Sound Control for Fenestration Products
TIR-A1-03

Table of Contents

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PREFACE

The reduction of sound transmission through a building envelope is becoming an ever-increasing issue in the design and construction of commercial and residential buildings alike. No longer are sound control efforts targeted only towards urban and commercial construction. As residential construction moves closer to airports, freeways and railroads and as sound control regulations become more stringent, demand for products that help in the reduction of "noise" in these dwellings is growing.

This document is targeted towards anyone who requires information on what sound is, how it is transmitted, how it is measured and how its transmission can be controlled. Although technical in nature, this document is organized to be useful to anyone from the window designer who is trying to meet an architect's sound control specification to a window salesman who just wants to help a customer understand how sound travels and what can be done to "cut down on the noise". Furthermore, this document will clarify and differentiate between the two methods of product classification, STC (Sound Transmission Class) and OITC (Outdoor-Indoor Transmission Class), and their appropriate use.

1.0 BASIC ACOUSTICS

1.1 Sound and Noise

Sound[1] (sownd) *n*. 1. The sensation produced in the organs of hearing by certain vibrations in the air. 2. vibrations; any auditory effect. "...an alteration in pressure, stress, particle displacement and particle velocity which is propagated in an elastic material."

Noise (noiz) n. 1. Sound or a sound that is loud, disagreeable or unwanted. 2. Sound or a sound of any sort. 3. A loud, confused clamor or commotion. 4. *Physics*. A usually random, persistent disturbance of a signal. 5. *Computer Sci*. Meaningless data generated along with desired data.

For the purpose of this document, sound is anything that the human ear can detect. Granted, dogs, whales and bats can hear different sounds than humans but for this discourse this definition will suffice. "Sounds" are vibrations that are propagated through a medium to a receiving ear. When a person speaks, a car passes by or a glass is dropped to the floor, vibrations from the vocal cords, running engine or glass impacting the tile respectively, are set into motion in the surrounding air. This is very similar to dropping a rock into a calm lake. As the rock impacts the surface of the water small waves are projected outward from the point of impact in all directions. One impact will produce multiple waves that follow a repeating pattern across the surface of the water. Sound waves act the same as they travel through air.

Figure 1.1 is an illustrative comparison between waves in a lake and sound waves in air. As opposed to following a true wave pattern, sound travels in air through a series of pressure pulses. Each pulse has a point of maximum pressure separated by a period of lesser pressure. The distance between two points of maximum pressure defines the wavelength of the sound. The number of wavelength "periods" that occurs in one second determines the frequency of the sound.

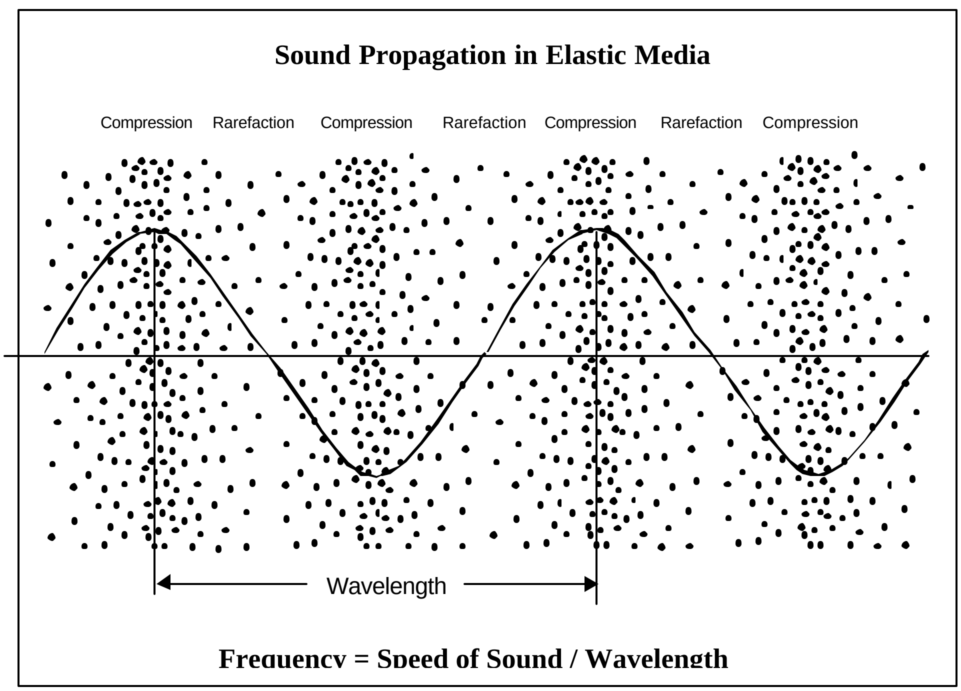

Figure 1.1 - Sound Propagation

1.2 Frequency

Frequency is, therefore, defined in terms of wavelength "cycles" (number of wavelengths) per second. Cycles per second (cps) is otherwise known as "Hertz" and is abbreviated "Hz".

The frequency of a given sound is detected as the pitch of the sound. The higher the frequency of the sound, the higher its pitch will be. Sounds with long wavelengths e.g. 3.4 m (11.3 ft) have a low frequency (100 Hz) and therefore a low pitch. Conversely, sounds that have much higher frequency (10,000 Hz) and a much higher pitch have a shorter wavelength 0.03 m (0.113 ft). The average, healthy human ear is capable of detecting sounds in the frequency range between 20 Hz and 20,000 Hz. Table 1.2 lists the standard 1/3 octave and octave band frequencies, the frequencies that are contained in each band, and the bandwidth of the 1/3 octave and octave bands.

Nominal One Third Octave Band Frequencies and Ranges

Reference ANSI , IEC standards. Frequency band limits rounded to nearest hertz.

Third Octave Band Number	Center Frequency, Hz.	Frequency Range, Hz.	Corresponding Octave Band	1/3 Octave Bandwidth, Hz.	1/1 Octave Bandwidth, Hz.
14	25	22 - 28	Sub Octave	6	
15	31.5	28 - 36		8	23
16	40	35 - 45	22 -45	10	
17	50	45 - 56	1	11	
18	63	56 - 71		15	44
19	80	71 - 89	45 - 89	18	
20	100	89 - 112	2	23	
21	125	112 - 141		29	89
22	160	141 - 178	89 - 178	37	
23	200	178 - 224	3	46	
24	250	224 - 282		58	177
25	315	282 - 355	178 - 355	73	
26	400	355 - 447	4	92	
27	500	447 - 563		116	355
28	630	563 - 708	354 - 709	145	
29	800	708 - 892	5	184	
30	1000	891 - 1123		232	707
31	1250	1122 -1413	707 - 1414	291	
32	1600	1412 - 1779	6	367	
33	2000	1778 - 2240		462	1411
34	2500	2238 - 2819	1411 - 2822	581	
35	3150	2817 - 3549	7	732	
36	4000	3547 - 4469		922	2815
37	5000	4465 - 5625	2815 - 5630	1160	
38	6300	5621 - 7082	8	1461	
39	8000	7077 - 8916		1839	5617
40	10000	8909 - 11225	5617 - 11234	2316	

Table 1.2 - Standardized Frequency Bands

1.3 Sound Pressure Level, Sound Intensity & Loudness

The second component of a sound wave is its amplitude. The sound at each frequency has a corresponding amplitude that is represented by its Sound Pressure Level (SPL). Figure 1.1 illustrates the amplitude of a water wave as the distance between the crest and the trough of the wave. The amplitude of a sound pulse is the difference between the maximum and minimum pressure that is developed. This difference is represented as the Sound Pressure Level (SPL) and is perceived as the "loudness" of the sound. The greater the amplitude of a sound wave the higher the SPL and the louder the sound. The amplitude of a sound wave determines the pressure that the sound exerts. The ratio of this pressure to a standardized reference sound pressure results in a dimensionless quantity termed the "relative pressure" of the sound. The SPL is derived from the relative pressure based on the following relation:

Eq. 1: SPL = 20 log (relative pressure)

For example, a sound that has a relative pressure of 1000 has a SPL of 60 dB.

SPL = 20 log(1000) = 60

The SPL of a sound is measured in decibels (dB). A comparison between sound pressure level, decibel level and sound intensity can be found in Table 1.3.1. The human ear is sensitive to SPL's over a range of 0 - 130 dB; the lower of the range being the threshold of audibility and the greater being the threshold of pain.

Sound Intensity (W/m^2)	**Relative Pressure**	**SPL** (dB)	**Relative Loudness**	**Typical Sound**
1,000,000,000,000	1,000,000	120	4096	Thunder Clap
100,000,000,000	316,228	110	2048	Nearby Riveter
1,000,000,000	31,623	90	512	Loud Street Noise
100,000,000	10,000	80	256	Noisy Office
10,000,000	3,162	70	128	Average Street Noise
1,000,000	1,000	60	64	Average Office
100,000	316	50	32	Restaurant Chatter
10,000	100	40	16	Private Office
1,000	32	30	8	Bedroom
100	10	20	4	Whisper
10	3	10	2	Normal Breathing
1	1	0	1	Audibility Threshold

Table 1.3.1 - Relationship Between Sound Intensity, Pressure, Sound Pressure Level & Loudness

Another means of representing the strength of a sound is by its Sound Intensity. Sound intensity is a function of the power of a sound and is expressed in terms of power per unit area. Typical representation of sound intensity is "watts per square meter (W/m^2)".

Sound Pressure Level, sound intensity and the perceived loudness of a sound are all related. Since the workings of the ear are sensitive to pressure differences versus power differences, SPL is the most commonly referenced means of representation.

The human ear can distinguish between varying amplitude levels within the hearing range, but for any given amplitude level, the human ear can only detect an amplitude change if it is 3 dB or more as shown in Table 1.3.2 below.

Change in Decibels	**Change in Perceptable Loudness**
1 dB	Imperceptable change
3 dB	Just barely distinguishable
5 dB	25% Change in Loudness
10 dB	50% Change in Loudness
15 dB	63% Change in Loudness
20 dB	75% Change in Loudness

Table 1.3.2 - Comparison of Changes in Sound Pressure Level & Loudness

1.4 A-Weighting

The human ear actually has a built-in filtering system that is less sensitive to low frequency sounds and more sensitive to mid to high frequency sounds. Sound pressure level measurements are usually measured with sound level meters, which incorporate an A-weighting filter to approximate the human ear perception. The A-weighted sound pressure level (dBA) is a single number, which is a logarithmic summation of all the A-weighted sound pressure levels at the measured frequencies. Table 1.4 contains the un-weighted transportation noise spectrum and the A-weighting correction that is specified in ANSI S1-4. The A-weighted sound pressure level for the transportation noise spectrum is 100.13 dBA.

Frequency, Hz.	Transportation Noise Spectrum	A-Weighting Correction	A-Weighted SPL
80	103.00	-22.50	80.50
100	102.00	-19.10	82.90
125	101.00	-16.10	84.90
160	98.00	-13.40	84.60
200	97.00	-10.90	86.10
250	95.00	-8.60	86.40
315	94.00	-6.60	87.40
400	93.00	-4.80	88.20
500	93.00	-3.20	89.80
630	91.00	-1.90	89.10
800	90.00	-0.80	89.20
1000	89.00	0.00	89.00
1250	89.00	0.60	89.60
1600	88.00	1.00	89.00
2000	88.00	1.20	89.20
2500	87.00	1.30	88.30
3150	85.00	1.20	86.20
4000	84.00	1.00	85.00
5000	29.73	0.50	30.23

Table 1.4 - A-weighting Correction

1.5 Limp Mass Law

The most frequently referenced method for improving the sound transmission loss characteristics of a barrier is based on the Mass Law. Mass Law works well with limp mass systems (such as lead) and will work well at mid frequencies for stiff materials (such as glass). Mass Law calculations, however will not work well in the frequency ranges where the mass-air-mass and the coincidence effect occur (refer to the next section). The Mass Law states:

Eq. 2: $TL = 20 \log(m_s \text{ x } f) - 47$ [SI units]
$TL = 20 \log(m_s \text{ x } f) - 33$ [IP units]

Where: TL = the transmission loss across the barrier (dB)

m_s = mass per unit area of the barrier (kg/m^2 ; lbf/ft^2)

f = frequency of the incident sound wave (Hz)

Based on the above relation, given a fixed incident frequency, the transmission loss across a barrier can be increased approximately 6 dB for every doubling of the mass per unit area. For example, a single glazed unit with double strength glass 3 mm (1/8 in) thick has a mass per unit area of approximately 8.2 kg/m^2 (1.7 lb/ft^2). A fixed lite (not including frame effects nor air leakage) should have a STL at 500 Hz of:

$TL_{3\,mm} = 20 \log(8.2\ kg/m^2 \text{ x } 500\ Hz) - 47$
$TL_{3\,mm} = 25$ dB

Doubling the thickness of this lite (and therefore, the mass) will result in a STL at 500 Hz of:

$TL_{6\,mm} = 20 \log_{10}(16.4\ kg/m^2 \text{ x } 500\ Hz) - 47$
$TL_{6\,mm} = 31$ dB

The limitations to this method of improvement are obvious; if a 1 m x 1.5 m (3 ft x 5 ft) unit requires a STL at 500 Hz of 40 dB, a 25 mm (1 in) thick glazing will be required. This relatively average sized unit will weigh in excess of 91 kg (200 lbs). Although an option, this is typically not the most effective means of improving the sound transmission loss characteristics of a window.

1.6 Coincidence Effect & Mass Air Mass Resonance

Coincidence Effect

Glass, steel, aluminum, wood and many other common building materials will resonate or vibrate at a particular frequency when they are exposed to sounds containing that frequency. The frequency at which the material resonates is called its natural frequency or coincidence frequency. For glass panels, this "*coincidence effect*" occurs when the sound wave coincides with the shear wave of the panel. The amplitude of the resonance is a function of the panel's dimensions, its stiffness and how the panel is installed. As a result, the impinging sound is not blocked or dissipated by the panel at that frequency, but passes through with little attenuation. Theoretically, the transmission loss at this frequency would drop to zero; but because of some internal damping, and edge damping a dip or plateau occurs in the transmission loss curve. Several frequencies that are adjacent to the natural frequency will also be affected. The dip in the sound transmission loss data for various thicknesses of annealed glass, as a result of this "coincidence effect" or "coincidence dip", is shown in Figure 1.6.1.

For many building materials, the reduction in acoustical performance coincides with the frequency range that is most important for speech intelligibility as well as the noise generated by automobiles, trains and aircraft. When the coincidence effect occurs, these sounds can easily be heard through the panels or materials used for the building facade.

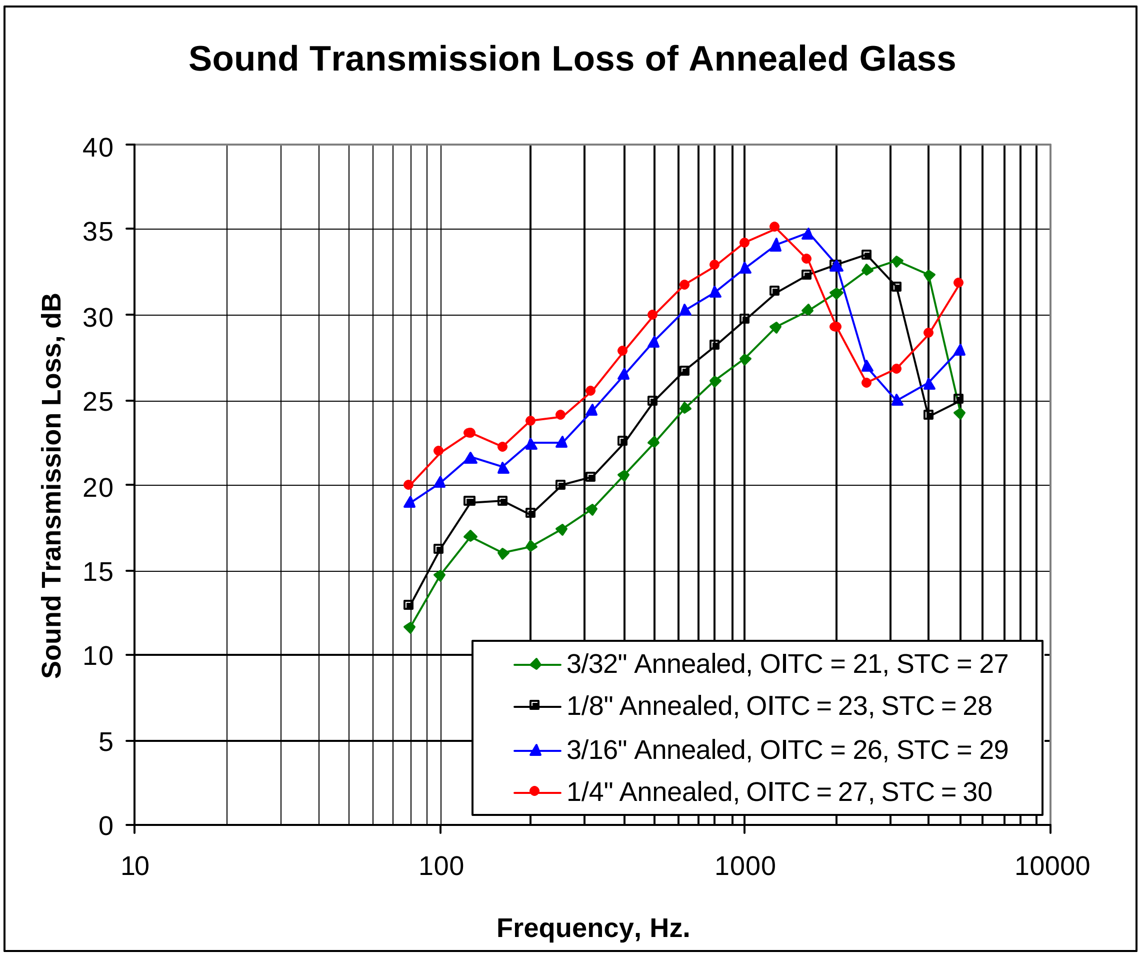

Figure 1.6.1 - Coincidence Dip for Various Glass Thickness

NOTE: *The OITC rating is the Outdoor-Indoor Transmission Class rating which is defined in section 2.2. The STC rating is the Sound Transmission Class rating which is defined in section 2.1. The methods used to calculate these ratings are explained in Appendix A1.*

Mass-Air-Mass Resonance
It is also possible to have degradation in TL performance due to "mass-air-mass" resonance. A specific combination of glass thickness and air space gap can result in a condition whereby the sound transmission loss is reduced at a particular frequency. The air space virtually acts as a spring between the glass lites and it aides in the transfer of vibration energy from one layer to the other. The mass-air-mass resonant frequency (F_r) can be determined through the following relation:

Eq. 3: $F_r = (1150 \times \sqrt{(t_1 + t_2)}) / \sqrt{(t_1 \times t_2 \times d)}$

Where: t_1, t_2 are the respective glass lite thickness and d is the airspace gap in millimeters

If specific frequencies within the acoustical spectrum are to be addressed, IG design should be such that the mass-air-mass resonant frequency does not fall within the range of concern. The use of larger air spaces will move the mass-air-mass resonance dip to a lower frequency as seen below in Figure 1.6.2. Equation 3 correlates well with the actual measured data listed below.

