Acoustical Guide – Table of Contents

Table of Contents for the Acoustical Guide (click on a bullet below to navigate to sub sections

- Introduction
- Rating
- Principles
- Data
- Methodologies
- Glossary
- Worksheets
- References
- Example

Purpose

This Acoustical Glazing Design Guide has been prepared for the building design professional, manufacturer of Saflex protective interlayer used in laminated glass. This guide includes the most comprehensive and up-to-date collection of laboratory-tested sound transmission loss data for laminated, monolithic and air-spaced glass configurations. It is an indispensable reference for anyone concerned about sound transmission through windows.

The primary purpose of this publication is to present easy-to-follow methodologies for estimating the minimum required sound transmission loss (TL) for exterior glazing exposed to the most common sources of exterior environmental noise: aircraft, highway traffic and rail transportation. These methodologies are devised to enable the architect to explore glazing options early in project development.

The need for this planning tool is great and ever-increasing due to more extensive use of land areas close to airports, highways and rail transportation lines. This, coupled with greater building owner/user expectations for noise control and wider use of lightweight, lower-cost building materials, has heightened the importance of exterior environmental noise considerations.

Organization

To provide a “user friendly” design tool, this guide has been organized as follows:

Section 1 presents methodologies for determining the minimum required window sound transmission class (STC) rating and various glazing alternatives that will satisfy this requirement. Also included in this section are typical examples illustrating the use of these methodologies and a compilation of window STC data measured by Riverbank Acoustical Laboratories (RALTM) in tests.

Acoustical Guide

Section 2 presents a summary of the fundamental principles of acoustics relevant to the methodologies presented.

Section 3 provides one-third octave band TL data for the wide variety of glass configurations listed in Figure 1.14a in Section 1. This data will be helpful to acoustical consultants and others needing to undertake detailed noise reduction (NR) estimates.

Section 4 provides a highly detailed discussion of the methodologies. This discussion would be of most interest to those with special expertise in acoustics.

Section 5 presents a glossary of terms for easy reference.

Section 6 presents key figures from Section 1 for use as worksheets.

Section 7 contains a list of references for additional information.

Section 8 provides information for specifiers to assist in the specification of Saflex laminated architectural glass.

Acoustical Glazing

Isolation of interior building spaces from exterior sound is important if building spaces are to properly serve their intended purposes. A space that has too much noise transmitted from outside may provide inadequate conditions. For example, a hotel near an airport that has windows that do not sufficiently limit the amount of aircraft sound transmitted into guest rooms may fail to provide what hotel guests are seeking in the hotel, i.e., a good night's sleep. Although hotels are obvious targets for concerns about sound in the environment, almost all types of buildings have at least some areas within that could be adversely affected by high levels of environmental sound transmitted from outside the building.

As discussed in this guide, sound transmission into building spaces is generally through the weakest element, and the weakest element is usually the windows. The guide discusses glazing designs that strengthen this weakest link, i.e., designs that increase the ability of windows to resist sound transmission into building spaces. The resistance of a building material to the transmission of sound is called the sound transmission loss (TL).

When usual glazing configurations are not sufficient to limit the transmission of sound into building spaces, glazing configurations with enhanced sound transmission losses, or acoustical glazing, must be considered. There is no specific definition of acoustical glazing, but most acoustical glazing makes use of some combination of polyvinyl butyral (PVB) plastic interlayer, such as Saflex, and an air space between multiple lights of glass. This publica-tion discusses these and other glazing features that enhance the TL of glass configurations.

Specifying Laminated Glass

The laminated glass industry has established standard designations for conventional laminated glass. These are provided in Figure i-1. When specifying these stan- dard thicknesses, only the "nominal" thickness must be cited. The unit construction provided by the laminator will be that listed in Figure i-1. If nominal thicknesses and unit constructions not listed in Figure i-1 are to be specified, the nominal thickness of each glass ply and each interlayer thickness must be cited. Exact glass ply thicknesses which are provided by the laminator will fall

Acoustical Guide

within ranges specified in ASTM C1036 (see Figure i-2). Saflex PVB interlayer thicknesses will be multiples of 0.015” beginning with 0.030” (e.g., 0.030”, 0.045”, 0.060”).

Laminated Glass Designation	Unit Construction: Glass (nominal) - *Saflex* PVB (in) - Glass (nominal)
("nominal" thickness)	(See Figure i.2 for glass ply thicknesses)
1/4" (6 mm)	Lami - 0.030" - Lami*
3/8" (10 mm)	3/16" - 0.030" - 3/16" or
	1/8" - 0.030" - 1/4"
1/2" (12 mm)	1/4" - 0.030" - 1/4"
9/16" (13 mm)**	1/4" - 0.060" - 1/4"
3/4" (19 mm)	1/4" - 0.060" - 1/2" or
	3/8" - 0.060" - 3/8"

*1/8" - 0.030" - 1/8" also is referred to as 1/4" laminated glass.

**ASTM does not contain this nominal thickness.

Figure i.1

Dimensional Tolerance for Rectangular Shapes for Transparent, Flat Glass*

Thickness			Thickness Range			
			mm		in	
Designation, mm	Traditional Designation	Nominal Decimal, in	min	max	min	max
1.0	Micro-slide	0.04	0.79	1.24	0.031	0.049
1.5	Photo	0.06	1.27	1.78	0.050	0.070
2.0	Picture	0.08	1.80	2.13	0.071	0.084
2.5	SIngle	0.09	2.16	2.57	0.085	0.101
2.7	Lami	0.11	2.59	2.90	0.102	0.114
3.0	Double-1/8"	0.12	2.92	3.40	0.115	0.134
4.0	5/32"	0.16	3.78	4.19	0.149	0.165
5.0	3/16"	0.19	4.57	5.05	0.180	0.199
5.5	7/32"	0.21	5.08	5.54	0.200	0.218
6.0	1/4"	0.23	5.56	6.20	0.219	0.244
8.0	5/16"	0.32	7.42	8.43	0.292	0.332
10.0	3/8"	0.39	9.02	10.31	0.355	0.406
12.0	1/2"	0.49	11.91	13.49	0.469	0.531
16.0	5/8"	0.63	15.09	16.66	0.595	0.656
19.0	3/4"	0.75	18.26	19.84	0.719	0.781
22.0	7/8"	0.87	21.44	23.01	0.844	0.906
25.0	1"	1.00	24.61	26.19	0.969	1.031
32.0	1-1/4"	1.23	28.58	34.93	1.125	1.375

*From ASTM C1036, Table 2 [3].

Figure i.2

Other Considerations

Besides acoustical design, security, strength and architectural load design issues also need to be addressed in window design. For a full discussion of these, the reader is directed to the Security Glazing Design Guide [1] and A Guide to the Structural Performance of Laminated Architectural Glass [2].

Acoustical Guide – Determining Minimum STC Rating

- Selecting, Procuring and Installing Acceptable Windows
- Methods for Determining Required Window STC Rating
- Aircraft Noise Methodology
- Traffic Noise Methodology
- Rail Noise Methodology
- More Than One Noise Source
- Glazing Selection
- Estimating Glazing Sound Transmission Loss

Selecting, Procuring and Installing Acceptable Windows

This section establishes a simplified procedure that can be followed by a building designer to make a preliminary evaluation of the minimum required window sound transmission class (STC) rating or weighted sound reduction index (Rw) needed for exterior windows of a building subject to aircraft, highway traffic or rail noise. These are the most commonly occurring sources of excessive exterior noise exposure.

The ultimate installation of windows that provide an acceptable noise reduction (NR) involves the following:

- Assessment of environmental noise
- Determination of the minimum acceptable window STC or Rw
- Glazing and window selection
- Window design, installation and inspection

The first two of the above items involve an acoustical analysis that has been presented here as abbreviated four-step methodologies -- one methodology for each of three major transportation types -- aircraft, traffic and rail. Then follows a table of sound transmission loss descriptors including STC, Rw and OITC (outdoor-indoor transmission class) for various glass configurations which have been measured by Riverbank Acoustical Laboratories under sponsorship. All three sound transmission loss descriptors are discussed in Section 2. Finally, the procedure involves designing the frame, entering the minimum required STC or Rw into the project specification and inspecting the final window installations.

These methodologies are simplifications of more exact and more complicated methodologies and are intended to provide conservative estimates of required STC or Rw ratings to be used by the building designer as a planning tool for window glazing. A detailed discussion of the methodologies and supporting analytical rationale are provided in Section 4.

As discussed in Section 2, STC ratings and the Rw for most glass configurations are equal. STC ratings are predominantly used in the United States. Rw is predominately used in international (ISO) and European standards. Because they are most often equal, STC and Rw can usually be used interchangeably, although most of the discussions and examples in the guide cite only the STC rating.

Acoustical Guide – Determining Minimum STC Rating

Methods for Determining Required Window STC Rating

The three methodologies discussed below for determining the minimum required STC of windows are identical in format. Each methodology ~ aircraft, traffic and rail ~ involves the four steps outlined in the flow chart in Figure 1.1. These steps are:

Step One: Noise Exposure

Through use of a contour map, estimation technique or actual noise measurements, the noise exposure produced by the three transportation noise sources must be determined.

Step Two: Composite Noise Reduction

Using appropriate building interior criteria and the noise exposure level determined in Step One, the minimum required noise reduction (NR) of the building and exterior wall construction is determined. As this NR is a combination of the wall and window NRs, it is referred to as the composite noise reduction (NRc).

Step Three: Window Noise Reduction

Using the wall NR, which can be determined from Figure 1.15, and the NRc, determined in Step Two, the minimum required window NR can be determined.

Step Four: Window STC Rating

Using charts discussed in each methodology and the minimum required NR determined in Step Three, the minimum required window STC or Rw can be determined.

When using these methodologies, it is important to remember that:

- A minimum required window STC or Rw determined for one transportation source may be greater than or less than what might be needed for another transportation source producing an equal exterior noise exposure.
- These methodologies are a planning tool. They may be conservative by indicating a minimum required window STC or Rw that might be higher than determined through a more exact analysis.
- Windows with an STC or Rw equal to or higher than that determined in Step Four should be used.

Acoustical Guide – Determining Minimum STC Rating

Aircraft Noise Methodology

The Federal Aviation Administration has issued Federal Aviation Regulation (FAR) Part 150. This document contains a Land Use Compatibility Table which is discussed in Section 2. For airports electing to engage in a Part 150 process, the regulation requires that airports prepare current and future (5 years) airport day-night average sound level contour maps. A typical example of a contour map is given in Figure 1.2. With the FAR Part 150 Land Use Compatibility Table and an airport noise contour map, it is possible to determine that a particular land use is either acceptable, not acceptable, or acceptable providing that a certain aircraft noise level reduction can be achieved in the exterior construction.

Figure 1.3 is essentially a graphic representation of the FAR Part 150 criteria. It is a chart which enables the determination of the minimum required wall/window composite noise reduction (NRc). The horizontal axis is yearly day-night average sound level (DNL) in decibels. The vertical axis is the minimum required NRc needed to maintain acceptable aircraft sound levels within building spaces. Because acceptable sound levels within building spaces depend upon their use, two lines relating day-night average sound level and minimum required NRc are provided. The lower line (requiring a lower NRc for a given DNL) is for use with offices, retail spaces and general work spaces. The upper line, representing more critical usage, is for use with residential and other noise-sensitive spaces.

The criteria of Figure 1.3 are used with Figures 1.4 and 1.5 to determine the minimum required window sound transmission class (STC) rating or weighted sound reduction index (Rw). These three figures are used in the following four-step procedure:

Step One: Noise Exposure

a) Obtain the latest airport noise contours from the airport noise abatement office.

b) Locate the proposed building site on the contour map and read the yearly day-night average sound level (DNL).

Example:

From the airport noise contour map of Figure 1.2, a proposed project site is determined to have a DNL of 77 dB.

Step One

Determine the aircraft DNL at the site.

Figure 1.2

Airport DNL noise contour map.

Acoustical Guide – Determining Minimum STC Rating

Step Two: Composite Noise Reduction

Locate the DNL for site aircraft noise exposure on the horizontal axis of Figure 1.3. Using either of the two criterion lines, determine the minimum required exterior wall-window composite noise reduction (NRc) from the vertical axis.

Example:

In Figure 1.3, locate the DNL of 77 dB on the horizontal axis. Assuming the project is to be for residential or other noise-sensitive use, read the minimum required NRc of 37 dB on the vertical axis.

Step Two

Determine minimum required composite NR for the building.

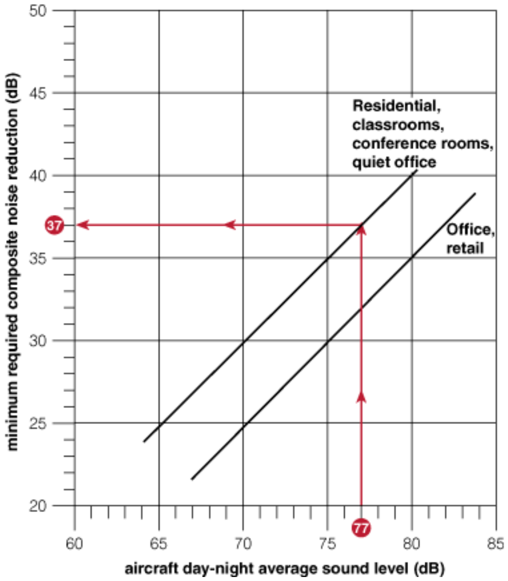


Figure 1.3 Chart for determining minimum required composite NR from aircraft DNL (Based on reference [4]).

Step Three: Window Noise Reduction

Using Figure 1.4 and the minimum NRc, the minimum required window noise reduction (NR) can be determined. Figure 1.4, however, requires knowing the NR of the exterior building wall. Presumably, the building exterior wall design is fixed earlier in the building design phase. The building wall aircraft NR can be determined from Figure 1.15. Using the aircraft NR for the exterior wall and Figure 1.4, the minimum required window NR can be determined.

Example:

Assume the exterior wall to be 4” (100 mm) face brick, 1” (24 mm) air space, 1/2” (12 mm) GWB sheathing, 3-5/8” (90 mm) metal stud, glass fiber batt, and two layers of 1/2” (12 mm) interior GWB (gypsum wall board). An aircraft wall NR value of 50 dB is determined from Figure 1.15d.

Step Three

Determine minimum required window NR from composite NR and wall NR.

In Figure 1.4, the horizontal axis is the wall NR (50 dB) minus the NRc (37 dB) which equals 13 dB.

Supposing the windows of the project in the example occupy 30% of the exterior wall, locate the vertical axis value as shown in Figure 1.4.

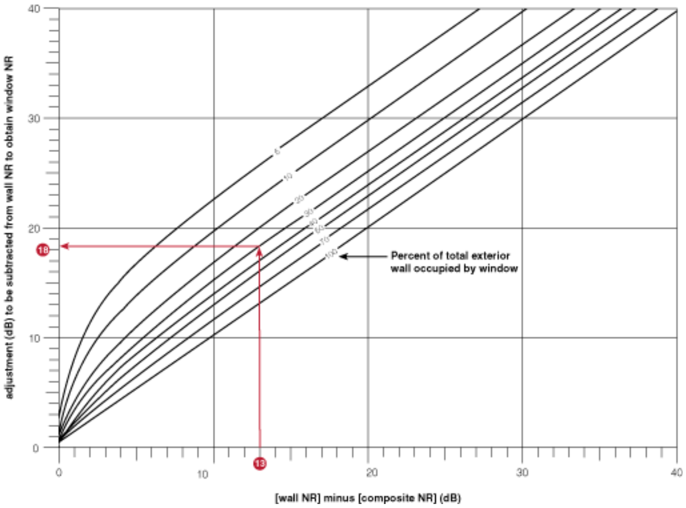


Figure 1.4 Chart for determining window sound transmission class (STC) from window aircraft noise reduction (NR).

Acoustical Guide – Determining Minimum STC Rating

The 18 dB value obtained from the vertical axis in Figure 1.4 is to be subtracted from the wall NR (50 dB) to obtain the minimum required window NR. The minimum required window NR in the example is:

50 dB Ð 18 dB = 32 dB

Step Four: Window Sound Transmission Class

Figure 1.5 contains a method for determining the window sound transmission class (STC) rating that corresponds to the window NR determined from Step Three. This is necessary since windows are laboratory-rated according to STC. Unlike NR, STC is a rating parameter that is independent of the conditions under which a window is used. These conditions include window area and receiving room sound absorption. NR, on the other hand, is affected by these conditions so that windows having the same STC rating might result in different NRs when used in different situations.

Now, using Figure 1.5 and the minimum required window NR, the minimum required window STC can be obtained.

Example:

From Step Three, the minimum required window NR was determined to be 32 dB. By locating the 32 dB NR value on the horizontal axis of Figure 1.5, the corresponding minimum required window STC of 41 dB for single glazing and 43 dB for double glazing can be read on the vertical axis.

Separate STC ratings are given for single and double glazing configurations since, for single and double glass configurations having the same STC rating, the single glazing will typically provide a higher aircraft NR.

Step Four

Determine minimum required window STC from window NR.

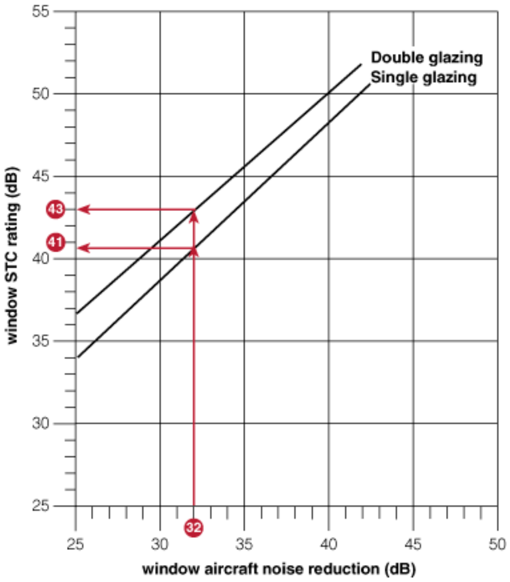


Figure 1.5 Chart for determining window sound transmission class (STC) from window aircraft noise reduction (NR).

Acoustical Guide – Determining Minimum STC Rating

Traffic Noise Methodology

Noise contours for highways, unlike airports, generally are not available. So, for a specific project site, it is necessary to determine the level of traffic noise exposure, either by actual noise measurements or through the use of a traffic noise prediction methodology. Perhaps the most widely used is that developed by the Federal Highway Administration and presented in FHWA Publication RD-77-108 (FHWA Highway Traffic Noise Prediction Model) [5]. Although the methodology in this publication is straightforward, the following is an abbreviated version which makes certain assumptions regarding baseline traffic and road conditions. These baseline assumptions are:

1) Heavy, free-flowing traffic with 7.5% heavy truck traffic and 7.5% medium truck traffic. Heavy trucks are defined as those having three axles or more and having a gross vehicle weight of more than 10,000 lbs. Medium trucks are defined as those having two axles and having a gross vehicle weight of less than 10,000 lbs.

2) The design speed of the highway is 70 mph.

3) The highway carries traffic at a level-of-service “C” with an average speed of 55 mph resulting in a traffic volume of 1,434 vehicles per hour per lane (including the 15% trucks).

Figure 1.6 presents a worksheet indicating the base traffic sound pressure level at 50 ft from a single lane of highway traffic, having the above indicated volumes and conditions. This base level is an equivalent sound level of 76 dBA. Following the base level are several adjustments accounting for numbers of lanes, distance from the road to the building, truck traffic volume, traffic speed and stop-and-go conditions. The selection of each of these adjustments is from tables located to the right of each adjustment entry.

The sum of the base traffic noise level and adjustments (a) through (g) produces a traffic equivalent sound level which can be used with Figure 1.7 to determine the minimum required composite noise reduction (NRc) for the building exterior wall/window construction. This figure contains three criteria corresponding to interior traffic noise levels of noise criteria (NC) 30, 35 and 40. Once the minimum required NRc is obtained from Figure 1.7, Figures 1.8 and 1.9 can be used to determine the minimum required window sound transmission class (STC). In short, the procedure is as follows:

Step One: Noise Exposure

Complete the Traffic Noise Level Estimation Worksheet of Figure 1.6.

Example:

Refer to Figure 1.6 for a typical application where the traffic noise level is determined to be 76 dBA.

Step One

Determine traffic noise exposure.

Acoustical Guide – Determining Minimum STC Rating

Maximum Hourly Baseline Level (Leq)1 76 dBA

a) Number of lanes ___ dB	No. of lanes	Adj.
	1	0
	2	3
	3	5
	4	6
	5	7
	6	8
	7	8
	8	9
b) Distance to road ___ dB	**Distance to road**	**Adj.**
	50'	0
	100'	-3
	150'	-6
	200'	-7
	250'	-9
	300'	-10
	350'	-11
	400'	-12
	500'	-13
c) Truck traffic volume ___ dB	**Truck traffic volume**	**Adj. Speed (mph) 35 45 55**
	Heavy	0 0 0
	Light	-7 -6 -5
d) Traffic speed ___ dB	**Posted traffic speed**	**Adj.**
	55 mph or higher	0
	45 mph	-3
	35 mph	-6
	Traffic	Adj.
	Free flow	0
e) Stop-and-go traffic ___ dB	**Stop-and-go**	**Adj.**
	Stop-and-go	+5
f) Shielding by foliage ___ dB	**Depth of foliage from road**	**Adj.2**
	0	0
	50'	-1
	100'	-3
	200'	-6
	300'	-9
g) Shielding by row of buildings ___ dB	**% of road view shielded Angle3**	**Adj.**
	0-20%	0
	20-40%	-1
	40-65%	-3
	65-90%	-5

TOTAL dBA

(baseline plus adjustments) Level of Service "C."

1 Level at 50' from one lane of traffic carrying 1,434 vehicles per hour (7.5% medium truck, 7.5% heavy truck) at 55 mph.

2 -10dB Max.

3 where 180º=100%.

Figure 1.6 Traffic noise level estimation worksheet.

Acoustical Guide – Determining Minimum STC Rating

Step Two: Composite Noise Reduction

Using the estimated traffic equivalent sound level determined from Figure 1.6, use Figure 1.7 to determine the minimum required exterior wall/window composite noise reduction (NRc).

Example:

Supposing that the interior noise criteria is NC 30, locate the traffic noise level (76 dBA) on the horizontal axis in Figure 1.7 and read the minimum required NRc of 43 dB on the vertical axis.

Step Two

Determine minimum required composite NR for the building.

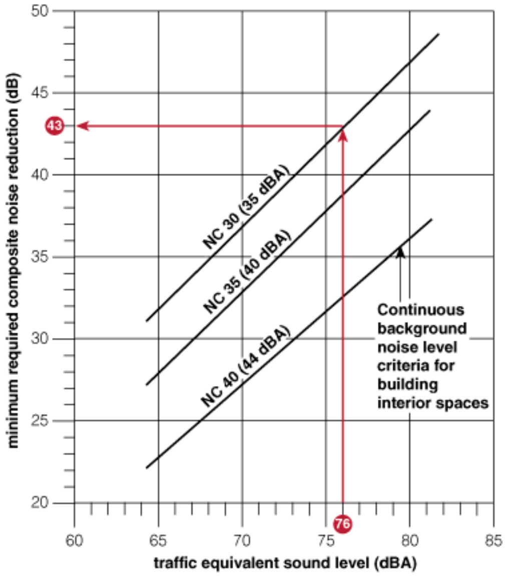


Figure 1.7 Chart for determining minimum required composite NR from traffic equivalent sound levels.

Step Three: Window Noise Reduction

a) Using the wall sound transmission loss (TL) data in Figure 1.15, determine the exterior wall traffic noise reduction (NR).

b) Using the wall traffic NR and the minimum required NRc from Step Two, determine the minimum required window NR from Figure 1.8.

Example:

Assume the exterior wall is 1/8” cementitious finish on 4” rigid urethane foam attached to 1/2” GWB sheathing, 3-5/8” metal studs and 1/2” interior GWB. A traffic NR of 46 dBA is determined from Figure 1.15b.

Step Three

Determine minimum required window NR from composite NR and wall NR.

In Figure 1.8, the horizontal axis is the wall NR (46 dBA) minus the NRc (43 dBA) which equals 3 dBA.

Supposing the windows of the project in this example occupy 20% of the exterior wall, locate the vertical axis value as shown in Figure 1.8.

In Figure 1.8, the vertical axis gives the value (8 dB) to be subtracted from the wall NR (46 dBA) to obtain the minimum required window NR. The minimum required window NR in this example is:

46 dBA - 8 dB = 38 dBA.

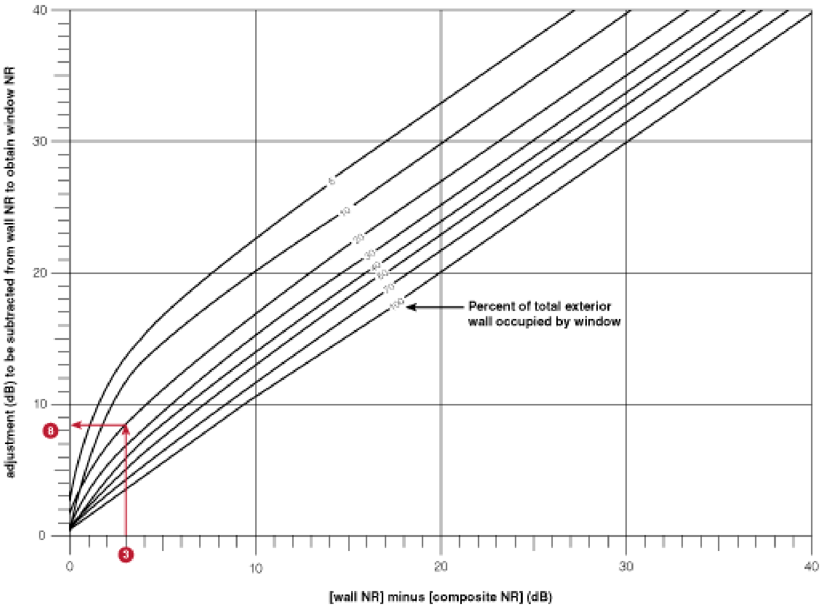


Figure 1.8 Chart for determining minimum required window NR from wall NR and composite NR (Same as Figure 1.4).

Acoustical Guide – Determining Minimum STC Rating

Step Four: Window Sound Transmission Class

Using the minimum required window noise reduction (NR), determine the minimum required window sound transmission class (STC) from Figure 1.9. NOTE: There is only one STC rating for both single and double glazing. [See Section 4 for further discussion.]

Example:

From Step Three, the minimum required window NR was determined to be 38 dB. By locating the 38 dB NR value on the horizontal axis of Figure 1.9, the corresponding minimum required window STC value of 44 is read on the vertical axis.

Step Four

Determine minimum required window STC from window NR.

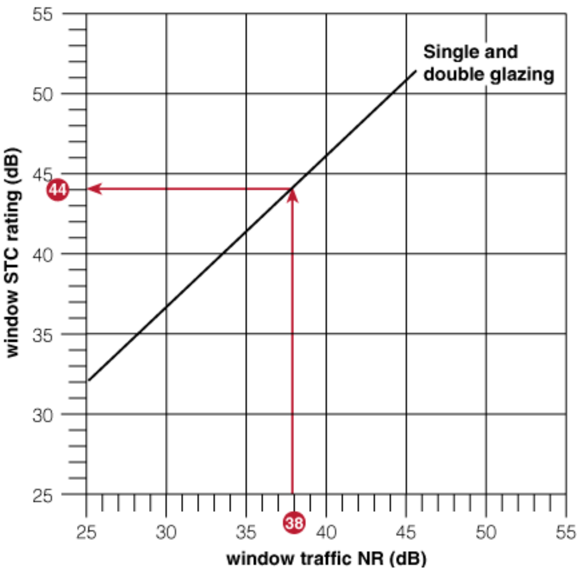


Figure 1.9 Chart for determining window sound transmission class (STC) from window traffic noise reduction (NR).

Acoustical Guide – Determining Minimum STC Rating

Rail Noise Methodology

As with traffic noise, noise levels from rail vehicle passbys must be either measured or estimated from various features such as rail equipment type, distance from the track, etc. There is no single, universally recognized method for assessing rail noise exposure at a building site. Certainly, in the case of a U.S. Department of Housing and Urban Development-supported project[6], the day-night average sound level would be used. It has been the experience, however, that averaging train passby noise levels over a 24-hour period sometimes underestimates the actual perceived impact of train noise. This is particularly true near lightly traveled lines, e.g., those with two or three trains per day. In such instances, the day-night average sound level could be acceptable, yet the maximum A-weighted sound pressure level reached during train passbys might be excessive.

Noise criteria (NC) curves, devised to quantify continuous background noise levels in buildings, often are used to set limits on transient noise levels such as those produced by passing trains. Limits on transient noise are generally set 5 to 10 NC points above those for continuous noise sources. For example, a space with a background noise limit for continuous noise sources of NC 40 might have a noise limit of NC 45 or 50 for transient noise sources such as passing trains. Many times, limits on maximum train passby noise levels within building spaces are more restrictive than 24-hour average limits such as that used by HUD, which are more appropriate for continuous sound or sound from more frequently occuring transient events.

All rail vehicles produce noise associated with wheel-rail interaction [7]. Although other sources of wayside noise such as train control and air-conditioning equipment can be important, wheel-rail noise most often dominates. Chief factors that contribute to wheel-rail noise are:

- Rail roughness
- Wheel roughness or out-of-round conditions
- Rail joints
- Wheel squeal on sharp curves
- Train passage over bridges or other light structures

Each of the above has obvious potential for producing noise. Some of the above track quality features can be easily observed. For example, jointed rail produces a wheel-rail impact every time a wheel passes over a joint. The absence of joints in continuously welded track helps in reducing wheel-rail noise.

In lieu of actual train passby noise levels measured at a project site, Figures 1.10a and 1.10b can be used to determine the maximum train passby noise levels produced by rolling stock and locomotives. As with the traffic method-ology, a number of adjustments accounting for train length, distance from track, etc., are applied to a baseline level to arrive at a maximum passby noise level. Rolling stock and locomotive noise levels are added together using the procedure outlined in Figure 1.10c. In the case of electrically self-propelled rail cars, the estimations produced in Figures 1.10b and 1.10c are skipped, and the total train maximum passby noise level is that level estimated alone in Figure 1.10a.

Acoustical Guide – Determining Minimum STC Rating

The procedure for determining the minimum required window sound transmission class (STC) when the outside noise exposure is produced by rail traffic is as follows:

Step One: Noise Exposure

Complete the train passby sound level estimation worksheets of Figures 1.10a, 1.10b and 1.10c.

Example:

Refer to Figures 1.10a, 1.10b and 1.10c for a typical application where the maximum train passby noise level is determined to be 89 dBA.

Step One

Determine train noise exposure.

ROLLING STOCK
(or electric self-propelled rail car)
Rolling Stock
Baseline 75 dBA

a) Speed ___ dBA	Speed (mph)	Speed adj.
	20	-8
	30	-3
	40	+1
	50	+4
	60	+6
	70	+8
	80	+10
	90	+12
b) Distance ___ dBA	**Distance to tracks**	**Distance adj.**
	50'	+3
	100'	0
	200'	-3
	400'	-6
	800'	-9
c) Train length ___ dBA	**Distance from tracks**	**Number of cars 2 4 8 16 32 64**
	50'	0 0 0 0 0 0
	100'	-1 0 0 0 0 0
	200'	3 1 0 0 0 0
	400'	-6 -3 -1 0 0 0
	800'	-9 -6 -3 -1 0 0
d) Track quality ___ dBA	**Track quality**	**adj.***
	Cont. welded	
	- passenger	0
	- freight	+7
	Jointed	
	- passenger	+7
	- freight	+2
	Switch	+6
	Rough Wheels	+5
TOTAL ___ dBA *Use only the highest applicable adj. (baseline plus adjustments)		

Figure 1.10a Rolling stock noise level estimation worksheet.

Acoustical Guide – Determining Minimum STC Rating

LOCOMOTIVES

Locomotive Baseline 92 dBA

Figure 1.10b Locomotive passby sound level estimation worksheet.

a) Locomotive type ___ dBA	**Locomotive type**	**Adj.**
	Diesel	0
	Turbine	-6
	Electric	-6
b) Distance adjustment ___ dBA	**Distance from track**	**Adj.**
	50'	+3
	100'	0
	200'	-6
	400'	-12
	800'	-18
c) Adjustment for number of locomotives ___ dBA	**Number of locomotives**	**Adj.**
	1	0
	2	3
	3	5
	4	6
	5	7
	6	8
TOTAL ___ dBA (baseline plus adjustments)		

SUMMATION

To find the sum of rail car and locomotive maximum passby noise levels:

a) Find the arithmetic difference between the two levels.

Higher Level: ___ dBA
Lower Level: ___ dBA
Arithmetic
Difference ____ dBA

b) Add to the higher of the two the adjustment from the following table:

Difference between two levels to be added together	**Adj. to be added to the higher to obtain sum**
0-1	3
2-3	2
4-9	1
10 or more	0
Higher Level:	___ dBA
Adjustment:	___ dBA
Total Sound Level: ___ dBA	

Figure 1.10c Summation of rolling stock and locomotive sound levels.

Acoustical Guide – Determining Minimum STC Rating

Step Two: Composite Noise Reduction

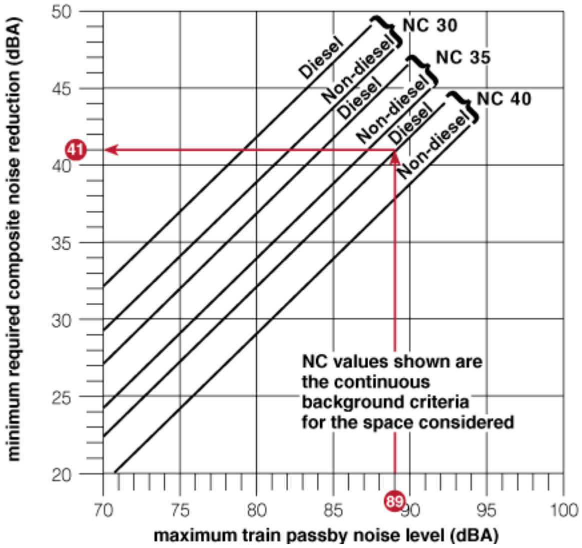
Using the estimated train passby sound level determined from Figures 1.10a, 1.10b and 1.10c, use Figure 1.11 to determine the minimum required exterior wall/window composite noise reduction (NRc). This requires selecting the curve in Figure 1.11 with the same noise criteria (NC) level as that used as a limit for continuous background noise in the space. The methodology has been devised to result in a maximum train passby level which is 10 NC points higher than the indicated continuous background limit.

Example:

In this example, it is assumed that the interior NC for background noise in the space is NC 40. Noting that the train in this example is powered by a diesel locomotive, locate the proper line in Figure 1.11 marked NC 40 w/ diesel. Locate the train passby noise level (89 dBA) on the horizontal axis of Figure 1.11 and read the NRc value (41 dBA) on the vertical axis.

Step Two

Determine minimum required composite NR for the building.



NC values shown are the continuous background criteria for the space considered

Figure 1.11 Chart for determining minimum required composite NR from train passby noise level.

Step Three: Window Noise Reduction

a) Using the wall sound transmission loss (TL) data in Figure 1.15, determine the exterior wall train passby noise reduction (NR).

b) Using the wall train NR and the minimum required NRc from Step Two, determine the minimum required window NR from Figure 1.12.

Example:

Assuming the exterior wall (from outside to inside) is a 2" pre-cast concrete panel, 1" airspace, 6" lightweight concrete block and 1/2" GWB adhered directly to the block, a train NR of 46 dBA is determined from Figure 1.15c.

In Figure 1.12, the horizontal axis is the wall NR (46 dBA) minus the NRc (41 dBA) which equals 5 dB.

Supposing the windows of the project in this example occupy 20% of the exterior wall, locate the vertical axis value (10 dB) as shown in Figure 1.12.

Acoustical Guide – Determining Minimum STC Rating

The 11 dB value obtained from the vertical axis in Figure 1.12 is to be subtracted from the wall NR (46 dBA) to obtain the minimum required window NR. The minimum required window NR in this example is:

46 dBA - 10 dB = 36 dBA.

Step Three

Determine minimum required window NR from composite NR and wall NR.

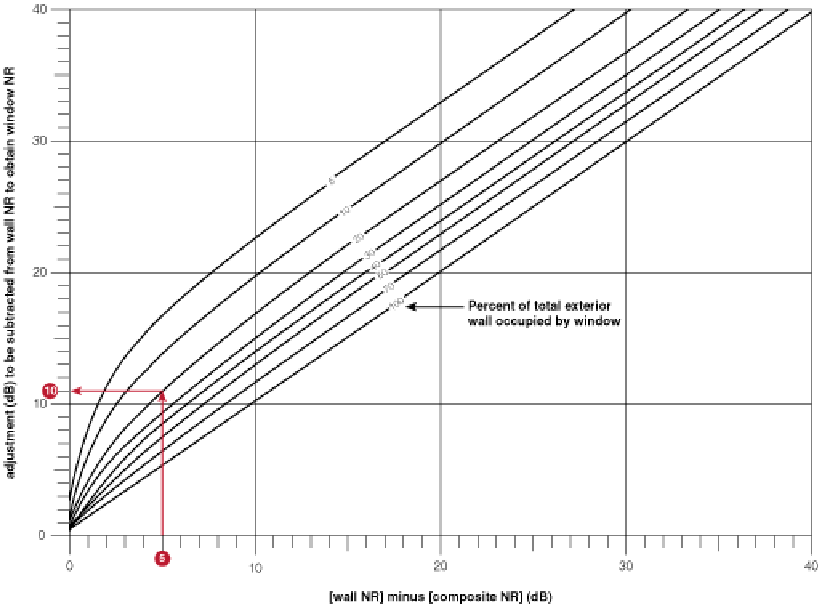


Figure 1.12 Chart for determining minimum required window NR from wall NR and composite NR (Same as Figure 1.4).

Step Four: Window Sound Transmission Class

Using the minimum required window noise reduction (NR), determine the minimum required window sound transmission class (STC) from Figure 1.13.

Example:

From Step Three, the minimum required window NR was determined to be 36 dBA. By locating the 36 dBA NR value on the horizontal axis of Figure 1.13, the corresponding minimum required window STC value of 47 for single glazing and 50 for double glazing is determined on the horizontal axis.

Step Four

Determine minimum required window STC from window NR.

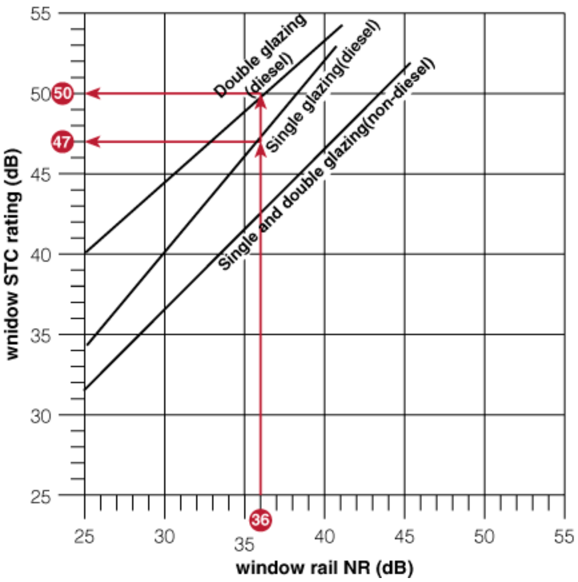


Figure 1.13 Chart for determining window sound transmission class (STC) from window rail noise reduction (NR).

Acoustical Guide – Determining Minimum STC Rating

More Than One Noise Source

Sometimes noise exposures from two or more noise sources combine in such a way as to produce a net noise exposure that is greater than that produced by either source individually. Many times, however, the additive effect of two transportation noise sources can be ignored. For example, with both rail and aircraft noise, the chief concern is for controlling maximum noise levels during passbys and flyovers. In most situations, it is highly unlikely that both a train passby and aircraft flyover would occur simultaneously; hence, it is usually sufficient only to use the higher minimum sound transmission class (STC) predicted from either methodology for glazing selection.

