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Summary

This report presents extensive laboratory measurements to evaluate a new speech security quick test intended to provide accurate estimates of the results of the full speech security test (ASTM E2638-08). The proposed new quick test procedure would measure level differences from a calibrated source on one side of a wall to a spot receiver 0.25 m from the other side of the wall as illustrated in Fig. A.

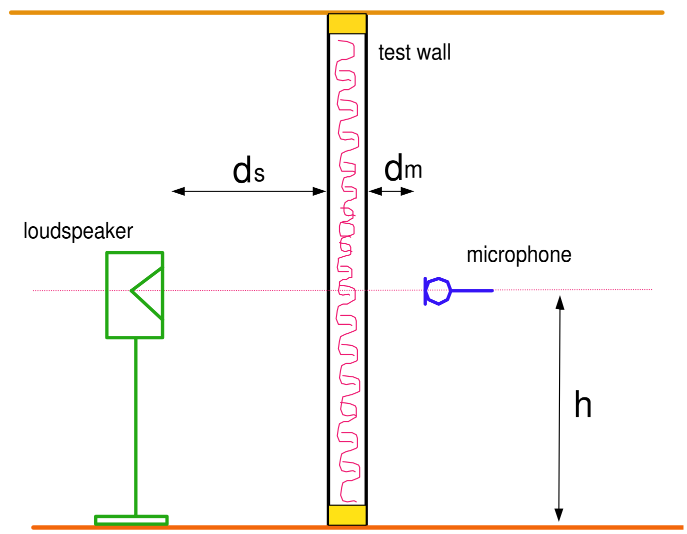

Fig. A. Source and receiver positions for the new quick test procedure.

The measurement results in this report evaluated the effects of various parameters on the results of the quick test procedure and compared them to those obtained using the full speech security test. The comparisons included measurements of a typical wall construction and the same wall with 2 variations of a door included. The tests also included systematic variations of the sound absorption in the test rooms.

The quick test procedure resulted in lower measured level difference values than the full test procedure and the differences varied with the amount of room absorption. However, the differences did not vary greatly over frequency and this was particularly true when a dodecahedron loudspeaker was used.

By correcting for the effects of room absorption, it was possible to provide quite accurate predictions of the level differences (LD), averaged over frequency, obtained from the full test. For tests using a dodecahedron loudspeaker, the RMS difference between the predicted and measured LD(avg) values was only 0.56 dB, which increased to 1.46 dB when a directional source was used.

Differences between the two measurement approaches can be larger at individual 1/3-octave band frequencies, but agreement was again better for predictions from quick test measurements made using a dodecahedron loudspeaker. Fig. B illustrates the agreement possible between predicted and measured level differences for the wall-with-no-door construction in the upper panel and for the wall-with-a-door in the lower panel. For the constructions and room absorption conditions tested, the RMS differences of the 1/3-octave band measurements varied between 1 and 2 dB depending on the loudspeaker type, construction details and room absorption.

Additional investigations showed that another variation the quick test approach could be applied to measuring the sound transmission loss characteristics of installed doors in field situations. Since doors and door seals are often the source of speech security problems, a more efficient means of assessing their performance could be practically very useful.

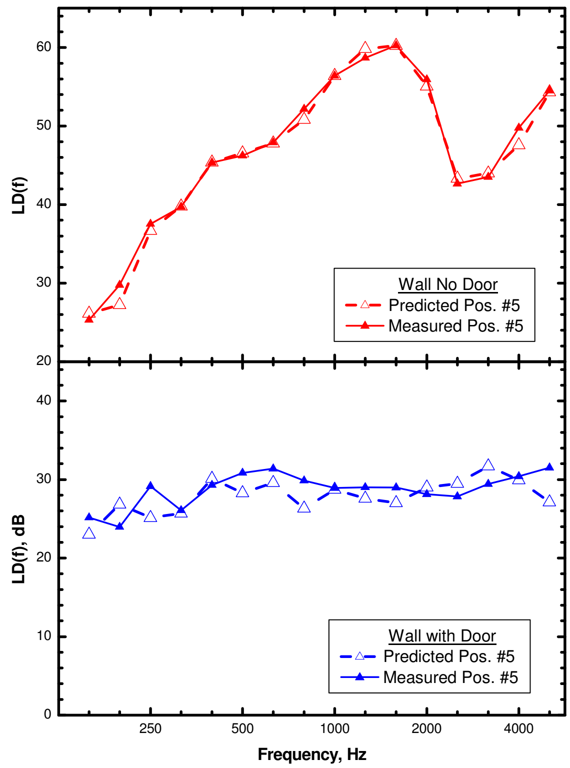

Fig. B. Example comparisons of predicted and measured full test LD(f) values for a wall with no door (upper) and for a wall with a door (lower).

It was also demonstrated that impulse response measurement software could be adapted to provide a more efficient but equally accurate approach to making quick test measurements. With the ability to provide immediate results, this approach could be a useful tool for assessing and diagnosing speech security problems in situ.

Evaluations of the quick test procedure for a broader range of combinations of doors and walls are required to more generally establish the accuracy of the approach.

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Acknowledgements

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1. Introduction

A number of previous studies [1-6] have led to the development of a new speech security assessment procedure for measuring the speech privacy of closed rooms [7]. The new method is different than standard sound transmission loss tests between rooms [8]. As illustrated in Fig. 1(a), a conventional sound transmission loss test measures room-average levels of a test sound using multiple microphone positions in both source and receiving rooms, and multiple loudspeaker positions in the source room. With the addition of reverberation time measurements in the receiving space, the average sound transmission loss between the two spaces can be calculated.

The new speech privacy test [7] measures the attenuation of speech sounds in terms of the level differences between an average source room level and the levels at spot receiver positions 0.25 m from the separating wall in the receiving space (see Fig 1(b)). A room average is used in the source room because the talker could be anywhere in the source room. The receiver is located at positions 0.25 m from the test wall because: (a) these represent more sensitive positions for eavesdroppers, (b) they don't require the receiving space to have a diffuse field, and (c) they make it possible to measure variations in the attenuation of speech sounds to detect weak points in the sound insulation such as near doors.

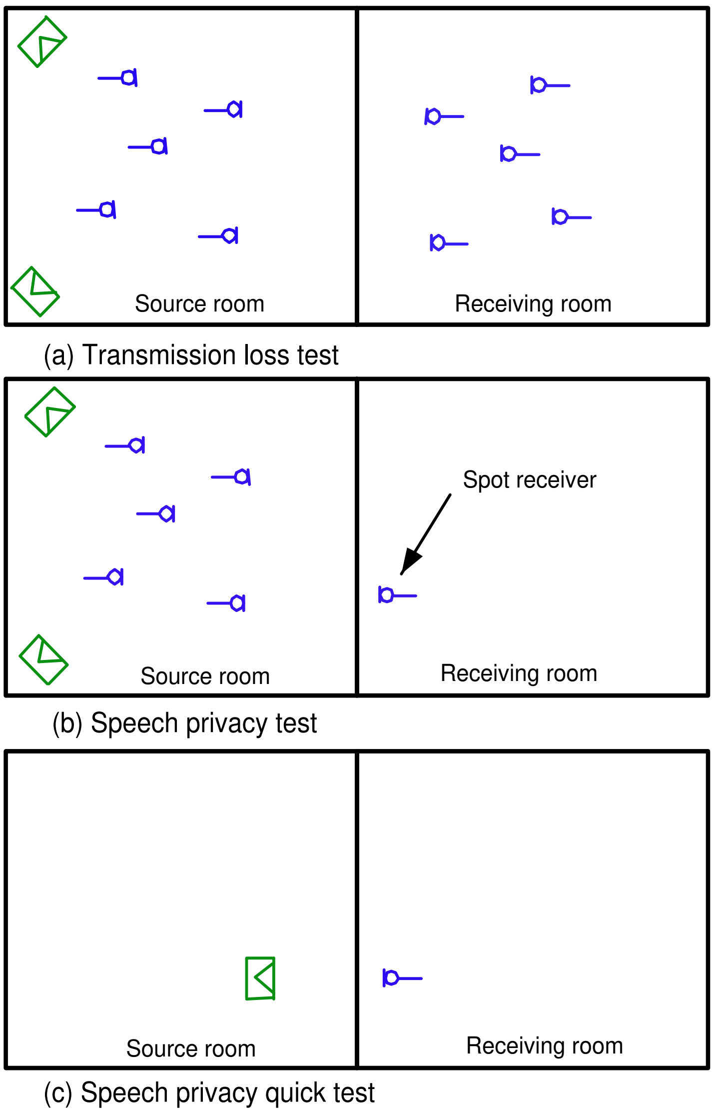


Fig. 1. Comparison of measurement approaches for: (a) conventional transmission loss test[8], (b) new speech privacy test [7], and proposed Speech Privacy Quick Test.

