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SOUND CONTROL IN GLASS ASSEMBLIES

17.1.1 OVERVIEW

Noise has been an environmental issue through the ages. Noise has been called 'the natural by-product of expanding human technology'. Automotive traffic, airplanes, trains, generators, air-conditioning units and household appliances are common sounds often described as noise. Environmental noise can distract attention, disturb sleep and create anxiety. Prolonged exposure to sound levels above 85 dB can impair hearing and can be hazardous to overall health.

Noise might be described as any sound that is annoying. In many situations, a noise problem is defined as not being in compliance with a particular specification or regulation. Unfortunately, compliance to specific regulations is not a guarantee that individuals, communities and organizations will not complain about perceived noise levels. Their concerns and complaints need to be addressed.

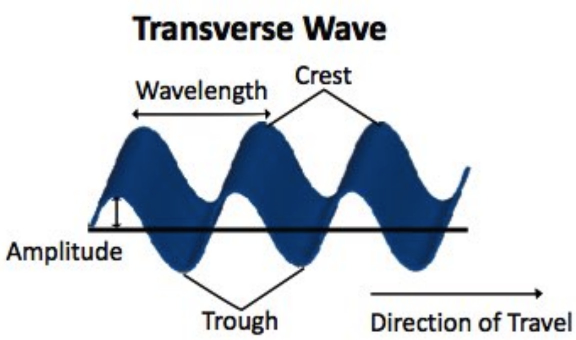
The first goal when dealing with noise complaints is determining a reasonable solution. Understanding the subjective nature of sound is a step in the right direction for finding a reasonable solution.

17.1.2 UNDERSTANDING SOUND

How Sound Travels

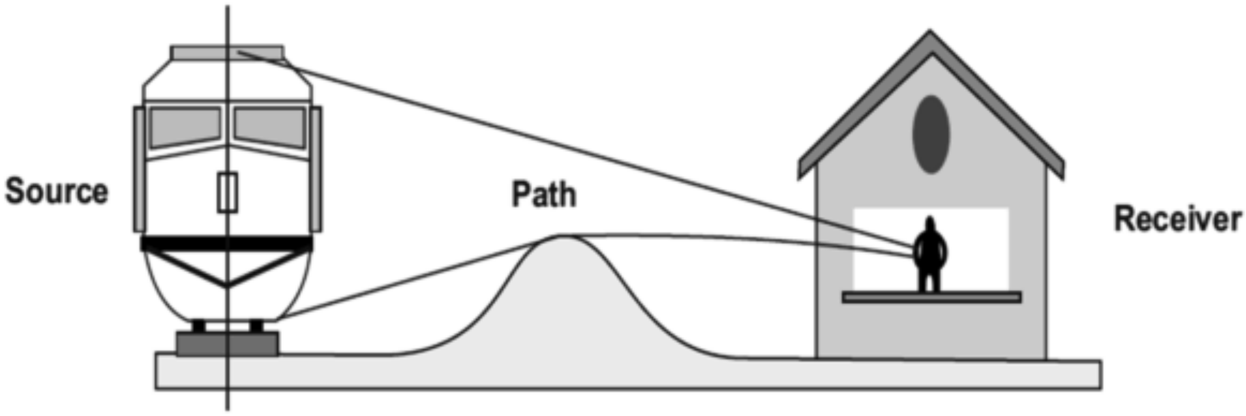
The vibration of an object, a sound source, causes waves to be transmitted through air (usually) to our ears. It is this undulatory motion of air particles that triggers a cascade of mechanical and electrical events leading, ultimately, to the sensation of hearing. While we usually consider sound waves in air, they can propagate through any elastic medium such as glass.

The mechanical vibrations of sound move forward using wave motion. This means that although the individual particles of material such as air molecules return to their original position, the sound energy obviously travels forward. The front of the wave spreads our equally in all directions unless it is affected by an object or by another material in its path. The sound waves can travel through solids, liquids and gases, but not through vacuum. The velocity of the sound waves depends on the medium it travels in (for instance, in air a sound wave travels with a speed of 344 m/s when measured in dry at 20 degrees centigrade, while in glass it can travel with a speed of up to 5000 m/s.