If it is observed that aircraft take-offs and landings and train passbys do often occur simultaneously, the procedure for arriving at the STC rating for the combined noise source condition is as follows:

- Determine the STC for each source independently.
- If the higher STC exceeds the lower STC by 0 or 1 dB, add 3 dB to the higher to arrive at the STC rating for the combined noise source condition.
- If the higher STC exceeds the lower STC by 2 or 3 dB, add 2 dB to the higher rating to arrive at the STC rating for the combined source condition.
- If the higher STC exceeds the lower STC by 4 to 9 dB, add 1 dB to the higher to arrive at the STC rating for the combined source condition.
- If the higher STC exceeds the lower STC by 10 dB or more, the rating for the combined source condition simply equals the higher STC.

NOTE:
Use the combined STC only when train and aircraft events frequently occur simultaneously. In the case of a building site affected by both traffic noise and rail or aircraft noise, the above procedure for combining STC ratings can also be used.

Acoustical Guide – Determining Minimum STC Rating

Glazing Selection

In the immediately preceding discussions, four-step methodologies for determining minimum required window sound transmission class (STC) ratings have been outlined for aircraft, traffic and rail noise exposures. The next step is to use the minimum required STC to arrive at an acceptable window glass configuration. This involves selecting, from Figure 1.14a, a few glass configurations having STC values equal to or higher than the minimum required window STC determined in one of the preceding methodologies. These preliminary glazing selections would then be studied, in light of other criteria such as thermal performance, safety, security, solar control, cost and other factors. Using the procedure described in the following subsection, it is possible to estimate STC ratings and noise reductions (NR) for glazing configurations other than those shown in Figure 1.14a.

In Figure 1.14a, STC, Rw and OITC ratings are given for five basic types of glazing configurations. These are:

Monolithic - a single light of glass.

Laminated - two lights of glass bonded together with Saflex interlayer.

Insulating - two lights of monolithic glass separated by an air space.

Laminated Insulating - one light of laminated glass and one light of monolithic glass separated by an air space.

Double Laminated Insulating - two lights of laminated glass separated by an air space.

Obviously, a wide range of glass configurations can be devised. Those discussed in this manual represent a spectrum of types considered for usual architectural applications.

Acoustical Guide – Determining Minimum STC Rating

Estimating Glazing Sound Transmission Loss

The three basic features of glazing design discussed in this guide that affect sound transmission loss characteristics are as follows:

- Insulating glass air space thickness
- Glass thickness
- Interlayer damping

Insulating glass air space thickness generally varies between 1/4" and 6". In this range, air space thicknesses between 1/4" and 1/2" are hermetically sealed with desiccant. Air spaces greater than 1/2" usually are not sealed.

Glass thicknesses usually range between 1/8" and 1/4" with thicknesses up to 1/2" used in special architectural applications. The use of thicker glass is rare due to cost and handling reasons.

Saflex interlayer is a polyvinyl butyral material regularly available in 0.030" and 0.060" thicknesses. Other thicknesses also can be specially fabricated. For most architectural applications, a single interlayer is used between two pieces of glass.

Quirt [8, 9] has developed and tested methods for computing one-third octave band TLs for arbitrary glass configurations. These methods are intricate and require an advanced understanding of acoustics. Through a careful investigation of measured TLs and STC ratings for various configurations in Figure 1.14a, general "rules of thumb" have been developed that allow estimates of STC ratings for a wide range of other glass configurations. These "rules of thumb," given in Figure 1.14b, are presented as adjustments accounting for changes in the three above mentioned glass features: air space thickness, damping and glass thickness.

For example, consider the following glass configuration:

- 1/8" Glass
- 0.030" Saflex
- 1/8" Glass
- 1/2" Air Space (sealed)
- 1/4" Glass

According to the adjustments in Figure 1.14b, were the sealed air space in the above configuration to be doubled from 1/2" to 1", the sound transmission class rating would increase from 39 (RAL Test TL 85-235) to 42. If the new 1" air space sample is unsealed, the STC would be 1 dB less, i.e., 41 instead of 42.

It should be noted that the adjustments in Figure 1.14b can be applied to noise reductions as well as STC ratings in order to reflect changes in a glass configuration.

Acoustical Guide – Determining Minimum STC Rating

A second example of the use of the "rules of thumb" in Figure 1.14b is as follows:

Suppose it was determined from one of the above methodologies that windows in a particular building must have a minimum STC rating of 44 and the window design is such that the total glass thickness cannot exceed 2".

There is no unique approach to designing a glass configuration that meets the STC 44 requirement. However, we suggest first selecting a glass configuration from Figure 1.14a that is thinner than the maximum allowed (2"). Then apply adjustments in Figure 1.14b to this base glass configuration to arrive at the required design.

For example, choosing as a base configuration: unsealed 1/8" glass --0.030" Saflex --1/8" glass--1" air space--3/16" glass, the configuration thickness is 1-7/16" and the STC rating is 42. Increasing the air space thickness of this configuration by 9/16" to 1-9/16" (1.56") would increase the STC rating by 10 log [1.56"/1"], which is equal to 2 dB. Hence, the new 2" glazing would have an STC rating of 44.

Approaching this analysis from the other direction, it can be seen in Figure 1.14a that a base configuration of 1/8" glass--0.030" Saflex --1/8" glass--4" air space--3/16" glass has an STC rating of 48 (RAL, Test TL 85-174). Decreasing the air space thickness in this configuration from 4" to 1-9/16" (1.56") would decrease the STC rating by 10 log [1.56"/4"], which is equal to -4 dB, to an STC rating of 44.

Note that the adjustments in Figure 1.14b are approximations. In the two preceding examples, adjusting the two different base glass configurations resulted in identical STC ratings estimated for the 1-9/16" air spaced configuration. This is somewhat fortuitous since similar adjustments (particularly adjustments for glass thickness) applied to two different base glass configurations may differ by as much as 2 STC rating points.

It is suggested that when seeking modifications to laboratory tested base configurations, the order of consideration be:

1. Adding damping
2. Increasing air space thickness
3. Increasing glass thickness

NOTE:
As indicated above, the method of applying the adjustments of Figure 1.14b is a guideline for estimating glass sound transmission class (STC) ratings. Window frames and other features can affect sound isolation performance so that the final approval of a window design should be on the basis of a laboratory sound transmission loss (TL) test of a complete window assembly.

Acoustical Guide – Determining Minimum STC Rating

1 RAL TL 85 and TL 95 sound transmission loss tests are in accordance with ASTM E90. STCratings have been determined from TL data using ASTME413. See Section 3 for actual TLdata.

2 Estimated. Computation based on a one-third octave band TL at 80 Hz (which was not measured in the laboratory) that is equal to the 100 Hz one-third octave band TL minus 2dB.

3 The overall heat transfer coefficient in BTU/hr/sq ft/¡F

4 AS - Air Space

5 Unsealed configurations are individual glass panels separated by wood stops and caulked into the laboratory test opening using glazing putty.

6 0.030”, 0.060” - Saflex¨ interlayer thicknesses

7 The second and third glass panels of the triple glass configurations tested are sealed insulating glass units. After sealed IG units were installed into the laboratory test opening, the first glass panel and wood spacers were used to complete the triple glass configurations.

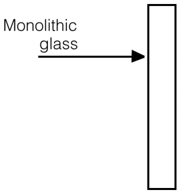
Riverbank Acoustical Laboratories TEST NO.[1]	Nominal Thickness - (Configuration)	STC	OITC[2]	Rw	U-Value[3] Summer	U-Value[3] Winter
	Monolithic					
TL 85-169	1/4"	31	29	32	1.01	1.08
TL 85-198	1/2"	36	33	37	.97	1.03
	Laminated					
TL 85-218	1/4" - (Lami - 0.030" - Lami)	35	31	35	1.00	1.06
TL 85-170	1/4" - (1/8" - 0.030" - 1/8")	35	31	35	.99	1.05
TL 85-224	1/4" - (1/8" - 0.060" - 1/8")	35	32	35	.97	1.03
TL 85-234	1/4" - (1/8" - 0.045" - 1/8")	35	31	35	.98	1.04
TL 85-200	3/8" - (3/16" - 0.030" - 3/16")	36	33	36	.97	1.03
TL 85-229	3/8" - (1/4" - 0.030" - 1/8")	36	33	36	.97	1.03
TL 85-223	3/8" - (1/4" - 0.060" - 1/8")	37	33	37	.95	1.00
TL 85-225	1/2" - (1/4" - 0.030" - 1/4")	38	34	38	.95	1.01
TL 85-232	1/2" - (1/4" - 0.045" - 1/4")	38	34	38	.94	.99
TL 85-228	1/2" - (1/4" - 0.060" - 1/4")	39	34	39	.93	.98
TL 85-222	5/8" - (3/8" - 0.030" - 1/4")	40	36	40	.93	.99
TL 85-230	3/4" - (1/2" - 0.060" - 1/4")	41	36	41	.90	.95
	Insulating [4,5]					
TL 85-212	1/2" - (1/8" - 1/4" AS - 1/8") (SEALED)	28	26	30	.62	.57
TL 85-213	5/8" - (1/8" - 3/8" AS - 1/8") (SEALED)	31	26	32	.57	.52
TL 85-294	1" - (1/4" - 1/2" AS - 1/4") (SEALED)	35	28	35	.54	.48
TL 85-215	1-3/8" - (3/16" - 1" AS - 3/16") (SEALED)	35	27	37	.54	.48
TL 85-293	1-1/2" - (1/4" - 1" AS - 1/4") (UNSEALED)	37	30	37	.52	.48
TL 85-216	4-3/8" - (3/16" - 4" AS - 3/16") (UNSEALED)	44	35	44	.52	.48
	Laminated Insulating [4,5, 6]					
TL 95-296	5/8" - (1/8" - 0.030" - 1/8"- 1/4" AS - 1/8") (SEALED)	35	31	35	.61	.56
TL 85-189	13/16" - (1/8" - 0.030" - 1/8" - 3/8" AS - 3/16") (SEALED)	37	31	37	.55	.50
TL 85-238	15/16" - (1/8" - 0.030" - 1/8" - 1/2" AS - 3/16") (SEALED)	39	31	39	.53	.48
TL 85-235	1" - (1/8" - 0.030" - 1/8" - 1/2" AS - 1/4") (SEALED)	39	31	39	.53	.48
TL 85-192	1-1/8" - (1/8" - 0.030" - 1/4" - 1/2" AS - 1/4") (SEALED)	40	31	40	.53	.47
TL 85-239	1-7/16" - (1/8" - 0.030" - 1/8" - 1" AS - 3/16") (UNSEALED)	42	33	42	.51	.48
TL 85-173	2-7/16" - (1/8" - 0.030" - 1/8" - 2" AS - 3/16") (UNSEALED)	45	35	45	.51	.48
TL 85-194	2-11/16" - (1/4" - 0.030" - 1/4" - 2" AS - 3/16") (UNSEALED)	46	38	46	.50	.47
TL 85-196	2-7/8" - (1/4" - 0.030" - 1/4" - 2" AS - 3/8") (UNSEALED)	46	42	47	.49	.46
TL 95-298	1-11/16" - (1/4" - 0.030" - 1/4" - 1" AS - 3/16") (UNSEALED)	47	36	47	.52	.47
TL 85-174	4-7/16" - (1/8" - 0.030" - 1/8" - 4" AS - 3/16") (UNSEALED)	48	39	48	.51	.48
TL 85-195	4-11/16" - (1/4" - 0.030" - 1/4" - 4" AS - 3/16") (UNSEALED)	49	41	49	.50	.47
TL 85-197	4-7/8" - (1/4" - 0.030" - 1/4" - 4" AS - 3/8") (UNSEALED)	49	44	50	.49	.46
TL 85-240	4-7/8" - (1/2" - 0.030" - 1/4" - 4" AS - 1/8") (UNSEALED)	49	40	49	.49	.46
	Double Laminated Insulating [4,5, 6]					
TL 85-172	1-1/16" - (1/8" - 0.030" - 1/8" - 1/2" AS - 1/8" - 0.030" - 1/8") (SEALED)	42	33	42	.52	.47
TL 95-299	1-9/16" - (1/8" - 0.030" - 1/8" - 1" AS - 1/8" - 0.030" - 1/8") (UNSEALED)	46	37	46	.52	.47
TL 85-236	1-13/16" - (1/4" - 0.030" - 1/4" - 1" AS - 1/8" - 0.060" - 1/8") (UNSEALED)	46	34	46	.49	.46
TL 85-221	5-1/16" - (1/4" - 0.060" - 1/4" - 4" AS - 1/4" - 0.030" - 1/4") (UNSEALED)	50	42	50	.48	.45
TL 85-220	5-5/16" - (1/2" - 0.060" - 1/4" - 4" AS - 1/4" - 0.030" - 1/4") (UNSEALED)	50	42	50	.47	.44
TL 85-237	4-13/16" - (1/4" - 0.030" - 1/4" - 4" AS - 1/8" - 0.060" - 1/8") (UNSEALED)	51	44	51	.49	.46
TL 95-301A	4-9/16" - (1/8" - 0.030" - 1/8" - 4" AS - 1/8" - 0.030" - 1/8") (UNSEALED)	52	38	51	.51	.47
TL 95-302	4-13/16" - (1/8" - 0.030" - 1/8" - 4" AS - 1/4" - 0.060" - 1/4") (UNSEALED)	53	45	53	.49	.46
	Triple Glazing [4,6, 7]					
TL 95-294	1-3/4" - (1/4" - 1/2" AS - 1/4" - 1/2" AS - 1/4") (SEALED)	39	31	39	.37	.31
TL 95-295	1-13/16" - (1/4" LAM. - 1/2" AS - 1/4" LAM. -1/2" AS - 1/4" LAM.) (UNSEALED)	44	33	44	.36	.30
TL 95-297	2-1/4" - (1/4" - 1" AS - 1/4"-1/2" AS - 1/4") (UNSEALED)	46	37	47	.36	.30
TL 95-300	2-5/16" - (1/4" LAM. - 1" AS - 1/4" LAM. -1/2" AS - 1/4" LAM.) (UNSEALED)	49	39	49	.35	.30

Figure 1.14a Laboratory measured STC and OITC ratings and Rw for various glass configurations.*

* [The data and information set forth are based on samples tested and are not guaranteed for all samples or applications.]

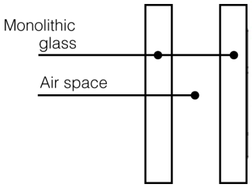
Acoustical Guide – Determining Minimum STC Rating

Monolithic



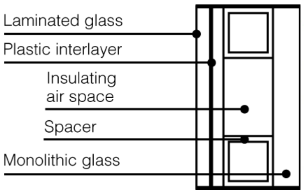
Glass Configuration Change	Adjustment
Replacing monolithic glass with single laminated glass (equal weight)	+3dB
Double interlayer thickness from 0.030" to 0.060" Saflex® (for 3/8" total glass thickness or greater)	+1dB

Insulating



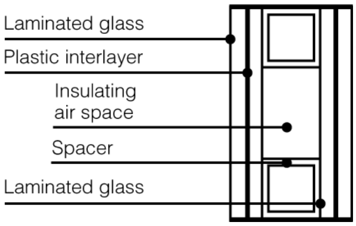
Glass Configuration Change	Adjustment
Replace one light with equal thickness of laminated glass	+4dB
Double air space	+3dB*
Double total glass weight	+1dB
Change from unsealed to sealed insulating glass	+1dB

Laminated Insulating



Glass Configuration Change	Adjustment
Change from insulating to laminated insulating (equal weight, equal air space)	+4dB
Double air space	+3dB*
Double glass weight	
air space thickness less than 1"	+3dB
air space thickness greater than 1"	+1dB
Change from unsealed to sealed insulating glass	+1dB

Double Laminated Insulating



Glass Configuration Change	Adjustment
Change from laminated insulating to double laminated insulating	+3dB
Double air space	+3dB*
Double glass weight	+1dB

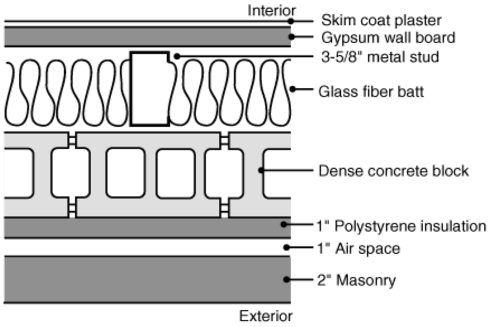
Figure 1.14b Estimated STC, OITC, Rw and NR adjustments to be applied to laboratory and field test data to obtain sound isolation performances of untested glass configurations.

*Air space adjustment equals 10 log (t2/t1) where t1 and t2 are air space thicknesses.

NOTE:
These adjustments are approximations only.

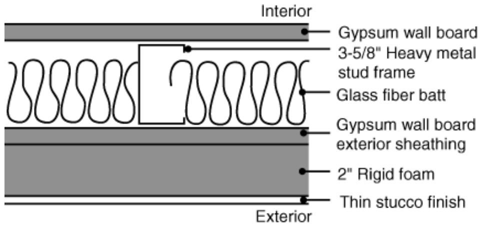
Acoustical Guide – Determining Minimum STC Rating

Exterior Wall Noise Reductions - Plan Sections



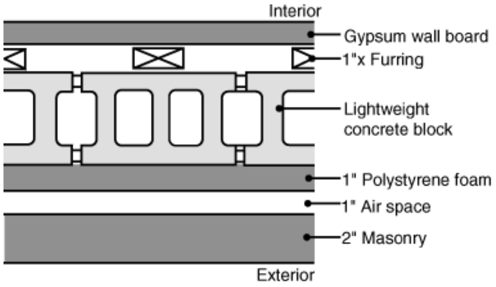
A-Weighted Noise Reduction (dBA)			
Estimated STC	Aircraft	Traffic	Rail
67	60	64	66/58
Adjustments			
Add one layer GWB to interior side			+2 dB
Delete glass fiber batt			-6 dB
Add loose insulation to block cells			+2 dB
Delete polystyrene insulation			0 dB
Double thickness of exterior masonry			+2 dB

Figure 1.15a



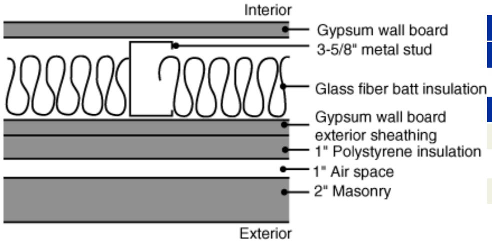
A-Weighted Noise Reduction (dBA)			
Estimated STC	Aircraft	Traffic	Rail
49	48	51	52/45
Adjustments			
Add one layer GWB to interior side			+5 dB
Delete glass fiber batt			-6 dB
Halve thickness of urethane foam			-3 dB
Double thickness of urethane foam			+1 dB
Add resilient channels between interior GWB and stud			+4 dB

Figure 1.15b



A-Weighted Noise Reduction (dBA)			
Estimated STC	Aircraft	Traffic	Rail
58	51	55	57/49
Adjustments			
Add one layer GWB to interior side			+2 dB
Replace 1"x furring with 1/2" resilient channels			+3 dB
Delete 1"x furring, adhere GWB to block			-3 dB
Add loose insulation to block cells			+2 dB
Delete polystyrene foam			0 dB
Double thickness of exterior masonry			+2 dB

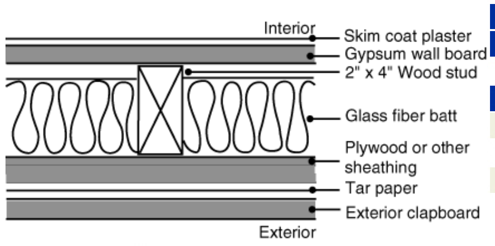
Figure 1.15c



A-Weighted Noise Reduction (dBA)			
Estimated STC	Aircraft	Traffic	Rail
52	45	49	51/43
Adjustments			
Add one layer GWB to interior side			+2 dB
Replace 1"x furring with 1/2" resilient channels			-5 dB
Double masonry thickness			+3 dB
Delete polystyrene insulation			0 dB

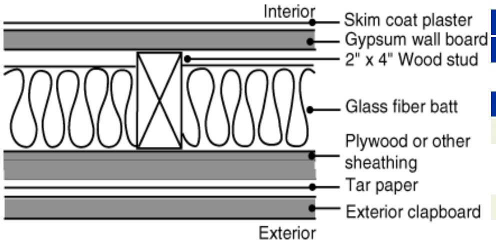
Figure 1.15d

Acoustical Guide – Determining Minimum STC Rating



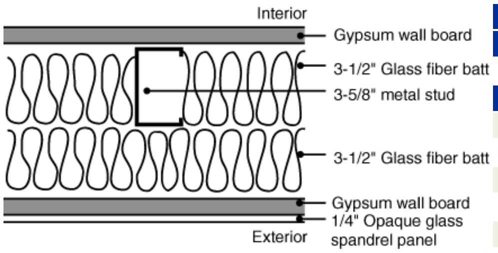
A-Weighted Noise Reduction (dBA)			
Estimated STC	**Aircraft**	**Traffic**	**Rail**
54	47	51	53/45
Adjustments			
Add resilient channels between interior GWB and stud			+8 dB
Delete polystyrene foam			0 dB
Replace brick with 2" solid masonry			-3 dB
Replace 4" brick with 6" hollow masonry units			-1 dB

Figure 1.15e



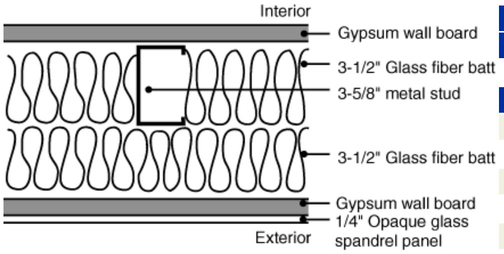
A-Weighted Noise Reduction (dBA)			
Estimated STC	**Aircraft**	**Traffic**	**Rail**
40	34	39	41/30
Adjustments			
Add resilient channels between interior GWB and stud			+8 dB
Replace tar paper and clapboard with foam insulation and vinyl or aluminum siding			-2 dB
Delete skim coat			-1 dB

Figure 1.15f



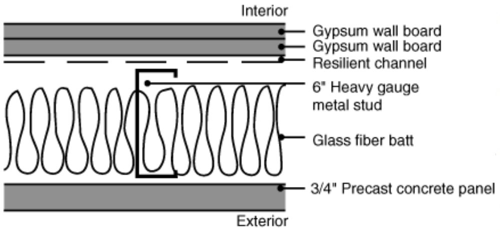
A-Weighted Noise Reduction (dBA)			
Estimated STC	**Aircraft**	**Traffic**	**Rail**
55	50	54	55/48
Adjustments			
Delete exterior GWB			-3 dB
Delete glass fiber batt			-5 dB
Add interior GWB			+2 dB
Increase glass to 1/2" thickness			+2 dB
Add Saflex¨ interlayer			+4 dB

Figure 1.15g



A-Weighted Noise Reduction (dBA)			
Estimated STC	**Aircraft**	**Traffic**	**Rail**
63	53	57	58/49
Adjustments			
Delete 1 layer GWB			-3 dB
Delete resilient channels			-13 dB
Delete both batt and resilient channels			-15 dB
Delete batt, leave resilient channels in			-8 dB
Double concrete panel thickness			+2 dB

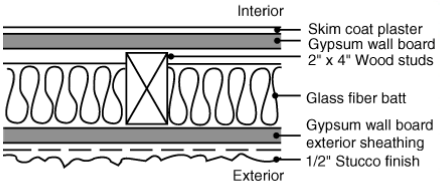
Figure 1.15h



A-Weighted Noise Reduction (dBA)			
Estimated STC	**Aircraft**	**Traffic**	**Rail**
53	44	47	48/41
Adjustments			
Add resilient channels			0 dB
Add one layer GWB to interior side			+1 dB
Delete exterior GWB sheathing, apply lath and stucco to studs			-5 dB
Substitute equal thickness plywood for GWB			0 dB
Delete glass fiber batt			-6 dB
Change wood studs to metal studs			0 dB

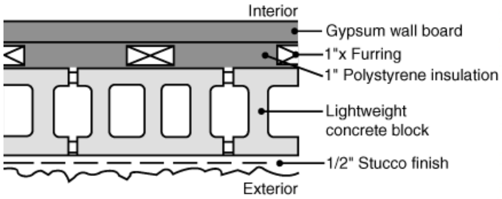
Figure 1.15i

Acoustical Guide – Determining Minimum STC Rating



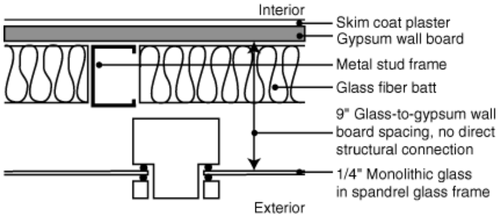
A-Weighted Noise Reduction (dBA)			
Estimated STC	Aircraft	Traffic	Rail
40	29	34	36/25
Adjustments			
Add one layer GWB to interior			+3 dB
Delete glass fiber batt			-3 dB
Add resilient channels to wood studs with glass fiber in cavity without glass fiber in cavity			+9 dB +4dB
Delete exterior GWB sheathing, apply lath and stucco to studs			-3 dB
Substitute equal thickness plywood for GWB			0 dB
Substitute heavy metal studs for wood studs			+5 dB

Figure 1.15j



A-Weighted Noise Reduction (dBA)			
Estimated STC	Aircraft	Traffic	Rail
50	48	50	52/46
Adjustments			
Add one layer GWB to interior side			+2 dB
Replace 1"x furring with 1/2" resilient channels			+1 dB
Delete 1"x furring, adhere GWB to block			-2 dB
Add loose insulation to block cells			+2 dB
Delete polystyrene insulation			0 dB
Use dense concrete block instead of lightweight			+3 dB

Figure 1.15k



A-Weighted Noise Reduction (dBA)			
Estimated STC	Aircraft	Traffic	Rail
50	52	54	53/50
Adjustments			
Replace 1/4" monolithic with 1/4" laminated			+4 dB
Increase glass-to-GWB spacing to 12"			+1 dB
Increase glass thickness to 1/2"			+5 dB
Use standard 1" insulating glass in lieu of 1/4" monolithic glass			+1 dB
Add one layer of GWB			+5 dB
Delete skim coat plaster			-1 dB
Delete glass fiber batt			-10 dB

Figure 1.15l

NOTE:

Find the exterior wall construction that most closely resembles that designed.

Use the adjustments to account for differences between actual exterior wall construction and those shown in this figure.

Adjustments are applicable to estimated STC and OITC ratings and Rws, and to aircraft, traffic and rail noise reductions.

Two noise reduction values are provided for rail transportation noise sources. The first is for rolling stock, electric self-propelled vehicles and non-diesel locomotive trains. The second is for diesel-powered locomotive trains.

Acoustical Guide - Principles of Acoustics

Part I

- A-weighting
- Octave Band Sound Pressure Level
- Environmental Noise Descriptors
- Equivalent Sound Level
- Day-Night Average Sound Level

Part II

- Agency Regulations and Guidelines
- U.S. Environmental Protections Agency
- U.S. Department of Housing and Urban Development
- Federal Highway Administration
- Federal Aviation Administration
- American National Standards Institute
- Background Sound in Buildings

Part III

- Sound Transmission Loss Fundamentals
- Sound Transmission Loss Characteristics of Materials
- Damping
- Single Thickness Glass
- Air Spaced Glass
- Acoustical Storm Sash
- Gas Filled Insulating Glass
- Sound Absorptive Reveal
- Frame Effects
- Sound Transmission Class
- Outdoor-Indoor Transmission Class
- Weighted Sound Reduction Index

Acoustical Guide - Principles of Acoustics

Part I

A-weighting

Generally, the sensitivity of human hearing is restricted to the frequency range of 20 Hz to 20,000 Hz. The human ear, however, is most sensitive to sound in the 500 to 8,000 Hz frequency range. Above and below this range, the ear becomes progressively less sensitive. To account for this feature of human hearing, sound level meters incorporate a filtering of acoustic signals according to frequency. This filtering is devised to correspond to the varying sensitivity of the human ear to sound over the audible frequency range. This filtering is called A-weighting. Sound pressure level values obtained using this weighting are referred to as A-weighted sound pressure levels and are signified by the identifier dBA. To provide some perspective, Figure 2.1 gives typical A-weighted sound pressure levels of various common sounds.

An important feature of the human perception of continuous sound is that an increase or decrease in sound pressure level by 3 dB or less is barely perceptible; an increase or decrease of 5 dB is clearly perceptible; and an increase or decrease of 10 dB is perceived as a doubling or halving of noise level.

Figure 2.1 Loudness ratio and decibel scale (dBA) for common sounds.

Acoustical Guide - Principles of Acoustics

Octave Band Sound Pressure Level

For general environmental sounds, inside and outside of buildings, acoustic analysis usually involves determining the sound pressure level in groups or bands of frequencies. It is customary to divide the audible frequency range into octave frequency bands. Figure 2.2 provides a list of octave band frequencies which have been defined in ANSI Standard S1.6Ð1984 Preferred Reference Quantities for Acoustical Measurements [10]. The ANSI standard does not define octave band numbers. These have been given in Figure 2.2 as they are commonly used in technical literature, particularly information pertinent to buildings.

Octave Band No.	Low Frequency Limit (Hz)	Center Frequency* (Hz)	High Frequency Limit (Hz)
	22.4	31.5	44.7
1	44.7	63.0	89.1
2	89.1	125.0	178.0
3	178.0	250.0	355.0
4	355.0	500.0	708.0
5	708.0	1,000.0	1,413.0
6	1,413.0	2,000.0	2,818.0
7	2,818.0	4,000.0	5,623.0
8	5,623.0	8,000.0	11,200.0
9	11,220.0	16,000.0	22,387.0
*Nominal Values			

Figure 2.2 Preferred octave band frequencies.

Sound level meters often are outfitted with octave band measurement capabilities. This allows the instrument user to directly measure the sound pressure level in each octave band. Although this data can be listed in tabular form, it is more useful to graph octave band values on a chart, as shown in Figure 2.3. This allows the user to more easily identify specific features of background noise which might be of concern. Data presented in this fashion are referred to as an octave band spectrum. Also shown in Figure 2.3 is an octave band spectrum of noise produced by an aircraft taking-off at a distance of 1,000 feet.

Under certain circumstances, more frequency resolution in acoustical data is needed so that one-third octave band sound level spectra are used. For example, the 1,000 Hz octave band is divided into one-third octave bands with center frequencies at 800 Hz, 1,000 Hz and 1,250 Hz. In Section 3 of this guide, sound transmission loss (TL) for various glass configurations is reported in one-third octave band frequencies as required by applicable standards.

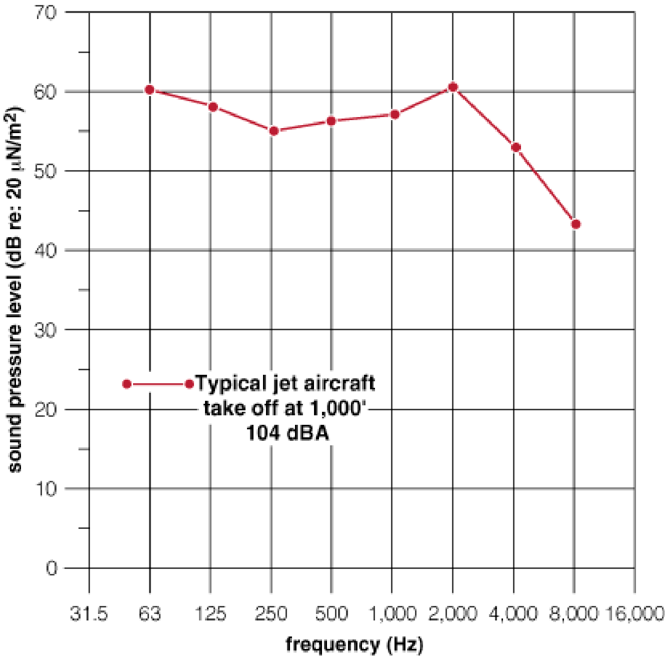


Figure 2.3 Octave band sound pressure level spectrum for typical commercial jet aircraft take-off.

Acoustical Guide - Principles of Acoustics

Environmental Noise Descriptors

Besides frequency and level, environmental sounds exhibit a time-varying or temporal characteristic. The temporal character of noise level can be illustrated by considering noise levels that occur near a highway. During the day, noise levels are generally high, increasing to higher peaks when a noisy truck passes and decreasing to a lower level between vehicle platoons. At night, when traffic volumes are lower, the same variation occurs, but is centered around a lower level.

Noise descriptors are quantifications of noise that combine, into a single value, the three chief features of environmental noise: level, frequency and temporal characteristics. The use of A-weighted sound pressure level combines the first two characteristics -- level and frequency -- into a single number. Then, by averaging A-weighted sound pressure levels over time in various fashions, noise descriptors that combine all three features can be developed.

A commonly used descriptor is percentile A-weighted sound levels, A-weighted sound pressure levels exceeded for specific percentages of time within a noise monitoring period. For example, the one-hour 50 percentile A-weighted noise level, symbolized as the L50 (1 hour), is the A-weighted noise level exceeded a total of 30 minutes out of a continuous 60-minute period. Likewise, the L10 (20 minutes) is the A-weighted noise level exceeded a total of two minutes out of a continuous 20-minute period.

Percentile A-weighted noise levels most often are used to assess the time-varying character of noise. The residual noise level (defined as the nearly constant, low level of noise produced by distant motor vehicle traffic or industrial activity) is indicative of the lowest level in a monitoring period. Residual noise level is commonly defined as the L90, i.e., the A-weighted sound level exceeded 90% of a monitoring time period. Intrusive noise is characterized as a high noise level that endures for only a short period and is produced by such events as aircraft flyovers and truck passbys.

Intrusive noise level is often defined as the L10, i.e., the A-weighted sound level exceeded 10% of a monitoring time period. Although the L10 is useful for understanding environmental noise, it is no longer used by any federal agency in setting standards. Instead, the equivalent sound level has become commonly adopted as discussed below.

Equivalent Sound Level

For several years, the U.S. Environmental Protection Agency (EPA) has encouraged the use of the equivalent sound level: a descriptor that uses the average A-weighted energy and differs significantly from 50th percentile, or median, sound pressure level. Unlike the 50th percentile sound level which is not influenced by peak noise levels of short duration, the equivalent sound level is. Therefore, the A-weighted equivalent sound level combines level, frequency and temporal character into a single-valued descriptor. Equivalent sound level, symbolized as Leq, is always higher than the L50, as it is influenced by noise contributions of high level and short duration such as aircraft flyovers or noisy truck passbys.

Acoustical Guide - Principles of Acoustics

Day-Night Average Sound Level

Noise levels occurring at night generally produce greater annoyance than do the same levels which occur during the day. It is generally agreed that community perception of nighttime noise levels is 10 dBA higher [11]. That is, a given level of environmental noise during the day would appear to be approximately 10 dBA louder at night -- at least in terms of its potential for causing community annoyance. This is largely because nighttime ambient environmental noise levels in most areas are approximately 10 dBA lower than daytime noise levels.

This feature of nighttime annoyance has been incorporated into a day-night noise descriptor which uses the equivalent sound level. This descriptor, referred to as the day-night average sound level (DNL) applies a 10 dBA "penalty" to noise levels occurring between 10:00 p.m. and 7:00 a.m., thus accounting for increased community sensitivity to nighttime noise levels. To help place day-night average sound levels into perspective, Figure 2.4 contains a scale showing DNL values for various types of outdoor locations.

Note that the mathematical symbol for day-night average sound level is Ldn. Ldn and DNL (the abbreviation) are often used interchangeably, as has been done in this guide.

Because of their sensitivity to frequency and temporal characteristics of noise, both the Leq and the DNL have become widely accepted for use in environmental noise regulations and criteria. Among the federal agencies using Leq or DNL sound levels are the U.S. Environmental Protection Agency, the Federal Highway Administration, the U.S. Department of Housing and Urban Development, the Federal Aviation Administration and the Department of Defense.

Figure 2.4 Examples of outdoor day-night average sound levels in dB measured at various locations [11].

Acoustical Guide - Principles of Acoustics

Part II

Agency Regulations and Guidelines

The following discussion of various agency regulations and guidelines should be helpful in understanding how noise limits are expressed. It also provides much needed guidance in assessing environmental noise exposure. It must be noted, however, the federal government recognizes that it is the states' and local governments' right and responsibility to set noise limits as a function of land use. Federal agencies do not have the authority to do so. In discussing noise exposure and land use, information is presented only as recommended guidelines. Such guidelines function as regulations only when used within an agency's statutory authority.

For example, the U.S. Department of Housing and Urban Development (HUD) has the authority to establish regulations relative to noise exposure for housing projects that it supports under its jurisdiction. The Federal Highway Administration (FHWA) has the right to regulate the design and construction of highways that are federally supported, etc. Hence, how these guidelines function in connection with a specific project depends upon applicable authority over a project.

Acoustical Guide - Principles of Acoustics

U.S. Environmental Protection Agency

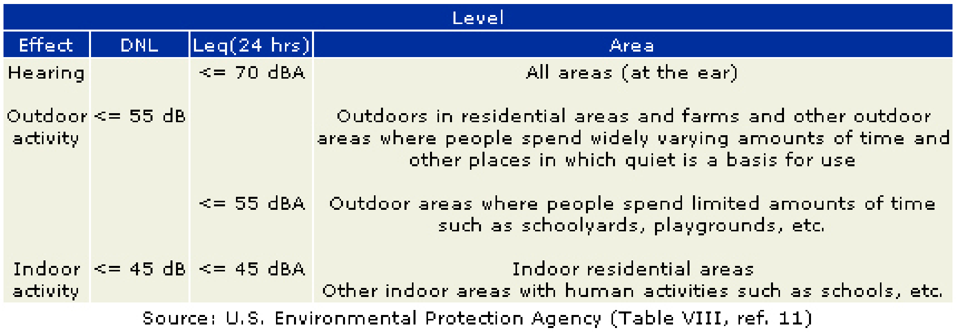
The U.S. Environmental Protection Agency (EPA) has taken the lead among all federal agencies in studying the general impact of environmental noise. In spite of this, however, it has not promulgated specific regulations setting limits on general environmental noise levels. (It has promulgated noise limits for specific types of equipment such as air compressors.)

More importantly, the EPA has unified usage of environmental noise descriptors among federal agencies and has produced an extensive log of environmental noise measurements in different environmental settings. Also, it has recommended day-night average sound levels which represent "... values that protect public health and welfare with a margin of safety." A summary of these levels is provided in Figure 2.5 (taken from Table VIII of *Protective Noise Levels --Condensed Version of EPA Levels Document*) [11].

The EPA carefully guards against misuse of these levels by stating that:

> "On the basis of its interpretation of available scientific information, EPA has identified a range of yearly day-night sound levels sufficient to protect public health and welfare from the effects of environmental noise. It is very important that these noise levels summarized in Table VIII not be misconstrued. Since the protective levels were derived without concern for technical or economic feasibility and contain a margin of safety to ensure their protective value, they must not be viewed as standards, criteria, regulations, or goals. Rather, they should be viewed as levels below which there is no reason to suspect that the general population will be at risk from any of the identified effects of noise."

According to the EPA, outdoor yearly levels are sufficient to protect public health and welfare if they do not exceed a day-night average sound level (DNL) of 55 dB in sensitive areas (residences, schools and hospitals). Inside buildings, yearly levels are sufficient to protect public health and welfare if they do not exceed a DNL of 45 dB. Maintaining a DNL of 55 dB outdoors should ensure adequate protection for indoor living. To protect against hearing damage, one's 24-hour equivalent sound level exposure at the ear should not exceed 70 dB.



Level			
Effect	DNL	Leq(24 hrs)	Area
Hearing		<= 70 dBA	All areas (at the ear)
Outdoor activity	<= 55 dB		Outdoors in residential areas and farms and other outdoor 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 schoolyards, playgrounds, etc.
Indoor activity	<= 45 dB	<= 45 dBA	Indoor residential areas Other indoor areas with human activities such as schools, etc.

