Noise Control

Noise and Annoyance

Any sound that is annoying, distracting or unwanted is commonly referred to as noise.

- Persons are usually not annoyed by noise originating from their own activities.
- Persons are often greatly annoyed by noise originating from the apparently unnecessary activities of others.
- Annoyance is a function of:
  1. Sound pressure level (SPL).
  2. Frequency spectrum.
  3. Individual tolerance level.
  4. State of mind.
- Unexpected and impulsive sounds may increase the pulse rate and cause involuntary muscular contractions.
- Individuals vary greatly in their tolerance, conditioning ability and reaction to noise.

Copyright © 2003

Noise Control

Noise and Legislation

**Health is a state of complete physical, mental and social well-being, and not merely an absence of disease and infirmity.
(World Health Organization)**

- Noise can be a health hazard even when there is no risk of hearing damage.
- Government legislation is normally based on the control of maximum noise levels.
- Noise legislation varies from country to country and from state to state in the US.
- Generally legislation is aimed at preventing exposure to prolonged noise levels above 85 dBA in the external environment.
- Legislation requires hearing protectors to be worn by persons exposed to high noise levels in their working environment.

Copyright © 2003

Noise Control

Typical Legislated Maximum Noise Levels

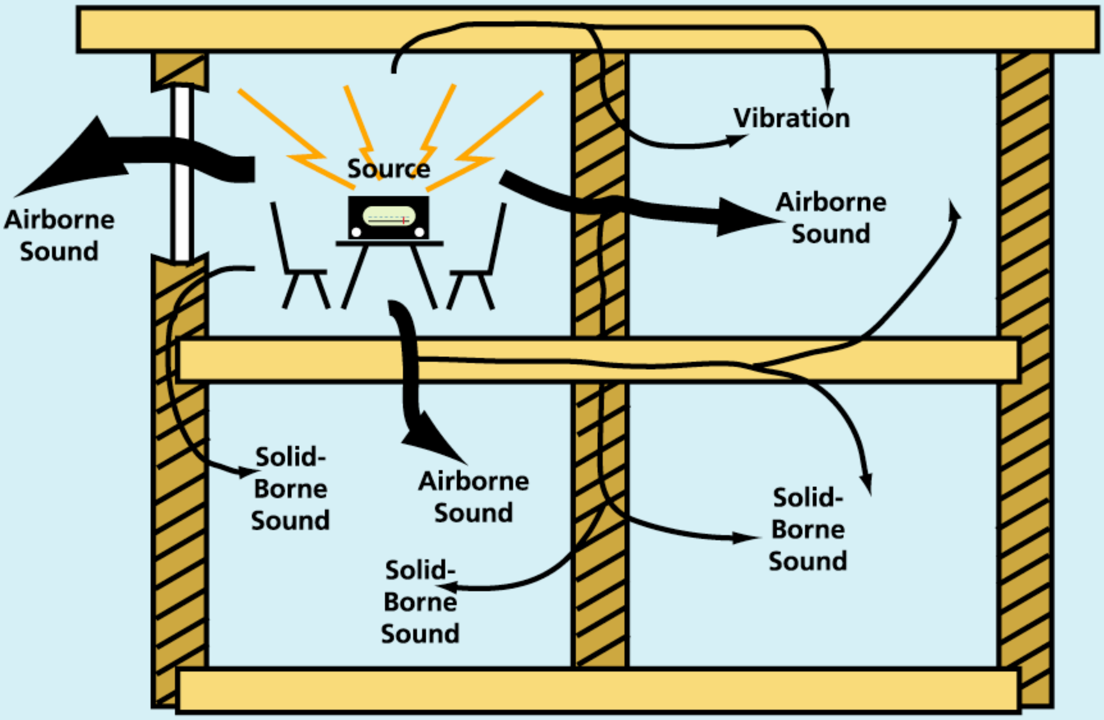
Type of External Noise Source	Maximum SPL	Distance from Source	US State or Country
Diesel-powered tractors, trucks and buses.	95 dBA	25 FT	California
Motorcycles.	90 dBA	25 FT	California
Regular passenger cars and sports vehicles.	85 dBA	25 FT	California
All vehicles travelling at more than 35 mph.	94 dBA	25 FT	New York
All new vehicles with more than two wheels.	85 dBA	17 FT	England
New motorcycles and other mechanically propelled two-wheeled vehicles.	90 dBA	17 FT	England

Copyright © 2003

Noise Control

Noise Transmission in Buildings

Most of the noise in buildings is due to airborne sound such as speech, music, fans, motors, aircraft, and automobiles.



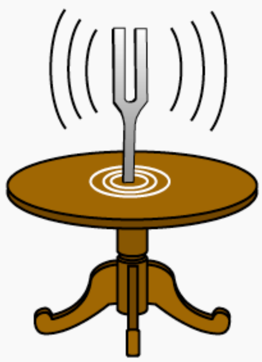
Solid-borne sound is produced by sources that act directly on the structure of a building such as footsteps, banging of doors, and traffic noise transmitted through the footings of the building.

Copyright © 2003

Noise Control

Airborne Sound: Natural Amplification

An airborne sound source may be amplified when it sets a solid element into vibration.



Tuning fork is much louder when placed on a table, which vibrates in unison with the tuning fork.

The sound produced by a guitar is greatly magnified by the wooden body acting as a sounding board.

Explanation:

The amplification occurs because of the efficient conversion of vibrational energy into sound energy, if the dimensions of the vibrating element are at least of the same order of magnitude as the wavelength of the sound.

(A tuning fork and a guitar string are much smaller than the wavelength of the sound they produce. Therefore, the addition of the table or the wooden body of the guitar amplifies the sound through their larger size.)

Copyright © 2003

Noise Control

Airborne Sound: Theoretical Mass Law

A single-leaf panel (i.e., composed of only one material) subjected to sound vibration behaves as if it is composed of many interconnected parts that oscillate independently. The Transmission Loss (TL) of such an idealized panel obeys the Mass Law.

According to the Mass Law the Transmission Loss (TL) of a single-leaf panel is given by:

$$TL = 20\log_{10}\left[\,(\text{frequency}) \times (\text{density}) \times (\text{thickness})\,\right] - C \quad (\text{dB})$$

(where 'C' is a constant and equal to '33' if 'density' is in LB/CF and 'thickness' is in FT; or '47' if 'density' is in kg/m³ and 'thickness' is in m.)

Example:

What is the theoretical TL of an 8 inch thick concrete panel at a frequency of 500 cps, if the density of concrete is 150 LB/CF?

$$TL_{500} = 20\log_{10}\left[\,(500) \times (150) \times (8/12)\,\right] - 33 = 61 \text{ dB}$$

Copyright © 2003

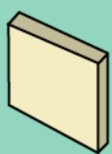
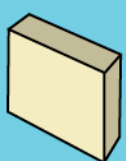
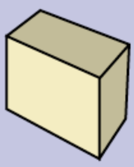
Noise Control

Airborne Sound: Impact of Panel Thickness

For an idealized single-leaf panel doubling of the thickness of the panel will increase the TL value by 6 dB.

TL = $20\log_{10}$ [(frequency) x (density) x (thickness)] - 33 (dB)

For a concrete panel with a density of 150 LB/CF and a sound frequency of 1,000 cps:

Concrete Panel	Thickness	Frequency	Transmission Loss Calculation	TL
 (25 LB/SF)	2 in.	1,000 cps	$20\log_{10}$ (1000 x 150 x 2/12) - 33	55 dB
 (50 LB/SF)	4 in.	1,000 cps	$20\log_{10}$ (1000 x 150 x 4/12) - 33	61 dB
 (75 LB/SF)	6 in.	1,000 cps	$20\log_{10}$ (1000 x 150 x 6/12) - 33	65 dB

Copyright © 2003

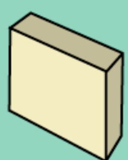
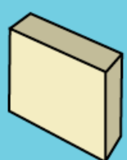
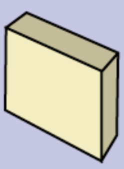
Noise Control

Airborne Sound: Impact of Frequency

For an idealized single-leaf panel doubling of the frequency of the sound will increase the TL value by 6 dB.

$$TL = 20\log_{10}\left[\,(\text{frequency}) \times (\text{density}) \times (\text{thickness})\,\right] - 33\ (\text{dB})$$

For a concrete panel with a density of 150 LB/CF and a thickness of 4 in.:

Concrete Panel	Thickness	Frequency	Transmission Loss Calculation	TL
 (50 LB/SF)	4 in.	500 cps	$20\log_{10}(500 \times 150 \times 4/12) - 33$	55 dB
 (50 LB/SF)	4 in.	1,000 cps	$20\log_{10}(1000 \times 150 \times 4/12) - 33$	61 dB
 (50 LB/SF)	4 in.	2,000 cps	$20\log_{10}(2000 \times 150 \times 4/12) - 33$	67 dB

Copyright © 2003

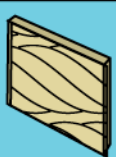
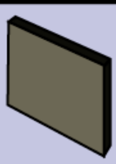
Noise Control

Airborne Sound: Impact of Panel Mass

For an idealized single-leaf panel doubling of the mass (i.e., density) of the panel will increase the TL value by 6 dB.

$$TL = 20\log_{10}\left[\text{(frequency)} \times \text{(density)} \times \text{(thickness)}\right] - 33 \text{ (dB)}$$

For a sound frequency of 4000 cps and three 1/2 in. thick panels made of corkboard (35 LB/CF), plywood (70 LB/CF) and gypsum (140 LB/CF).

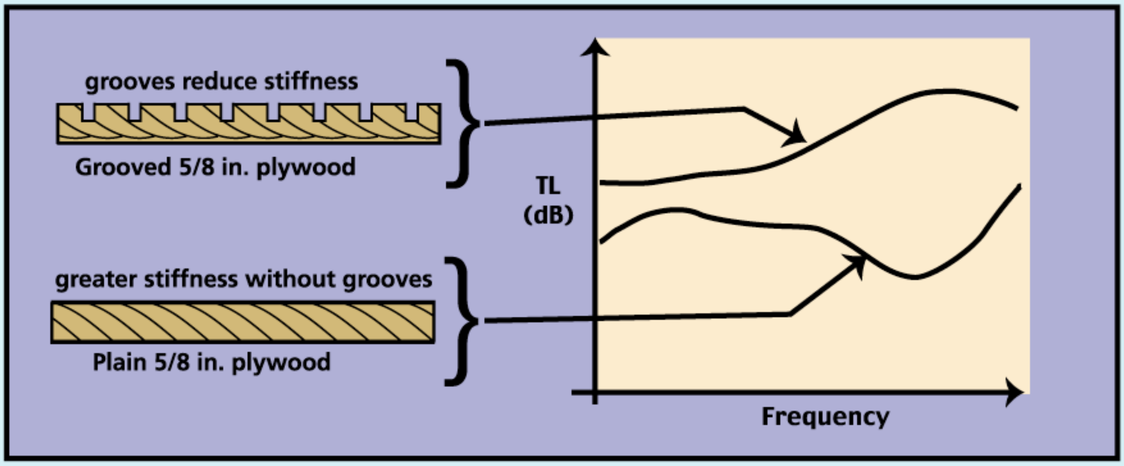
Panel Type	Thickness	Frequency	Transmission Loss Calculation	TL
 (1 LB/SF)	1/2 in.	4,000 cps	$20\log_{10}(4000 \times 35 \times 1/24) - 33$	42 dB
 (3 LB/SF)	1/2 in.	4,000 cps	$20\log_{10}(4000 \times 70 \times 1/24) - 33$	48 dB
 (6 LB/SF)	1/2 in.	4,000 cps	$20\log_{10}(4000 \times 140 \times 1/24) - 33$	54 dB

Copyright © 2003

Noise Control

Airborne Sound: Mass Law Limitations

The Mass Law assumes that the particles in a panel oscillate independently of each other (i.e., that the panel has no stiffness) similar to molecules in air. In fact, all solid materials have some stiffness, and the stiffer the panel the lower its TL.