The new speech privacy test can more accurately assess the speech privacy afforded by a closed room. However, for the most accurate results it can be time consuming. In some cases, a less precise test would be adequate. For example, the speech privacy of most meeting rooms is limited by sound leaks through doors and door seals. There is often no need to precisely evaluate the complete room until the problem of the door can be rectified. Alternatively, if a room has been evaluated and a door found to be a problem, it is desirable to be able to quickly evaluate improvements to the door without retesting the complete room.

The proposed speech security/privacy quick test would measure attenuations between a loudspeaker 1 m from one side of a wall to a measurement point 0.25 m from the other side of the wall (see Fig. 1(c) and Fig. 2). The output of the test loudspeaker would first be measured in free field conditions at a distance of 1 m. This same level of the test signal would be used as the source level in the measurements of sound transmission through the element to be tested and the transmitted levels would be measured 0.25 from the element in the receiving space.

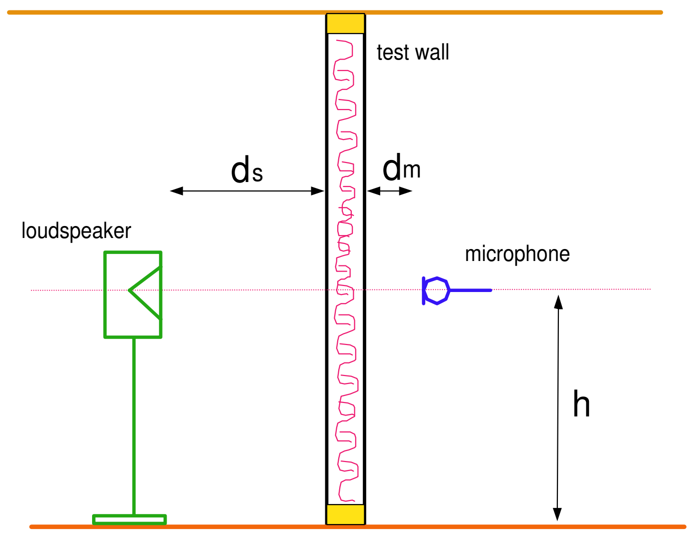


Fig. 2. Measurement setup for the new speech security quick test procedure. Source-to-wall distance, d_S, microphone-to-wall distance d_m (always 0.25 m) and source and receiver height, h.

Calibrating the output of the source in free field conditions avoids the large errors that can occur when trying to measure the source levels close to several reflecting surfaces such as the floor and the test wall and possibly others. Previous procedures have included measurement of the source output between the source and the wall in the source room. This was shown to lead to large variations between that method and the complete speech privacy test of ±8 dB or more [3].

The new work described in this report was primarily intended to determine if the proposed quick test procedure could be used to obtain measures of the speech privacy of closed rooms that would closely approximate the results of the complete speech privacy test. This included determining the effects of various parameters on the test results and how best to optimise the proposed quick test to obtain the best estimates of the expected result from a complete speech privacy test of the same situation.

Some additional investigations were also carried out. These included initial investigations of the feasibility of an efficient computer based measurement system to perform the quick test. These tests used the new SPMSoft program [9, 10] for measuring speech privacy in open-plan offices using impulse response techniques.

Since many full speech privacy tests were carried out as part of this work the results were used to re-consider the adequacy of a minimum of 2 source positions currently included in the ASTM standard [7]. The accuracy of predictions of sound transmission loss values from the level differences obtained in the complete speech privacy were re-considered and the results included in this report in Appendix II.

Appendix III presents an evaluation of using a variation of the quick test procedure to estimate the sound transmission loss characteristics of installed doors in field conditions.

2. Experimental Details

The experimental studies in this report were carried in the wall sound transmission loss suite in building M27 of NRC-IRC. This consists of two reverberation chambers with a large (12' by 8') opening between them into which walls can be constructed to measure their sound transmission characteristics. The large chamber has a volume of 250 m^3 and the small chamber a volume of 140 m^3. Walls are constructed in massive test frames that can be rolled into place between the two chambers and sealed in place with pneumatic seals.

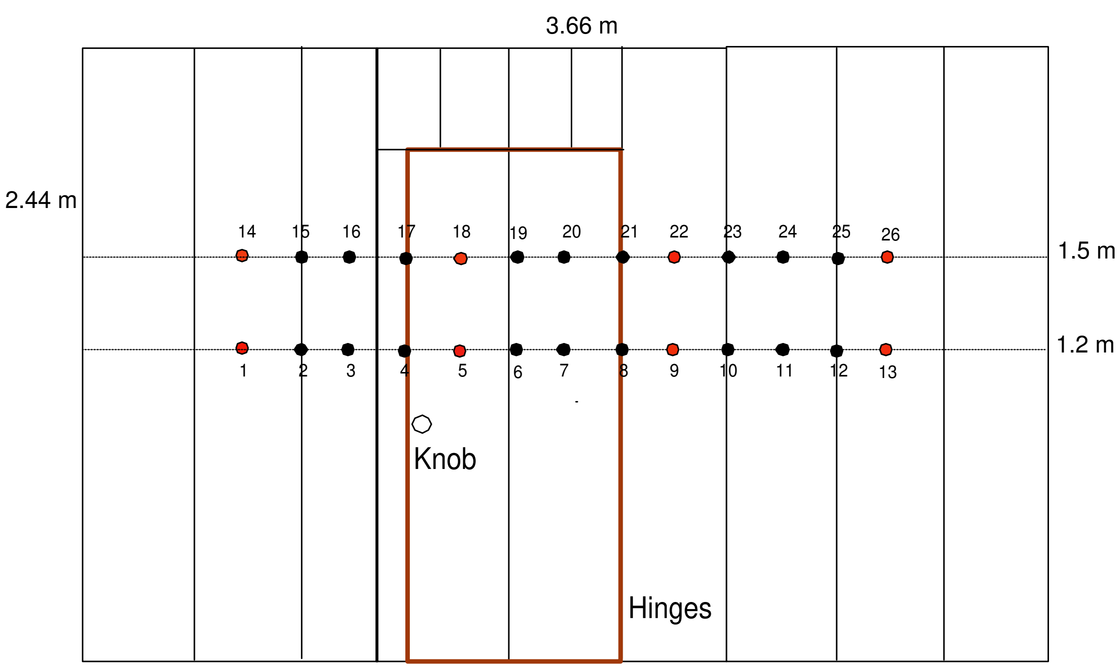
Each reverberation chamber includes 4 loudspeakers for producing test sounds driven by independent noise generators. There is also a robot microphone system in each chamber so that the microphone can be moved automatically under computer control to each measurement position. For standard sound transmission loss tests carried out according to the ASTM E90 procedure, sound levels are measured at 9 independent positions in each chamber and level differences between the source and receiving rooms calculated. After also measuring reverberation times in the receiving room, sound transmission loss (TL) values are calculated in 1/3-octave bands from 50 Hz to 6.3k Hz.

As the new experiments concerned speech security tests intended to evaluate conditions for meeting rooms, sound absorption was added to the reverberation chambers for some of the tests. The added sound absorption created conditions with reverberation times similar to meeting rooms and measured reverberations times for each absorption treatment are described in the following section of this report.

The complete speech security test, now described in ASTM E2638-08, involves measuring room average levels in the source room and at positions 0.25 m from the test wall in the receiving space. To obtain accurate room average source room levels, measurements were usually made for 5 independent source positions in the current studies. For most of the speech security tests the large chamber was the source room because the robot microphone in the small chamber could then be used to measure the received levels at positions 0.25 m from the test wall. The received levels were measured at 26 positions 0.25 m from the test wall in the small chamber, arranged in two rows of 13 positions 1.2 and 1.5 m above the base of the test wall as illustrated in Fig. 3.

Four different constructions were measured for various purposes in the tests described in this report. The initial construction was a steel stud wall intended to be representative of many office walls. It was constructed of (92 mm) light-weight steel studs with one layer 13 mm gypsum board on each face and glass fibre batts in the cavity. The surface density of the gypsum board was 9.7 kg/m^2. The measured sound transmission loss characteristics and STC values are included in the following section.

After initial tests of the wall, a door was added to it to create a wall-with-a-door. Fig. 3 shows the steel studs included for the initial wall construction. The studs shown in the door opening were removed when the door was installed. The door was a solid core wood door with a surface density of 24.7 kg/m^2 and was initially installed without door seals. Extensive testing was carried out for this condition of a door without seals in a typical office wall.



View from small chamber side.