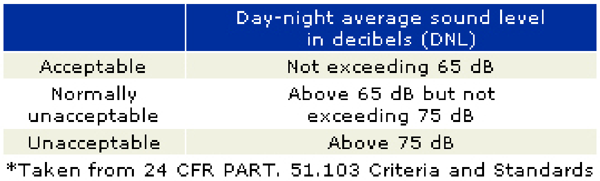
Source: U.S. Environmental Protection Agency (Table VIII, ref. 11)

Figure 2.5 Yearly DNL and Leq values that protect public health and welfare with a margin of safety.

Acoustical Guide - Principles of Acoustics

U.S. Department of Housing and Urban Development

The U.S. Department of Housing and Urban Development (HUD) is the lead federal agency setting standards for interior and exterior noise for housing. These standards, outlined in 24 CFR Part 51, establish Site Acceptability Standard based on day-night average sound levels [6]. These are presented in Figure 2.6.



	Day-night average sound level in decibels (DNL)
Acceptable	Not exceeding 65 dB
Normally unacceptable	Above 65 dB but not exceeding 75 dB
Unacceptable	Above 75 dB

*Taken from 24 CFR PART. 51.103 Criteria and Standards

Figure 2.6 HUD site acceptability criteria [6].
U.S. Department of Housing and Urban Development
Site Acceptability Criteria*

In Figure 2.6, ranges of DNL 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, i.e., a day-night average sound level not exceeding 45 dB. “Acceptable” sites are those where noise levels do not exceed a DNL of 65 dB. Housing on acceptable sites does not require additional noise attenuation other than that provided in customary building techniques.

“Normally unacceptable” sites are those where the DNL is above 65 dB, but does not exceed 75 dB. Housing on normally unacceptable sites requires some means of noise abatement, either at the property line or in the building exterior construction, to assure that interior noise levels are acceptable. From a practical standpoint, this usually means that buildings must be air-conditioned so that windows can be closed to reduce exterior sound transmission into interior spaces.

“Unacceptable” sites are those where the DNL is 75 dB or higher. The term “unacceptable” does not necessarily mean that housing cannot be built on these sites, but rather that more sophisticated sound attenuation would likely be needed and that there must exist some benefits that outweigh the disadvantages caused by high noise levels. Most often, housing on unacceptable sites requires high sound transmission loss glazing and air-conditioning.

Acoustical Guide - Principles of Acoustics

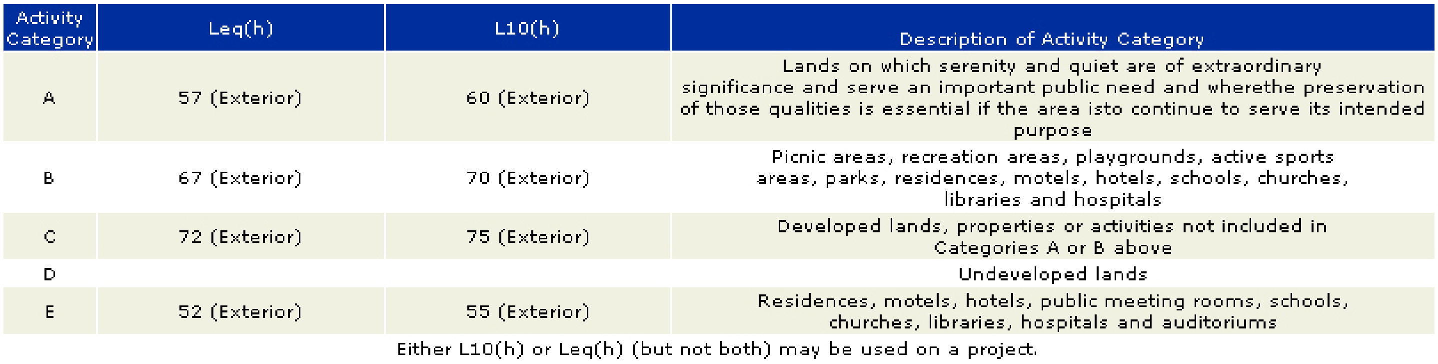
Federal Highway Administration

Among criteria established by the Federal Highway Administration (FHWA) for the design of highways is a set of design goals for traffic noise exposure. The FHWA noise abatement criteria are given in 23 CFR Part 772. These define various categories of land use and ascribe corresponding maximum hourly equivalent sound levels. Figure 2.7 contains a table presenting the FHWA limits expressed as hourly equivalent sound levels for various categories of land use identified as A through E.

These limits are viewed by the FHWA as goals in the design and evaluation of highway facilities and are helpful for planning building projects near existing or future highways. Also of use to the building designer are various traffic noise prediction methodologies that have been developed. Up to now, the most widely used methodology is that developed by the U.S. Department of Transportation and described in FHWA Publication RD-77-108. Through the use of various charts and tables, and by knowing traffic volume, speed, auto and truck mix and highway geometry, it is possible to predict noise levels at building locations. This methodology has been developed into a FORTRAN program by FHWA and is called STAMINA II. Various other institutional and commercial enterprises have produced versions able to be used on personal computers and have incorporated various input/output enhancements beyond the basic program.

In 1996, the RD-77-108 methodology and the STAMINA program are being replaced by a new computer program called FHWA Traffic Noise Model Version 1.0. This new program will operate on personal computers under Windows 3.1. It will incorporate convenient data handling and graphing capabilities, and a means for defining new classes of vehicles. Besides automobiles, medium and heavy trucks, the new program will also include motorcycles and buses as additional standard classes of vehicles.

In the case of a proposed building site near an existing highway, actual measurement of traffic noise levels can be used in lieu of traffic noise modeling. Traffic noise measurements may also be preferred as they can usually be completed more quickly than can computer modeling of traffic noise levels. This is especially true if all that is required is determining the maximum traffic sound level typically occurring at a building site during weekday rush-hour periods.



Activity Category	Leq(h)	L10(h)	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 wherethe preservation of those qualities is essential if the area isto 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 (Exterior)	55 (Exterior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals and auditoriums

Either L10(h) or Leq(h) (but not both) may be used on a project.

Figure 2.7 FHWA Traffic Noise Abatement Criteria [23 CFR Part 772].

Acoustical Guide - Principles of Acoustics

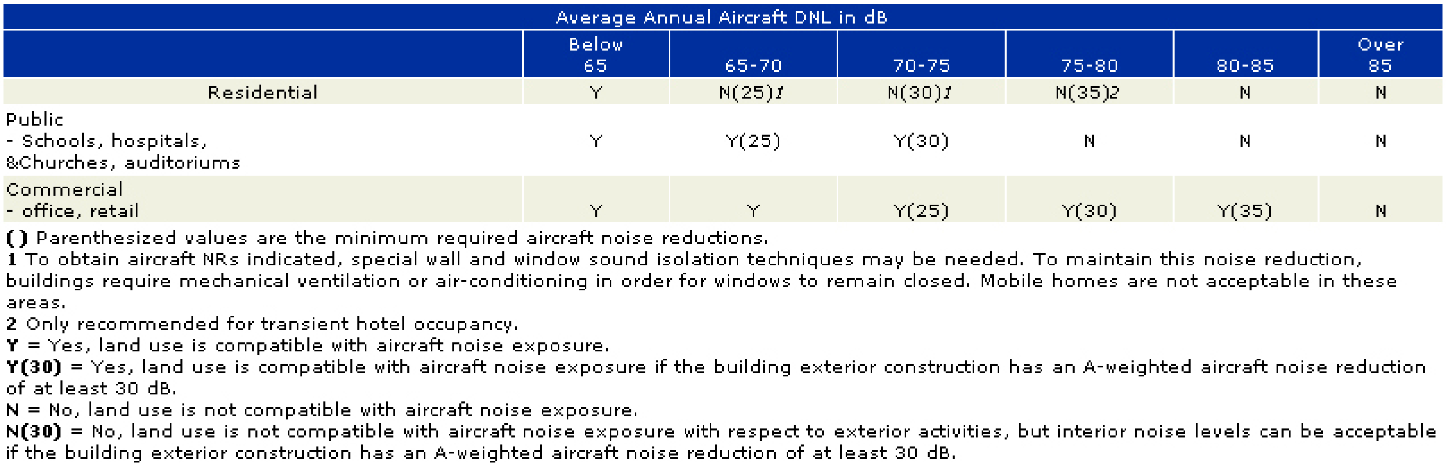
Federal Aviation Administration

The Federal Aviation Administration (FAA) does not set specific aircraft noise exposure limits in the community. Instead, it sets limits on noise emissions from individual types of aircraft. These limits are not of any particular interest in the design of buildings; however, the limits have been useful to airport operators enabling them to assess aircraft noise exposure around airports. This information is usually available in an airport master plan. An airport master plan is a document which outlines all airport activity, assesses environmental effects and forecasts future airport growth.

Aircraft noise exposure information is normally presented as yearly day-night average sound level contours around the airport. Aircraft noise contours are generally presented in increments of 5 dB beginning with a yearly day-night average sound level of 65 dB. Around major urban airports, day-night average sound levels as high as 80 dB sometimes occur at locations near the end of major runways. A building designer can use these contour maps to interpolate the aircraft noise exposure at his/her project site.

It should be noted that the FAA, through its 14 CFR Part 150 Airport Noise Compatibility Planning Program [4], has recommended sound transmission loss (TL) characteristics of exterior building constructions. TL characteristics have been related to aircraft noise exposure expressed as ranges of day-night average sound level.

Figure 2.8 contains a table summarizing the recommended FAA noise reductions from the 14 CFR Part 150 document.



	Average Annual Aircraft DNL in dB					
	Below 65	65-70	70-75	75-80	80-85	Over 85
Residential	Y	N(25)[1]	N(30)[1]	N(35)[2]	N	N
Public - Schools, hospitals, &Churches, auditoriums	Y	Y(25)	Y(30)	N	N	N
Commercial - office, retail	Y	Y	Y(25)	Y(30)	Y(35)	N

() Parenthesized values are the minimum required aircraft noise reductions.
1 To obtain aircraft NRs indicated, special wall and window sound isolation techniques may be needed. To maintain this noise reduction, buildings require mechanical ventilation or air-conditioning in order for windows to remain closed. Mobile homes are not acceptable in these areas.
2 Only recommended for transient hotel occupancy.
Y = Yes, land use is compatible with aircraft noise exposure.
Y(30) = Yes, land use is compatible with aircraft noise exposure if the building exterior construction has an A-weighted aircraft noise reduction of at least 30 dB.
N = No, land use is not compatible with aircraft noise exposure.
N(30) = No, land use is not compatible with aircraft noise exposure with respect to exterior activities, but interior noise levels can be acceptable if the building exterior construction has an A-weighted aircraft noise reduction of at least 30 dB.

Figure 2.8 Summary of land use compatibility with various aircraft noise levels (DNL) in dB based on Appendix A 14 CFR Part 150.

Acoustical Guide - Principles of Acoustics

American National Standards Institute

The American National Standards Institute (ANSI) has published ANSI Standard S12.40-1990 Sound Level Descriptors for Determination of Compatible Land Use [12]. This document focuses on defining basic environmental noise descriptors suggested for use in assessing the acceptability or compatibility of ambient noise for various types of land use.

Among the types of environmental noise descriptors defined are the time-average sound level (same as the equivalent sound level), sound exposure level (usually used for assessing transient sound events) and the day-night average sound level.

The standard also defines the yearly day-night average sound level for community sound averaged over a continuous 365-day period.

ANSI S12.40 also presents the bar graph shown in Figure 2.9. The document indicates that this is not part of the standard per se, but is given in an appendix for informational purposes only. It establishes classifications defined as “compatible,” “marginally compatible,” “compatible indoors with building sound isolation installed” and “incompatible.” For each land use, the classifications are expressed as ranges of yearly day-night average sound level. 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. This is the same as the interior noise level goal used by the U.S. Department of Housing and Urban Development.

It should also be noted that levels given in Figure 2.9 are in agreement with recommendations of the U.S. Environmental Protection Agency (EPA). As with EPA recommendations, ANSI S12.40 should be viewed as a recommended guideline and is not an enforceable regulation.

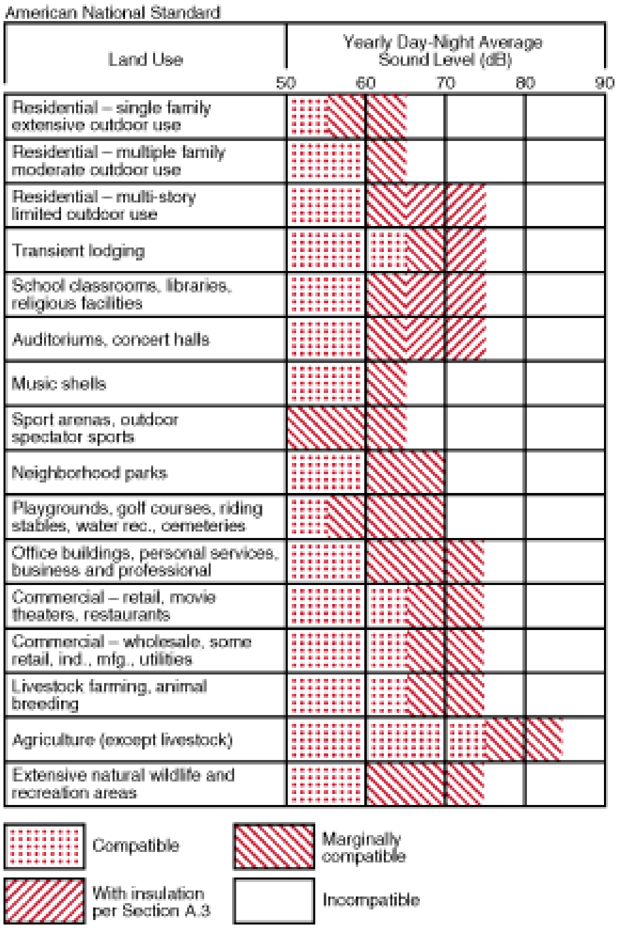


Figure 2.9 Land use compatibility with yearly day-night average sound level at a site for buildings as commonly constructed. (For information only; not a part of American National Standard for Sound Level Descriptors for Determination of Compatible Land Use S12.40-1990.)[12]

Acoustical Guide - Principles of Acoustics

Background Sound in Buildings

Background sound in building spaces produced by mechanical systems is 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 criteria have been the design guidelines for HVAC system noise in unoccupied spaces established by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). For most of the many years that ASHRAE has published recommended design criteria for spaces, it has expressed them as acceptable ranges of noise criteria (NC) curves.

In recent years, it has introduced a new set of curves called room criteria (RC) curves. On their first introduction, ASHRAE publications suggested that RC curves could be used in lieu of NC curves. As the years progressed, the use of RC curves was cited as preferred to the use of NC curves. Finally, the 1995 ASHRAE Applications Handbook lists recommended ranges of background sound in building spaces expressed only as ranges of RC(N) curves. No listing of criteria using NC curves is given in the 1995 Handbook except that the guidelines state that "... If the quality of the sound in the space is of secondary concern, the criteria may be specified in terms of NC levels." Although RC curves represent a better quality of background sound, NC curves are still in wider use at this time because of the HVAC and acoustical design professionals' familiarity with them.

In July 1995, the American National Standards Institute published ANSI S12.2 Criteria for evaluating room noise [13]. It formally defines room criteria (RC) curves and a newer set of criteria curves called balanced noise criteria (NCB) curves. The standard describes how the sets of curves are used to evaluate a room sound level spectrum and how RC and NCB curves can be used to establish limits for sound in building spaces. Although the ASHRAE Applications Handbook will continue to be used widely by the design profession, it is likely that ANSI S12.2 will now become the standard for using RC and NCB curves for establishing background noise criteria in building spaces and for evaluating sound levels measured in building spaces.

The standard, in its appendices, also provides acceptable ranges of RC and NCB curves. However, the standard specifically indicates that these recommendations are not part of the standard, but are provided in the appendices for informational purposes only. The two tables, one each for recommended RC and NCB ranges in ANSI S12.2, have been combined into a single table in Figure 2.11.

The following describes NC, RC and NCB curves and their use in evaluating sound inside building spaces. The explanations are in accord with ANSI S12.2 and may differ slightly from descriptions of use in the ASHRAE Applications Handbook.

Acoustical Guide - Principles of Acoustics

Noise Criteria Curves

Noise criteria curves, most often called NCÊcurves, are curves of approximate equal perceived loudness for sound over the audible frequency range [14]. Figure 2.10 displays a family of NC curves. In order to provide some perspective on the significance of NC levels, Figure 2.10 also shows the A-weighted sound pressure levels corresponding to each NC curve. Also indicated is the subjective loudness for ranges of background sound spectra in a typical office environment, expressed as ranges of NC curves.

Normally, the ambient sound level produced by mechanical equipment and general activities in buildings is evaluated by measuring noise levels in the 31.5 Hz to 8,000 Hz octave bands. Two typical octave band spectra of building ambient noise are shown in Figure 2.12. The noise criteria (NC) value of each spectrum is equal to the value of the highest NC curve reached in any one octave band, i.e., the NC curve that is tangent to the spectrum being evaluated. For example, in Figure 2.12, the highest NC curves reached by each spectrum are NC 40 and NC 55 which occur in the 1,000 Hz and 63 Hz bands, respectively. Hence, these would be referred to as NC 40 and NC 55 spectra, respectively.

This method for determining an NC value of a spectrum is referred to as the “tangent method.” Although it may work well for assessing the potential interference of background sound with speech sound, it may not properly assess the quality of background sound. For example, a background sound spectrum with energy predominantly in the 1,000 Hz octave band, although falling within the required NC curve range, would probably sound “hissy.” A background sound spectrum with energy predominantly in the 63 Hz band may, on the other hand, sound “rumbly.” Hence, in establishing criteria based on NC curves, it is best to require that background sound level spectra have at least three contiguous octave bands that roughly lie on the required NC curve. Ensuring that background sound roughly corresponds to an NC curve shape is as important as ensuring that sound not exceed upper limits of an NC criteria range [14].

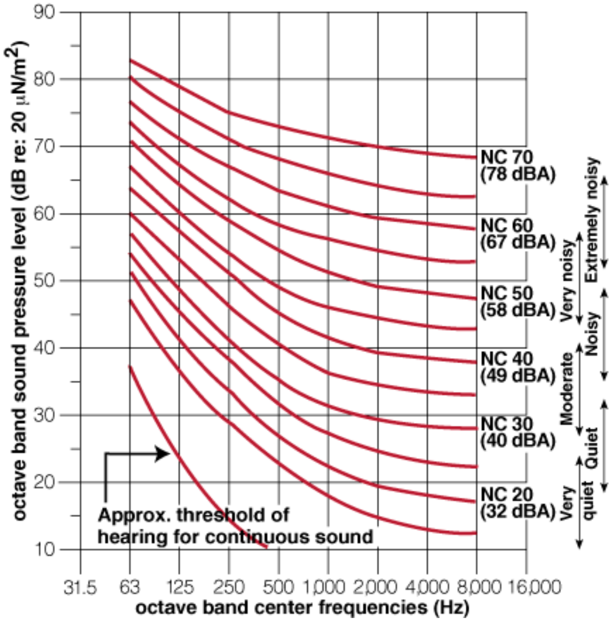


Figure 2.10 Noise criteria (NC) curves used for specifying acceptable background noise levels in buildings.

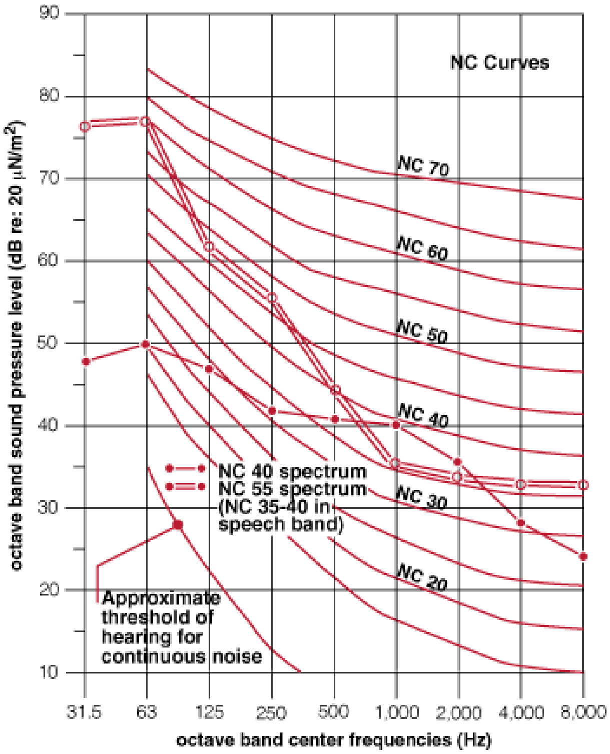


Figure 2.12 Typical octave band sound pressure level spectra and corresponding NC values

Acoustical Guide - Principles of Acoustics

Sometimes the NC value reached by a spectrum at very low frequencies is ignored and only the NC value associated with mid-range frequencies (250-1,000 Hz) and high frequencies (2,000-8,000 Hz) are considered as they affect speech intelligibility. In Figure 2.12, the NC 55 spectrum falls in a much lower NC range in the 500-8,000 Hz frequency range. This spectrum would appear to an observer to be "boomy" because of its excessive low frequency content as compared with the mid-range sound energy content. Although this "boominess" may be undesirable from a comfort standpoint, it may not significantly affect speech communication. It should be noted that the A-weighted sound levels of the NC 40 and NC 55 spectra shown in Figure 2.12 are 45 dBA and 53 dBA, respectively.

Room Criteria Curves

Figure 2.13 contains a set of standard room criteria (RC) curves as defined by ANSI S12.2. RC curves differ from NC curves in that they have a constant slope of -5 dB per octave. They have been derived principally for evaluating spaces with sound produced by HVAC systems and, therefore, are used to evaluate sound in unoccupied spaces.

RC curves have been derived by surveying people's response to the quality or desirability of background sound levels in building spaces and arriving at optimum spectrum shapes, in this case constant slopes. These spectra are judged as optimally innocuous, i.e., having a sound quality that is neither "rumbly" (rich in low-frequency energy) nor "hissy" (rich in high-frequency energy).

The RC value of a spectrum is determined by averaging the 500, 1,000, 2,000 Hz octave band spectrum sound pressure levels together. Once the spectrum RC curve has been determined by this procedure, the subjective quality of the spectrum is determined through methods detailed in ANSI S12.2. Spectra fairly well conforming to the RC curve are subjectively perceived as "neutral" and are denoted by (N) after the RC value. Spectra significantly exceeding the spectrum RC curve in low frequencies are subjectively perceived as "rumbly" and are denoted by (R) after the RC value. Spectra significantly exceeding the spectrum RC curve in the high frequencies are subjectively perceived as "hissy" and are denoted by (H) after the RC value.

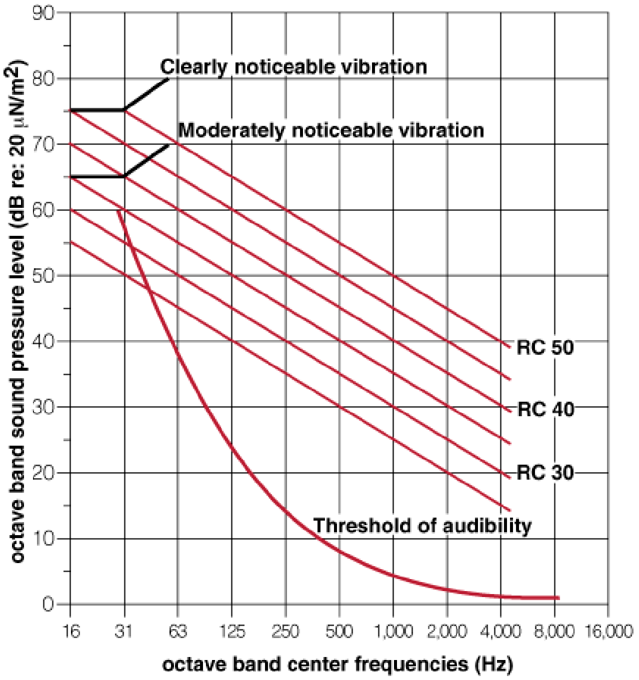


Figure 2.13 Room criteria (RC) curves for specifying HVAC sound levels in terms of a balanced spectrum shape [13].

Acoustical Guide - Principles of Acoustics

Building specifications usually require a neutral spectrum shape, e.g., RC 30(N). In actuality, if a background sound level generally follows an RC 30 curve, but has excessive low-frequency energy, it would be denoted RC 30(R). Accordingly, were the sound spectrum instead to have excessive high-frequency energy, it would be denoted RC 30(H). For specifics on how the RC evaluation is used, refer to ANSI S12.2.

ANSI S12.2 also defines sound levels in the 16 through 63 Hz octave bands above which sound may produce perceptible vibration in lightweight structures or audible rattling in light fixture and ceiling systems. Octave band spectra with levels this high are identified with the abbreviation (RV).

Balanced Noise Criteria (NCB) Curves

Balanced noise criteria (NCB) curves are very similar to NC curves, but differ in that they extend down to the 16 Hz octave band. Figure 2.14 contains a set of NCB curves. The NCB value of a spectrum is determined by averaging the 500, 1,000, 2,000 and 4,000 Hz octave band sound pressure levels of the spectrum being evaluated. The NCB value of the spectrum is this value rounded to the nearest whole number. Using procedures described in ANSI S12.2, rumbly and hissy features are evaluated. As with RC criteria, rumbly spectra are denoted by (R). Hissy spectra are denoted by (H). Spectra with octave band sound levels in the 16 through 63 Hz range exceeding the criteria of the perceived vibration criteria of the standard are denoted by (RV).

The ANSI S12.2 standard indicates that the NCB curves are intended to evaluate sound in occupied rooms where noise produced by occupants contributes to background sound level. The standard also suggests that the ranges of acceptable sound provided in the appendix to the standard should be reduced to account for occupant noise that might otherwise exist if NCB curves are to be used to evaluate unoccupied rooms.

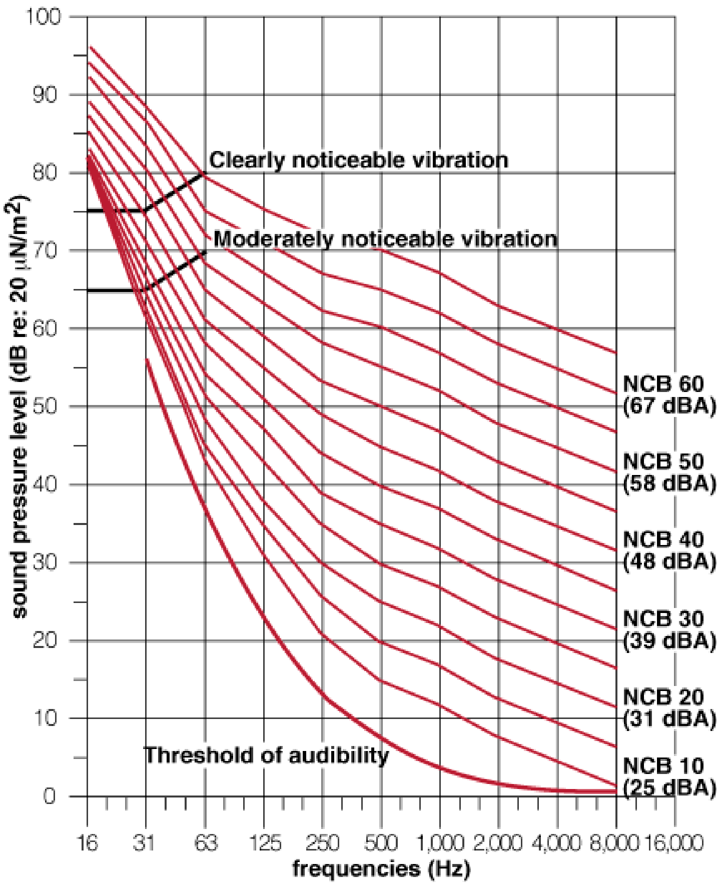


Figure 2.14 Balanced noise criteria (NCB) curves [13].

Acoustical Guide - Principles of Acoustics

Occupancy		RC Level 1,2,4	NCB Level 1,3,4
Private Residences		25-30 (N)	
Apartments		30-35 (N)	28-38
Hotels/Motels	Individual rooms or suites	30-35 (N)	28-38
	Meeting/banquet rooms	30-35 (N)	25-35
	Halls, corridors, lobbies	35-40 (N)	38-43
	Service/support areas	40-45 (N)	38-48
Offices	Executive	25-30 (N)	25-30
	Conference rooms	25-30 (N)	
	Conference rooms, large		25-30
	Conference rooms, small		30-35
	Private	30-35 (N)	30-35
	Open-plan areas	35-40 (N)	35-40
	Business machines/computers	40-45 (N)	38-43
	General secretarial areas		38-43
	Public circulations	40-45 (N)	38-48
Hospitals and Clinics	Private rooms	25-30 (N)	25-30
	Wards	30-35 (N)	30-35
	Operating rooms	25-30 (N)	25-30
	Laboratories	30-35 (N)	33-43
	Corridors	35-40 (N)	33-43
	Public areas	30-35 (N)	38-43
Churches		25-30 (N)	30-35
Schools	Lecture and classrooms	25-30 (N)	25-30
	Open-plan classrooms	35-40 (N)	33-37
Libraries		35-40 (N)	33-37
Courtrooms		35-40 (N)	33-37
Legitimate theaters		20-25 (N)	20-25
Movie theaters		30-35 (N)	27-37
Restaurants		40-45 (N)	38-43
Concerts and recital halls		15-20 (N)	10-15
Recording studios		15-20 (N)	
TV studios		20-25 (N)	15-25
Broadcast studios (distant microphone pickup used)			10
Large auditoriums, large drama theaters and large churches (for very good speech articulation)			15-20
Light maintenance shops, industrial plant control rooms, kitchens and laundries**5**			43-50
Shops, garages**5**			50-60

1 The values and ranges are based on judgment and experience, not on quantitative evaluations of human reactions. They represent general limits of acceptability for typical building occupancies. Higher or lower values may be appropriate and should be based on a careful analysis of economics, space usage and user needs. They are not intended to serve by themselves as a basis for a contractual requirement.
2 RC levels are for use in unoccupied spaces.
3 NCB levels are for occupied spaces. Levels may be used to assess sound in occupied spaces if sound produced by occupancy does not significantly affect background sound levels, otherwise some reduction may be required.
4 An experienced acoustical consultant should be retained for guidance on acoustically critical spaces (below RC-30, NCB-30) and for all performing arts spaces.
5 Spectrum levels and sound quality are of lesser importance in these spaces than overall sound levels.

Figure 2.11 Design guidelines for HVAC system sound in building spaces. (Based on ANSI S12.2 Criteria for evaluating room noise [13] and Table 2, 1995 ASHRAE Applications Handbook, p.43.5.)

Acoustical Guide - Principles of Acoustics

Part III

Sound Transmission Loss Fundamentals

The ability of a material to minimize the passage of sound through it is quantified using the sound transmission coefficient (t). This is defined as the ratio of the sound energy transmitted through a material to the sound energy incident on the material. Mathematically, it is represented as:

$t = ETrans / EIncident$

The sound transmission loss (TL), which is more commonly used than the sound transmission coefficient, is expressed in decibels. Mathematically, this is represented as:

$TL = 10 \log 1/t$

The TL of a material is measured by mounting a sample of the material in an opening of a wall separating two reverberant test rooms. Broad-band sound is played into one room (the source room). The difference between the sound levels in the source room and the other room (the receiving room) is defined as the noise reduction (NR).

For outdoor (free field) sound transmission into a building space, the NR is related to the TL as follows:

$NR = TL + 10 \log (AR/S) - 5$

In the above equation, AR is the receiving room absorption in Sabins and S is the exterior wall area. The term 10 log AR /S is called a room effect and usually falls in a range of ± 5 dB. For exterior windows in most furnished rectangular rooms, the room effect is approximately zero.

Acoustical Guide - Principles of Acoustics

Sound Transmission Loss Characteristics of Materials

The sound transmission loss of a material is dependent on its mass, damping and stiffness.

It has been widely thought that increasing glass thickness, i.e., the mass, was the only practical way to increase sound isolation performance. Changing glass stiffness also is not practical. (Glass stiffness should not be confused with glass strength, which refers to the resistance of glass to breakage.) As noted, an air space between two lights of glass also can increase sound isolation performance, but only if the air space thickness is larger than that used conventionally (generally 1/2" maximum) for most sealed insulating glass configurations.

The only remaining variable is glass damping. Generally, glass has very low inherent damping. As shown below, using a special protective interlayer to increase glass damping can result in TL increases, which can only be otherwise obtained through significant increases in glass thickness. Hence, in the domain of single thickness glass, laminated glass offers several practical advantages, as well as many cost advantages.

When laminated glass is used in air spaced or insulating glass configurations, the benefits of damping are even greater.

Acoustical Guide - Principles of Acoustics

Damping

Damping is a mechanical property of a material or system which quantifies the rate of dissipation of vibratory motion into heat energy. A bell and a tuning fork are examples of systems with low damping. When they are struck, or excited, vibration persists or rings, resulting in sound that correspondingly persists. It also should be noted that ringing occurs at one discrete frequency in the case of the tuning fork and several discrete frequencies in the case of a bell.

The ringing or persistence of vibration can be diminished by holding the tuning fork tines or bell with one's hand. This acts to transfer the vibratory motion into heat energy which is dissipated in the hand. Although vibratory motion can be felt, producing a tingling sensation, the transfer of thermal energy is not perceptible.

Since glass has more damping than a tuning fork or bell, it does not display the same ringing characteristic. Nevertheless, the lack of damping in glass is usually sufficient to result in reduced sound transmission loss in certain frequency ranges.

Damping affects TL in some ways that are similar to its effect upon the ringing of a bell or tuning fork, but also in ways which are quite different. In a typical TL situation, sound energy is incident on the source side of a light of glass. The incident sound excites bending waves in the glass, which then excites particle motion of the air on the other side, i.e., the receiver side. At a certain frequency, the bending wave speed in the glass equals the speed of sound in the air. At this frequency, referred to as the critical frequency, there is an efficient transfer of acoustical energy from the air to the glass. This more efficient transfer of sound energy from the source side to the glass, and then from the glass to the receiver side, results in a lower TL.

The addition of damping to glass makes it less susceptible to excitation by incident sound at the critical frequency by reducing the "build-up" of bending wave energy within the glass that causes a corresponding, larger transfer of energy through the glass, resulting in reduced TL.

The most effective way for increasing the damping in glass is through the use of a viscous interlayer which is sandwiched between two pieces of glass. The bending waves in the glass excited by incident sound cause shear strains within the viscous interlayer material. Because the interlayer material has inherently high damping, bending wave energy in the glass is then transformed into heat energy by the viscous interlayer.

Acoustical Guide - Principles of Acoustics

Single Thickness Glass

Because the sound transmission loss of all materials is frequency-dependent, it is most often presented as a one-third octave band frequency spectrum as indicated in Figure 2.15 for 1/4" monolithic glass and 1/4" laminated glass. In Figure 2.15, the horizontal axis is frequency and the vertical axis is TL. Notice that at frequencies below 1,000 Hz, the 1/4" laminated glass TL is slightly higher than that for 1/4" monolithic glass. In this frequency range, the TL performance of these materials is dominated by their mass. Since the surface weights of both materials are nearly equal, only insignificant differences in TL are expected in this frequency range.

At about 2,500 Hz, the 1/4" monolithic glass TL drops significantly, whereas the 1/4" laminated glass TL remains nearly level with frequency. At this frequency, known as the critical frequency, the bending wave speed in the glass is equal to the speed of sound in air. As previously explained, at the critical frequency, sound is very efficiently radiated from the material, thus resulting in a reduced TL. At frequencies below the critical frequency, the bending wave speed in 1/4" glass is lower than the speed of sound in air; at frequencies higher than the critical frequency, the bending wave speed in 1/4" glass is higher than the speed of sound in air.

For plate materials, the critical frequency will vary with thickness, surface weight and stiffness. Comparing materials of the same surface weight, the stiffer materials will have lower critical frequencies than those which are less stiff, or "limp." Nevertheless, the basic behavior of the TL above and below critical frequency in all single thickness, homogeneous materials is similar to that illustrated for 1/4" glass.

At the critical frequency, TL is dominated by damping. In Figure 2.15 the sizable difference observed between 1/4" monolithic and 1/4" laminated glass TL at 2,500 Hz is a result of the Saflex polyvinyl butryal (PVB) interlayer damping. Materials having low damping, such as glass and steel, tend to have deeper TL dips at critical frequency than materials with inherently high damping, such as lead and some plastics. Although damping controls the TL at the critical frequency, as mentioned above, it is the material stiffness and mass density that dictate at what frequency the critical frequency occurs.

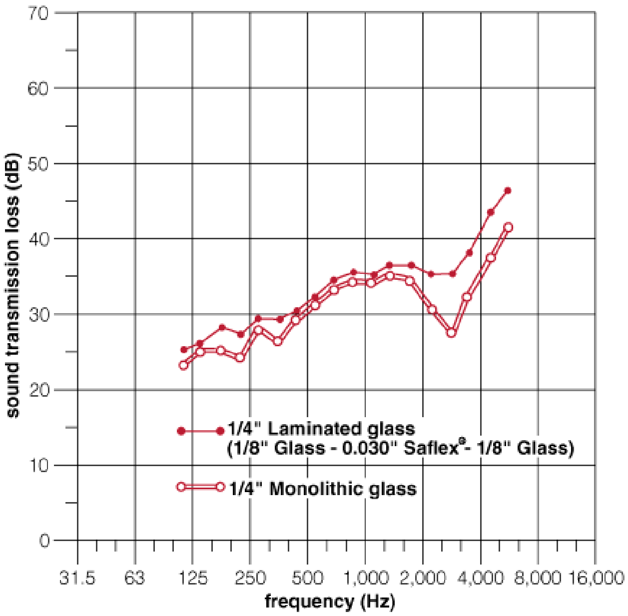


Figure 2.15 Comparison of sound transmission losses for 1/4" monolithic and 1/4" laminated glass with Saflex¨ interlayer.

From Figure 2.15, it can be seen that the Saflex interlayer can increase glazing TL without significantly increasing the glass thickness or mass. Accordingly, 1/4" laminated glass has a TL performance nearly equal to that of monolithic glass having nearly twice its surface weight (slightly less than 1/2" monolithic glass). As seen in Figure 1.14a, 1/4" laminated glass has a sound transmission class (STC) rating of 35 which is only 1 dB less than the STC of 1/2" glass. Hence, interlayer damping is a very effective means for increasing sound isolation performance with a negligible increase in surface weight and total glass thickness.

NOTE:
The data and information set forth are based on samples tested and are not guaranteed for all samples or applications.

Acoustical Guide - Principles of Acoustics

Air Spaced Glass

The sound transmission loss (TL) characteristics of air spaced glass (insulating glass, IG) are considerably more complicated than those for non-air spaced glass. Differences between air spaced and non-air spaced glass are illustrated in Figure 2.16. Figure 2.16 presents a comparison between TLs for 1/4” monolithic glass and 1/2” insulating glass composed of 1/8” monolithic glass - 1/4” air space - 1/8” monolithic glass. The comparison of these two glass configurations is particularly interesting since they are of the same surface weight, i.e., 1/4” total glass thickness, yet their TL performances are quite different.

In the data of Figure 2.16, the two TLs are nearly equal in the 100 Hz to 250 Hz range. Between 250 Hz and 1,000 Hz, the 1/4” monolithic glass TL is considerably higher than the insulated glass TL because of a resonance associated with the 1/4” air space. Between 1,000 Hz and 4,000 Hz, the 1/4” monolithic glass critical frequency causes it to have a considerably lower TL than insulating glass. At 4,000 Hz, the critical frequencies of the individual 1/8” lights cause the insulating glass TL to be slightly lower than that for the 1/4” monolithic glass.

An inspection of the sound transmission class (STC) values in Figure 1.14a indicates that doubling the air space thickness in insulating glass increases the STC rating by 2 to 6 dB per air space thickness doubling with the average being about 3 dB per air space thickness doubling. As noted below, STC is a single-value descriptor quantifying the TL of a material.