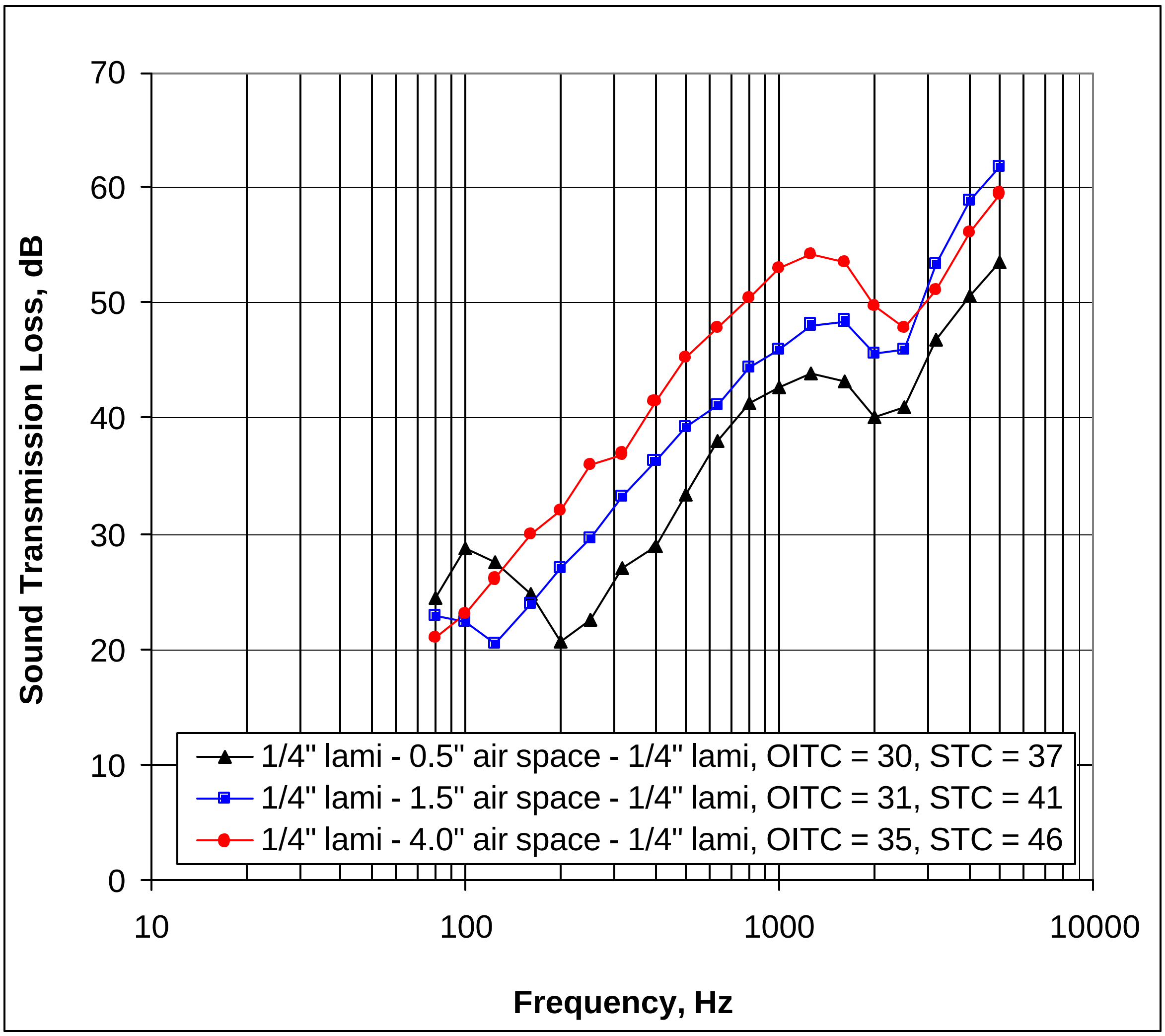

Figure 1.6.2 - Shift in Mass-Air-Mass Resonance with Larger Air Spaces

1.7 Flanking

Flanking is basically described as sound transmission from the source to the receiving location by a path other than through the test specimen. In a laboratory environment, the flanking problems can be significantly reduced and virtually eliminated. For the ASTM E90 test method, the laboratory initially needs to determine the sound transmission loss (TL) of the filler wall surrounding the test specimen. The filler wall is usually designed to have a much higher sound transmission loss than the specimen being tested. The filler wall sound transmission loss test data is used as a correction in the calculation of the window TL.

The laboratory also needs to determine the flanking limit between the two test chambers when testing high sound transmission loss specimens. Flanking noise can not only travel through the filler wall but can also be transmitted through the surrounding walls as shown in Figure 1.7.1 below. Laboratories need to have a significant amount of structural isolation or vibration breaks between the two test chambers.

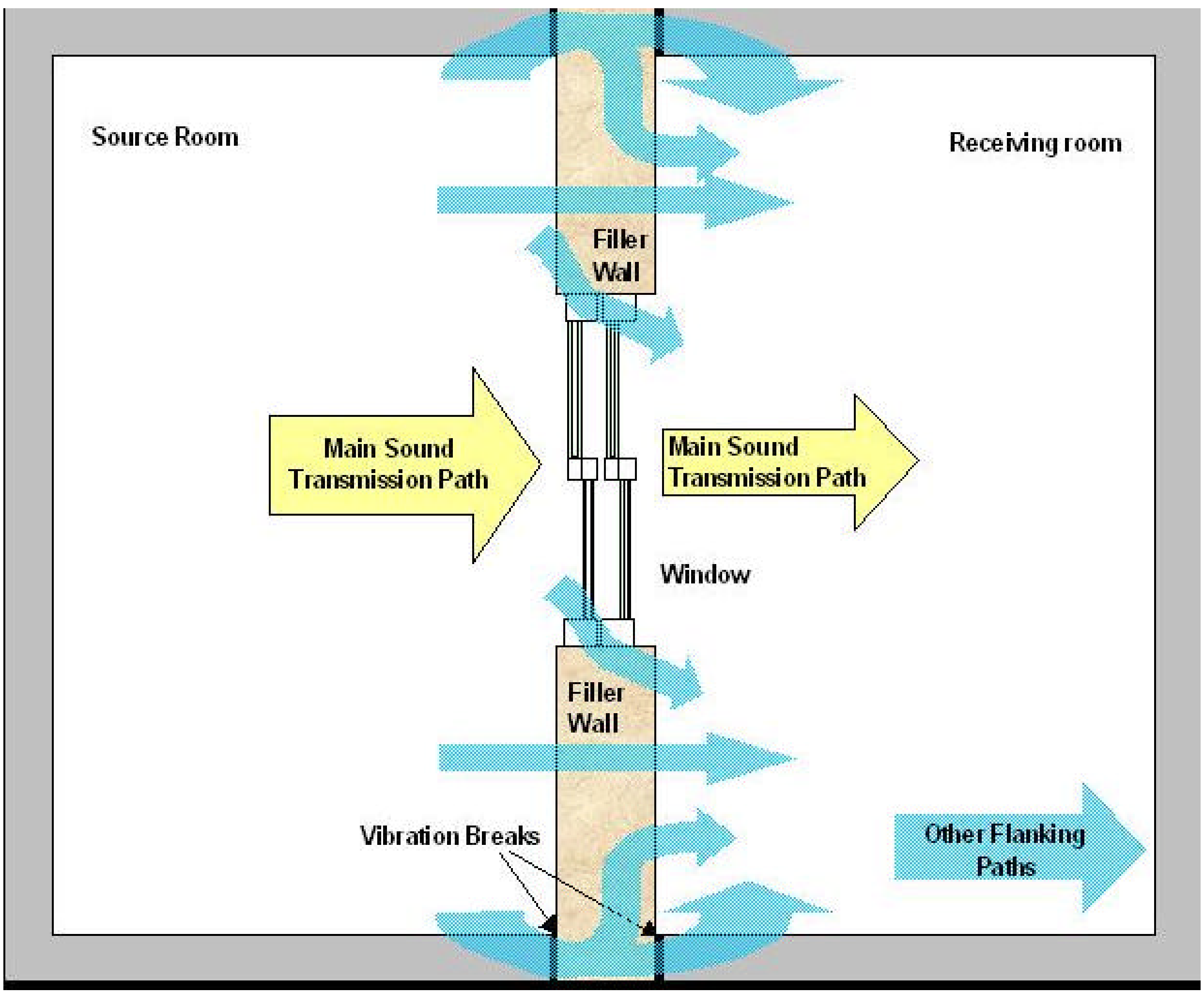

Figure 1.7.1 - Flanking Effects on Sound Transmission Loss in the Laboratory

A building facade is usually made up of many elements, such as walls, windows, doors, vents, air conditioners, etc. If you are trying to determine the sound transmission loss of a window in a facade, and the surrounding elements have a lower sound transmission loss than the window, you will have a flanking problem and will not be able to determine the true transmission loss of the window itself. Figure 1.7.2 shows the sound transmission paths for a common residence.

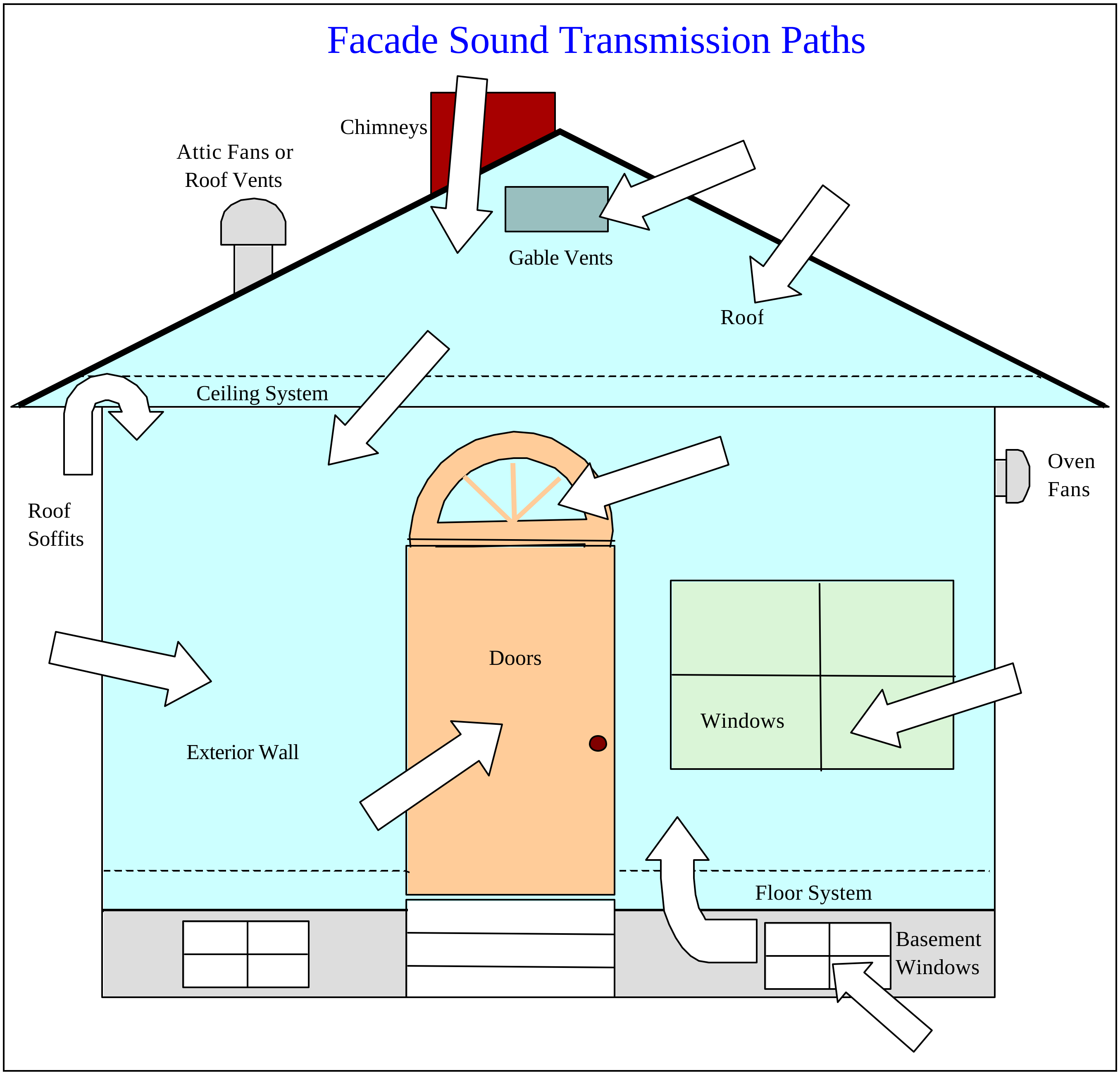

Figure 1.7.2 Residential Flanking Problems

Fenestration installation may affect overall building performance. ASTM C919 addresses the contribution of sealing small gaps between the interfaces of materials to reduce sound. Using foam, sealants or other materials to fill the gap between the window frame and the rough opening may reduce sound transmission.

In commercial applications, the spandrel areas of a curtain wall assembly can provide a flanking problem. The transmission loss of the spandrel area needs to comparable to the TL of the curtain wall assembly, or the interior floor/ceiling assemblies need to be modified with additional mass and leakage paths need to be sealed. Figure 1.7.3 shows an example of an interior floor/ceiling assembly and its associated flanking paths.

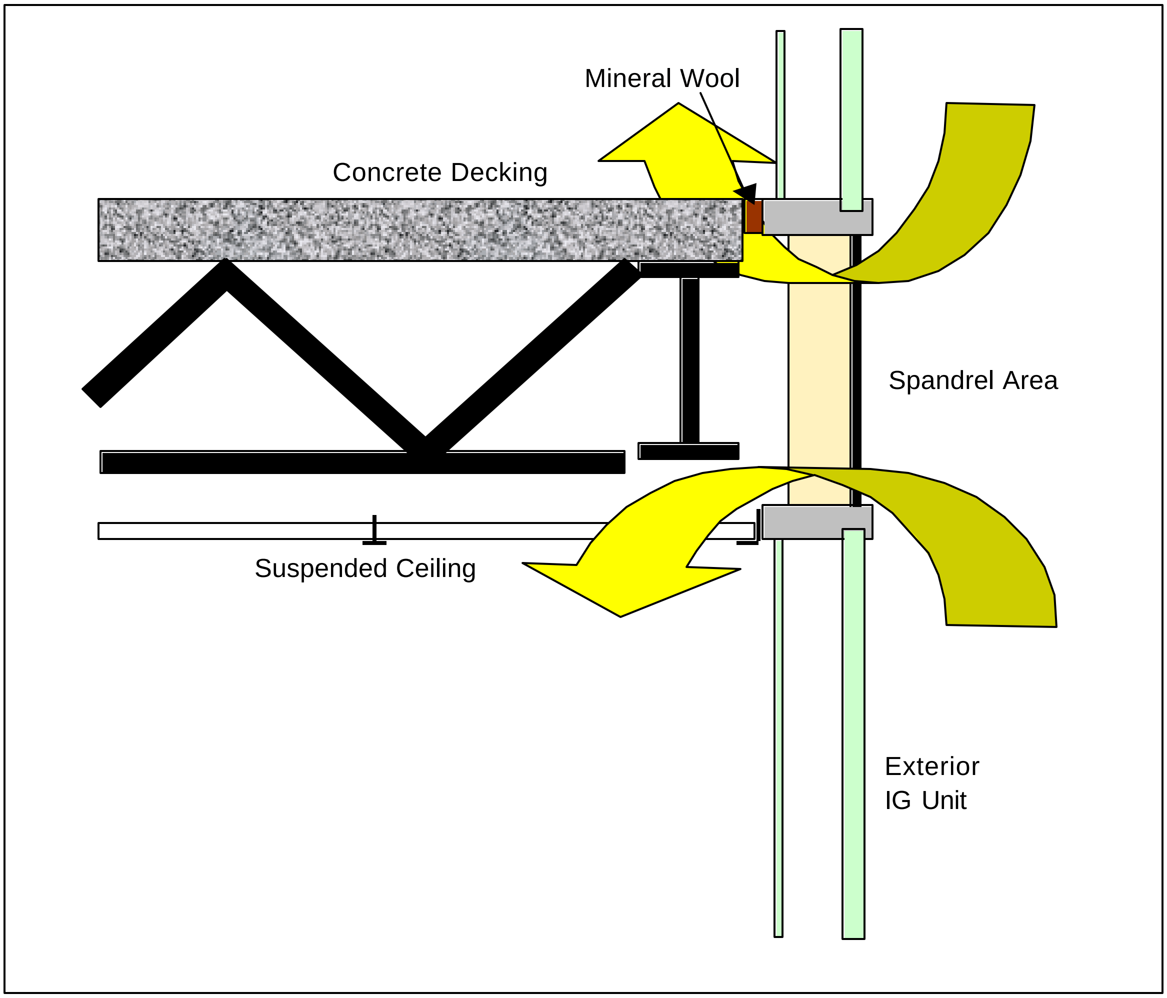

Figure 1.7.3 - Flanking Paths for a Curtain Wall Assembly

A layer of gypsum board covering the interior side of the insulated spandrel panel can reduce sound transmission through this area. The gypsum board must be sealed to the upper and lower curtain wall sections with an acoustical sealant.

1.8 Noise Reduction, Normalized Noise Reduction & Sound Transmission Loss

Noise Reduction

Noise Reduction (NR) is basically the difference in sound levels between two rooms inside a building. Noise reduction tests are usually conducted in the field on existing constructions. The pair of rooms could be located on opposite sides of a wall partition or they could be positioned with one above the other. The noise reduction measurement evaluates not only the sound passing directly through the common wall or floor/ceiling but also the flanking sound, which travels through the side walls, floors and/or ceilings. For testing purposes, the room where the noise is being generated is called the source room and the other room is referred to as the receiving room. From the values of NR, the Noise Isolation Class (NIC) rating can be calculated in accordance with ASTM E413.

Normalized Noise Reduction

Normalized Noise Reduction (NNR) is the difference in sound levels between two unfurnished rooms. The NNR is similar to the NR except that the sound absorption of the receiving room needs to measured and used in the calculation. The NNR is used to predict the noise isolation that would be expected between two normally furnished rooms. From the values of NNR, the Normalized Noise Isolation Class (NNIC) rating can be calculated in accordance with ASTM E413.

Sound Transmission Loss

Sound Transmission loss (TL) is a measurement of the sound isolation of a building element, such as a window, door, or wall partition. This test is usually conducted in a laboratory where flanking problems can be minimized. Laboratory sound transmission loss tests are conducted in accordance with ASTM E90 or ISO 140 part 3 (see Appendix A5 for more details). This test can also be conducted in the field but eliminating the sound flanking problems is difficult or sometimes impossible. The field sound transmission loss (FTL) tests are conducted in accordance with ASTM E336 or ISO 140 part 4(see Appendix A4 for more details). The TL test requires the measurement of the source and receiving room SPL's and the sound absorption in the receiving room.

The ASTM sound transmission loss (TL) or ISO sound reduction index (R) is calculated as:

Eq. 4: $TL = L_1 - L_2 + 10 \log S/A$

$R = L_1 - L_2 + 10 \log S/A$

Where:

L_1 is the average sound pressure level in the source room in decibels.

L_2 is the average sound pressure level in the receiving room in decibels.

S is the area of the test specimen in square feet or square meters.

A is the absorption of the receiving room in sabins.

To determine if flanking problems exist in field applications, the building element would need to be covered with a flanking screen consisting of 3 to 4 inches of fiberglass insulation and a layer of gypsum board. If the flanking test is not conducted, the FTL results need to be referred to as the Apparent Field Sound Transmission Loss.