Fig. 3. Steel stud construction of 2.44 m by 3.66 m test wall showing location of door and the measurement positions along the wall. View is from small chamber to large chamber. Studs in door opening were later removed when the door was installed.

The door was subsequently improved by completely sealing it with metal tape. This was intended to represent a solid core door with near perfect seals.

Some later tests used what is described as a ‘patched’ wall in order to return to conditions similar to the original wall without a door. For this wall construction, the door and door frame were removed, the door opening was filled with glass fibre batts and one layer of 13 mm gypsum board was attached to each side of the wall to completely cover and extend past the door opening. As seen in the following section this had similar sound transmission characteristics to the original wall.

The speech security tests were carried out using two different types of loudspeaker. One was a dodecahedron loudspeaker, which included 12 drivers each 100 mm diameter and is intended to be an approximately omni-directional source. The other was a directional loudspeaker consisting of one 250 mm diameter driver in a vented rectangular box. These two loudspeakers are representative of the two extremes in possible test loudspeakers. Further details and measured directional radiation patters for both loudspeakers are included in Appendix I.

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3. Standard Test Results of Experimental Conditions

3.1 Test room sound absorption

Most tests were carried out with one of three different amounts of sound absorbing material in the two test chambers. This made it possible to investigate various details of the speech security tests as a function of room acoustics conditions. The room absorption was varied by adding sound absorbing foam to both test chambers. The three absorption conditions are referred to as 'no foam' (NF), 'half foam' (HF) and 'full foam' (FF). 'No foam' was the most reverberant condition with no added sound absorption. 'Full foam' was the most absorptive case for which conditions were least reverberant and approximately representative of typical meeting rooms. Fig. 4 shows the measured reverberation times versus frequency in the large chamber for the three absorption conditions and Fig. 5 shows similar results in the small chamber. Average reverberation times over the speech frequencies from 160 to 5k Hz were about 0.7 s for 'full foam' condition in both chambers.

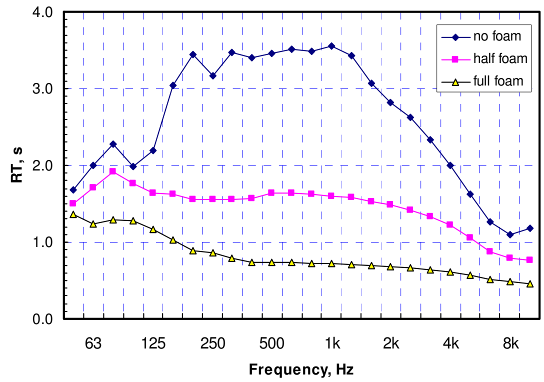


Fig. 4. Measured reverberation times in the large reverberation chamber for the 3 absorption conditions.

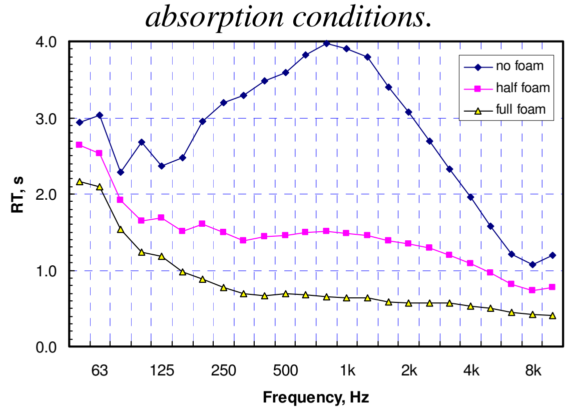


Fig. 5. Measured reverberation times in the small reverberation chamber for the 3 absorption conditions.

3.2 Sound transmission loss (TL) of test constructions

Standard (ASTM E90) sound transmission loss (TL) measurements were made of all 4 test constructions and for all 3 absorption treatments to the test chambers. Fig. 6 shows the measured TL values for the wall without a door construction and for each of the 3 room absorption cases. There are very small variations with the changes in sound absorption condition but no systematic effect. That is, the 3 plot lines in Fig. 6 cross each other and no condition leads to increased or decreased TL values at all frequencies. The R_w rating for the half foam condition was 42 compared to 43 for the other conditions. The STC value for all 3 conditions was 43.

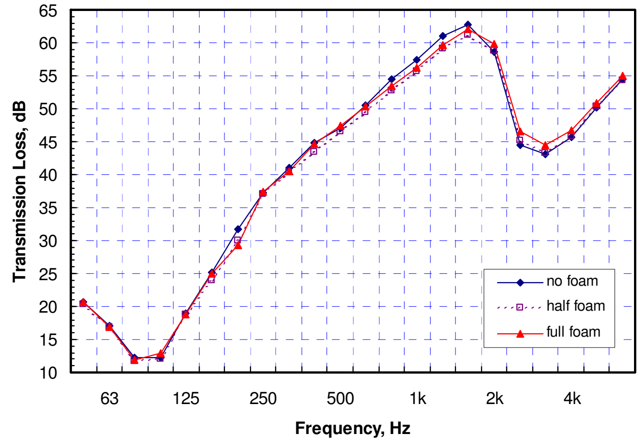


Fig. 6. Measured sound transmission loss versus frequency for the wall-with-no-door and for the 3 absorption conditions.

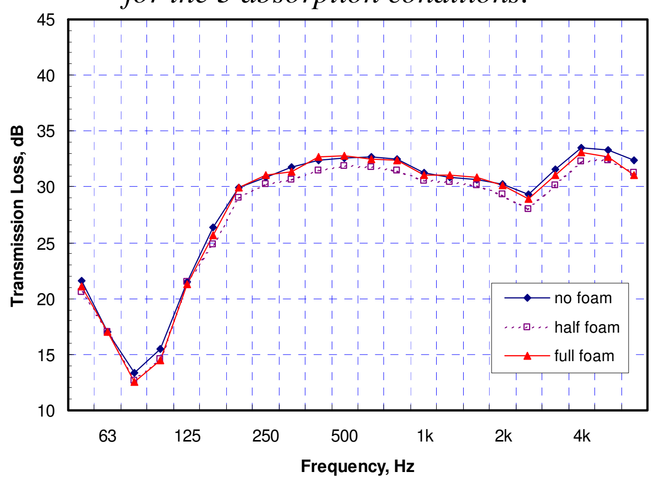


Fig. 7. Measured sound transmission loss versus frequency for the wall-with-a-door and for the 3 absorption conditions.

Fig. 7 plots the measured TL versus frequency for the wall-with-a-door and for the 3 absorption cases. For the full foam and the no foam cases the STC and the R_w values were all 31. For the half foam case the STC and R_w were both 30. For the half foam case, Fig. 7 indicates that all TL values were approximately 1 dB lower than the other cases. This is thought to be due to removing test frame holding the wall with the door from the test chambers to accommodate other testing that used the other test frame. Although the test frame was moved back into place without changes to the wall-with-a-door, there may be some small differences in how the test frame was sealed in place between the two test chambers. This was unfortunate but does not affect any of the subsequent comparisons between the standard TL test results and various speech security test results because all testing on each construction was completed without any changes to the wall or test frame. The test frame was only moved once between the testing of different test conditions.

The wall with the door was re-tested after the door was completely sealed by taping the periphery to the door frame. This was intended to simulate very good door seals. Comparing the results in Figure 7 (with no seals) with those in Figure 8 (sealed door) shows that the TL was improved and improved most at higher frequencies when the door was sealed. The sealed door had STC and R_w values of 37 for all cases except the full foam case for which the STC was 38 and the R_w 37.

The fourth construction is referred to as the 'patched' wall. For this wall construction, the door and door frame were removed, the door opening was filled with glass fibre batts and one layer of 13 mm gypsum board was attached to each side of the wall to completely cover and extend past the door opening. The measured TL versus frequency values are shown in Fig. 9 and are seen to be similar to those for the original wall in Fig. 6. The STC and R_w for the no foam and the full foam conditions were all 47. For the half foam case, the STC was 47 and the R_w was 46.

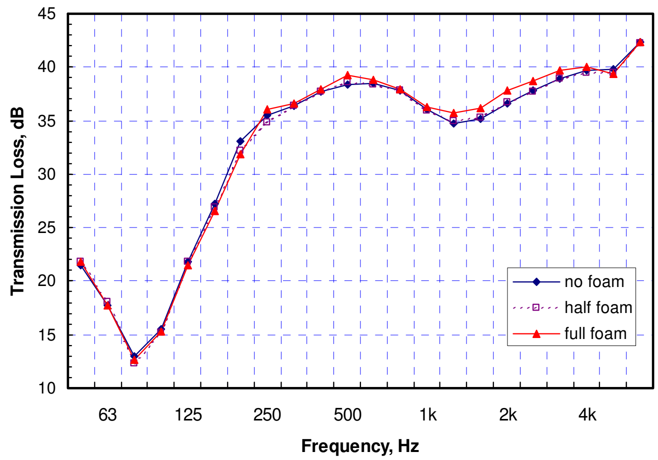


Fig. 8. Measured sound transmission loss versus frequency for the wall-with-sealed-door and for the 3 absorption conditions.