As with monolithic glass, the sound isolation performance of insulating glass can be increased significantly through the use of laminated glass. Figure 2.17 presents a comparison between two 1” insulating glass configurations, one using two lights of 1/4” monolithic glass and the other using two lights of 1/4” laminated glass. The 1/4” laminated glass consisted of two lights of 1/8” monolithic glass laminated together with 0.030” Saflex. As a reference, the TL for 1/2” monolithic glass is provided for comparison.

These three glass configurations have nearly the same surface weight, but the combination of air space and Saflex interlayer results in a TL for the double laminated insulating configuration which is significantly higher than that for either standard insulating or monolithic glass. Here again, laminated glass has resulted in a TL that could only have been accomplished through either a significant increase in glass and/or air space thickness.

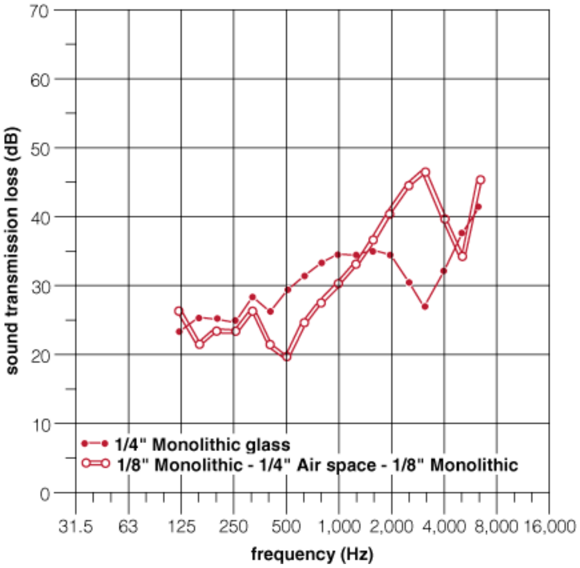


Figure 2.16 Comparison of monolithic and insulating glazing units having the same surface weight.

NOTE:
The data and information set forth are based on samples tested and are not guaranteed for all samples or applications.

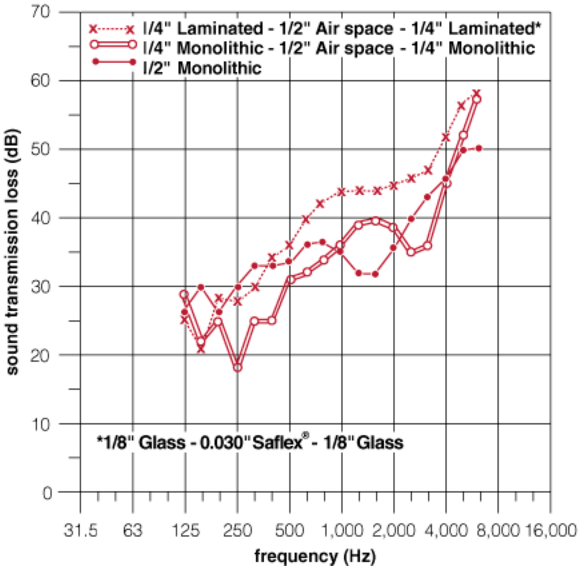


Figure 2.17 Comparison of insulating glass with and without laminated glass and equivalent weight monolithic glass.

NOTE:
The data and information set forth are based on samples tested and are not guaranteed for all samples or applications.

Acoustical Guide - Principles of Acoustics

Acoustical Storm Sash

Often, acoustically deficient windows of an existing building are replaced with new ones that provide the needed sound isolation performance. Other times, it is desirable to maintain the existing windows and to improve their sound isolation performance through the installation of acoustical storm sash.

Storm sash is usually a monolithic glazing system applied to the interior or the exterior of an existing window. Exterior storm sash, also known as "storm windows," uses lightweight monolithic glass in a vented, operable aluminum frame. Because they are lightweight and are usually vented, conventional storm windows are unsuited for sound isolation purposes.

Acoustical storm sash requires thicker glass, often laminated glass. It must be well sealed and must be generously spaced away from the prime window glass. These installation requirements are usually more easily satisfied inside the prime window, hence the term interior acoustical storm sash.

Generally, the sound isolation performance improvement produced by the installation of acoustical storm sash is expressed as insertion loss (IL). IL is the arithmetic difference between the sound pressure level in a room with and without acoustical storm sash installed. It is similar to noise reduction and is expressed in decibels (dB) in frequency bands, or in A-weighted decibels (dBA).

Many of the features for improving glass sound isolation discussed in this section are also true for acoustical storm sash. For example, the greater the storm sash glass surface weight, the higher the insertion loss. Similarly, the greater the distance between the prime window glass and the storm sash glass, the higher the insertion loss. In addition, the use of laminated glass in acoustical storm sash further increases insertion loss, particularly at critical frequency (2,500 Hz for 1/4" glass).

Storm sash is sometimes attached to, or has contact with, prime windows. This direct physical contact, or structural coupling, can reduce acoustical storm sash insertion loss. This is the result of exterior sound exciting vibration in the prime sash, which is then transmitted by contact to the acoustical storm sash, which reradiates sound to the interior of the building. In addition, the attachment of acoustical interior storm sash panels to a prime sash often leaves cracks uncovered, therefore not always fully attenuating sound transmitted through prime window frames. In spite of the these limitations, attachment of interior storm sash directly to prime sash can offer advantages that sometimes outweigh possible losses in sound isolation performance.

Solutia has sponsored the testing of a variety of windows at Riverbank Acoustical Laboratories. A discussion and presentation of these data are contained in Section 3. These data have been used to estimate the insertion loss of 1/4" laminated acoustical storm sash when used to improve the sound isolation performance of windows glazed with lightweight single and insulating glass, and when the exterior noise source is transportation noise produced by aircraft, highway traffic or trains. The two prime window glazing types, 1/8" monolithic and 1/2" insulating (1/8" glass - 1/4" air space - 1/8" glass), are the lightest commercially available prime glass, and are those most likely needing additional sound isolation performance. Estimated acoustical storm sash insertion losses are presented in Figure 2.18.

Figure 2.18 presents two tables, one for single glazed windows, the other for prime windows glazed with insulating glass. Presented in these tables are estimated insertion losses in A-weighted decibels expected from

Acoustical Guide - Principles of Acoustics

the installation of 1/4" laminated glass acoustical storm sash when installed at indicated spacings from prime window glass. The insertion losses of Figure 2.18 can be used to determine the benefit of 1/4" laminated acoustical storm sash for either 1) reducing transportation sound level inside an existing room or 2) to increase the NR of a window in a design situation which would otherwise have a deficient sound isolation performance on its own.

The first is an example of a case where the A-weighted sound pressure level measured in an existing room with windows outfitted with single or insulating glass is higher than desired. If sound levels in the room are produced by transportation sound, the reduction in room sound level that can be obtained through the installation of 1/4" laminated acoustical storm sash can be read from the tables in Figure 2.18. These reductions, i.e., insertion losses, are subtracted from the measured A-weighted sound pressure level to obtain an estimate of the A-weighted sound pressure level once the acoustical storm sash as been installed.

The second is an example of a case where the required STC rating determined from the methodologies in Section 1 cannot be obtained through the use of conventional glass configurations, such as those listed in Figure 1.14a, or if it is desired to use for the prime window a glass configuration that provides a lower than required STC rating. The STC rating shortfall can be offset through the installation of 1/4" laminated acoustical storm sash spaced a minimum required distance away from the prime glazing in order to obtain an insertion loss equal to or greater than the shortfall in STC rating.

Estimated 1/4" Laminated Glass Acoustical Storm Sash Insertion Losses									
Interior Storm Sash Insertion Loss in dBA Prime Window - 1/8" Monolithic Glass					Interior Storm Sash Insertion Loss in dBA Prime Window - 1/2" Insulating Glass				
Prime to Acoustical Storm Sash Air Space:	3/4"	1-1/2"	3"	6"	Prime to Acoustical Storm Sash Air Space:	3/4"	1-1/2"	3"	6"
Aircraft	3	6	9	12	Aircraft	6	10	14	17
Traffic	5	9	12	16	Traffic	9	12	16	20
Rail	6	9	13	17	Rail	9	13	16	20
Rail-Diesel	2	5	7	10	Rail-Diesel	3	7	11	14

Figure 2.18 Estimated 1/4" laminated glass acoustical storm sash insertion losses when used with prime windows glazed with monolithic and insulating glass and when exposed to transportation noise.

Acoustical Guide - Principles of Acoustics

Gas Filled Insulating Glass

Since the 1960s, the benefit of gas filling of the space between glass lights in an insulating glass configuration has been known to produce a significant increase in sound transmission loss over a broad frequency range. It has been generally noticed that increases of sound transmission loss at certain frequencies are offset by reduced sound transmission loss at other frequencies.

A wide variety of gases are used in insulating glass. The ability of gases used between two lights of glass for reducing sound transmission depends on how much their wave speeds differ from the wave speed (speed of sound) in air. These gases break down into two categories: those that have a lower speed of sound than air, and those that have a higher speed of sound. Gases such as carbon dioxide (CO2) and sulfur hexafloride (SF6) have lower wave speeds than air, partly because they are heavier than air. Argon (Ar) and helium (He), on the other hand, are lighter than air and have higher speeds of sound than air. The higher speeds of sound permit sound energy to ÒsloshÓ across the source side glass instead of coupling with the receiver side glass light, thus also reducing sound transmission. These gases need not be used in high concentration and are usually mixed with air in gas-to-air ratios of 1:4 to 4:1 [30].

Attached Figure 2.19 illustrates the benefits and drawbacks of gas filling. Note that sound transmission is increased over a wide frequency range, but at low frequencies in particular, the sound transmission loss of the gas filled configurations has a lower sound transmission loss. Since transportation noise is most often rich in low frequency sound energy, the degraded sound transmission losses at low frequencies can off-set the benefits of improved TL at higher frequencies.

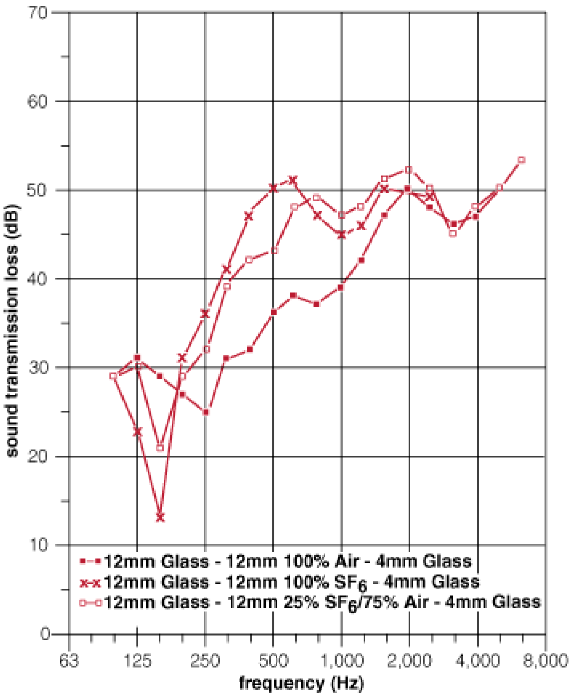


Figure 2.19 Examples of gas filled glass configurations [15].

Acoustical Guide - Principles of Acoustics

Sound Absorptive Reveal

As discussed in detail, the sound transmission loss of an insulating glass configuration can be improved significantly through the use of Saflex laminating interlayer. A similar, but generally not quite so great an improvement in TL can be obtained by lining the periphery of the space between the two lights of glass in an insulating glass configuration with a sound absorptive material. A sound absorptive reveal, as it is called, acts to reduce acoustic coupling between the lights of glass, thereby increasing the TL, particularly at the mass-air-mass resonance.

The mass-air-mass resonance is the interaction between the lights of glass in an insulating glass configuration and the air space that separates them. The air in the space between the two lights of glass acts as a spring separating two masses, i.e., the lights of glass. As any spring-mass system, at a specific frequency -- the resonance frequency -- vibration coupling between the lights of glass is particularly strong. This mass-air-mass resonance effect also promotes efficient sound transmission through the insulating glass, thus reducing the TL at this frequency.

The frequency at which the mass-air-mass resonance occurs depends on the thicknesses of the lights of glass and the thickness of the air space separating them. The thicker the glass and/or the thicker the air space, the lower the resonance frequency. Accordingly, the thinner the glass and/or the thinner the air space, the higher the resonance frequency. As an example, the mass-air-mass resonance frequency for standard 1” IG composed of 1/4” glass - 1/2” air space - 1/4” glass is approximately 200 Hz. As with 1” IG, the mass-air-mass resonance in insulating glass configurations generally reduces TL at low frequencies, where glass TLs are typical already low. Since transportation noise is rich in low frequency energy, much can sometimes be gained by treating this resonance condition using sound absorptive reveals.

Generally, 1/2” to 1” thick urethane foam is used in glass configurations outfitted with sound absorptive reveals. Other types of materials may be used, such as glass fiber, as long as it has a sound absorption exceeding an NRC of 0.75 and can withstand a wide range in temperature exposure and exposure to bright sunlight. Often, a decorative facing is applied to the surface of the sound absorptive reveal exposed to the cavity between the two lights of glass. This facing is almost always perforated and may be of vinyl or aluminum or other finish material. This facing material itself need not be sound absorptive, but must be at least 15% perforated to allow sound to enter into the sound absorptive material behind.

It is possible to configure a sound absorptive reveal that is reactive and does not have sound absorptive materials such as foams or fibrous fill. Reactive sound absorptive reveals are very much like hollow desiccant frames. Like a desiccant frame, the reactive sound absorptive frame would have an open slot on the inner face of the tube, i.e., the face exposed to the air space between the two lights of glass. Air inside the tube would act as a spring and air in the slot would act as a mass. If configured in the correct proportions, the resulting spring-mass arrangement, called a Helmholtz resonator, could be highly absorptive at the mass-air-mass resonance of an insulating glass configuration, thereby increasing the TL at this frequency.

Figure 2.20 presents sound transmission loss data for an approximate 4-1/4” thick insulating glass configuration (4 mm glass - 100 mm air space - 4 mm glass) with and without a 2” (50 mm) thick sound

Acoustical Guide - Principles of Acoustics

absorptive reveal. As with the use of laminated glass in an insulating glass configuration, the use of a sound absorptive reveal increases TL over a wide frequency range.

In a broad sense, the sound absorptive reveal adds damping to an insulating glass configuration that can be alternatively obtained through laminated glass. However, a further benefit is obtained when laminated glass is added to an insulating glass configuration already outfitted with a sound absorptive reveal. Correspondingly, adding a sound absorptive reveal to an insulating glass configuration outfitted with laminated glass also provides a further benefit. Typically, adding laminated glass to an insulating glass configuration already outfitted with a sound absorptive reveal can increase the STC rating by 2 or more rating points.

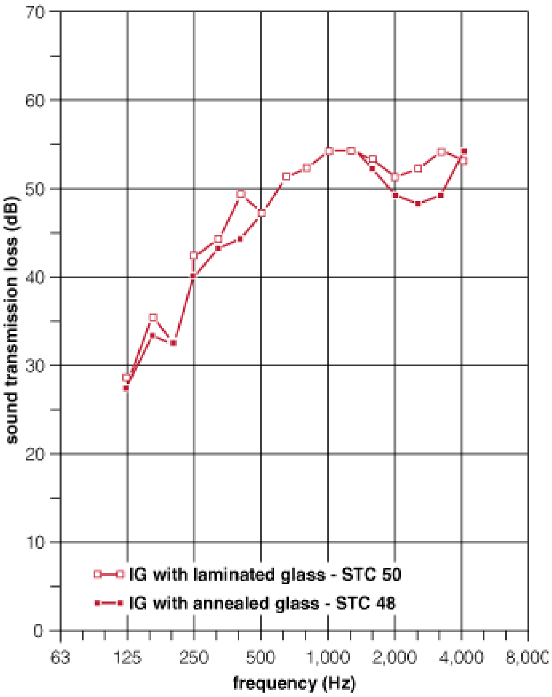


Figure 2.20 Sound transmission loss data for insulating glass windows (4mm glass - 100mm air space - 4mm glass) with and without sound absorptive periphery [32].

Acoustical Guide - Principles of Acoustics

Frame Effects

As elsewhere described, the sound transmission loss data tested at Riverbank Acoustical Laboratories was collected for unframed glass configurations mounted directly into the laboratory masonry test opening. Sealing the glass edges directly to the masonry opening restrains the glass edge from vibratory excitation by sound on the source side. Glass in framed windows, on the other hand, is not so tightly restrained, particularly in lightweight frames. This allows the glass edges to vibrate more, resulting in more sound transmission to the receiving side of the laboratory TL test suite. Hence, glass configurations when tested in window frames, even though well sealed, often exhibit sound transmission losses that are 1 to 3 STC rating points lower than glass tested unframed.

Frames play an important part in the sound transmission loss of windows and sometimes can compromise the sound transmission loss that would otherwise be obtained by glass if used unframed, alone. It is the challenge of window manufacturers to design and build window frames that maximize the available sound transmission loss of glass configurations used. There are no fixed guidelines for designing window frames that maximize sound transmission loss, but a few observations are as follows:

- The lower the sound transmission loss of the glass used in a window frame, the less likely it is that the window frame will compromise window STC rating.
- Windows with lightweight frames that use glass configurations with high sound transmission losses should be designed such that the glass surface area is as large as possible, extending as far as possible between edges of building openings (i.e., extending as deeply as possible into window frames).
- Window frames that rely on glass positioning by means of blocking should make use of continuous blocks. Continuous blocks should also be used on sides and tops of windows.
- Window frames should have a surface weight as great as that of the glass. Often this is not the case, particularly in windows with acoustical glass.
- Packing large, hollow-tube sections of frames with loose, dense glass fiber fill has been noted to improve window sound transmission loss.
- Sometimes frames exhibit insufficient damping, or ringing, that manifests itself as a reduction in TL at a particular frequency, generally less than 500 Hz. Although laminated glass can contribute to frame damping, direct application of damping compounds to window frame components can more efficiently increase frame damping.
- Very sophisticated window constructions, e.g., those used between studios, most often avoid vibration coupling by creating separate frames for inner and outer lights of glass. These frames are separately anchored and sealed to the building walls. Note that the thermal break used in many window frames is structurally too rigid to provide sufficient decoupling between inner and outer lights to prevent vibration coupling.
- Always ensure adequate sealing of all glazing components and frame joints to eliminate sound leakage.

Acoustical Guide - Principles of Acoustics

Many of the above suggestions require testing to ascertain their benefit. Others may require additional tooling or labor to properly implement. It is not uncommon to see window frames result in an STC rating that is up to 5 points less than the STC rating obtained for the glass alone. Seeking to offset this loss through enhancement to the glass only, would be inefficient at best and would likely be much more expensive than implementing frame improvements.

Figures 2.21 and 2.22 present unframed glass TLs and TLs for windows with the corresponding glass configurations. Figure 2.21 presents unframed 1/2” IG sound transmission loss data and a window glazed with the same configuration. The generally reduced window TLs at higher frequencies in this figure are symptomatic of sound leakage at frame joints. Remedial efforts at improving window TL might include improved gasketting and/or more precise frame alignment to ensure that the operable sash is uniformly seated at gasket points.

Figure 2.22 exhibits a situation where the frame, a wood window frame in this case, resulted in a slightly higher window STC rating than was obtained for testing of the 1/2” IG glass configuration alone. This result was likely because of damping imposed by the window frame on the glass, increasing the TL at 400 Hz resulting in a modest 1 dB increase in STC rating. At least one manufacturer, Stanlock, has taken advantage of this phenomena, i.e., increasing glass damping through frame effects, by manufacturing a window gasketting system from a specially compounded elastomeric material with high damping. Manufacturers’ data indicates that when used in a metal frame, a 2 point increase in STC rating can be obtained through the use of their glass gasket system.

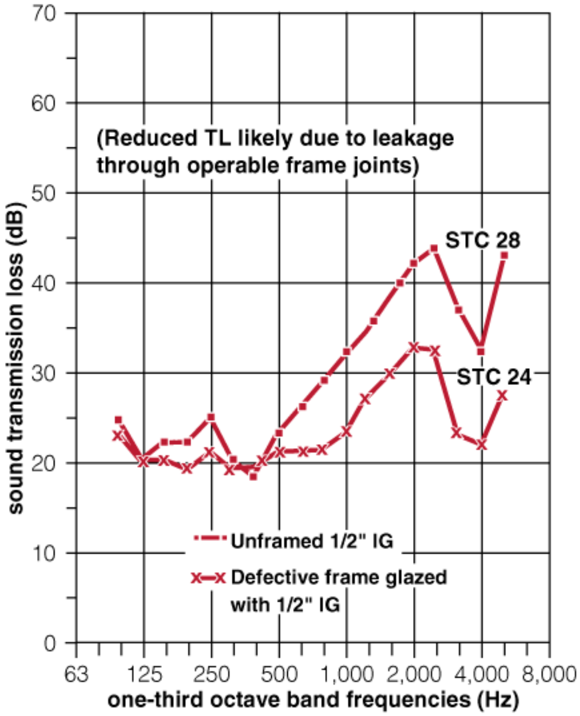


Figure 2.21 Comparison of unframed 1/2” IG with defective window also glazed with 1/2” IG.

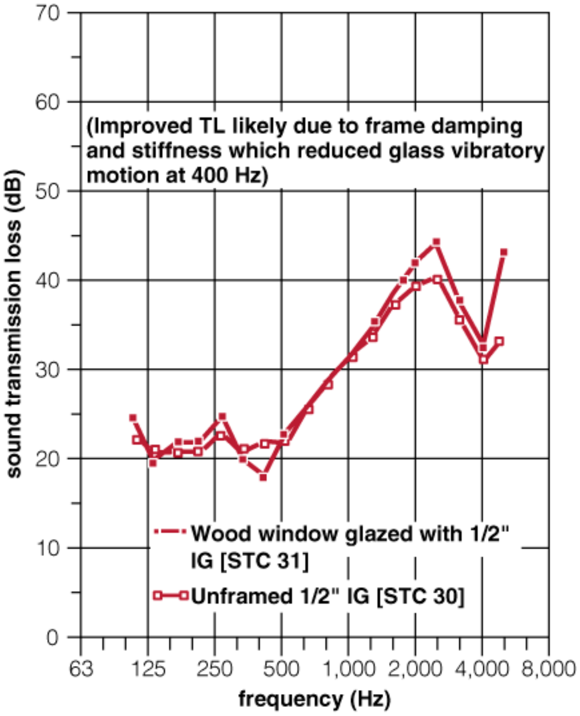


Figure 2.22 Comparison of unframed 1/2” IG with wood window also glazed with 1/2” IG.

Acoustical Guide - Principles of Acoustics

Sound Transmission Class

Since sound transmission loss (TL) is very frequency-dependent, it is generally reported in the third octave frequency bands between, as a minimum, 125 Hz and 4,000 Hz. As a convenience, a single number rating method has been developed which allows a single value to be given to a transmission loss spectrum which is a set of 16 one-third octave band TL values. This rating is referred to as the sound transmission class (STC) rating which has been defined in the American Society for Testing and Materials (ASTM) Standard E413 [16].

This standard defines a procedure for determining the STC rating for a TL spectrum by fitting a contour to the one-third octave band TL data. This contour is shown in Figure 2.23. This procedure involves raising or lowering the contour until the following two rules are met:

1. The contour may not be raised above the point at which the TL in any one-third octave band falls more than 8 dB below the contour.
2. The contour may not be raised above the point at which the total number of deficiencies is greater than 32.

A deficiency occurs when the TL data in any one one-third octave band falls below the contour. For example, three deficiencies would be when the TL data in any one-third octave falls 3 dB below the contour, or when the data in three one-third octave bands fall 1 dB below the contour. Figure 2.20 further illustrates the meaning of deficiency.

The STC rating resulting from the contour fitting procedure is the TL value of the contour at 500 Hz. This is illustrated in Figures 2.24 and 2.25.

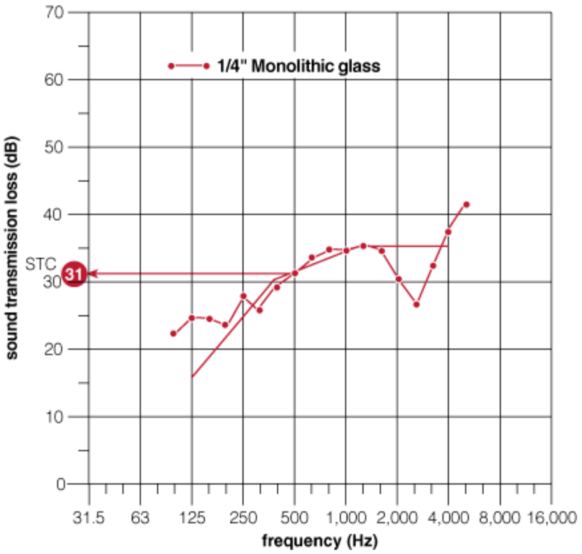


Figure 2.24 Sound transmission loss data and STC contour for 1/4" monolithic glass.

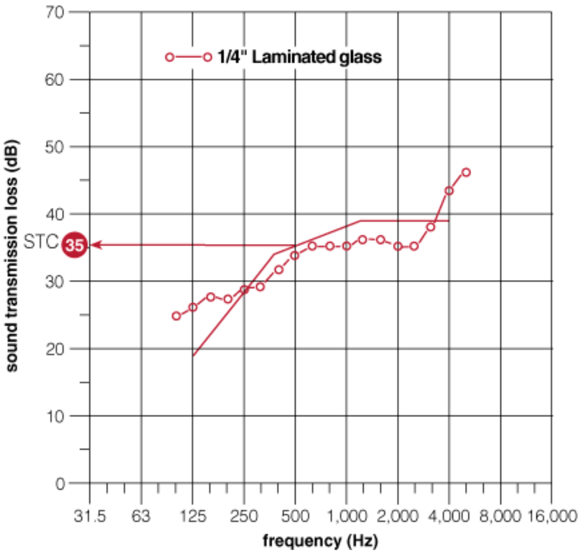


Figure 2.25 Sound transmission loss data and STC contour for 1/4" laminated glass.*
(*1/8" glass - 0.030" Saflex - 1/8" glass).

NOTE:
The data and information set forth are based on samples tested and are not guaranteed for all samples or applications.

Acoustical Guide - Principles of Acoustics

In Figure 2.24, 1/4” monolithic glass is shown to have an STC rating of 31. In this example, the STC contour placement is constrained by the maximum allowed 8 dB deficiency at 2,500 Hz (rule 1).

In Figure 2.25, which shows TL data for 1/4” laminated glass, the dip in the TL data, characteristic of 1/4” monolithic glass, is removed by the damping interlayer. In the case of 1/4” laminated glass, the STC contour placement is constrained by the maximum 32 dB deficiency requirement (rule 2).

Figures 2.24 and 2.25 illustrate the benefits of interlayer damping and how it also increases STC rating by as much as 4 dB.

It should be noted that the STC value has been developed to approximate the performance of a material in reducing the transmission of intelligible speech sounds. The STC characterization of TL is useful for a quick comparison of materials, but it is not necessarily useful for assessing the performance of a material with respect to other non-speech sounds such as aircraft, highway traffic, train passbys, etc. For this purpose, it is necessary to consider octave or one-third octave band TL spectra as has been done in developing the methodologies of Section 1.

Acoustical Guide - Principles of Acoustics

Outdoor-Indoor Transmission Class

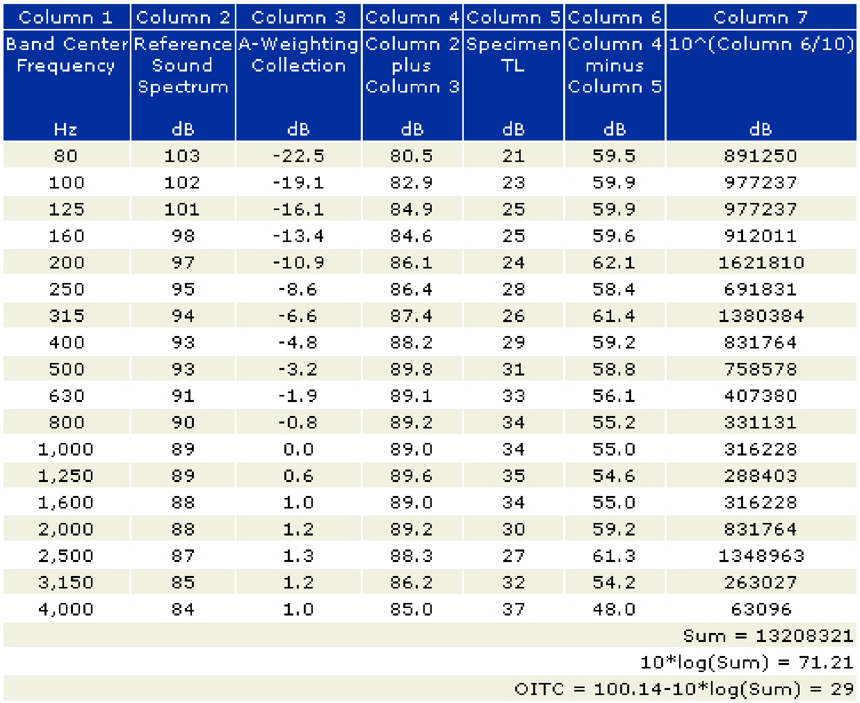
The outdoor-indoor transmission class (OITC) provides a single-number rating that can be used for comparing the sound isolation performance of building facades and facade elements. The rating has been devised to quantify the ability of these to reduce the perceived loudness of ground and air transportation noise transmitted into buildings. This standard is contained in ASTM E1332-90 Standard Classification for Determination of Outdoor-Indoor Transmission Class.

The standard establishes a single-number rating, the OITC, by defining a standard spectrum of ground and air transportation noise. This spectrum is used with sound transmission loss data, measured in a laboratory using the ASTM E90 method, and a mathematical relationship given in the standard to calculate the OITC rating.

The OITC rating is similar to the STC rating in that it uses ASTM E90 TL data and uses this data to derive a single-number rating that increases with increasing sound isolation ability. It differs in that the OITC does not involve a contour fitting process, but instead uses a standard spectrum and a mathematical relationship. The mathematical relationship is as follows:

$OITC = 100.14 - 10 \log 10 ((Lf\text{-}TLf+Af)/10)$ dB

Figure 2.26 presents a worksheet summarizing the method for calculating the OITC rating for 1/4” glass. As indicated in this figure, the OITC rating for 1/4” glass is 29. Note that the TL in the 80 Hz band in the worksheet of Figure 2.26 was not measured and has been estimated to be 21 dB, 2 dB less than the measured 100 Hz TL. In Section 3, the OITC ratings for all glazing configurations tested at Riverbank Acoustical Laboratories have been computed, again assuming that the 80 Hz one-third octave band TLs are 2 dB less than the measured 100 Hz octave band TLs.



Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Band Center Frequency	Reference Sound Spectrum	A-Weighting Collection	Column 2 plus Column 3	Specimen TL	Column 4 minus Column 5	10^(Column 6/10)
Hz	dB	dB	dB	dB	dB	dB
80	103	-22.5	80.5	21	59.5	891250
100	102	-19.1	82.9	23	59.9	977237
125	101	-16.1	84.9	25	59.9	977237
160	98	-13.4	84.6	25	59.6	912011
200	97	-10.9	86.1	24	62.1	1621810
250	95	-8.6	86.4	28	58.4	691831
315	94	-6.6	87.4	26	61.4	1380384
400	93	-4.8	88.2	29	59.2	831764
500	93	-3.2	89.8	31	58.8	758578
630	91	-1.9	89.1	33	56.1	407380
800	90	-0.8	89.2	34	55.2	331131
1,000	89	0.0	89.0	34	55.0	316228
1,250	89	0.6	89.6	35	54.6	288403
1,600	88	1.0	89.0	34	55.0	316228
2,000	88	1.2	89.2	30	59.2	831764
2,500	87	1.3	88.3	27	61.3	1348963
3,150	85	1.2	86.2	32	54.2	263027
4,000	84	1.0	85.0	37	48.0	63096
						Sum = 13208321
						10*log(Sum) = 71.21
						OITC = 100.14-10*log(Sum) = 29

Figure 2.26 Worksheet for calculating the OITC rating of 1/4” glass.

Acoustical Guide - Principles of Acoustics

Weighted Sound Reduction Index

The International Standards Organization (ISO) is a worldwide federation of national standards institutes. ISO, located in Switzerland, organizes technical committees that develop standards for various facets of industry. ISO TC (Technical Committee) 43 -- Acoustics has developed several standards pertaining to sound isolation in buildings. Unlike the U.S. counterpart standards, the ISO system of standards divides the evaluation of sound transmission loss into 13 parts. Those parts that are of immediate interest to persons evaluating the sound isolation performance of exterior walls and windows of buildings are as follows:

ISO 140/3:1978

Acoustics -- Measurement of sound insulation in buildings and of building elements -- Part 3: Laboratory measurements of airborne sound insulation of building elements

This standard is applicable to the testing of building materials and systems, including windows, and indicates how and what quantities are to be measured in order to determine the one-third octave band sound reduction index (sound transmission loss) spectra.

ISO 140/5:1978

Acoustics -- Measurement of sound insulation in buildings and of building elements -- Part 5: Field measurements of airborne sound insulation of facade elements and facades

Similarly, this standard is the field counterpart of ISO 140/3 for measuring one-third octave band sound reduction indices of exterior windows, doors and wall/window constructions in buildings.

ISO 717/1:1982

Acoustics -- Rating of sound insulation in buildings and of building elements -- Part 1: Airborne sound insulation in buildings and of interior building elements

This standard defines a single-number rating procedure for evaluating one-third octave band sound reduction index spectra measured in a laboratory using ISO 140/3 and 140/4 standards applicable to building elements.

ISO 717/3:1982

Acoustics -- Rating of sound insulation in buildings and of building elements -- Part 3: Airborne sound insulation of facade elements and facades

Similarly, this standard defines a single-number rating procedure for evaluating one-third octave band sound reduction index spectra and noise reductions measured using ISO 140/3 and 140/5 standards applicable to exterior facade elements.

Note that there are two groups of ISO standards: ISO 140 standards and ISO 717 standards. The ISO 140 standards address the measurement of sound transmission loss. Other ISO 140 standards define other methods

Acoustical Guide - Principles of Acoustics

including a method for measuring the impact sound isolation performance of floor/ceiling constructions in buildings and the sound isolation performance of interior building components. The ISO 717 standards present single-number evaluation procedures for one-third and full octave band data collected using ISO 140 measurement methods.

ISO 140/1 laboratory sound transmission loss measurement methods use the same test laboratory arrangement as established in ASTM standards, i.e., two test rooms joined by an opening into which the test specimen is mounted, as discussed in Section 2 under Sound Transmission Loss Fundamentals. As in the ASTM standards, one-third octave band sound transmission losses are measured. ISO refers to these measured values as sound reduction indices (R). ASTM standards define a method for determining the STC rating, a single-number rating of a one-third octave band sound transmission loss spectrum. Correspondingly, ISO 717/1 defines a standard contour and a procedure for fitting the contour to sound reduction indices to determine a single-number rating of a sound transmission loss spectrum. This rating is called the weighted sound reduction index (Rw). Unlike the STC contour, the Rw contour is defined over a slightly lower fre-quency range: 100 to 3,150 Hz. Figure 2.27 presents both the ISO and STC contours for comparison. Note that the two contours are nearly identical in shape, and differ only in that the ISO contour is defined over a lower range than is the STC contour.

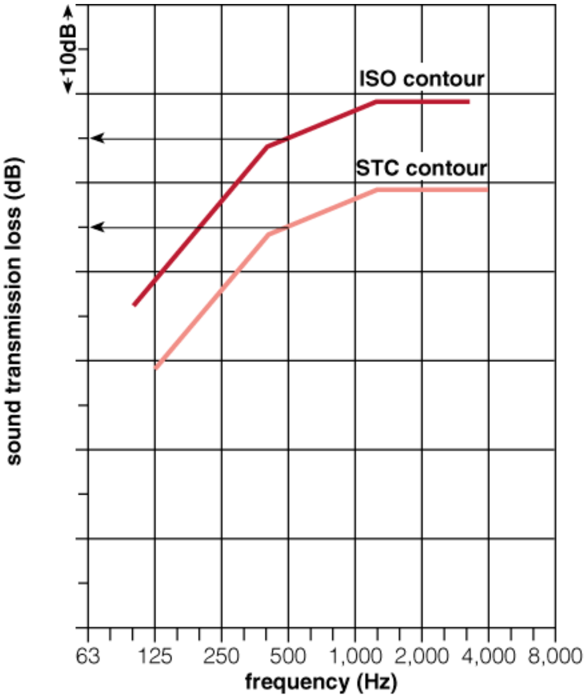


Figure 2.27 Comparison of ISO sound reduction index and sound transmission class contours.

As with the STC rating, the Rw is equal to the fitted contour value at 500 Hz. The contour fitting procedure involves only one rule. The rule requires that the sound reduction values be determined to one decimal place and that the contour be raised in 1 dB increments to a point where the average deficiency over the contour frequency range is as close to, but not exceeding, 2.0 dB. The average deficiency is the sum of all deficiencies in all frequency bands divided by 16, the number of one-third octave frequency bands spanned by the contour.

Unlike the STC contour fitting procedure, there is no “8 dB rule” limiting the height to which the contour can be raised while satisfying the deficiencies limit. However, ISO 717 standards require that if an 8 dB or larger deficiency exists in sound reduction index data, then the deficiency amounts in dB and frequencies at which they occur must be reported.

Data measured at Riverbank Acoustical Laboratories in accordance with ASTM E90 requirements and procedures are equivalent to TL data measured in accordance with ISO 140. Hence, the terms sound reduction index used by ISO and sound transmission loss used by ASTM are nearly identical. It is therefore permissible to evaluate sound transmission loss data, gathered under applicable ASTM laboratory standards, using ISO 717 contour fitting procedures, as has been done and reported in Sections 1 and 3.

Acoustical Guide - Principles of Acoustics

The ISO 140/5 standard is for the field measurement of airborne sound insulation of facade elements and complete facades. It establishes two methods for measuring sound transmission loss Ñ one using noise produced by traffic on a nearby road or highway, and a second using an electronic broad-band noise source. The standard has a variety of requirements regarding how loud the traffic and electronic noise sources must be to obtain valid data, location of microphones inside and outside the facade, simultaneous measurement of indoor and outdoor sound levels when using traffic as the test noise source, etc.

As in ISO 140/3, ISO 140/5 establishes a procedure for measuring sound reduction indices in one-third octave bands from 100 to 3,150 Hz. These are denoted as Rtr for the sound reduction indices determined using traffic as the noise source and Rq for the sound reduction indices using an electronic noise source located outside the building. The subscript q (Greek letter theta) is the angle in plan that the electronic noise source axis is oriented with respect to the center of the facade or facade element being tested. The standard requires that, as a minimum, one test with q equal to 45° be conducted; however, it recommends that tests be conducted with q equal to 0°, 15°, 30°, 60° and 75° as well, and that the resulting sound reduction indices be averaged together.

Using one-third octave band sound reduction indices measured according to ISO 140/5, the corresponding weighted sound reduction indices (single-valued quantities) can be determined using procedures of ISO 717/3. These procedures use the same contour and contour fitting rules as those in ISO 717/1 for determining Rw. The weighted sound reduction index for the one-third octave band sound reduction indices measured using traffic as a source is denoted as Rtr,w. The weighted sound reduction index for the one-third octave band sound reduction indices measured using an electronic noise source is denoted as Rq,w.

Acoustical Guide - Sound Transmission Loss Data

Sound Transmission Loss Data

- Glass Sound Transmission Loss Studies
- Use of Laminated Glass
- Acoustical Storm Sash Insertion Loss Studies
- Acoustical Storm Sash TL Data Analysis
- Acoustical Storm Sash Design
- Kawneer Window Systems

Acoustical Guide - Sound Transmission Loss Data

Glass Sound Transmission Loss Studies

Solutia, along with the Laminators Safety Glass Association, has sponsored a program of sound transmission loss (TL) measurements of a wide range of glass configurations. These tests have been conducted by Riverbank Acoustical Laboratories, a National Voluntary Laboratory Accreditation Program (NVLAP) approved acoustical test laboratory. Tests have been conducted in conformance with ASTM E90-83 [17] (tests in 1985), ASTM E90-90 [17] (tests in 1995), and E413-73.