The TL, FTL or Apparent FTL data can then be used to calculate the STC, FSTC (Field Sound Transmission Class or Apparent FSTC ratings respectively in accordance with ASTM E413, as discussed in Section 2.1.

1.9 Outdoor-Indoor Level Reduction & Outdoor-Indoor Transmission Loss

Outdoor-Indoor Level Reduction (OILR) is basically the difference between the exterior sound pressure level and the interior sound pressure level. Outdoor-Indoor Level Reduction tests are conducted in the field on existing constructions. The outdoor and indoor measurements are conducted on opposite sides of a common facade. The OILR measurement evaluates the sound passing through all of the facade elements such as the wall, windows, doors, air conditioners, etc. The OILR measurement is conducted in accordance with ASTM E966 or ISO 140 part 5. There are several ways to perform the outdoor-indoor level reduction measurement. The most common is to use the flush microphone method with the sound projected at a 45 degree angle to exterior surface of the facade or facade element.

Outdoor-Indoor Transmission Loss (OITL) is a measurement of the sound isolation of a facade or facade element, such as a window, door, or wall partition. This test is conducted in the field, but eliminating the sound flanking problems is difficult or sometimes impossible. The OITL requires the measurement of the outdoor SPL, indoor SPL, and the indoor sound absorption. The area of the facade or the facade element (window, door, etc.) is also used in the OITL calculation. The OITL test is conducted in accordance with ASTM E966 or ISO 140 part 5 (see Appendix A4 for more details). To determine if flanking problems exist, the building element would need to be covered with a flanking screen consisting of 3 to 4 inches of fiberglass insulation and a layer of gypsum board. If the flanking test is not conducted, the OITL results need to be referred to as the Apparent Outdoor-Indoor Transmission Loss results. The OITL or Apparent OITL data can then be used to calculate the FOITC (Field Outdoor-Indoor Transmission Class) or Apparent FOITC rating in accordance with ASTM E1332 as discussed later in section 2.2.

The TL data from laboratory sound transmission loss tests (ASTM E90 or ISO 140-3) can also be used to calculate an OITC rating. The OITC rating from a laboratory test is usually higher than the OITC rating from a field test, due to the flanking problems.

1.10 Ldn & CNEL

Day-Night Average Sound Level, Ldn or DNL

The Day-Night Average Sound Level (Ldn) is commonly used to assess the noise levels for exterior and interior locations. This measurement is usually required to determine compliance to local, state and federal noise ordinances. This measurement is normally conducted for a minimum of 24 hours but yearly averages are not uncommon for the assessment of noise around airports. The daytime average is measured from 7:00 am to 10:00 pm. The nighttime average is measured from 10:00 pm to 7:00 am. A 10 dB penalty is added to the measurements conducted during the nighttime measurements. The Ldn measurements are conducted utilizing the A-weighted filter network of the sound level meter.

Day-Evening-Night Average Sound Level, Lden or CNEL

The Day-Evening-Night Average Sound Level (Lden) is used to assess the noise levels for exterior and interior locations and is primarily used in California where it is called the Community Noise Exposure Level (CNEL). This measurement is usually conducted for a minimum of 24 hours. The daytime average is measured from 7:00 am to 7:00 pm. The evening measurement is conducted from 7:00 pm to 10:00 pm. The nighttime average is measured from 10:00 pm to 7:00 am. A 5 dB penalty is added to the measurements conducted during the evening measurements. A 10 dB penalty is added to the measurements conducted during the nighttime measurements. The Lden or CNEL measurements are conducted utilizing the A-weighted filter network of the sound level meter.

1.11 Noise Criteria (1)

Background noise in building spaces, produced by mechanical systems and sound transmission from exterior activities, are not limited by any specific regulation or agency. Instead, the building design profession has, through various organizations, established design criteria for noise in architectural spaces. The most commonly used set of criteria is that recommended by the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE). Background noise criteria suggested by ASHRAE are expressed in terms of acceptable ranges of Noise Criteria (NC).

Noise Criteria curves, better known as NC curves, are curves of approximate equal perceived loudness for sound over the audible frequency range. Figure 1.11 displays a family of NC curves. In order to provide some perspective on the significance of NC levels, Figure 1.11 also shows the equivalent A-weighted sound pressure levels corresponding to each NC curve. Also indicated is the subjective loudness for ranges of background noise spectra, expressed as ranges of NC curves, in a typical office environment.

The appropriate NC range to be used for the design of a facility can be taken from the criteria recommended in Table 1.11. It should be noted that Table 1.11 provides ranges of acceptable background noise levels in buildings. It is recommended that the upper limit of the range not be exceeded to avoid excessive noise exposure that could precipitate complaints from occupants. On the other hand, sound levels should not fall below the lower limit of the ranges given in order to avoid problems of inadequate speech privacy.

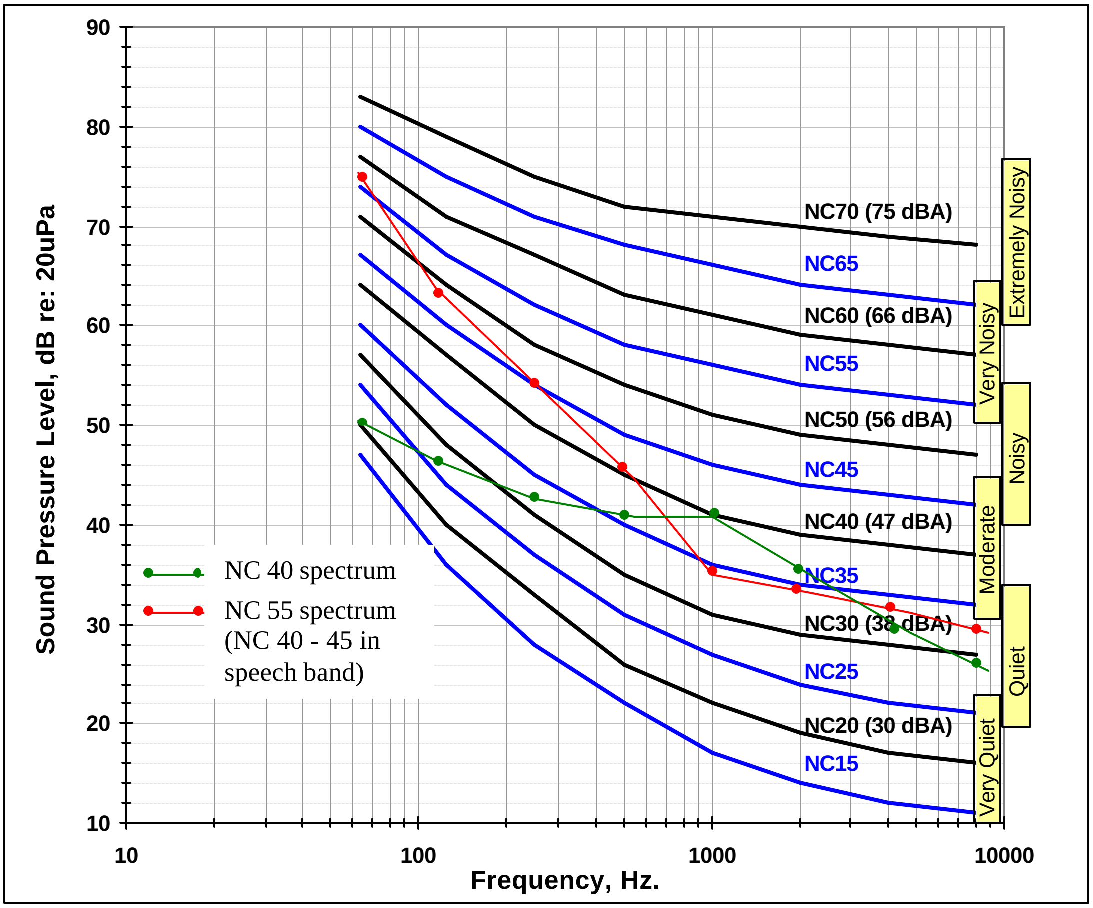

Figure 1.11 - Noise Criteria Curves

Recommended Noise Criteria Levels for Various Types of Buildings					
Classification	**Type of Area**	**NC Range**	**Classification**	**Type of Area**	**NC Range**
Quiet	Audiometric Rooms	< 15	**Noisy**	Public Circulation	40 - 45
NC 15 - 30	Anechoic Rooms	< 15	**NC 40 - 55**	Computer Rooms	40 - 45
	Recording Studios	20 - 25		Service Areas	40 - 45
	Broadcasting Studios	20 - 30		Stores and Shops	40 - 50
	Private Hospital Rooms	30		Supermarkets	40 - 50
	Doctors Offices	30		Restaurants	45
	Executive Offices	30		Stenography Rooms	50
	Libraries and Courtrooms	30		Banking Areas	50
	Churches	25 - 30		Kitchens	55
	Lecture and Classrooms	25 - 30			
	School Auditoriums	< 30	**Very Noisy**	Arenas and Stadiums	45 - 55
	Assembly Halls	< 30	**NC 55 and up**	Airports	55 - 65
	Legitimate Theater	25		Railroad Stations	55 - 65
	Concert, Recital Halls	25 - 30		Parking Garages	55 - 65
	Private Residences	25 - 30		Accounting Rooms	65 - 70
	Apartments	25 - 30		Mechanical Rooms	70
				Industrial Areas	70 - 80
Normal	Conference Rooms	25 - 35		Highways	75
NC 30 - 40	Normal Private Offices	35 - 40		Expressways	75
	Open Plan Areas	35 - 40		Railroads	75
	Hospital Wards	30 - 35		Switchyards	75
	Hospital Operating Rooms	35 - 40		Airport Aprons	> 75
	Halls, Corridors & Lobbies	35 - 40		Airport Runways	> 75
	Laboratories	35 - 40			
	Movie Theaters	30 - 35			

Table 1.11 - Recommended Noise Criteria

2.0 SINGLE NUMBER RATINGS

2.1 STC & Rw

The Sound Transmission Class (STC) classification system used in North America was introduced in 1970 under ASTM E413 "Classification for Rating Sound Insulation". It is based on the amount of attenuation required to reduce each octave-based level of a somewhat arbitrary "standard household noise" spectrum (a composite of live speech, radio and television music and speech, vacuum cleaner noise and air conditioning noise) to match the NC-25 contour. The contour value corresponds roughly to the reduction, calculated as an A-weighted level difference, between the incident and transmitted sound power when a sound dominated by mid and high frequency energy is incident.

This procedure dramatically simplifies the process of comparing the acoustical performance of different products. Products with higher STC numbers perform better than products with lower numbers. The application of this procedure, however, expanded beyond its intended use. As stated in E 413's Scope:

"4.2 These single-number ratings correlate in a general way with subjective impressions of sound transmission for speech, radio, television and similar sources of noise in offices and buildings. This classification method is not appropriate for sound sources with spectra significantly different from those sources listed above. Such sources include machinery, industrial processes, and transportation noises such as motor vehicles, aircraft and trains."

The procedure of converting sound transmission loss (TL) data to an STC single rating number under ASTM E413 is described in detail in Appendix A1. The same procedure can be applied to field sound transmission loss data to produce a Field Sound Transmission Class (FSTC) rating. An 8 dB maximum deficiency rule protects against significant local weakness ("notches") in any portion of the TL spectrum covered by the contour.

The STC classification system performs adequately (rank orders products with acceptable accuracy) in situations where the incident sound is broadband and dominated by mid and high frequency sound energy (500 Hz and greater). Rank ordering of products is also successful for broadband sounds with somewhat lower frequency characteristics (e.g., automobiles, trucks and aircraft) if the TL performance of the product is free of low frequency TL "notches". The STC classification system begins to give spurious rank-ordering results when the incident sound is dominated by low frequency energy (125 Hz and below), such as in the case of railway, airport and highway noise.

The STC rating will usually provide the same ranking as the ISO Weighted Sound Reduction Index (Rw) if there are no significant notches in the TL spectrum. The term R, "sound reduction index," used in ISO R140-3, is equivalent to TL, "transmission loss," as described in the ASTM E90-97 procedure.

These procedures differ slightly in the frequency range used for determining the transmission loss. The American (ASTM) measurement range is 125 to 4,000 Hz, while the International Standard (ISO) is 100 to 3,150 Hz. The International Standard does not use the 8 dB rule for adjusting the contour curve in the calculation of Rw but requires that the maximum unfavorable deviation at any frequency be recorded if it exceeds 8 dB.

Being the first acoustical rating system available, STC is well entrenched in acoustical literature, building codes and many governmental regulations. Considerable educational effort will be required by the fenestration industry to modify and amend the use of STC by practitioners who are not noise control professionals. Remember that the single-number ratings are to be used as a guide rather than an absolute standard.

2.2 OITC & Rw+Ctr

The "Outdoor-Indoor Transmission Class" (OITC) rating was created within ASTM during the late 1980's as E1332, Standard Classification for Determination of Outdoor-Indoor Transmission Class in response to a perceived need for a more robust classification system that also performed adequately for low frequency incident sounds. Such sounds are common when a building is placed in close proximity to an airport, highway or a railway line.

An incident sound power spectrum was devised from an average between typical vehicular, aircraft and railway traffic spectra covering the frequency range from 80 Hz to 4000 Hz. Low frequency sounds in the 80 to 100 Hz range were found to contribute significantly to the perception of loudness of the transmitted sound in some cases. Using the ASTM E1332 procedure (also found in detail in Appendix A1) the TL of the product is subtracted on a one-third octave band basis to give the transmitted sound power level spectrum. The OITC rating is calculated as the difference between the A-weighted value for the incident and transmitted spectra. Control against frequency regions of weak TL notches is implicit in the method: the A-weighted level calculation correlates with loudness perception of low level sounds.

The OITC classification system performs adequately (rank-orders product with acceptable accuracy) in situations where the incident sound is broadband and dominated by low frequency noise. Thus, it is appropriate for vehicular traffic, aircraft traffic and railway traffic noise sources. The OITC classification system begins to give spurious rank-ordering results when incident sound is dominated by very low frequency energy (63 Hz and below).

The OITC rating is usually 5 to 10 dB lower than the STC rating, due primarily to the calculation differences between ASTM methods E1332 (OITC) and E413 (STC), with the difference increasing with sound isolation performance. This is indicative of the generally poorer performance of acoustical products against low frequency incident sound that is assumed to be dominant for the purposes of the OITC rating system. After the introduction of OITC, it was reported at ASTM that representatives of manufacturers using the OITC rating had to educate their customers as to why the ratings of their products had "dropped" so dramatically.

Of note concerning existing TL data for fenestration products, older data may not include the 80 and 100 Hz bands rendering it impossible to calculate the corresponding OITC value. Some laboratories also may not have equipment necessary to test at these lower frequencies. The OITC rating is relatively new in acoustical literature, building codes and many governmental regulations related to sound isolation. This document is intended to assist the educational effort necessary to ensure the use of OITC ratings in fenestration products requiring control of transportation and industrial noises.

The International Standards Organization (ISO) has also developed a single number rating called the Rw+Ctr, which is to be used for building facades that are exposed to transportation noise. The ISO 717 procedure uses a slightly different transportation noise spectrum than the ASTM E1332 method, but the Rw+Ctr and OITC ratings compare favorably when the same frequency range is used. The ISO 717 procedure specifies four different frequency ranges for the Rw+Ctr rating; 50 – 3150 Hz, 100 – 3150 Hz, 100 – 5000 Hz and 50 – 5000 Hz. The frequency range for the rating will be based on the existing exterior noise spectrum. The rating will be reported as Rw+Ctr for the standard frequency range of 100 to 3150 hertz or it will be reported as Rw+Ctr, 50-3150, Rw+Ctr, 100-5000, or Rw+Ctr,50-5000 for the other frequency ranges.

2.3 Comparison of Rating Systems

Both of the classification systems described (STC and OITC) are based on sound transmission loss (TL) data obtained in accordance with ASTM E90, Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions. High values mean small amounts of transmitted sound and vice versa. OITC is principally controlled by low frequency performance. STC is principally controlled by mid to high frequency performance. Reported data typically spans a range from 80 to 5000 Hz, one-third octave bands, inclusive. Some laboratories report TL data at lower (down to 50 Hz) and at higher frequencies (up to 8000 Hz).

The most correct and thorough way to evaluate the acoustical isolation performance of a product for a particular application is to compare the spectrum of incident sound energy with the TL of the candidate product to allow an estimate of the transmitted sound. The size of the sound transmitting element, the frequency response and sound absorbing properties of the receiving space (the space to be isolated) as well as the presence or absence of other acceptable noises which could mask intruding sounds should also be taken into account.

A noise control professional usually performs this estimate on a one-third octave band or octave band basis depending on the noise sensitivity of the application. This level of detail is, however, too great for those outside of the noise control profession who would generally prefer to pick products based on a single number classification system. It is sufficient for the classification to provide a basis for comparison of products; it does not necessarily produce any useful engineering or design information.

What a single number rating gains from ease of use it looses in range of applicability. The reduction from 18 one-third octave bands of data to a single number means that detailed information has been discarded and that generalized assumptions have been substituted for the discarded details. The result is that single number classification systems perform adequately over a range of generalized cases but perform extremely well in almost none. The selection of acoustical products by comparison of single number ratings is only an appropriate design approach in situations **where an acoustical rating is not critical**.

Of the classification systems discussed, OITC is more robust than STC in that it has the additional capability to preserve appropriate rank orderings for certain lower frequency sounds. If low frequency sound is present in a lesser proportion than indicated by the basic assumptions of OITC (vehicular, aircraft and railway noise), the relative advantages of the OITC method dissipate. In cases where the incident sound band is narrow in range (such as a tone, instead of a broadband noise), neither the OITC nor the STC methods should be trusted. If actual conditions do not correspond to those assumed the classification system can produce misleading comparisons.

The ASTM E90 Sound Transmission Loss test is performed in a laboratory, where very diffuse sound fields are present on both sides of the test specimen. This is the only, appropriate test method that will provide an accurate STC rating. The OITC rating can also be calculated from the E 90 test results, provided the test facility is qualified and calibrated down to at least 80 Hz.

AAMA 1801 allows the user the means to rate a fenestration product utilizing the OITC number. Using this OITC rating number, a manufacturer may certify and label the product for acoustical performance under ANSI/AAMA/NWWDA 101/I.S.2. The STC number and the plotted STL spectrum for the product are also provided from this document.

As noted, single number ratings can be extremely useful when evaluating the general performance of a product or when comparing different products to each other. An important point, though, is that these numbers can be misused. Single number classification systems produce rank ordering of products based on certain generalized assumptions, which, like the concept of the "average" person, apply somewhat in many cases but precisely in almost no case. OITC and STC are essentially weighted averages of the performance of the product. These numbers do not provide information on the product at specific ranges within the overall tested frequency spectrum. It is possible to have two products having the same OITC or STC values perform significantly different within a given frequency range. Application requirements may demand a product to perform extremely well in the high-end frequencies while not having much need of significant low frequency performance. Utilizing either rating number alone to evaluate a product's performance will not provide the user sufficient information to make an appropriate product decision. For this reason, it is extremely important that the specifier and user of acoustical control products understand the requirements of the application and utilize the STL data of a product across the entire frequency spectrum.

