Sound Transmission Class – Field Testing and Results

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This article presents the results of field measurements that were made using a simplified version of the data collection procedure presented in ASTM E336-96, which is used to determine the sound transmission class (STC). This simplified approach provides a less tedious and more efficient method of estimating the sound insulation of partitions and pathways. Several factors are examined, including the effect of speaker type and location, source signal type, room geometry, type of microphone and placement. All of these influence the collection of the transmission loss measurements used in determining STC ratings. The spatial variation and repeatability of measurements on a particular partition and a comparison of results collected on a similar partition under different field conditions are also included to demonstrate a practical application of the STC method.

Sound transmission class (STC) is a method commonly used in architectural acoustics and noise control problems to provide a single number rating to the speech privacy of common building partitions. The rating is determined by measuring the transmission loss (TL) of the partition of interest and then applying a curve fitting procedure as outlined by ASTM standards.

While these standards provide a highly detailed data collection and processing procedure, they give limited insight into the type of response and deviation that may be expected from actual field measurements. Likewise, there is a tremendous amount of discussion in the literature on this topic, with some attempts to relate STC values to human perception and to provide ratings for common partitions. However, what is generally lacking is a detailed discussion involving the collection of field data under real conditions.

The focus of this article is to relate the results of field measurements from a simplified version of the data collection procedure presented in ASTM E336-96 to the theoretical STC presented in the literature. This simplified procedure is an attempt to provide a less tedious, more efficient method of estimating the sound insulation of partitions and pathways. In particular, the effect of speaker type and location, source signal type, recording time, room geometry, type of microphone and placement, the spatial variation and repeatability of measurements on a particular partition and a comparison of results collected on a similar partition under different field conditions are analyzed and discussed in detail.

STC Theory

The calculation of an STC rating* involves the careful measurement of the field (as opposed to laboratory) TL for a particular partition or pathway, which can be most precisely done following ASTM standards.[1] A curve fitting procedure, also defined in the standards, is then applied to achieve an STC value.[2] As there is detailed discussion in the literature with regard to this procedure[3-5] as well as in the standards,[2] the actual calculation will not be discussed in this article. However, Table 1 summarizes the general interpretations and conclusions that can be drawn from a particular STC value.

Background

Test Areas. We chose three different test areas to perform TL measurements. Rooms included a square conference room, a rectangular storage room and an office. These three spaces included a number of different room sizes, shapes and constructions. Details regarding each test area as well as their layouts are included in the following sections.

Square Conference Room. Figure 1 is a layout of the square conference room test area along with the 11 corresponding interior and exterior microphone positions (9 in the source room and 11 in the receive rooms) used for the TL measurements. Positions within the source room are given a number, and the corresponding microphone positions in the receive room are given the same number and a ′ or prime symbol. Some microphones in the source room have two corresponding microphones, each in different receive rooms. The second of these receive room positions receives a ″ or double-prime symbol. This nomenclature will be used throughout this article to provide a reference for discussing the results of individual TL measurements. The square conference room contains a number of common partitions, which might be encountered during field measurements, including a gasket-sealed door, a door without a gasket-seal, cinder block firewall, bathroom tile wall and sound-insulated 2-layer 1/2-in. gypsum board walls.

Rectangular Storage Room. Figure 2 shows the rectangular storage room test area along with the six corresponding interior and exterior microphone positions. The rectangular storage room contains a number of common partitions, including a cinder block firewall, a door without a gasket-seal and 2-layer 1/2 in. gypsum board 'regular' walls.

Office Room. Figure 3 shows the layout of the office room test area along with the eight corresponding interior and exterior microphone positions. The office room contains a number of common partitions including three 2-layer 1/2-in. gypsum board walls, a cinder block firewall and a door without a gasket-seal.