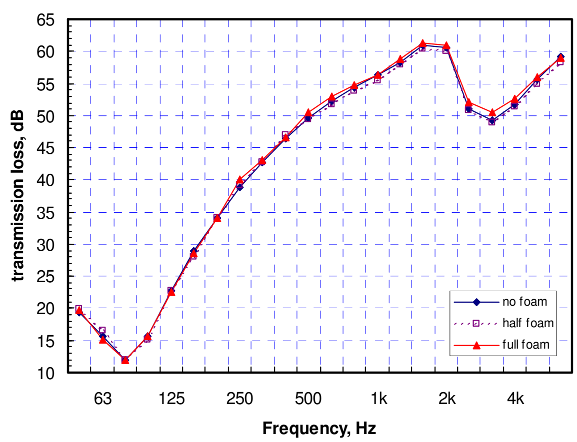


Fig. 9. Measured sound transmission loss versus frequency for the patched wall-with-no-door and for the 3 absorption conditions.

The TL versus frequency data for all four constructions are compared in Fig. 10. The results for the patched wall are a little different to those for the original wall and especially around the 3150 Hz coincidence dip. This was probably because the gypsum board patches modified the bending wave vibrations of the wall surfaces possibly by changes in the damping.

The sealed door is seen to result in higher TL values at most frequencies and the differences are largest at the highest frequencies.

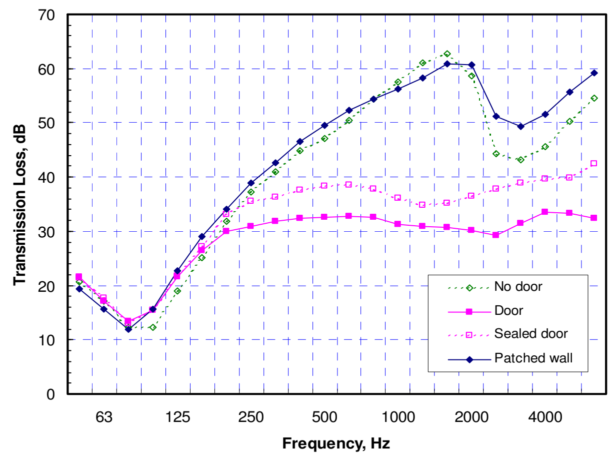


Fig. 10. Comparison of measured transmission loss versus frequency results for all 4 constructions and the case of no added absorption (i.e. 'no foam).

Figure 11 plots the differences in measured TL values for 'forward' and 'reverse' propagation between the two test chambers. Forward propagation was from the small chamber to the large chamber; reverse propagation was from the large chamber to the small chamber. The differences are very small but indicate larger TL values at lower frequencies for forward propagation and larger TL values at higher frequency for reverse propagation. Such differences are not fully understood and are included because they may influence speech security test results.

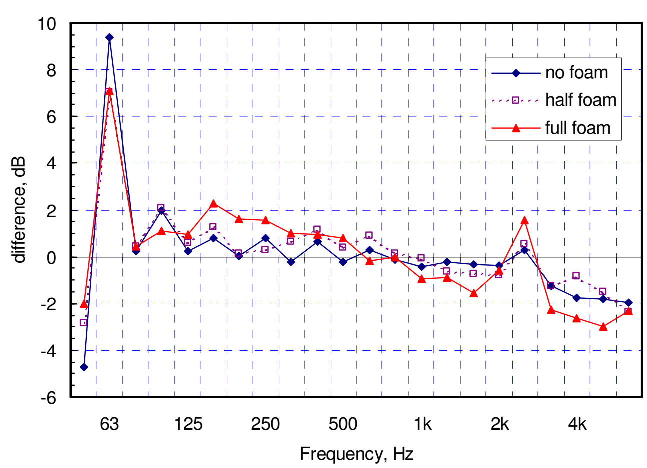


Fig. 11. Forward – Reverse propagation differences in TL values for the patched wall-with-no-door and for the 3 absorption conditions.

4. Full Speech Security Test (FSST) Results

The effects of various parameters on the results of the full speech security test were first measured for each construction to establish the expected results when using the proposed quick test procedure and for subsequent comparisons with the quick test results. The effects of microphone height in the receiving space and loudspeaker type were investigated and measured level differences, LD(f), were compared with the measured transmission loss, TL(f), values. The variation in average level difference values over frequency, LD(avg), as well as variations in the spectrum of the level differences , LD(f), were examined as a function of position along the test walls. All full speech security test results in this section are based on averages of results for measurements at 9 microphone positions in the source room using 5 independent source positions and measured at the 26 spot receiver positions in the adjacent room (shown in Fig. 3).

4.1 Effects of microphone height at receiving points

Fig. 12, 13 and 14 show the effects of microphone height in the receiving space. As shown in Fig. 3 there were13 microphone positions along the test wall at 1.2 or 1.5 m heights above the base of the wall. Fig. 12 compares the results averaged over the 13 positions at each microphone height for the wall-with-no-door in terms of average measured level differences.

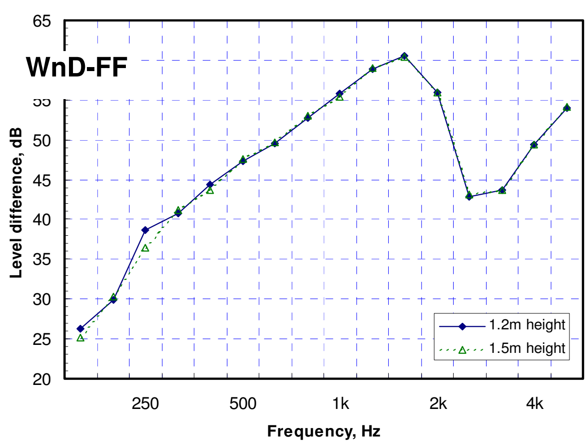


Fig. 12. Comparison of average measured level difference over position along the wall for two different microphone heights, for the wall-with-no-door (WnD) construction.

Fig. 13 and 14 similarly compare average level differences for each microphone height for the constructions that included the wall-with-a-door and the wall-with-a-sealed-door respectively. All three figures show very little effect of microphone height. There are some small differences in the 250, 315 and 400 Hz 1/3-octave bands. The test walls were mounted in a small niche, which is the height of the test wall (2.44 m). These small differences may be due to vertical resonances in this niche which could cause measured transmitted levels to vary with microphone height at the positions 0.25 m from the test wall. However, they may not occur for situations where the microphones were not in such a niche.

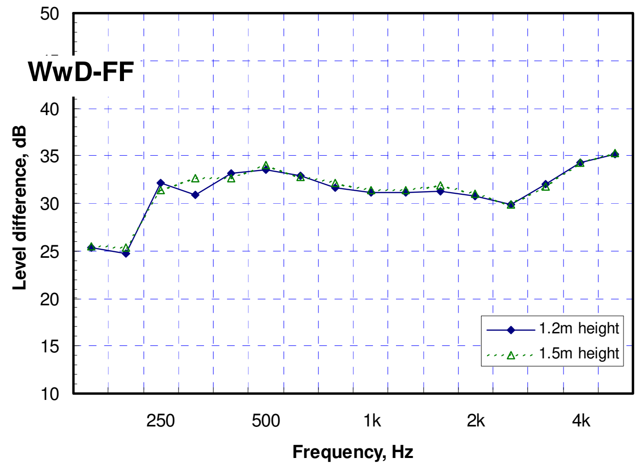


Fig. 13. Comparison of average measured level differences over position along the wall for two different microphone heights, for the wall-with-a-door (WwD) construction.

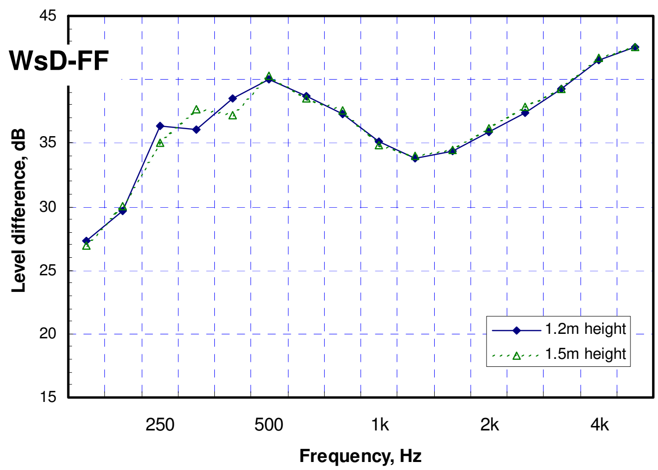


Fig. 14. Comparison of average measured level differences over position along the wall for two different microphone heights, for the wall-with-sealed-door (WsD) construction.