Figure 1.7 compares the sound transmission loss characteristics of a vinyl double hung window with clear/clear and clear/laminated glazing, respectively. Note that for frequencies above approximately 950 Hz, the clear/clear glazing actually performs better than the clear/laminated glazing (i.e. greater transmission loss across the unit in this frequency range). When performing either the curve fitting of E 413 or the numerical manipulation of E 1332, however, the clear/laminated window achieves a higher rating than the clear/clear unit. If an application requiring greater attenuation in the 1000+ Hz range were required and only the single number rating system were used for comparing these windows, the wrong window would be picked for the job! In this specific case, the clear/clear unit would actually be more effective than the clear/laminated unit for this application. This illustrates but one example of the danger of relying on the unit rating number alone without evaluating the full spectrum performance characteristics of the unit in correlation with the application.

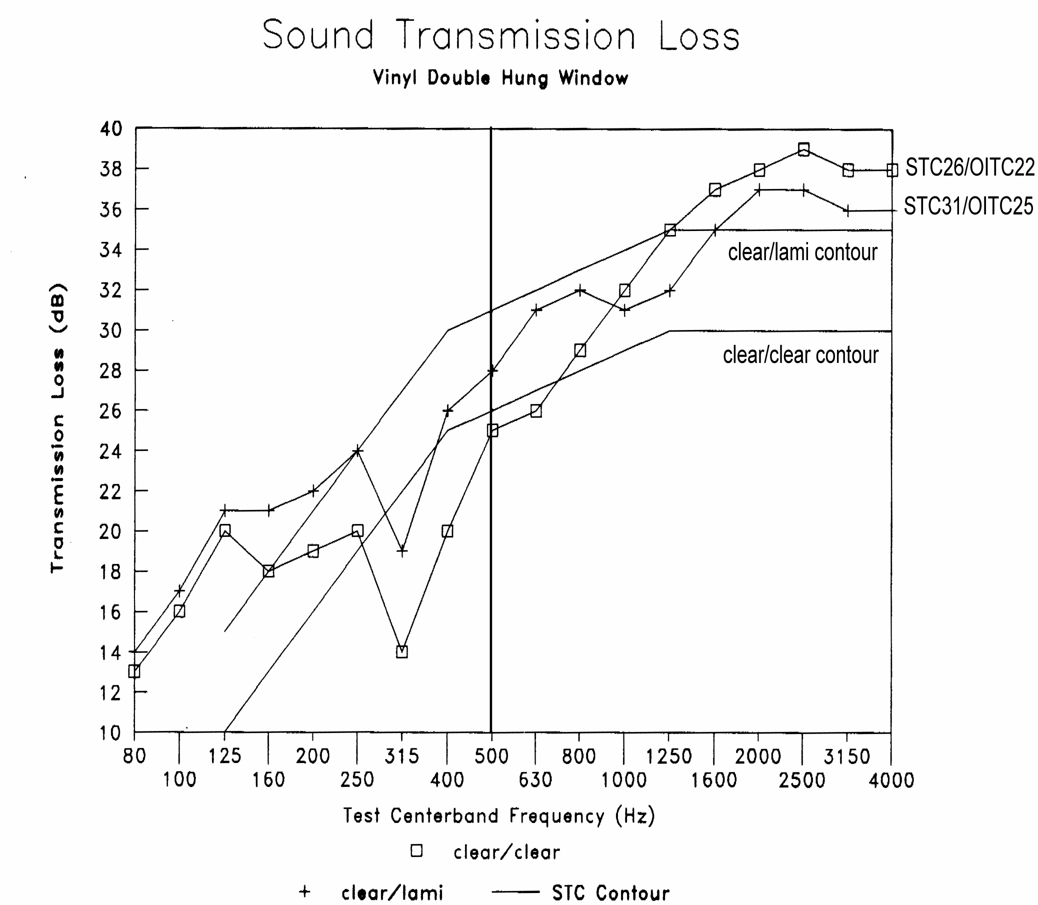

Figure 1.7

3.0 GLASS PERFORMANCE

3.1 Glass Thickness

Increasing the thickness of the glass lites in an insulating glass will improve the sound transmission loss. In figure 3.1 shown below, one IG has almost double the mass of the other IG. If only the Mass Law was used to predict the improvement, by doubling the mass, you would expect a 6 dB improvement. There is approximately a 6 dB improvement in some of the mid frequencies but the STC and OITC ratings only increased by 3 dB. This is due to the mass-air-mass resonance and coincidence effect at the low and high frequencies respectively.

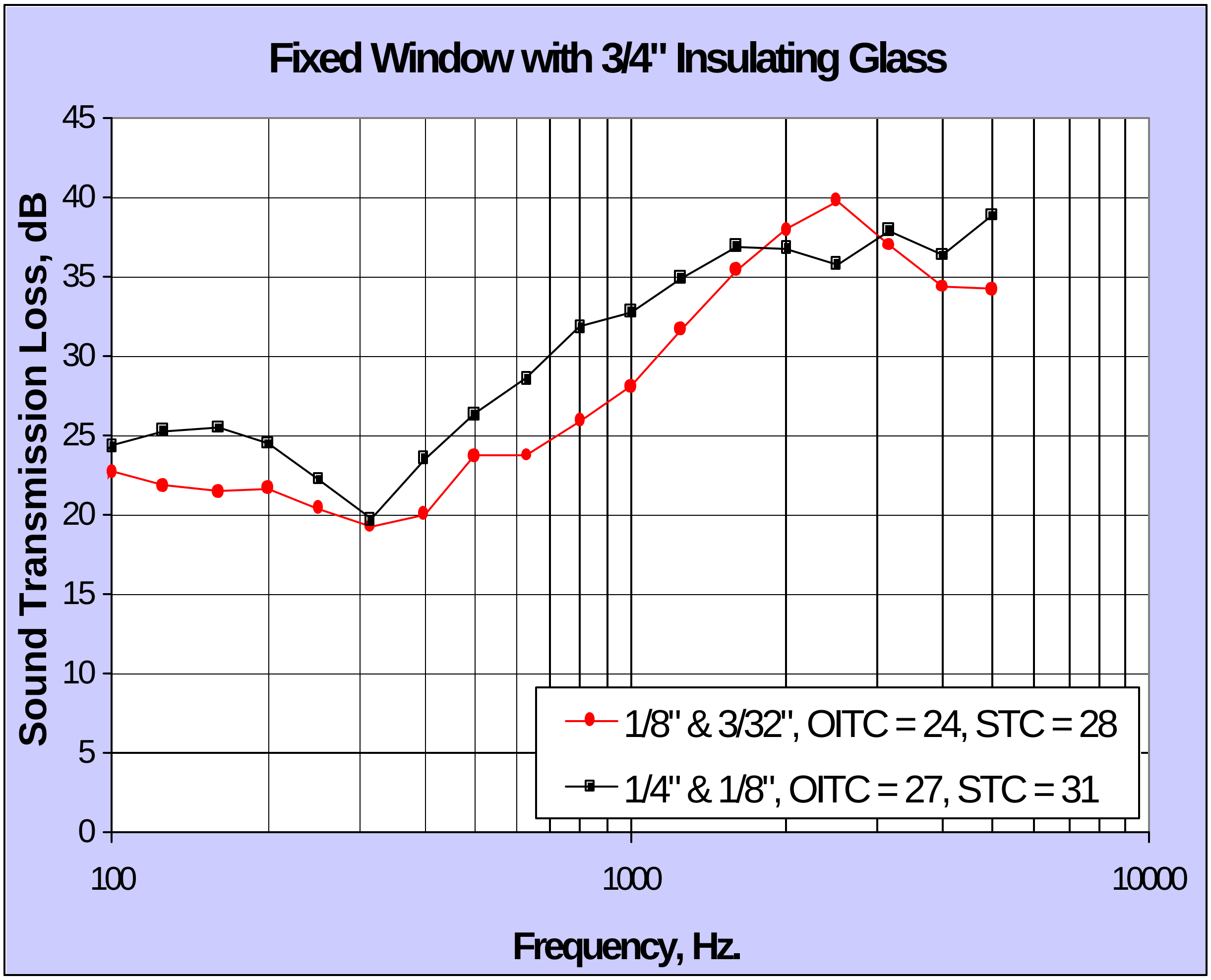

Figure 3.1 - Glass thickness (mass) effect on sound transmission loss

3.2 Annealed vs. Laminated

Figure 3.2 shows the sound transmission loss improvement that can be achieved by using laminated glass in insulating glass units. Laminated glass is two lites of glass bonded together with an interlayer material. This configuration provides constrained layer damping, which significantly reduces the resonance at critical frequency. The sound transmission loss of laminated glass is highly affected by the temperature of the glass during the test. Higher glass temperatures produce higher sound transmission loss test results, as shown in Figure 3.3 of the next section. AAMA and ASTM have made recent changes to their transmission loss test procedures, which require that fenestration products be tested within a specific temperature range. This requirement will provide better reproducibility of test results among acoustical laboratories.

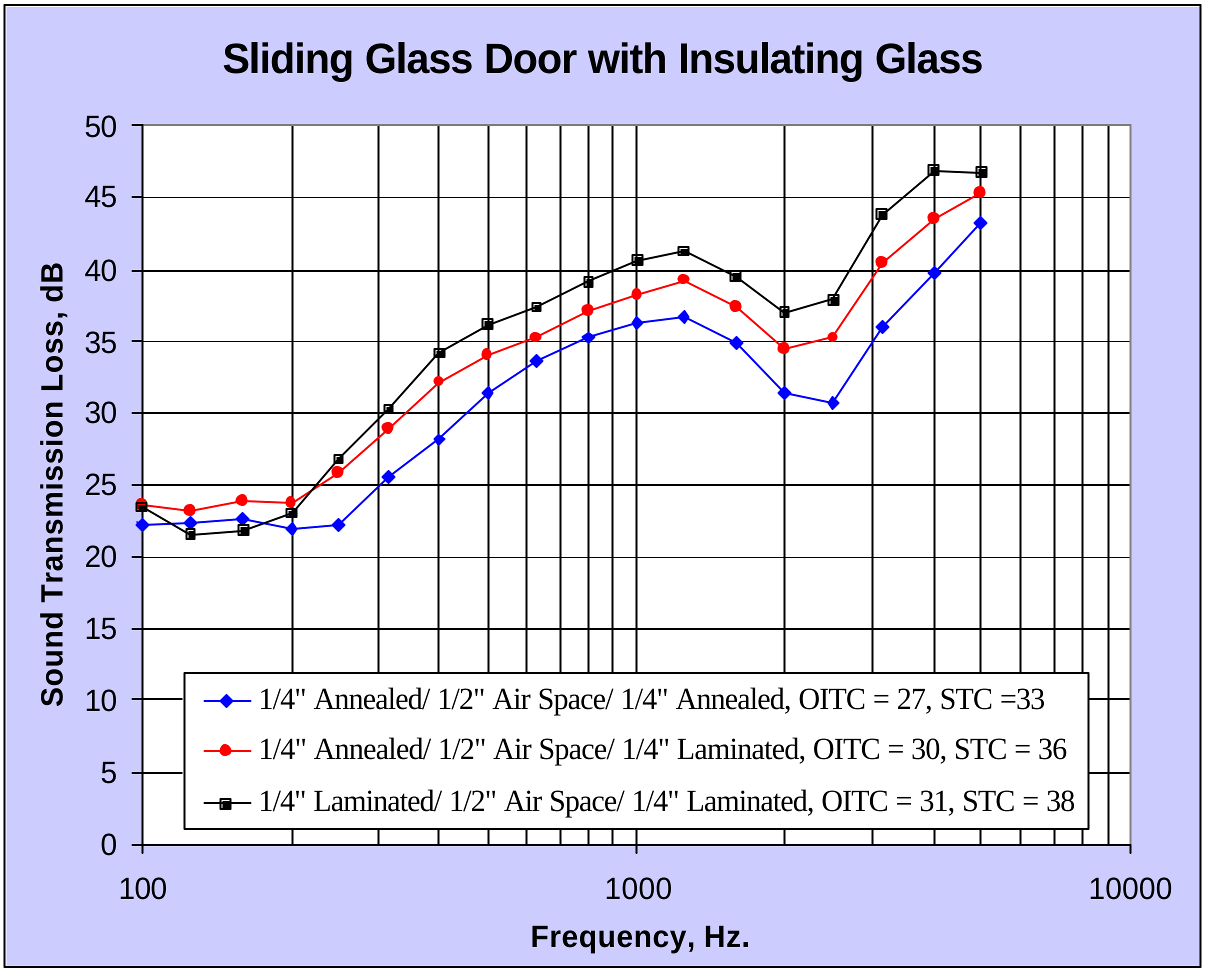

Figure 3.2 - Annealed versus laminated glass performance

3.3 Temperature Effects

Figure 3.3 depicts the effects of temperature on laminated glass performance. These tests were conducted during the AAMA round robin testing of a fixed window with two lites of 1/4" laminated glass separated by a four inch air space. The sound transmission loss improved as the glass temperature was increased, especially at the coincidence dip frequency of 2500 hertz. These test results were provided by Architectural Testing Incorporated. At lower temperature ranges, similar effects were documented by the University of Alberta, Canada.

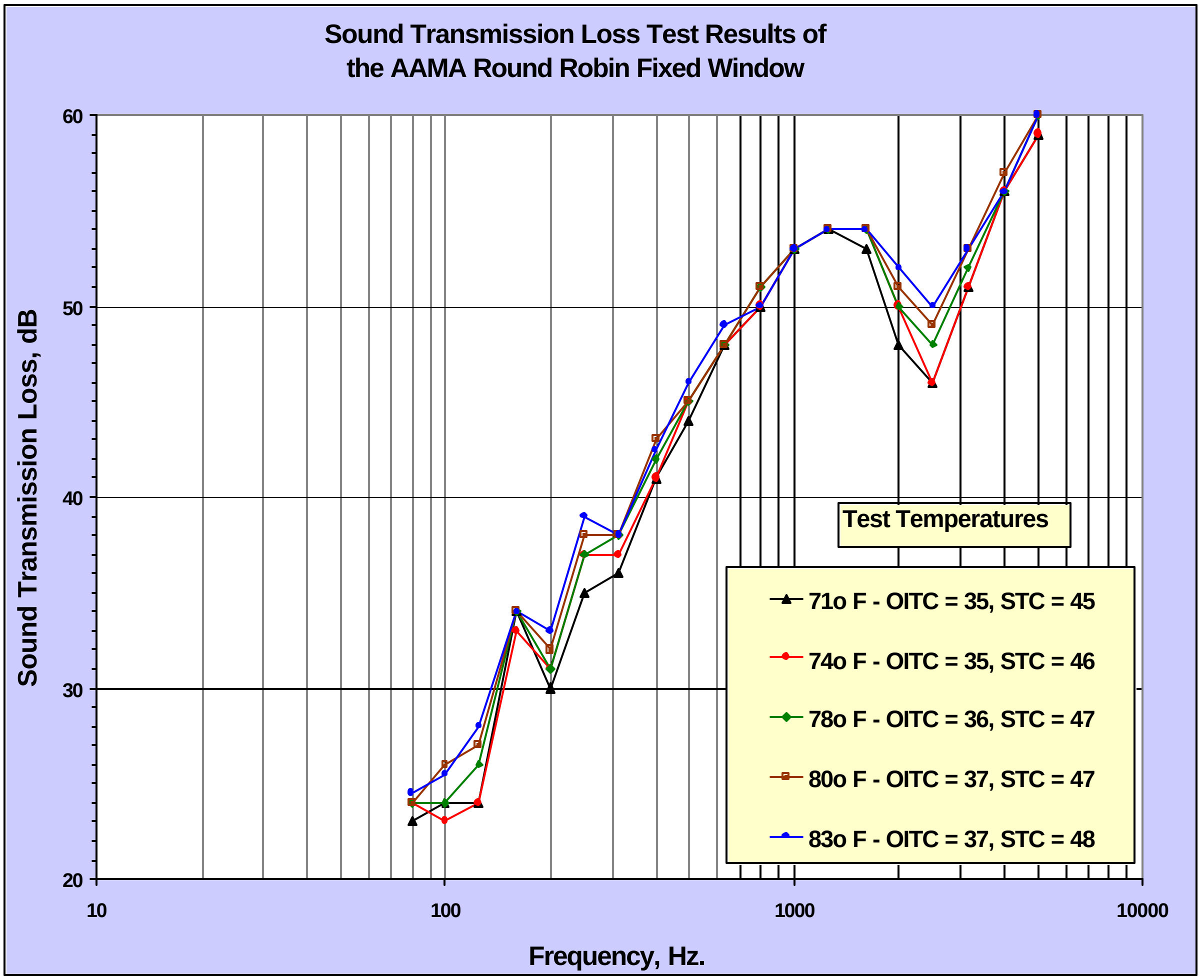

Figure 3.3 - Temperature effect on laminated glass

3.4 Air Space

Increasing the air space between two lites of glass in a window unit can improve its sound transmission loss. The rule of thumb is, if you double the air space, you will get a 3 dB improvement. This works pretty well for the STC rating and with air spaces over 3/4" but does not work well with the OITC rating.

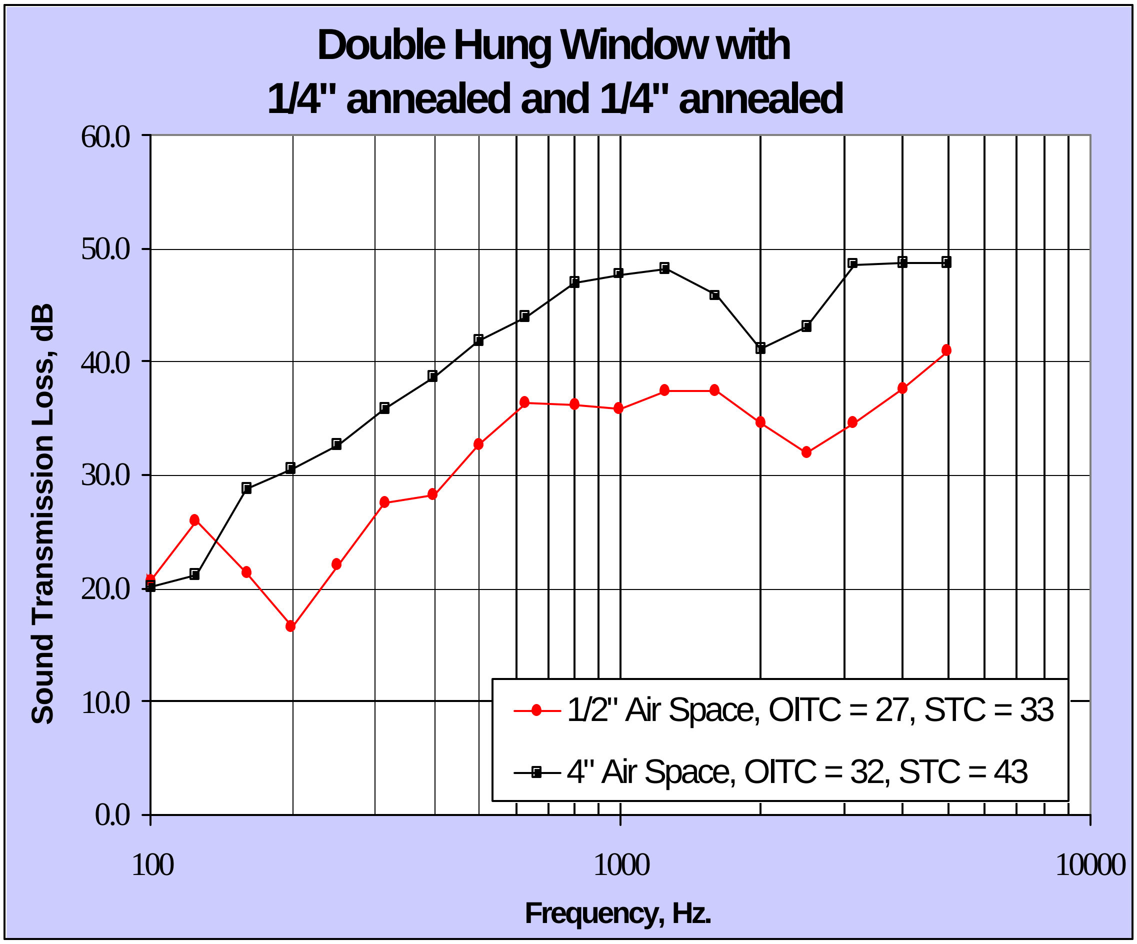

Figure 3.4 - Air Space Effect on Sound Transmission Loss

3.5 Suspended Films

The use of suspended films in insulating glass units can improve the sound transmission loss properties of fenestration products, especially in the mid frequency range of 300 to 3000 hertz which is where most speech occurs. Some improvement at the mass-air-mass and coincidence dip frequency can also be seen in Figure 3.5. This 1" insulating glass unit contained two 5/32" annealed glass lites separated by an 11/16" air space.