Test Equipment and General Setup

As the ASTM standards are not specific for the loudspeaker source, only requiring that it should "radiate sound over a wide angle,"[1] two different loudspeakers including a Norsonic, Inc., Nor 250 omnidirectional architectural acoustics testing speaker and a Community CSX43-S2 conventional loudspeaker[1] were used. The omni speaker was always placed at the geometric center of the source room as designated by the speaker's design,[6,7] and the conventional speaker was placed facing a cor-

Table 1. Typical hearing quality for a wall of rated noise isolation class STC.[4]

STC Value	Hearing Quantity
25	Normal speech can be heard quite easily and distinctly.
30	Loud speech can be understood fairly well; normal speech can be heard but not understood.
35	Loud speech can be heard but is not intelligible.
42	Loud speech is audible as a murmur.
45	Loud speech is not audible.
50	Very loud sounds such as musical instruments or a stereo can be faintly heard.

*STC values for common materials or partitions reported in the literature generally reflect the results of measurements made under laboratory conditions. The actual measurement of a partition's STC under field conditions will generally be different due to the contribution of flanking and ambient noise, which can be difficult to characterize or control. However, both of these factors must be considered to provide as accurate an FSTC (field sound transmission class) for a particular partition as possible. Also, the STC value of a partition separating two measurement positions while only considering the contribution of ambient noise is technically referred to as noise isolation class or NIC. This distinction will not be made in this article, but should be recognized by the reader.

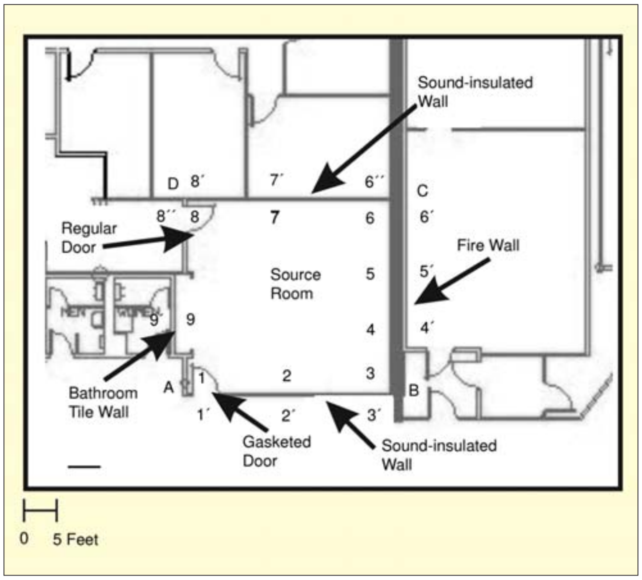

Figure 1. Layout for the conference room test area. Included are the microphone positions used for the TL measurements. Corners are labeled A, B, C or D for reference.

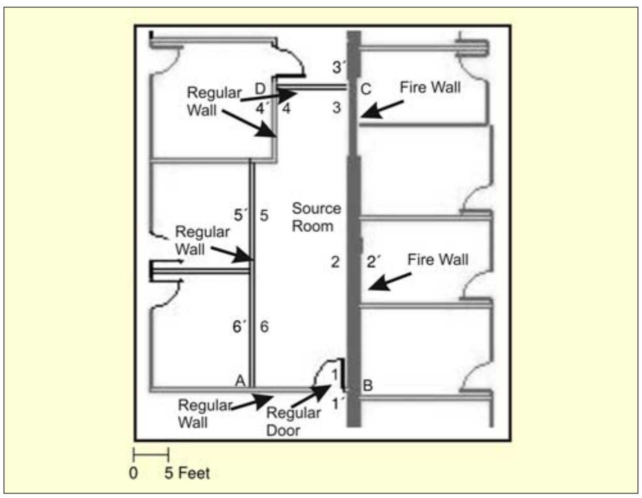

Figure 2. Layout for the rectangular storage room test area. Included are the microphone positions used for the TL measurements. Corners are labeled A, B, C or D for reference.

