

# Single-Number Ratings for Outdoor-Indoor Sound Insulation

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All of the single-number indices currently used to assess the sound insulation of walls use one-third octave band sound transmission loss data in the frequency range 125 to 4,000 Hz. Forty-two walls were measured over the range 50 to 5,000 Hz. None of the existing indices correlated well with the calculated 50- to 4,000-Hz loudness reduction using the International Organization for Standardization method. A new proposed rating, the outdoor-indoor transmission class (OITC), which is based on A-weighted sound reduction in the range 80 to 5,000 Hz, shows significant improvement over other methods. Typically, both the loudness reduction and OITC give lower numbers than sound transmission class for wall constructions.

Single-number sound insulation ratings have been used for many years to determine if the acoustical performance of interior walls between dwellings, offices, and rooms in general was adequate to provide speech privacy and control of radio and television sounds. The sound transmission class (STC) (1) and the International Organization for Standardization (ISO) weighted sound reduction index ( $R_w$ ) (2) were designed for these purposes, but they were never intended for use in describing sound insulation performance against outdoor traffic and other sounds with strong low-frequency content. Despite these limitations, these rating methods have been used many times to select and compare the performance of exterior walls, windows, and doors, with resultant failure to achieve satisfactory results. The limitations of STC and similar ratings when comparing the loudness reduction of a series of light-weight design walls in the range STC 30 to 69, which were measured for sound transmission loss (TL) at 50 to 5,000 Hz, are demonstrated, and an alternative rating method based on A-weighted sound reduction is offered (3). There were no data available below 80 Hz for exterior wall or window constructions; however, the range of constructions used is believed to be adequately wide.

## STATISTICAL STUDIES

Correlation between STC and the loudness reduction ( $D_L$ ) calculated using ISO 532B (4) was studied by linear regression for a series of 42 gypsum board and steel stud walls subjected to three assumed transportation sound spectra (5, 6) and speech (7) (Figure 1). The spectrum for railroad noise was unpublished (K. W. Walker, USG Corporation). The spectra have been moved relative to each other so that the shapes can be more easily seen. Figure 1 also shows an averaged spectrum that is used later. The slope, intercept, correlation coefficient,

and standard deviation of the slope were calculated for STC versus  $D_L$  for each sound source. The loudness of each source was calculated in phons(GF) (G indicates the calculation is based on critical bands, F designates a free field condition). Phons were obtained by calculating the loudness in sones in one-third octave bands, taking the logarithm to the base 2 of the sones, and adding 40, all in accordance with ISO 532B. The building interior sound levels were then calculated by subtracting the measured TL from the sound source one-third octave band levels for the 50- to 5,000-Hz range; no correction was made for room sound absorption. The indoor loudness was calculated in phons(GD) (D designates a diffuse field condition) and subtracted from the source phons(GF) to obtain the  $D_L$  value. Figures 2, 3, 4, and 5 indicate plots of STC versus  $D_L$  for each sound source and display the statistical data. STC is shown to work well for speech but is seriously deficient as a descriptor when used with the other sources. For example, with a Y-intercept of 15.2 and a slope of 1.094 in Figure 4, STC 50 corresponds to a  $D_L$  value of approximately 32 dB with a standard deviation of 6.1 dB. Thus, STC overestimates the loudness reduction by a significant amount and is inconsistent, preventing the adoption of a simple correction factor. Similar studies on  $R_w$  and the FAA's exterior wall rating (EWR) (8) have shown little improvement over STC even though  $R_w$  includes the 100-Hz one-third octave band.

## DEVELOPMENT OF THE NEW RATING METHOD

Several attempts have been made to develop an improved version of the STC method. STC is obtained by fitting a grading curve to the transmission loss graph of a wall. The grading curve is a contiguous series of three straight lines as shown in Figure 6. The curve is moved on the vertical axis so that no part lies more than 8 dB above the transmission loss curve, and the total of the transmission loss deficiencies below the grade curve (at the center frequencies) does not exceed 32 dB. When these requirements are satisfied, the STC is read from the intersection of the grade curve and the Y-axis at the 500-Hz center frequency. Figure 6 demonstrates the concept.