In practice, the TL of a single-leaf panel is a function of:

- Mass (most important factor)
- Stiffness (elasticity of material)
- Damping (boundary conditions)
- Angle of incidence of the sound

Copyright © 2003

Noise Control

Airborne Sound: Mass Law in Practice

The theoretical TL value of 6 dB for each doubling of barrier thickness or sound frequency reduces to at least 5 dB in practice. This discrepancy is due mostly to the stiffness of the barrier.

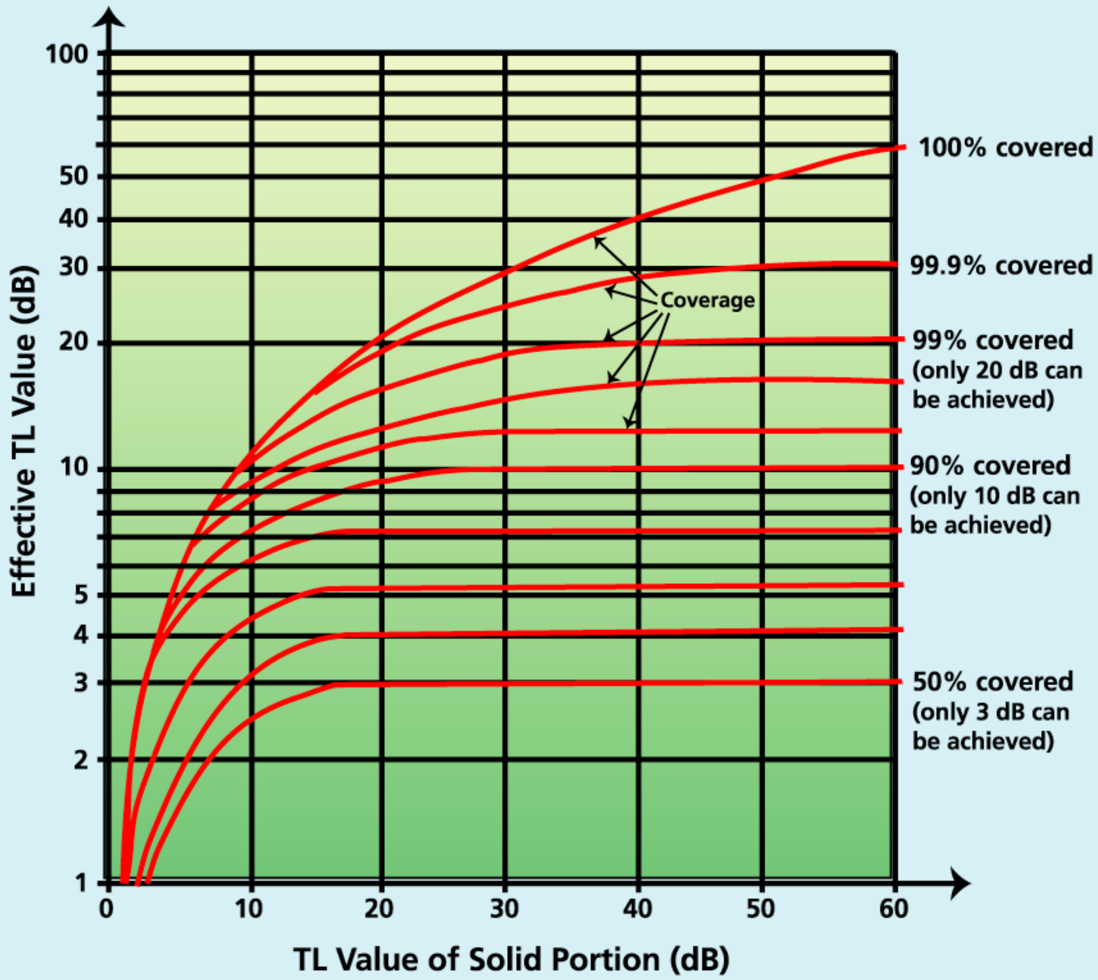
- Generally, the heavier a wall the more effective its sound insulation capabilities.
- Stiffness reduces the sound insulation capabilities of a barrier.
- Lead is the most effective sound insulation material because it is very heavy, and limp at the same time. (However, lead is so limp that it cannot support its own weight in most structural configurations.)
- The smallest air path such as a badly fitting door or even a key hole will transmit sound directly through a barrier.
- If a sound barrier has an acoustically 'weak' element then its overall TL value is closer to the TL of the weak element.

Copyright © 2003

Noise Control

Airborne Sound: Direct Air Paths

If a sound barrier contains more than 10% of openings then its overall sound insulation will be no more than 10 dB regardless of the TL value of the solid portion of the barrier.



Copyright © 2003

Noise Control

Airborne Sound: TL of Assemblies

When a sound barrier contains different components, such as windows and doors, then the effective TL value of the barrier is not directly proportional to the relative areas of the components (as would be the case for thermal insulation).

The effective sound insulation of a barrier consisting of two different components can be determined with a table that relates the difference in TL values of the two components to the percentage area of the smaller component.

Difference in TL Values	Area of Smaller Component as Percentage of Total Area							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
5	3.0	1.5	1.0	0.5	0.0	0.0	0.0	0.0
6	4.0	2.0	1.0	0.5	0.0	0.0	0.0	0.0
7	5.0	2.5	1.5	1.0	0.5	0.0	0.0	0.0
8	6.0	3.0	2.0	1.0	0.5	0.0	0.0	0.0
9	6.5	4.0	2.5	1.0	0.5	0.5	0.0	0.0
10	7.5	4.5	3.0	2.0	1.0	0.5	0.0	0.0
15	12.0	8.5	6.0	4.0	2.0	1.0	1.0	0.0
20	17.0	13.0	10.5	8.0	5.0	3.0	2.0	0.5
30	27.0	23.0	20.0	17.0	13.0	10.0	8.0	3.0
40	47.0	33.0	30.0	27.0	23.0	20.0	17.0	10.5

Reduction in TL Value of the Assembly (dB)

Copyright © 2003

Noise Control

Airborne Sound: Wall with Door

Example (1): Determine the overall TL value of a wall (10 FT high by 21 FT long) containing a door (7 FT high by 3 FT wide) if the TL of the wall portion is 45 dB and the door is 25 dB.

Step 1: Calculate the door area as a percentage of the total wall area:

door area = 7 x 3 = 21 SF
wall area = 10 x 21 = 210 SF
— door area = 10%

Step 2: Determine difference between TL values of wall and door:

$$TL_{wall} - TL_{door} = 45 - 25 = 20 \text{ dB}$$

Step 3: Look up reduction in wall TL value in table:

Difference in TL Values	Area of Smaller Component as Percentage of Total Area							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
15	12.0	8.5	6.0	4.0	2.0	1.0	1.0	0.0
20	17.0	13.0	10.5	8.0	5.0	3.0	2.0	0.5
30	27.0	23.0	20.0	17.0	13.0	10.0	8.0	3.0

Overall TL value of wall = 34.5 dB

Copyright © 2003

Noise Control

Airborne Sound: Poorly Fitting Door

Example (2): What would be the impact on the TL value of the wall if the door were to be poorly fitted with a 2 in. gap between the bottom edge of the door and the floor?

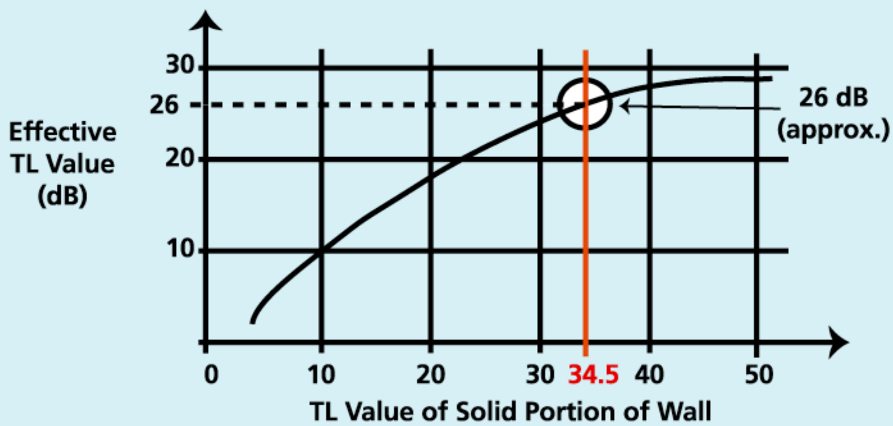
Step 1 : Calculate percentage of solid portion of wall (including door):

$$\text{air gap area} = \frac{2}{12} \times 3 = 0.5 \text{ SF}$$

$$\text{wall area} = 10 \times 21 = 210 \text{ SF}$$

$$\text{solid portion of wall} = \frac{209.5}{210} \times \frac{100}{1} = 99.7\%$$

Step 2 : Determine the effective TL value of wall from graph:



Effective TL value of wall = 26 dB (approx.)

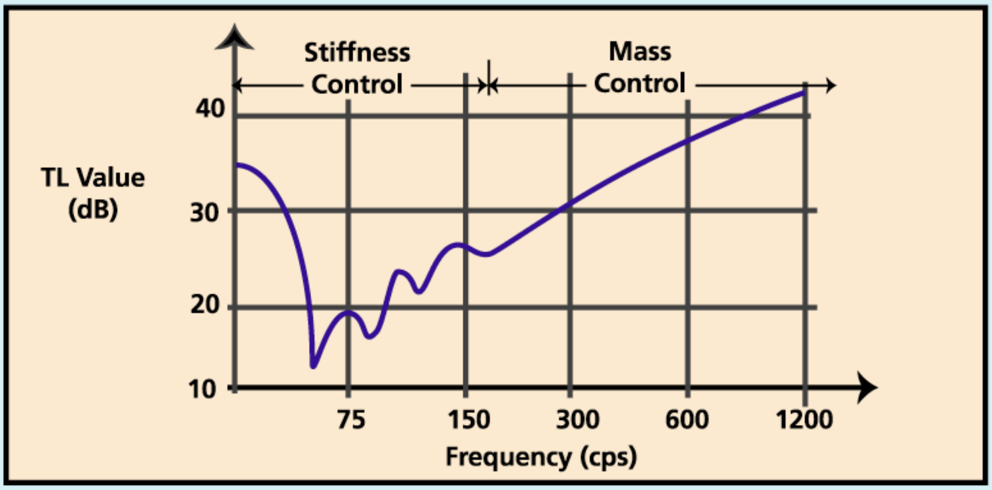
Copyright © 2003

Noise Control

Airborne Sound: Impact of Resonance

If a sound barrier is forced to vibrate at its natural frequency then the amplitude of the vibrations will be much larger and the TL value of the barrier will be greatly reduced.

- Resonance of building elements such as walls typically occurs at low frequencies.
- The greater the stiffness of the barrier the more sound is transmitted.



- Stiffness and mass of a sound barrier are opposed to each other, and tend to cancel each other out.