Source, Path and Receiver

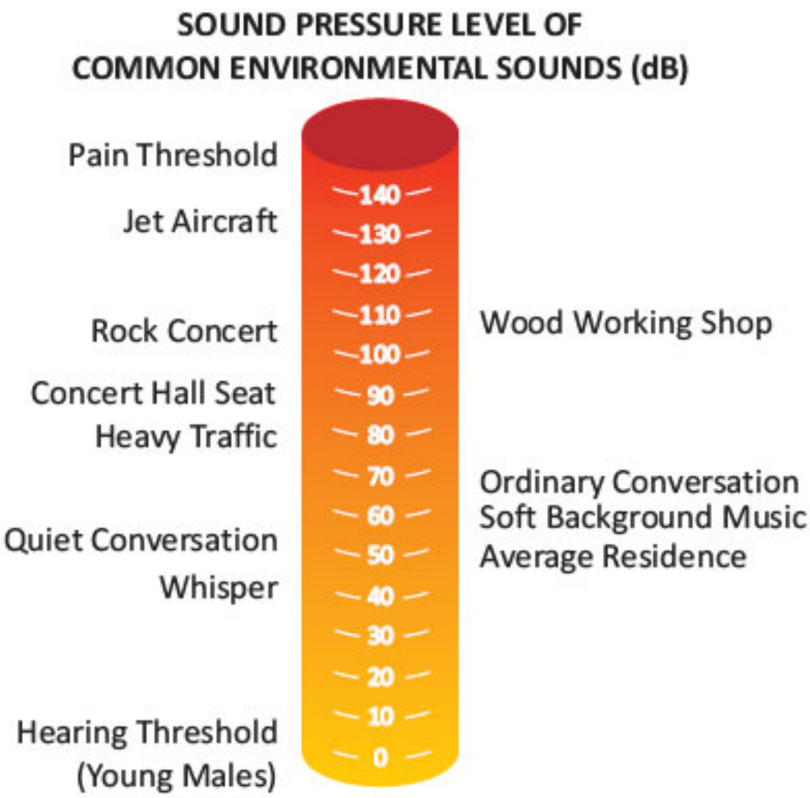
Three components must be present for sound to exist:
1.Source
2.Path
3.Receiver
Without a source there obviously is no sound. Without a path, the medium through which sound passes to the receiver, there is no sound. Without a receiver, someone who hears the sound, there is no sound problem.



Source
Sound is the result of rapid fluctuations of pressure, which reach a receiver. The frequency of sound is the number of times in a period of one second that the pressure changes from zero to maximum to minimum to zero, thus completing a cycle. In music it is perceived as the pitch or tone of a note. Frequencies produce sound waves; the length of the sound wave depends on the specific frequency. Humans tend to be more sensitive to high and mid range frequencies such as sirens, whistles and traffic noise. Lower frequencies tend to be less irritating.

Amplitude refers to the loudness of sound. The loudness of sound is often expressed in decibels (dB). Human hearing is impacted by the way it perceives sound levels. Higher and lower frequencies of the same magnitude can be perceived as less intense; therefore, to approximate the response of the human ear adjustments are made to account for human sensitivity to certain frequencies. These adjustments are identified as dBA's.

The following chart demonstrates some of the common sounds and their pressure levels in decibels.



A change of 3 dBA is the smallest change most people can recognize. A change of 10 dBA is generally thought to be "twice as loud." Decibels are logarithmic units; therefore, multiple dB cannot be added by ordinary arithmetic means. For example, if one automobile generates 70 dB when it passes an individual, two cars passing simultaneously would not produce 140 dB but would combine to produce 73 dB.