In was concluded that, in general, the microphone heights used in the receiver space had only very minor effects and their effects could be ignored in most tests. Most of the other test results using the full speech security test are averages over all 26 microphone positions at both the 1.2 and 1.5 m microphone heights. Of course larger variations in microphone height could lead to larger effects and especially if the microphone is located close to significant sound leaks.

4.2 Effects of loudspeaker directionality and test room absorption on LD(f) and TL(f) comparisons

Fig. 15 compares measured average (over microphone positions) level difference using the dodecahedron and directional loudspeakers with transmission loss values for the wall-with-no-door and no added foam absorption. The average level differences for the two loudspeaker types were very similar with some small differences around the frequency of the coincidence dip (2.5k and 3.15k Hz). Since the coincidence dip is influenced by the angle of incidence of the test sound, the differences in loudspeaker directionality may explain these small differences.

The average level differences and the transmission loss values seem to follow approximately parallel trends. Although the average LD(f) values are approximately 5 dB lower than the TL(f) values for most frequencies, the two curves come together and cross at 4k Hz.

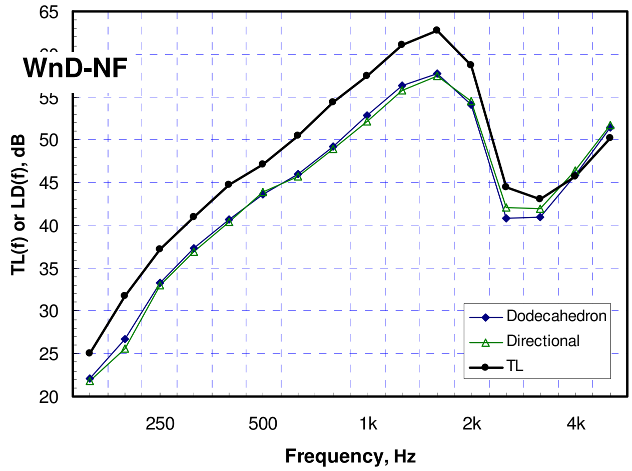


Fig. 15. Comparison of transmission loss TL(f) and average level differences (over microphone position), LD(f), using the directional and dodecahedron loudspeakers for the wall-with-no-door (WnD) construction and no added foam absorption (NF).

Adding sound absorbing foam to the test rooms leads to systematic increases in the average measured level differences as seen in the results of Fig. 16 and 17 for the half foam and full foam absorption cases. For the full foam absorption results in Fig. 17. the average level differences are in quite close agreement with the TL(f) values for frequencies up to about 1.25k Hz. The approximately parallel LD(f) and TL(f) results and variation of the difference between them with varied room absorption were previously noted and approximated by a factor that accounted for the variation with room absorption but was constant for all frequencies important for speech (160 to 5k Hz) [4].

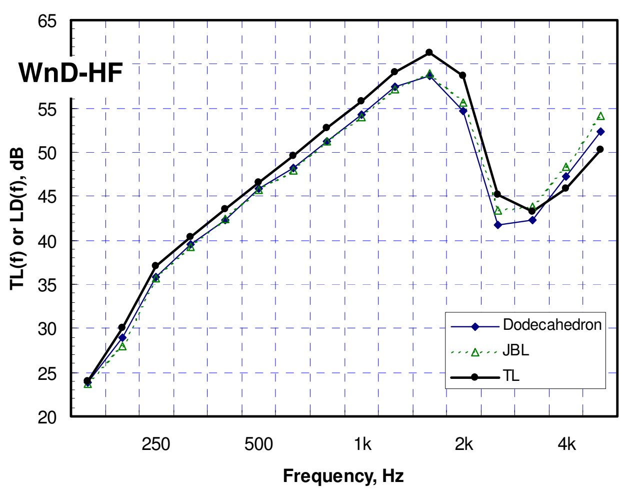


Fig. 16. Comparison of transmission loss TL(f) and average level differences (over microphone position), LD(f), using the directional and dodecahedron loudspeakers for the wall-with-no-door (WwD) construction and the half foam (HF) absorption case.

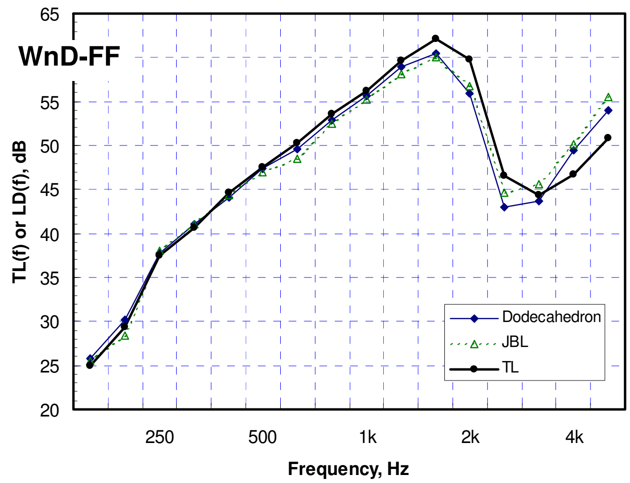


Fig. 17. Comparison of transmission loss TL(f) and average level differences (over microphone position), LD(f), using the directional and dodecahedron loudspeakers for the wall-with-no-door (WnD) construction and the full foam (FF) absorption case.

Figures 18, 19 and 20 compare measured average (over microphone position) level differences using the dodecahedron and directional loudspeakers with transmission loss values for the wall-with-a-door and varied added foam absorption. Again the LD(f) and TL(f) values follow approximately parallel trends and the difference between them decrease with added sound absorption. As for the results for the wall-with-no-door construction, there are again only very small differences between the LD(f) values for the two different loudspeakers.

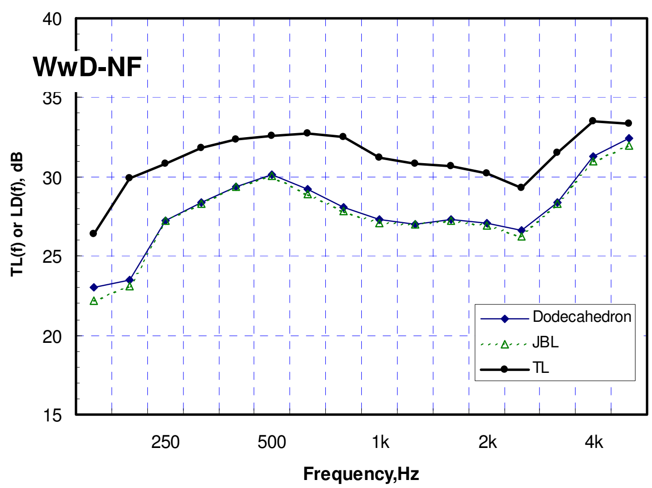


Fig. 18. Comparison of transmission loss TL(f) and average level differences (over microphone position), LD(f), using the directional and dodecahedron loudspeakers for the wall-with-a-door construction and no added foam absorption.

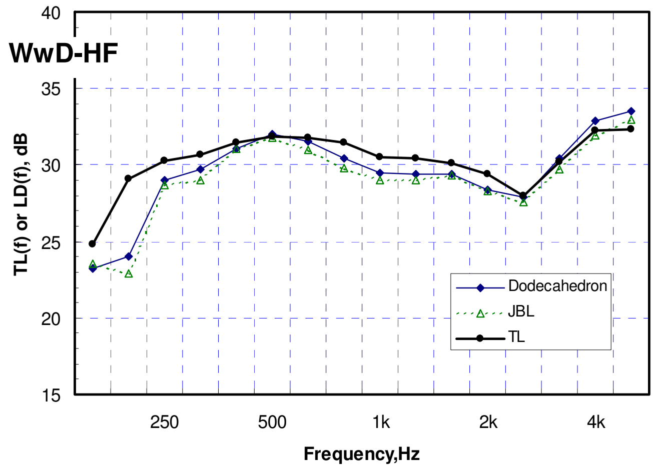


Fig. 19. Comparison of transmission loss TL(f) and average level differences (over microphone position), LD(f), using the directional and dodecahedron loudspeakers for the wall-with-a-door (WwD(construction and the half foam (HF) absorption case.