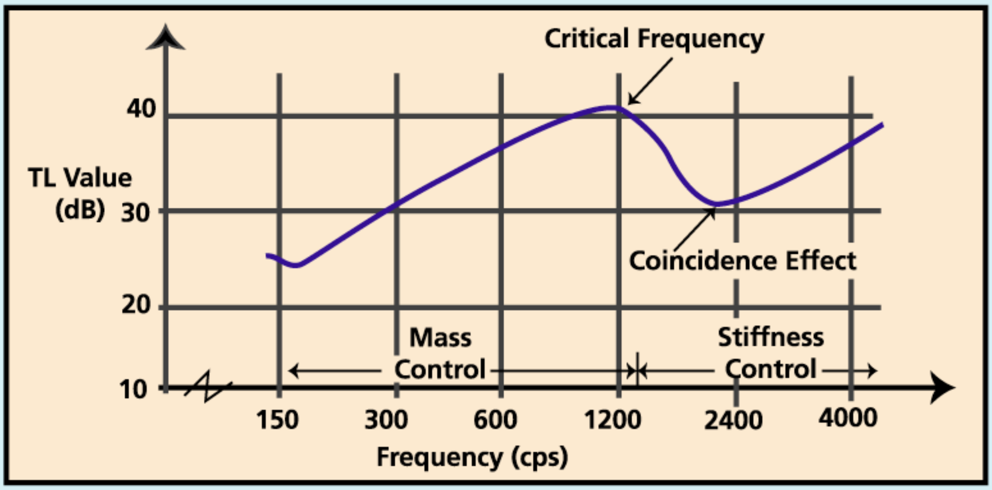
Copyright © 2003

Noise Control

Airborne Sound: Coincidence Effect (1/2)

At higher frequencies the bending waves induced by sound in a barrier may approach the velocity of sound and reduce the TL value of the barrier., This is known as the Coincidence Effect.

- The incidence of sound on the surface of a barrier will set the barrier in vibration, producing bending waves.
- The velocity of the bending waves increases with higher frequencies.
- At the Critical Frequency the velocity of the bending waves approaches the velocity of sound resulting in a more efficient transmission of sound through the barrier.



Copyright © 2003

Noise Control

Airborne Sound: Coincidence Effect (2/2)

The Critical Frequency may be moved beyond the frequency range of the transmitted sound by reducing the thickness of the barrier.

- The Critical Frequency of a sound barrier is a function of the density of the material, the modulus of elasticity, and the thickness. Therefore, for a given material:

$$\text{Critical Frequency} \propto \frac{1}{\text{Panel Thickness}}$$

- Typical Critical Frequencies of selected materials:

Type of Material	Thickness (inches)	Critical Frequency
concrete	8 in.	110 cps
brick	8 in.	115 cps
glass	1/8 in.	5,000 cps
plywood	1/2 in.	1,700 cps
gypsum	1/2 in.	2,500 cps
aluminum	1/8 in.	4,000 cps
lead	1/8 in.	17,000 cps

Copyright © 2003

Noise Control

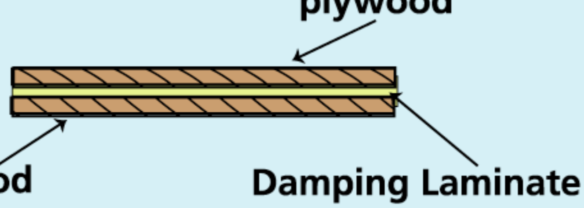
Airborne Sound: Single-Leaf Design Issues

Critical Frequency: Decreasing the thickness of a panel to increase the Critical Frequency will also reduce the TL value at the lower frequencies (i.e., in the 'mass control' region).

Thickness: In practice the Coincidence Effect is of concern only for relatively thin panels such as plywood, glass and gypsum panels.

Damping: Another way of reducing the Coincidence Effect is to increase the damping of a barrier by adding a viscoelastic layer (e.g., mastic, acrylic sheet, etc.).

e.g.,



Material: A new type of material with superior damping characteristics is loaded vinyl, which consists of a polymer mixed with a relatively heavyweight inorganic material such as barium sulfate or calcium carbonate.

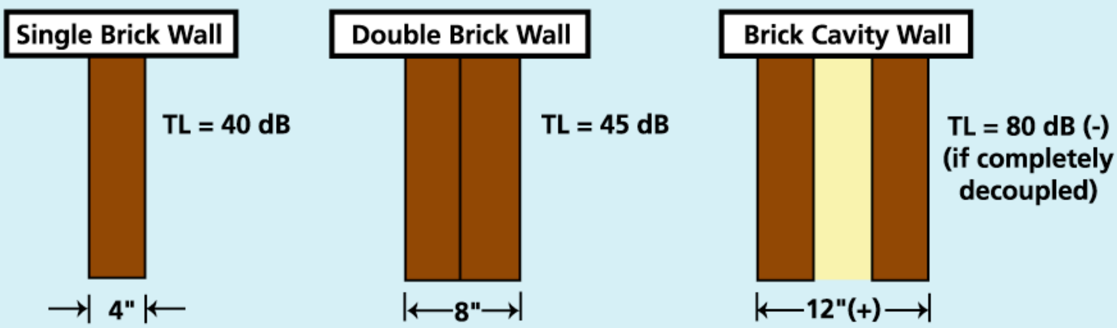
Copyright © 2003

Noise Control

Airborne Sound: Multi-Leaf Barriers

Since doubling the thickness of a single-leaf barrier increases the TL value by only 5 dB it is more economical to use multi-leaf barriers.

- If the two leaves of a double-leaf barrier are not connected and the cavity between the leaves is wide enough (i.e., several inches wide) then the effective TL would be the sum of the two individual TL values.



- In practice the two leaves of a double-leaf barrier will never be completely decoupled. Even the air in the cavity acts as springs that couple the two leaves. The coupling effect may be reduced by increasing the width of the cavity or adding sound absorbing material.
- Due to this coupling effect a conventional double-glazed unit (for thermal insulation) may have a lower TL value than a single-glazed unit.

Copyright © 2003

Noise Control

Airborne Sound: Two-Leaf Design Issues

Mass: The mass of the barrier (i.e., in terms of material density and thickness) is the most critical characteristic for sound insulation.

Stiffness: Materials of low stiffness provide a higher TL value.

Decoupling: This is the single most important potential advantage that two-leaf barriers have over single-leaf barriers. Total decoupling of the two leaves (which is impossible in practice) would be ideal. Any ties between the leaves should be as flexible as possible.

Cavity Width: An effective air cavity for sound insulation needs to be much wider than an air cavity for thermal insulation. A minimum width of 4 inches is recommended.

Porous Absorbers: A layer of porous absorber in the air cavity improves the TL value by reducing the potential for air resonance (i.e., through damping). However, the absorber will not be effective if the two leaves are not well decoupled.

Dissimilar Materials: Using leaves of either different materials or different thickness increases the TL value of a two-leaf barrier.

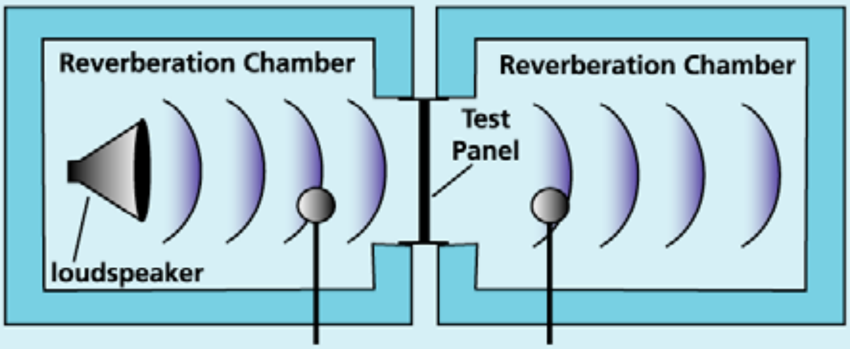
Copyright © 2003

Noise Control

Airborne Sound: Sound Transmission Class (STC)

The Sound Transmission Class (STC) provides an index (i.e., a single 'dB' value) to rate the sound insulation capabilities of a barrier.

- Governed by ASTM standard E90, the STC rating of a barrier is established on the basis of sound measurements in a laboratory.



SPL is measured on either side of panel
(in 1/3rd octave bands between 125 cps and 4000 cps)

The measured TL values at each 1/3rd octave band frequency are compared with the standard STC Contour to determine the STC of the panel.

- STC values do not provide any information about decreases in TL at particular frequencies (e.g., due to resonance and Coincidence Effect).
- STC values are limited to the 125 cps - 4,000 cps frequency region (i.e., speech).

Copyright © 2003

Noise Control

Solid-Borne Sound

Impact and vibration are the most common sources of solid-borne sound. Footsteps, slamming of doors and machinery are typical examples of such sources.

- The sound radiated by a vibrating element reaches the listener as air-born sound. Therefore, many of the principles (e.g., mass) of air-borne sound apply to solid-borne sound.
- Structural isolation or discontinuity is the single most important factor in providing solid-borne sound insulation.

  1. Resilient floor covering to reduce vibration due to impact.
  2. Isolation of machinery through the use of flexible mountings.
  3. Discontinuous construction with isolated walls and floating floors.

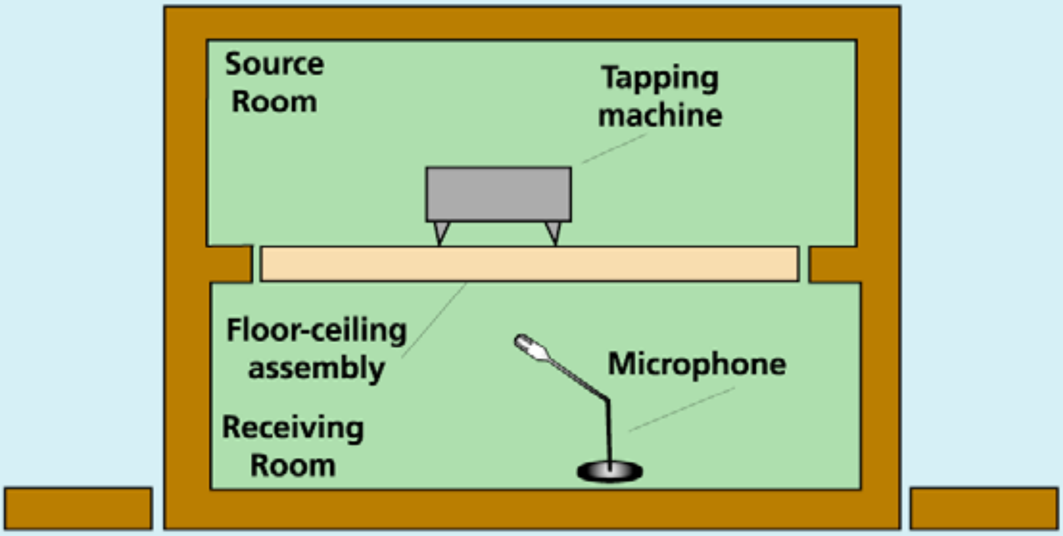
- The terms structure-borne sound and solid-borne sound are synonymous.

Copyright © 2003

Noise Control

Solid-Borne Sound: Impact Insulation Class

A standard tapping machine (with five hammers) is used to rate the Impact Insulation Class (IIC) of a sound barrier.



The measured TL values at each 1/3rd octave band frequency (100 to 3,150 cps) are compared with the standard IIC Contour to determine the IIC of the floor-ceiling assembly.