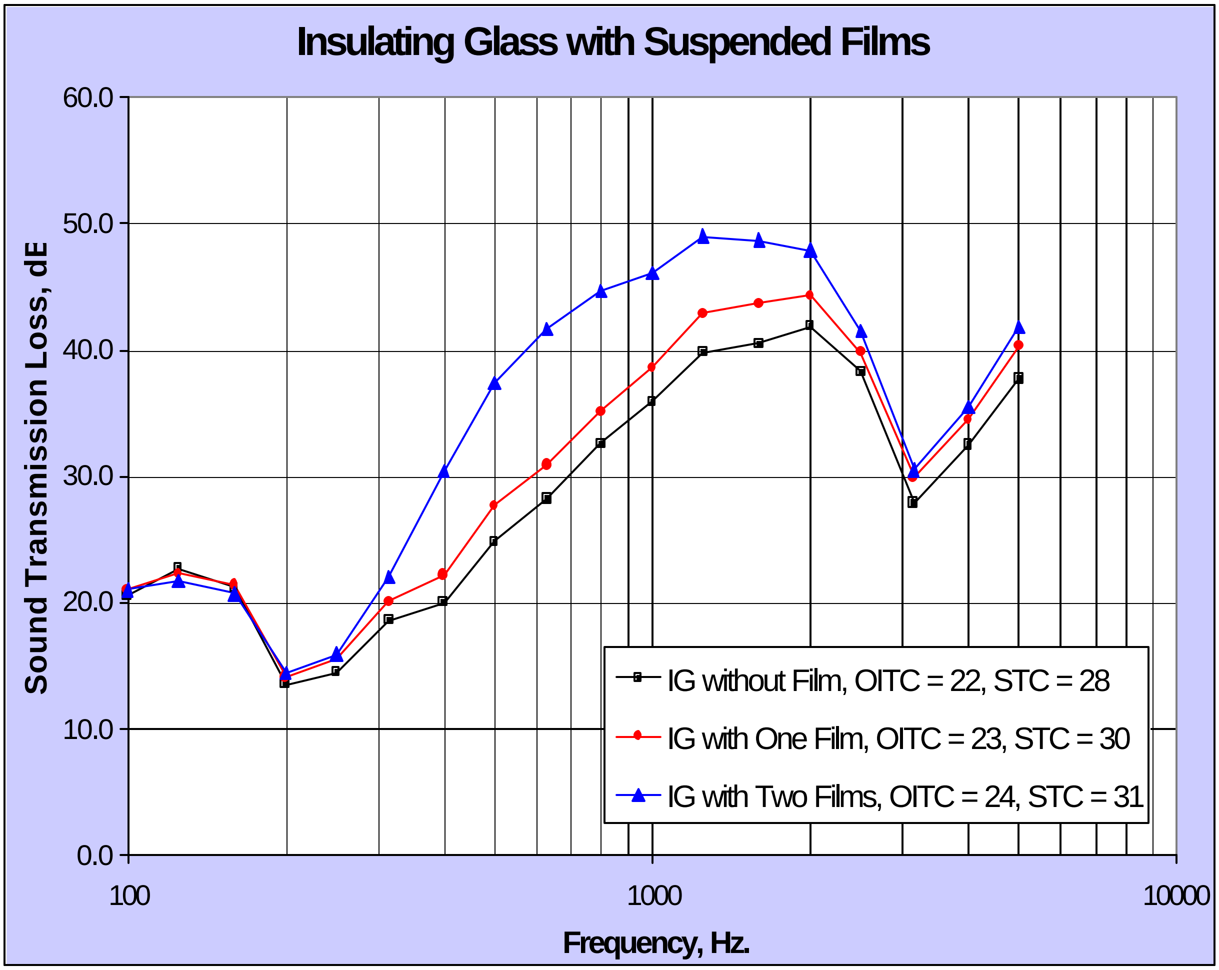

Figure 3.5 - Suspended films in insulating glass units

3.6 Gas Filling

The gas used inside an insulated glass unit can affect the acoustical properties of a fenestration product. The fixed window TL data depicted in Figure 3.6 shows the effect of filling the IG with air and argon gas. The STC rating did not change and the OITC rating only changed by one point. The shape of the TL curve however did change significantly at several frequencies. For low and high frequency noise reduction, the window with the air filled IG would perform better. For mid frequency noise reduction, the window with the argon filled IG would have superior performance.

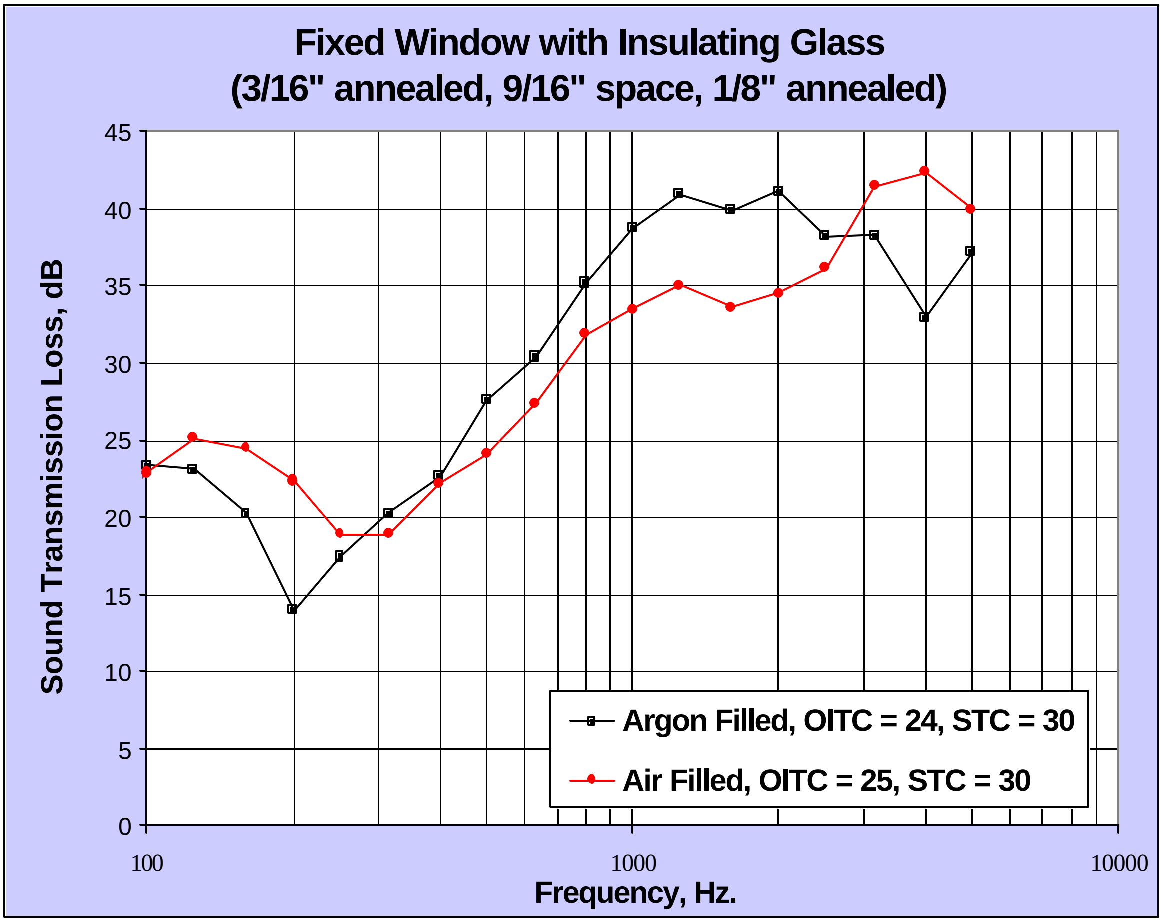

Figure 3.6 - Gas fill effect sound transmission loss

3.7 IG Spacer Systems

For insulating glass units, decoupling the two glass lites from each other will provide better sound transmission loss. As seen below in Figure 3.7, the softer foam spacer system outperformed the more rigid metal u-channel spacer system, at frequencies ranging from 1000 to 5000 hertz, which caused the STC rating to improve by 2 dB. The low frequency TL however was not affected by the spacer type so the OITC rating did not change

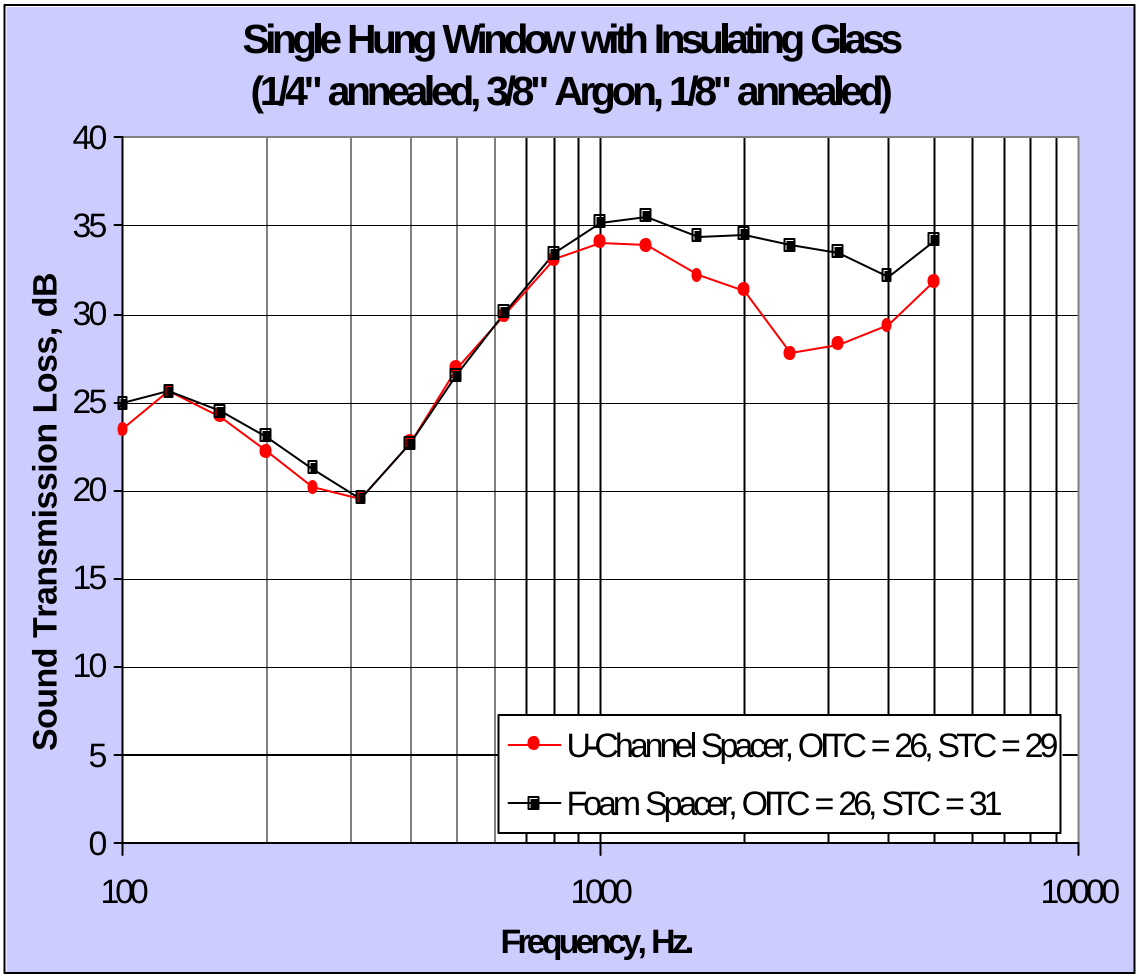

Figure 3.7 - Spacer Effect on Sound Transmission Loss

3.8 Edge Damping

Damping is the process of reducing the vibrations or resonance of a material. Edge damping takes places when a material is placed in direct contact with the perimeter of the test specimen. The bite or perimeter coverage and the type of material used will determine the amount of the damping. Figure 3.8 demonstrates the difference between sealing a glass panel with 1/8" foam glazing tape & wood blocks and then sealing the same glass panel with a 1/2" diameter bead of duct seal. Both sealing materials covered approximately 1/2" of the glass around the perimeter on both sides.

The glass panel sealed with duct seal material had a 3 dB higher STC rating than the glass panel sealed with foam glazing tape and wood blocks. The foam tape is a common glazing material for fenestration products. The duct seal material is dense mastic putty, which is commonly used to seal the perimeter of samples for acoustical tests but it is not used to glaze windows or other fenestration products. Glass panels and insulating glass panels should be tested with a glazing material that is more representative of the actual application. Using duct seal as a perimeter sealant will over-inflate the acoustical ratings and be misleading to window manufacturers.

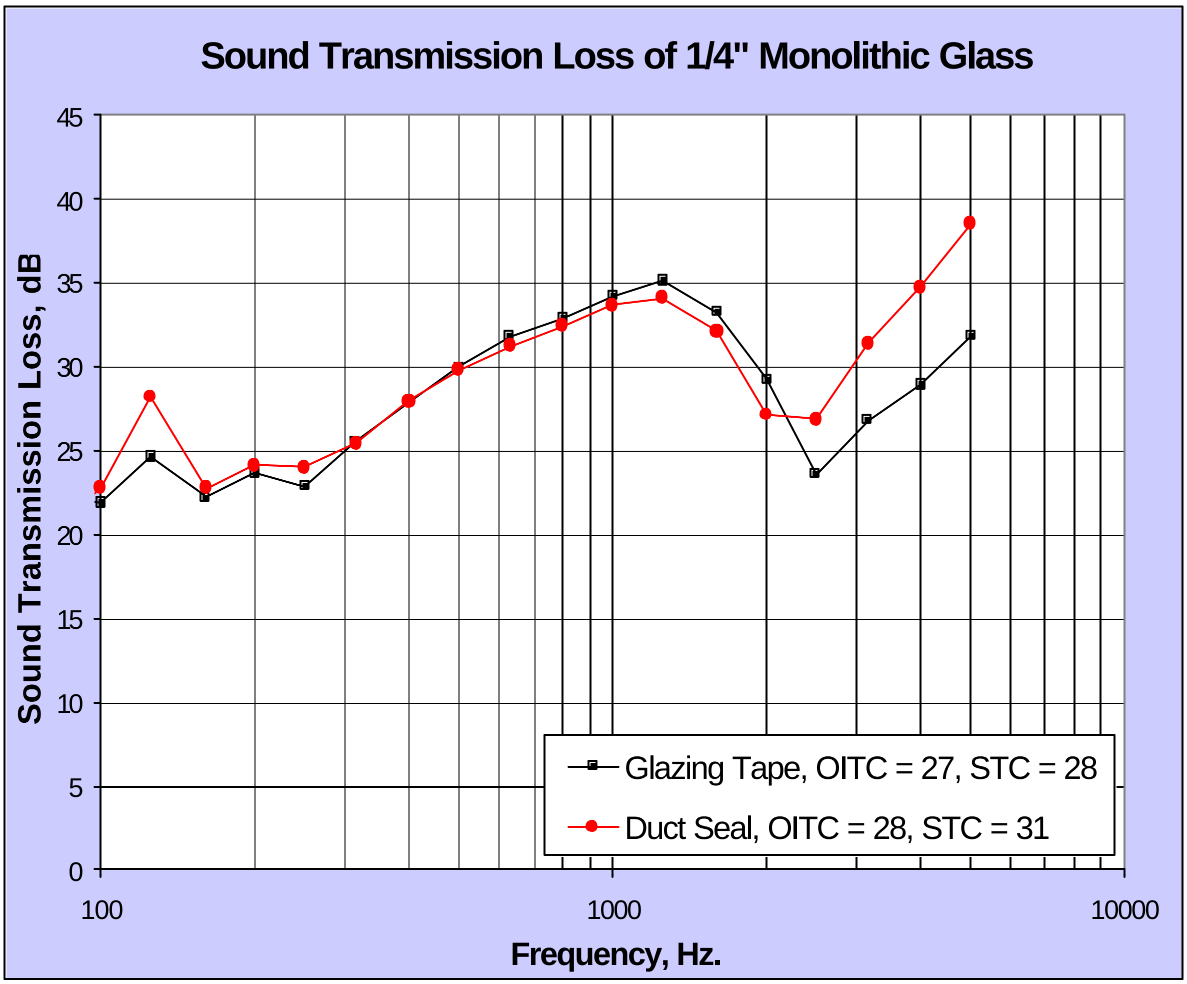

Figure 3.8 - Edge Damping Effect on Glass Panels

3.9 Glass Size

The sound transmission loss performance of glass is dependent upon the size of the test specimen. The glass stiffness changes with physical dimensions of the glass. A larger or thinner piece of glass is going to be more flexible than a smaller or thicker piece of glass. The more flexible it is, the more it will vibrate when it is exposed to a noise source, which will produce lower sound transmission loss values.