Path

Although frequency and amplitude originate at the source, both are significantly altered by the physical variables in the path to the receivers. For example, walls, structures, ground absorption, atmospheric conditions such as temperature, humidity, wind and rain all contribute to changes in source noise levels before it reaches the receiver. A detailed study of the path is a critical step in understanding how to reduce noise levels at specific locations.

Receiver

Ultimately, we are concerned with the effect and perception of sound on the receiver. Two elements determine the sound levels upon the receiver: the sound power levels of the source and the characteristics of the path between the source and receiver. A third and critical element is the individual sensitivity of the human receiver. The individual's sensitivity plays a significant role in his perception of noise levels.

17.1.3 SOUND INSULATION

Sound insulation is the screening of a room against a noise source. Two types of sound insulation can be distinguished: airborne sound insulation and impact sound insulation. Airborne sound insulation is the insulation against sound that propagates by air (e.g., insulation against traffic noise). Impact sound insulation is the insulation against sound that arises by direct contact of an object on the building element (e.g., the impact of rain on a glazing). Since facades mainly are liable to airborne sound, the discussions here will concentrate on airborne sound insulation only.

The best place to control noise is close to the source. Enclosing a noise source is an effective method and commonly used in commercial and industrial applications but impractical when addressing traffic noise issues. When the noise source has been minimized or isolated the next step is to interrupt the direct noise path by introducing a sound barrier. The next objective is to remove reflected sound energy. The most practical method is to replace reflective surfaces with absorptive surfaces.

Sound-absorptive walls installed between the noise source and the receivers are effective in reducing reflective noise. The height, location and orientation of the sound wall play a significant role in the wall's effectiveness. Sound walls are most effective when built close to the source or close to the receiver. The height of the wall should interrupt line-of-sight between the source and the receiver.

If reflections can be subdued quickly, they cannot develop into reverberations. Reverberations become new sources and add to the original noise source. Minimizing reflections means noise is localized to the extent whereby only direct sound, line-of-sight sound will be heard.

When the direct sound diminishes in intensity as per the inverse law, the multitude of reflective sound intensities combine to produce an increase in the reflected sound levels to a point where the reflected sound can be higher than the direct sound. A typical example of this phenomena would be a voluminous, hard surfaced gymnasium that can experience a significant build up of reflective sound intensity.

Where the direct sound and reflected sound are about equal is called the critical distance. In a typical classroom critical distance is about 12" from the source. Beyond the critical distance the sound reduction will be less than 6 dB.

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Decibel Reduction

People often ask how decibel (dB) reduction numbers relate to changes in sound levels to the human ear. Here you can listen to a recording of a skill saw at normal operating level conditions followed by six different noise level conditions, showing a 3dB, 6dB, 10dB and a 20dB noise reduction.

Change in Sound Levels (dB)	Change in Apparent Loudness to the Human Ear
3 dB	just barely perceptible
6 dB	clearly noticeable
10 dB	half as loud
20 dB	one fourth as loud

Decibel Addition and Subtraction

Sound level decibels are logarithmic and so cannot be manipulated without being converted back to a linear scale. You must first antilog each number, add or subtract and then log them again in the following way:

$$L = 10 \, Log_{10} \left(\sum_{i=1}^{n} 10^{(L_i / 10)} \right)$$

For example, adding three levels 94.0 + 96.0 + 98.0:

$$L = 10 \, Log_{10} \left(10^{9.4} + 10^{9.6} + 10^{9.8} \right) = 101.1 \text{ dB}$$

Measuring Sound Reduction

There are several ways by which sound reduction is measured. The Sound Transmission Class (STC), measured in dB, is the common measure by which acoustical performance is rated. It is the weighted average over the frequency range 100 to 5000 Hz of the STL (Sound Transmission Loss). The higher the STC rating, the more able the material is to resist the transmission of sound. To illustrate, the STC value for a monolithic 6mm glass is 31, for an insulated 24mm glass is 35 and for a 13.52mm laminated glass is 39.

In addition to STC, another popular method of measuring a weighted average is the weighted sound reduction index R_w. The European Standard EN ISO 717-1 describes a method to express the airborne sound insulation by the single-number quantity.