Changing the STC grading curve shape only or changing the curve fit method to be more controlled by the low frequencies was not useful because the standard test range does not go below 125 Hz. Some improvement was achieved by extending the range down to 50 Hz. Few laboratories have rooms of a size that permits reasonable test accuracy down to 50 Hz. Even if large rooms were available, when the wavelength is longer than the test wall dimensions, the transmission loss is largely controlled by the wall stiffness and is often

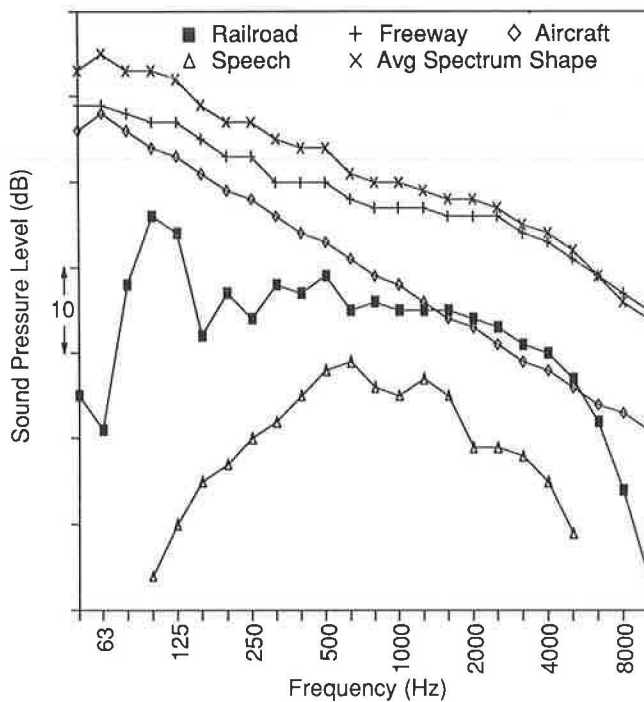


FIGURE 1 Four typical noise spectra and averaged spectrum used in study.

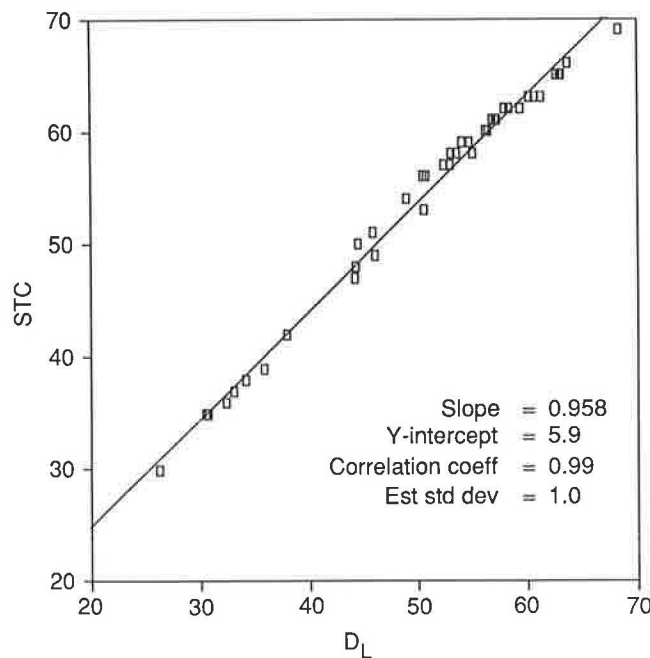


FIGURE 2 Scatter plot for STC versus  $D_L$  for speech noise source.

dependent on how the wall is tied into the surrounding test frame. The low-frequency TL dependence on the mounting method is significant because there is no way to ensure that the test wall stiffness can be replicated in the field, particularly in nonmasonry building structures. It is unreasonable to expect laboratories to provide data to 50 Hz on a routine basis, and even if available, the information would have a low credibility.