- As for STC ratings the IIC ratings are stated simply as numerical values without the unit 'dB'.
- IIC values are highly skewed in favor of low frequencies and therefore do not correlate well with the human perception of sound.

Copyright © 2003

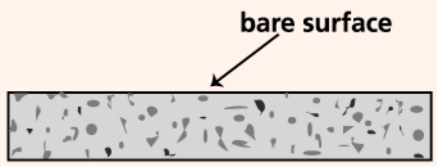
Noise Control

Solid-Borne Sound: Resilient Floor Covering (1/2)

The most effective way of insulating the floor of a building against structure-borne sound is to weaken the impact of the noise source on the floor.

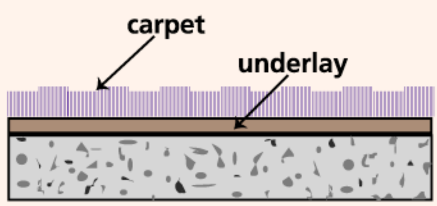
- A soft floor covering is an excellent way of improving the structure-borne noise insulation of a floor.

Bare Concrete Slab



IIC = 25 and STC = 55

Carpet with Underlay



IIC = 85 and STC = 55

- The Sound Transmission Class (STC) of a floor may remain unchanged while the IIC value may increase greatly due to a resilient floor covering.

Copyright © 2003

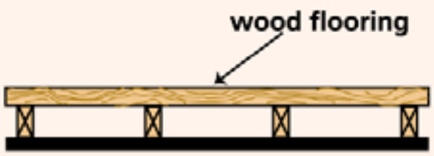
Noise Control

Solid-Borne Sound: Resilient Floor Covering (2/2)

The increase in structure-borne noise insulation due to a resilient floor covering is far greater for a hard inflexible floor such as a concrete slab, than a more flexible wood floor.

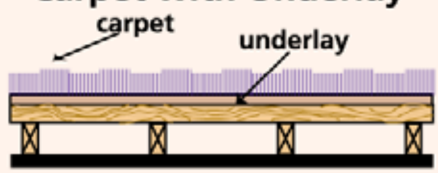
- A resilient floor covering has virtually no effect on airborne noise insulation, except that the carpet will provide some sound absorption.

Bare Wood Floor



IIC = 34 and STC = 38

Carpet with Underlay



IIC = 55 and STC = 39

- Approximate expected increase in IIC for different floor coverings.

Floor and Covering	IIC Increase
Carpet and underlay on:	
wood flooring	20
concrete slab	60
Vinyl or rubber on:	
wood flooring	5
concrete slab	7

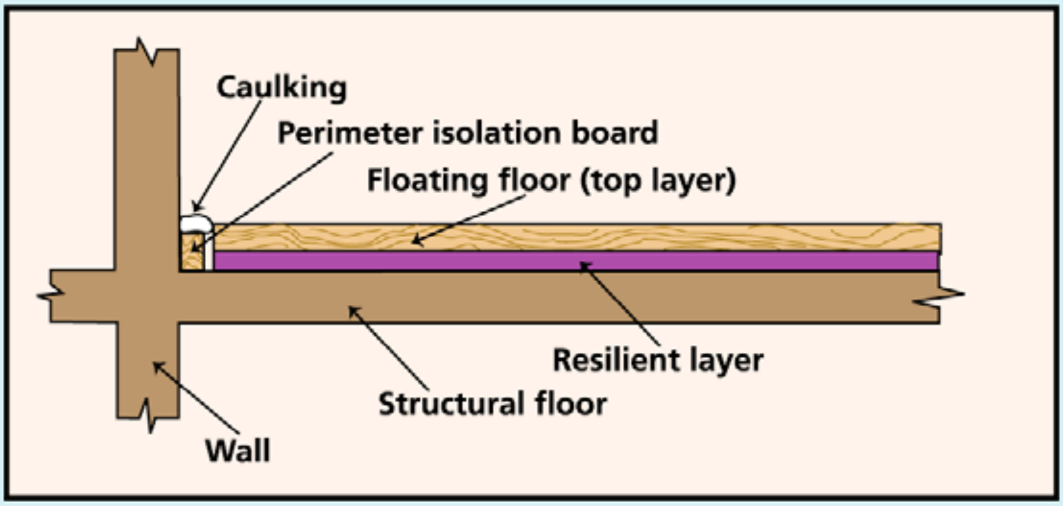
Copyright © 2003

Noise Control

Solid-Borne Sound: Floating Floor Principles

A floating floor is a form of discontinuous construction that increases both the structure-borne and airborne noise insulation.

- To be effective the top layer of a floating floor must be separated at all sides from walls and other structural components.



- Floating floors are used where high values of STC (above 50) and IIC (above 50) are required.
- Perimeter isolation is usually provided by fiberglass board or plastic foam.

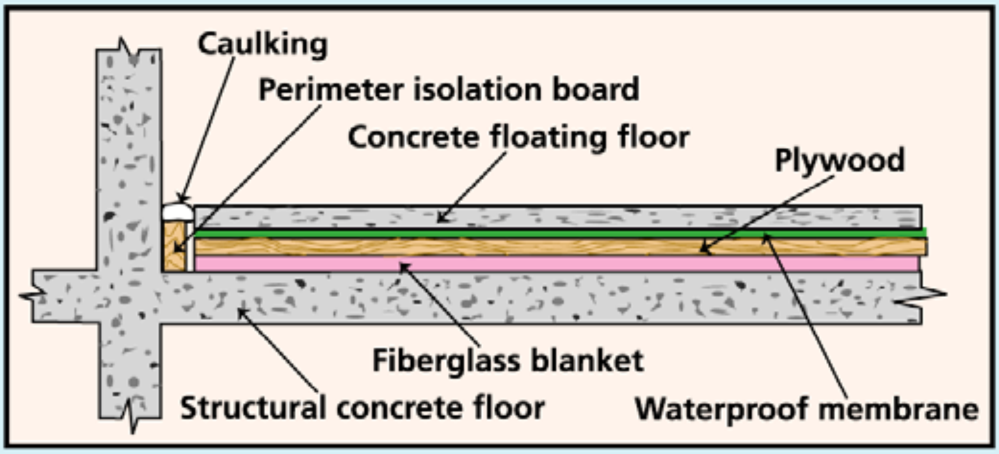
Copyright © 2003

Noise Control

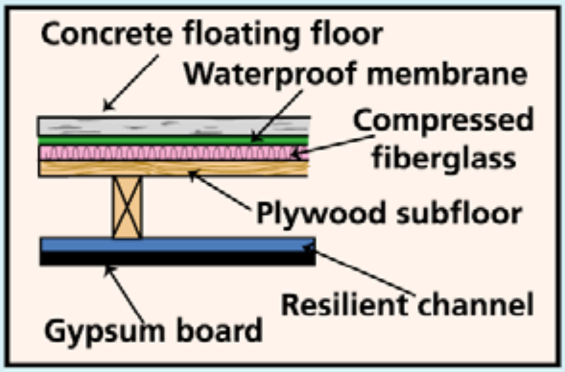
Solid-Borne Sound: Concrete Floating Floors

Either a concrete or a wood structural floor may have a concrete floating floor layer.

- The floating concrete slab is normally 2 to 4 inches thick and reinforced with wire mesh.



A honeycomb resilient floor board consisting of a cellulosic honeycomb core sandwiched between two layers of fiberglass (5/8 in) is available as an alternative to compressed fiberglass.



- A concrete floating floor provides the following ratings:

On concrete floor structure: IIC = 74 and STC = 62
On wood floor structure: IIC = 58 and STC = 60

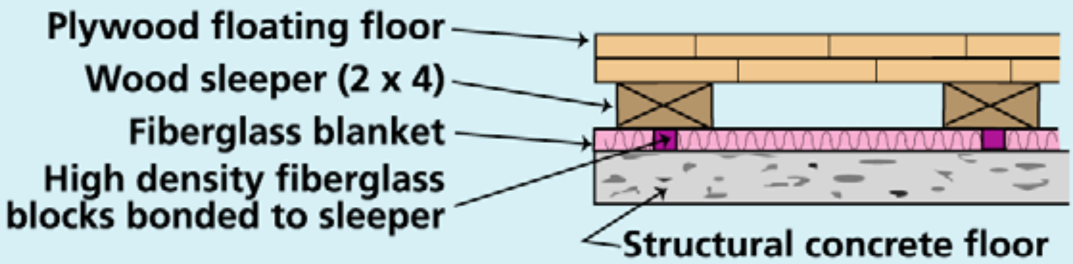
Copyright © 2003

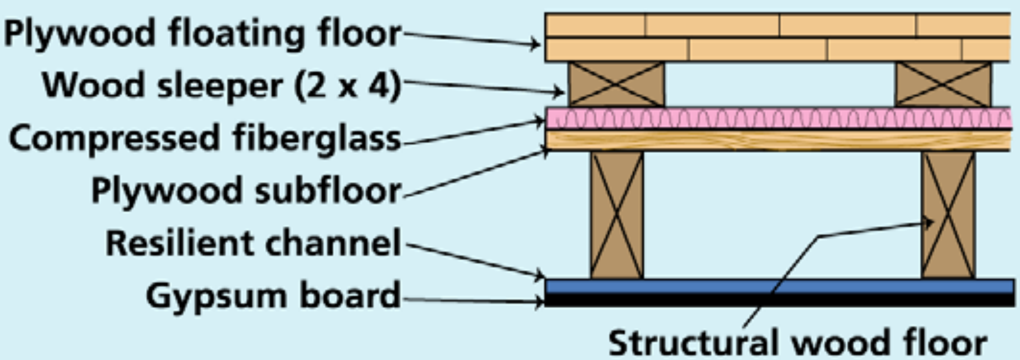
Noise Control

Solid-Borne Sound: Wood Floating Floors

Either a concrete or a wood structural floor may have a wood floating floor layer.

- The floating wood floor normally consists of two layers of plywood with staggered joints, glued and nailed to sleepers.





- A wood floating floor provides the following ratings:

On concrete floor structure: IIC = 64 and STC = 62
On wood floor structure: IIC = 52 and STC = 58

Copyright © 2003

Noise Control

Solid-Borne Sound: Insulation Strategies

There are five basic strategies available for reducing the transmission of impact noise and structure-borne noise in a building.

1. Soft or resilient floor covering such as carpet on heavy underlay to dampen impact sound.
2. Isolation of sources of vibration such as fans and air conditioning units from floors, using rubber blocks or steel springs.
3. Resiliently supported floating floors placed on top of the structural floor to dampen impact sound and reduce the transmission of vibration.
4. Resiliently supported ceilings to reduce the transmission of vibration.
5. Structural discontinuity in floors and ceilings to reduce flanking transmission through the building structure.

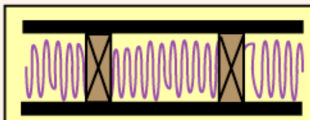
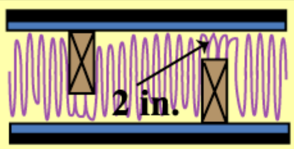
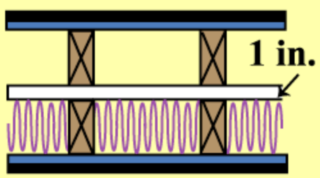
Copyright © 2003

Noise Control

Wood Frame Walls

The STC rating of a wood stud wall (approx. 40) can be increased by using staggered studs (approx. 50) or double wall construction (approx. 55).