The transmission of sound from outside a building into building spaces is a combination of sound transmission through both the wall and windows. Normally, the exterior wall TL is significantly higher than the window TL. It is necessary that the TL characteristic of the wall, as well as the windows, be known in a typical analysis of exterior sound transmission. Because of a wide variety of building construction techniques and materials, a large TL data bank is needed for the evaluation of even common building window and partition types. Many firms and organizations have developed wall TL data banks. Among these are U.S. Gypsum, National Gypsum and the California Department of Health and Services Office of Noise Control. They have assembled TL data files for common building wall and partition systems. Up to this point, no such comprehensive file has existed for glass.

Solutia, recognizing the need for a comprehensive glass TL data file, has sponsored TL measurements of various glass configurations.

This data file is provided in Tables 3.1a, 3.1b, 3.1c, and 3.1d. It should be noted that these tests were conducted on 3’-0” by 7’-0” glass samples. This is the most prevalently tested size for glazing configurations. Although the TL test procedure minimizes the effect of sample area size, it has been commonly observed that sound transmission testing of a 4’-0” by 8’-0” sample size results in a 1 to 2 dB higher sound transmission class (STC). This difference is largely the result of secondary effects associated with the test mounting configuration.

Perhaps the most significant difference between the Solutia-sponsored glazing TL tests and those conducted by window manufacturers is that the Solutia-sponsored tests are with glass configurations mounted directly in the test opening without a frame. TL tests conducted by window manufacturers have glass configurations mounted in the manufacturer’s frame. As discussed in Section 2, window frames often result in somewhat lower TLs than would be the case for the testing of glass alone.

Also included in Tables 3.1a through 3.1d are estimated outdoor-indoor transmission class (OITC) ratings and weighted sound reduction indices (Rw). OITC ratings shown are approximate since they have been estimated assuming an 80 Hz TL that is 2 dB less than measured 100 Hz TLs. It is believed that estimated OITCs are within ±1 dB of actual values. Refer to SectionÊ2 for detailed discussions of OITC and Rw.

NOTE:
Although the data in this section are extremely useful for design purposes, they do not eliminate the need for testing actual window assemblies to ascertain the effects of window frames on total window system sound transmission loss (TL).

Acoustical Guide - Sound Transmission Loss Data

Table 3.1a Glass Sound Transmission Loss Data*

One-third octave band (Hz)	100	125	160	200	250	315	400	500	630	800	1,000	1,250	1,600	2,000	2,500	3,150	4,000	5,000	STC	OITC	Rw
1/4" RAL-TL85-169	23	25	25	24	28	26	29	31	33	34	34	35	34	30	27	32	37	41	31	29	32
1/2" RAL-TL85-198	26	30	26	30	33	33	34	36	37	35	32	32	36	40	43	46	50	51	36	33	37
Lami - 0.030" - Lami RAL-TL85-218	24	26	27	27	28	29	30	32	34	35	36	36	36	35	35	39	43	46	35	31	35
1/8" - 0.030" - 1/8" RAL-TL85-170	25	26	28	27	29	29	30	32	34	35	35	36	36	35	35	38	43	46	35	31	35
1/8" - 0.060" - 1/8" RAL-TL85-224	25	26	27	28	28	29	30	33	34	35	36	37	37	37	36	38	42	46	35	32	35
1/8" - 0.045" - 1/8" RAL-TL85-234	24	27	27	28	28	29	30	32	34	35	36	36	37	36	35	38	43	46	35	31	35
3/16" - 0.030" - 3/16" RAL-TL85-200	27	27	27	30	31	31	33	34	35	36	36	35	34	37	41	45	49	52	36	33	36
1/4" - 0.030" - 1/8" RAL-TL85-229	27	27	28	31	30	31	32	34	35	36	36	36	35	36	40	44	48	52	36	33	36
1/4" - 0.060" - 1/8" RAL-TL85-223	27	28	27	30	31	31	33	35	36	37	37	37	36	37	41	44	48	51	37	33	37
1/4" - 0.030" - 1/4" RAL-TL85-225	25	29	28	30	33	33	34	36	37	37	37	36	37	41	45	48	51	53	38	34	38
1/4" - 0.045" - 1/4" RAL-TL85-232	26	30	27	30	33	33	34	36	37	38	37	36	37	41	45	48	51	54	38	34	38
1/4" - 0.060" - 1/4" RAL-TL85-228	26	29	28	30	33	33	35	36	37	38	38	37	38	41	44	47	51	54	39	34	39
3/8" - 0.030" - 1/4" RAL-TL85-222	29	30	28	32	34	35	36	38	38	38	36	38	42	46	49	52	55	57	40	36	40
1/2" - 0.060" - 1/4" RAL-TL85-230	29	30	29	32	35	35	37	38	38	38	37	41	44	48	50	53	56	56	41	36	41

*The data and information set forth are based on samples tested and are not guaranteed for all samples or applications. Riverbank Acoustical Laboratories.

Acoustical Guide - Sound Transmission Loss Data

Table 3.1b Glass Sound Transmission Loss Data*

One-third octave band (Hz)	100	125	160	200	250	315	400	500	630	800	1,000	1,250	1,600	2,000	2,500	3,150	4,000	5,000	STC	OITC	Rw
1/8" - 1/4" AS** - 1/8" (SEALED) RAL-TL85-212	26	21	23	23	26	21	19	24	27	30	33	36	40	44	46	39	34	45	28	26	30
1/8" - 3/8" AS** - 1/8" (SEALED) RAL-TL85-213	26	23	23	20	23	19	23	27	29	32	35	39	44	47	48	41	36	43	31	26	32
1/4" - 1/2" AS** - 1/4" (SEALED) RAL-TL85-294	29	22	26	18	25	25	31	32	34	36	39	40	39	35	36	46	52	58	35	28	35
3/16" - 1" AS** - 3/16" (SEALED) RAL-TL85-215	20	25	18	17	26	28	33	36	38	39	41	44	46	43	38	40	48	51	35	27	37
1/4" - 1" AS** - 1/4" (UNSEALED) RAL-TL85-293	22	19	27	23	31	30	35	35	36	39	41	42	41	36	37	46	51	56	37	30	37
3/16" - 4" AS** - 3/16" (UNSEALED) RAL-TL85-216	24	28	30	33	30	38	38	44	46	50	50	50	51	49	41	42	50	52	44	35	44

*The data and information set forth are based on samples tested and are not guaranteed for all samples or applications. Riverbank Acoustical Laboratories.
**Air space.

Acoustical Guide - Sound Transmission Loss Data

Table 3.1c Glass Sound Transmission Loss Data*

One-third octave band (Hz)	100	125	160	200	250	315	400	500	630	800	1,000	1,250	1,600	2,000	2,500	3,150	4,000	5,000	STC	OITC	Rw
1/4" Lam. - 1/4" AS** - 1/8" (SEALED) RAL-TL95-296	32	31	30	28	27	24	26	28	31	34	37	39	41	43	49	52	51	57	35	31	35
1/4" Lam. - 3/8" AS** - 3/16" (SEALED) RAL-TL85-189	27	27	26	24	22	28	32	35	38	38	39	40	42	43	41	45	52	57	37	31	37
1/4" Lam. - 1/2" AS** - 3/16" (SEALED) RAL-TL85-238	26	23	25	23	27	31	34	36	38	39	41	43	45	46	43	49	55	55	39	31	39
1/4" Lam. - 1/2" AS** - 1/4" (SEALED) RAL-TL85-235	28	20	29	24	26	30	34	36	39	42	43	44	44	41	40	47	52	56	39	31	39
3/8" Lam. - 1/2" AS** - 1/4" (SEALED) RAL-TL85-192	28	17	28	29	33	34	38	40	40	41	41	41	41	40	43	49	54	58	40	31	40
1/4" Lam. - 1" AS** - 3/16" (UNSEALED) RAL-TL85-239	22	27	27	28	31	35	38	41	42	43	44	45	47	47	45	50	58	61	42	33	42
1/4" Lam. - 2" AS** - 3/16" (UNSEALED) RAL-TL85-173	24	25	34	33	34	40	41	44	44	46	47	47	48	48	46	50	55	56	45	35	45
1/2" Lam. - 2" AS** - 3/16" (UNSEALED) RAL-TL85-194	27	36	33	33	35	39	41	45	45	46	46	46	49	51	52	56	60	62	46	38	46
1/2" Lam. - 2" AS** - 3/8" (UNSEALED) RAL-TL85-196	34	37	33	38	40	42	44	48	47	46	45	42	46	51	55	59	61	62	46	42	47
1/2" Lam. - 1" AS** - 3/16" (UNSEALED) RAL-TL95-298	24	30	32	32	36	39	42	45	47	50	51	50	53	57	57	60	62	63	47	36	47
1/4" Lam. - 4" AS** - 3/16" (UNSEALED) RAL-TL85-174	26	36	34	37	37	43	44	48	49	51	51	50	51	50	47	51	58	60	48	39	48
1/2" Lam. - 4" AS** - 3/16" (UNSEALED) RAL-TL85-195	30	37	33	38	37	42	45	49	50	51	50	48	50	53	53	57	61	64	49	41	49
1/2" Lam. - 4" AS** - 3/8" (UNSEALED) RAL-TL85-197	38	38	33	40	40	43	46	51	52	52	50	45	48	53	56	59	62	64	49	44	50
3/4" Lam. - 4" AS** - 1/8" (UNSEALED) RAL-TL85-240	29	33	31	36	38	43	44	46	47	49	50	52	52	55	59	59	58	60	49	40	49

The data and information set forth are based on samples tested and are not guaranteed for all samples or applications. Riverbank Acoustical Laboratories.

Acoustical Guide - Sound Transmission Loss Data

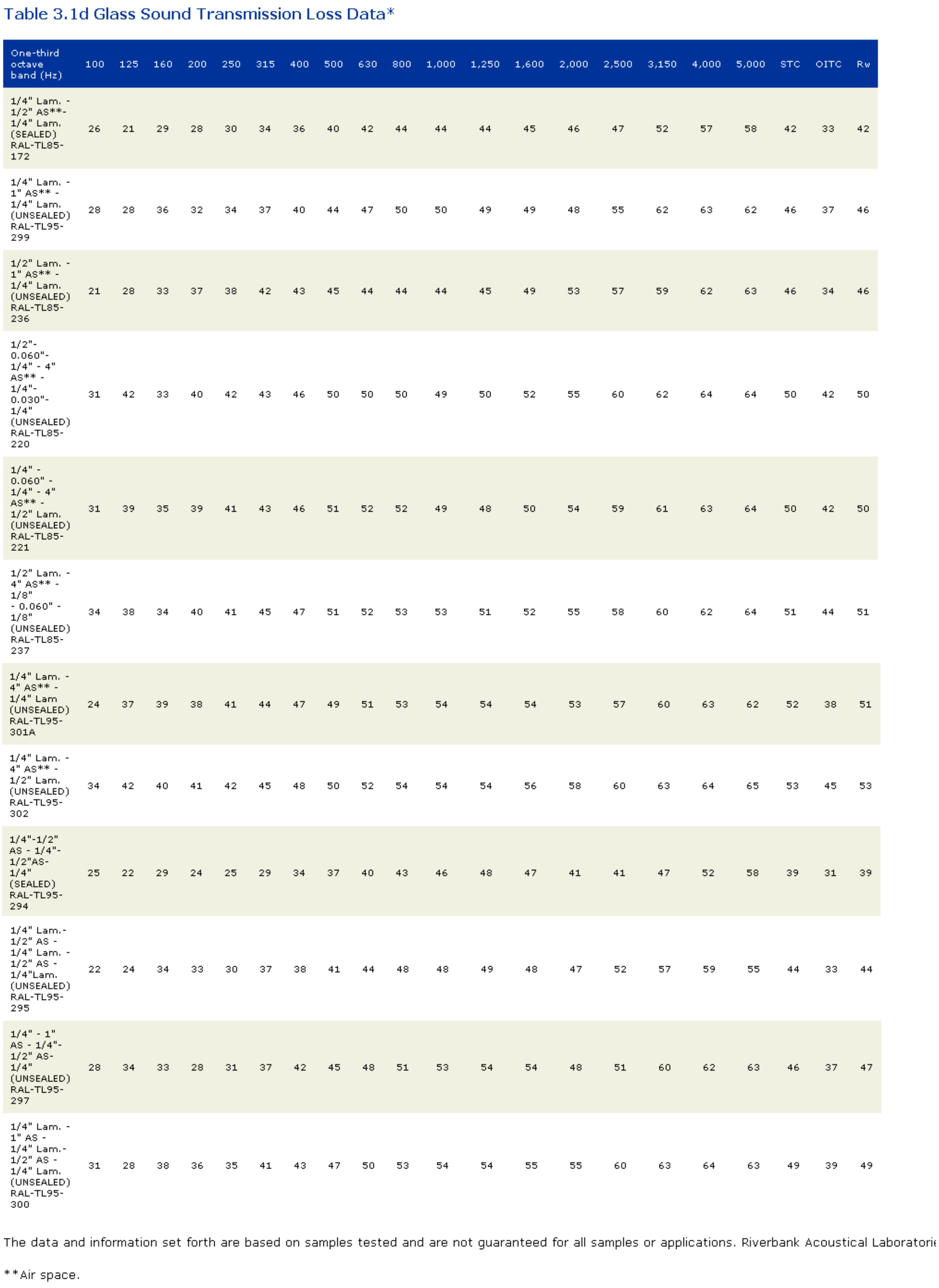


Table 3.1d Glass Sound Transmission Loss Data*

One-third octave band (Hz)	100	125	160	200	250	315	400	500	630	800	1,000	1,250	1,600	2,000	2,500	3,150	4,000	5,000	STC	OITC	Rw
1/4" Lam. - 1/2" AS**- 1/4" Lam. (SEALED) RAL-TL85-172	26	21	29	28	30	34	36	40	42	44	44	44	45	46	47	52	57	58	42	33	42
1/4" Lam. - 1" AS** - 1/4" Lam. (UNSEALED) RAL-TL95-299	28	28	36	32	34	37	40	44	47	50	50	49	49	48	55	62	63	62	46	37	46
1/2" Lam. - 1" AS** - 1/4" Lam. (UNSEALED) RAL-TL85-236	21	28	33	37	38	42	43	45	44	44	44	45	49	53	57	59	62	63	46	34	46
1/2"- 0.060"- 1/4" - 4" AS** - 1/4"- 0.030"- 1/4" (UNSEALED) RAL-TL85-220	31	42	33	40	42	43	46	50	50	50	49	50	52	55	60	62	64	64	50	42	50
1/4" - 0.060" - 1/4" - 4" AS** - 1/2" Lam. (UNSEALED) RAL-TL85-221	31	39	35	39	41	43	46	51	52	52	49	48	50	54	59	61	63	64	50	42	50
1/2" Lam. - 4" AS** - 1/8" - 0.060" - 1/8" (UNSEALED) RAL-TL85-237	34	38	34	40	41	45	47	51	52	53	53	51	52	55	58	60	62	64	51	44	51
1/4" Lam. - 4" AS** - 1/4" Lam (UNSEALED) RAL-TL95-301A	24	37	39	38	41	44	47	49	51	53	54	54	54	53	57	60	63	62	52	38	51
1/4" Lam. - 4" AS** - 1/2" Lam. (UNSEALED) RAL-TL95-302	34	42	40	41	42	45	48	50	52	54	54	54	56	58	60	63	64	65	53	45	53
1/4"-1/2" AS - 1/4"- 1/2"AS- 1/4" (SEALED) RAL-TL95-294	25	22	29	24	25	29	34	37	40	43	46	48	47	41	41	47	52	58	39	31	39
1/4" Lam.- 1/2" AS - 1/4" Lam. - 1/2" AS - 1/4"Lam. (UNSEALED) RAL-TL95-295	22	24	34	33	30	37	38	41	44	48	48	49	48	47	52	57	59	55	44	33	44
1/4" - 1" AS - 1/4"- 1/2" AS- 1/4" (UNSEALED) RAL-TL95-297	28	34	33	28	31	37	42	45	48	51	53	54	54	48	51	60	62	63	46	37	47
1/4" Lam. - 1" AS - 1/4" Lam.- 1/2" AS - 1/4" Lam. (UNSEALED) RAL-TL95-300	31	28	38	36	35	41	43	47	50	53	54	54	55	55	60	63	64	63	49	39	49

The data and information set forth are based on samples tested and are not guaranteed for all samples or applications. Riverbank Acoustical Laboratori

**Air space.

Solutions for a better life.

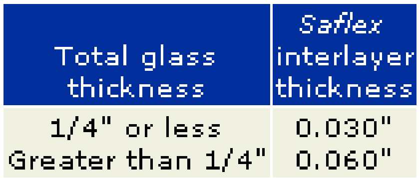
Acoustical Guide - Sound Transmission Loss Data

Use of Laminated Glass

No special handling techniques or conditions are needed in connection with the use of laminated glass. The following points may be useful:

It has been observed that the sound transmission loss (TL) of laminated glass increases with temperature. So, the best acoustical performance is obtained when the laminated glass of a laminated insulating glass configuration is situated on the warm side of the window. This obviously requires some judgment. In warm climates, the laminated glass is best used on the outside of the building. In cooler climates, the laminated glass is best used on the interior side of the window.

Single laminated glass TL loss tests indicate that the thicker the glass components, the thicker should be the interlayer. As a "rule-of-thumb," the following interlayer thickness guideline should be used:



Total glass thickness	Saflex interlayer thickness
1/4" or less	0.030"
Greater than 1/4"	0.060"

Although some benefit might be logically expected from the use of dissimilar glass thicknesses in a laminated glass composition, no significant advantage has been noted in laboratory test data.

A number of relationships between sound transmission loss (TL) and glass characteristics can be observed in the data of Figures 3.1a through 3.1d. Among these features are:

- Glass thickness
- Air space thickness
- Sealed vs. non-sealed air spaced glass
- Interlayer damping

The relationships between these features and TL are discussed in Sections 1 and 2.

Table 3.1a: Glass Sound Transmission Loss Data

Table 3.1b: Glass Sound Transmission Loss Data

Table 3.1c: Glass Sound Transmission Loss Data

Table 3.1d: Glass Sound Transmission Loss Data

Acoustical Guide - Sound Transmission Loss Data

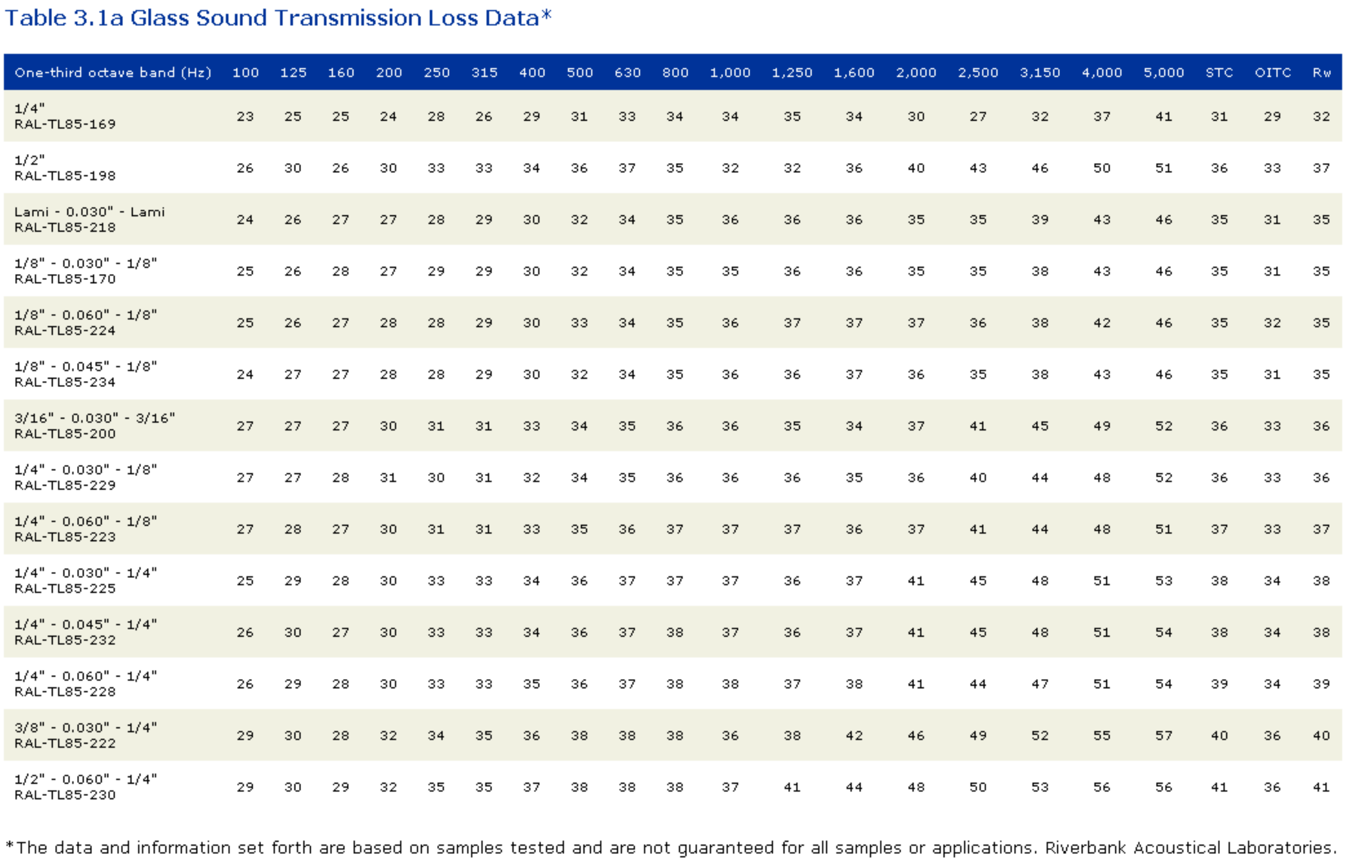


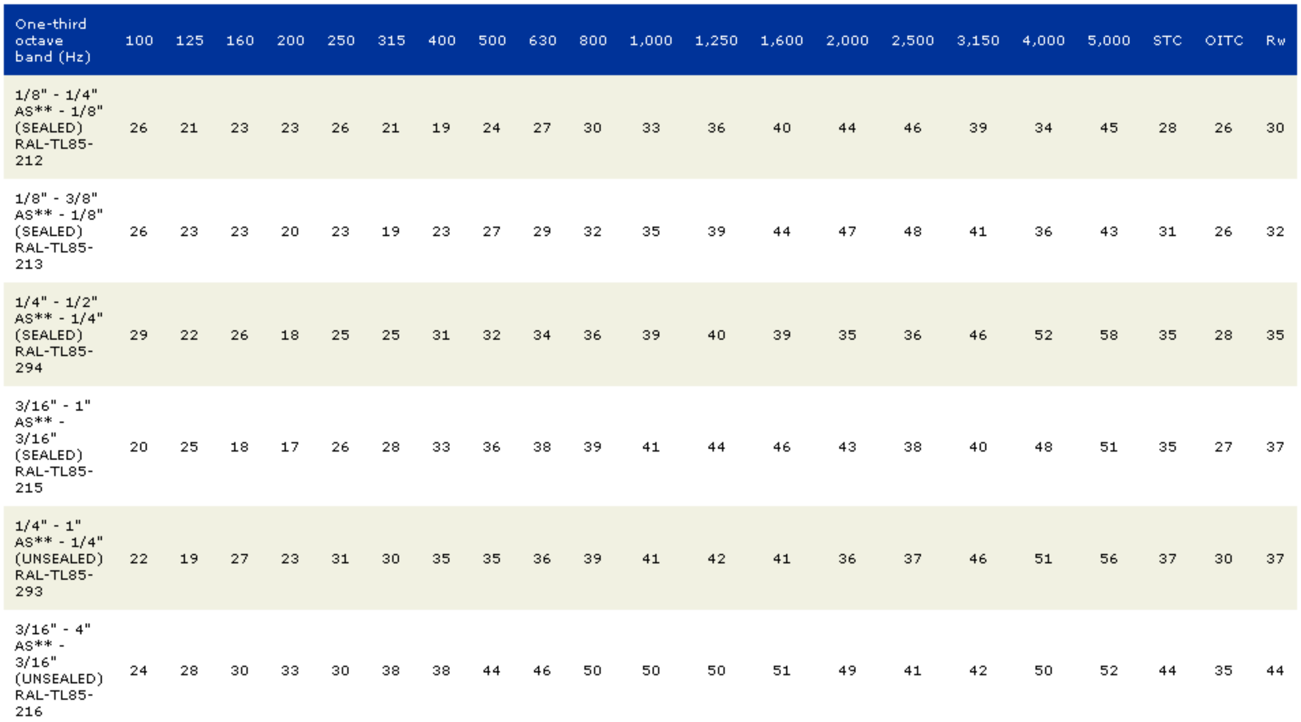
Table 3.1a Glass Sound Transmission Loss Data*

One-third octave band (Hz)	100	125	160	200	250	315	400	500	630	800	1,000	1,250	1,600	2,000	2,500	3,150	4,000	5,000	STC	OITC	Rw
1/4" RAL-TL85-169	23	25	25	24	28	26	29	31	33	34	34	35	34	30	27	32	37	41	31	29	32
1/2" RAL-TL85-198	26	30	26	30	33	33	34	36	37	35	32	32	36	40	43	46	50	51	36	33	37
Lami - 0.030" - Lami RAL-TL85-218	24	26	27	27	28	29	30	32	34	35	36	36	36	35	35	39	43	46	35	31	35
1/8" - 0.030" - 1/8" RAL-TL85-170	25	26	28	27	29	29	30	32	34	35	35	36	36	35	35	38	43	46	35	31	35
1/8" - 0.060" - 1/8" RAL-TL85-224	25	26	27	28	28	29	30	33	34	35	36	37	37	37	36	38	42	46	35	32	35
1/8" - 0.045" - 1/8" RAL-TL85-234	24	27	27	28	28	29	30	32	34	35	36	36	37	36	35	38	43	46	35	31	35
3/16" - 0.030" - 3/16" RAL-TL85-200	27	27	27	30	31	31	33	34	35	36	36	35	34	37	41	45	49	52	36	33	36
1/4" - 0.030" - 1/8" RAL-TL85-229	27	27	28	31	30	31	32	34	35	36	36	36	35	36	40	44	48	52	36	33	36
1/4" - 0.060" - 1/8" RAL-TL85-223	27	28	27	30	31	31	33	35	36	37	37	37	36	37	41	44	48	51	37	33	37
1/4" - 0.030" - 1/4" RAL-TL85-225	25	29	28	30	33	33	34	36	37	37	37	36	37	41	45	48	51	53	38	34	38
1/4" - 0.045" - 1/4" RAL-TL85-232	26	30	27	30	33	33	34	36	37	38	37	36	37	41	45	48	51	54	38	34	38
1/4" - 0.060" - 1/4" RAL-TL85-228	26	29	28	30	33	33	35	36	37	38	38	37	38	41	44	47	51	54	39	34	39
3/8" - 0.030" - 1/4" RAL-TL85-222	29	30	28	32	34	35	36	38	38	38	36	38	42	46	49	52	55	57	40	36	40
1/2" - 0.060" - 1/4" RAL-TL85-230	29	30	29	32	35	35	37	38	38	38	37	41	44	48	50	53	56	56	41	36	41

*The data and information set forth are based on samples tested and are not guaranteed for all samples or applications. Riverbank Acoustical Laboratories.

Acoustical Guide - Sound Transmission Loss Data

Table 3.1b Glass Sound Transmission Loss Data*



One-third octave band (Hz)	100	125	160	200	250	315	400	500	630	800	1,000	1,250	1,600	2,000	2,500	3,150	4,000	5,000	STC	OITC	Rw
1/8" - 1/4" AS** - 1/8" (SEALED) RAL-TL85-212	26	21	23	23	26	21	19	24	27	30	33	36	40	44	46	39	34	45	28	26	30
1/8" - 3/8" AS** - 1/8" (SEALED) RAL-TL85-213	26	23	23	20	23	19	23	27	29	32	35	39	44	47	48	41	36	43	31	26	32
1/4" - 1/2" AS** - 1/4" (SEALED) RAL-TL85-294	29	22	26	18	25	25	31	32	34	36	39	40	39	35	36	46	52	58	35	28	35
3/16" - 1" AS** - 3/16" (SEALED) RAL-TL85-215	20	25	18	17	26	28	33	36	38	39	41	44	46	43	38	40	48	51	35	27	37
1/4" - 1" AS** - 1/4" (UNSEALED) RAL-TL85-293	22	19	27	23	31	30	35	35	36	39	41	42	41	36	37	46	51	56	37	30	37
3/16" - 4" AS** - 3/16" (UNSEALED) RAL-TL85-216	24	28	30	33	30	38	38	44	46	50	50	50	51	49	41	42	50	52	44	35	44

*The data and information set forth are based on samples tested and are not guaranteed for all samples or applications. Riverbank Acoustical Laboratories.
**Air space.

Acoustical Guide - Sound Transmission Loss Data

Table 3.1c Glass Sound Transmission Loss Data*

One-third octave band (Hz)	100	125	160	200	250	315	400	500	630	800	1,000	1,250	1,600	2,000	2,500	3,150	4,000	5,000	STC	OITC	Rw
1/4" Lam. - 1/4" AS** - 1/8" (SEALED) RAL-TL95-296	32	31	30	28	27	24	26	28	31	34	37	39	41	43	49	52	51	57	35	31	35
1/4" Lam. - 3/8" AS** - 3/16" (SEALED) RAL-TL85-189	27	27	26	24	22	28	32	35	38	38	39	40	42	43	41	45	52	57	37	31	37
1/4" Lam. - 1/2" AS** - 3/16" (SEALED) RAL-TL85-238	26	23	25	23	27	31	34	36	38	39	41	43	45	46	43	49	55	55	39	31	39
1/4" Lam. - 1/2" AS** - 1/4" (SEALED) RAL-TL85-235	28	20	29	24	26	30	34	36	39	42	43	44	44	41	40	47	52	56	39	31	39
3/8" Lam. - 1/2" AS** - 1/4" (SEALED) RAL-TL85-192	28	17	28	29	33	34	38	40	40	41	41	41	41	40	43	49	54	58	40	31	40
1/4" Lam. - 1" AS** - 3/16" (UNSEALED) RAL-TL85-239	22	27	27	28	31	35	38	41	42	43	44	45	47	47	45	50	58	61	42	33	42
1/4" Lam. - 2" AS** - 3/16" (UNSEALED) RAL-TL85-173	24	25	34	33	34	40	41	44	44	46	47	47	48	48	46	50	55	56	45	35	45
1/2" Lam. - 2" AS** - 3/16" (UNSEALED) RAL-TL85-194	27	36	33	33	35	39	41	45	45	46	46	46	49	51	52	56	60	62	46	38	46
1/2" Lam. - 2" AS** - 3/8" (UNSEALED) RAL-TL85-196	34	37	33	38	40	42	44	48	47	46	45	42	46	51	55	59	61	62	46	42	47
1/2" Lam. - 1" AS** - 3/16" (UNSEALED) RAL-TL95-298	24	30	32	32	36	39	42	45	47	50	51	50	53	57	57	60	62	63	47	36	47
1/4" Lam. - 4" AS** - 3/16" (UNSEALED) RAL-TL85-174	26	36	34	37	37	43	44	48	49	51	51	50	51	50	47	51	58	60	48	39	48
1/2" Lam. - 4" AS** - 3/16" (UNSEALED) RAL-TL85-195	30	37	33	38	37	42	45	49	50	51	50	48	50	53	53	57	61	64	49	41	49
1/2" Lam. - 4" AS** - 3/8" (UNSEALED) RAL-TL85-197	38	38	33	40	40	43	46	51	52	52	50	45	48	53	56	59	62	64	49	44	50
3/4" Lam. - 4" AS** - 1/8" (UNSEALED) RAL-TL85-240	29	33	31	36	38	43	44	46	47	49	50	52	52	55	59	59	58	60	49	40	49

The data and information set forth are based on samples tested and are not guaranteed for all samples or applications. Riverbank Acoustical Laboratories.

Acoustical Guide - Sound Transmission Loss Data

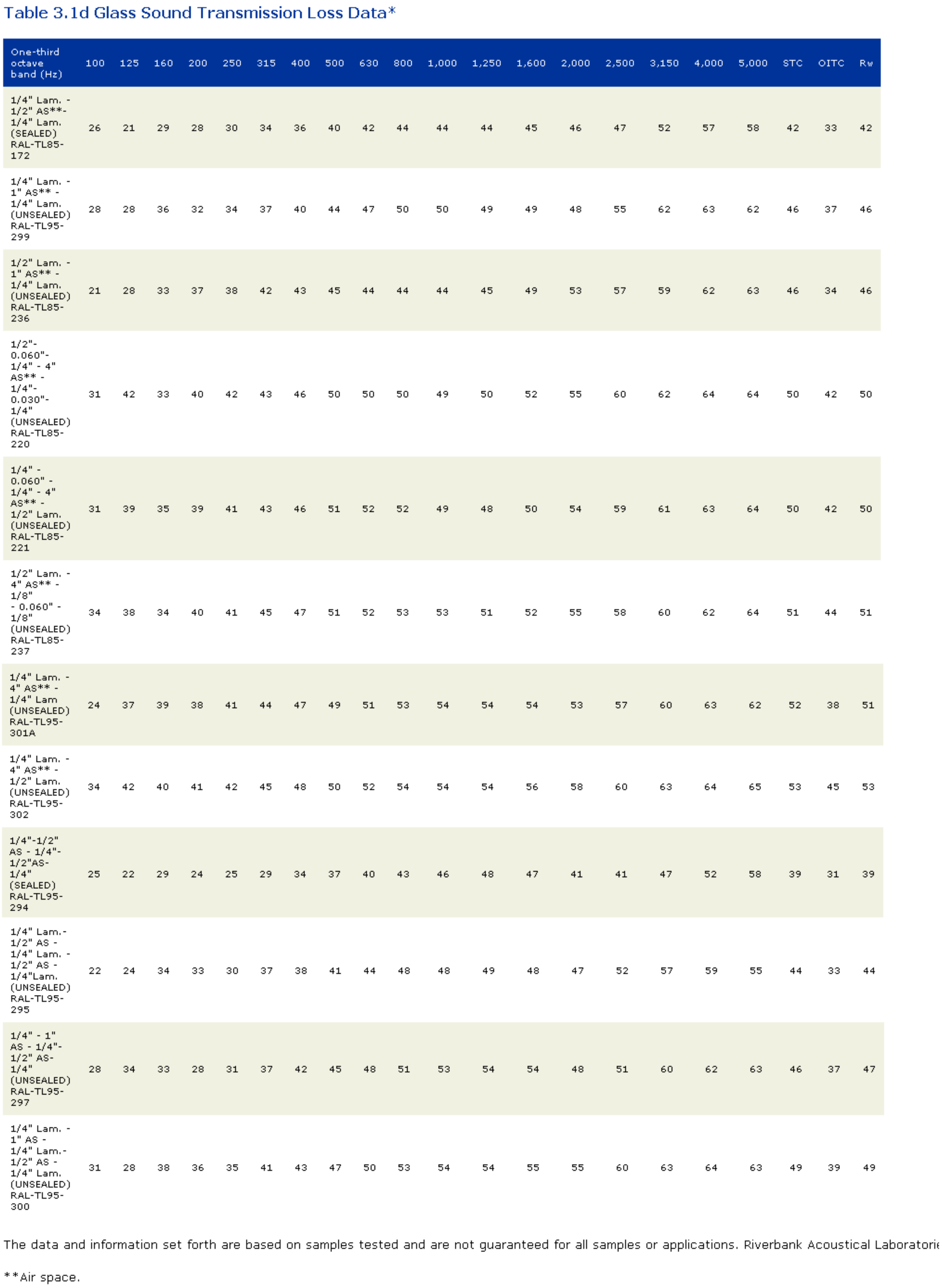


Table 3.1d Glass Sound Transmission Loss Data*

One-third octave band (Hz)	100	125	160	200	250	315	400	500	630	800	1,000	1,250	1,600	2,000	2,500	3,150	4,000	5,000	STC	OITC	Rw
1/4" Lam. - 1/2" AS**- 1/4" Lam. (SEALED) RAL-TL85-172	26	21	29	28	30	34	36	40	42	44	44	44	45	46	47	52	57	58	42	33	42
1/4" Lam. - 1" AS** - 1/4" Lam. (UNSEALED) RAL-TL95-299	28	28	36	32	34	37	40	44	47	50	50	49	49	48	55	62	63	62	46	37	46
1/2" Lam. - 1" AS** - 1/4" Lam. (UNSEALED) RAL-TL85-236	21	28	33	37	38	42	43	45	44	44	44	45	49	53	57	59	62	63	46	34	46
1/2"- 0.060"- 1/4" - 4" AS** - 1/4"- 0.030"- 1/4" (UNSEALED) RAL-TL85-220	31	42	33	40	42	43	46	50	50	50	49	50	52	55	60	62	64	64	50	42	50
1/4" - 0.060" - 1/4" - 4" AS** - 1/2" Lam. (UNSEALED) RAL-TL85-221	31	39	35	39	41	43	46	51	52	52	49	48	50	54	59	61	63	64	50	42	50
1/2" Lam. - 4" AS** - 1/8" - 0.060" - 1/8" (UNSEALED) RAL-TL85-237	34	38	34	40	41	45	47	51	52	53	53	51	52	55	58	60	62	64	51	44	51
1/4" Lam. - 4" AS** - 1/4" Lam (UNSEALED) RAL-TL95-301A	24	37	39	38	41	44	47	49	51	53	54	54	54	53	57	60	63	62	52	38	51
1/4" Lam. - 4" AS** - 1/2" Lam. (UNSEALED) RAL-TL95-302	34	42	40	41	42	45	48	50	52	54	54	54	56	58	60	63	64	65	53	45	53
1/4"-1/2" AS - 1/4"- 1/2"AS- 1/4" (SEALED) RAL-TL95-294	25	22	29	24	25	29	34	37	40	43	46	48	47	41	41	47	52	58	39	31	39
1/4" Lam.- 1/2" AS - 1/4" Lam. - 1/2" AS - 1/4"Lam. (UNSEALED) RAL-TL95-295	22	24	34	33	30	37	38	41	44	48	48	49	48	47	52	57	59	55	44	33	44
1/4" - 1" AS - 1/4"- 1/2" AS- 1/4" (UNSEALED) RAL-TL95-297	28	34	33	28	31	37	42	45	48	51	53	54	54	48	51	60	62	63	46	37	47
1/4" Lam. - 1" AS - 1/4" Lam.- 1/2" AS - 1/4" Lam. (UNSEALED) RAL-TL95-300	31	28	38	36	35	41	43	47	50	53	54	54	55	55	60	63	64	63	49	39	49

The data and information set forth are based on samples tested and are not guaranteed for all samples or applications. Riverbank Acoustical Laboratorie

**Air space.

Acoustical Guide - Sound Transmission Loss Data

Acoustical Storm Sash Insertion Loss Studies

Section 2 discusses the benefits of acoustical storm sash glazed with 1/4” laminated glass for increasing the sound isolation performance of existing windows in a building or for enhancing the sound isolation performance of new windows that might otherwise be deficient. SectionÊ2 also presents a technique for estimating the insertion loss obtained through the use of acoustical storm sash. This technique is based on data presented and discussed in this section. This data is sound transmission loss data measured at Riverbank Acoustical Laboratories for combinations of acoustical storm sash glazed with 1/4”Êlaminated glass and a variety of window types and styles.

NOTE: Data in this section are not intended to show the benefits of one material or frame type over another, but rather to show the potential benefit that laminated inte-rior acoustical storm sash can offer, particularly when used with windows having lightweight glass. It is lightweight glass that most often requires, and benefits significantly from, the use of acoustical storm sash.

The research supporting the methodologies presented here was conducted on laminated glass fabricated with Saflex PVB interlayer. Extrapolation to other systems, whether PVB-based or not, should be avoided.

Windows most likely to require retrofitting with interior storm sash are those that are already acoustically deficient. This section explores the use of 1/4” laminated storm sash when used with prime windows having the lightest weight glass conventionally used. This is 1/8” monolithic and 1/2” insulating glass (1/8” monolithic - 1/4” air space - 1/8” monolithic).

