JELD-WEN WINDOWS & DOORS

SOUND INVESTMENT
How the Acoustical Properties of Building Products Are Measured and Why This Is Important

Introduction

Acoustics and noise control have become important issues since the late 1950s with the introduction of the commercial aircraft, along with the expansion of suburbs and high-density housing. Today acoustical performance of fenestration products is a major topic in the minds of consumers, architects, and code-writing agencies. Manufacturers are recognizing the need for acoustically rated products and the importance of sound isolation in product design. They are incorporating various frame and profile designs, glass combinations and spacing, weatherstrip schemes, along with installation training to achieve maximum sound attenuation. This is the next step in the evolution of product development and designers are juggling the variables to achieve high structural, thermal, and acoustical ratings. The purpose of this paper is to introduce the reader to acoustical performance of building products. It will describe the importance of noise control, sound transmission loss in fenestration products, how acoustical ratings are determined, performance factors for fenestration products, and common ratings for doors and windows.

Why Noise Control Is Important

Noise is defined as an unwanted sound or a sound you are trying to eliminate. However, noise has some benefits. It lets you know if your car is running properly and is used to communicate safety warnings (ambulance sirens, fire alarms, etc.). Unfortunately, there are several negative effects of noise. The main consequence is long-term hearing loss. A noisy household can prevent a person from receiving adequate rest, which can increase stress, fatigue, and irritability. Noise can also interfere with speech communication, which is imperative in a classroom or learning environment. In an effort to control noise, acceptable noise levels and product performance standards have been established by several agencies. These include the Federal Aviation Administration, American National Standards Institute (ANSI), Federal Highway Administration, U.S. Department of Housing and Urban Development, and agencies at the local level. The quantitative value used to assess the noise isolation of fenestration products is sound transmission loss.

Sound Transmission Loss

Sound transmission loss (STL) is a measure of the sound energy lost through a partition. This partition could be a door, window, wall assembly, roof, floor-ceiling assembly, or operable panel. Sound transmission loss is calculated using the following relationship.

$$TL = L_1 - L_2 + 10 \text{ Log } (S/A_2) = L_1 - L_2 + 10 \text{ Log } (S) - 10 \text{ Log } (A_2)$$

L_1 = Source Room Sound Level (Decibels)

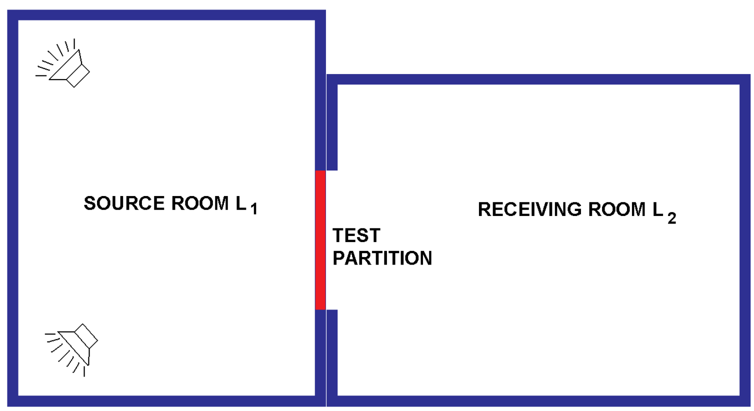
L_2 = Receiving Room Sound Level (Decibels)

S = Specimen Area

A_2 = Receiving Room Sound Absorption

In an acoustical laboratory, pink noise (a broad frequency noise spectrum) is generated in the source room (Figure 1).

