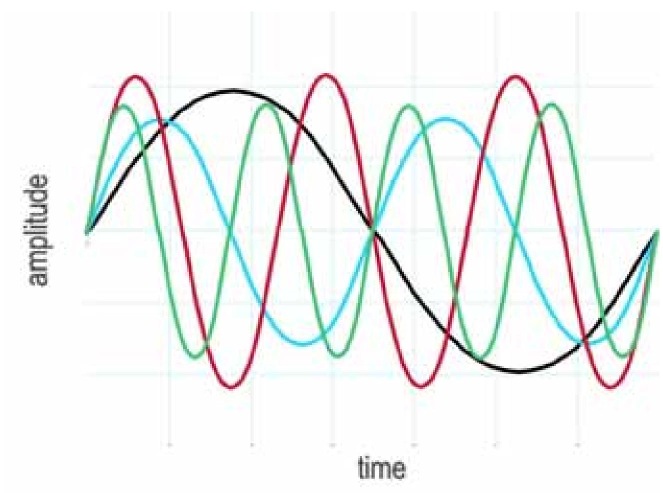
Sound is audible when the frequency rate is between about 20 and 20,000 times per second, expressed in Hertz (Hz or cps)

DISTRIBUTION OF FREQUENCIES , QUALITY OF SOUND, OR FREQUECY SPECTRUM

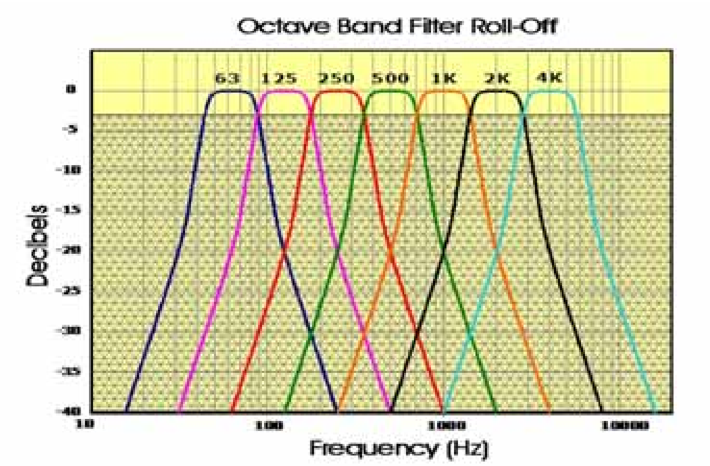
<u>Broadband</u>	***<u>Tonal</u>***
Rain	***Hum***
Wind	***Buzz***
Shhh	***Whine***
Hiss	***Whistle***

Rumble

BROADBAND SOUND AS MEASURED IN OCTAVES



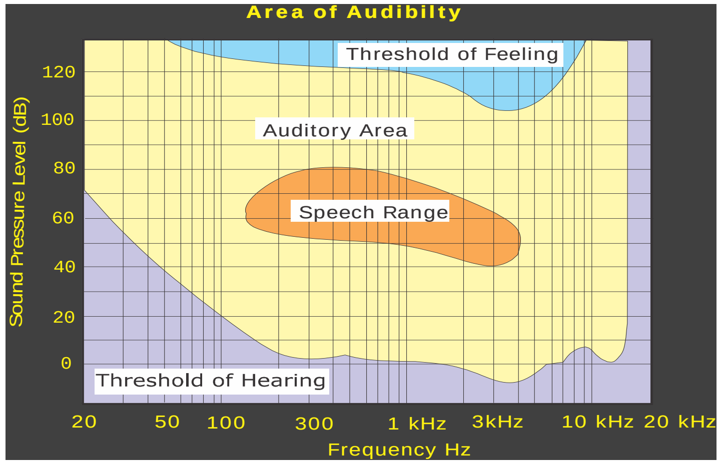
OCTAVE BAND FILTERS



BROAD BAND OCTAVE BANDS

octave band	center frequency (Hz)	frequency range (Hz)
1	63	45 to 90
2	125	90 to 180
3	250	180 to 355
4	500	355 to 710
5	1,000	710 to 1,400
6	2,000	1,400 to 2,800
7	4,000	2,800 to 5,600
8	8,000	5,600 to 11,200

