5aNSb1. Evaluation of proposed ASTM standard to measure the normalized insertion loss of doors

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There is currently no ASTM method for field measurement of the acoustical noise isolation specific to doors. Measurement of the overall noise reduction of the composite wall/door assembly or the Apparent Sound Transmission Class of the door can be attempted using the methods in ASTM E336, but these methods are not well suited to measuring doors. Doors typically have poorly defined source and receiving rooms, such as long and narrow corridors, stairwells, or outdoor spaces, which often do not meet the room requirements of ASTM E336. The sound fields are rarely diffuse, and the measurement locations are not well defined in the ASTM standard. An alternative insertion loss method (i.e., a comparison of the sound pressure levels with the door open and closed) was developed by MJM Acoustical Consultants (Michel Morin, "Research project on the noise isolation provided by access doors in multi-dwelling buildings," 1993), and a draft ASTM standard has been developed based on this method. A laboratory testing program has been designed to evaluate the proposed method and investigate variations in the test method. The results of the laboratory testing program are presented.

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MOTIVATION

There are no existing test methods for field measurements of airborne noise insulation intended for doors. Using the methods and metrics of ASTM E 336\(^1\), one option is to measure the Apparent Sound Transmission Class (ASTC) of the door, but this method is not well suited to measuring doors. The spaces on either side of a door are typically poorly defined, such as long and narrow corridors, entries, stairwells, or outdoors. One or both spaces is typically too small or too absorptive to meet the requirements for measuring ASTC per ASTM E 336. Because the sound field on the receiving side is often non-diffuse, the measurement results can vary depending on where in the room the engineer chooses to measure the receiving room, and the ASTM standard provides no guidance. Even if the measurement can be performed according to the standard, it remains a measurement of the composite wall/door assembly.

An alternative measurement method was described by Michel Morin\(^2\) in 1993. (The motivations mentioned in that document involved the awkwardness and time involved in measuring the absorption in the receiving room.) A proposed ASTM test method, “Standard Test Method for Measurement of the Normalized Insertion Loss of Doors,” is being developed to formalize the method, which is based on Morin’s basic procedure. However, no additional studies had been conducted, to our knowledge, since the first studies were performed in 1993. To evaluate the proposed method, a testing program has been performed on two doors. The intent of the testing program is to compare the measured results to the traditional STC ratings in a laboratory, controlled testing environment. These results could be used to evaluate if field tests using the method will yield results that are correlated with the laboratory acoustical ratings, while providing a potential test method that resolves some of the ambiguity associated with the ASTM E336 method. The method is an acoustical measurement specific to doors that can be conducted in spaces that do not meet the requirements set forth in the existing standard.

METHOD

The method in the proposed standard is a normalized insertion loss (NIL) measurement, defined as follows

\[
NIL = (L_{\text{rec open}} - L_{\text{rec closed}}) + (L_{\text{source closed}} - L_{\text{source open}})
\]

where \(L\) is the average sound pressure level measured in the receiving or source room (indicated by subscripts “rec” and “source”, respectively) with the door specimen in the open or closed position (indicated by the second subscript). The first term in Eq. (1) is the insertion loss of the door. The second term is a normalization term to compensate for any changes in the sound field in the source room due to opening the door. Morin indicates that the NIL is equivalent to the transmission loss (TL as defined in ASTM E90\(^3\)) “since it represents the difference between the sound energy incident on the door and the sound energy transmitted through it.”\(^2\) The draft standard also proposed a single number rating called Door Transmission Class (DTC) is calculated from the NIL in each third octave band in the same manner as Sound Transmission Class (STC) per ASTM E 413\(^4\).

The sound pressure levels are averaged from six microphone locations (nine if the door is more than one meter (3.28 feet) wide) arrayed in a rectangle one meter in front of the door with the microphone diaphragm parallel to the door. The proposed standard does not specify how far the door is to be opened; for this testing the door was opened 180 degrees (parallel to the laboratory filler chamber wall).

In addition to performing the tests as described in the proposed standard, measurements were performed using a swept microphone measurement to determine the accuracy of that method and compare with the proposed method. The swept method performed by scanning a microphone approximately 1 m from the door surface tracing the rectangle defined by the fixed microphone positions. The acoustical testing was then repeated with acoustical absorption added to both source and receiving chambers to emulate various field conditions. The goal was to determine if field testing using this method would correlate with the laboratory method and to complete this under controlled conditions.