For this guide, Solutia has studied the acoustical performance of 1/4” laminated glass fabricated with Saflex interlayer when used with various combinations of prime window frame material and frame type, as well as the two above-mentioned prime glass configurations. Another variable studied was the air space thickness, i.e., the distance between the prime window glass and the 1/4” laminated storm sash. The specific features studied are as follows:

FRAME MATERIALS

- Wood
- Aluminum
- Vinyl

FRAME TYPES

- Double-hung
- Awning

Acoustical Guide - Sound Transmission Loss Data

GLASS CONFIGURATIONS

- 1/8” Monolithic
- 1/2” Insulating

PRIME GLASS TO STORM SASH GLASS SPACING

- 1-1/2”
- 3”

The features have been arranged into 24 prime and storm configurations. The 36 TL tests were conducted at Riverbank Acoustical Laboratories. Of the 36 tests, 24 were the prime and acoustical storm combinations. The remaining 12 were for the 12 prime windows resulting from the combination of three frame materials, two frame types and two glass configurations.

The two window frame types selected for study, double-hung and awning, differ from an acoustical standpoint. A double-hung window has two lights of glass offset into two separate planes, where an awning window has two lights of glass in the same plane. When an interior acoustical storm sash panel is spaced 1-1/2” away from the bottom prime sash of a double-hung window, a larger space is created at the top. As a result, the sound isolation performance of interior storm sash used when spaced a certain distance away from a double-hung window will provide slightly better sound isolation than when spaced the same distance away from an awning prime window. It has been assumed that window pivot arrangements are not acoustically significant so that casement or awning windows would have equal performance as long as the window areas and crack lengths are approximately the same.

NOTE: Prime window and acoustical storm sash sound isolation performance is extremely sensitive to sound leakage through frame openings. Tests have shown that a leaking window with a properly sealed acoustical storm sash may even provide less sound isolation than the same window alone, without acoustical storm sash, when properly sealed. Hence, the use of acoustical storm sash to improve window sound isolation should be accompanied by improvements in prime window sealing.

Also note that a single-hung window differs from a double-hung window in that the upper sash of a single-hung window is fixed. Both sashes in a double-hung are operable. From an acoustic standpoint, single-hung and double-hung windows are usually the same if the offset between the upper and lower sashes is the same.

Acoustical Guide - Sound Transmission Loss Data

Acoustical Storm Sash TL Data Analysis

Figures 3.1 through 3.4 contain descriptions of all 24 window and storm sash configurations tested. All windows tested were 4'-0" x 6'-0" in dimension. These fit snugly within the Riverbank Acoustical Laboratories test opening and were caulked at the perimeter to avoid leakage between the window frame and the test opening. In most cases, the interior storm sash was an unframed piece of 1/4" laminated glass with Saflex 0.030" interlayer, also 4'-0" by 6'-0" in dimension. Stops were applied to the test opening in order to seat the glass at the desired spacing from the prime window.

In some instances, prime window frames were thick enough to require some structural contact between the prime frame and the storm sash in order to achieve the desired prime glass to storm sash spacing. In certain circumstances, this actually involved recessing the interior storm sash into the window frame, as seen in Figures 3.1 through 3.4. In other cases, the interior storm sash was adhered to the surface of the frame by means of a gasket material and caulking. When the interior storm sash had contact with the prime window frame, a certain degradation of insertion loss (IL) was sometimes experienced as a result of structure-borne coupling and sound leakage through uncovered cracks.

Figures 3.1 through 3.4 present sections through prime window and storm sash configurations studied. These figures also present corresponding sound transmission loss (TL) data for prime windows with interior storm sash. Each figure is for a different frame and glazing type. Within each figure, window sections and graphs are arranged by frame material: wood, aluminum and vinyl. By carefully considering the window details and data presented in Figures 3.1 through 3.4, several conclusions explaining variations in interior storm sash sound isolation performance can be reached.

Double-hung, Single Glazed Prime Windows

Figures 3.1 detail the placement of interior storm sash 1-1/2" and 3" from wood, aluminum and vinyl windows, respectively. Corresponding sound transmission loss (TL) data for prime windows alone and with interior storm sash at both spacings tested also are presented in these figures.

NOTE: TLs for wood, aluminum and vinyl windows alone are approximately the same. This is as expected if window frames have about equal sound transmission.

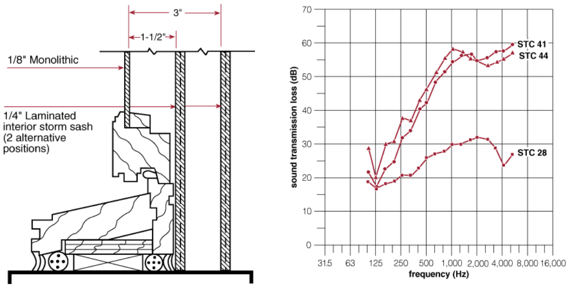
The 1/4" laminated storm sash spaced 3" away from the wood window produced a 3 to 5 dB higher TL than with the aluminum and vinyl prime windows. This is probably due to the larger air space occurring between the upper sash of the wood window and the interior storm sash as compared with the aluminum and vinyl windows.

The 1/4" laminated storm sash spaced 1-1/2" away from the aluminum and vinyl windows produced a 15 to 20 dB lower TL than for wood. As before, the larger air space between the upper sash and the storm sash in the wood window also must account for part of this difference. Structural coupling between the vinyl prime frame and the interior storm sash also is partly responsible for lower TLs measured for the vinyl window.

Acoustical Guide - Sound Transmission Loss Data

Increases in TL of Double-hung, Single Glazed Prime Windows Produced by Acoustical Storm Sash

Wood

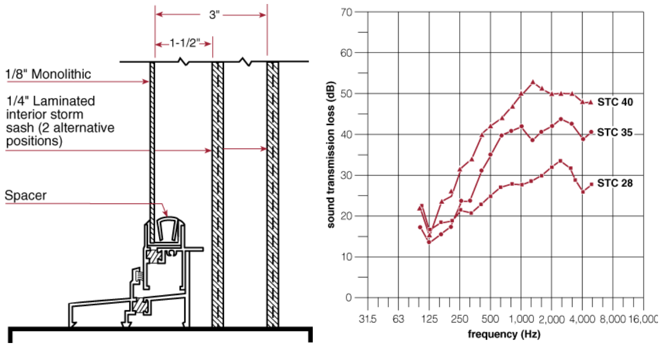


one-third octave band frequency (Hz)

	100	125	160	200	250	315	400	500	630	800	1,000	1,250	1,600	2,000	2,500	3,150	4,000	5,000	STC
Prime Window	19	17	18	19	21	21	23	26	27	28	30	30	31	32	31	29	24	27	28
1.5" AS	22	17	12	15	32	34	40	42	48	51	54	56	56	54	55	57	57	59	41
3.0" AS	29	20	30	31	38	37	43	46	51	55	58	57	55	54	53	54	55	57	44

Figure 3.1a

Aluminum

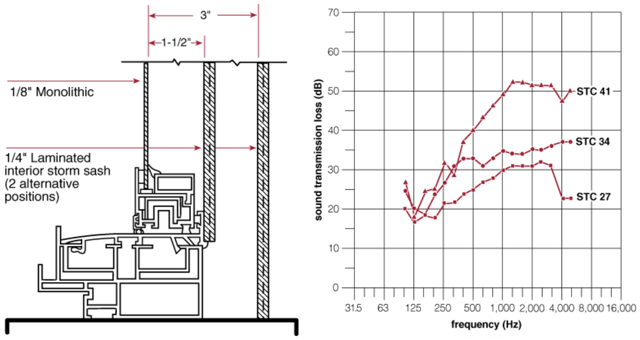


one-third octave band frequency (Hz)

	100	125	160	200	250	315	400	500	630	800	1,000	1,250	1,600	2,000	2,500	3,150	4,000	5,000	STC
Prime Window	23	17	19	19	22	21	23	25	27	28	28	29	30	32	34	32	26	28	28
1.5" AS	18	14	16	18	24	24	31	35	40	41	42	39	41	42	44	43	39	41	35
3.0" AS	23	16	24	26	33	33	40	42	44	47	50	53	51	50	50	50	48	48	40

Figure 3.1b

Vinyl



one-third octave band frequency (Hz)

	100	125	160	200	250	315	400	500	630	800	1,000	1,250	1,600	2,000	2,500	3,150	4,000	5,000	STC
Prime Window	20	17	19	18	22	22	24	25	27	28	30	31	31	31	32	31	23	23	27
1.5" AS	25	20	19	24	27	31	33	33	31	33	35	34	34	35	35	36	37	37	34
3.0" AS	27	18	25	25	32	29	37	40	43	46	49	52	52	51	51	51	47	50	41

Figure 3.1c

Acoustical Guide - Sound Transmission Loss Data

Double-hung Double Glazed Prime Windows

Figures 3.2 detail the placement of interior storm sash 1-1/2” and 3” from wood, aluminum and vinyl windows, respectively. Corresponding sound transmission loss (TL) data for prime windows alone and with interior storm sash at both spacings tested also are presented in these figures.

NOTE: TLs for wood, aluminum and vinyl windows alone are approximately the same. The TL for the vinyl prime window alone is higher than that for both wood and aluminum at frequencies around 2,000 Hz. Comparison with TLs of unframed insulating glass suggests that wood and aluminum windows may have been leaking during testing.

Above 2,000 Hz, the 1/4” laminated storm sash spaced 1-1/2” away from the wood window produced a TL that is higher than the 3” air spaced interior storm sash. Leakage of sound through the wood frame crack during the 3” air space test may explain this anomaly.

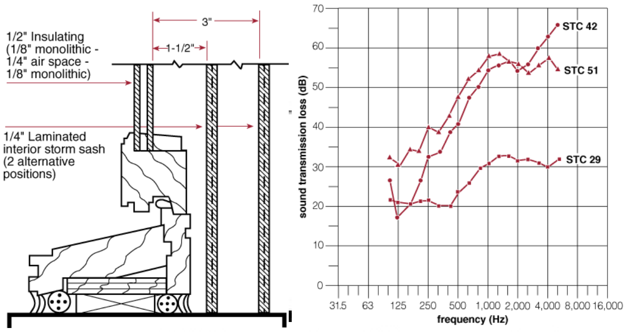
As discussed for double-hung single glazed windows, the larger air space occurring between the upper sash of the wood window and the interior storm sash, as compared with the aluminum and vinyl windows, probably accounts for the better interior storm sash performance with wood in general.

The difference between TLs for the 1-1/2” and 3” spacings in the aluminum data is larger than that for the wood window. A possible explanation is that the aluminum prime window, during the 1-1/2” interior storm sash spacing test, may have been leaking.

The interior storm sash TLs for the vinyl windows are about 10 dB lower than those for the wood window. A difference of only 3 to 5 dB is expected, based on a similar comparison for double-hung single glazed prime windows. This suggests that some amount of leakage may have occurred during vinyl window tests.

Increases in TL of Double-hung, Double Glazed Prime Windows Produced by Acoustical Storm Sash

Wood



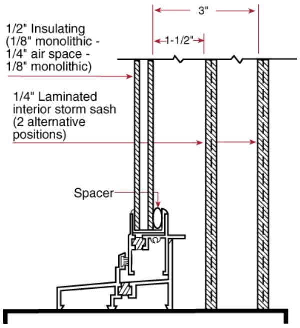
one-third octave band frequency (Hz)

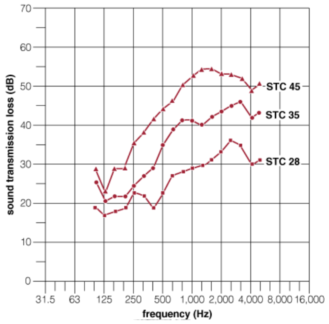
	100	125	160	200	250	315	400	500	630	800	1,000	1,250	1,600	2,000	2,500	3,150	4,000	5,000	STC
Prime Window	23	22	22	23	23	21	21	25	27	30	31	34	34	33	33	32	30	33	29
1.5" AS	28	18	22	28	34	35	40	42	48	51	55	56	57	55	56	60	63	66	42
3.0" AS	34	32	36	35	41	40	44	48	53	55	58	59	57	56	54	56	58	55	51

Figure 3.2a

Acoustical Guide - Sound Transmission Loss Data

Aluminum



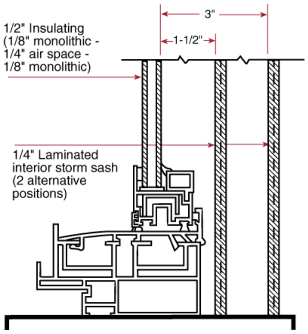


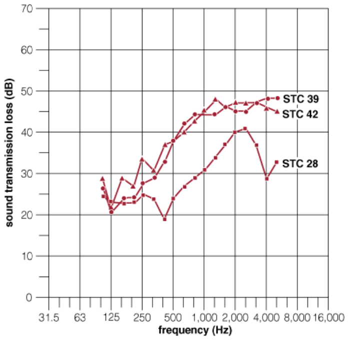
one-third octave band frequency (Hz)

	100	125	160	200	250	315	400	500	630	800	1,000	1,250	1,600	2,000	2,500	3,150	4,000	5,000	STC
Prime Window	26	21	22	22	23	22	19	23	27	28	29	30	31	33	36	35	30	31	28
1.5" AS	19	17	18	19	24	27	29	34	39	41	41	40	42	43	45	45	42	43	35
3.0" AS	29	22	29	29	35	38	41	44	46	50	52	54	54	53	53	52	49	50	45

Figure 3.2b

Vinyl





one-third octave band frequency (Hz)

	100	125	160	200	250	315	400	500	630	800	1,000	1,250	1,600	2,000	2,500	3,150	4,000	5,000	STC
Prime Window	25	22	23	23	25	24	19	24	27	29	31	34	37	40	41	37	29	33	28
1.5" AS	27	20	24	24	28	29	33	38	42	44	44	44	46	45	45	47	48	48	39
3.0" AS	29	21	29	27	34	31	37	38	40	43	45	48	46	47	47	47	46	45	42

Figure 3.2c

Awning, Single Glazed Prime Windows

Figures 3.3 detail the placement of interior storm sash 1-1/2" and 3" from wood, aluminum and vinyl windows, respectively. Corresponding sound transmission loss (TL) data for prime windows alone and with interior storm sash at both spacings tested also are presented in these figures.

NOTE: TLs for wood, aluminum and vinyl windows alone are approximately the same. This is as expected if window frames have about equal sound transmission.

TLs for the wood window with the storm sash in place are somewhat lower than those measured for the double-hung wood configurations. This is probably the result of structural coupling between the frame and the storm sash.

Acoustical Guide - Sound Transmission Loss Data

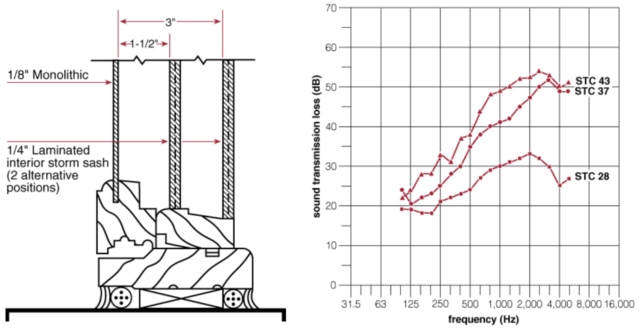
At frequencies above 2,000 Hz, the TLs for the aluminum window with the interior storm sash spaced at 1-1/2" from the prime glass are higher than those spaced 3" away. This is especially unusual since the 1-1/2" air spaced storm sash glass fell within the aluminum window frame, leaving frame cracks uncovered.

The lower TLs above 2,000 Hz for the storm sash spaced 3" away are probably the result of window leakage during this test. In spite of this leakage, the STC rating for the storm sash spaced 3" away is higher than the STC rating for the storm sash spaced 1-1/2" away. This is because the STC ratings, in both cases, are more significantly influenced by low frequency TLs where the 3" air spaced performance is slightly better.

The TL for the 1/4" laminated storm sash spaced 1-1/2" away from the vinyl window glass is unexpectedly low. This probably is the result of structural contact between the storm sash and the vinyl window, and uncovered crack leakage.

Increases in TL of Awning, Single Glazed Prime Windows Produced by Acoustical Storm Sash

Wood

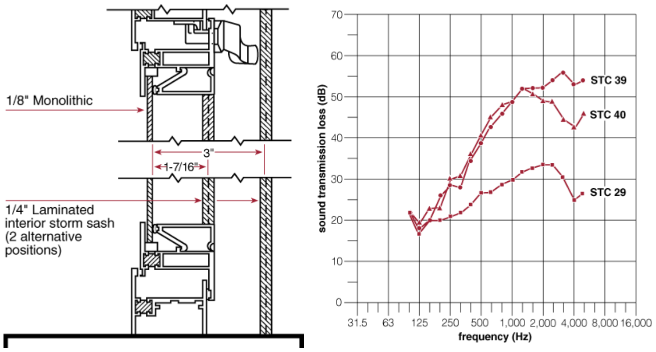


one-third octave band frequency (Hz)

	100	125	160	200	250	315	400	500	630	800	1,000	1,250	1,600	2,000	2,500	3,150	4,000	5,000	STC
Prime Window	19	19	18	18	21	22	23	24	27	29	30	31	32	33	32	30	25	27	28
1.5" AS	24	20	22	23	25	28	30	35	38	40	41	42	45	47	50	52	49	49	37
3.0" AS	22	24	28	28	33	31	37	38	344	48	49	50	52	52	54	53	50	51	43

Figure 3.3a

Aluminum



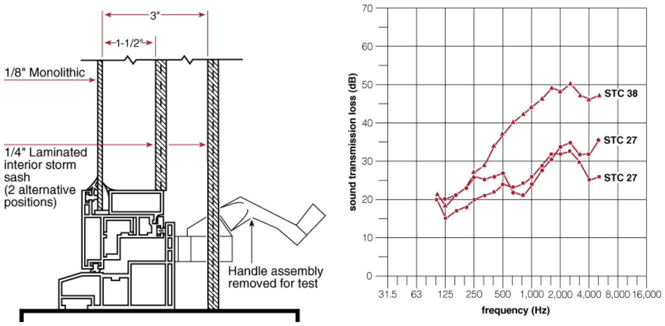
one-third octave band frequency (Hz)

	100	125	160	200	250	315	400	500	630	800	1,000	1,250	1,600	2,000	2,500	3,150	4,000	5,000	STC
Prime Window	22	17	20	20	21	22	24	27	27	29	30	32	33	34	34	31	25	27	29
1.5" AS	22	18	20	26	29	28	35	39	43	46	49	52	52	52	54	56	53	54	39
3.0" AS	22	19	23	23	30	31	36	41	45	48	49	52	51	49	49	45	43	46	40

Figure 3.3b

Acoustical Guide - Sound Transmission Loss Data

Vinyl



one-third octave band frequency (Hz)

	100	125	160	200	250	315	400	500	630	800	1,000	1,250	1,600	2,000	2,500	3,150	4,000	5,000	STC
Prime Window	20	15	17	18	20	21	22	24	23	24	26	29	32	32	33	30	25	26	27
1.5" AS	20	20	21	23	26	25	26	27	22	21	24	28	31	34	35	32	32	36	27
3.0" AS	21	18	21	23	27	29	34	37	40	42	44	46	49	48	50	47	46	47	38

Figure 3.3c

Awning, Double Glazed Prime Windows

Figures 3.4 detail the placement of interior storm sash 1-1/2” from wood, aluminum and vinyl windows, respectively. Corresponding sound transmission loss (TL) data for prime windows alone and with interior storm sash at both spacings tested also are presented in these figures.

NOTE: TLs for wood, aluminum and vinyl windows alone are approximately the same. The TL for the vinyl prime window without interior storm sash is lower than that for both wood and aluminum at frequencies above 1,000 Hz. Data suggest that the vinyl prime window, when tested without storm sash in place, may have been leaking during testing.

The TLs for the wood window with storm sash in place are about the same as those measured for the double-hung configurations. This is in spite of structural coupling that occurs in this (awning) configuration and which is absent in the double-hung configuration.

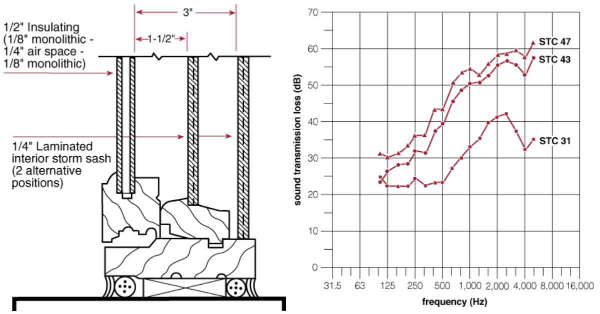
The TLs for the aluminum window with storm sash spaced 1-1/2” from the prime glass are as expected in spite of structural coupling and uncovered frame cracks.

Similarly, the TL for the vinyl window with the interior storm sash spaced 1-1/2” from the prime glass is as expected in spite of structural coupling.

Acoustical Guide - Sound Transmission Loss Data

Increases in TL of Awning, Double Glazed Prime Windows Produced by Acoustical Storm Sash

Wood

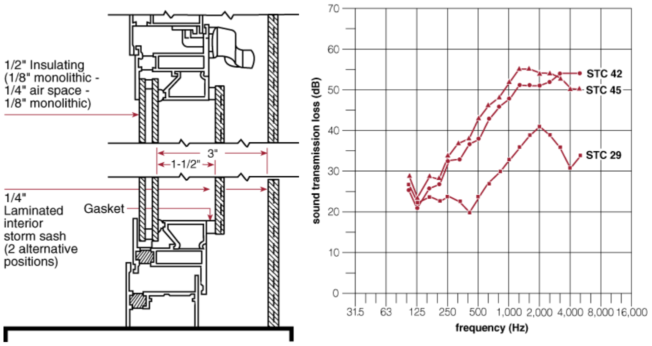


one-third octave band frequency (Hz)

	100	125	160	200	250	315	400	500	630	800	1,000	1,250	1,600	2,000	2,500	3,150	4,000	5,000	STC
Prime Window	24	22	22	22	24	22	23	23	27	30	33	35	39	41	42	37	32	35	31
1.5" AS	23	26	28	28	32	31	37	39	45	48	50	50	52	55	56	55	52	57	43
3.0" AS	31	30	31	33	36	36	43	43	50	53	54	52	55	58	58	59	57	61	47

Figure 3.4a

Aluminum

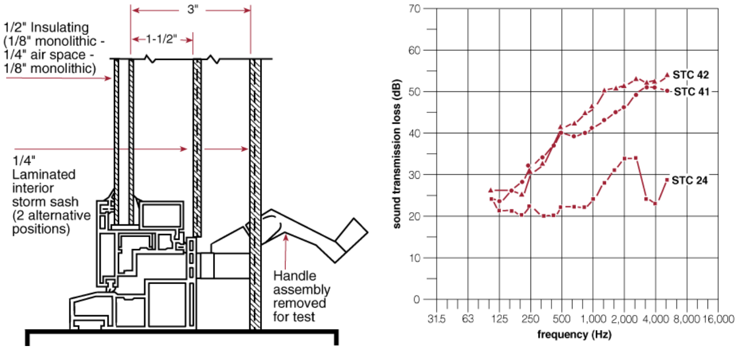


one-third octave band frequency (Hz)

	100	125	160	200	250	315	400	500	630	800	1,000	1,250	1,600	2,000	2,500	3,150	4,000	5,000	STC
Prime Window	27	22	24	23	24	23	20	24	27	30	33	36	39	41	39	36	31	34	29
1.5" AS	26	21	26	27	33	33	37	38	43	46	48	51	51	51	52	54	54	54	42
3.0" AS	29	23	29	28	34	37	37	43	46	48	52	55	55	54	54	53	50	50	45

Figure 3.4b

Vinyl



one-third octave band frequency (Hz)

	100	125	160	200	250	315	400	500	630	800	1,000	1,250	1,600	2,000	2,500	3,150	4,000	5,000	STC
Prime Window	24	21	21	20	22	20	20	22	22	22	24	28	31	34	34	24	23	29	24
1.5" AS	24	23	26	28	32	34	37	40	39	40	41	43	45	46	49	51	51	50	41
3.0" AS	26	21	26	25	31	33	37	41	42	45	46	50	50	51	53	52	52	54	42

Figure 3.4c

Acoustical Guide - Sound Transmission Loss Data

Acoustical Storm Sash Design

Although the use of 1/4” laminated acoustical storm sash can be an ideal solution to sound isolation problems, its implementation can be challenging. Normally, interior acoustical storm sash for double-hung and sliding windows is configured to match as double-hung and sliding. With awning or casement windows, the best interior storm sash configuration needs to be determined on a case-by-case basis.

In Figures 3.5a through 3.5f, there are examples of matching operable prime and interior storm sash for several prime window frame configurations. Obviously, there is no limit to the number of combinations that one might develop.

Many window manufacturers now have product lines catering to acoustical applications of interior storm sash. These manufacturers can assist the building owner in selecting the most workable interior storm sash configuration. Local custom window and storm sash fabricators, as well as national window manufacturers, are often capable of fabricating interior storm sash that suit sound isolation purposes.

For typical transportation noise sources, the interior acoustical storm sash configurations tested in this program can provide an additional 5-20 dB of reduction, depending on prime glass to storm sash spacing. As noted in Section 2, a 10 dB reduction in sound is perceived as roughly a halving of loudness. Often a 10 dB reduction is used as a minimum design goal in storm sash retrofitting in order that occupants will experience, in their view, a significant reduction.

As in the case with this guide, the insertion loss (IL) estimation technique described in this section enables a person without special expertise in acoustics to make a preliminary estimate of the IL that can be expected in common storm sash applications. An acoustical consultant should be contacted to provide guidance in the final design of an interior storm sash system. A direc-tory with the names of local acoustical consultants, who can provide assistance in such instances, is available from the National Council of Acoustical Consultants (NCAC), (201) 564-5859, 66 Morris Avenue, Suite 1A, Springfield, NJ 07081-1409.

Typical Prime and Acoustical Storm Sash Configurations

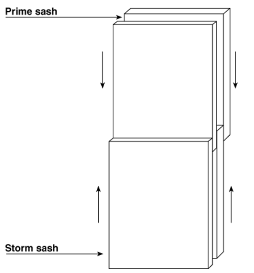


Figure 3.5a Double-hung prime, double-hung acoustical storm sash.

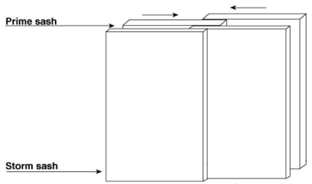


Figure 3.5b Double-slider prime, double-slider acoustical storm sash.

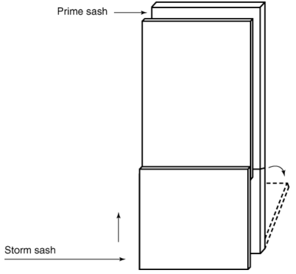


Figure 3.5c Single-awning prime, single-hung acoustical storm sash.

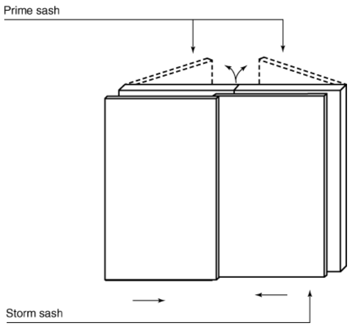


Figure 3.5d Double-casement prime, double-slider acoustical storm sash.

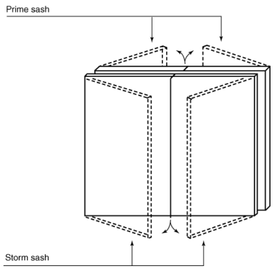


Figure 3.5e Double-casement prime, double-casement acoustical storm sash.

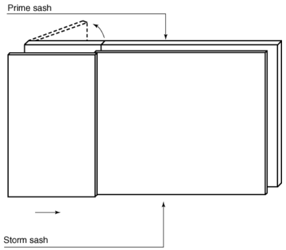


Figure 3.5f Casement/fixed prime, single-slider/fixed acoustical storm sash.

Acoustical Guide - Sound Transmission Loss Data

Kawneer Window Systems

Kawneer Model 8225 T°L projected windows are available glazed with a variety of glass configurations. These include 1” insulating glass (1/4” glass ~ 1/2” air space ~ 1/4” glass) with an STC rating of 34. When 1” double laminated insulating glass (1/4” laminated glass ~ 1/2” air space ~ 1/4” laminated glass) is used instead, the STC rating increases to 38. The four-point increase in STC rating is the result of damping provided by the Saflex PVB interlayer used in the laminated glass.

Figure 3.6a presents one-third octave band sound transmission loss data for the Kawneer 8225 T°L projected window glazed with these two glass configurations. The sound transmission loss data show that damping has its greatest benefit in the mid- and high- frequency ranges.

Similarly, the Kawneer Model 1600 curtain wall system exhibits similar improvements in sound transmission loss resulting from the use of laminated glass. Figure 3.6b compares one-third octave sound transmission loss data for the 1600 curtain wall system glazed with 1” standard insulating glass and with 1” double laminated insulating glass

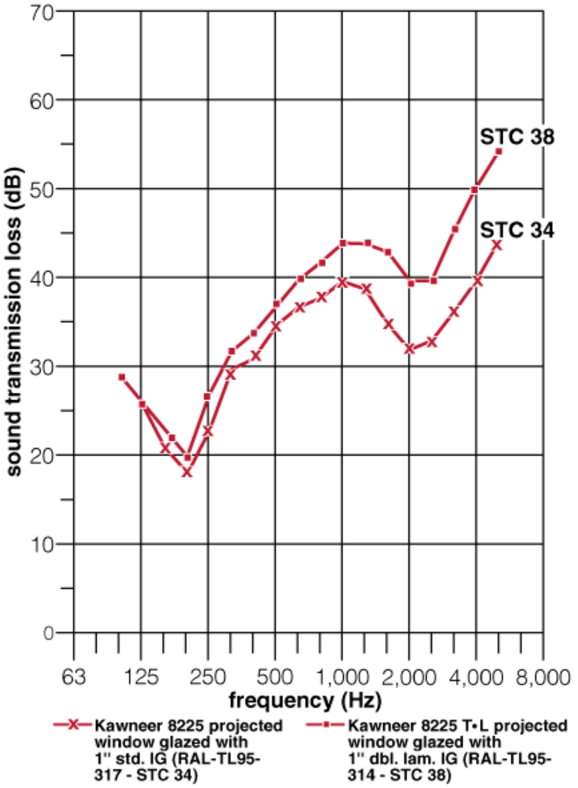


Figure 3.6a Kawneer 8225 T°L projected window glazed with 1” standard insulating glass and 1” double laminated insulating glass.

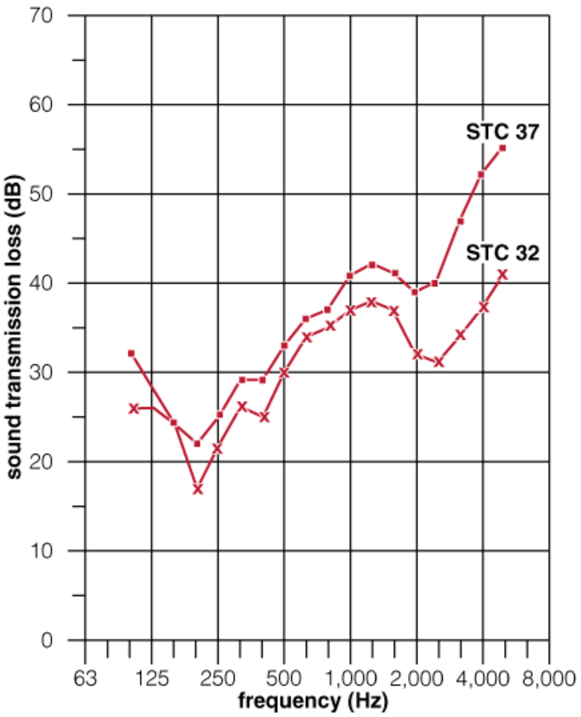


Figure 3.6b Kawneer 1600 curtain wall system glazed with 1” standard insulating glass and 1” double laminated insulating glass.

Kawneer storefront framing systems also exhibit similar improvements in sound transmission loss resulting from the use of laminated glass. A test of Kawneer 451 T storefront framing glazed with 1” standard insulating glass indicates an STC rating of 32. When 1” double laminated insulating glass is used instead, the STC rating improves to 36.

Solutia would like to express their appreciation to Kawneer Company, Inc. for sponsoring sound transmission loss tests and allowing the information to be published in this guide. Kawneer Company, Inc., 555 Guthridge Court, Norcross, GA 30092.

Acoustical Guide - Transmission Loss Methodologies

Transmission Loss Methodologies

- General
- Step One -- Noise Exposure
- Step Two -- Composite Noise Reduction
- Step Three -- Window Noise Reduction
- Step Four -- Window Sound Transmission Class

General

The purpose of this section is to provide a technical explanation of the methodologies presented in Section 1. This explanation is geared to those familiar with environmental and architectural acoustics who wish to learn the foundations of this methodology. As previously mentioned, one purpose of this guide is to present a tool that can be used by lay persons interested in estimating the minimum required sound transmission class (STC) needed in specific circumstances where a building is exposed to noise from aircraft, traffic or rail vehicle passbys. Obviously, there are some simplifications that need to be and have been introduced. These have been devised to result, wherever possible, in conservative estimates of minimum required window STC ratings to provide some margin of safety.

The methodology for estimating the minimum required window STC is a four-step process that is outlined in the flow chart of Figure 4.1. The following is a step-by-step description of this methodology.

Figure 4.1 Minimum required window STC methodology flow chart (Same as Figure 1.1).

Acoustical Guide - Transmission Loss Methodologies

Step One - Noise Exposure

Aircraft Noise

Step One involves a few simple parameters, describing a noise exposure situation, that are used to arrive at a noise exposure level. In the case of aircraft, this simply involves locating a project site on an airport noise contour map and identifying the day-night average sound level.

It must be remembered that noise contour maps are best used as a planning tool to compare noise-related benefits of various runway utilization plans. Actual day-night average sound levels determined from airport noise contour maps sometimes are less accurate than they may appear. This is particularly true for aircraft take-offs where scattering of aircraft, both vertically and horizontally along various destination flight tracks, can reduce aircraft sound levels in some places and slightly increase them in others. This also applies to carefully controlled airports, although new radar tracking techniques are helping to maintain aircraft closer to well-defined flight tracks.

It should also be noted that airport noise contours are lines of equal annual day-night average sound level, so that the day-night average sound level for any one day could be higher or lower than the annual average, depending on runway usage.

In addition, the 10 dB penalty used in the day-night average sound level is more appropriate for residential, health care and hospital usage, but it may be inappropriate for commercial application.

Hence, although the 14 CFR Part 150 guidelines and the methodology presented are helpful in assessing aircraft noise impact, further consideration of day-to-day aircraft noise exposure and land use may be needed.

Traffic Noise

The traffic noise estimation technique is based on the Federal Highway Administration Highway Noise Prediction Methodology (FHWA Publication RD-77-109, December 1978) [5]. This methodology uses reference sound levels for three classes of vehicles: automobiles, medium trucks and heavy trucks. These are defined as follows:

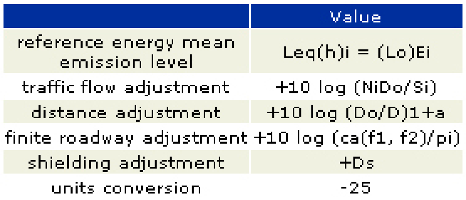
Automobiles (A) are all vehicles with two axles and four wheels designed primarily for transportation of nine or fewer passengers (automobiles), or transportation of cargo (light trucks). Generally, an automobile gross weight is less than 10,000 lbs.

Medium Trucks (MT) are all vehicles having two axles and six wheels designed for transportation of cargo. Generally, the gross vehicle weight is greater than 10,000 lbs. but less than 25,000 lbs. Because of their noise characteristics, buses and motorcycles are often included in this category.

Heavy Trucks (HT) are all vehicles having three or more axles and designed for the transportation of cargo. Generally, the gross weight is greater than 25,000 lbs.

Acoustical Guide - Transmission Loss Methodologies

Equation 4.1 Equation 4.1 presents the functional relationship between traffic hourly equivalent sound level produced by the i th class of vehicles and various parameters including the reference energy mean emission level, traffic flow, distance, finite road length and shielding adjustments.



	Value
reference energy mean emission level	Leq(h)i = (Lo)Ei
traffic flow adjustment	+10 log (NiDo/Si)
distance adjustment	+10 log (Do/D)1+a
finite roadway adjustment	+10 log (ca(f1, f2)/pi)
shielding adjustment	+Ds
units conversion	-25

In Equation 4.1:

Leq(h)i is the hourly equivalent sound level of the i th class of vehicles.

(Lo)Ei is the reference energy mean emission level of the i th class of vehicles. This can be obtained from reference [5] or reference [18].

Ni is the number of vehicles in the i th class passing a specified point during some specified time period (1 hour).

D is the perpendicular distance, in meters, from the center line of the traffic lane to the observer.

Do is the reference distance at which the emission levels are measured. In the FHWA model, Do is 15 meters.

Si is the average speed of the i th class of vehicles and is measured in kilometers per hour (km/h).

a is a site parameter whose values depend upon site conditions.

ca is an adjustment for finite length roadways.

Ds is the attenuation, in dB, provided by some type of shielding such as barriers, rows of houses, densely wooded areas, etc.

Equation 4.2

The total traffic hourly equivalent sound level at a roadside location is given by Equation 4.2:

Leq(h)=10 log [10Leq(h)A/10+10Leq(h)MT/10+10Leq(h)HT/10]

Traffic Flow Adjustments

The traffic noise prediction method presented in Figure 1.5 is based on Equations 4.1 and 4.2. It begins with a baseline traffic hourly equivalent sound level to which various adjustments accounting for traffic flow and other conditions are determined and added to the baseline.

For simplicity, it has been assumed that the user of the guide is concerned with a level-of-service "C" traffic condition on nearby roads. From the standpoint of acoustics, this usually corresponds to the greatest traffic noise exposure. In reference [19], level-of-service "C" traffic is described as stable traffic flow at a level at which a small increase in flow will cause substantial deterioration in service. In addition, freedom to maneuver within the traffic stream is significantly restricted. Figure 4.2 contains a relationship between level-of-service "C" traffic, average vehicle speed and automobiles per hour. Three data points taken from reference [13] are shown plus an extrapolated data point for an average traffic speed of 30 mph. It should be noted that, depending on the road design speed, only one unique level-of-service "C" speed-volume relationship would occur. The higher the design speed, the higher the traffic volume and traffic speed for a level-of-service "C" flow condition. Obviously, a user of this guide will not be able to evaluate the road design speed and other traffic flow parameters. It has been assumed in this guide that the level-of-service "C" speed to be used in the traffic noise methodology is the posted speed limit of the road under consideration.

Acoustical Guide - Transmission Loss Methodologies

Using the data points of Figure 4.2, the first three terms of the right-hand side of Equation 4.1 have been calculated and are reported in Figure 4.3. This computation has been performed for 15% truck traffic mix (i.e., typically large truck traffic volume) and 0% truck traffic. The 15% truck traffic mix was divided into 7.5% medium trucks and 7.5% heavy trucks. In order to develop the methodology, a baseline traffic hourly equivalent sound level (76 dBA) was taken for the condition of level-of-service "C" traffic traveling at 55 mph and with a truck traffic mix of 15%. Traffic sound levels for other speeds and other truck mixes are determined by means of insert tables in Figure 1.6. These tables provide adjustments accounting for variations in traffic flow conditions and are based on data in Figures 4.2 and 4.3.

The adjustment needed to determine levels at distances from the road greater than 50 feet has presumed a sound reflective site (}=0) for the first 125 feet (-3 dB/distance doubling) and a sound absorptive site (}=0.5) beyond 125 feet (-4.5 dB/distance doubling).

The shielding adjustment for foliage is based on an attenuation rate of -3 dB/100 feet (to maximum atten-uation of 10 dB) of dense foliage. This is slightly less than the -5 dB/100 feet suggested by FHWA [5].