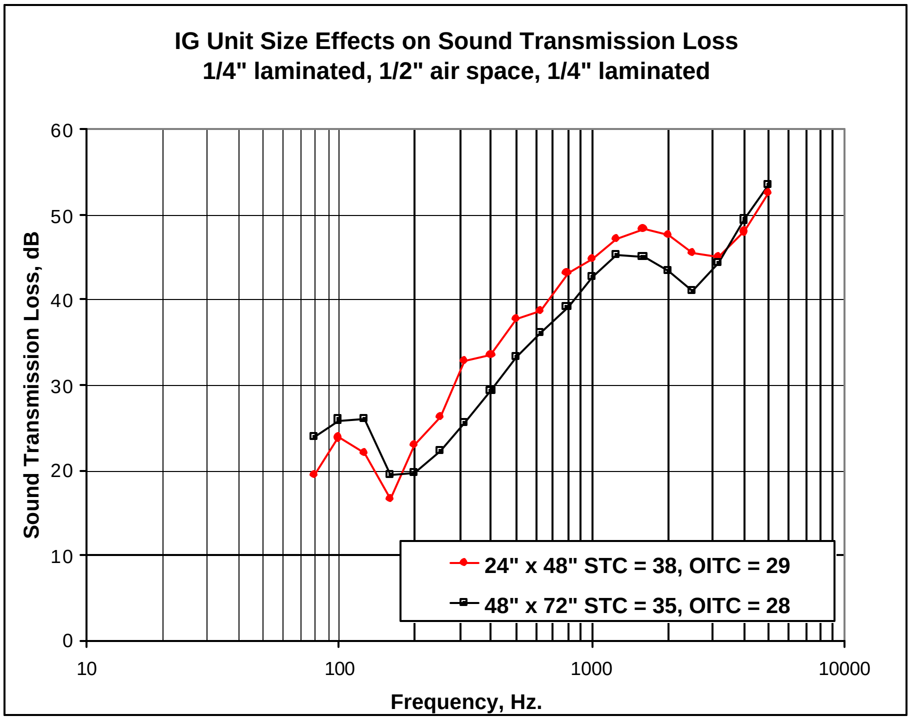

Figure 3.9.1 - Glass Size Effect for Annealed Glass

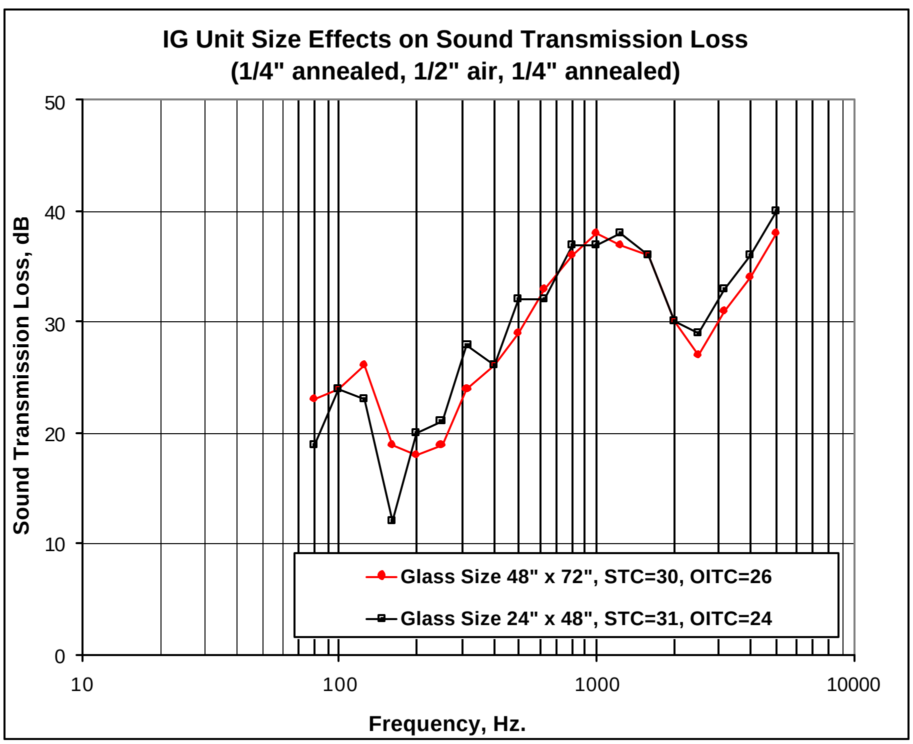

Figure 3.9.2 - Glass Size Effect for Laminated Glass

4.0 WINDOW & CURTAIN WALL PERFORMANCE

4.1 Air Leakage

Air leakage is one of the biggest factors in the acoustical performance of fenestration products. AAMA 101 requires a maximum air infiltration rate of 0.3 cfm per square foot for most of the window and door products. To achieve optimum sound transmission loss test results, the product should have a maximum air infiltration rate of 0.1 cfm per square foot. Air leakage will be most apparent with a reduced TL at the higher frequencies but as shown in Figure 4.1 it can affect the TL at all frequencies, if the leakage is very high.

For dual windows, with weather-stripping on both the interior and exterior sets of sash, it is more difficult to determine if there is a leakage problem. Usually there will be a dip in the TL curve at mid frequencies, which indicates that either the exterior or interior weather-stripping is not making a good seal.

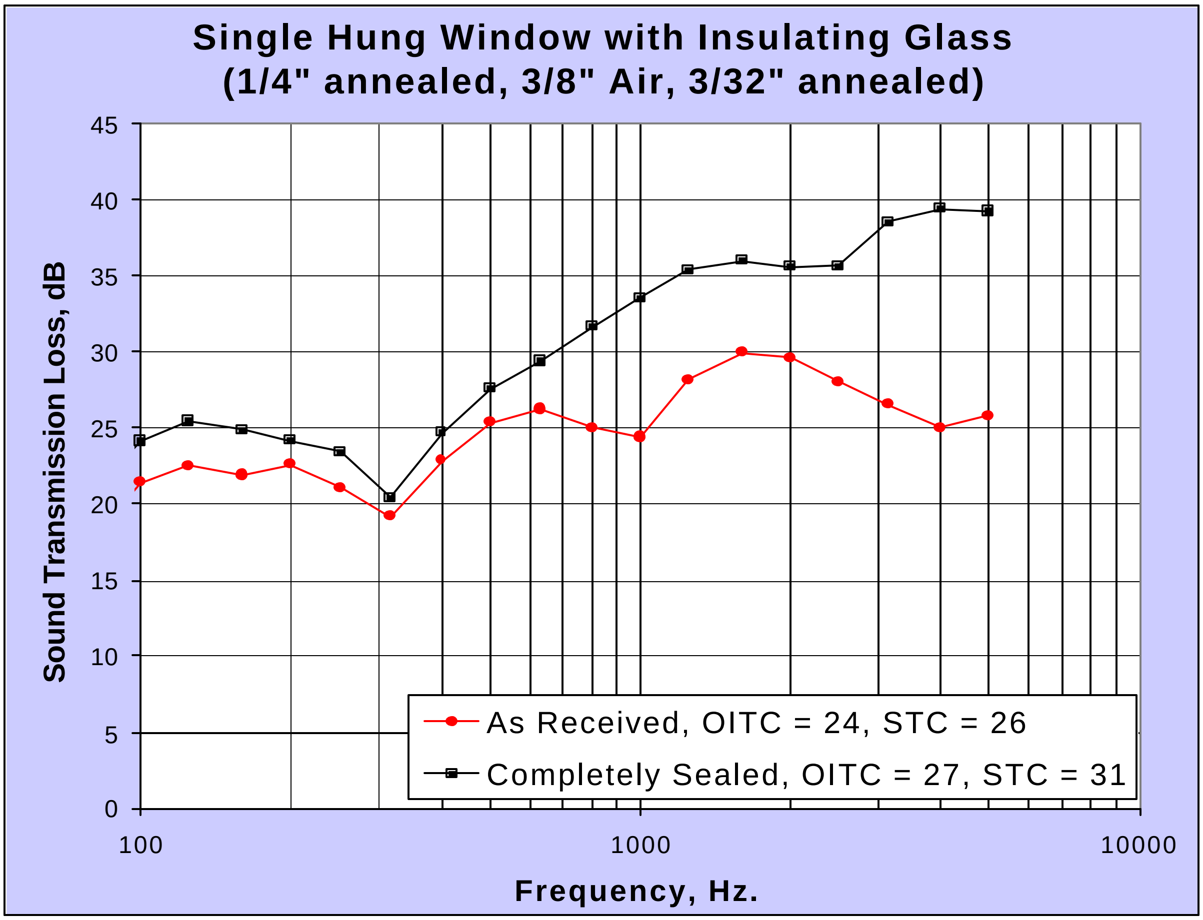

Figure 4.1 - Air Leakage Effect on Sound Transmission Loss

4.2 Frame Extrusions

The sound transmission loss of a fenestration product is not only dependent upon the type of glazing and the other factors previously discussed, but it can also be affected by the design of frame extrusions. For most windows, doors and glazed wall sections (curtain walls), the frame material and design will not be a factor if the goal is to achieve an OITC rating less than 30 or an STC rating lower than 38. But to achieve ratings higher than this, the frame extrusions might need to be modified or redesigned.

The transmission loss is based on how much sound power radiates through the entire test specimen. The TL of each of the elements (glazing, frame, sash, etc) and the exposed area of each of these elements will determine the composite or total TL of the test specimen. It is a power ratio based on the TL and area for each of these elements so the complete product could be significantly affected by its weakest element.

As discussed earlier, mass and air space play a big role in the design of glazing materials. The same is true for the framing members because a portion of the incident sound field is also going to strike these areas. Thicker frame extrusions, especially the inner most and outermost surfaces, should be used when trying to achieve high transmission loss performance. Increasing the air space or adding sound deadening materials between the inner most and outermost frame surfaces will also increase the transmission loss of the frame.

The type of material used will also affect the sound transmitting through the frame. Aluminum framing members will readily transmit sound from the outside to the inside, if a vibration break is not utilized. For thermal isolation, aluminum extrusions with rigid polyurethane thermal breaks, reduce the conduction of thermal energy from the outside to the inside surfaces. For acoustical isolation, less rigid materials should be used in the framing members to reduce the exterior to interior structural borne vibrations.

4.3 Estimated Window & Curtain Wall Performance

Table 4.3.1 provides a range of sound transmission loss ratings that can be achieved on most types of window and curtain wall systems. Fixed and casement windows will generally perform at the upper end of the range since they usually have a lower amount of air leakage. An STC rating of 40 or OITC of 30 is difficult to achieve on a conventional window or curtain wall system with 1" insulating glass.

Window/Curtain Wall IG Glazing	OITC Rating	STC Rating
1/8" annealed, 1/2" air space, 1/8" annealed	23-24	27-28
1/4" annealed, 1/2" air space, 1/4" annealed	25-26	31-32
1/4" annealed, 1/2" air space, 1/4" laminated	27-28	34-35
1/4" laminated, 1/2" air space, 1/4" laminated	28-29	37-38

Table 4.3.1

To achieve STC ratings of 40 or OITC ratings of 30 and above, a dual window configuration with two sets of sash or a prime window with an exterior or interior storm panel is generally required. Table 4.3.2 provides estimates of the sound transmission loss ratings for primary and secondary window systems.

Prime Window/Curtain Wall IG Glazing	Prime to Secondary Air Space	Secondary Window/ Curtain Wall Glazing	OITC Rating	STC Rating
1/8" annealed, 1/2" air space, 1/8" annealed	2"	1/8" annealed	28-30	39-41
1/4" annealed, 1/2" air space, 1/8" annealed	2"	1/4" annealed	32-35	42-44
1/4" laminated, 1/2" air space, 1/8" annealed	2"	1/4" annealed	34-36	43-45
1/4" laminated, 1/2" air space, 1/8" annealed	2"	1/4" laminated	35-37	44-46

Table 4.3.2

The ratings listed above are not specific to any one type of frame material. These ratings may be lower if there is significant air leakage or if there are flanking problems between the primary and secondary sash. To accurately determine the acoustical performance of a window or curtain wall system, a sound transmission loss test is required.

5.0 MATCHING WINDOW & WALL PERFORMANCE

There are many factors to consider when selecting a window configuration that will match the transmission loss (TL) performance of a wall system. The building facade should be designed to reduce exterior noise levels to acceptable interior sound pressure levels. If the exterior wall system is poorly designed, even the highest quality, acoustical window will not keep noise from entering the building. The composite transmission loss of an exterior facade is based on the transmission loss of the individual elements (wall, doors and windows etc.) and the area of these elements. To estimate the required OITC (Outdoor-Indoor Transmission Class) rating of the window, so that the specified OITC rating of complete facade is not degraded, use the three equations in the following section.

The two following equations show the relationship between transmission loss and the sound transmission coefficient (τ).

Eq. 5: $TL = 10 \log (1/\tau)$

Eq. 6: $\tau = 10^{(-TL/10)}$

To estimate the required OITC rating of the window, you need to know the OITC rating that is specified for the entire facade, and the OITC rating of the exterior wall system. You also need to know the total facade area m^2 (sq. ft.), the wall area m^2 (sq. ft.) and the window area m^2 (sq. ft.) such that:

$S_{facade} = S_{wall} + S_{window}$

Where:

S_{facade} is the total area of the facade (window area plus wall area) in square meter (square feet).

S_{wall} is the wall area in square meter (square feet).

S_{window} is the window area in square meter (square feet)

The OITC ratings of the elements are substituted for the TL in Eq. 6 to obtain the transmission coefficients (τ) of the individual elements. The required window sound transmission coefficient can then be calculated with Eq.7.

Eq.7: $\tau_{window} = [(\tau_{facade} \times S_{facade}) - (\tau_{wall} \times S_{wall})] / S_{window}$

Where:

τ_{window} is the required sound transmission coefficient of the window.

τ_{facade} is the sound transmission coefficient of the facade.

τ_{wall} is the sound transmission coefficient of the wall.

After you calculate the required window sound transmission coefficient, you can use Eq. 5 to calculate the required OITC of the window. These equations will only provide an approximation of the required OITC rating of the window. To provide more accurate analysis, the previous calculations need to be performed at all of the 1/3-octave band frequencies ranging from 80 to 4000 hertz.

6.0 CODES & REGULATIONS

6.1 FAA Part 150

The Part 150 program was developed under the Aviation Safety and Noise Abatement Act of 1979. It is a federal program that distributes aviation-generating funds (PFC - Passenger Facility Charge) to airport authorities for the purpose of aircraft noise mitigation measures in communities surrounding airports. Implementation of this program was delegated to the Federal Aviation Administration (FAA).

To participate in this program, airport authorities need to:

- Develop a Noise Exposure Map (NEM) of the area surrounding the airport
- Use the FAA's Integrated Noise Model (INM) or the Heliport Noise Model (HNM) to predict future noise contour plots
- Develop a Noise Compatibility Program (NCP) which provides a description and schedule of their noise abatement measures.

The airport's NCP is an on-going program, which will change over time based on aviation and environmental conditions. The NCP can contain one or more of the following elements:

- A noise hotline for recording and addressing complaints from the community
- An airport noise monitoring system for measuring and recording noise levels
- Aircraft departure and arrival procedures for daytime & nighttime operations
- A penalty or award system for quiet aircraft operations
- A land acquisition or relocation program
- A residential sound insulation program

Table 6.1 gives the land usage compatibility as recommended by the FAA. Local, city or state governments can revise these recommendations to make them more stringent. FAA approval of these changes would still be required in order to receive federal funding.

Homeowners can usually apply for the residential sound insulation program (RSIP) if their residence is in the 65 dBA or higher contour on the Noise Exposure Map. The airport authority or noise abatement manager is usually in charge of the RSIP program.

Federal Aviation Administration

Specification No. 14 CFR Part 150 (1/1/98 edition) Appendix A

Table 1 - Land Use Compatibility with Yearly Day-Night Average Sound Levels

Land Use	Yearly day-night average sound level (Ldn) in decibels					
	Below 65	65 - 70	70 - 75	75 - 80	80 - 85	Over 85
Residential						
Residential, other than mobile homes and transient lodgings	Y	N(1)	N(1)	N	N	N
Mobile home parks	Y	N	N	N	N	N
Transient lodgings	Y	N(1)	N(1)	N(1)	N	N
Public Use						
Schools	Y	N(1)	N(1)	N	N	N
Hospitals and nursing homes	Y	25	30	N	N	N
Churches, auditoriums and concert halls	Y	25	30	N	N	N
Governmental services	Y	Y	25	30	N	N
Transportation	Y	Y	Y(2)	Y(3)	Y(4)	Y(4)
Parking	Y	Y	Y(2)	Y(3)	Y(4)	N
Commercial Use						
Offices, business and professional	Y	Y	25	30	N	N
Wholesale and retail - building materials, hardware, and farm equipment	Y	Y	Y(2)	Y(3)	Y(4)	N
Retail trade - general	Y	Y	25	30	N	N
Utilities	Y	Y	Y(2)	Y(3)	Y(4)	N
Communication	Y	Y	25	30	N	N
Manufacturing and Production						
Manufacturing, general	Y	Y	Y(2)	Y(3)	Y(4)	N
Photographic and optical	Y	Y	25	30	N	N
Agriculture (except livestock) and forestry	Y	Y(6)	Y(7)	Y(8)	Y(8)	Y(8)
Livestock farming and breeding	Y	Y(6)	Y(7)	N	N	N
Mining and fishing, resource production and extraction	Y	Y	Y	Y	Y	Y
Recreational						
Outdoor sports arenas & spectator sports	Y	Y(5)	Y(5)	N	N	N
Outdoor Music shells, amphitheaters	Y	N	N	N	N	N
Nature exhibits and zoos	Y	Y	N	N	N	N
Amusements, parks, resorts and camps	Y	Y	Y	N	N	N
Golf courses, riding stables and water recreation	Y	Y	25	30	N	N

Key to Table 1

Y (Yes) = Land use and related structures compatible without restrictions.

N (No) = Land use and related structures not compatible and should be prohibited.

(1) Where the community determines that residential or school uses must be allowed, measures to outdoor to indoor Noise Level Reduction (NLR) of at least 25 dB and 30 dB should be incorporated into the building codes and be considered in individual approvals. Normal residential construction can be expected to provide an NLR of 20 dB, thus, the reduction requirements are often stated as 5, 10 or 15 dB over standard construction and normally assume mechanical ventilation and closed windows year round. However, the use of the NLR criteria will not eliminate outdoor noise problems

(2) Measures to achieve NLR 25 dB must be incorporated into the designs and construction of portions of these buildings where the public is received, office areas, noise sensitive areas, or where the normal noise level is low.

(3) Measures to achieve NLR 30 dB must be incorporated into the designs and construction of portions of these buildings where the public is received, office areas, noise sensitive areas, or where the normal noise level is low.

(4) Measures to achieve NLR 35 dB must be incorporated into the designs and construction of portions of these buildings where the public is received, office areas, noise sensitive areas, or where the normal noise level is low.

(5) Land use compatible provided special sound reinforcement systems are installed.

(6) Residential buildings require an NLR of 25.

(7) Residential buildings require an NLR of 30.

(8) Residential buildings not permitted.

Table 6.1 - FAA Land Use Compatibility Chart

6.2 U.S. Department of Housing and Urban Development

The U.S. Department of Housing and Urban Development provides the following exterior noise level require ments (Table 6.2) for HUD approved housing. The goal, as in other federal regulations is to achieve an interior noise that does not exceed 45 dB.

U.S Department of Housing and Urban Development

Specification No. 24 CFR Part 51

Site Acceptability Standards listed in table below:

	Day-Night Equivalent Sound Level in Decibels (Ldn)
Acceptable	Not exceeding 65 dB
Normally Unacceptable	Above 65 dB but not exceeding 75 dB
Unacceptable	Above 75 dB

Figure 2.6 HUD site acceptability criteria

In Figure 2.6, ranges of Ldn are correlated with various dispositions that classify HUD approval procedures and identify the need for noise abatement, either at the site property line or in the construction of the building exterior. These have been devised to achieve the HUD goal for interior noise levels of a day-night equivalent noise level not exceeding 45 dB

Table 6.2 - HUD Requirements

6.3 U.S. Environmental Protection Agency

The U.S. Environmental Protection Agency provides the requirements listed in Table 6.3 to protect the public from hearing damage.

U.S. Environmental Protection Agency

Specification N EPA Pub. No. 550/9-79-100 (November 1978)

Effect	Sound Pressure Level		Area
	Ldn	Leq (24 hrs)	
Hearing		≤ 70 dBA	All areas (at the ear)
Outdoor Activity	≤ 55 dB		Outdoors in residential areas and farms and other areas where people spend widely varying amounts of time and other places in which quiet is a basis for use.
		≤ 55 dBA	Outdoor areas where people spend limited amounts of time such as school yards, playgrounds, etc.
Indoor Activity	≤ 45 dB		Indoor residential areas
		≤ 45 dBA	Other indoor areas with human activities such as schools, etc.