Types of 2" x 4" wood stud wall construction with one or more layers of 1/2" thick gypsum board.

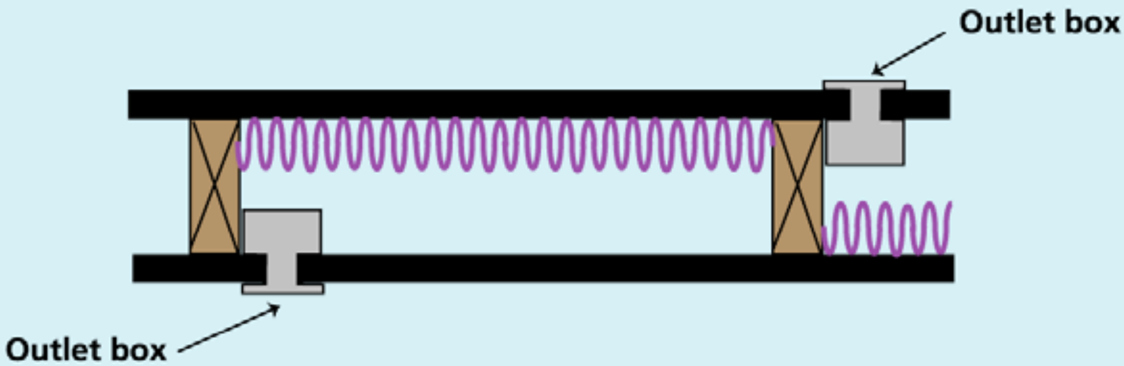
	Layers of Gypsum Board					
	Without Cavity Absorption			With Cavity Absorption		
	1+1	1+2	2+2	1+1	1+2	2+2
	37	40	43	40	43	46
	41	48	52	50	54	58
	46	53	57	57	61	63

Copyright © 2003

Noise Control

Outlet Boxes in Walls

Outlets in the wall of two adjoining rooms should not be placed in the same stud cavity, but should have at least one intervening stud between them.



- The back and side surfaces of outlet boxes in sound insulating walls should be sealed (to render them fully air tight) with preformed sealant tape.
- Stud cavities containing outlet boxes should be lined with fiberglass or mineral wool.

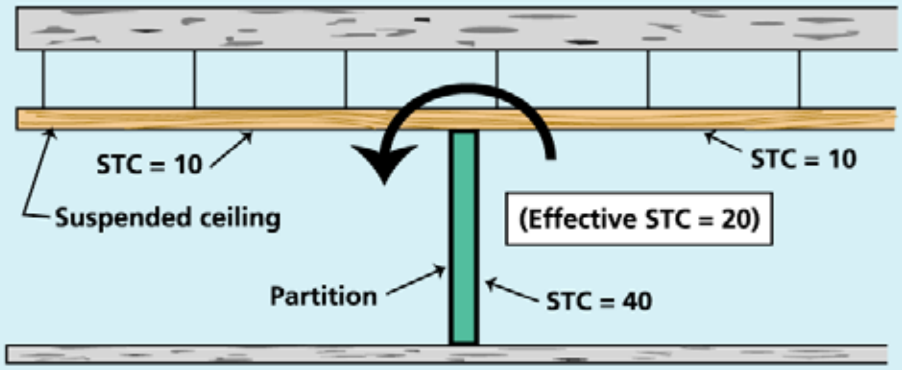
Sound insulating construction is highly sensitive to flanking air paths.

Copyright © 2003

Noise Control

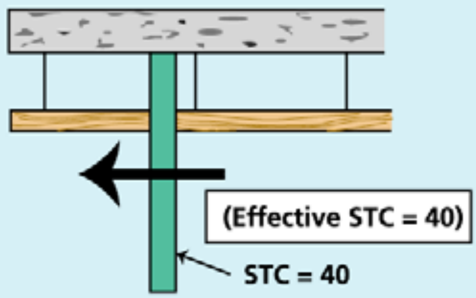
Suspended Ceilings

Sound will travel through a false ceiling from one space to another.



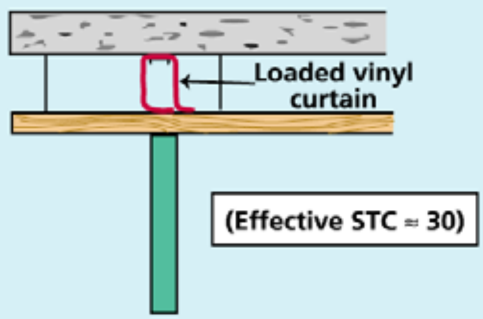
Remedy 1

Extend the partition up to the floor (or roof) above.



Remedy 2

Place a loaded vinyl curtain between the top of the partition and the floor (or roof) above.



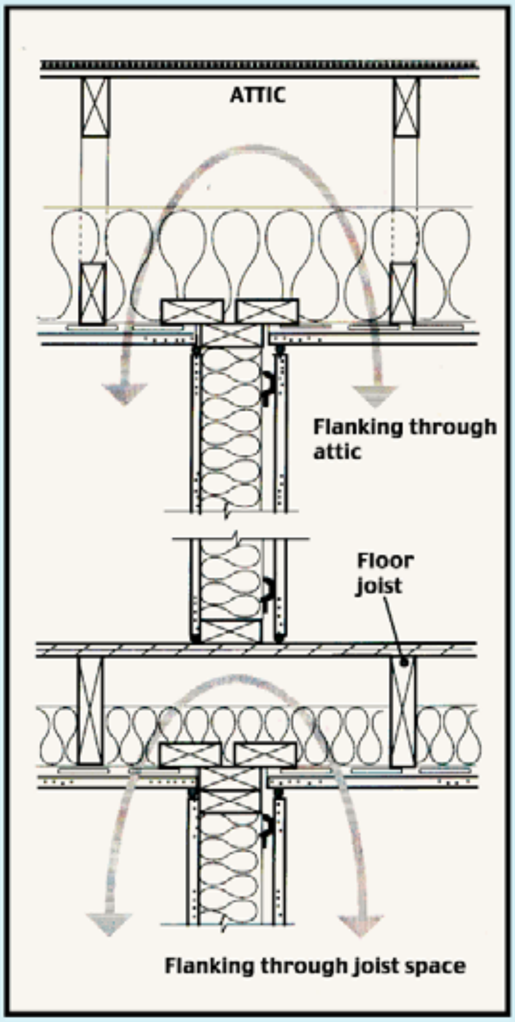
Copyright © 2003

Noise Control

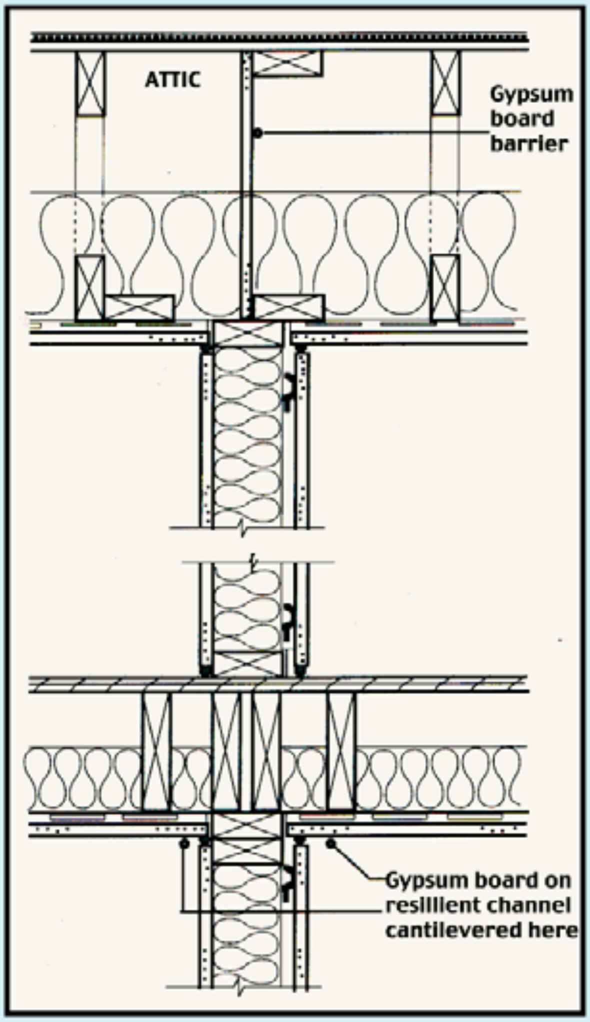
Party Walls

An attic bridging between adjoining apartments can act as a flanking air path unless special precautions are taken to block the path.

Poorly Detailed



Well Detailed



Copyright © 2003

Noise Control

Windows

A typical fixed window with a single 1/8" glass pane has a STC value of about 29.

- An openable window lowers the STC value by 3 to 5 points. Sliding glass doors are particularly prone to air flanking paths.
- According to the Mass Law the thicker the glass the higher the TL value. However, for thicker glass the critical frequency of the Coincidence Effect is lower and reduces the STC value.

Glass Thickness	Mass Law Transmission Loss (TL)	Actual STC*
1/8 in.	29	29
1/4 in.	35	31
1/2 in.	41	33
1 in.	47	37

- The recommended width of the air cavity in a double-glazed window is 3 in. (for noise insulation).

Copyright © 2003

Noise Control

Architectural Design

The simplest and most efficient means of controlling noise inside buildings is through architectural design.

1. Separate noisy rooms from noise-sensitive rooms. For example, in multistory apartments or condominiums, bedrooms should be separated from community corridors and lobbies.
2. In all buildings noisier rooms should be used to buffer noise-sensitive rooms from external noise sources.
3. In very 'reflective' (i.e., 'live') rooms the noise level can be reduced by sound absorption. However, the Law of Diminishing Returns applies.
4. Loud internal noise sources can be mitigated through isolation and surrounding sound absorption.

The transmitted noise level should be at least 5dB lower than the background noise level of the receiving room, to ensure that the background noise level will not be significantly raised.