The shielding of traffic noise by rows of buildings suggested by FHWA [5] has been used, but with a lower range of coverage (20-40% of road view shielded) added.

Shielding by barriers has been neglected since most buildings would view over a barrier from upper stories.

The finite roadway adjustment, accounting for less than 180û view of a road, has also been ignored since this effect would probably be adequately accounted for through the building shielding adjustment.

Although the 1996 FHWA Traffic Noise Model will provide some added accuracy, by considering additional vehicle classes and by incorporating new baseline vehicle noise emissions data, the methodology developed for this guide will remain acceptably accurate for its purposes.

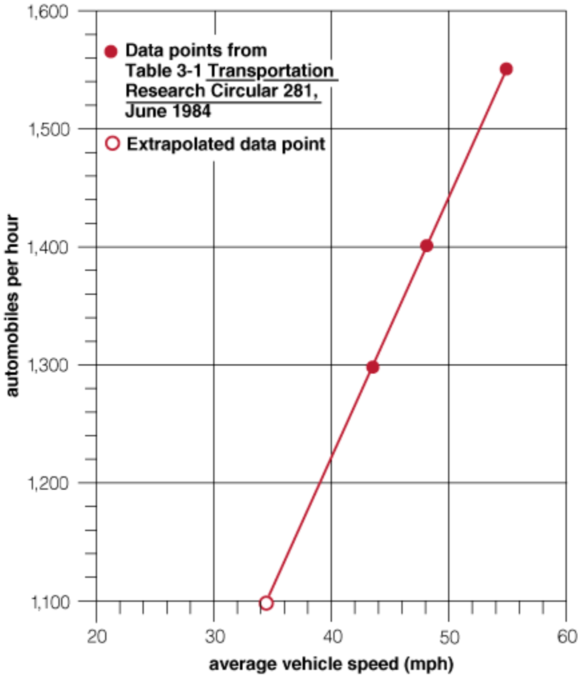


Figure 4.2 Automobiles per hour as a function of traffic speed for level-of-service "C" traffic.

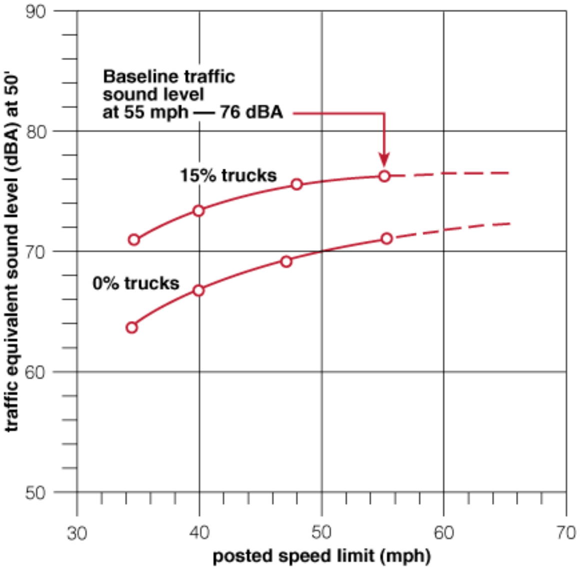


Figure 4.3 Level-of-service "C" traffic sound levels for 15% and 0% truck traffic mix.

Acoustical Guide - Transmission Loss Methodologies

Rail Noise

The basic rail noise methodology has been developed by modeling the directivity of sound radiated from a train as a string of incoherent dipole sources with axes parallel to the ground and normal to the train direction.

Figure 4.4 Train noise level model.

For simplicity, train noise has been modeled by calculating the sound pressure level at a location centered with respect to train length and a distance x from the track. Figure 4.4 depicts the geometry used. The computation procedure involves dividing the train into differential elements. The dipole intensity and sound power of the i th element can be found in Reynolds [20] and leads to an expression for pi2, the squared sound pressure at the measurement location produced by the i th element of the dipole train:

Equation 4.3

pi2(x,y)=W/l * Dy * 3rc/4pi * x2/(x2+y2)2

In Equation 4.3:

W is the total train sound power in watts.
rc is the specific acoustic impedance of air (415 rayls).
l is the train length.

Equation 4.4

Integrating over the train length [31] and expressing sound pressure in decibels reveals:

LA(x) = Lwl+10 log 3Worc/4pi*po2 + 10 log 1/x + 10 log [l/2x / 1+(l/2x)2 + tan-1(l/2x)]

In Equation 4.4:

Wo is the reference sound power (10-12watts).
po is the reference sound pressure (2x10-5N/m2).
Lwl is the train sound power level normalized by train length (i.e., 10 log (Wo/l).

Equation 4.5

In C. Harris [21] it is indicated that for passenger trains on continuous welded rail, 90% of the test data measured at 100 feet (30 meters) for several systems lies within ±6 dB of the following:

LA = 75+30 log v/vo + K

In Equation 4.5:

LA is the maximum A-weighted train passby noise level in dBA for a train length much greater than the reference distance (infinite train length model).
v is train speed in km/hr.
vo is the reference train speed which equals 60 km/hr (37 mph).
K is the constant accounting for noise increases associated with jointed rail, rough wheels, etc.

Acoustical Guide - Transmission Loss Methodologies

Equation 4.6

It is possible to combine Equations 4.4 and 4.5 toproduce an equation for A-weighted train passby sound level [LA(x)] that accounts for finite train lengths. This is as follows:

$LA(x) = 75$	baseline sound level in dBA
$+30 \log v/vo$	speed adjustment
$+K$	train wheel/rail condition adjustment
$+10 \log 30/x$	distance adjustment (x is distance from track in meters)
-2	constant
$+10 \log [l/2x \ / \ 1+(l/2x)2 + \tan-1(l/2x)]$	train length adjustment where l is train length in meters

Figure 1.10a presents a simple methodology based on Equation 4.6. It uses the baseline sound level of this equation and presents adjustments for speed, distance from the track and track conditions. The track condition adjustments have been taken from Harris [21].

For diesel electric locomotives, the average, i.e., 92 dBA, of the reported range has been used in the methodology.

The diesel engine noise estimation technique of Figure 1.10b also has been taken from Harris. This reference indicates that 90% of the diesel trains measured at 30 meters lie between 87 and 96 dBA with electric and turbine-driven locomotives being 6 to 7 dBA quieter.

Acoustical Guide - Transmission Loss Methodologies

Step Two - Composite Noise Reduction

This step uses acceptability criteria to determine the minimum composite noise reduction (NRc) where:

Equation 4.7

NRc = LA - Lcriteria

LA is the A-weighted exterior sound pressure level produced by either aircraft, traffic or trains.

Lcriteria is the maximum acceptable A-weighted sound level within the building space which depends on both noise source type and use of the building space.

Figure 4.5 contains the spectra for aircraft, traffic and rail transportation noise used in this study. These are typical and have A-weighted sound pressure levels that are generally high enough to require special consideration.

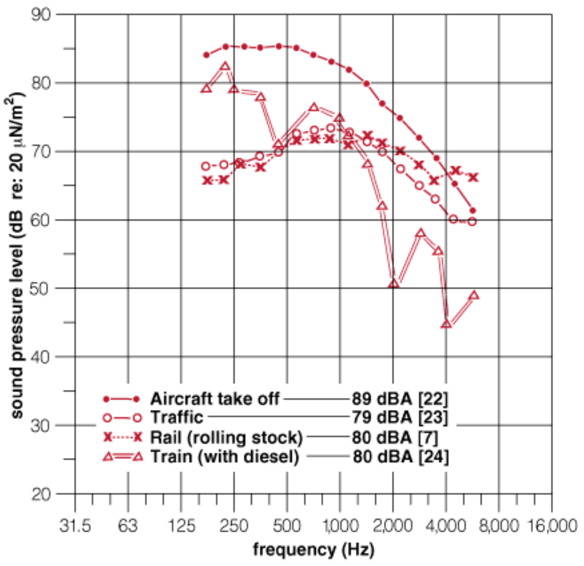


Figure 4.5 Transportation noise source spectra.

Aircraft Noise

In the case of aircraft noise, the direct use of Lcriteria is circumvented by the FAA which provides the needed NCc as a function of aircraft noise (DNL). These criteria are given in 14 CFR Part 150 [4] and are the basis for Figures 1.3 and 2.8.

In the case of traffic noise, the criteria selected are in terms of acceptable noise criteria (NC) values of noise exposure within building spaces. Since exterior traffic noise exposure is determined in terms of A-weighted sound pressure levels, a conversion between NC values and traffic noise spectra was needed.

This was done by considering a hypothetical situation where an exterior wall of a room in a building is 100% glass, and the room effect at all frequencies is equal to zero. By assuming an exterior traffic sound level given by the spectrum in Figure 4.5, traffic sound levels inside the hypothetical room were calculated for all of the glazing configurations given in Figure 1.14a.

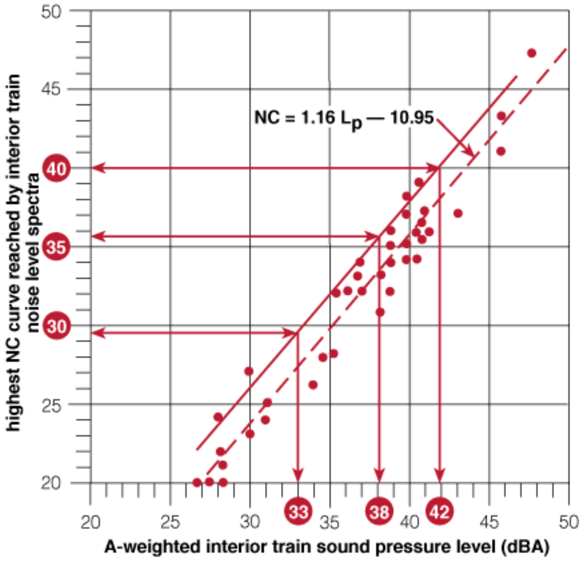


Figure 4.6 Relationship between A-weighted traffic sound level and NC level.

Acoustical Guide - Transmission Loss Methodologies

For each glazing configuration in Figure 1.14a, the corresponding A-weighted traffic sound level and NC levels have been plotted in Figure 4.6. Looking at this from a statistical standpoint, linear regression [25, 26] has been used to develop a straight-line relationship between NC and A-weighted sound level (Lp). For the sake of conservatism, a linear relationship between NC and Lp has been used which is approximately 3 dB higher than the linear regression curve. Using this latter curve, it can be seen that NC 30, 35 and 40 traffic sound levels correspond to A-weighted sound levels of approximately 33, 38 and 42 dBA, respectively. Hence, these A-weighted sound levels are the interior criteria levels (Lcriteria) in Equation 4.7. For each NC, Equation 4.7 can be rewritten as:

For NC 30 NRc = LA traffic -33 dBA
For NC 35 NRc = LA traffic -38 dBA
For NC 40 NRc = LA traffic -42 dBA

In the above equations:

NRc is the building composite noise reduction.

LA traffic is the traffic hourly equivalent sound level.

30, 38, 42 dBA are the A-weighted traffic sound level values that correspond to the NC 30, 35 and 40 criteria values.

NOTE: It should be noted that had the exterior traffic sound level of Figure 4.5 been higher or lower, a slightly different relationship between noise criteria (NC) and interior traffic noise level in Figure 4.6 would have resulted. This is because the NC curves are not uniformly spaced with respect to level in dB.

Rail Noise

A similar analysis of interior A-weighted rail sound levels has been conducted resulting in the data given in Figure 4.6. As noted in Section 1, the criteria used for rail noise levels in buildings are that train passby noise levels in building spaces should not exceed the background NC by more than 10 NC points. These criteria can be expressed as follows:

NC 30 space: NRc = Lp train -41 dBA
NC 35 space: NRc = Lp train -46 dBA
NC 40 space: NRc = Lp train -51 dBA

In the above equations:

NRc is the building composite noise reduction in dB.

Lp train is the A-weighted maximum train passby sound level outside the building.

41, 46, 51 dBA are the A-weighted train sound level values that correspond to NC 40, 45 and 50 as seen from Figure 4.7. These NC levels are 10 NC points above the continuous background criteria used in Figure 1.11 which are NC 30, 35 and 40.

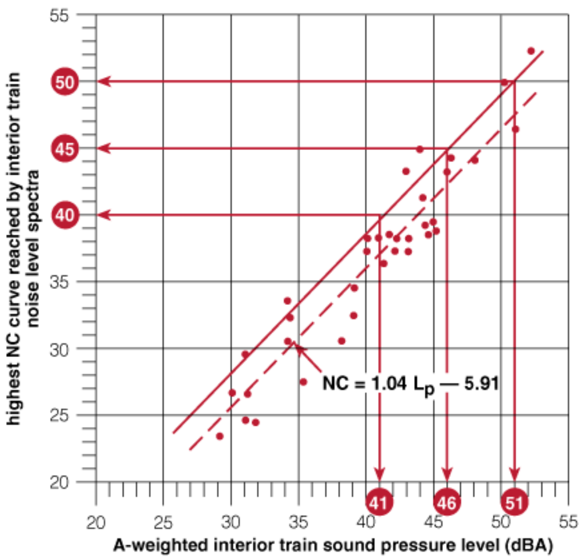


Figure 4.7 Relationship between A-weighted train sound level and NC level (rolling stock only).

Acoustical Guide - Transmission Loss Methodologies

Step Three - Window Noise Reduction

The purpose of Step Three is to determine the mini-mum window noise reduction (NR) that would satisfy the composite noise reduction (NRc) requirement. The NRc is a combination of the wall NR and the window NR. A graphic representation of these three parameters has been devised using arguments presented in Egan [27] and Reynolds [20]. Both authors define the composite sound transmission coefficient tc as:

$$tc = A1t1 + A2t2 / A1 + A2$$

Where A1 and A2 are window and wall areas, respectively, and t1 and t2 are window and wall sound transmission coefficients, respectively:

If we define the window area percentage "a" as follows:

$$a = A1/ A1 + A2$$

tc can be rewritten as follows:

$$tc = at1 + (1- a)t2$$

Dividing this last expression by tc and defining a dummy variable "b" as follows:

$$b = tc / t2$$

It can be shown that

$$t1 / t2 = a+b -1 / a$$

Taking 10 log of the two immediately preceding expressions, the following results:

$$TL2 -TL1 = 10 \log a+b-1 / a$$

Where

$$10 \log b = TL2 -TLc$$

Figures 1.4, 1.8 and 1.12 show this result plotted for "a" equal to 0.05, 0.10, 0.20, 0.30, 0.40, 0.50, 0.70 and 1.00. In these figures, noise reduction (NR) and sound transmission loss (TL) have been used interchangeably such that the horizontal axis is NR2 - NRc and the vertical axis is NR2 - NR1. To assist in the user's understanding of these figures, the horizontal axis is defined as the wall NR minus the NRc. The vertical axis has been described as an "adjustment in dB to be subtracted from the wall NR to obtain the window NR."

Algebraically:

$$NR2 - NR1 = Adjustment$$

So that

$$NR1 = NR2 - Adjustment$$

The wall NR values in Figure 1.15 are to be used with Figures 1.4, 1.8 and 1.12 and have been estimated from simple constructions such as those found in reference [28].

Acoustical Guide - Transmission Loss Methodologies

Step Four - Window Sound Transmission Class

Having now determined the minimum required noise reduction (NR), a corresponding sound transmission class (STC) value must be determined. Since the NR performance of a glazing configuration depends on both the exterior sound level spectrum and transmission loss spectrum shapes, it has been necessary to analyze tested glass configurations in order to determine their A-weighted NR performance for various exterior sources of noise. The spectrum shapes used for a typical aircraft take-off, automobile traffic and rail transportation noise are given in Figure 4.5. Using the spectra of Figure 4.5 and laboratory sound transmission loss (TL) data of Section 3 and Equation 4.7, glazing NRs for each transportation noise source have been determined. The relationship between TL and NR is as follows:

Equation 4.7

$NR = TL + 10 \log AR / S - K$

In Equation 4.7:

AR is the receiving room absorption in Sabins.

S is the common wall area.

K

- is 0 for reverberant room to reverberant room.

- is 6 theoretically for free field to reverberant room.

- is 5 based on actual measurements for free field to reverberant room [29].

For free field analyses performed in connection with this guide, a value of 5 has been used for K in Equation 4.7, based on recommendations and experiences of reference [29].

Using Equation 4.7, relationships between NR and STC have been developed and are given in Figures 4.8, 4.9, 4.10a and 4.10b. Using linear regression [25, 26], simple algebraic relations between STC and glazing NRs for each transportation noise source have also been developed. These relationships all have the form:

Equation 4.8

$STC = A(NR) + B + 2 + C$

In Equation 4.8:

A and B are the slope and intercept obtained through a linear regression analysis of the computed NRs and the associated STCs for glazing configurations tested. The factor of 2 dB has been subtracted as a means to account for the consistent field experience that STC values estimated for actual installed windows are about 2 STC points less than that value determined in the laboratory for glass alone. C is a constant to account for scatter in computed data. Figures 4.8, 4.9, 4.10a and 4.10b provide linear regressions used in developing the STC minimum required window NR relationships, given in Figures 1.5, 1.9 and 1.13. The figures also illustrate how values for C were determined. Generally, values for C range between 1 and 2 STC points (dB).

Acoustical Guide - Transmission Loss Methodologies

It is important to note that the room effect used in computing NRs was zero. This is a typical value for commercial interiors. For residential spaces, the room effect is more likely to fall in a range of +1 to +3 dB [29].

It also has been interesting to note that the relationship between NR and STC for single and double glazing differs. In short, a single glazed window will have a somewhat higher NR for most transportation noise than will a double glazed window having the same STC. With most transportation noise sources, the A-weighted sound energy is concentrated at low frequencies, below critical frequency, and in a frequency range where air space resonances degrade the sound isolation performance of double glass, resulting in a lower A-weighted NR.

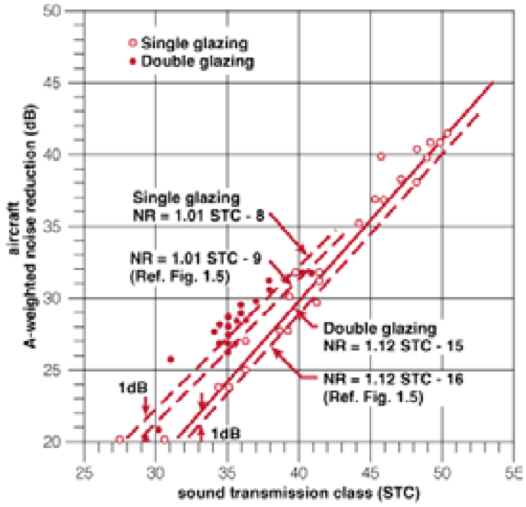


Figure 4.8 Relationship between glass STC and aircraft noise reduction.

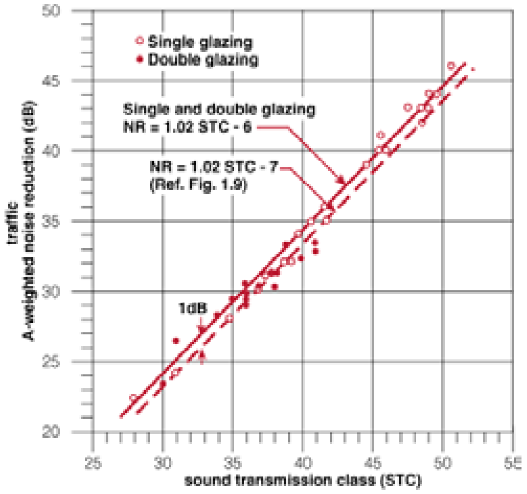


Figure 4.9 Relationship between glass STC and traffic noise reduction.

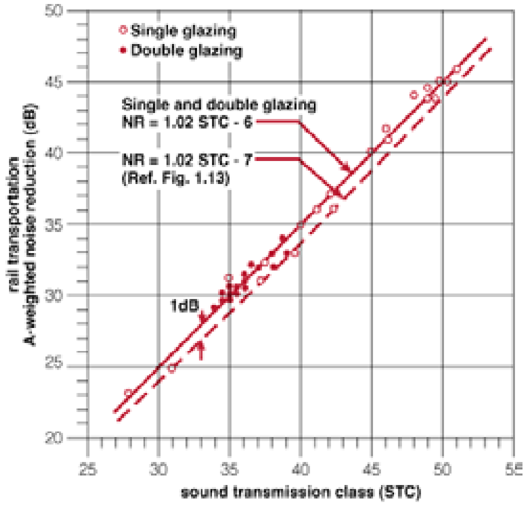


Figure 4.10a Relationship between glass STC and rail transportation (rolling stock only) noise reduction.

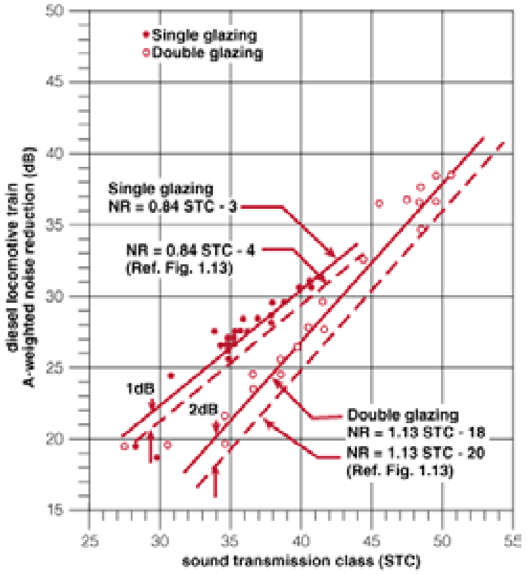


Figure 4.10b Relationship between glass STC and diesel locomotive train noise reduction.

Acoustical Guide - Glossary

Glossary

- Glossary
- Terms
- Frequently Asked Questions About Acoustics
- Abbreviations and Symbols

Acoustical Guide - Glossary

Glossary

The definitions of acoustical terms used in this publication are most often based on American National Standards Institute (ANSI) S1.1-1994 Acoustical Terminology. Some of the acoustical terms briefly defined below are explained in greater detail else-where in this Acoustical Glazing Design Guide.

A-Weighting (dBA)

The filtering of sound that replicates the human hearing frequency response. The human ear is most sensitive to sound at mid frequencies (500 to 4,000 Hz) and is progressively less sensitive to sound at frequencies above and below this range. A-weighted sound level is the most commonly used descriptor to quantify the relative loudness of various types of sounds with similar or differing frequency characteristics.

Absorption

The attenuation (or reduction) of sound level that results when sound propagates through a medium (usually air) or when reflected from a dissipative material (sound absorptive material) such as glass fiber or open-cell urethane foam. In the case of sound absorptive materials used in the building industry, attenuation of sound is produced by the conversion of molecular motion, which is sound, into thermal energy due to friction of air molecules with fiberous or cellular materials.

Acoustics

(1) Acoustics is the science of sound, including its production, transmission and effects.

(2) The acoustics of a room are those qualities that together determine its character with respect to the perception of sound.

Ambient Noise

Ambient noise encompasses all sound present in a given environment, being usually a composite of sounds from many sources near and far.

Band Pass Filter

The filtering of sound within specified frequency limits or frequency bands. The audible frequency range is often subdivided into octave, one-third octave or other fractions of octave bands.

Barriers

An obstacle, such as a wall, that blocks the line-of-sight between a sound source and a receiver, thereby providing a barrier attenuation, i.e., a reduction of sound level at the receptor. Sound attenuation provided by barriers is principally related to the diffraction of sound over and around the barrier, and the sound transmission loss through the barrier material.

Acoustical Guide - Glossary

Coincidence Effect/Critical Frequency

A significant reduction in sound transmission loss (i.e., a significant increase in the transmission of sound) through a partition that occurs at critical frequency. The critical frequency is the frequency at which the wavelength of sound in air equals the flexural bending wavelength in the partition or material.

Damping

Damping is the dissipation of vibratory energy in solid media and structures with time or distance. It is analogous to the absorption of sound in air.

Day-Night Average Sound Level (DNL, Ldn)

The 24-hour energy average sound level where a 10 dB "penalty" is applied to sound occurring at night between 10:00 PM and 7:00 AM. The 10 dB penalty is intended to account for the increased sensitivity of a community to sound occurring at night.

Decibel (dB)

A dimensionless unit which denotes the ratio between two quantities that are proportional to power, energy or intensity. One of these quantities is a designated reference by which all other quantities of identical units are divided. The sound pressure level in decibels is equal to 10 times the logarithm (to the base 10) of the ratio between the pressure squared divided by the reference pressure squared. The reference pressure used in acoustics is 20 microPascals.

Energy Average Sound Level

Typically, in real world circumstances, sound levels vary considerably over time. The Leq is the energy average sound level over a monitoring time interval. It is a hypothetical continuous sound level that contains the same sound energy as the actual sound occurring during the time interval. The letter symbol Leq typically implies A-weighting, i.e., the energy average sound level in dBA. Also the duration of measurement is typically stated, e.g., Leq (1 hour).

Field Sound Transmission Class (FSTC)

The same as STC rating except as measured in the field in accordance with standard methods. The FSTC is used to quantify actual as-built partition transmission loss across the frequency range of speech sounds. The FSTC incorporates corrections for receiving room sound absorption and requirements to assess and eliminate sound flanking paths.

Flanking

The transmission of sound around the perimeter or through holes within partitions (or barriers) that reduces the otherwise obtainable sound transmission loss of a partition. Examples of flanking paths within buildings are ceiling plena above partitions; ductwork, piping, and electrical conduit penetrations through partitions; back-to-back electrical boxes within partitions, window mullions, etc.

Acoustical Guide - Glossary

Frequency

Frequency is the number of oscillations or cycles per unit time. In acoustics, frequency usually is expressed in units of Hertz (Hz) where one Hertz is equal to one cycle per second.

Fundamental Frequency

The fundamental frequency of an oscillating system is the lowest natural frequency of that system.

Mass

Mass is the fundamental property of a material relevant to sound transmission loss through that material. Generally, the more massive the material, the greater the sound transmission loss.

Mass Law Sound Transmission Loss

Below about half the critical frequency, sound transmission loss is generally only related to the mass of a material or partition. Mass law helps quantify the sound transmission loss at these frequencies. At these frequencies, doubling the mass per unit area of a partition panel, or doubling the frequency for a given mass per unit area, increases the sound transmission loss by 6 decibels in the frequencies controlled by mass law.

Noise

(1) Noise is any undesired sound. By extension, noise is any unwanted disturbance within a useful frequency band, such as excessive traffic sound transmission into a sensitive building space.

(2) Noise is an erratic, intermittent or statistically random oscillation.

Noise Criterion Curves (NC)

A set of approximate equal loudness curves used to assess the acceptability of background sound in buildings. The curves are used along with a measured or estimated octave band spectrum to determine the NC rating of the spectrum. Criteria for acceptable sound in buildings are often expressed as ranges of acceptable NC ratings. NC criteria are generally applied to background sound in buildings produced by building heating, ventilating and air conditioning (HVAC) equipment. The NC rating of sound produced by an HVAC noise source involves overlaying the measured or estimated octave band spectrum on a series of noise criteria curves. The highest NC curve tangent to the measured spectrum in any octave band is the NC rating of that spectrum.

Noise Reduction Between Rooms

The arithmetic difference between the sound level in a source room and the sound level produced by that source in an adjacent receiving room. The noise reduction (NR) is expressed in decibels.

Octave

The ratio of higher and lower frequencies that equals two.

Acoustical Guide - Glossary

Octave Band

Groups of frequencies defined by standards where the upper frequency of each band is equal to twice the lower frequency of the next higher band. Octave bands are usually named by their geometric center frequency. For example, the octave band extending between 44.7 Hz and 89.1 Hz is called the 63 Hz octave band. The octave band extending between 89.1 Hz and 178 Hz is called the 125 Hz octave band. The full complement of octave bands in the audible frequency range is as follows: 31.5, 63, 125, 250, 500, 1,000, 2,000, 4,000, 8,000 and 16,000 Hz.

Octave Band Sound Pressure Level

Sound pressure level for all sound contained within a specified octave band.

Oscillation

In acoustics, pressure oscillation is the variation of sound pressure with time alternately above and below the ambient static pressure.

Pitch

That attribute of auditory sensation expressed in terms of sounds being ordered on a scale extending from low to high. Pitch depends primarily upon the frequency of the sound stimulus.

Residual Noise

The lowest levels of sound reached during a monitoring interval, usually produced by distant traffic or industrial activity.

Reverberation

Reverberation is the persistence of sound in an enclosed space resulting from multiple reflections after a sound source has stopped.

Reverberation Time

The reverberation time of a room is the time it takes for sound to decay by 60 dB once the source of sound has stopped.

Room Criteria Curves (RC)

A set of contours that serves as optimum spectrum shapes for background sound in buildings. Octave band spectra that align with a single RC curve are considered neutrally balanced. Neutrally balanced spectra have the proper amounts of low-, mid- and high-frequency sound energy to cause them to be perceived as innocuous, even though audible. RC curves are straight lines set at -5 dB/octave slopes. The RC rating of a spectrum is determined through methods defined in ANSI S12.2. The rating method arrives at a single-number rating with other designators identifying neutral, rumbly or hissy characteristics.

Acoustical Guide - Glossary

Sabin

A unit of absorption having the dimensions of square feet or square meters, as appropriate.

Sound

(1) Sound is an oscillation in pressure, stress, particle displacement, particle velocity, etc., in a medium.

(2) Sound is an auditory sensation evoked by the oscillation described above.

Sound Absorption

Sound absorption is the property possessed by materials and objects, including air, of converting sound energy into heat energy.

Sound Absorption Coefficient

The sound absorption coefficient of a material is the fraction of incident sound energy absorbed or otherwise not reflected by the surface. Unless otherwise specified, a diffuse sound field is assumed.

Sound Pressure

The sound pressure is the total instantaneous pressure at a point in space, in the presence of a sound wave, minus the static pressure at that point.

Sound Pressure Level

The sound pressure level, in decibels, of a sound is 20 times the logarithm to the base 10 of the ratio of the sound pressure to the reference pressure. The reference pressure shall be explicitly stated and is defined by standards.

Sound Transmission Class (STC)

A single number rating of partition airborne sound transmission loss across 16 one-third octave bands between 125 Hz and 4,000 Hz as measured in an acoustical laboratory under carefully controlled test conditions. The STC is used during the building design phase to select a particular partition/window configuration to obtain desired sound isolation performance.

Sound Transmission Coefficient (t)

The sound transmission coefficient of a partition is the fraction of incident sound transmitted through it. Unless otherwise specified, transmission of sound energy between two diffuse sound fields is assumed.

Acoustical Guide - Glossary

Sound Transmission Loss

Sound transmission loss (TL) of a material or building partition is a measure of sound isolation ability. Expressed in decibels, it is 10 times the logarithm to the base 10 of the reciprocal of the sound transmission coefficient of the partition. Mathematically, this is represented as:

TL = 10 log 1/t

Unless otherwise specified, the sound fields on both sides of the partition are assumed to be diffuse.

Spectrum

A group of sound levels in frequency bands covering a wide frequency range. Generally, this term is used with some modifier indicating the resolution band-width, e.g., octave band spectrum or one-third octave band spectrum.

Stiffness

Stiffness characterizes the ability of a material to resist bending.

Wave

In acoustics, physical disturbance, usually a pressure disturbance, which propagates through a medium, typically air, and building components.

Acoustical Guide - Glossary

Terms

Acoustical Double Glazing

Two monolithic glass panels, set into a frame, with an air space between the two panels that is usually larger than 1” and most often not hermetically sealed.

Double Laminated Insulating Glazing

Two laminated glass panels set into a frame that provide an air space between the two glass panels. Such units may or may not be hermetically sealed and can have varying air space thicknesses, depending on acoustical/ thermal requirements.

Glazing

Glass and glazing components such as interlayer, desiccant, frames, air space, etc., that are installed into a window frame.

Interlayer

The transparent damping material used in laminated glass, e.g., Saflex polyvinyl butyral.

Laminated Glass

A glazing panel composed to two or more panels of monolithic glass separated by a transparent damping material, such as Saflex.

Laminated Insulating Glazing

A laminated glass panel and a monolithic glass panel set into a frame that provides an air space between the two glass panels.

Monolithic Glass

Glass having a single uniform thickness.

Thermal Double Glazing or Insulating Glass

Two monolithic glass panels set into a common frame providing an air space between the two panels that is generally not larger than 3/4”. Such glazing units are most often hermetically sealed.

Acoustical Guide - Glossary

Frequently Asked Questions About Acoustics

The following are answers to frequently asked questions concerning sound isolation in buildings. Answers are brief and it is suggested that the reader refer to applicable portions of Section 2 for more detailed discussions.

1. What is the difference between dB and dBA?

dB is the abbreviation for decibel which is a measure of the amplitude of sound. dBA is the abbreviation for A-weighted decibels. The higher the number of decibels, the louder the sound. Decibels and A-weighted decibels are very nearly the same, except A-weighted decibels include an adjustment to measured or calculated sound pressure levels that accounts for the varying sensitivity of human hearing to sound at different frequencies. In sound level meters, this adjustment is accomplished using electronic A-weight filtering. In calculated sound levels, A-weighting is accomplished by applying adjustments to sound pressure levels in octave or one-third octave frequency bands.

2. What is the difference between dB and Hz?

Decibel (dB) only quantifies the loudness of sound and does not quantify other characteristics of sound. For example, a jet aircraft flyover and a lawn mower, at different distances, may both produce sound levels that are measured to be 80 dBA; however, they will sound quite different. The reason they sound different is because they have sound energy distributed differently across the audible frequency spectrum.

Hz is the abbreviation for Hertz which is a measure of frequency, where 1 Hz equals 1 cps (cycle per second) of air pressure. Frequency is the measure of the tonal or pitch quality of sound, not amplitude. The higher the frequency, the higher the pitch. The musical note “A” played on a piano has a frequency of 440 Hz. If played quietly, it might have a sound pressure level (amplitude) of 50 dBA; if played loudly, it might have a sound pressure level of 70 dBA. Irrespective of how loud the note is played, it will sound the same; i.e., it will have the same pitch or tonal characteristic.

3. What is the difference between STC and dB?

An STC (sound transmission class) rating is a single-number value quantifying the ability of a material to resist the transmission of sound. For example, the STC rating of 1/4” laminated glass is 35; the STC rating of 1/4” monolithic glass is 31. The higher the STC rating, the more able the material is to resist the transmission of sound.

Normally, STC ratings are only reported as whole numbers without units and, in some cases, are referred to as rating points. In the preceding glass configurations, one would refer to 1/4” laminated glass as having an STC rating that is 4 points (or 4 rating points) higher than that of 1/4” monolithic glass.

However, other uses imply that an STC rating has units of decibels (dB), particularly when used in context with noise reduction (NR). For example, consider a building located next to a highway, with a room that has an exterior window overlooking the highway. Let us assume that this window is glazed with 1/4” monolithic glass. Also suppose that it was determined that the exterior wall/window noise reduction (the difference between the sound level outside and inside the room) is 33 dBA. Now suppose that the 1/4” monolithic glass in the window

Acoustical Guide - Glossary

was replaced with 1/4” laminated glass that has an STC rating that is 4 points higher, the new noise reduction will be 37 dBA, i.e., 33 dBA + 4 dB. In this sense, the units of STC rating are decibels (dB).

On one hand, in the above example, the arithmetic difference in STC ratings between 1/4” monolithic and laminated glass is applied to the existing NR to determine a future NR which is expressed in decibels. On the other hand, it is not correct to apply an STC rating directly to an exterior sound level to determine the corresponding interior sound level inside a room of a building. This is, to a large extent, why STC rating is reported without the units of dB to avoid its misusein this way.

4. What is the difference between isolation and insulation?

The dictionary makes little distinction between isolation and insulation. The same is true in acoustics, except that the standard method for quantifying the ability of a floor/ceiling system to resist the transmission of footfall sound to spaces below is called the impact insulation class (IIC) rating. Insulation is also generally used in the context of a material, such as glass fiber, applied to a structure, such as a pipe, to reduce its sound (and heat) radiation into a space. In most other circumstances, the word isolation is used when referring to acoustically setting two spaces apart.

5. Does sound absorption applied to a wall surface improve TL?

Applying sound absorptive materials to a wall surface does slightly improve its transmission loss, providing that the sound absorptive material is applied over the entire wall surface. The increase in TL (sound transmission loss) below 500 Hz is typically less than 2 dB; above 500 Hz it is typically less than 5 dB. The increase in TL also depends on the thickness and surface weight of the sound absorptive material. The heavier and thicker the material, the higher the TL increase.

Because of their negligible benefit, sound absorptive materials are rarely applied directly to wall surfaces for the sole purpose of increasing wall TL. However, application of sound absorptive materials to room surfaces is widely used to reduce sound reverberation in building spaces, thus also reducing sound levels, but typically by no more than 5 dBA.

6. Does “blown-in” insulation in walls and floor/ceiling constructions improve sound isolation?

The use of “blown-in” insulation in wall and floor/ceiling constructions can improve TL. However, blown-in insulation that becomes packed inside a wall stud cavity can create a vibration short-circuit between the layers of gypsum wallboard on opposite sides of studs, thereby offsetting the benefit that otherwise is usually obtained when a sound absorptive material is used in a wall stud cavity.

7. Why is it more important to reduce sound from primary noise sources first, before dealing with secondary noise sources?

Sound from primary (loudest) noise sources must be reduced before reducing sound from less significant noise sources. As a brief example, consider two noise sources, source 1 and source 2. If source 1 produces a sound level of 70 dBA at a given location and source 2 produces a sound level of 61 dBA at the same location, the two operating together will produce a total sound level of 71 dBA.

Acoustical Guide - Glossary

Removing or otherwise treating source 2, the secondary source, to eliminate its contribution to the total, reduces the total sound level from 71 to 70 dBA, only a 1 dBA reduction. Inversely, removing or otherwise treating source 1 first, the primary source, reduces the total sound level from 71 to 61 dBA, a 10 dBA reduction.

This example illustrates the logic behind treating the predominant noise source first in situations where a reduction in total sound level produced by several noise sources is required. This arises from the fact that sound levels in decibels do not add arithmetically, they add logarithmically. As seen in the above example, where the sound levels of two sources, one 70 dBA and the other 61 dBA, did not total 131 dBA, but rather 71 dBA. Further information on how to add sound levels in decibels together can be obtained from a variety of basic acoustical references [20, 27].

8. Why canÕt we just add STC ratings of individual layers of a building wall or window construction together to arrive at the STC rating of the complete construction?

STC ratings of individual components of multi-layered wall or window constructions cannot be arithmetically added together to arrive at the STC rating of the complete system. This is largely because of acoustic and vibration coupling that occurs between such components in typical building wall and window constructions. Generally, the STC rating of a building construction is several rating points below the arithmetic sum of the STC rating of the individual components. Estimating the TL of composite materials is difficult. Such information is generally determined through laboratory testing rather than through the use of analytic techniques.

9. Can I use banners or flags to control sound in large atria?

Banners and flags can be used under certain circumstances to reduce reverberant sound in large building spaces such as atria. Successful use of banners and flags generally requires their use draped against a hard wall with a glass fiber panel mounted behind the fabric material. This is needed since flags and banners, by themselves, generally do not have significant sound absorption, hence the need for a sound absorptive panel behind.

Banners and flags can be used suspended in free space if they are used as a facing for a glass fiber or other sound absorptive panel. Such panels are usually a minimum of 1” thick.

The minimum quantity of banner or flag surface needed is approximately equal to the square footage of the floor. For complicated atria spaces, a qualified acoustical consultant should be retained for advice.

In the case of drapes, sound absorption can be obtained if the drape is heavily lapped, in essence creating a thick sound absorptive material.

It also should be noted that large atria sometimes do not require sound absorptive treatment for a variety of reasons related to the acoustical characteristics of adjoining spaces and the types of activities taking place in such spaces.

Acoustical Guide - Glossary

10. Which is better, increasing mass, air space thickness, etc., for improving the TL of windows?

There is no generally accepted guideline for determining which -- mass, air space thickness or glass thickness -- should be changed first for improving the TL of windows. For most glass configurations using 1/4” or thicker glass, the most cost-effective method is generally to first add damping (Saflex polyvinyl butyral interlayer), then increase air space and finally increase glass weight. The advantage of damping interlayer is that an improvement in window TL can be obtained without increasing glass configuration thickness, thus enabling the use of less expensive frames and possibly continuing the use of sealed desiccant frames. Increasing air spaces above 1/2” usually requires the use of unsealed glass and more costly frame components.