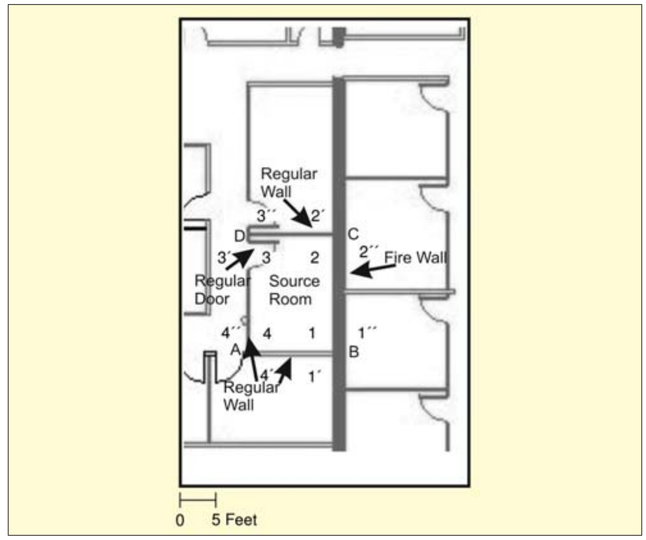

Figure 3. Layout for the office room test area. Included are the microphone positions used for the TL measurements. Corners are labeled A, B, C or D for reference.

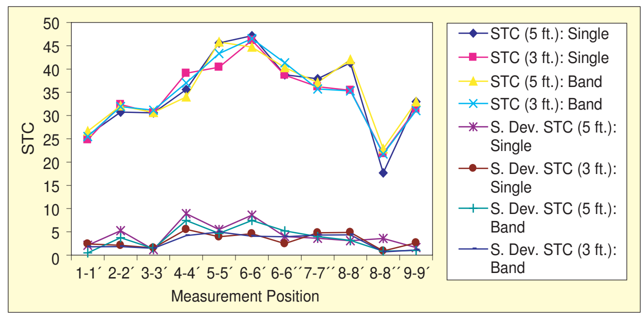

Figure 4. STC measurements for each position (Figure 1) in the square conference room for white noise excitation and omni speaker.

ner at a distance of 1.5 ft to help create a more dispersed sound field within the room, assuring that measurements would not be made within the direct field of the speaker.[1,3,6] The corner in which the speaker was placed will be referenced where relevant. Pink and white noise, at approximately 115 dB (nonweighted) as measured at a distance of 1 ft from the speaker, were used as room excitation sources.

The microphones, which were 'free-field,' were placed inside and outside of the source room(s), as recommended by the ASTM standards,[1] and every effort was made to keep the microphones approximately 3.1 ft away from any extended surface (walls, ceilings and floors) and oriented perpendicular to the closest wall and directed toward the source. However, exceptions had to be made for some measurements (exterior microphone positions in the hallways, for example) along with certain modifications to the requirements. In these cases, the microphone was always placed 3.1 ft away from the partition in the path between the microphones in the source and receive rooms. Microphones were also placed at heights of approximately 3 and 5 ft from the floor (for simplicity) and were spaced, when possible, in strict accordance with the standards. Previous experiments showed that these minor changes from the standard were reasonable and provide satisfactory results. All receive room measurements were made with the doors shut in both the source and receive rooms. The only exceptions were measurements made in the square conference room across the firewall, as the door to the room containing the exterior microphone positions could not be closed on the cables used for measuring.

Data Acquisition. The data collection system and software were engineered in-house, and were used to sample the sound field with two channels simultaneously at a sampling rate of 50 kSPS, for a total of 8192 samples per channel. This sampling rate provided sampling at greater than two times the maximum frequency of interest (4 kHz) so that appropriate amplitude information could be collected. Also, to enable long-term averaging of data, 8192 multiple, successive sample clips were collected at each position.

Data Analysis. We analyzed the data using one-third octave frequency bands, along with individual one-third octave frequencies (previous related research at ENSCO involved using individual tones as a source in addition to white and pink noise) extracted from the recorded sound field. The one-third octave frequency bands and frequencies were chosen to match the standards, which we also followed to calculate an STC value for TL data acquired at each measurement position.[2]

Transmission Loss Measurement – Square Room

Measurements were made in the square conference room using the omni speaker (emitting white and pink noise) and the conventional speaker (white noise). While emphasis was placed on TL measurements made using white noise, the results from the data collected with pink noise are included for comparison as pink noise is commonly used for architectural acoustic measurements.