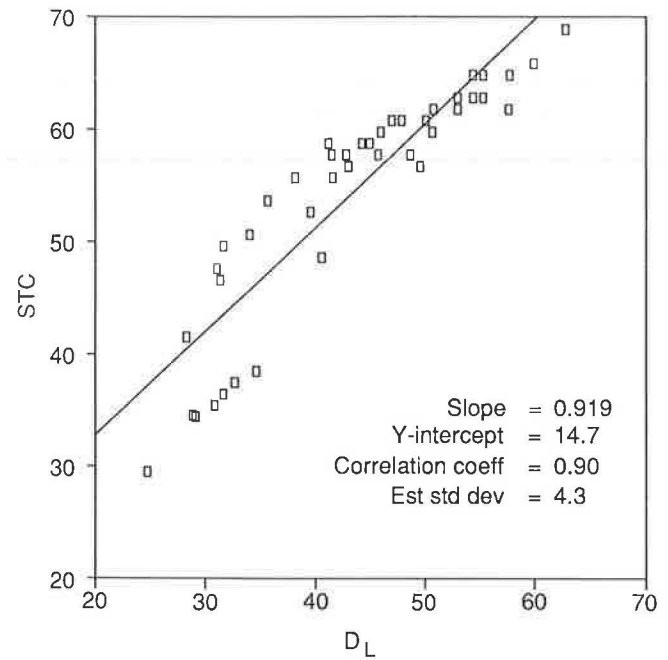


FIGURE 3 Scatter plot for STC versus  $D_L$  for railroad noise source.

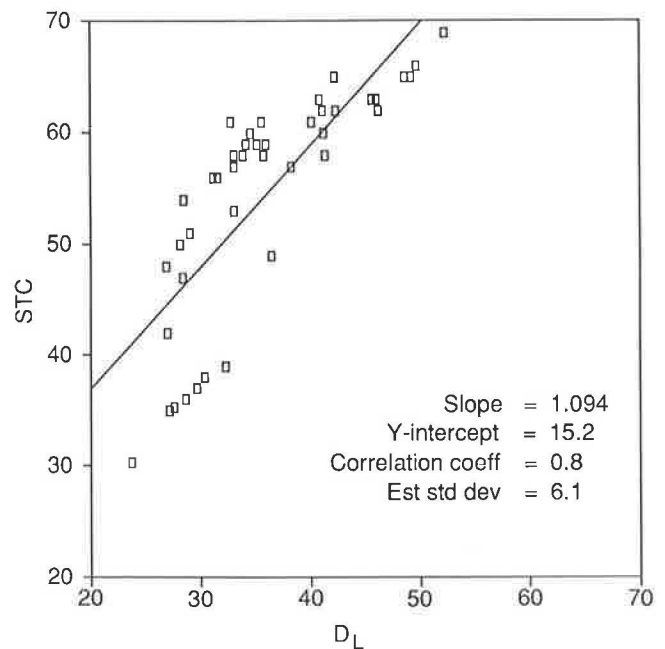


FIGURE 4 Scatter plot for STC versus  $D_L$  for freeway noise source.

Finally, it was determined that a calculation of A-weighted sound reduction provided a significantly improved correlation with  $D_L$ . A-weighted sound levels were calculated from Equation 1 by adding the corrections published in IEC 123 (9) to each one-third octave band sound level in the frequency range of interest and summing the corrected levels.