HEARING RESPONSE

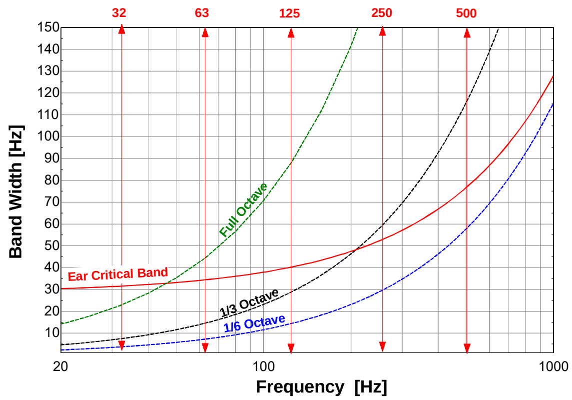


HUMAN SENSITIVITY TO LEVEL DIFFERENCE

Psychoacoustic Response	***Octave Band***		
	63	***125***	***250+***
Just Noticeable Difference	*1 dB*	*1.5 dB*	*2 dB*
Significantly Different	*3 dB*	*4 dB*	*5 dB*
Twice/Half as Loud	*6 dB*	*8 dB*	*10 dB*

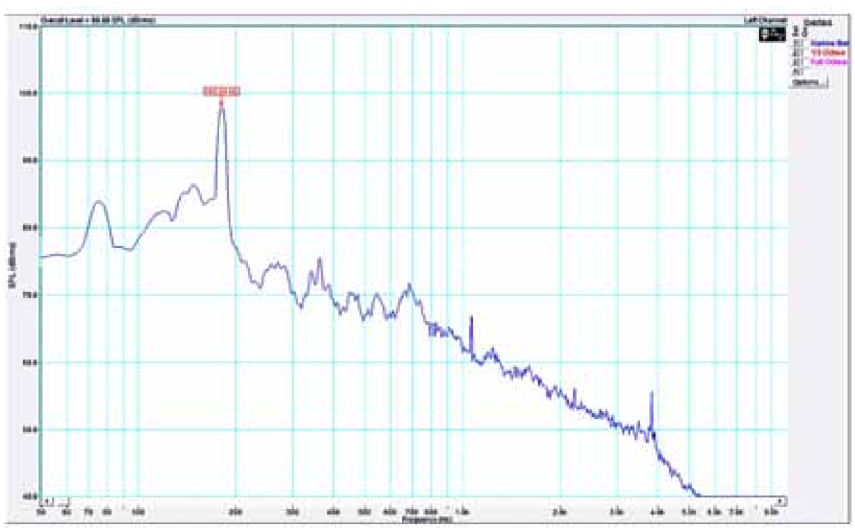
Fractions of a dB are not perceptible and do not matter

PURE TONE CRITICAL BAND FILTERING IN HUMAN HEARING



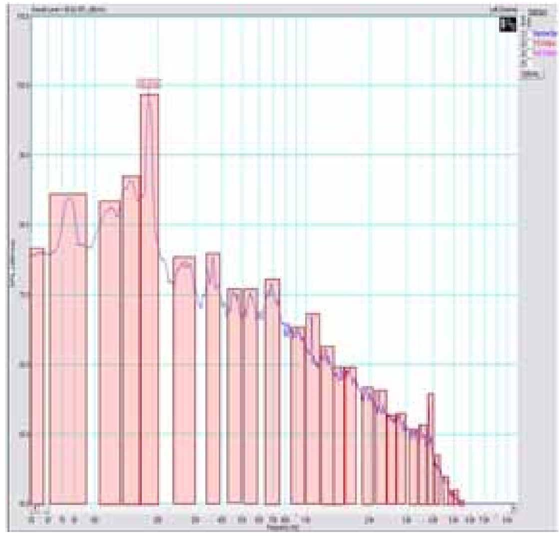
- The human ear functions as a dynamic band pass filter.
- Only one tone can be distinguished within a critical band.
- At mid frequencies the critical band width is close to the $\frac{1}{3}$ octave band.