Figure 4 is a plot of the STC values (averaged for all the sample clips collected at each location) calculated using one-third octave bands ('band') and individual one-third octave frequencies ('single') along with the standard deviation of the

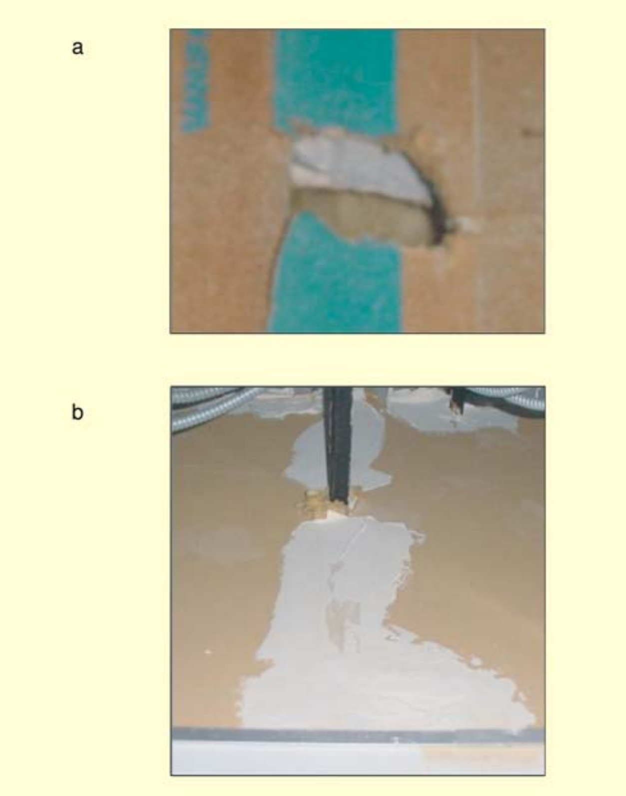

Figure 5. Picture of the 1-in. square hole found on the inside of the conference room (a) and 4-in. square patch (tape and spackling) on the front wall of the square conference room (b).

STC values for all of the collected sample clips. Measured values around 25 at the front doorway (1-1′) indicate a relatively poor degree of privacy. Along the insulated front wall (2-2′ and 3-3′), STC values of 30 indicate a moderate degree of privacy. Along the cinder block firewall we obtained an interesting set of variations. At station 4-4′ we obtained STC values of 35 to 40. Moving to stations 5-5′ and 6-6′ we received values of 40-45 and approximately 45, respectively. While these all indicate a high degree of privacy, the variation is significant. However, this variation can be attributed to an open door in the receive room, which could not be closed during the measurements, that has increased the contribution of acoustical flanking. Along the back wall, positions 6-6″, 7-7′ and 8-8′, we get consistent values of 35-40, indicating good privacy. These values are significantly better than the front wall readings although the construction of these two walls is similar. At the rear door – station 8-8″ – values around 20 were measured. This indicates an unacceptable degree of privacy and it is explained by the door itself, which has badly deteriorated gaskets and a missing floor sweeper. On the bathroom side wall, station 9-9′ had STC values around 32-33, indicating a fair degree of privacy.

With the exception of the doorways, three sides of the room were constructed with insulated sheet rock and should provide equivalent performance. In fact, the back wall STC 35-40, bathroom wall STC 32-33 and front wall STC 30-33 show significant variation. The reduced performance in the bathroom is probably due to the highly reflective surfaces within the bathroom as it has tiled walls and floor. The poor performance of the front wall might be attributed to a hole in the partition that was 1 in. on the inside wall of the room and 4 in. on the other side of the wall (Figure 5), which is a little less then 0.1% of the total area of the wall partition (resulting in around a 10 dB drop in performance[4]). This is a possible cause for the decreased STC values in the front wall due to the increased flanking that would result.

The square conference room offers the unique opportunity to examine several different types of walls and other noise pathways (doors) under identical field conditions (room geometry, ambient noise level, etc.). The results observed in the TL data help clarify a number of questions regarding the repeatability of STC measurements including the repeatability along a single partition, the ability to discriminate between different types of partitions and how well two sets of measurements made along similar partitions within the same room directly compare.