Copyright © 2003

Noise Control

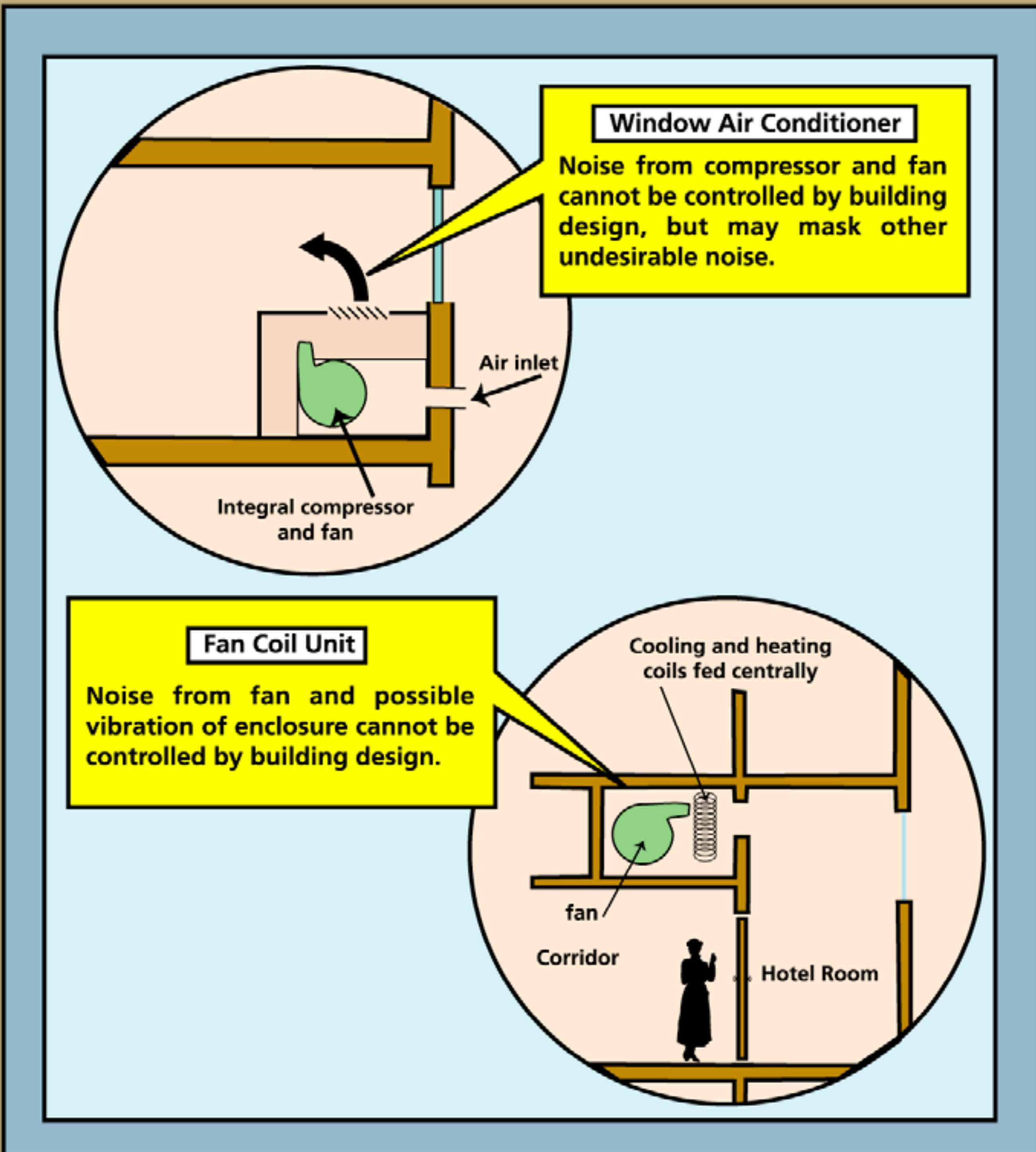
Recommended STC Values

Primary Room	Adjacent Room	Recommended STC
Classroom	Classroom	45
	Laboratory	50
	Corridor/Lobby	50
	Music Room	55 (+)
Office	Office	50
	General Office	45
	Corridor/Lobby	50
	Mechanical Room	60
Conference Room	Conference Room	50
	Office	50
	Corridor/Lobby	50
	Mechanical Room	60
Bedroom	Bedroom	55
	Corridor/Lobby	55
	Mechanical Room	60

Copyright © 2003

Noise Control

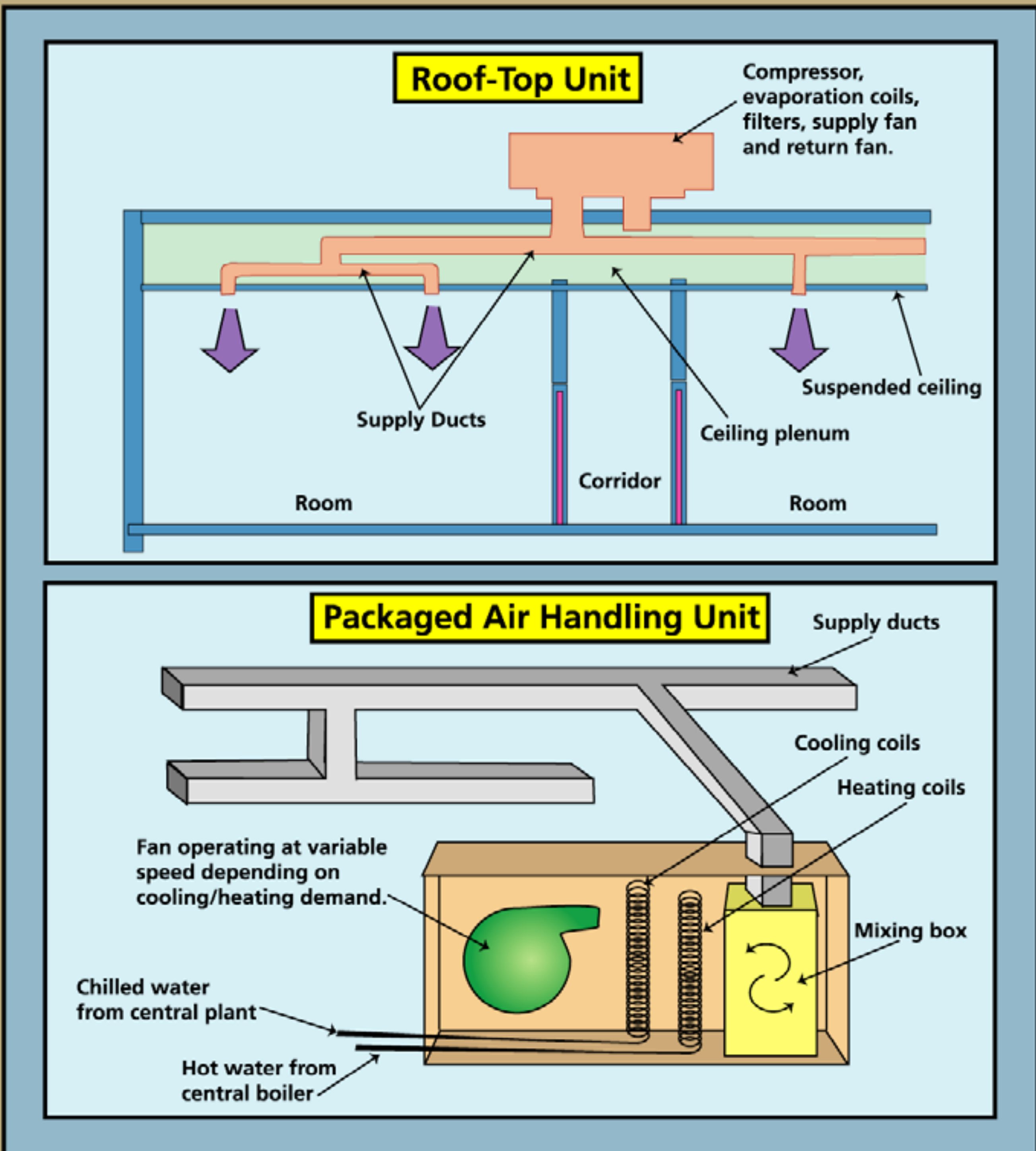
HVAC: Single Room Units



Copyright © 2003

Noise Control

HVAC: Multi-Room Units

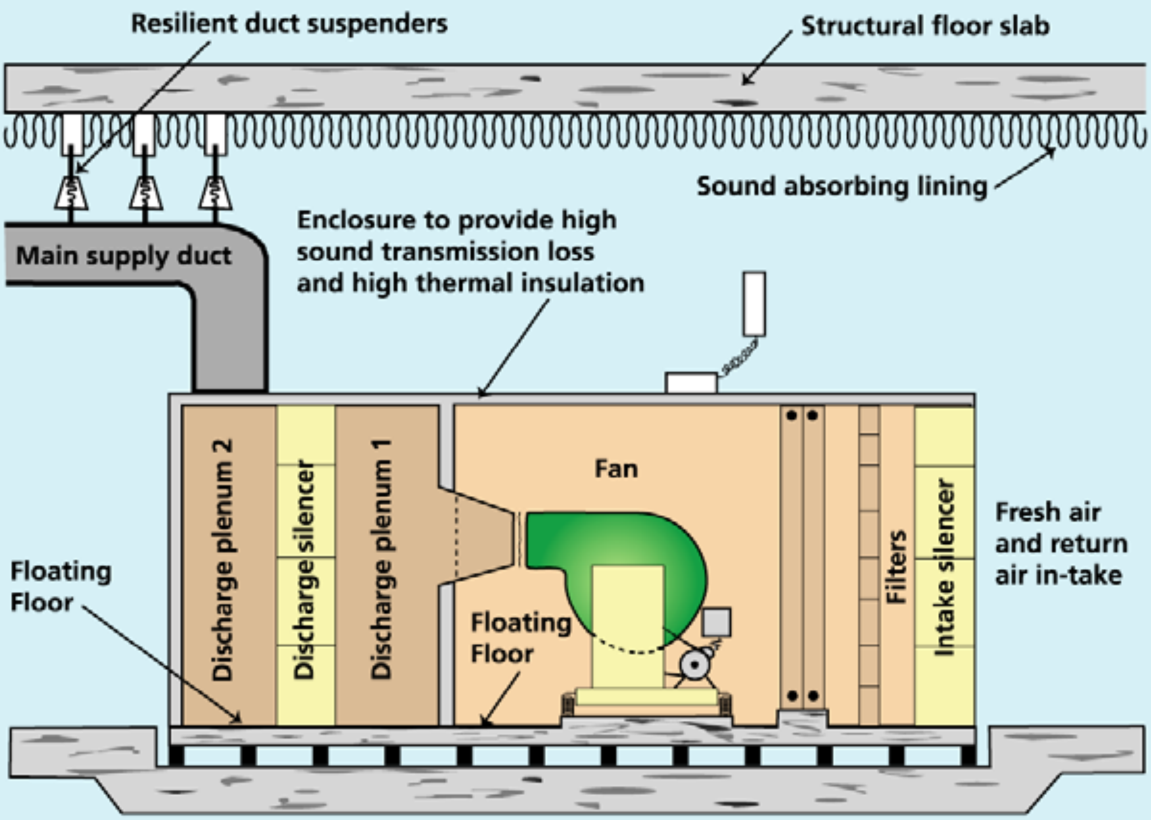


Copyright © 2003

Noise Control

HVAC: Built-Up Air Handling Unit

A built-up air handling unit is a larger version of a packaged air handling unit, with its components assembled on site (i.e., fan(s), filter(s), coils, noise silencer banks, supply plenum(s), and supply ducts).



Copyright © 2003

CHOBUGROUP

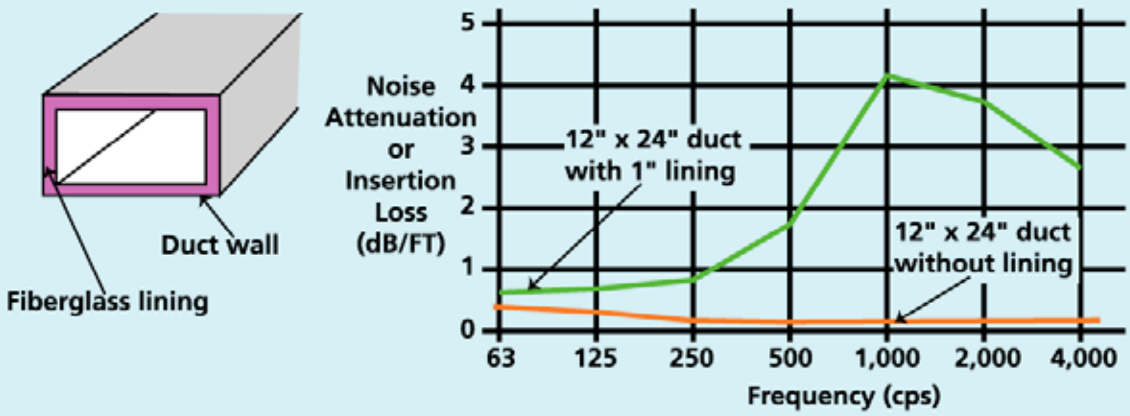
BUILDING SCIENCE (BSC)

Noise Control

HVAC: Fan Noise Reduction

Most of the noise in a HVAC system is produced by the fan and transmitted through the supply ducts by the air stream and by vibration of the duct walls.