Figure 1. Acoustics Lab Design



The sound level in decibels is measured in both the source room (L_1) and the receiving room (L_2). The room sound levels are combined with the receiving room sound absorption (A_2) and specimen area (S) to calculate the sound transmission loss. Sound transmission loss is proportional to the specimen area. A large specimen will result in an increase in the sound transmission loss. STL is also dependant on the receiving room sound absorption. Absorption in the receiving room needs to be known since it absorbs and reduces the sound level. The sound transmission loss for a partition is typically calculated between the 80-4,000 Hz frequency range. This range is broken down into one-third octave bands, which is analogous to splitting up the color spectrum and evaluating the acoustical performance of a product when exposed to a specific frequency. The sound transmission loss measurements are then plotted as a function of the frequency and used to calculate single-number acoustical ratings. In order to obtain accurate measurements, most laboratories will have a receiving room that is structurally isolated from the source room, which prevents structure borne vibrations from being transmitted. This is accomplished using spring isolators or a structural break in the receiving room foundation. Anyone who has visited an acoustics laboratory that conducts sound transmission loss testing is familiar with a reverberant chamber. A reverberant acoustical chamber has significant sound reflections, which are required to evenly distribute the sound energy (known as a reverberant field). Another type of acoustical chamber is an anechoic chamber, which has absorbing materials (usually in the form of wedges) on the walls to limit the amount of sound reflections (known as a free-field). ASTM E-90 describes the calculations and laboratory requirements for sound transmission loss testing.

Acoustical Ratings

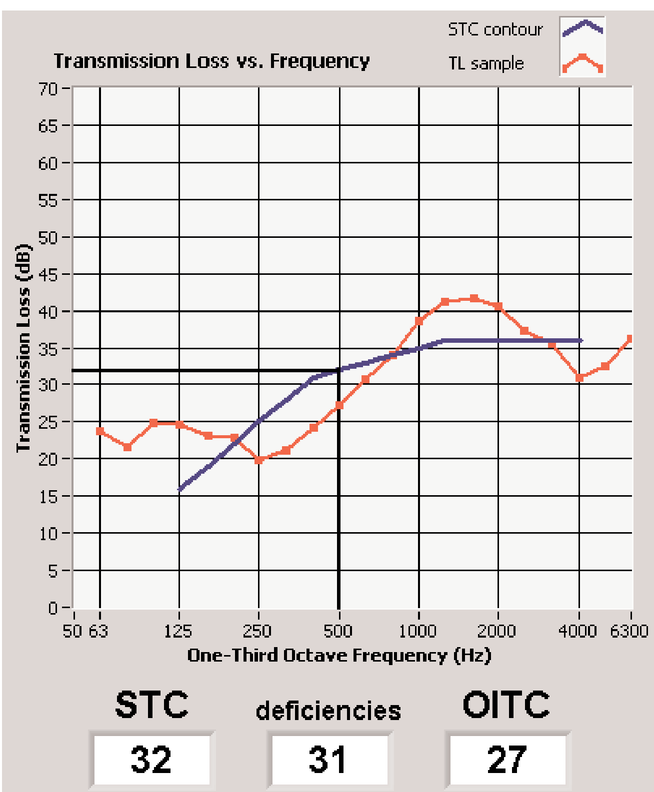
The development of acoustical ratings began in the 1950s. During this time, a transmission loss rating known as the "Nine Frequency Average" was developed. It was a single number rating, which used the arithmetic transmission loss average of nine one-half octave band frequencies. In the 1970s the Sound Transmission Class (STC) rating was developed and it is still one of the most common acoustical ratings. Descriptions of the STC, Outdoor-Indoor Transmission Class (OITC), and Sound Reduction Index (Rw) ratings are provided below.

Sound Transmission Class (STC)

The STC rating represents the acoustical performance of a fenestration product exposed to an interior or office noise spectrum. The frequency range for the test is 125-4,000 Hz (one-third octave bands). The test curve is plotted as a function of the frequency. A reference curve, which represents the office noise spectrum, is superimposed and adjusted vertically on the test curve until one of the following conditions is met:

1. The total number of deficiencies is less than or equal to 32.
2. The number of deficiencies at any one-third octave band is equal to 8.