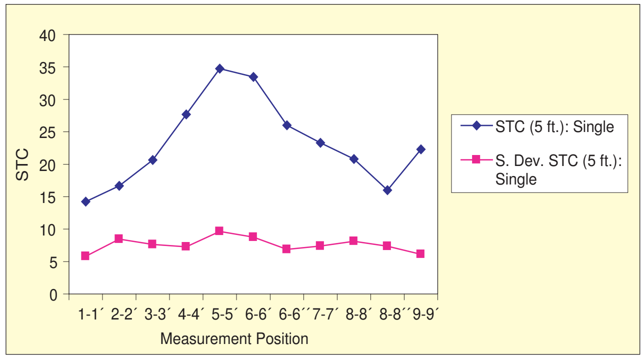

Figure 6. STC measurements for each position (Figure 1) in the square conference room for pink noise excitation and omni speaker.

The repeatability of measurements along a partition is clearly possible (depending on the level of accuracy required). Measurements 6-6″, 7-7′ and 8-8′ all show excellent agreement as they all fall within 5 dB of each other. Measurements 2-2′ and 3-3′ also support this conclusion, as they both show a high level of repeatability for the 3- and 5-ft measurements (all within 2 dB), even though they have a lower STC than expected.

The ability to clearly discriminate a number of different pathways has also been shown. For example, the regular door is clearly predicted as a weak point in the room (STC 17 through 22). All of the other measurements show an acceptable ability to discriminate between poor insulators (regular and gasket-sealed door), moderate insulators (front wall measurements 2-2′ and 3-3′), good insulators (back wall measurements 6-6″, 7-7′ and 8-8″) and excellent insulators (firewall measurements 5-5´ and 6-6′). The only measurement within question is 4-4′, whose drop in expected performance is explained by the lowered insulation of the front wall as well as the partially open door of the receive room.

It is not always possible to directly compare measurements along the same type of partition within the same room. For example, measurements made along the sound-insulated front wall are not consistent with STC values obtained for the back wall. This demonstrates that the results from one partition cannot automatically be assumed to be the same as those that would be obtained along a similar partition, even under the same field conditions. Therefore, if the complete characterization of a room is desired, all walls and partitions must be measured.

Figure 6 is a plot of the calculated STC values using pink noise and the omni speaker for the 5-ft microphone heights. It verifies all of the observations made using white noise although its emphasis on the lower frequencies tends to produce lower STC numbers which do not as accurately characterize the level of acoustical insulation (as determined by the subjective opinion of the author). In particular, it supports the conclusion that pathways 5-5′ and 6-6′ offer a higher level of privacy compared to the other pathways even though pink noise emphasizes lower frequencies, which generally do not have as high an attenuation rate. And while position 4-4′ also shows a lower STC for pink noise, this supports the conclusion that there is probably some degree of acoustical flanking occurring within the structure separating the two rooms, particularly in the lower frequencies.

TL curves were also collected using the conventional speaker so that a comparison could be made with the omni speaker. For measurements made along the front sound-insulated wall, the speaker was placed in corner D (Figure 1) and the firewall and for all other measurements was placed in corner B.

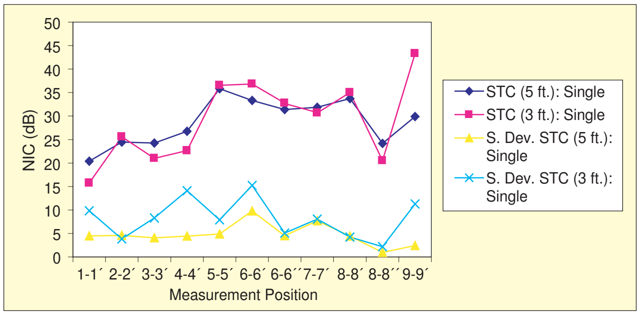

Figure 7. STC measurements for each position (Figure 1) of the square conference room and a conventional speaker.