- It is common practice to line portions of a duct with fiberglass (1" to 2" thick). The resulting *insertion loss* (i.e., attenuation) is about 4 dB/FT at 1,000 cps, but much less at lower and higher frequencies.



- Some manufacturers treat duct lining with bactericidal material to reduce the possibility of microbial contamination.

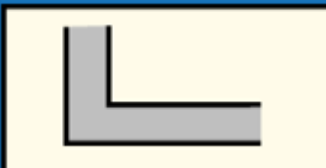
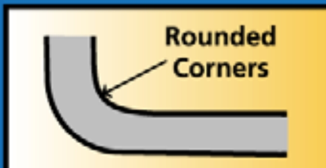
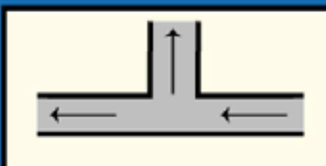
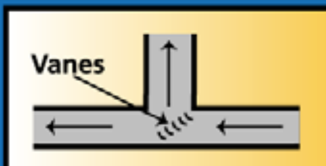
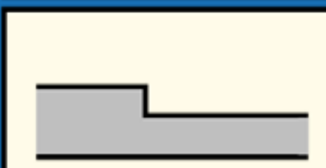
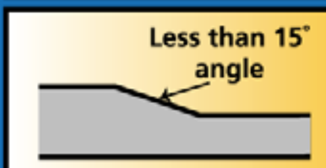
The noise attenuation due to duct lining is referred to as *insertion loss*.

Copyright © 2003

Noise Control

HVAC: Air Flow Noise

Air turbulence due to excessive air speed or poorly designed duct transitions (i.e., connections and changes in diameter) increases the noise level due to air flow.

Type of Transition	Poor Design Practice	Good Design Practice
Duct Elbows		
Right Angle Duct Branches		
Change in Cross-Section of Duct		

ASHRAE recommends maximum air speeds for rectangular and circular ducts based on the Noise Criteria (NC) rating of the space.

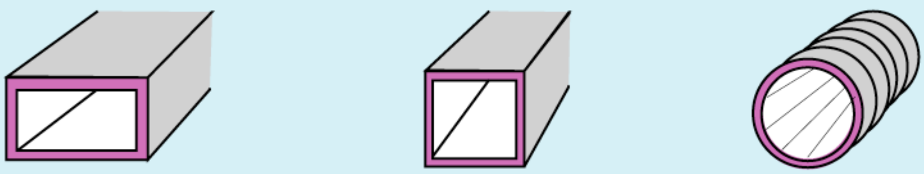
Copyright © 2003

Noise Control

HVAC: Duct Break-Out Noise

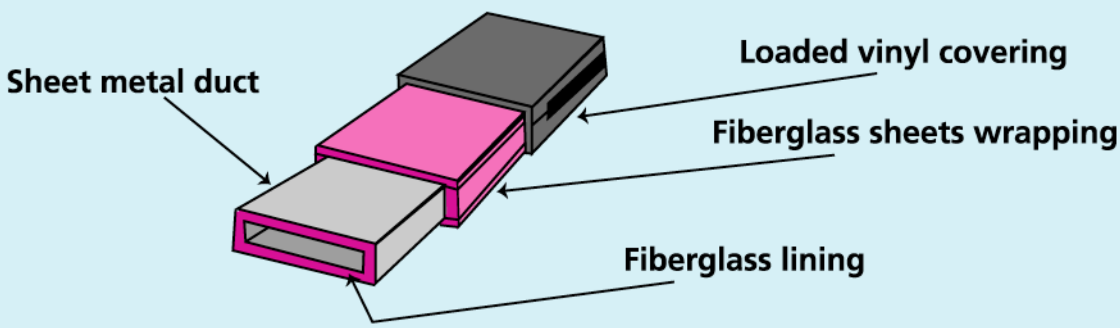
Duct break-out noise is the fan noise that is transmitted by the vibrating walls of a duct and re-radiated into a space as airborne noise.

- More serious in high velocity than low velocity systems.
- Duct *shape* is a factor.



Not so good | Better | Best

- Duct may be *lagged* with fiberglass wrapping.



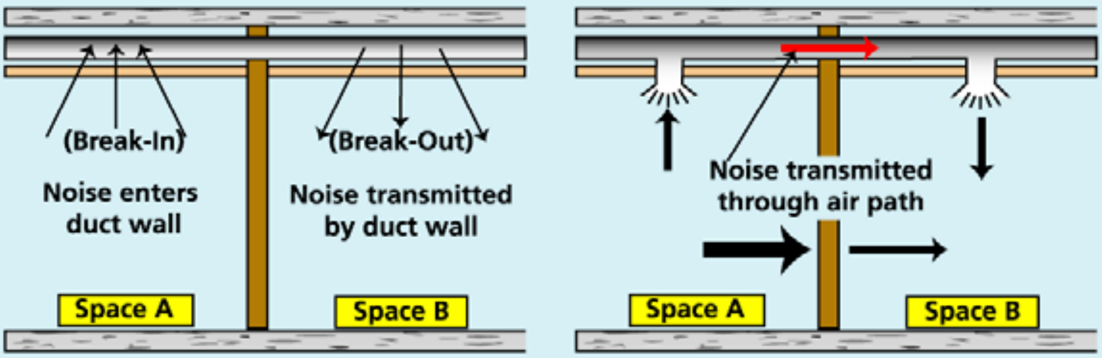
Duct stiffness reduces the tendency for the duct walls to vibrate and therefore decreases the break-out noise.

Copyright © 2003

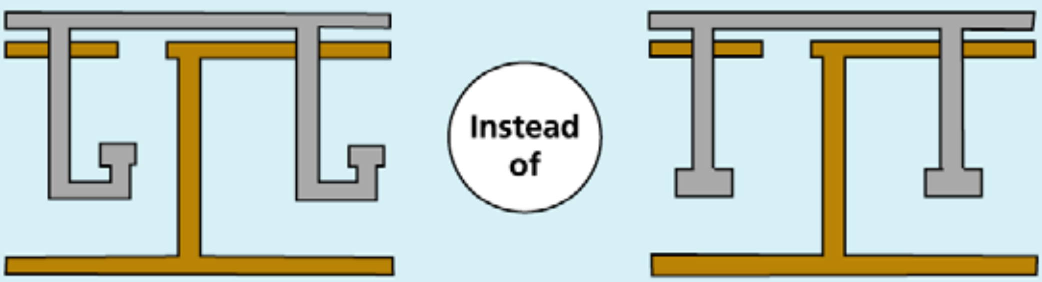
Noise Control

HVAC: Duct Break-In Noise

Duct *break-in noise* is the noise transmitted between two adjoining spaces by either the walls of a duct or by the direct air path provided by the duct.



- **Duct layouts that increase the noise path will reduce the *break-in noise* transmitted (i.e., the *cross transmission*).**



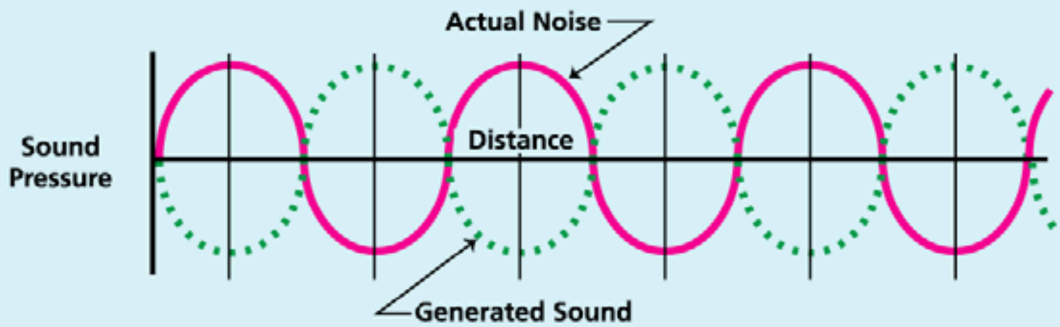
Noise travels equally well with or against the flow of air in a duct because the velocity of sound is 20 to 50 times faster than the velocity of the air.

Copyright © 2003

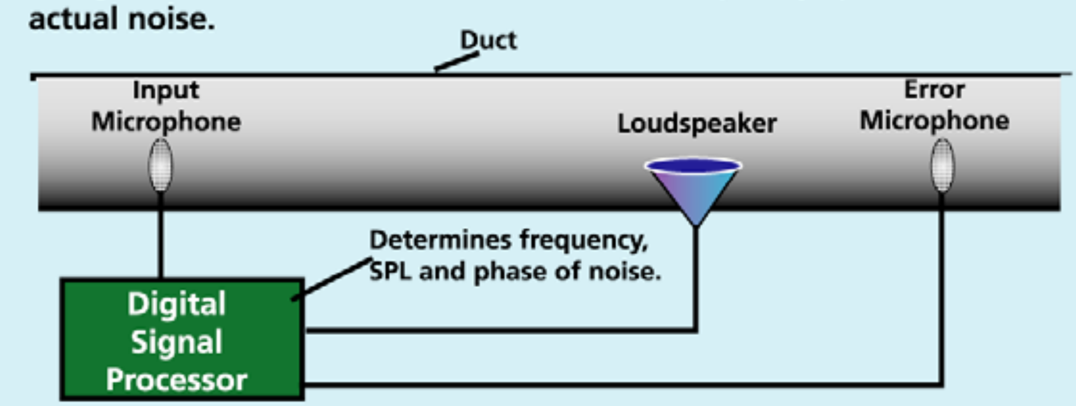
Noise Control

HVAC: Duct Break-In Noise

In *active noise control* noise is cancelled out by the production of an identical sound that is exactly 180° out of phase.



The generated sound must have the same frequency spectrum as the actual noise.



The loudspeaker (i.e., generated sound) must be far enough away from the input microphone to allow adequate time for the signal analysis.

First patent awarded in 1930s but did not become practical until 1980s when computer-based digital signal processors became economical.