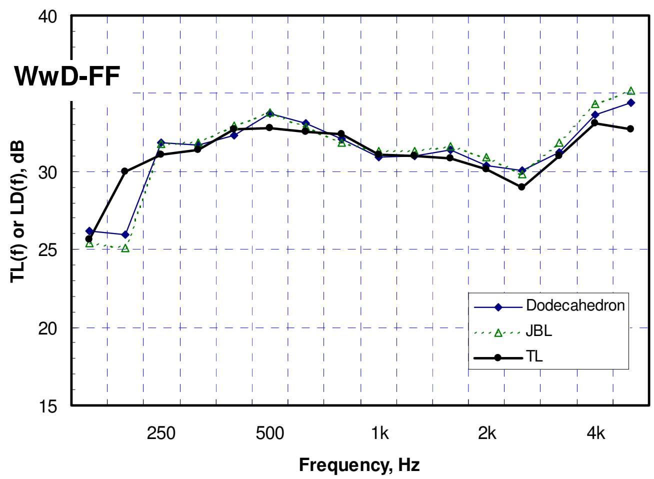


Fig. 20. Comparison of transmission loss TL(f) and average level difference (over microphone position), LD(f), using the directional and dodecahedron loudspeakers for the wall-with-a-door (WwD) construction and the full foam (FF) absorption case.

The comparisons of measured average (over microphone position) level differences using the dodecahedron and directional loudspeakers with transmission loss values for the wall-with-sealed-door and varied added foam absorption are shown in Fig. 21, 22 and 23.

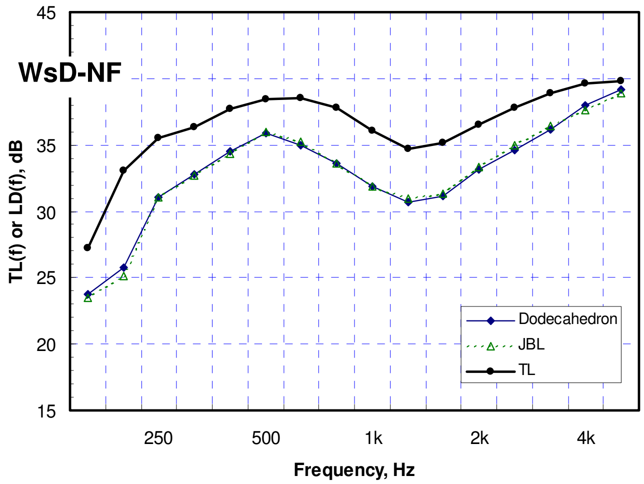


Fig. 21. Comparison of transmission loss TL(f) and average level differences (over microphone position), LD(f), for the directional and dodecahedron loudspeakers for the wall-with-sealed-door (WsD) construction and no added foam (NF) absorption.

As for the other constructions, there are only very minor differences in level differences obtained using the two different loudspeakers. The average difference between TL(f) values and LD(f) decreases with increasing added room absorption. For the full foam absorption case, the TL(f) and LD(f) values have quite similar values.

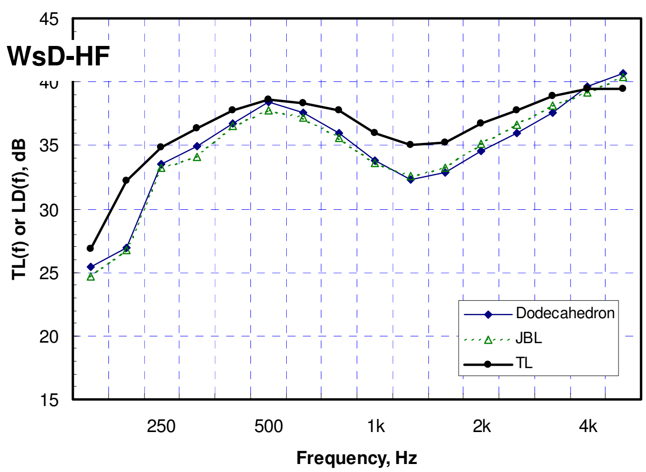


Fig. 22. Comparison of transmission loss TL(f) and average level differences (over microphone position), LD(f), using the directional and dodecahedron loudspeakers for the wall-with-sealed-door (WsD) construction and the half foam (HF) absorption case.

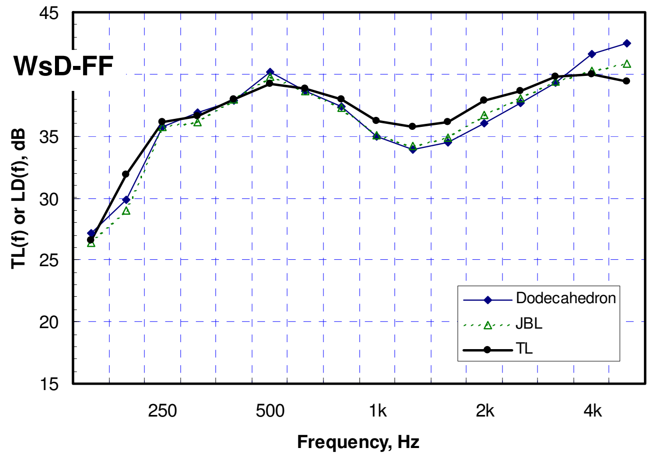


Fig. 24. Comparison of transmission loss TL(f) and average level differences (over microphone position), LD(f), using the directional and dodecahedron loudspeakers for the wall-with-sealed-door (WsD) construction and the full foam (FF) absorption case.

4.3 Variations of LD(avg) values along the walls

LD(avg) values are arithmetic averages of level differences over the speech frequencies from 160 to 5k Hz. Fig. 24 and 25 plot LD(avg) values versus position along the wall separately for each microphone height and absorption condition for the wall-with-no-door construction. Since the wall had no sound leaks or weak spots, we expect approximately the same LD(avg) values at all measurement locations. The figures show that as expected the variations of LD(avg) values with position along the wall were mostly less than 1 dB in magnitude.

There is a small trend for the measured LD(avg) values to increase slightly towards both ends of the test wall. This effect may be because higher transmitted sound levels are measured near the centre of the test wall. For a microphone near the centre of the wall the measured levels are due to transmitted sound arriving from all around the microphone location. Near the edge of the wall, the transmitted sounds only arrive at the microphone from one side of the microphone. The higher measured levels near the centre of the wall would correspond to lower LD(avg) values seen in these plots.

Fig. 24 and 25 show some small differences between the two microphone heights and these differences increase with increasing amounts of added sound absorbing material. As in the previous plots increasing the added sound absorption increased the measured LD(avg) values.

The trends in Fig. 24 for the dodecahedron loudspeaker are very similar to those in and Fig. 25 for the directional loudspeaker. There are some small differences indicating there is less effect of microphone height when using the directional loudspeaker. This may be due to the incident sound being more concentrated on the wall immediately opposite the microphone position when the directional source is used.

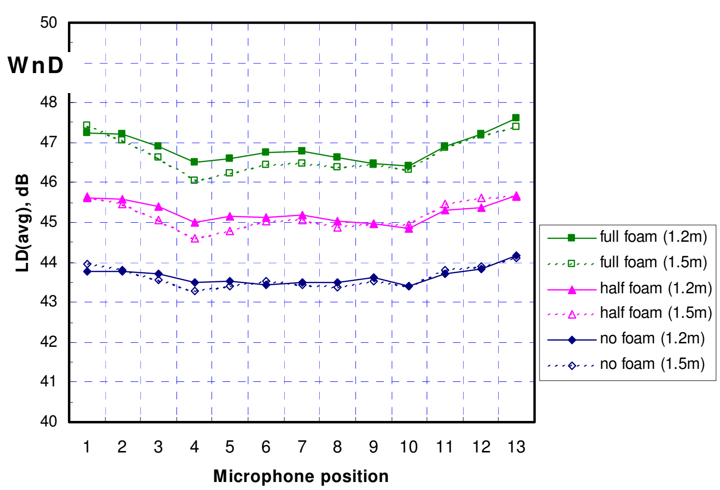


Fig. 24. Measured LD(avg) values versus microphone position along the wall for the wall-with-no-door (WnD) shown separately for two microphone heights and three room absorption conditions for the dodecahedron loudspeaker source.