PURE TONES MEASURED WITH FFT METHOD



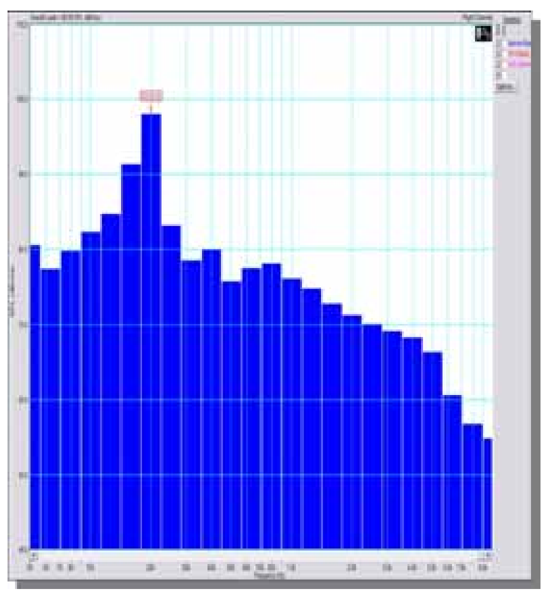
HUMAN EAR PERCEPTION

- Tones are generally perceptible when they are 5-6 dB above the average of the adjacent critical bands.
- Many find any perceptible tone objectionable.
- This fact lead to MP3 encoding of music to make smaller files.



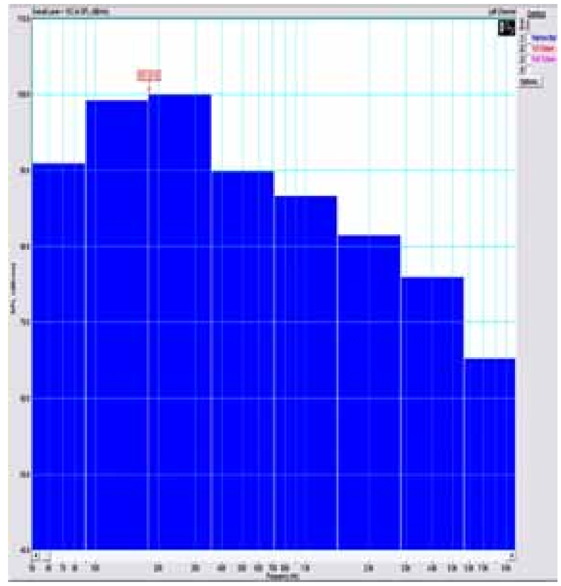
TONE WITH 1/3 OCTAVES

- If the tone is close to the center of a 1/3 octave band, at frequencies below 500 Hz, then the meter does a credible job of recording tones that will be close to perception.



TONE WITH FULL OCTAVE BAND

- With full octave measurements, much information can be lost depending on where the tone occurs.



HEARING TEST VIDEO

https://vimeo.com/466148301

WHY DO WE SPECIFY SOUND

- Meet local codes
- Meet specified design requirement
- Create a comfortable environment for the occupants

NOISE CRITERIA SYSTEMS

- dB A, B and C
- NC and NCB
- RC and RCM-II

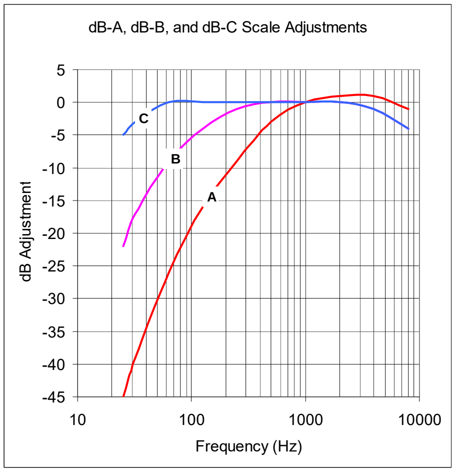
OUTDOOR LOCAL CODES

- Most local codes involve noise transmitted to the property line.
- They are generally a very simplified representation of overall noise levels that can be measured with low cost meter and easily interpreted by local building inspectors.
- Most are given as **dBA** levels.