Copyright © 2003

Noise Control

HVAC: Summary Guidelines

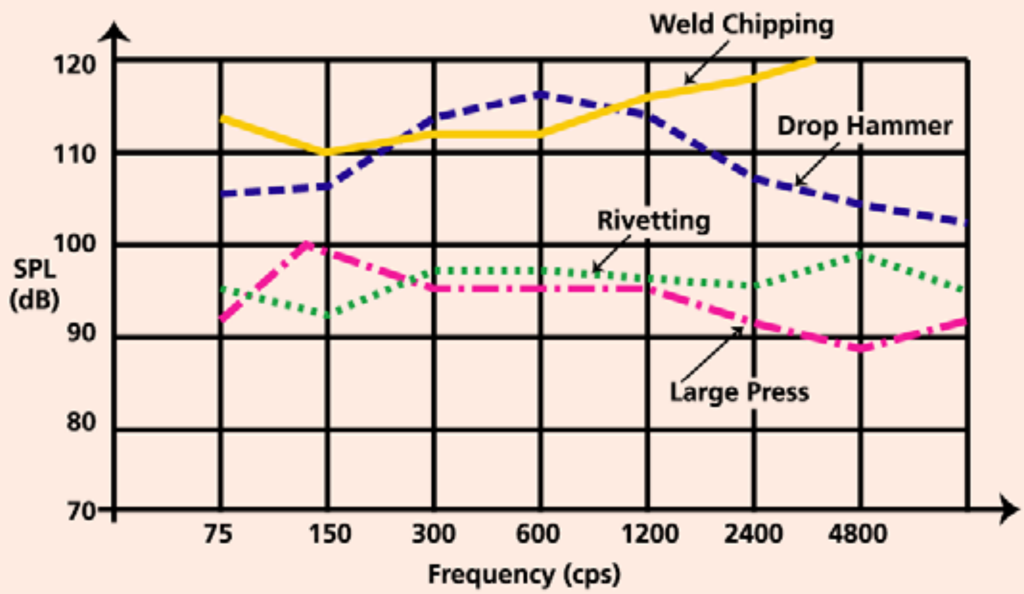
1. Mount fans and other HVAC equipment on anti-vibration pads.
2. Use flexible connectors to isolate fans from ducts to reduce *break-out noise.*
3. Select motors of higher horsepower and operate at less than maximum output.
4. Avoid sharp bends in the main supply ducts.
5. Line duct sections internally with absorbent material (e.g., fiberglass).
6. Line ducts externally with lagging when they pass through noisy spaces to reduce *break-in noise.*
7. Seal around edge of ducts when they pass through walls, floors or ceilings.
8. Insert bends in secondary ducts to decrease *cross transmission* between adjoining spaces.

Copyright © 2003

Noise Sources

Industrial Process Noise

Industrial noise **is mostly due to impulsive forces to form metals, abrasive actions to grind surfaces, saws and mills to cut materials, and compressed gasses (e.g., compressors, pneumatic hammers, combustion engines, and safety valves).**



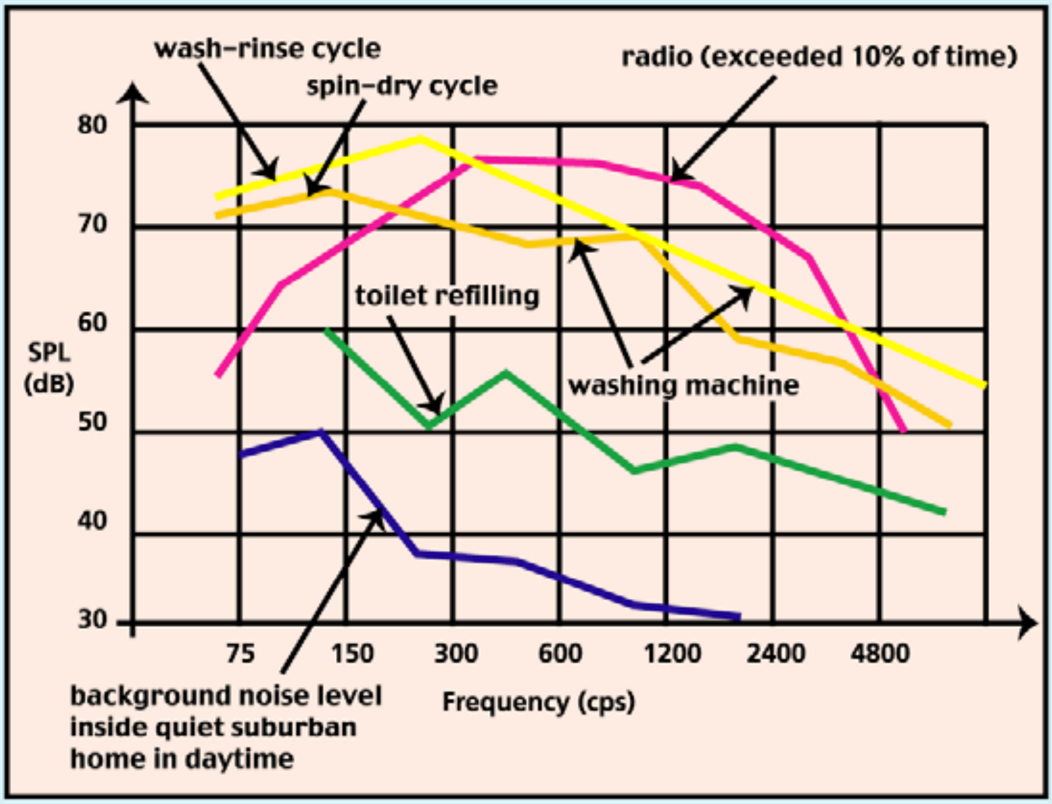
Noise reduction at the source is the best strategy (e.g., absorption lined housings, silencers for compressed gas equipment, and substitution of a quiet process for a noisy process).

Copyright © 2003

Noise Sources

Residential Noise

Apart from washing machines most noise sources generated inside buildings are in the mid to high frequency range



Impact noise is generated inside buildings by footsteps, slamming doors and the movement of chairs.

Copyright © 2003

Noise Sources

Road Traffic Noise

Vehicular traffic noise is predominantly low frequency noise. Maximum noise levels are produced by the motor when accelerating at low speed and by tires when traveling at high speed.

Type of Road and Environment	Expected Noise Levels (80% of time)	
	Day (8 a.m. to 6 p.m.)	Night (1 a.m. to 6 a.m.)
Highways and Freeways	75 - 85 dBA	65 - 70 dBA
Major heavy traffic roads	65 - 75 dBA	50 - 60 dBA
Residential roads	55 - 65 dBA	45 - 55 dBA
Minor roads	50 - 60 dBA	45 - 50 dBA
Residential areas remote from traffic routes (e.g. parks)	50 - 55 dBA	40-45 dBA

Traffic noise is a *line source* reduced by only about *3 dB* for each doubling of distance (compared to 6 dB for a point source).

Copyright © 2003

Noise Sources

Typical Noise Levels

Noise Source	Distance	125 cps	700 cps	3500 cps
Aircraft (jet)	1,000 FT	95 dB	98 dB	90 dB
Aircraft (prop.)	1,000 FT	95 dB	88 dB	83 dB
Bus	20 FT	85 dB	75 dB	65 dB
Car	20 FT	70 dB	60 dB	45 dB
Clothes Dryer	5 FT	65 dB	55 dB	42 dB
Compressor	10 FT	85 dB	90 dB	85 dB
Construction Site	100 FT	-	85 dB	-
Dish Washer	5 FT	70 dB	64 dB	60 dB
Garbage Disposal	5 fT	73 dB	72 dB	74 dB
Industrial Area	100 FT	-	90 dB	-
Motorcycle	20 FT	90 dB	83 dB	78 dB
Residential Area	20 FT	60 dB	45 dB	40 dB
Rural Area	20 FT	43 dB	32 dB	30 dB
Surf (ocean)	100 FT	75 dB	-	-
Train (pulling)	100 FT	95 dB	85 dB	83 dB
Train (coasting)	100 FT	85 dB	83 dB	80 dB
Truck (diesel)	20 FT	95 dB	90 dB	80 dB
Waterfall	100 FT	-	50 dB	-

Copyright © 2003

Noise Control

Landscaping: General Principles

Combinations of trees and shrubs can reduce external sound levels by 5 to 8 dB, which may be perceived by human ears to be as much as a 50% reduction in noise.

1. Plant *evergreen* trees with dense foliage for year-round noise protection.
2. Select taller trees (if permitted) with lower level shrubs in between and soft ground cover (tall grass is best) instead of paved surfaces.
3. Plant the noise buffer *close to the noise source* instead of close to the area to be protected.
4. Plant trees and shrubs as close together as the plant species allow.
5. The effectiveness of a tree belt will be *reduced by wind* from the direction of the noise source.

Copyright © 2003

Noise Control

Landscaping: Vehicular Noise

Carefully designed tree/shrub belts can provide a moderate buffer for vehicular traffic noise in residential areas.

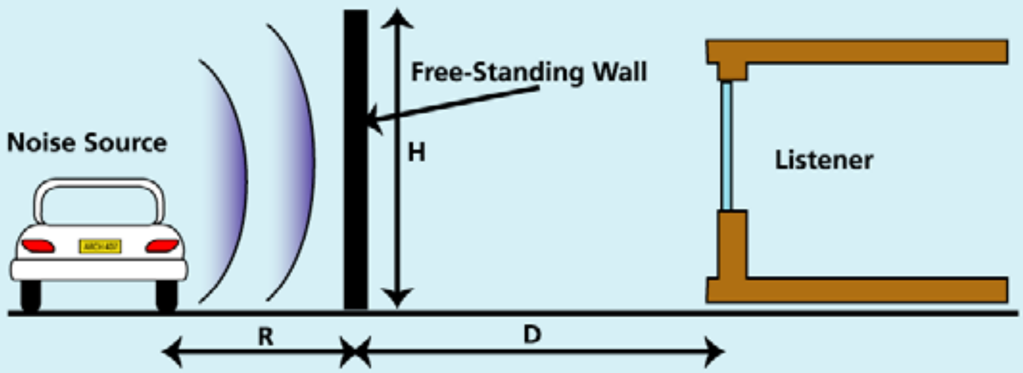
- Tree belts should be 20 to 100 FT wide depending on the severity of the noise source.
- Use 6 to 8 FT high shrubs in front of and between the trees.
- Plant the shrubs and trees as close as possible to the noise source (within 20 to 50 FT).
- Length of the tree/shrub belt should be at least twice as long as the distance from the area to be protected.
- The tree/shrub belt should extend equal distance in both directions parallel to the road.

Copyright © 2003

Noise Control

Free Standing Walls: General Principles

Free-standing walls (20 to 30 FT high) can reduce external noise levels by up to 12 dB.



$$\text{Approximate Reduction (NdB)} = 10\log_{10}20\left[\frac{2\left[R[Y^{0.5} - 1] + D[Z^{0.5} - 1]\right]}{y\ (\text{Wavelength})}\right] \text{dB}$$

Where: $Y = [1 + \frac{H^2}{R^2}]$

$Z = [1 + \frac{H^2}{D^2}]$

$$\text{Wavelength} = \left[\frac{1{,}100}{\text{Frequency (cps)}}\right] \text{FT}$$

Speed of Sound

Copyright © 2003

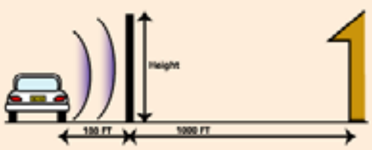
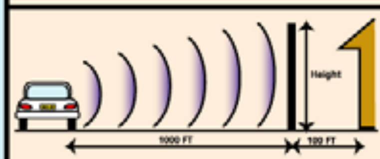
Noise Control

Free Standing Walls: Vehicular Noise

External free-standing sound barriers tend to be expensive because they must be quite tall to be effective and therefore they have to resist considerable wind forces.

For best results:

1. The wall needs to be 20 to 30 feet high (and resist a wind force of up to 1,000 LB per linear FT (vertically)).
2. The wall needs to be as close to the noise source as possible.

Relative Wall Distances (from source and building)	Approximate Reduction at Building		
	Height = 20 FT	Height = 30 FT	Height = 40 FT
	18 dB	21 dB	23 dB
	11 dB	14 dB	17 dB

3. The walls are often slightly concave (toward the noise source) to increase their effectiveness and stability.

Copyright © 2003