R_w (C; C_{tr}) in which,
R_w is the weighted sound reduction index in dB,
C is the adaptation term for pink noise (sound dominated by mid and high tones) and
C_{tr} the adaptation term for road traffic noise (sound dominated by low and mid tones).

According to the nature of the sound source to be insulated the right adaptation term can be chosen.

Type of Noise Source	Adaptation Term
living activities (talking, music, radio, tv) children playing railway traffic at medium and high speed highway road traffic > 80 km/h jet aircraft, short distance factories emitting mainly medium and high frequency noise	C
urban road traffic railway traffic at low speeds aircraft, propeller driven jet aircraft, large distance disco music factories emitting mainly low and medium frequency noise	C_{tr}

The airborne sound insulation is then simple the sum of the weighted sound reduction index and the adaptation term i.e., Rw + C or Rw +Ctr. The higher the Rw + C or Rw +Ctr the better the airborne sound insulation. If for instance the acoustic performance of a window is characterizes by 40 (-2, -6) dB and disco music has to be suppressed, the airborne sound insulation is 40 - 6 = 34 dB.

17.1.4 GLASS PERFORMANCE IN ACOUSTIC INSULATION

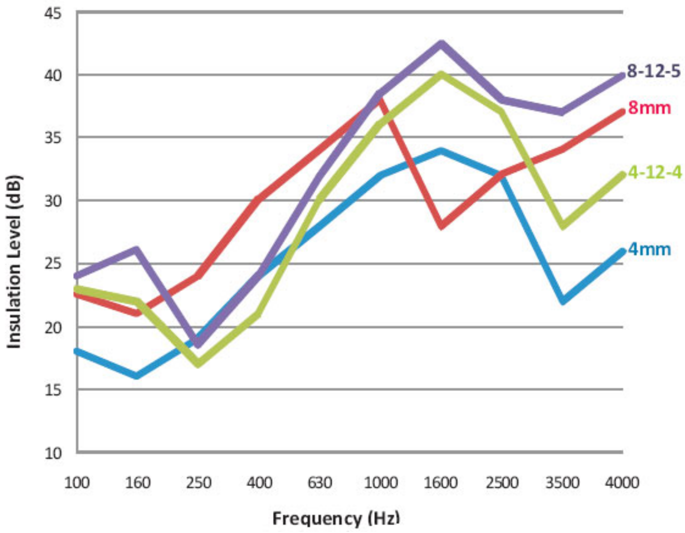
Unwanted sound is considered noise when it intrudes on our daily lives. To minimize this instruction all aspects of the building construction need to be evaluated, however in this instance we will only analyze the acoustic qualities of glass. The first step in this analysis is to determine the source of the unwanted noise. This is a critical step, as the noise source can vary from low frequency traffic noise to high frequency aircraft noise. Starting from a single 6mm glass lite with an STC of 31, we can achieve STC ratings of as high as 50 with different combinations of laminated and insulated glasses. Although the increase in absolute numbers seems small, it results in a big difference in performance. An increase from 28 to 38 means 90% of the noise is reduced. A change from 28 to 43 represents a noise reduction of over 95%.

Use Thicker Glasses

Increasing the thickness of a single-pane glass enhances the glazing's sound insulation, for e.g., a 4mm thick glass provides an R_w of 29 dB, which can increase to 35 dB for a thickness of 12mm. However, increasing glass thickness is generally a poor choice for applications such as city structures which are primarily subjected to lower pitched sounds. This is because increasing glass thickness shifts the critical-frequency trough towards lower frequencies which results in weakened protection against low-pitched sounds.