Figure 2. Transmission Loss Curve



A deficiency occurs when the test curve falls at least one decibel below the reference curve at any one-third octave band. Once the curve is adjusted upwards vertically to the maximum level, the STC rating is the sound transmission loss value of the reference curve at 500 Hz. An example of a test data sheet is provided in Figure 2. The blue line represents the reference spectrum and the product curve is shown in red. Unfortunately, there is a concern with using the STC rating to specify fenestration products. It evaluates the product's performance relative to interior noises; however, most fenestration products are exposed to more low frequency dominant sources such as transportation and machinery noise. STC is still used because it is embedded in the architectural literature and training. The standard used to determine the STC rating is ASTM E413.

Sound Reduction Index (Rw)

Rw is a single-number acoustical rating used in the European market. It is calculated in accordance with the ISO 717 standard. The Rw rating is very similar to the STC rating. However, the frequency range for this test is 100-3,150 Hz. Additionally, the 8-deficiency rule is ignored and the reference spectrum is adjusted vertically until the total number of deficiencies is equal to 32. Just like the STC rating, the Rw rating shouldn't be used to specify products exposed to an exterior noise spectrum.

Outdoor-Indoor Transmission Class (OITC)

The OITC rating is a single-number value, which compares the acoustical performance of a product against a ground and air transportation noise spectrum. The spectrum is an average of three sources, which include: aircraft takeoff, freeway, and railroad pass-by. The frequency range for this test is 80-4,000 Hz (one-third octave bands). The average transportation noise spectrum is A-weighted to simulate human hearing. The transmission loss value is then subtracted from the A-weighted noise spectrum at all test frequencies. The result is then plugged into the following equation to obtain the OITC rating.

$$OITC = 100.14 - 10 \text{ Log } \left(\sum_f 10^{\frac{\text{Difference}}{10}}\right)$$

The OITC rating is a better measure for products exposed to an exterior noise environment. The standard used to calculate the OITC rating is ASTM E1332.

Performance Factors

Several factors affect the sound transmission loss of fenestration products. The variables that will be presented include mass, coincidence dip, mass-air-mass resonance, and air infiltration, which are valid for all fenestration products.

Mass

Product mass is an important factor for sound transmission loss performance. This relates to Newton's second law of motion, which states the sum of the forces on a mass is equal to the mass times its acceleration (F = MA). An imbalance of forces on a surface is the source of vibrations. Sound is defined as a vibration within an elastic medium. The goal is to reduce the amount of vibrations, which in turn reduces the transmission of sound. This can be accomplished by increasing the mass of a product. The mass law provides an estimate of the sound transmission loss for a given material at a specific frequency. It is valid for a thin, homogeneous, single-layer panel.

The transmission loss approximation using the mass law is calculated using the following relationship.