MEETING INDOOR DESIGN REQUIREMENT

- ASHRAE and others “Recommend” various sound levels for different indoor type spaces.
- These levels are usually represented as single number criteria levels to be met.
- The ASHRAE Handbooks give criteria as values of NC or RC.

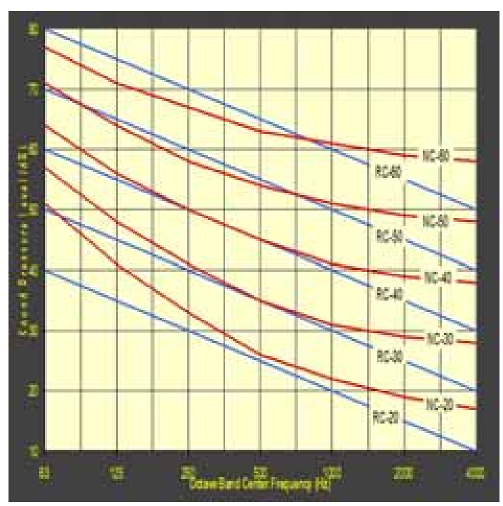
DB-A DEFINED



- A-weighting began with work by Fletcher and Munson which resulted in their publication, in 1933, of a set of equal-loudness contours.
- **dB-A** is a simple weighting filter applied to the sound spectrum.
- It was developed to approximate the level vs. frequency response of the human ear.
- There are also **dB-B** and **dB-C** filter used for louder industrial sound applications.

NC & RC BALANCED SPECTRUM

- **NC** by Leo Beranek of BBN (1957) and is the most common octave design criteria. It is derived by the peak tangent of the spectrum to the NC cures.
- **RC** by Warran Blazer developed RC for ASHRAE (1981) to better represent spectra in indoor spaces. This rating is uses the arithmetic average of the 500 through 2K to set the level. RC also uses (N) for neutral, (LF) for low frequency rumble and (HF) for high frequency hiss.



ASHRAE TYPICAL ROOM SOUND LEVELS

Occupancy	NC/RC Curve
Private Residences	25-30 (N)
Apartments	30-35 (N)
Hotels/Motels	
Individual rooms or suites	30-35 (N)
Meeting/banquet rooms	30-35 (N)
Halls, corridors, lobbies	35-40 (N)
Service/support areas	40-45 (N)
Offices	
Executive	25-30 (N)
Conference rooms	25-30 (N)
Private	30-35 (N)
Open-plan areas	35-40 (N)
Business machines/computers	40-45 (N)
Public circulations	40-45 (N)
Hospitals and Clinics	
Private rooms	25-30 (N)
Wards	30-35 (N)
Operating rooms	25-30 (N)
Laboratories	35-40 (N)
Corridors	30-35 (N)
Public areas	35-40 (N)

Occupancy	NC/RC Curve
Churches	30-35 (N)
Schools	
Lecture and classrooms	25-30 (N)
Open-plan classrooms	35-40 (N)
Libraries	35-40 (N)
Courtrooms	35-40 (N)
Legitimate theaters	20-25 (N)
Movie theaters	30-35 (N)
Restaurants	40-45 (N)
Concert and recital halls	15-20 (N)
Recording studios	15-20 (N)
TV studios	20-25 (N)

With-

- ***No audible tones***
- ***No audible level fluctuations in time***

SOUND CRITERIA

https://vimeo.com/466149395

SOUND MEASUREMENT

FREE FIELD MEASUREMENTS

- ARI Standard 370 - Sound Rating of Large Outdoor Refrigeration and Air Conditioning Equipment
- ANSI S12.34 – Engineering Methods for the Determination of Sound Power for Essentially Free-Field Conditions Over a Reflective Plane.