Table 6.3 - EPA Noise Guidelines

6.4 ANSI

The American National Standards Institute has developed the following guidelines for assessing the acceptability or compatibility of background noise levels for various types of land use. This standard uses the yearly day-night average sound level, which is the average Ldn level over a continuous 365 day measurement period.

American National Standards Institute (ANSI)

Specification No. ANSI S3.23 - 1980

Land Use	Yearly Day-Night Average Sound Level in Decibels							
	50		60		70		80	90
Residential - single family, extensive outdoor use	Compatible	Marginally Compatible	Marginally Compatible	Incompatible	Incompatible	Incompatible	Incompatible	Incompatible
Residential - multiple family, moderate outdoor use	Compatible	Compatible	Marginally Compatible	Incompatible	Incompatible	Incompatible	Incompatible	Incompatible
Residential - multi-story, limited outdoor use	Compatible	Compatible	Marginally Compatible	With Insulation	With Insulation	Incompatible	Incompatible	Incompatible
Transient lodging	Compatible	Compatible	Compatible	Marginally Compatible	With Insulation	Incompatible	Incompatible	Incompatible
School classrooms, libraries, religious facilities	Compatible	Compatible	Marginally Compatible	With Insulation	With Insulation	Incompatible	Incompatible	Incompatible
Hospitals, clinics, nursing homes, health-related facilities	Compatible	Compatible	Marginally Compatible	With Insulation	With Insulation	Incompatible	Incompatible	Incompatible
Auditoriums, concert halls	Compatible	Compatible	Marginally Compatible	Incompatible	Incompatible	Incompatible	Incompatible	Incompatible
Music shells	Marginally Compatible	Marginally Compatible	Marginally Compatible	Incompatible	Incompatible	Incompatible	Incompatible	Incompatible
Sports arenas, outdoor spectator sports	Compatible	Compatible	Marginally Compatible	Marginally Compatible	Incompatible	Incompatible	Incompatible	Incompatible
Neighborhood parks	Compatible	Marginally Compatible	Marginally Compatible	Marginally Compatible	Incompatible	Incompatible	Incompatible	Incompatible
Playgrounds, golf courses, riding stables, water rec., cemeteries	Compatible	Compatible	Marginally Compatible	Marginally Compatible	Marginally Compatible	Incompatible	Incompatible	Incompatible
Office buildings, personal services, business and professional	Compatible	Compatible	Compatible	Marginally Compatible	Marginally Compatible	Incompatible	Incompatible	Incompatible
Commercial - retail, movie theaters, restaurants	Compatible	Compatible	Compatible	Marginally Compatible	Marginally Compatible	Incompatible	Incompatible	Incompatible
Commercial - Wholesale, some retail, ind., mfg., utilities	Compatible	Compatible	Compatible	Compatible	Marginally Compatible	Marginally Compatible	Incompatible	Incompatible
Livestock farming, animal breeding	Compatible	Compatible	Compatible	Marginally Compatible	Marginally Compatible	Incompatible	Incompatible	Incompatible
Agriculture (except livestock	Compatible	Compatible	Compatible	Compatible	Compatible	Marginally Compatible	Marginally Compatible	Incompatible
Extensive natural wildlife and recreation areas	Compatible	Compatible	Marginally Compatible	Marginally Compatible	Marginally Compatible	Incompatible	Incompatible	Incompatible

Compatible; Marginally Compatible; With Insulation per Section A.3; Incompatible

Note: This document also recommends that interior sound levels due to exterior noise should not exceed a yearly day-night average sound level of 45 dB

Table 6.4 - ANSI Land Usage Guidelines

6.5 Federal Highway Administration

The guidelines established by the Federal Highway Administration, in Table 6.5, are used to determine noise compatibility along federal highways. Areas exceeding the recommended levels could receive federal funding for installation of highway barriers or other noise abatement treatments.

Federal Highway Administration

Specification No. 23 CFR Part 772

Activity Category	L_{1h}	1-hour 10-percentile exceeded level	Description of Activity Category
A	57 (exterior)	60 (exterior)	Lands on which serenity and quiet are of extraordinary significance and serve an important public need and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose.
B	67 (exterior)	70 (exterior)	Picnic areas, recreation areas, playgrounds, active sports areas, parks residences, motels, hotels, schools, churches, libraries and hospitals
C	72 (exterior)	75 (exterior)	Developed lands, properties or activities not included in Categories A or B above.
D			Undeveloped Lands
E	52 (interior)	55 (interior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals and auditoriums.

Note: Must use either the L_{1h} (Leq for 1 hour) or the 1-hour 10-percentile execeeded level (L_{10} for 1 hour) but not both.

Table 6.5 FHWA Guidelines

6.6 OSHA

The Occupational Safety & Health Administration has set allowable noise exposure limits to protect individuals from hearing damage. The maximum allowable noise level and duration is contained in federal regulation 29 CFR 1910.95, and is listed below in Figure 6.6.

ComparisonTable of Duration Per Day in Hours to Allowable Sound Level in dBA (Slow-Response SPL)

Duration Per Day, Hours	*Sound Level, dBA, slow -response*
8.0	90
6.0	92
4.0	95
2.0	100
1.0	105
0.5	110
0.25	115

Figure 6.6 - OSHA Maximum Allowable Noise Exposure

7.0 GLOSSARY OF TERMS

Amplitude: the difference between the maximum and minimum pressure that is developed in a sound pulse.

Coincidence Dip: a frequency or set of frequencies at which the sound transmission loss across a material will decrease due to the resonant characteristics of the material.

Coupling: is the ability of materials that are rigidly connected, to transmit vibrations or sound energy from one point to another location. The amount of energy transfer will depend upon the type of material.

Decoupling: is the ability of materials to isolate vibrations or sound energy from one point to another location. Resilient materials, such as foam or rubber would provide this type of isolation.

Flanking transmission: sound transmission from the source to the receiving location by a path other than through the test specimen.

Field Sound Transmission Class (FSTC): a single number rating system, similar to STC, that is applied to field test data under ASTM E336.

Frequency: the number of sound wavelength cycles that occur within one (1) second represented as **cycles per second (cps)**.

Hertz (Hz): dimension of a sound frequency in cycles per second.

Laminated Glass: glass sheet composite comprising one or more layers of glass laminated with a flexible, plastic film known as an interlayer.

Mass Law: a rule of sound attenuation stating that the sound transmission loss across a barrier will increase approximately 6 decibels for every doubling of the barrier's mass per projected unit area.

Noise Reduction (NR): the difference between the Sound Pressure Level on each side of a barrier for a given measured frequency.

Outdoor-Indoor Transmission Class (OITC): a single number rating that is used to classify wall partitions, doors and windows which are exposed to lower frequency noise sources such as cars, trains and aircraft. The ASTM E1332 test method specifies the transportation spectrum and logarithmic summation that is applied to the transmission loss data to obtain the OITC rating.

Pitch: the perceived tone of a sound based upon its representative frequency

Relative Pressure: the dimensionless ratio of a sound's pressure to a standardized reference sound pressure.

Sympathetic Resonance: is the phenomenon whereby materials of similar characteristics (mass, stiffness, etc.) respond to incident sound frequencies in a similar manner thereby aiding in the transmission of the sound. The use of dissimilar materials can reduce the transmission of sound.

Sone: the unit of measure of loudness defined as 40 dB at 1000 Hz.

Sound Intensity: the square of the relative pressure of a sound representing the power per unit area of the sound in "watts per square meter" (W/m^2).

Sound Power (W): rate of transmission of a sound's energy in "Watts" (W).

Sound Pressure Level (SPL): twenty times (20x) the base ten logarithm of a sound's relative pressure represented in decibels (dB).

Sound Transmission Class (STC): a single number rating, that is calculated using the ASTM E413 classification for rating the sound insulation characteristics of interior wall and floor partitions that are exposed to noise typical of offices and buildings (e.g., speech, radio, television, etc.). An STC contour curve is applied to the actual measured transmission loss data and the transmission loss value on the contour curve at 500 hertz is the STC single number rating.

Sound Transmission Coefficient: the fraction of the airborne sound power incident on the test specimen that is transmitted by the specimen and radiated on the other side.

Sound Transmission Loss (STL): ten times (10x) the common logarithm of the reciprocal of the sound transmission coefficient. The quantity so obtained is expressed in decibels (dB).

STC Reference Contour: a curve that is fitted to the measured transmission loss data from 125 Hz to 4000 Hz to determine the Sound Transmission Class of a barrier.

Transmission Loss (TL): see Sound Transmission Loss

Wavelength: the distance between two consecutive points of maximum pressure in a sound pulse. Represented as "λ" or "lambda".

Weighting: the manipulation of a source sound level profile to better represent the sensitivity of the human ear to sound at specific frequencies. "A" weighting is used for standard evaluation of sound sources but "B" and "C" weightings are also available.

8.0 REFERENCES

1. “Acoustical Glazing Design Guide”; St. Louis, MO; Monsanto Company; 1987.

2. Occupational Safety & Health Administration (OSHA), federal regulation 29 CFR 1910.95

3. U.S. Department of Housing and Urban Development (HUD), regulation 24 CFR Part 51

4. Federal Aviation Administration (FAA), regulation 14 CFR Part 150

5. American National Standards Institute (ANSI) regulation S1.23-1980

6. U.S. Environmental Protection Agency (EPA) publication 550/9-79-100

7. Federal Highway Administration (FHWA) regulation 23 CFR Part 772

8. Sound, Noise & Vibration Control by Lyle F. Yerges 1978

A1. STC/OITC CALCULATION METHODS

STC Calculation

To actually determine the Sound Transmission Class (STC) for an acoustical barrier, the Sound Transmission Loss is recorded for a series of 16 frequency bands. Each band encompasses one third of an octave over the range of 125 to 4,000 Hz (cycles per second) in accordance with ASTM E90-97.

The TL values in decibels are plotted as a function of frequency and compared to the STC contour curve. This STC contour curve (Red line in Figure 8) is designed to give equal weight to low and high frequency loudness. For the human ear, sounds below 500 Hz must be more intense than sounds at higher frequencies to have equal loudness. Thus, the contour curve is drawn so that it increases 15dB from 125 to 400 Hz, 5dB from 400 to 1,250 Hz, and is flat from 1,250 to 4,000 Hz. The contour curve is placed on the STL vs. frequency plot so that the following conditions are met:

1. The sum of the deficiencies (that is, the deviations below the contour curve) shall not be greater than 32dB;

2. The deficiency at any frequency from 125 to 4,000 Hz shall not be greater than 8dB.

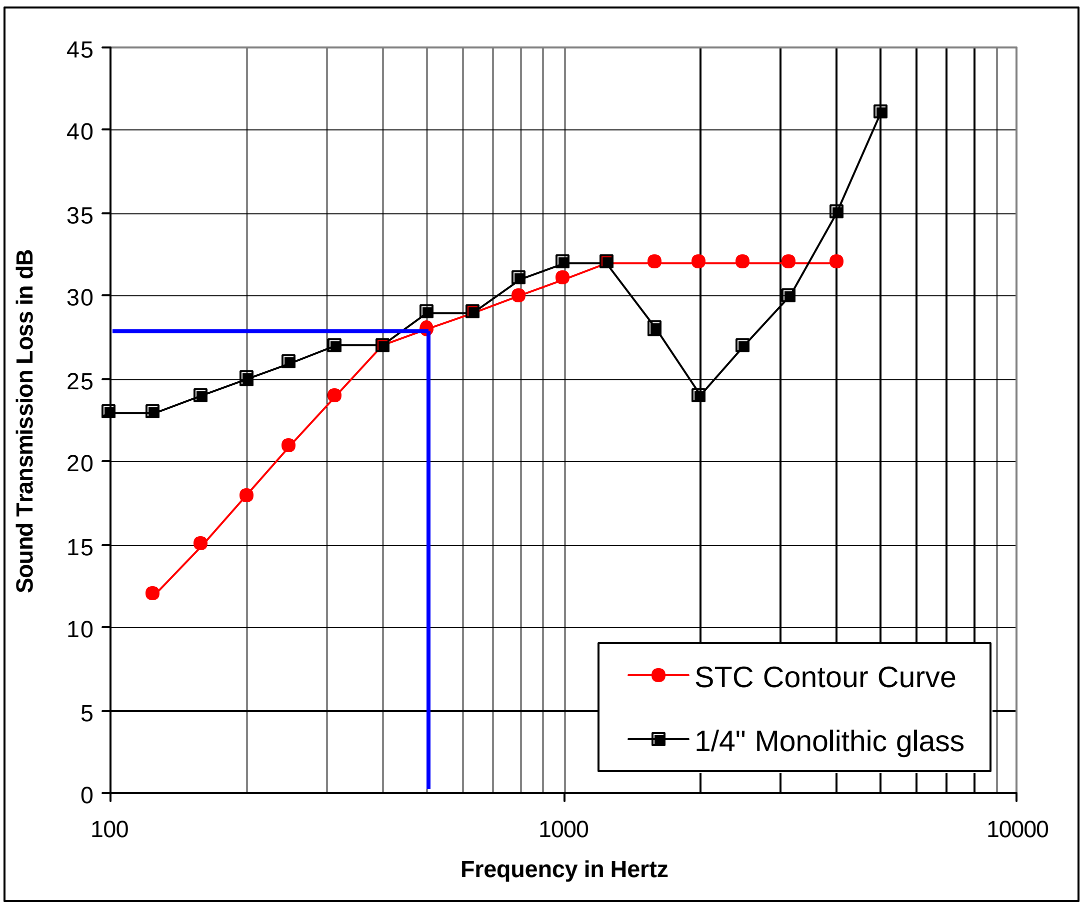

Figure A1.1 - Typical STC Contour (STC-28).

When the contour curve is adjusted to the highest value (in decibels) that meets the above requirements, the Sound Transmission Class for the panel is reported as the STL value that corresponds to the intersection of the contour curve and the 500 Hz line (blue line). The contour curve used for calculating the STC of a four-foot-by-six-foot pane of one-quarter-inch monolithic plate glass is shown in Figure A1.1.

OITC Calculation

The Outdoor-Indoor Transmission Class (OITC) assigns a single number rating to measured sound Transmission Loss (TL) data obtained in accordance with ASTM E90. The OITC is defined as the A-weighted sound level reduction of a test specimen in the presence of an idealized mixture of transportation noises: aircraft takeoff, freeway and railroad pass by. The rating is computed from the measured TL data in one-third octave bands from 80 Hz to 4000 Hz, inclusive.

To compute the OITC:

1. Subtract the measured specimen TL, for each one-third octave band, from the A-weighted Reference Transportation Noise levels. The A-weighted Reference Transportation Noise levels are:

1/3 Octave and (Hz)	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000
A-weighted Spectrum (dB)	80.5	82.9	84.9	84.6	86.1	86.4	87.4	88.2	89.8	89.1	89.2	89.0	89.6	89.0	89.2	88.3	86.2	85.0

2. Perform a logarithmic summation of the one-third octave band results of Step 1.

3. The OITC is the difference, rounded to the nearest decibel, between the value 100.13 and the logarithmic sum from Step 2.

Another way of calculating the OITC rating is by using the following mathematical relation:

$$OITC = 100.13 - 10 \log \{ \sum_{i = 80\ Hz}^{4000\ Hz} 10^{(AWRSi - TLi/10)} \}$$

Where:
$AWRS_i$ is the A-weighted Reference Sound Level
TL_i is the Sound Transmission Loss for each one-third octave band, i, respectively. (The second term of this equation is the logarithmic sum of Step 2.)

NOTE: *Older TL test reports and TL test reports from some laboratories with smaller reverberation chambers may not include data for the 80 Hz and 100 Hz bands. Such test reports cannot be used to calculate OITC.*

A2. GLAZING CONFIGURATIONS & PERFORMANCE

The following tables contain the sound transmission loss ratings for monolithic glass, laminated glass, insulating glass, laminated insulating glass, double laminated insulated glass and triple glazed units with various air space combinations. The data in these tables is for the glazing only and is not applicable for the glazing installed in a window system. These tests were conducted on 3'0" x 7'0" glass samples and the results could vary for other sizes. The frame design, air leakage, spacer system, glazing system and other variables could cause the OITC and STC ratings of the window or curtain wall system to be 5 or more points less than those published in these tables.

MONOLITHIC GLASS				
Laboratory Test Number	**Nominal Thickness**	**Glass Thickness**	**OITC Rating**	**STC Rating**
TL85-169	1/4"	1/4"	29	31
TL85-198	1/2"	1/2"	33	36

LAMINATED GLASS						
Laboratory Test Number	**Nominal Thickness**	**Pane 1 Thickness**	**Laminate Thickness**	**Pane 2 Thickness**	**OITC Rating**	**STC Rating**
TL85-218	1/4"	3/32"	0.030"	3/32"	31	35
TL85-170	1/4"	1/8"	0.030"	1/8"	31	35
TL85-224	1/4"	1/8"	0.060"	1/8"	32	35
TL85-234	1/4"	1/8"	0.045"	1/8"	31	35
TL85-200	3/8"	3/16"	0.030"	3/16"	33	36
TL85-229	3/8"	1/4"	0.030"	1/8"	33	36
TL85-223	3/8"	1/4"	0.060"	1/8"	33	37
TL85-225	1/2"	1/4"	0.030"	1/4"	34	38
TL85-232	1/2"	1/4"	0.045"	1/4"	34	38
TL85-228	1/2"	1/4"	0.060"	1/4"	34	39
TL85-222	5/8"	3/8"	0.030"	1/4"	36	40
TL85-230	3/4"	1/2"	0.060"	1/4"	36	41

INSULATING GLASS						
Laboratory Test Number	**Nominal Thickness**	**Pane 1 Thickness**	**Air Space**	**Pane 3 Thickness**	**OITC Rating**	**STC Rating**
TL85-212 (Sealed)	1/2"	1/8"	1/4"	1/8"	26	28
TL85-213 (Sealed)	5/8"	1/8"	3/8"	1/8"	26	31
TL85-215 (Sealed)	1-3/8"	3/16"	1"	3/16"	27	35
TL85-294 (Sealed)	1"	1/4"	1/2"	1/4"	28	35
TL85-293 (Unsealed)	1-1/2"	1/4"	1"	1/4"	30	37
TL85-216 (Unsealed)	1-3/8"	3/16"	4"	3/16"	35	44

LAMINATED INSULATING GLASS										
Laboratory Test Number	**Nominal Thickness**	**Pane 1 Thickness**	**Laminate Thickness**	**Pane 2 Thickness**	**Air Space**	**Pane 3 Thickness**	**Laminate Thickness**	**Pane 4 Thickness**	**OITC Rating**	**STC Rating**
TL95-296 (Sealed)	5/8"	1/8"	0.030"	1/8"	1/4"	1/8"	NA	NA	31	35
TL85-189 (Sealed)	13/16"	1/8"	0.030"	1/8"	3/8"	3/16"	NA	NA	31	37
TL85-238 (Sealed)	15/16"	1/8"	0.030"	1/8"	1/2"	3/16"	NA	NA	31	39
TL85-235 (Sealed)	1"	1/8"	0.030"	1/8"	1/2"	1/4"	NA	NA	31	39
TL85-192 (Sealed)	1-1/8"	1/8"	0.030"	1/4"	1/2"	1/4"	NA	NA	31	40
TL85-239 (Unsealed)	1-7/16"	1/8"	0.030"	1/8"	1"	3/16"	NA	NA	33	42
TL85-173 (Unsealed)	2-7/16"	1/8"	0.030"	1/8"	2"	3/16"	NA	NA	35	45
TL85-194 (Unsealed)	2-11/16"	1/4"	0.030"	1/4"	2"	3/16"	NA	NA	38	46
TL85-196 (Unsealed)	2-7/8"	1/4"	0.030"	1/4"	2"	3/8"	NA	NA	42	46
TL85-298 (Unsealed)	1-11/16"	1/4"	0.030"	1/4"	1"	3/16"	NA	NA	36	47
TL85-174 (Unsealed)	4-7/16"	1/8"	0.030"	1/8"	4"	3/16"	NA	NA	39	48
TL85-195 (Unsealed)	4-11/16"	1/4"	0.030"	1/4"	4"	3/16"	NA	NA	41	49
TL85-197 (Unsealed)	4-7/8"	1/4"	0.030"	1/4"	4"	3/8"	NA	NA	44	49
TL85-240 (Unsealed)	4-7/8"	1/2"	0.030"	1/4"	4"	1/8"	NA	NA	40	49