In the case of IG configurations using 1/8” glass, the first step in increasing sound transmission loss would be increasing glass weight, then adding damping interlayer if needed. This ordering of priorities is needed since 1/4” is the thinnest laminated glass able to be manufactured on a mass production basis.

In the case of monolithic glass 1/4” or thicker, the first most cost-effective step is usually to add Saflex damping interlayer and then increase glass thickness. However, the cost of glass thicknesses over 1/2” rapidly becomes prohibitive, in which case the use of double or insulating glass configurations may be more feasible.

The above considerations must be accompanied by attention paid to window frames to ensure that windows are properly constructed to minimize air leakage, to ensure that frame components are heavy, and that frame voids are kept small or packed with dense loose fill.

11. What is the difference between quiet and privacy? (It’s so quiet that it’s noisy!)

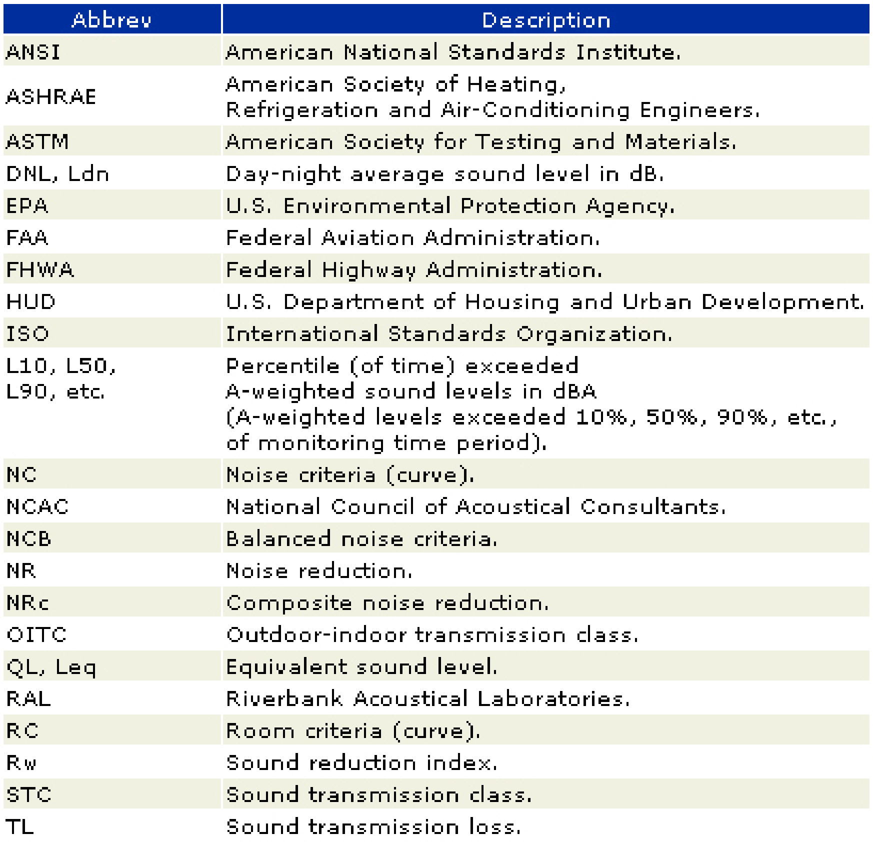
The general public, understandably, finds very confusing the difference between “quiet” and “privacy.” This is largely because when “quiet” is pursued by reducing background sound levels -- for example, sound levels produced by building HVAC systems -- speech between persons in an adjacent space, transmitted through a demising wall, often becomes audible, thus diminishing the “quiet” attribute sought. In this case, eliminating the intrusion of background sound results in the intrusion of unwanted speech.

This is easily explained by viewing this problem as a signal-to-noise issue. The higher the speech signal transmitted from an adjacent room relative to the background noise, the better the speech intelligibility. Good speech intelligibility means poor speech privacy; conversely, poor speech intelligibility means good speech privacy. “Speech privacy” and “speech intelligibility” are opposites. Therefore, achieving “quiet” must take into consideration both sound level and speech privacy.

To achieve “quiet” requires reducing both background sound and intrusive speech level. Typically, this would involve methods for reducing background sound levels in rooms, plus methods for increasing the TL of walls to reduce transmitted speech sounds between rooms.

Acoustical Guide - Glossary

Abbreviations and Symbols



Abbrev	Description
ANSI	American National Standards Institute.
ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning Engineers.
ASTM	American Society for Testing and Materials.
DNL, Ldn	Day-night average sound level in dB.
EPA	U.S. Environmental Protection Agency.
FAA	Federal Aviation Administration.
FHWA	Federal Highway Administration.
HUD	U.S. Department of Housing and Urban Development.
ISO	International Standards Organization.
L10, L50, L90, etc.	Percentile (of time) exceeded A-weighted sound levels in dBA (A-weighted levels exceeded 10%, 50%, 90%, etc., of monitoring time period).
NC	Noise criteria (curve).
NCAC	National Council of Acoustical Consultants.
NCB	Balanced noise criteria.
NR	Noise reduction.
NRc	Composite noise reduction.
OITC	Outdoor-indoor transmission class.
QL, Leq	Equivalent sound level.
RAL	Riverbank Acoustical Laboratories.
RC	Room criteria (curve).
Rw	Sound reduction index.
STC	Sound transmission class.
TL	Sound transmission loss.

Acoustical Guide - STL Worksheets

STL Worksheets

- Introduction to Worksheets
- Airport Noise Methodolgy Worksheet
- Traffic Noise Methodology Worksheet
- Rail Noise Methodology Worksheet

Acoustical Guide - STL Worksheets

Introduction to Worksheets

This section presents figures from the aircraft, traffic and rail methodology procedures in Section 1. These worksheets are provided for analyzing building glazing requirements.

Refer to Figures 1.14a and 1.14b for a listing of measured sound transmission loss ratings for various glazing configurations and adjustments.

Refer to Figures 1.15a through 1.15l for examples of estimated wall STC ratings and noise reductions (NR).

All of these figures are in Section 1 of this design guide. Section 1 presents the completed, step-by-step procedures for a representative glazing design problem. Refer to Section 1 for working examples to assist you in the completion of these worksheets.

For additional copies of these worksheets, please contact:

R.E. Wright

Saflex Market Development

1-800-248-6844

Acoustical Guide - STL Worksheets

Airport Noise Methodoloy Worksheet

As noted in Section 1, an airport noise contour map must be used to estimate noise levels at a project site. Figures 1.3, 1.4 and 1.5 are used to determine the minimum required window sound transmission class (STC).

Step One

Obtain the latest airport noise contour map from the airport noise abatement office, locate the proposed building site on the contour map, and read the yearly day-night average sound level (DNL) for that site.

Step Two

Use the DNL determined in Step One and Figure 1.3 to determine the minimum required wall/window composite noise reduction (NRc). This is done by locating the DNL value on the horizontal axis of Figure 1.3 and by using either of the two criteria lines to locate the NRc value on the vertical axis.

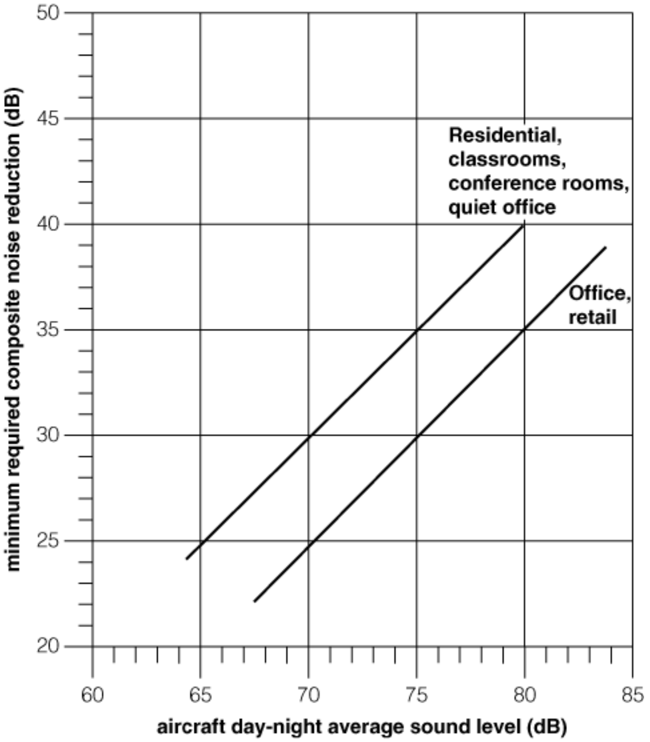


Figure 1.3 Chart for determining minimum required composite noise reduction from aircraft day-night average sound level (DNL). (Based on reference [4]).

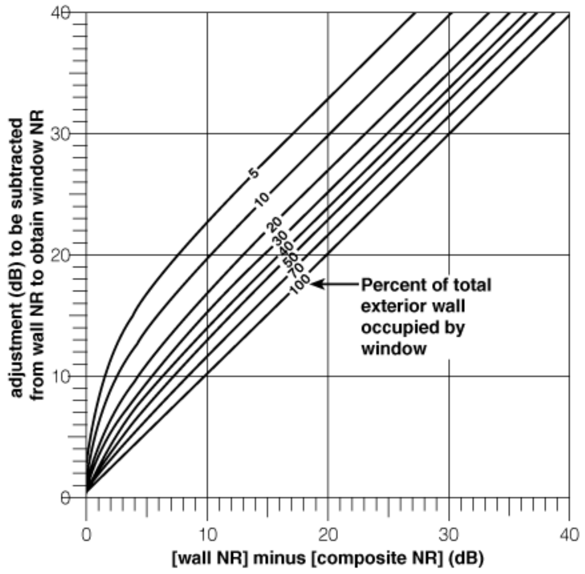


Figure 1.4 Chart for determining minimum required window NR from wall NR and composite NR.

Step Three

Use Figure 1.4 and the NRc determined in Step Two to find the minimum required window NR. This requires knowing the wall NR, which can be determined using information from Figures 1.15a through 1.15l in Section 1, and requires knowing the percentage of the exterior wall occupied by windows.

Acoustical Guide - STL Worksheets

Step Four

Use Figure 1.5 to determine the window STC rating corresponding to the window NR determined in Step Three. This is done by locating the NR value on the horizontal axis of figure 1.5 and by locating the corresponding window STC on the vertical axis.

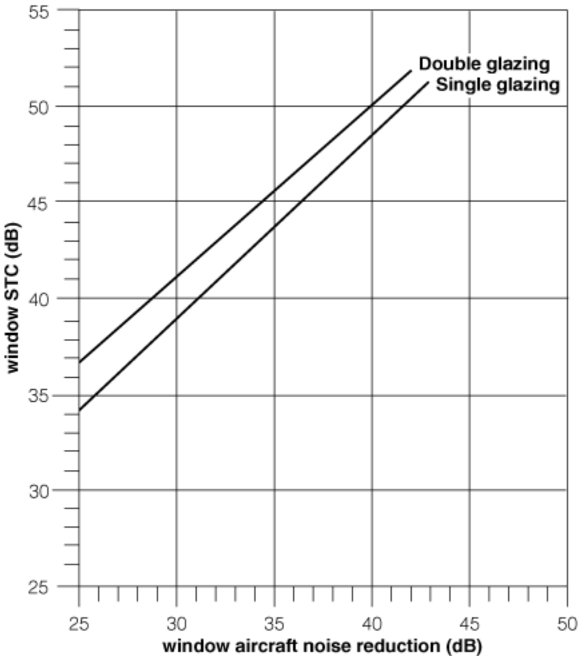


Figure 1.5 Chart for determining window sound transmission class (STC) from window aircraft noise reduction (NR).

Acoustical Guide - STL Worksheets

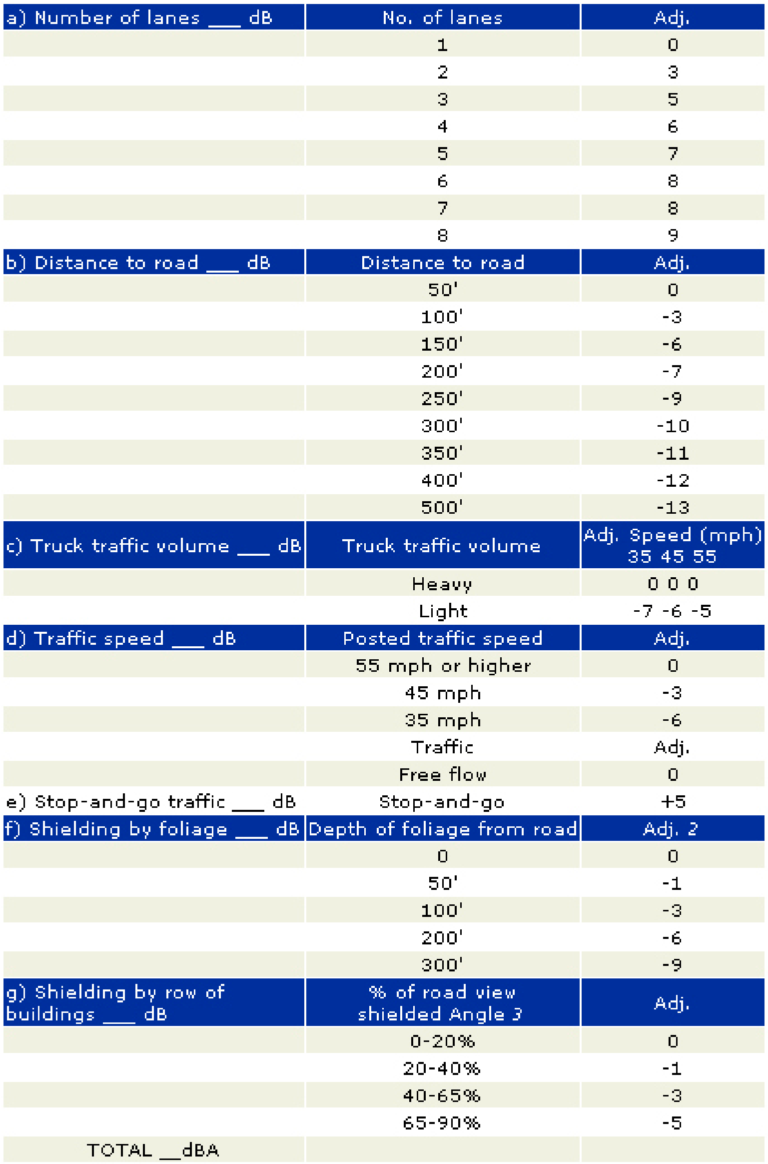
Traffic Noise Methodology Worksheet

If actual measured traffic noise data is not available for a project site, the methodology of Figure 1.6 can be used to estimate traffic sound levels. Figure 1.7, 1.8 and 1.9 can then be used to determine the minimum required window STC.

Step One

If actual noise level measurements are not available, complete the Traffic Noise Level Estimation Worksheet in Figure 1.6. Refer to Traffic Noise Methodology in Section 1.

Maximum Hourly Baseline Level (Leq)[1] 76 dBA (baseline plus adjustments) Level of Service "C."



a) Number of lanes ___ dB	No. of lanes	Adj.
	1	0
	2	3
	3	5
	4	6
	5	7
	6	8
	7	8
	8	9
b) Distance to road ___ dB	Distance to road	Adj.
	50'	0
	100'	-3
	150'	-6
	200'	-7
	250'	-9
	300'	-10
	350'	-11
	400'	-12
	500'	-13
c) Truck traffic volume ___ dB	Truck traffic volume	Adj. Speed (mph) 35 45 55
	Heavy	0 0 0
	Light	-7 -6 -5
d) Traffic speed ___ dB	Posted traffic speed	Adj.
	55 mph or higher	0
	45 mph	-3
	35 mph	-6
	Traffic	Adj.
	Free flow	0
e) Stop-and-go traffic ___ dB	Stop-and-go	+5
f) Shielding by foliage ___ dB	Depth of foliage from road	Adj.[2]
	0	0
	50'	-1
	100'	-3
	200'	-6
	300'	-9
g) Shielding by row of buildings ___ dB	% of road view shielded Angle[3]	Adj.
	0-20%	0
	20-40%	-1
	40-65%	-3
	65-90%	-5
TOTAL __dBA		

[1] Level at 50' from one lane of traffic carrying 1,434 vehicles per hour (7.5% medium truck, 7.5% heavy truck) at 55 mph.

[2] -10dB Max.

[3] where 180º=100%.

Figure 1.6 Traffic noise level estimation worksheet.

Acoustical Guide - STL Worksheets

Step Two

Use either the measured or the estimated traffic sound level determined in Figure 1.6, and use Figure 1.7to determine the minimum required composite noise reduction (NRc). This is done by locating the traffic sound level value on the horizontal axis of Figure 1.7 and by using either of the two criteria lines to locate the NRc value on the vertical axis.

Step Three

Use Figure 1.8 and the NRc discovered in Step Two to determine the minimum required window NR. This requires knowing the wall NR, which can be determined using information from Figures 1.15a through 1.15l in Section 1, and requires knowing the percentage of the exterior wall occupied by windows.

Step Four

Use Figure 1.9 to determine the window STC rating corresponding to the window NR determined in Step Three. This is done by locating the NR value on the horizontal axis of Figure 1.9 and by locating the corresponding window STC on the vertical axis.

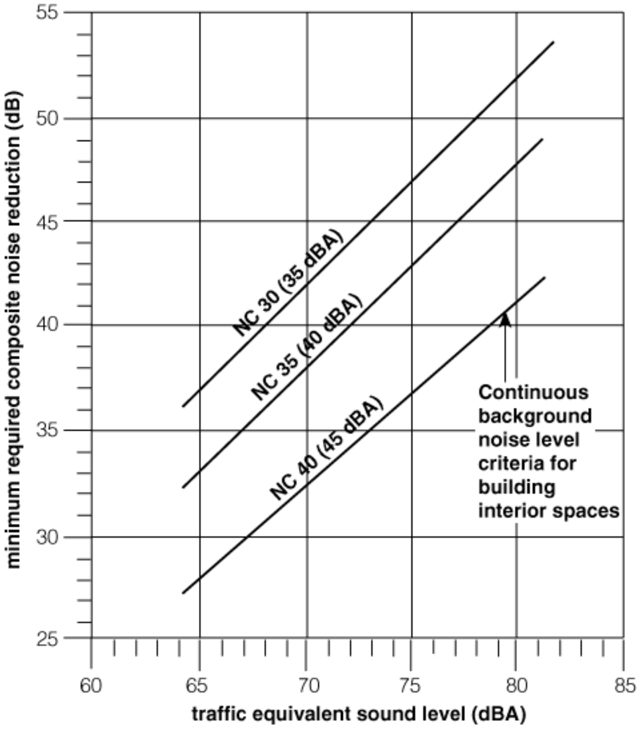


Figure 1.7 Chart for determining minimum required composite noise reduction from traffic equivalent sound levels.

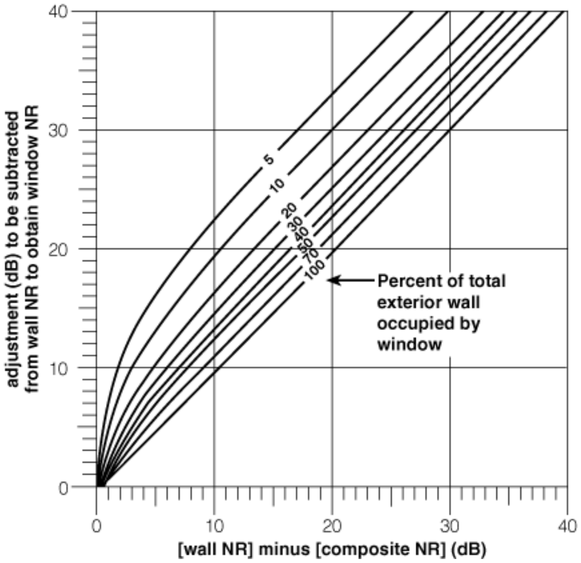


Figure 1.8 Chart for determining minimum required window NR from wall NR and composite NR (Same as Figure 1.4).

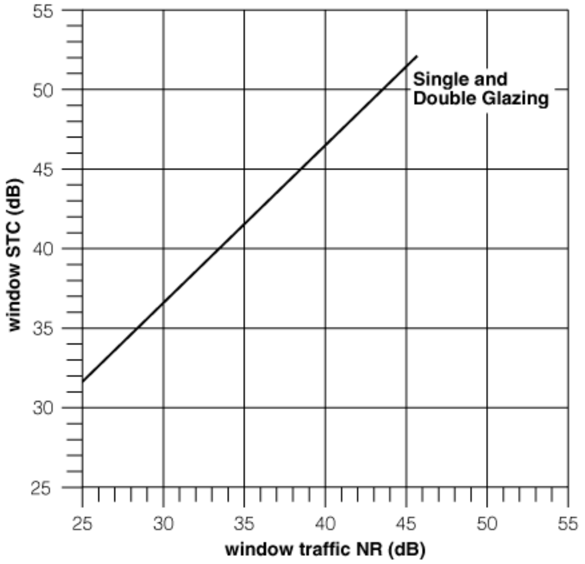


Figure 1.9 Chart for determining window sound transmission class (STC) from window traffic noise reduction (NR).

Acoustical Guide - STL Worksheets

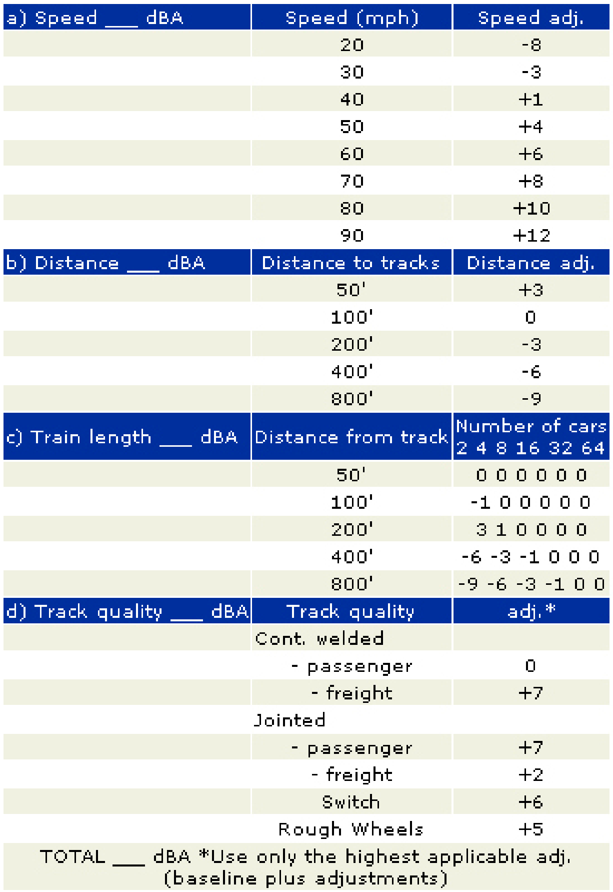
Rail Noise Methodology Worksheet

If actual measured rail noise level data is not available for a project site, the methodology of Figures 1.10a, 1.10b and 1.10c can be used to estimate rail passby noise levels. Figures 1.11, 1.12 and 1.13 can then be used to determine the minimum required window STC.

Step One

If measured rail noise levels are not available, complete the Rail Noise Methodology Worksheets in Figures 1.10a, 1.10b and 1.10c.

ROLLING STOCK (or electric self-propelled rail car)
Rolling Stock
Baseline 75 dBA



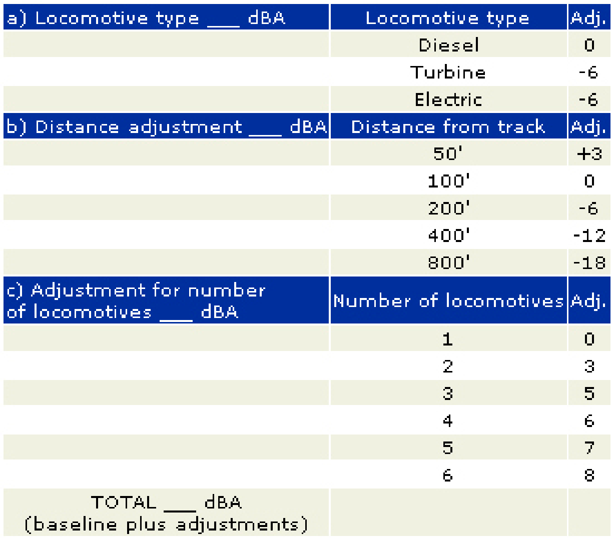
a) Speed ___ dBA	Speed (mph)	Speed adj.
	20	-8
	30	-3
	40	+1
	50	+4
	60	+6
	70	+8
	80	+10
	90	+12
b) Distance ___ dBA	**Distance to tracks**	**Distance adj.**
	50'	+3
	100'	0
	200'	-3
	400'	-6
	800'	-9
c) Train length ___ dBA	**Distance from track**	**Number of cars 2 4 8 16 32 64**
	50'	0 0 0 0 0 0
	100'	-1 0 0 0 0 0
	200'	3 1 0 0 0 0
	400'	-6 -3 -1 0 0 0
	800'	-9 -6 -3 -1 0 0
d) Track quality ___ dBA	**Track quality**	**adj.***
	Cont. welded	
	- passenger	0
	- freight	+7
	Jointed	
	- passenger	+7
	- freight	+2
	Switch	+6
	Rough Wheels	+5
TOTAL ___ dBA *Use only the highest applicable adj. (baseline plus adjustments)		

Figure 1.10a Rolling stock noise level estimation worksheet.

Acoustical Guide - STL Worksheets

LOCOMOTIVES

Locomotive Baseline 92 dBA



a) Locomotive type ___ dBA	Locomotive type	Adj.
	Diesel	0
	Turbine	-6
	Electric	-6
b) Distance adjustment ___ dBA	Distance from track	Adj.
	50'	+3
	100'	0
	200'	-6
	400'	-12
	800'	-18
c) Adjustment for number of locomotives ___ dBA	Number of locomotives	Adj.
	1	0
	2	3
	3	5
	4	6
	5	7
	6	8
TOTAL ___ dBA (baseline plus adjustments)		

Figure 1.10b Locomotive passby sound level estimation worksheet.

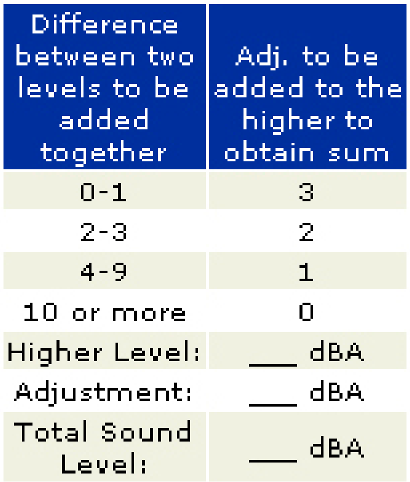
SUMMATION

To find the sum of rail car and locomotive maximum passby noise levels:

a) Find the arithmetic difference between the two levels.

Higher Level: ___ dBA
Lower Level: ___ dBA
Arithmetic Difference ____ dBA

b) Add to the higher of the two the adjustment from the following table:



Difference between two levels to be added together	Adj. to be added to the higher to obtain sum
0-1	3
2-3	2
4-9	1
10 or more	0
Higher Level:	___ dBA
Adjustment:	___ dBA
Total Sound Level:	___ dBA

Figure 1.10c Summation of rolling stock and locomotive sound levels.

Acoustical Guide - STL Worksheets

Step Two

Use either the measured or the estimated train passby sound level determined from Figures 1.10a, 1.10b, and 1.10c, and use Figure 1.11 to determine the minimum required composite noise reduction (NRc). This is done by locating the train passby sound level value on the horizontal axis of Figure 1.11 and by using one of the several criteria lines to locate the NRc value on the vertical axis. The appropriate pair of criterion lines to use is that having a noise criteria (NC) value equal to that used as an upper limit for continuous background noise in spaces considered. Finally, the upper criterion line of the pair is to be used with diesel-powered trains, the lower for non-diesel trains.

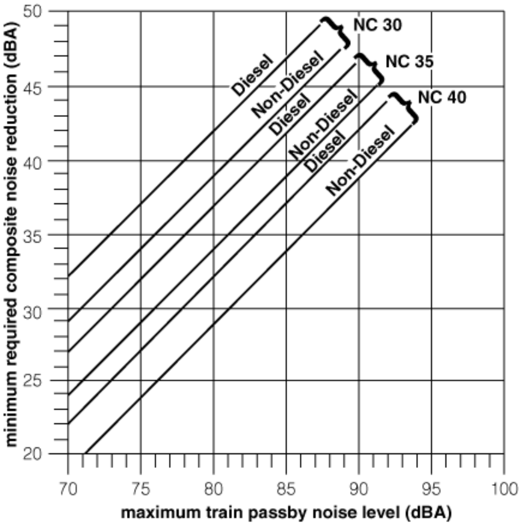


Figure 1.11 Chart for determining minimum required composite noise reduction from maximum train passby noise level.

Step Three

Use Figure 1.12 and the NRc determined in Step Two to determine the minimum required window NR. This requires knowing the wall NR, which can be determined using information from Figures 1.15a through 1.15l in Section 1, and requires knowing the percentage of the exterior wall occupied by windows.

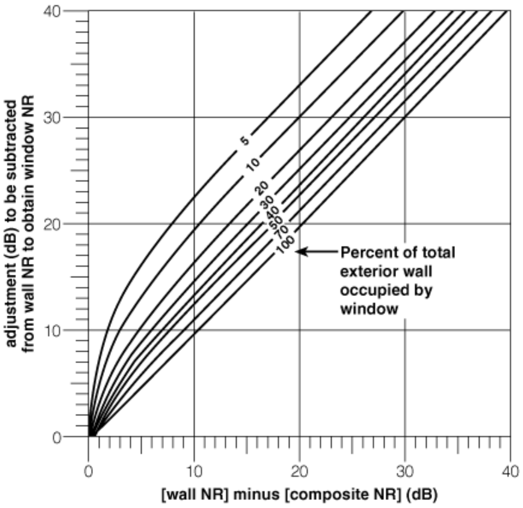


Figure 1.12 Chart for determining minimum required window NR from wall NR and composite NR (Same as Figure 1.4).

Step Four

Use Figure 1.13 to determine the window STC rating corresponding to the window NR determined in Step Three. This is done by locating the NR value on the horizontal axis of Figure 1.13 and by locating the corresponding minimum required window STC on the vertical axis.

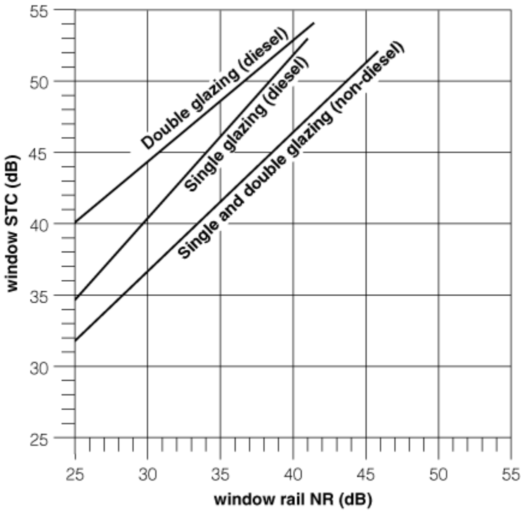


Figure 1.13 Chart for determining window sound transmission class (STC) from window rail noise reduction (NR).

Acoustical Guide - References

References

1 *Security Glazing Design Guide*; Solutia Chemical Company; St. Louis, MO; Publication No. 8104.

2 *A Guide to the Structural Performance of Laminated Architectural Glass*; Solutia Chemical Company; St. Louis, MO; Publication No. 8043.

3 ASTM Standard C1036-90: Standard Specifica-tion for Flat Glass; American Society for Testing and Materials; 1916 Race Street, Philadelphia, PA 19103.

4 Federal Aviation Administration Regulations on *Airport Noise Compatibility Planning Programs* (Code of Federal Regulations, Title 14, Chapter 1, sub-chapter 1 Part 150: issued at 49 FR 49269, December 18, 1984: corrected by 50 FR 5063, February 6, 1985.)

5 Barry, T.M.; Reagent, J.A.; *FHWA Highway Traffic Noise Frequency Model,* FHWA Pub. No. RD-77-108; December 1978.

6 Department of Housing and Urban Development *Environmental Criteria and Standards*, 24 CFR Part 51; July 12, 1979, amended January 6, 1984.

7 Saurenman, H. J.; Nelson, J. T.; Wilson, G. P.; *Handbook of Urban Rail Noise and Vibration Control*, Report No. UMTA-MA-06-0099-82-1; February 1982.

8 Quirt, J.D.; *Sound Transmission Through Windows l. Single and Double Glazing*; Acoustical Society of America 74(2); August 1983.

9 Quirt, J.D.; *Sound Transmission Through Windows lI. Double and Triple Glazing*; Acoustical Society of America 74(2); August 1983.

10 American National Standards S1.6-1984 *Preferred Frequencies and Band Numbers for Acoustical Measurements*. (Complete standard can be obtained from the Acoustical Society of America, 335 E. 45th St., New York, NY 10017.)

11 *Protective Noise Levels Ð Condensed Version of EPA Levels Document*, EPA 500/9-79-100; November 1978.

12 American National Standard S12.40-1990 *Sound Level Descriptors for Determination of Compatible Land Use*. (Complete standard can be obtained from the Acoustical Society of America, 335 E. 45th St., New York, NY 10017.)

13 American National Standard (ANSI) S12.2-1995 Criteria for Evaluating Room Noise.

14 Beranek, Leo L.; *Noise Reduction*; McGraw-Hill Book Company; New York, NY; 1960.

15 U.S. Patent No. 4,047,351. Derner et al.; September 13, 1977.

16 American Society for Testing and Materials; Standard E413-87 (R1994) *Standard Classification for Determination of Sound Transmission Class.*

Acoustical Guide - References

17 American Society for Testing and Materials; Standard E90-90 *Standard Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions.*

NOTE: Sound transmission loss test data identified as RAL TL-85 (1985) presented in this publication have been measured under the E90-83 Standard. Minor standard changes since 1985 have only negligible influence on measured TL data.

18 Department of Transportation; *Federal Highway Administration Procedures for Abatement of Highway Traffic Noise*, 23 CFR Part 772; June 19, 1973, with revisions through July 8,1982.

19 *Transportation Research Circular 281*; Transportation Research Board; Washington, D.C.; June 1984.

20 Reynolds, Douglas D.; *Engineering Principles of Acoustics – Noise and Vibration Control*; Allyn and Bacon, Inc.; Boston, MA; 1981.

21 Harris, Cyril M.; Handbook of Noise Control (3rd Edition); McGraw-Hill Book Company; New York, NY; 1991.

22 Massport 7 Schools Window Study file data; Cavanaugh Tocci Associates, Inc.; 1984.

23 Embassy Suites Hotel Design file data; Cavanaugh Tocci Associates, Inc.; 1983.

24 80 Ashford Street Multi-Residential Facility Design file data; Cavanaugh Tocci Associates, Inc.; 1985.

25 HP-15C *Owner's Handbook*; Hewlett Packard Company; Corvalliss, OR; September 1983.

26 HP-15C *Advance Functions Handbook*; Hewlett Packard Company; Corvalliss, OR; June 1984.

27 Egan, M. David; *Concepts in Architectural Acoustics*; McGraw-Hill Book Company; New York, NY; 1972.

28 *Catalog of STC and IIC Ratings for Wall and Floor/Ceiling Assemblies*; Office of Noise Control, California Department of Health Services; Berkeley, CA.

29 Mange, G. E.; Skale, S. R.; Sutherland, L. C.; *Background Report on Outdoor–Indoor Noise Reduction Calculation Procedures Employing the Exterior Wall Noise Reduction (EWNR) Method*, FHWA Report TS-77-220; March 1978.

30 Beranek, Leo L.; Ver, István L., editors; *Noise and Vibration Control Engineering: Principles and Applications*; John Wiley & Sons, Inc.; New York, NY; 1992.

31 Gradshteyn, I.S.; Ryzhik, I. M.; *Tables of Integrals, Series, and Products (4th Edition)*; Academic Press; Newton, NY; 1965.

32 Smith, O'Sullivan, Oakes, Conn, editors; Building Acoustics, The British Acoustical Society; Oriel Press Limited; Newcastle upon Tyne, England; 1971, p.138.

Acoustical Guide - Example

Specifying Acoustical Glazing

How to Specify Laminated Architectural Glass with Saflex Plastic Interlayer

Following is an example of the recommended procedure for the specification of laminated architectural glass with Saflex interlayer.

Laminated architectural glass consisting of (number) lites of (type, thickness, treatment) glass with (clear or color designation) Saflex interlayer.

The glass shall meet minimum requirements as specified in ASTM C1036 or C1048.

For solar control add: Laminate shall have a visible light transmittance of (value) % with a shading coefficient of ______ and a maximum UV energy transmittance of 1% below 380 nm.

For safety applications add: Laminate shall comply with CPSC 16 CFR 1201, Category (I or II), Safety Glazing Test Standard and/or ANSI Z-97.1.

For sound control add: The laminate or the glazing unit shall have an STC rating of (value).

For security applications add as appropriate: Laminate shall meet ASTM F1233 for bullet resistance from (specify weapon) and forced-entry resistance (specify class required or number of assault sequences resisted) or a combination thereof.

The glazing shall withstand blast loads at least as severe as those generated by a (weight of explosive) TNT-equivalent weight charge detonated on the ground at (altitude) at a distance of (minimum stand-off distance).

For electronic security glazing add: The lite, when properly grounded, shall provide radio frequency atten-uation of ______ dB over the frequency range from ______ MHz to ______ MHz.

For an insulating glass unit add: The laminate shall be installed as (interior, exterior, both) lites. (For sloped glazing, the laminate should always be an interior lite.)

Acoustical Guide - Example

Sales Offices

California, Los Angeles

24012 Calle de la Plata
Suite 250
Laguna Hills, CA 92653
(714) 855-7770

Michigan, Detroit

Ameritech Building
100 E. Big Beaver Road
Suite 300
Troy, MI 48083
(810) 740-2715

Missouri, St. Louis

575 Maryville Centre Dr.
St. Louis, MO 63141
(314) 674-1000

International Sales Offices

Europe

Solutia Europe SA
Avenue de Tervuren 270-272
B-1150 Brussels, Belgium
32-2-776-4111

Asia-Pacific

Solutia Australia Pty Ltd
Level 1, 437 Canterbury Road
Surrey Hills
Victoria 3127
Australia
Tel: 61-3-9888-4378
Fax: 61-3-9888-4562

Solutia Singapore Co.
(PTE). Ltd.
101 Thomson Road #19-00
United Square
Singapore 1130
65-250-2000

Solutia Japan Ltd.
Nihonbashi Daini Building
41-12, Nihonbashi
Hakozaki-cho
Chuo-ku, Tokyo 103
81-3-5644-1600 (Reception)

North America

Solutia Canada Inc.
2330 Argentia Road
Mississauga, Ontario
Canada L5M 2G4
(905) 826-9222
Solutia Comercial
SA de CV
Bosques de Durazno 61
3R Piso
Bosques de las Lomas
Mexico City, DF 11700
Mexico
525-251-2715

Solutia Inc.
575 Maryville Centre Dr.
St. Louis, MO 63141
USA
(314) 674-1000

South America

Solutia Argentina SAIC
Maipu 1210
6th Floor, Capital Federal
1006 Buenos Aires
Argentina
54-1-313-2429

Solutia do Brasil Ltda
Depto Saflex-Arquitetura
Rua Paes Leme 524
CEP: 05424-904
Sao Paulo SP
Brasil
(011) 817-6292

Solutia (Venezuela) CA
Avenida Francisco de
Miranda
Edificio Parque Cristal
Torre Este, Piso 8 Ofc 8-12
Los Palos Grandes
Caracas 1010 Venezuela
58-2-285-0944