ANECHOIC ROOM MEASUREMENT

- Determined by placing a microphone a know distance from the source.
- ANSI S12.35 - Determination of Sound Power Levels of Noise Sources in Anechoic Hemi-Anechoic Rooms.
- Limited ability to measure low frequencies.

SOUND INTENSITY MEASUREMENT

- ANSI S12.12 - Engineering Method for the Determination of Sound Power Levels of Noise Sources Using Sound Intensity.
- ISO 9614 - Determination of Sound Power Levels of Noise Sources Using Sound Intensity.
- Low frequency is an issue if in reflective space.

REVERBERANT ROOM MEASUREMENT

- AMCA 300 - Reverberant Room Method for Sound Testing of Fans
- ARI Standard 260 - Sound Rating of Ducted Air Moving and Conditioning Equipment
- ANSI S12.31 - Precision Method for the Determination of Sound Levels of Broad Band Noise Sources in Reverberation Rooms.
- ANSI S12.32 - Precision Method for the Determination of Sound Levels of Discrete Frequency and Narrow Band Noise Sources in Reverberation Rooms.
- Best method for low frequency Sound Power. Does not give directionality of sound.

REVERBERANT ROOM METHOD

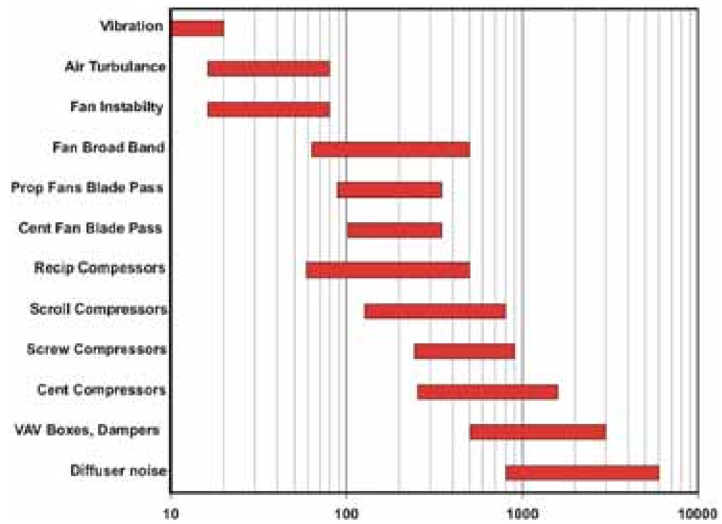
1. Measure sound pressure in the reverberant room with a reference sound source (RSS) running
2. Calculate the difference between the know sound power of the RSS and the measured sound pressure (Room Effect)
3. Measure the sound pressure of the device under test
4. Apply the Room Effect to the measured sound pressure to obtain sound power

HOW GOOD IS THE DATA YOU GET?

- AMCA 303 “Applications of Sound Power Level Ratings” states:
  - Differences of sound power levels of 2 dB or less are not significant.
  - When comparing between different manufacturers, it is good practice to disregard differences of less than 4 dB.
  - In the 63 Hz octave band differences of 6 dB or less should be disregarded.
- AMCA, AHRI, and ANSI requires all rooms used for reverberant testing be fully qualified for broad-band measurements.
- AMCA states that lack of pure tone qualification can add +/- 8 dB uncertainty in the 1/3 band containing the blade pass frequency.