DOUBLE LAMINATED INSULATING GLASS										
Laboratory Test Number	**Nominal Thickness**	**Pane 1 Thickness**	**Laminate Thickness**	**Pane 2 Thickness**	**Air Space**	**Pane 3 Thickness**	**Laminate Thickness**	**Pane 4 Thickness**	**OITC Rating**	**STC Rating**
TL85-172 (Sealed)	1-1/16"	1/8"	0.030"	1/8"	1/2"	1/8"	0.030"	1/8"	33	42
TL95-299 (Unsealed)	1-9/16"	1/8"	0.030"	1/8"	1"	1/8"	0.030"	1/8"	37	46
TL85-236 (Unsealed)	1-13/16"	1/4"	0.030"	1/4"	1"	1/8"	0.060"	1/8"	34	46
TL85-220 (Unsealed)	4-5/16"	1/2"	0.060"	1/4"	4"	1/4"	0.030"	1/4"	42	50
TL85-221 (Unsealed)	5-1/16"	1/4"	0.060"	1/4"	4"	1/4"	0.030"	1/4"	42	50
TL85-237 (Unsealed)	4-13/16"	1/4"	0.030"	1/4"	4"	1/8"	0.060"	1/8"	44	51
TL95-301A (Unsealed)	4-9/16"	1/8"	0.030"	1/8"	4"	1/8"	0.030"	1/8"	38	52
TL95-302 (Unsealed)	4-13/16"	1/8"	0.030"	1/8"	4"	1/4"	0.060"	1/4"	45	53

TRIPLE LITE INSULATING GLASS								
Laboratory Test Number	**Nominal Thickness**	**Pane 1 Thickness**	**Air Space**	**Pane 2 Thickness**	**Air Space**	**Pane 3 Thickness**	**OITC Rating**	**STC Rating**
TL95-294 (Sealed)	1-3/4"	1/4"	1/2"	1/4"	1/2"	1/4"	31	39
TL95-295 (Sealed)	1-13/16"	1/4" Lam.	1/2"	1/4" Lam.	1/2"	1/4" Lam.	33	44
TL95-297 (Sealed)	2-1/4"	1/4"	1"	1/4"	1/2"	1/4"	37	46
TL95-300 (Sealed)	2-5/16"	1/4" Lam.	1"	1/4" Lam.	1/2"	1/4" Lam.	39	49

A3. FACADE CONFIGURATIONS & PERFORMANCE

Even the best acoustical window will only perform as well as the wall that it is being installed into. The data in the following tables can be used to estimate the acoustical performance of common facade constructions. The single layer constructions contain a single layer of gypsum board on both sides of the wall. The unbalanced layer construction contains two layers of gypsum board on one side and one layer of gypsum board on the other side. The double layer constructions contain two layers of gypsum board on both sides of the wall. An insulated exterior wall with OSB board and vinyl siding on the outside and 1/2" gypsum board on the inside will have approximately the same STC rating as the "Single Layer 1/2" Gypsum" with insulation that is listed below. Variations in the type of wallboard (standard versus fire rated), construction techniques, and insulation can result in higher or lower ratings.

SINGLE WOOD STUD WALLS

Wall Description	Studs		Insulation	Resilient Channels	STC Rating
	Type	Spacing			
Single Layer 1/2" gypsum board	2" x 4"	16"	None	No	34
Single Layer 5/8" gypsum board	2" x 4"	16"	None	No	35
Single Layer 1/2" gypsum board	2" x 4"	24"	None	Yes	37
Single Layer 1/2" gypsum board	2" x 4"	16"	3½" Fiberglass	No	38
Single Layer 5/8" gypsum board	2" x 4"	24"	None	Yes	40
Single Layer 5/8" gypsum board	2" x 4"	16"	3½" Fiberglass	No	39
Single Layer 1/2" gypsum board	2" x 4"	24"	3½" Fiberglass	Yes	44
Single Layer 5/8" gypsum board	2" x 4"	24"	3½" Fiberglass	Yes	50
Unbalanced 1/2" gypsum board	2" x 4"	16"	None	No	38
Unbalanced 1/2" gypsum board	2" x 4"	16"	3½" Fiberglass	No	41
Unbalanced 1/2" gypsum board (Single layer on resilient channel side)	2" x 4"	24"	None	Yes	44
Unbalanced 1/2" gypsum board (Single layer on resilient channel side)	2" x 4"	24"	3½" Fiberglass	Yes	52
Double Layer 1/2" gypsum board	2" x 4"	16"	3½" Fiberglass	No	45
Double Layer 1/2" gypsum board	2" x 4"	24"	None	Yes	52
Double Layer 1/2" gypsum board	2" x 4"	24"	3½" Fiberglass	Yes	55

STAGGERED WOOD STUD WALLS						
Wall Description	**Studs**		**Insulation**	**Resilient Channels**	**STC Rating**
	Type	**Spacing**			
Single Layer 1/2” gypsum board	2” x 4” Studs 2” x 6” Plates	16”	None	No	38
Single Layer 5/8” gypsum board	2” x 4” Studs 2” x 6” Plates	16”	None	No	43
Single Layer 1/2” gypsum board	2” x 4” Studs 2” x 6” Plates	16”	3½” Fiberglass	No	45
Single Layer 5/8” gypsum board	2” x 4” Studs 2” x 6” Plates	16”	3½” Fiberglass	No	46
Single Layer 1/2” gypsum board	2” x 4” Studs 2” x 6” Plates	16”	2 layers of 3½” Fiberglass	No	49
Single Layer 1/2” gypsum board	2” x 4” Studs 2” x 6” Plates	24”	3½” Fiberglass	No	51
Single Layer 1/2” gypsum board	2” x 4” Studs 2” x 6” Plates	24”	2 layers of 3½” Fiberglass	No	54
Unbalanced 1/2” gypsum board	2” x 4” Studs 2” x 6” Plates	24”	None	No	46
Unbalanced 1/2” gypsum board	2” x 4” Studs 2” x 6” Plates	24”	3½” Fiberglass	No	53
Double Layer 1/2” gypsum board	2” x 4” Studs 2” x 6” Plates	24”	None	No	52
Double Layer 1/2” gypsum board	2” x 4” Studs 2” x 6” Plates	24”	3½” Fiberglass	No	55

DOUBLE WOOD STUD WALLS					
Wall Description	**Studs**		**Fiberglass**	**Resilient Channels**	**STC Rating**
	Type	**Spacing**			
Single Layer 1/2” gypsum board	Two Rows of 2” x 4” Studs	16”	None	No	45
Single Layer 5/8” gypsum board	Two Rows of 2” x 4” Studs	16”	None	No	45
Single Layer 1/2” gypsum board	Two Rows of 2” x 4” Studs	16”	3½” Fiberglass	No	54
Single Layer 5/8” gypsum board	Two Rows of 2” x 4” Studs	16”	3½” Fiberglass	No	55
Single Layer 1/2” gypsum board	Two Rows of 2” x 4” Studs	24”	3½” Fiberglass	No	56
Single Layer 1/2” gypsum board	Two Rows of 2” x 4” Studs	16”	2 layers of 3½” Fiberglass	No	58
Single Layer 1/2” gypsum board	Two Rows of 2” x 4” Studs	24”	2 layers of 3½” Fiberglass	No	60
Unbalanced 1/2” gypsum board	Two Rows of 2” x 4” Studs	16”	None	No	47
Unbalanced 1/2” gypsum board	Two Rows of 2” x 4” Studs	16”	3½” Fiberglass	No	56
Unbalanced 1/2” gypsum board	Two Rows of 2” x 4” Studs	16”	2 layers of 3½” Fiberglass	No	59
Unbalanced 1/2” gypsum board	Two Rows of 2” x 4” Studs	24”	2 layers of 3½” Fiberglass	No	64
Double Layer 1/2” gypsum board	Two Rows of 2” x 4” Studs	16”	None	No	53
Double Layer 1/2” gypsum board	Two Rows of 2” x 4” Studs	16”	3½” Fiberglass	No	63
Double Layer 1/2” gypsum board	Two Rows of 2” x 4” Studs	24”	3½” Fiberglass	No	65

SOLID MASONRY BLOCK WALLS		
Wall Description	**Weight lb/ft^2**	**STC Rating**
4” Brick *	38	41
8” Brick *	80	49
12” Brick *	120	54
6” Reinforced Dense Concrete	75	46
8” Reinforced Dense Concrete	95	51
12” Reinforced Dense Concrete	145	56
*Careful workmanship, airtight joints or surface sealed		

HOLLOW MASONRY BLOCK WALLS		
Wall Description	**Weight lb/ft^2**	**STC Rating**
4” Lightweight *	20	36
4” Dense	30	38
6” Lightweight *	28	41
6” Dense	43	43
8” Lightweight *	34	46
8” Dense	55	48
12” Lightweight *	50	51
12” Dense	80	53
*Sealed against air leakage with 2 coats of sealer paint on both sides		

A4. FIELD EQUIPMENT & TEST PROCEDURES

Equipment

Microphones, amplifiers and electronic circuitry used to process microphone signals must satisfy the requirements of ANSI S1.4 for Type 2 sound level meters. Where multiple microphones are used, they should be of the same model. Filters for defining the frequency bands used shall meet the Order III requirements of ANSI S1.11 for one-third octave and Order II requirements for octave band filters. Measurements shall be made in all 1/3-octave bands with mid-band frequencies specified in ANSI S1.6 from 80 to 5000 Hz.

ASTM E966 Standard Guide for Field Measurements of Airborne Sound Insulation of Building Facades and Facade Elements

The ASTM E966 method is the standard guide for the field measurement of airborne sound insulation of building facades and façade elements (such as windows, doors, etc.). For this test method, a free field environment exists on one side of the window or façade and a semi diffuse field exists on the other side. This test method provides for the measurement of Outdoor-Indoor Level Reduction (OILR), the Apparent Outdoor-Indoor Transmission Loss (Apparent OITL) and Outdoor-Indoor Transmission Loss (OITL). The Outdoor-Indoor Transmission Class (OITC) rating, calculated in accordance with ASTM E1332, was developed to evaluate the transmission loss of facades when they are exposed to transportation noise (planes, trains and automobiles). The E 966 tests are conducted at the 1/3-octave band frequencies from 80 to 5000 Hz, to include the transportation noise spectrum.

There are six different measurement techniques contained in ASTM E966. The measurement procedures contained in ASTM E966 are briefly described below. The OILR measurement can always by performed, but flanking problems can sometimes invalidate the OITL measurement.

Outdoor-Indoor Level Reduction (OILR)

To perform the OILR measurement, the sound field is projected at the exterior side of the window, at a 45-degree angle. The interior and exterior sound pressure levels are measured simultaneously at six different microphone positions. The OILR measurement is the difference between the exterior and interior SPL plus a correction for the angle of incidence and provides a good indication of how well the window or façade is performing. For the OILR measurement, the interior room does not need to meet the volume and sound absorption requirements listed in Section 7 of ASTM E966.

Apparent Outdoor-Indoor Transmission Loss (OITL)

To perform the Apparent OITL measurement, the OILR and Sound Absorption of the interior room needs to be measured. For the Apparent OITL measurement, the interior room has to meet the volume and sound absorption requirements listed in Section 7 of ASTM E966. The Apparent OITL values can be used to calculate an Apparent OITC rating. If the Apparent OITC rating exceeds the OITC rating required by the building specification, then flanking tests are not necessary. If it does not meet the building specification, then the complete OITL measurement (listed below), using flank screens, must be performed.

Outdoor-Indoor Transmission Loss (OITL)

To perform a complete OITL test, the OILR has to be measured with and without a flanking screen placed over the window. The Sound Absorption of the interior room also needs to be measured. For the complete OITL measurement, the interior room has to meet the volume and sound absorption requirements listed in Section 7 of ASTM E966 and flanking needs to be investigated as detailed in Annex A1. The OITC rating is calculated from the OITL values at a particular angle of incidence (usually 45 degrees), which needs to be noted in the report.

If the Apparent OITL of the window with the flanking screen is at least 10 dB higher than the Apparent OITL of the window without the flanking screen, at every frequency, then the Apparent OITL of the window without the flanking screen represents the true OITL of the window. If the difference is between 5 and 10 dB then corrections can be applied to the measurement. If the difference is less than 5 dB, this indicates that the sound is flanking or entering the interior room by paths other than the window. To determine the true OITL of the window and to eliminate these other paths, an additional room would have to be constructed around the interior side of the window and the test would have to be re-run. This procedure would be cost prohibitive and it would be better to investigate the flanking problems. It is of no benefit to install a high OITC rated window in a facade that has flanking problems.

ASTM E336 Standard Test Method for Measurement of Airborne Sound Insulation in Buildings

The ASTM E336 test method is used to evaluate the sound transmission loss of partition walls between two adjacent rooms inside a building. This method was not designed for testing windows and doors mounted in exterior walls. In this test method, semi-diffuse sound pressure levels are measured on both sides of the partition. This standard provides for the measurement of Noise Reduction (NR), Normalized Noise Reduction (NNR) and Field Transmission Loss (FTL). The Noise Isolation Class (NIC), Normalized Noise Isolation Class (NNIC) and Field Sound Transmission Class (FSTC) ratings can then be calculated in accordance with ASTM E413. The field transmission loss test should produce an

FSTC rating that is comparable to the STC rating produced by the E 90 test method, if all of the flanking paths between the two rooms have been eliminated. The STC and FSTC ratings were developed to evaluate the transmission loss of partitions when they are exposed to speech, radio, television and similar sources of noise in offices and buildings. The E 336 tests are conducted at the 1/3-octave band frequencies from 100 to 5000 Hz. The measurement procedures contained in ASTM E336, are briefly described below. The NR measurement can always be performed, but flanking problems can sometimes invalidate the FTL measurement.

Noise Reduction (NR)

To perform the NR measurement, broadband noise is produced in the designated source room and the sound pressure levels are measured simultaneously, at six different microphone positions, in both rooms. Noise Reduction is the difference between the source and receiving room SPL's and is an evaluation of the effective acoustical isolation between a pair of rooms, regardless of the paths by which the sound is transmitted. For the NR measurement, the rooms do not need to meet the minimum room volume and maximum room absorption requirements of Annex A1 of ASTM E336. The NIC rating can then be calculated from the measured NR values in accordance with ASTM E413.

Normalized Noise Reduction

If the source and receive rooms are not furnished, you can calculate the Normalized Noise Reduction (NNR) which approximates the noise isolation between furnished rooms. To perform the NNR measurement, the NR measurement and the Sound Absorption of the receive room needs to be measured. For the NNR measurement, the rooms do not need to meet the minimum room volume and maximum room absorption requirements of Annex A1 of ASTM E336. The NNIC rating can then be calculates from the measured NNR values in accordance with ASTM E413.

Field Transmission Loss (FTL)

To perform the FTL measurement, the NR measurement and the Sound Absorption of the receive room need to be measured. The Field Transmission Loss (FTL) is the difference between the Source and Receive room sound pressure levels, plus ten times the common logarithm of the area of the partition minus ten times the common logarithm of the absorption of the receive room. For the FTL measurement, the interior room has to meet the minimum volume and maximum sound absorption requirements listed in Annex A1 of ASTM E336. The FTL values can then be used to calculate an FSTC rating. If the calculated FSTC rating meets the FSTC rating required by the building specification then flanking tests are not necessary. If it does not meet the building specification, the FTL should be re-measured with an additional wall (as specified in Appendix A2 of ASTM E336) placed over the test partition. If, in each frequency band, the FTL of the modified partition is at least 10 dB higher than the initially measured FTL, then the initial measurements may be deemed to represent the true FTL of the test specimen. If the difference is between 5 and 10 dB then corrections can be applied to the measurement. If the difference is less than 5 dB, this indicates that the sound is flanking or entering the receiving room by paths other than the partition.

A5. LABORATORY EQUIPMENT & TEST PROCEDURES

Equipment

An AAMA accredited acoustical laboratory shall meet the requirements listed in Appendix A.2 of the AAMA Laboratory Accreditation Program Operations Manual and Annex A2 (mandatory) and Appendix X1 (Non-mandatory) of ASTM E90. Microphones, amplifiers and electronic circuitry used to process microphone signals must satisfy the requirements of ANSI S1.4 for Type 1 sound level meters. Where multiple microphones are used, they should be of the same model. For each test band, the overall frequency response of the electrical system, including the filter or filters in the source or microphone systems, shall satisfy the specifications given in ANSI Specification S1.11 for a one-third octave band filter set, Order 3 or higher, Type 1. Measurements shall be made in all 1/3-octave bands with mid-band frequencies specified in ANSI S1.6 from 80 to 5000 Hz.

ASTM E90 Sound Transmission Loss Test Procedure

The test specimen is installed in an opening between two adjacent reverberation rooms. If the test opening has to be reduced to accommodate the specimen, the transmission loss (TL) of the filler wall assembly must be determined. The filler wall TL must be significantly higher than that of the specimen so that the dominant sound transmission path between the two rooms is by way of the test specimen.

The following measurements can be conducted at several stationary microphone positions, or with a single microphone on a rotating boom or linear traverse. The ambient (background) sound pressure level of the receive room is measured with the specimen installed. Broadband noise is supplied to a loudspeaker system and a diffuse sound field is produced in the chamber designated as the source room. Sound incident on the test specimen causes it to vibrate and transmit a portion of the sound into the adjoining receive room. The space and time averaged sound pressure levels (SPL) are determined in both rooms. The receiving room sound pressure level shall be at least 10 dB higher than the background SPL at all test frequencies. With the test specimen in place, the sound absorption of the receiving room is also measured. The sound pressure levels in both rooms, the sound absorption of the receive room, the background SPL in the receive room, the filler wall transmission loss (if applicable) and the area of the test specimen are used to calculate the specimen transmission loss.

The specimen TL values are used to calculate the OITC (Outdoor-Indoor Transmission Class) rating in accordance with ASTM E1332. The TL values can also be used to calculate the STC (Sound Transmission Class) in accordance with ASTM E413.

AAMA 1801 Acoustical Rating of Windows, Doors and Glazed Wall Sections

The AAMA 1801 document specifies the use of the procedures contained in ASTM E1425 "Standard Practice for Determining the Acoustical Performance of Exterior Windows and Doors". The AAMA 1801 document also specifies the size requirements for the window and curtain wall systems. ASTM E1425 requires that the operating force (if applicable), air leakage and the sound transmission loss tests be conducted on the fenestration product. The operating force test is conducted in accordance with ASTM E1107. The air leakage test is conducted in accordance with ASTM E283. The sound transmission loss test is conducted in accordance with ASTM E90. The window or curtain wall system must pass the operating force and/or air leakage requirements listed in AAMA 101.