Two doors were tested, with nominal STC ratings of 25 (a light weight vision door provided by Jeld-wen) and 39 (a heavy steel door provided by Krieger) as measured by Western Electro-Acoustic Laboratory (WEAL). Testing was performed at (WEAL) in Santa Clarita, California in December 2012 and January 2013. WEAL is accredited for performing tests in accordance with ASTM E 90.

For each door, the testing procedure was as follows. The door was installed in WEAL’s transmission loss test suite and a standard TL test was conducted per ASTM E 90. In the normal condition of the test chambers (i.e. no
modification to the absorption within either source or receiving chamber), defined as “hard” within this paper, the reverberation times are around 3.5 to 4 seconds in the mid-frequencies. Then the Normalized Insertion Loss (NIL) – was measured in accordance with the proposed ASTM standard. In addition, an insertion loss test was performed using the swept method. Each scan was performed in approximately 15 seconds. A scan was completed on each side of the door with the door in the open position and then repeated for the door in the closed position. This same sequence of tests (standard TL test followed by a fixed microphone insertion loss test and a scanned microphone insertion loss test) was performed for 9 different room absorption conditions.

Absorption was added to lower the reverberation times to around 2 seconds in the mid-frequencies (defined as “medium” within this paper). Additional absorption was added to further lower the reverberation time to below 1 second in the mid-frequencies (defined as “soft” within this paper). The 9 acoustically measured absorption conditions are shown in Table 1. At the end of the 9 runs, an additional standard TL test was conducted with the hard-hard conditions.

### TABLE 1. TL and NIL Measurement Absorption Conditions in the Source and Receiving Room

<table>
<thead>
<tr>
<th>Condition</th>
<th>Source Room</th>
<th>Receiving Room</th>
</tr>
</thead>
<tbody>
<tr>
<td>HH</td>
<td>Hard</td>
<td>Hard</td>
</tr>
<tr>
<td>HM</td>
<td>Hard</td>
<td>Medium</td>
</tr>
<tr>
<td>HS</td>
<td>Hard</td>
<td>Soft</td>
</tr>
<tr>
<td>MH</td>
<td>Medium</td>
<td>Hard</td>
</tr>
<tr>
<td>MM</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>MS</td>
<td>Medium</td>
<td>Soft</td>
</tr>
<tr>
<td>SH</td>
<td>Soft</td>
<td>Hard</td>
</tr>
<tr>
<td>SM</td>
<td>Soft</td>
<td>Medium</td>
</tr>
<tr>
<td>SS</td>
<td>Soft</td>
<td>Soft</td>
</tr>
</tbody>
</table>

### RESULTS

Effects of Source and Receiving Room Absorption on TL and NIL

The results for both TL and NIL are largely insensitive to the amount of absorption in either the source or receiving rooms. Figure 1 shows the TL spectra for Door 2 for all 9 absorption conditions. Similar results (not shown) were measured for Door 1, and for NIL measurements of both doors. Since both of the metrics include a normalization term, this was clearly an anticipated result. Not only does changing the absorption have a small effect, there is no apparent trend or correlation between amount of absorption and TL or NIL. In analyzing the remaining variables and knowing that the change in absorption does not affect the TL or NIL significantly, we can average the data measured over all of the absorption conditions. The averaged results are shown in Table 2. Figure 1 and Table 2 clearly show that both the TL spectra and STC ratings, when averaged over all the absorption conditions, are very close to the “correct” values that would be measured using the ASTM E 90 standard, defined as those obtained when measuring per the standard. Note that the standard E 90 measurements are the same as the “hard-hard” (HH) condition.
FIGURE 1. TL spectra for Door 2 for all 9 absorption conditions. (HH condition was repeated.) The absorption conditions are described in Table 1.