FAN AND EQUIPMENT SOUND

HVAC EQUIPMENT NOISE FREQUENCY



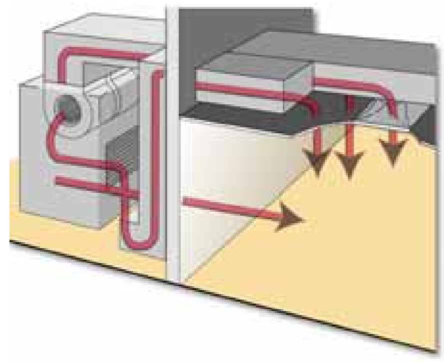
SOUND TRANSMISSION TYPES

Airborne
The sound source has no structural connection to the receiver.

Structure-borne
The sound source has 1 or more structural connections to the receiver.

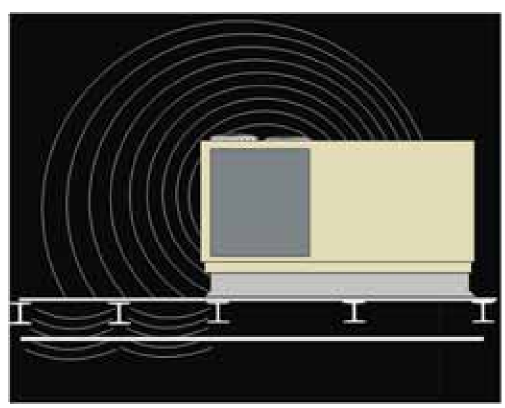
FACTORS CONSIDERED TO MEET CRITERIA

- To achieve desired levels, all parts of the HVAC system must be considered including both source and transmission paths:
  - Through Building Structure
  - Through Ductwork
  - Transmission Generated Noise (Damper, Elbows, VAV Boxes, Diffusers,…)
  - Room Absorption And Reverberation
  - Occupied Areas Of Rooms

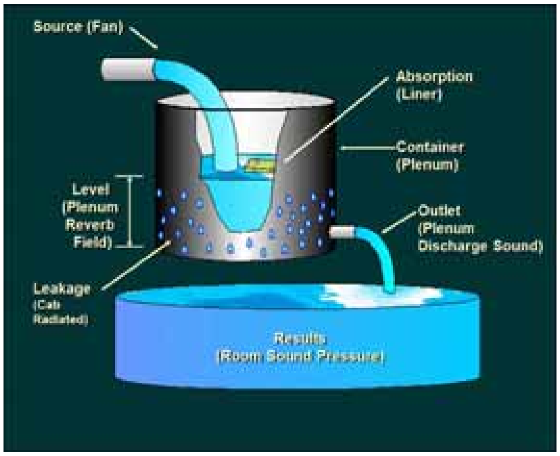


FLANKING PATH

- Light weight roofs also cause problems by allowing radiated sound to be transmitted through the adjacent roof and structure into the space



ENCLOSED SPACE SOUND - WATER ANALOGY

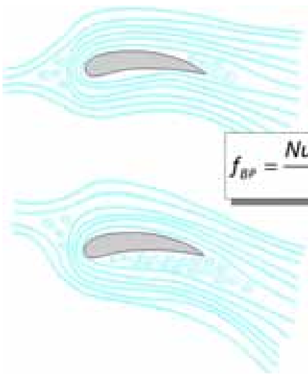


When sound power enters an enclosed area, the sound pressure will build up until the power exiting the enclosed area is the original power less what radiates out the walls and less the sound power absorbed (turned into heat) within the enclosed area.

The result of this process we call attenuation.

BLADE PASS TONE INTENSITY

- Optimum performance is obtained when the flow is "attached" to the blade as much as possible. This minimizes the tone produced.
- As flow, pressures and RPM change, then the blade is no longer at it's optimum pitch angle. More turbulence is generated and thus more noise. Much of this noise is produced at the blade pass tone.
- Any flow disturbance, especially at the inlet to the fan, will increase flow separation and blade pass tone.



$$f_{BP} = \frac{NumberBlades \bullet RPM}{60}$$

SOUND "FAN LAWS"
EFFECTS OF SP AND CFM CHANGES

- Fan Sound is related to the air flow and static pressure requirements.