Use Glass Configurations with Different Thicknesses

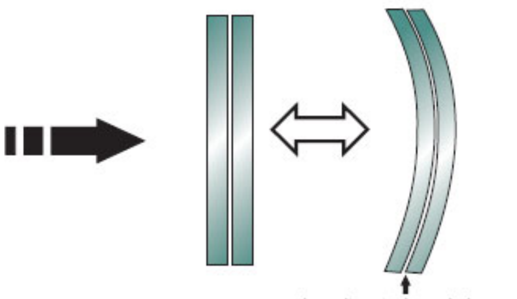
To enhance the level of sound insulation provided by double-glazing, glasses with sufficiently different thicknesses should be used so that they can hide each others' weaknesses when the overall unit reaches its critical frequency. This therefore produces a coincidence trough in a broader frequency zone but compared to symmetrical glazing the trough is less intense (as seen around 3,200 Hz). In this case, the increase in mass in relation to 4-12-4 glazing also helps to reduce the trough at low frequencies.



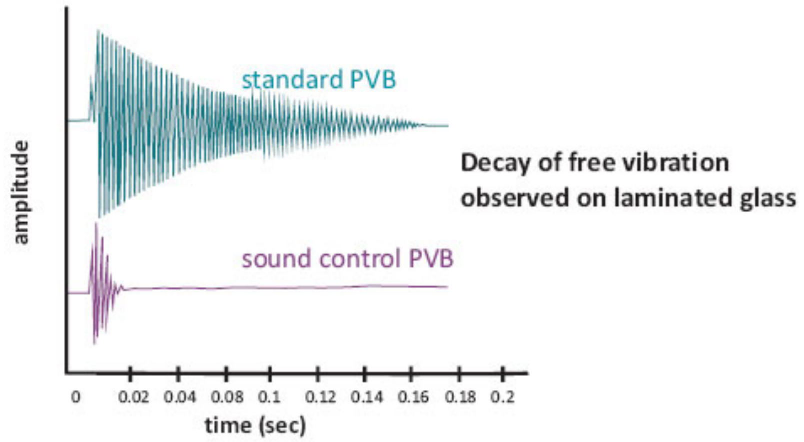
Use Laminated Glasses (preferably with Acoustic Interlayer)

The polyvinyl butyral interlayer (0.38mm to 1.52mm) used in laminated glass provides a dampening effect which reduces the loss of insulation at the coincidence frequency. The coincidence dip for laminated glass is significantly reduced when compared to float glass of equal thickness. Laminated glass also has superior sound insulation qualities in the higher frequency range where the noise from sources such as aircraft is a problem. Increasing the interlayer thickness will only have marginal effects on improving the sound insulation performance of laminated glass.

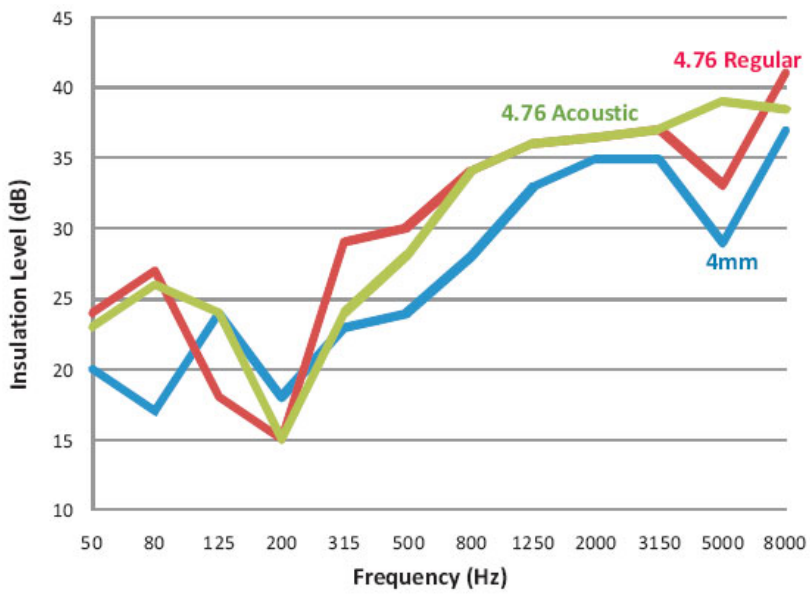
The PVB film used in laminated glasses have a shear damping effect that has substantial sound-attenuation characteristics. The main contribution of acoustically effective interlayers to reducing sound transmission resides in their capability to drastically reduce the amplitude of vibration the partition (in this case the laminated glass lite) is subjected to under resonance. This effect roots in the microscopic shear motion the interlayer is subjected each time a fraction of the glass laminate is displaced from its equilibrium position as it vibrates. While the whole laminate starts vibrating under the influence of the impinging sound waves, bending waves build up, consequently introducing a slight curvature in the whole structure as shown