$$L = 10 \log \sum_f 10^{(SPL_f + W_f)/10} \quad (\text{dB}) \quad (1)$$

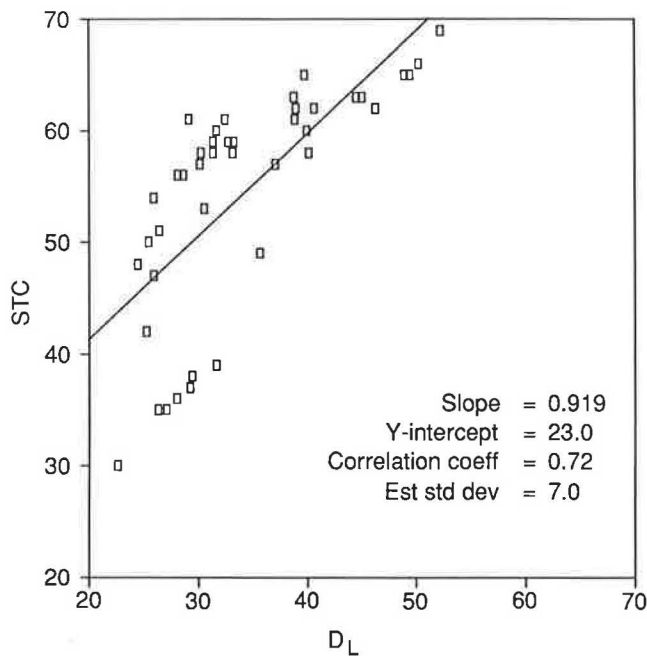


FIGURE 5 Scatter plot for STC versus  $D_L$  for aircraft noise source.

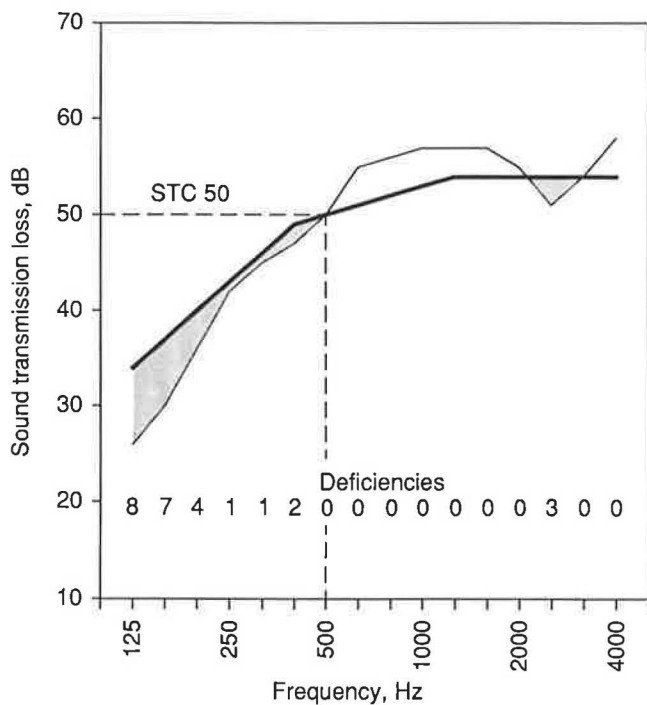


FIGURE 6 Application of the STC grading curve as described in ASTM E 413. The rating for the sound transmission loss graph in this example is STC 50.

where

$L$  = A-weighted sound level,

$f$  = one-third octave bands in the required frequency range,

$SPL_f$  = sound pressure level in each frequency band, and

$W_f$  = A-weighting correction for each frequency band.

The A-weighted sound level  $L_s$  for each source was calculated using Equation 1.  $L_r$  for the receiving side of each wall was obtained by substituting  $SPL_{rf}$  for  $SPL_f$  in Equation 1,  $SPL_{rf}$  being derived from

$$SPL_{rf} = SPL_{sf} - TL_f \quad (\text{dB}) \quad (2)$$

where  $SPL_{rf}$  is the sound level on the receiving side,  $SPL_{sf}$  is the sound level on the source side, and  $TL_f$  is the partition sound transmission loss for each one-third octave band.