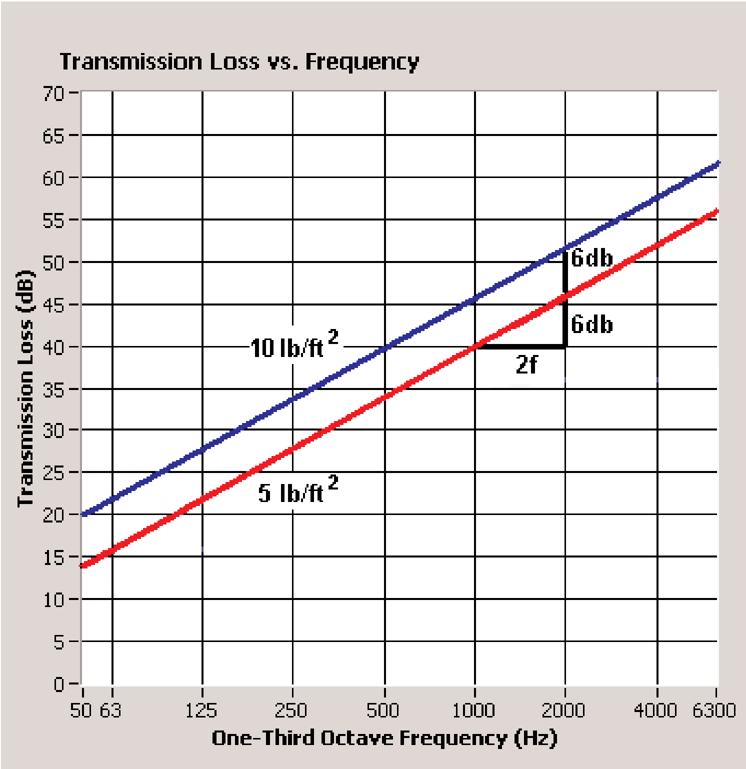
$TL = 20 \log (m_s f) - 34$ dB

m_s = Surface Mass (lb/ft^2)

f = Frequency

The mass law plotted as a function of frequency for a surface weighing 5 lb/ft^2 and 10 lb/ft^2 is displayed in Figure 3. According to the mass law, transmission loss will increase 6 decibels for each doubling of surface mass or frequency. Unfortunately, increasing the mass of a fenestration product will reach a point of diminishing returns. A product will eventually become too cumbersome to install or not economically feasible for the added acoustical performance.

Figure 3. Mass Law



Coincidence Dip

The coincidence dip commonly known as the critical frequency can severely limit a product's rating. The coincidence dip occurs when the incident sound wave is in phase with the bending wave of the panel (Figure 4). This will result in a dip in the transmission loss curve and a decrease in acoustical performance (shown in Figure 5).

Figure 4. Vibrating Partition

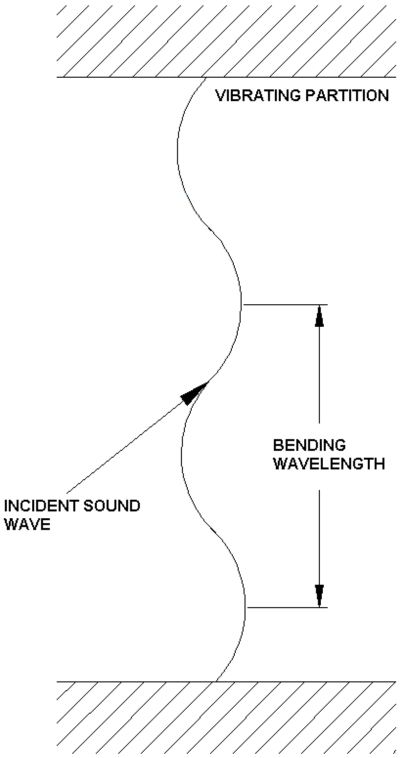
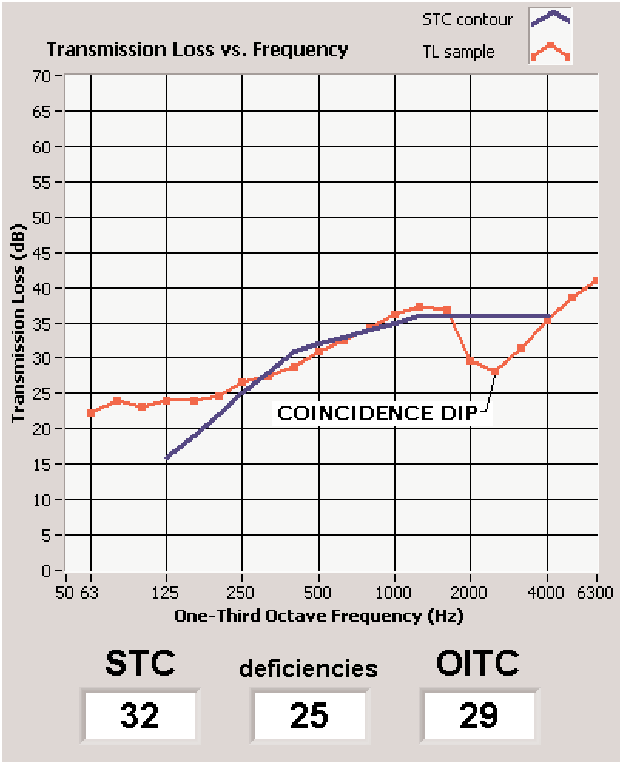