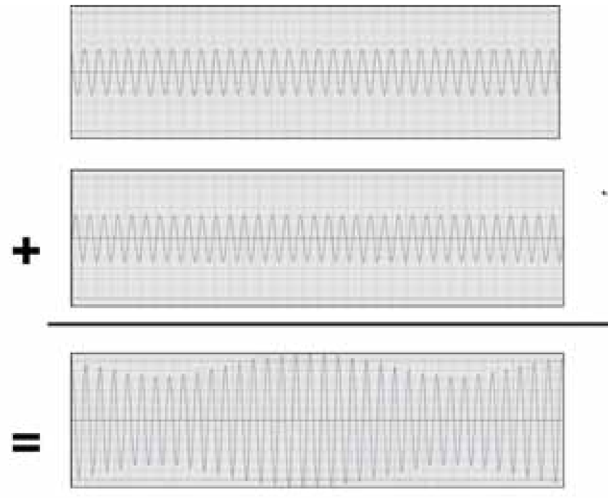
$$Sound\_Power \propto 10Log_{10}(CFM) + 20Log_{10}(SP)$$

- Air flow is set by the building sensible load but the static pressure required can be minimized by careful selection of system components.
- Applies best to fans operating along a system curve.

COMPRESSORS AND CONDENSER FANS

- Condenser fans are usually louder than compressors.
- Multiple belt drive fans are subject to phasing. Direct drive are less susceptible.
- A common VFD on all condenser fans is the best method of head pressure control and is the quietest in operation.

MULTI FAN TONE PHASING



$$f_{phase} = \frac{1}{f_2 - f_1}$$

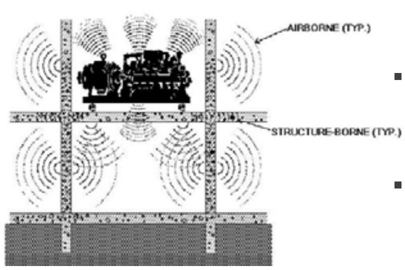
MAXIMUM DUCT VELOCITIES (FEET PER MINUTE)

NC or RC	*Square No Vanes*	*Radius No Vanes*	*Square Short Vanes*	*Square Long Vanes*	*Radius with Vanes*
50+	*2000*	*2500*	*2500*	*2800*	*3000*
45	*1600*	*2000*	*2000*	*2400*	*2600*
40	*1300*	*1700*	*1700*	*2200*	*2300*
35	*1000*	*1300*	*1300*	*1700*	*1900*
30	*800*	*1000*	*1000*	*1200*	*1400*
25	*600*	*800*	*800*	*1000*	*1200*
20-	*---*	*500*	*500*	*600*	*600*

REAL WORLD SOUNDS

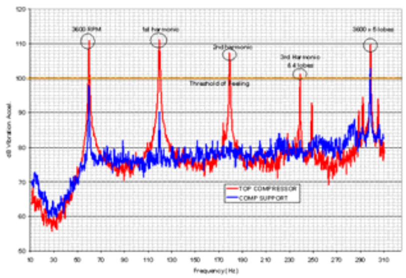
https://vimeo.com/466150462

SOUND & VIBRATION



- Sound Can Induce Vibration in the Building Structure and Vibration Can Induce Sound in the Occupied Space
- At Low Frequencies (Below 60 Hz) It Is Sometimes Difficult to Distinguish Between What Is Felt As Vibration and What Is Heard As Sound
- Sources of Vibration in HVAC Equipment
  - Fans
    - Fan RPM
    - Motor RPM
    - Belt RPM
    - Blade Pass Frequency (No. Of Blades Times Fan RPM)
  - Compressors
    - Motor RPM
    - No. Cylinders or Lobes Time Motor RPM