As the shear modulus of the interlayer comprises a significant non-elastic component, any shear deformation will lead to a dissipation of mechanical energy into heat. This process accounts for the damping action of the interlayer inside the laminate. Depending on the magnitude of the loss modulus at service temperature, large differences can exist from one interlayer type to another. Acoustic PVB's are designed around this principles and are formulated to exhibit a high loss modulus at service temperature.



The sound-attenuation characteristics of PVB and acoustical PVB films can be understood by the following comparative graph. Considered here is the performance of a monolithic 4mm glass with a 4.76mm (2-0.76-2) regular PVB and 4.76mm (2-0.76- 2) acoustic PVB.



Although the transmission curve for 4mm monolithic glass is shifted to lower values owing to its slightly smaller mass if compared to the laminated glasses, the superior performance of the PVB glass (and more so in the acoustic PVB laminate) is clearly evident in the coincidence region. The reduced plate vibrations below 800 Hz also help enhance the sound-reduction properties of the laminated glass assembly.

Use Combination of Insulated and Laminated Glasses

Further increases in sound-reduction performance can be achieved by using combinations of insulated and laminated glasses. These units offer the dual benefit of greater mass and different frequency resonance of insulated glasses coupled with the damping effects of PVB laminated glasses. The following chart demonstrates the STC and R_w performance of some common glass types.

	Overall Thickness	Inside	Air Space	Outside	STC Value	R_w
Monolithic Glass	6 mm	6 mm	-	-	31	32
	12 mm	12 mm	-	-	36	37
Insulated Glass	14 mm	3 mm	8 mm Air	3 mm	28	30
	24 mm	6 mm	12 mm Air	6 mm	35	35
	37 mm	6 mm	25 mm Air	6 mm	37	37
Laminated Glass	6.76 mm	3 mm	0.76 mm PVB	3 mm	35	35
	9.76 mm	6 mm	0.76 mm PVB	3 mm	36	36
	10.52 mm	6 mm	1.52 mm PVB	3 mm	37	37
	12.76 mm	6 mm	0.76 mm PVB	6 mm	38	38
	13.52 mm	6 mm	1.52 mm PVB	6 mm	39	39
	16.76mm	10 mm	0.76 mm PVB	6 mm	40	40
	19.52 mm	12 mm	1.52 mm PVB	6 mm	41	41
Laminated Insulated Glass	24.76 mm	6.76 mm	12 mm Air	6 mm	39	39
	23.76 mm	6.76 mm	12 mm Air	5 mm	39	39
	28.76 mm	10.76 mm	12 mm Air	6 mm	40	40
	36.76 mm	6.76 mm	25 mm Air	5 mm	42	42
	25.52 mm	6.76 mm	12 mm Air	6.76 mm	43	43

Areas around Windows
It is important to note that no matter how good the noise insulation qualities of the windows are, there should be no gaps or cracks around the window frame. As long as the R_w of a window remains under 35 dB and the frame area doesn't exceed 30% of the window area, the influence of the frame on the total acoustic performance can be neglected. However as soon as R_w lies between 35 and 40 dB, it is advised to reinforce each frame element. Windows with R_w larger than 40 dB are specific for the window concept itself which makes special advice necessary.

Factors not Affecting Insulation
The following factors have no effect on the sound insulation properties of glass assemblies:

- Tint/color of glass
- Coatings (reflective/low-e) on glass
- Position of glass
- Tempering
- Annealed glass of a particular company