Figure 5. Coincidence Dip



For example, a sharp dip in the 125-4,000 Hz frequency range will result in increased deficiencies and limit the STC rating. The frequency of the coincidence dip is a function of a material's stiffness and thickness. As the stiffness and thickness increase, the critical frequency will decrease. For optimum performance, it is best to have the coincidence dip occur outside of the measurement frequency. This can be accomplished using a limp material. Young's Modulus or the Modulus of Elasticity (MOE) of a material can be used as a measure of stiffness. A reduction in panel or component stiffness can also be accomplished by the profile design. Damping, which is defined as energy loss due to internal friction, can help reduce the coincidence dip depth. Materials such as lead have high internal damping, which results in a broad and shallow coincidence dip. Damping can be introduced through the use of flexible mounting materials, which will also reduce the severity of the coincidence dip.

Mass-Air-Mass Resonance

A key factor for the acoustical performance of windows with insulated glass is airspace depth. At certain frequencies, the airspace acts as a spring and readily transmits sound through the assembly. This is known as mass-air-mass resonance. The resonant frequency for an IGU is provided below:

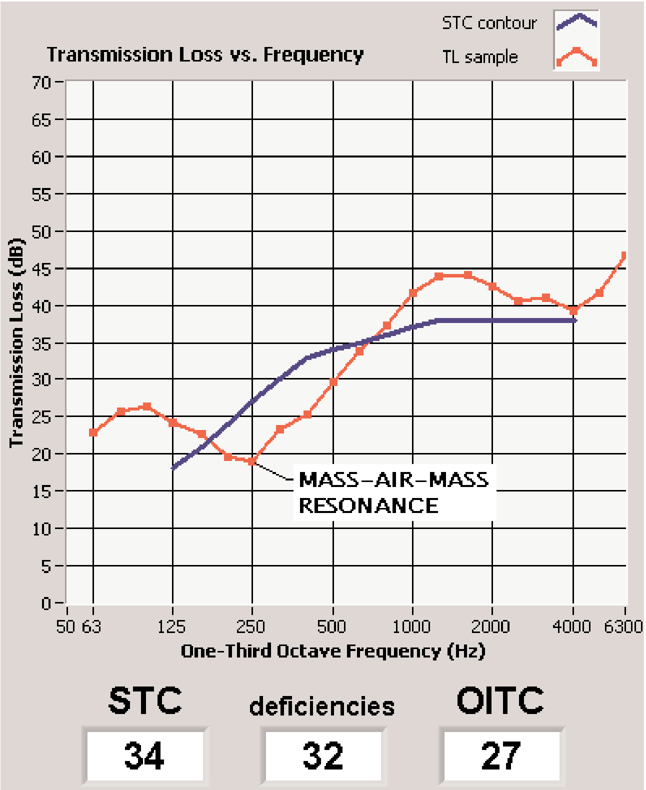
$$f_{mam} = \frac{1150 \sqrt{t_1 + t_2}}{\sqrt{t_1 \times t_2 \times d}}$$

t_1 = Pane 1 Glass Thickness (mm)

t_2 = Pane 2 Glass Thickness (mm)

d = airspace (mm)

Figure 6. Mass-Air-Mass



An example of mass-air-mass resonance on a tested window is shown in Figure 6. The IGU had the following dimensions: Pane 1 = 6.35 mm, Airspace = 10.67 mm, Pane 2 = 3.05 mm, which resulted in a resonance frequency of 245 Hz. Just like the coincidence effect, mass-air-mass resonance can decrease acoustical performance. Since the resonant frequency is inversely proportional to the square root of the airspace (d), increasing the airspace will result in a reduction in frequency. Ideally, the airspace will be large enough that the mass-air-mass frequency occurs outside the test frequency range. For example, an IGU with double-strength glass would require an air-space of at least 2.10" to drop the resonant frequency below 125 Hz (start of the STC test range).