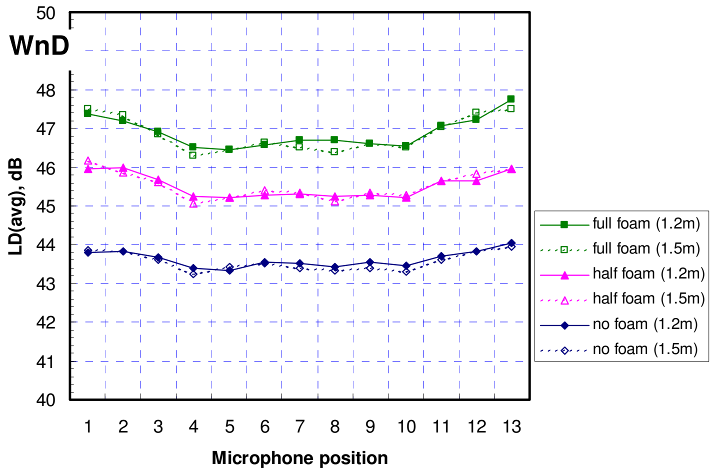


Fig. 25. Measured LD(avg) values versus microphone position along the wall for the wall-with-no-door (WnD) shown separately for two microphone heights and three room absorption conditions for the directional loudspeaker source

When LD(avg) values are plotted versus position along the wall-with-a-door we expect larger variations as are shown in Fig. 26 and 27.

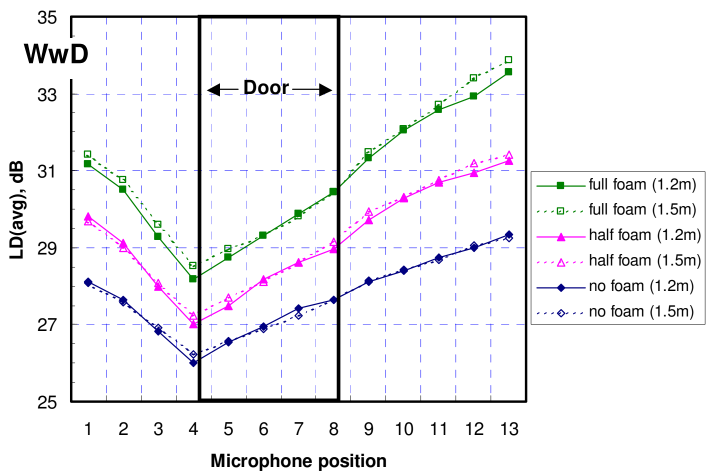


Fig. 26. Measured LD(avg) values versus microphone position along the wall for the wall-with-a-door (WwD) shown separately for two microphone heights and three room absorption conditions for the dodecahedron loudspeaker source.

The measured LD(avg) values were lowest close to the left side of the door on Fig. 26 and 27. As shown in Fig. 3 this was the latch side of the door and presumably there was a little larger sound leak at this side of the door than at the hinge side. The LD(avg) values increased monotonically as the microphone was move further away from the point of the lowest LD(avg) values. The sound transmission loss of the door is much lower than that of the wall and presumably at all points along the wall, the predominant source of transmitted sound is through the door and leaks around the door. Consequently transmitted sound levels decrease and LD(avg) values increase as the microphone is moved away from this weak point. However, the maximum increase in LD(avg) values was only about 4 dB for the case of full foam absorption and less when less absorption was added.

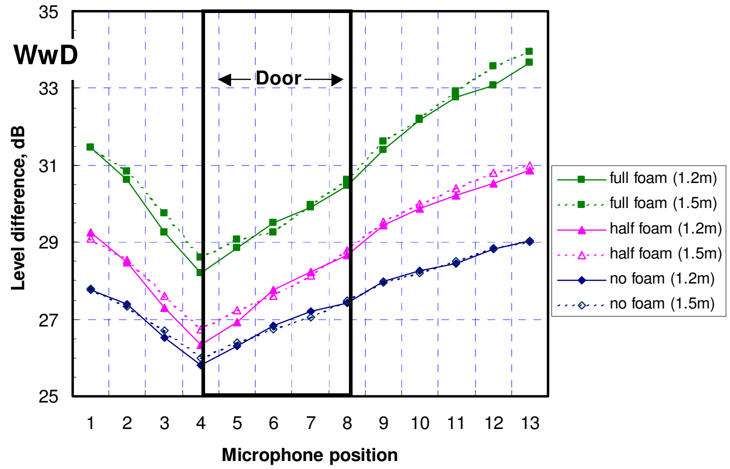


Fig. 27. Measured LD(avg) values versus microphone position along the wall for the wall-with-a-door (WwD) shown separately for two microphone heights and three room absorption conditions for the directional loudspeaker source.

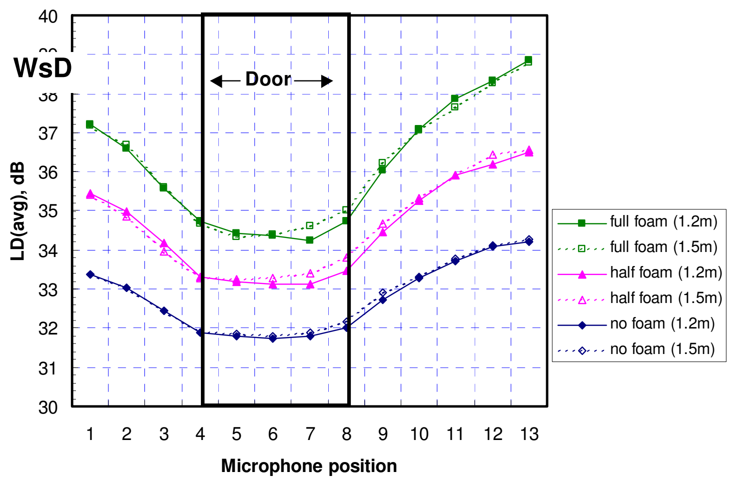


Fig. 28. Measured LD(avg) values versus microphone position along the wall for the wall-with-sealed-door (WsD) shown separately for two microphone heights and three room absorption conditions for the dodecahedron loudspeaker source.

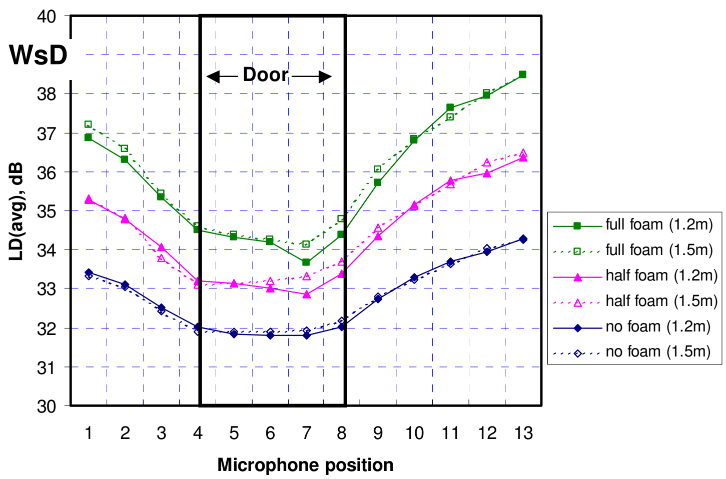


Fig. 29. Measured LD(avg) values versus microphone position along the wall for the wall-with-sealed-door (WsD) shown separately for two microphone heights and three room absorption conditions for the directional loudspeaker source.

The plots of LD(avg) versus microphone position in Fig, 28 and 29 for the sealed door show a more symmetric variation relative to the location of the door. With the door sealed with metal tape there were not more significant leaks on one side of the door compared to the other side of the door. The maximum variation in LD(avg) values was again about 4 dB.

4.4 Spectral variations of LD(f) along the test wall

The plots of LD(avg) values versus position along the test walls describe the variation of the measured average level differences along a particular construction. Another form of variation concerns how the spectrum of the measured level differences varies with position along the test walls. In this section plots of LD(f) are included for both types of loudspeaker source and at a position near the end of the wall (#13) and a position near the centre of the wall (#7). Fig. 30 and 31 show plots of level differences versus frequency (LD(f) values) for the dodecahedron loudspeaker and for the directional loudspeaker at positions #13 and #7 respectively. Results are given for both types of loudspeaker on each plot and all data were obtained for the full foam absorption condition.

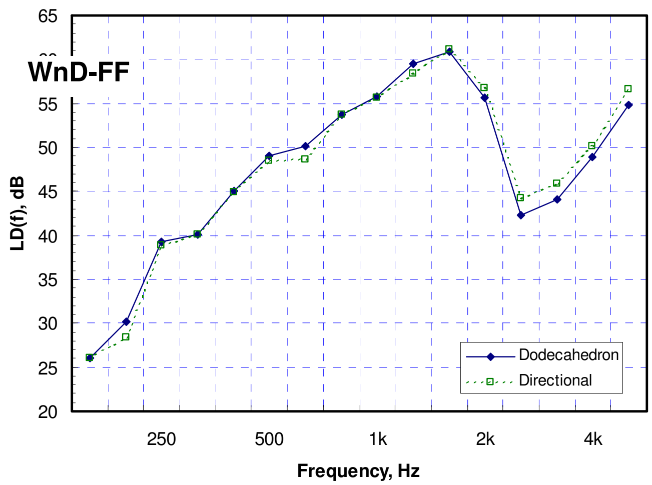


Fig. 30. Measured LD(f) at position #13 at the end of the wall for the dodecahedron and the directional loudspeaker source. Wall-with-no-door (WnD), full foam (FF) case.