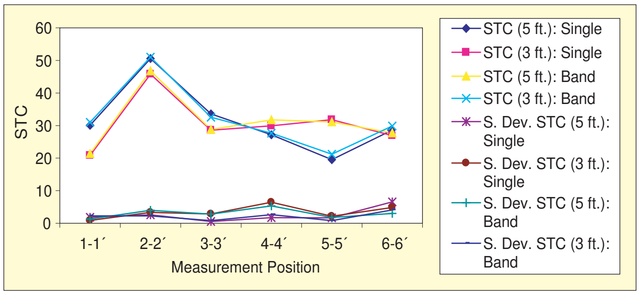

Figure 8. STC measurements for each position (Figure 2) in the rectangular room for white noise excitation and omni speaker.

Figure 7 is a plot of calculated STC values using the conventional speaker as the source. The STC values do not show the same magnitude and are not consistent with the results obtained with the omni speaker. This can probably be attributed to the positioning of the speaker so close to the walls and to the higher SPL that was attained (reported as high as 127). The combination of these two factors (especially the proximity to the wall) would have excited a higher degree of vibro-acoustical energy within the room structure. These numbers are not as realistic and are potentially unreliable given the generally high standard deviation, which can reach a maximum of 10 dB.

While the conventional speaker demonstrates the ability to discriminate between different partitions in the room in a relative sense, it also shows the potential for offering erroneous results (in particular, positions 9-9′ for the microphone placed at 3 ft) and the decreased ability to properly rate highly insulated walls (the fire-walls).

Transmission Loss Measurement – Rectangular Room

Data were collected in the rectangular room with the omni speaker using white noise excitation. As was the case with the square conference room, one-third octave band and individual one-third octave tones were used in calculating the STC values. Figure 8 is a plot of the STC values for the rectangular room along with the standard deviation of the calculated STC values using all of the sample clips.

A clear distinction is made between the firewall, regular office walls and the regular door. The office walls all rate at around STC 30 but fall as low as 20 (generally for measurements made closer to the bottom of the doorway). The firewall provides a model for privacy and rates as high as 50 and only as low as 47. Also of interest is the higher level of stability in the measurements, as demonstrated by the lower standard deviation. As with the square conference room, a number of different types of walls were tested, many of which are the same type of construction, and allow for direct comparison under different field conditions. For example, position 1-1′, which is a door without a gasket seal, shows better performance than the standard door in the square conference room, although a difference of approximately 3 would not be noticeable to the average listener.[3]

The STC values within the room show a high level of agreement for the regular walls for all measurements and similar STC values between the 3- and 5-ft measurements made along the firewall. Although some deviation does exist, it is entirely acceptable.

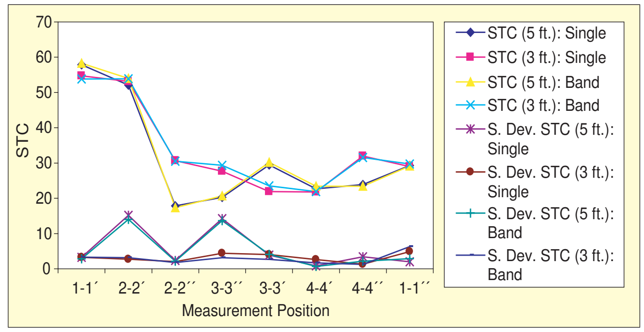

Figure 9. STC measurements for each position (Figure 3) in the office room for the omni speaker.

When comparing the results from the front wall of the square conference room to the values obtained for the regular walls of the rectangular storage room, it becomes clear that the decrease in the overall ratings makes its performance only slightly better than the regular walls. This indicates that while their construction may be quite different, their behavior is very similar. This further supports the conclusion that values achieved for one type of partition in a room may not represent the level of acoustical privacy afforded by all of the partitions within the room.