Air Infiltration

Air infiltration is another variable which can affect acoustical performance. According to David Egan, author of Architectural Acoustics, "A 1 in^2 hole in a 100 ft^2 gypsum board partition can transmit as much sound energy as the rest of the partition, thereby destroying its sound-isolating effectiveness." As product performance increases, so does the importance of preventing air infiltration. An example of a vinyl horizontal slider tested as an operable window is shown in Figure 7. The same window with the sash and weeps sealed to prevent air leakage (non-operable configuration) is displayed in Figure 8. This displays the drop in acoustical performance as a result of air infiltration. Proper weatherstrip design will reduce air infiltration and limit the decline in acoustical performance.

Figure 7. Operable Window

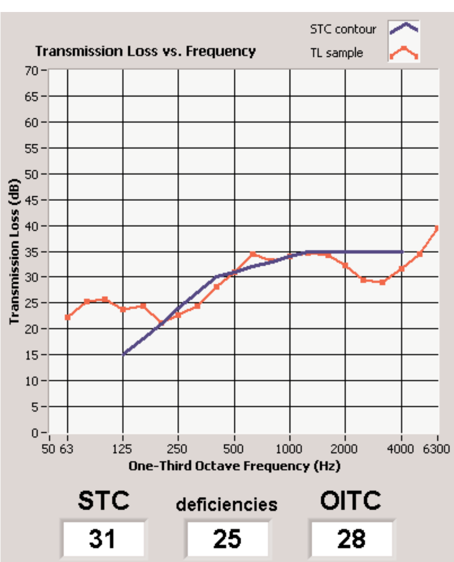
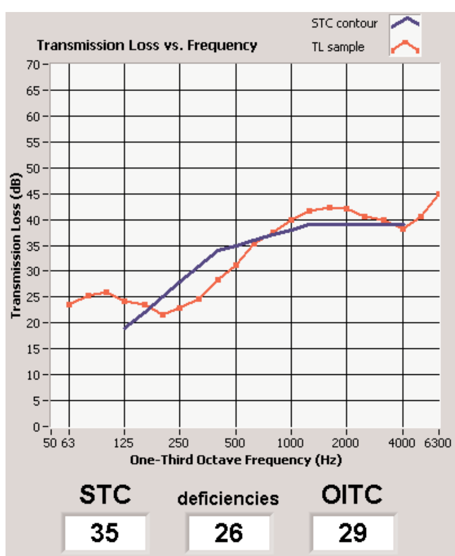


Figure 8. Nonoperable Window



Door and Window Acoustical Ratings

Sound Transmission Class ratings for common exterior doors are provided in Table I, and Table II lists values for nonoperable windows as a function of the glass combination and airspace depth.

Table I. Acoustical Performance of Exterior Doors with Weatherstripping

Door Type (1.75" Thick)	Surface Density (lb/ft^2)	STC Rating
Hollow-core wood	1.5	20
Hollow-core wood (30% of area glazed with 3 mm glass)	1.5	19
Solid-core wood	3.6	26
Steel-faced door (rigid polyurethane core)	3.2	26
Fiberglass-reinforced plastic door (rigid polyurethane core)	2.4	24

Table II. Acoustical Performance of Non-operable Windows

Single-Glazed	Double-Glazed 3 mm – 3 mm glass*	Double-Glazed 6 mm – 6 mm glass*	Double-Glazed 6 mm – 7 L mm glass*	Typical STC Rating
3 mm & 4mm	6 mm			30
6 mm	10 mm			32
6 L mm	20 mm	8 mm		34
12 mm	30 mm	13 mm		36
12 L mm	50 mm	20 mm	10 mm	38
20 L mm	70 mm	30 mm	16 mm	40
	100 mm	50 mm	25 mm	42
	150 mm	80 mm	40 mm	44
		120 mm	60 mm	46
			100 mm	48

* - Values indicate the airspace between the two layers of glass

L - Denotes laminated glass

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