The A-weighted sound reduction afforded by each wall is then

$$L_s - L_r \quad (\text{dB}) \quad (3)$$

Initially, a set of A-weighted reductions for each source was calculated for the range 80 to 5,000 Hz and correlated with  $D_L$  to determine the relationship. The data are presented in Table 1. In each case, the correlation with transportation noise was much better than for STC, and the correlation with speech was almost as good. Because it would not be reasonable to routinely perform calculations for every type of sound source, the three selected outdoor sound spectra were equalized in dBA level, and then sound intensity averaged to get the averaged spectrum shape shown in Figure 1. The A-weighted sound reduction using the averaged spectrum, designated outdoor-indoor transmission class (OITC), is then

$$\text{OITC} = L_s - L_r \quad (\text{dB}) \quad (4)$$

Separate OITC ratings were then calculated for each wall for each of three frequency ranges 50 to 5,000 Hz, 80 to 5,000 Hz, and 100 to 5,000 Hz and correlated with  $D_L$  for each sound source. Table 1 presents the statistical data.  $D_L$  is always calculated for the full 50- to 5,000-Hz range. The OITC value calculated for the 80- to 5,000-Hz range correlates with each transportation sound source to better than 0.9 and has much improved intercept and standard deviation characteristics than does STC. The ideal would be a slope of 1.0 and zero intercept, with a correlation of 1.0 and zero standard deviation. The 80- to 5,000-Hz range is significant because it extends only one-third octave lower than traditional measurements and would require only minor changes to current measurement standards. The statistics for the 100- to 5,000-Hz range are not acceptable for the aircraft noise source; however, the range could be used temporarily until 80-Hz data become available. OITC is still a significant improvement over STC or  $R_w$ .

TABLE 1 CORRELATION OF A-WEIGHTED SOUND LEVEL REDUCTION (80-5,000 Hz) WITH LOUDNESS REDUCTION (50-5,000 Hz)

Spectrum	Slope	Y-Intercept	Correlation	Standard Deviation of Slope
Railroad	0.871	6.6	1.00	0.8
Freeway	1.118	2.6	0.95	2.6
Aircraft	1.001	3.9	0.94	2.9
Speech	0.995	4.7	0.98	1.8

TABLE 2 CORRELATION OF OITC WITH LOUDNESS REDUCTION (50–5,000 Hz)

Spectrum	50–5,000 Hz				80–5,000 Hz				100–5,000 Hz			
	Slope	Y-Intercept	Correlation	Standard Deviation of Slope	Slope	Y-Intercept	Correlation	Standard Deviation of Slope	Slope	Y-Intercept	Correlation	Standard Deviation of Slope
Railroad	0.871	2.9	0.96	2.1	0.999	0.8	0.99	1.1	1.007	2.4	0.99	1.0
Freeway	1.051	0.4	0.99	0.9	1.120	1.0	0.95	2.6	1.081	4.2	0.91	3.4
Aircraft	1.078	4.3	0.98	1.6	1.113	6.2	0.91	3.5	1.050	10.1	0.85	4.4
Speech	0.603	7.2	0.82	4.3	0.727	4.0	0.90	3.8	0.766	3.8	0.94	2.9

## CONCLUSIONS

STC and (by implication)  $R_w$  ratings are not effective for characterizing the effectiveness of walls in providing protection from transportation noise. Calculation of loudness reduction in phons is complex, requiring graphic interpretation or a computer program. Use of frequency band limited A-weighted sound reduction based on a fixed spectrum shows promise. The calculation of A-weighted reduction is simple and the rating is relatively easy to explain to the layman. Until transmission loss data in the 80-Hz one-third octave band are available, the method could temporarily use the 100- to 5,000-Hz range. Further limitation to 3,150 Hz would result in little change in the OITC value. Because OITC has not been verified with sounds other than those described in this paper, its use should be limited to transportation noise until further statistical work is performed. This study has dealt only with loudness; no correlation between OITC and speech interference from transportation noises has been established.

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