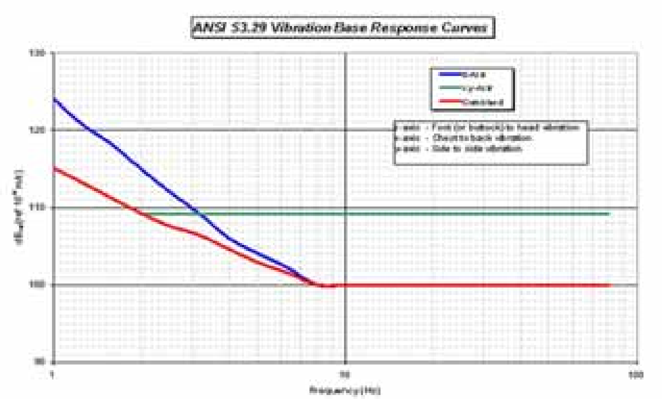
VIBRATION MEASUREMENTS



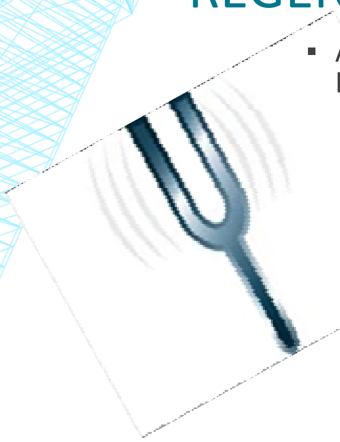
- Velocity (in/sec, m/sec)
  - Used by most equipment manufacturers and balancers
  - Filter in Implies an RMS Velocity Narrow Band Reading at the Rotating Frequency and Filter out Implies the Total RMS Velocity
  - Express in dB **Peak to Peak** when used by vibration and acoustics consultants
  - Decibels re: 10^{-9} m/sec for building acoustics
  - Decibels re: 10^{-8} m/sec for automotive applications
- Displacement (mils, mm)
  - An older system seldom used
- Specific Unbalance (oz-in, G-W/N)
  - Used by fan wheel manufactures
- Acceleration (G, in/sec2, mm/sec2)
  - Used in seismic calculations

VIBRATION CRITERIA

- Balance criteria is set for maintaining machine life
- Vibration criteria is set to avoid regenerated sound and for human comfort



AVOIDANCE OF VIBRATION REGENERATED SOUND



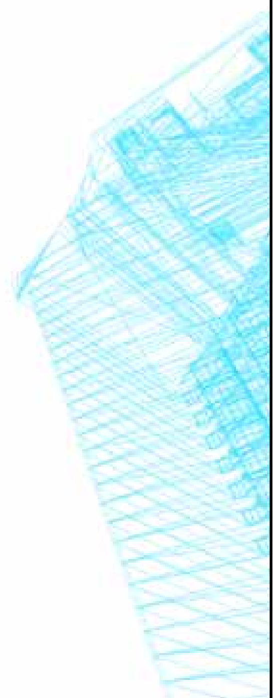
- ASHRAE Applications Handbook – Vibration Isolator Selection for Packaged Rooftop Equipment.
  - If additional roof deflection (due to weight of equipment) is under 0.25" then the isolators shall deflect 15 time more than this additional deflection.
  - If the additional roof deflection is greater than 0.25" then additional roof support is required.
  - For large equipment capable of generating substantial vibration and structure bone noise, increase isolator deflection so isolator stiffness is at least 0.10 times the floor stiffness.
  - An approximation for dB vibration (re 10-9 m/sec^2) conversion to dB of sound pressure in a space (assums the vibrating surface is an infinite plane in all directions) is:

$$L_P = L_V - 34$$

MY MOST COMMON FIELD PROBLEMS

- Vibration induced sound
  - From inadequate roof support structure
  - From isolators that need adjusting
- Pure Tones from fan blade pass frequency (includes phasing)
- Duct break out and turbulence from rectangular duct
- Flanking path noise
- Forgetting we are designing for people. Criteria and octave bands are only tools to get there.

QUESTIONS?



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