TABLE 2. Average and standard deviation of STC and DTC results for both doors. The first row shows the results of the two STC tests performed according to ASTM E 90. The remaining three rows show averages over all nine absorption conditions in Table 1. “Fixed” and “scanned” refer to using fixed microphone positions or a moving microphone method to measure the sound pressure levels.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Door 1 Average</th>
<th>Door 1 St. Dev.</th>
<th>Door 2 Average</th>
<th>Door 2 St. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>STC per standard (HH)</td>
<td>25.25</td>
<td>-</td>
<td>38.39</td>
<td>-</td>
</tr>
<tr>
<td>STC averaged</td>
<td>25.7</td>
<td>0.7</td>
<td>38.9</td>
<td>0.3</td>
</tr>
<tr>
<td>DTC fixed</td>
<td>24.7</td>
<td>0.5</td>
<td>38.1</td>
<td>0.9</td>
</tr>
<tr>
<td>DTC scanned</td>
<td>25.1</td>
<td>1.3</td>
<td>37.6</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Comparison to Transmission Loss

As Table 2 shows, the DTC is very close to the STC for each door. The third-octave spectra of the differences are shown in Figure 2. The difference between the TL and NIL at each frequency band was calculated for each of the 9 absorption conditions, and the averages (solid lines) and standard deviations (dashed lines) plotted. Positive differences mean that the measured TL was higher than the measured NIL. Overall the differences are small given the type of measurement, less than 1 dB at many frequencies and less than 2 dB at almost all frequencies. However the differences are not random. We have the following observations.
There is an overall positive bias to the differences, such that the STC is slightly higher than the DTC. The difference is less than 1 dB, which is probably smaller than the uncertainty in an individual STC measurement. There is insufficient information to determine if this result is a general property of the proposed NIL test method, a peculiarity of these particular door specimens, an effect at this laboratory, or simply a random fluctuation.

There is an obvious pattern of the peaks and valleys of Figure 2, with a dip at 200–250 Hz and a large peak at 80 Hz. There are no obvious reasons for these features. The fact that these peaks and dips appear in all of the testing (both Door 1 and Door 2 specimens, all of the absorption conditions) suggests that it may be related to the configuration or dimensions of this particular test chamber. This may be investigated by repeated a similar testing program at other testing laboratories. Note that the large discrepancy at 80 Hz does not affect the DTC rating.

There is larger spread in the results for the higher rated door, as can be seen by the higher standard deviations. Again there is no obvious reason. Also, only the STC 39 door had the large difference at 4000 Hz.

**Fixed vs. moving microphone**

Although not included in the proposed standard, as described all of the testing was performed using both fixed and moving microphone methods. As can be seen in Table 2, the scanned microphone method resulted in very similar average DTC ratings as the fixed position method, but the variance in the measurements is significantly higher. This can be easily seen by comparing the difference between TL and NIL for each of the absorption conditions. This comparison for Door 1 is shown in Figure 3.
FIGURE 3. Difference between TL and NIL for the STC 25 door (Door 1) for fixed microphone positions (left) and the scanned microphone (right). Each color corresponds to one of the absorption conditions. Positive values indicate that TL was greater than the NIL.

As can be seen from Figure 3, the two methods yield similar averages and the spectra share many of the same features. However, the moving microphone method has a much larger variance between the absorption conditions. There does not seem to be any correlation with specific absorption conditions.

Possible Errors

A problem occurred during the testing of the STC 39 door that may need to be addressed in the standard. Some IL measurements were conducted with the door not completely closed. An example result is shown in Figure 4. The problem was discovered and the NIL measurements were repeated.

FIGURE 4. Effect of not completely closing the door during the NIL measurements of the STC 39 door.
We noted above that the standard does not specify how far the door is to be opened. The standard may also need to provide guidance to ensure that the door is completely closed, or define better what it means to be closed. In this case, the error was easy to detect by comparison since so many tests were being performed. This could potentially go undiscovered for a single test of a single door.

CONCLUSIONS

The most important conclusion is that the proposed test method for measuring NIL and DTC of doors produces results that are in excellent agreement with the existing method of measuring TL and STC.

The NIL method appears to be largely independent of the acoustical absorption in both source and receiving rooms, without the need to measure decay rates (reverberation times).

The moving microphone method produces similar average results but considerably larger uncertainties compared to the fixed microphone position method.

We suggest that the standard be more specific defining the open and closed door positions.

The next steps should include verifying that this result is repeated at other accredited laboratories. A higher rated door should also be included in the study. Our original intent was to include an STC 50 door for this study, but it was unable to be procured in time. Field testing should also be performed to show that the method remains credible and accurate. Finally, repeatability and reproducibility should be assessed so that the proposed NIL standard can be completed.

ACKNOWLEDGMENTS

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REFERENCES

2 Michel Morin, “Research project on the noise isolation provided by access doors in multi-dwelling buildings,” prepared for Canada Mortgage and Housing Corporation, 1993.