Transmission Loss Measurement – Office

Data were collected in the rectangular room with the omni speaker using white noise excitation and the results were consistent with the square conference room and the rectangular room. In particular, measurement positions 1-1″ and 2-2″ (Figure 9), which have an STC rating between 52 and 58, respectively, show a high level of discrimination in comparison to the other office-type walls. The regular walls within the office room behave in a manner that is consistent with the level of sound privacy that would be expected, given their construction. And while the STC ratings calculated for the office walls are somewhat erratic, there is never a case where they rate higher than should be expected. This deviance also supports the conclusion that the measurement of a single partition may not provide proper characterization of similar walls within the room.

The STC values achieved for the office room support the assumption that a reasonable degree of repeatability can be achieved for measurements made on similar partitions under different field conditions. In particular, the fire-walls rate (as they have in the other two cases) at a very high level of acoustical privacy, although increased performance may indicate better construction in comparison to the other two cases (they are somewhat higher). The regular walls again rate between 20 and 30, indicating a relatively low level of privacy expected from the regular office walls. However, an overall comparison of the results indicates that under the appropriate field conditions, meaningful, repeatable and comparable results can be achieved from one location to the next.

Conclusions

Test Signals. Pink noise excitation does not provide the appropriate resolution between different types of partitions in terms of their sound insulation potential when compared with white noise. STC values provided by the pink noise are also unrealistic when compared to the qualitative descriptions[4] and tend to underestimate the sound insulation capabilities due to increased emphasis on the lower frequencies.

Uniformity of the Sound Field – Omni Versus Conventional Speaker. While the standards[1] do not provide a requirement for the speaker, the increased consistency that is gained with an omnidirectional speaker is significant. In terms of a reliable STC value, an omnidirectional speaker should be used, if available.

Room Geometry. The geometry of a room, in the case of the three rooms tested, has less of an effect on the sound field than the type of speaker and source used or the placement of the microphones. Therefore, if a white noise source is used along with the omnidirectional speaker and the appropriate considerations are made for microphone placement, the room geometry is not the dominant factor influencing the results.

Microphone Considerations. The number and placement of microphones is a crucial factor to successful TL or STC data collection. Due to the inherent level of variance that was observed in the results, the placement of microphones and the number used for characterizing a room must be carefully considered for meaningful, repeatable results.

Placement. The ASTM recommendations regarding placement of microphones within close proximity of an extended surface (wall or door) should be followed as strictly as possible. Microphones should not be placed any closer than 3.1 ft from the extended boundary separating two measurement positions. Also, the ASTM requirement of microphone separation of 3.1 ft should also be followed as closely as possible for proper spatial sampling. However, as was the case with the rectangular and office rooms, the number of measurement positions should not be sacrificed to meet this requirement.

Number of Positions for a Partition. The number of microphones on either side of a partition is as crucial an issue as their placement. It is not possible to completely eliminate microphone position-dependent variability from acoustic test results. Often, as the objective of making acoustical measurements in a room is to quantify the level of privacy that it offers in a time-efficient manner, the standard deviation for the STC calculations is of critical importance. The standard deviations, including the average, maximum and minimum, observed for the calculations made for the three rooms using white noise and the omni speaker, were found to be 3.6, 15 and 0.5 dB, respectively. These values indicate that one standardized measurement might be acceptable with an average accuracy of less than 4 dB. However, a maximum deviation, which was found for the firewall (2-2′) in the square office, indicates the potential for instability in making TL and STC-type measurements. Therefore, the number of microphone positions that should be used to properly characterize a partition, suspected to be a good insulator (properly gasket-sealed doors, fire walls, sound-insulated walls, etc.), should be at least 4 (ASTM recommends a minimum of 6), since, in general, it was found that a more significant standard deviation was reported for partitions that offered a higher degree of insulation. One properly placed microphone position may be used for partitions that are of moderate-to-low sound insulation (office walls and normal doors, etc.) for maximum time efficiency.

Time. A minimum number of sample clips may not be necessary for a well behaved field site, as was the case with the rectangular room and the office where an average of approximately 9 clips were used. For an environment that is not well behaved to be comparable, a minimum of 9.9 sec (with an error level of ±0.5 dB for 125 Hz) of recorded data should be used, as required by the standards.[1]

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