Fig. 30 and 31 show very similar trends. The differences between the results using the two different loudspeakers are also quite similar in the two plots and are largest at the coincidence dip frequencies of 2.5 and 3.15 k Hz. However, these differences between the loudspeaker source do not vary with position along the wall. There is no evidence of significant changes in the frequency response of the measured level differences for the construction of a wall without a door in these two figures.

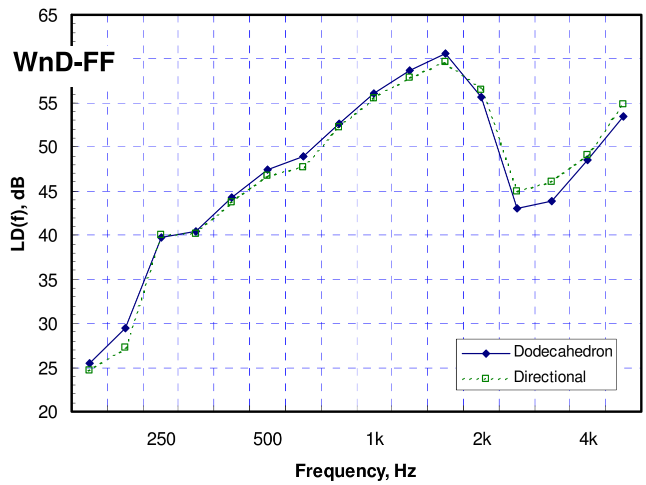


Fig. 31. Measured LD(f) at position #7 at the centre of the wall for the dodecahedron and the directional loudspeaker source. Wall-with-no-door (WnD), full foam (FF) case.

Fig. 32 and 33 show the frequency content of measured level differences for the wall-with-a-door. Again the results are for a position at the end of the wall (position #13 in Fig 32) and a position at the centre of the wall (position #7 in Fig 33). For this construction there was a significant difference in the average level difference between the two locations because of the presence of the door close to position #7. However, the spectral variations are again reasonably similar between the two positions.

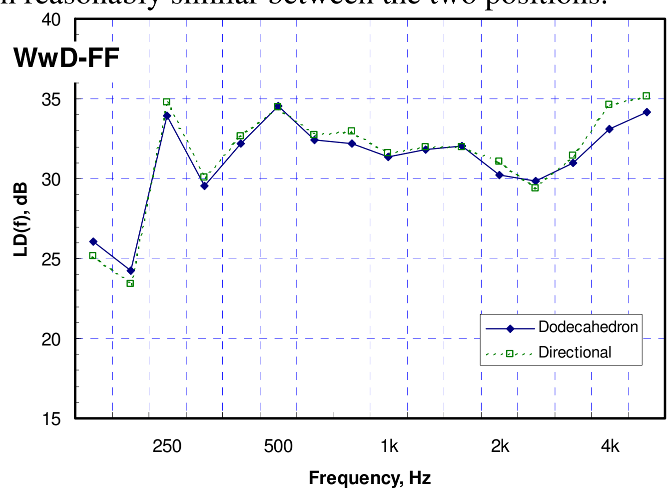
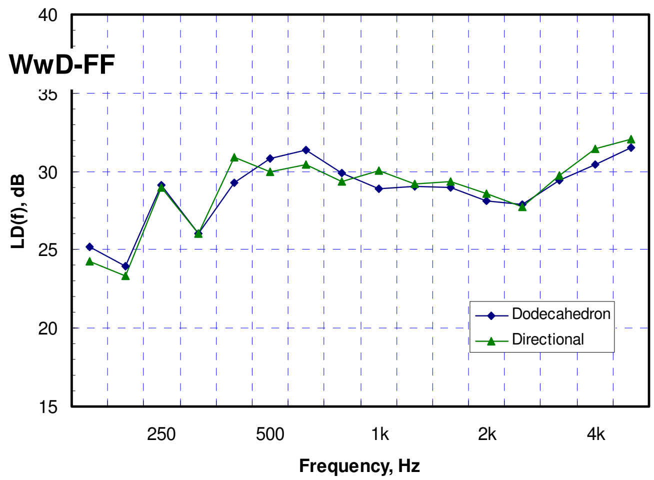


Fig. 32. Measured LD(f) at position #13 at the end of the wall-with-a-door (WwD) for the dodecahedron and the directional loudspeaker sources and the full foam (FF) case.



Fig, 33. Measured LD(f) at position #7 at the centre of the wall-with-a-door (WwD) for the dodecahedron and the directional loudspeaker sources and the full foam (FF) case.

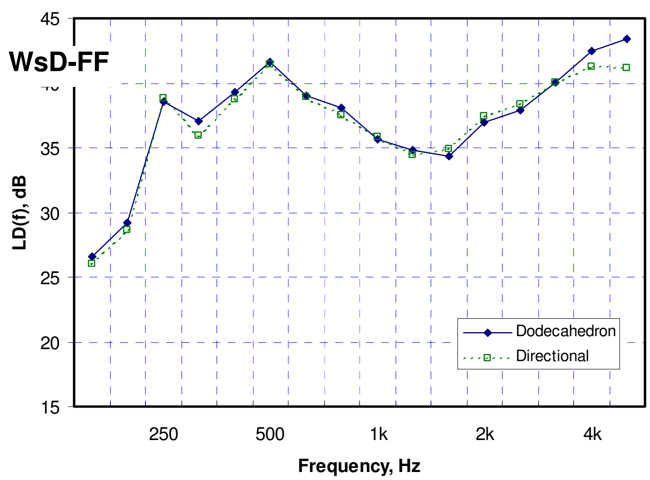


Fig. 34. Measured LD(f) at position #13 at the end of the wall-with-sealed-door (WsD) for the dodecahedron and the directional loudspeaker sources and the full foam (FF) case.

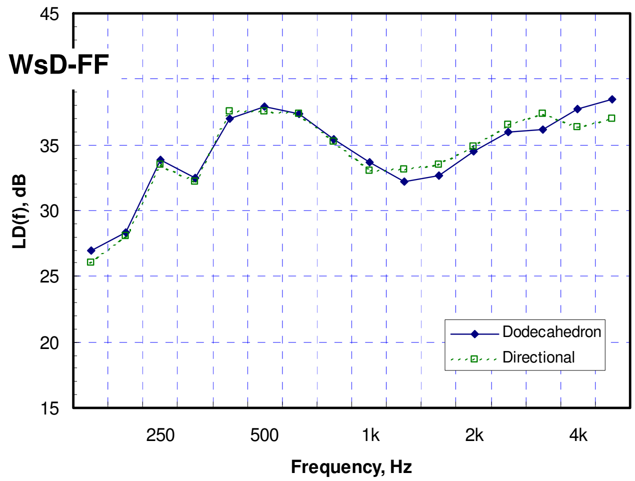


Fig. 35. Measured LD(f) at position #7 at the centre of the wall-with-sealed-door (WsD) for the dodecahedron and the directional loudspeaker source and the full foam (FF) case.

5. Evaluation of an Alternative Full Test

In the full test, level differences are measured from a room average source room level to individual spot receivers in adjacent spaces. Measuring the source room average levels requires measurements of source room levels for a number of combinations of loudspeaker position and microphone position in the source room. This can be time consuming and must be repeated for each room that is tested. A possible alternative approach would be to measure the sound power output of the test source and use this to calculate the average level (over direction) from the source at a distance of 1 m. This could be done once for the measurements of a number of meeting rooms. Data from the current measurements were used to evaluate this alternative speech security full test.

The average levels at 1 m were calculated in the large reverberation chamber from measurements in the no foam condition. First the sound power levels, $L_w(f)$, were calculated for each source.

$$L_w(f) = L_s(f) - 10\log\{4/(A(f))\}, dB \tag{1}$$

where $L_s(f)$ is the average source room level and $A(f)$ is the total sound absorption in m^2. From the sound power levels, the average level (over direction) at 1 m, L_1, in a free field can be calculated as follows,

$$L_1(f) = L_w(f) + 10Log\{1/(4\pi r^2)\} = L_w(f) - 11, dB \tag{2}$$

where r = 1 m

Fig. 36 compares measured LD(f) values from the two approaches for the wall-with-no-door construction and the no foam absorption case. Fig. 37 and 38 are similar results for the wall-with-a-door and the wall-with-a-sealed-door.

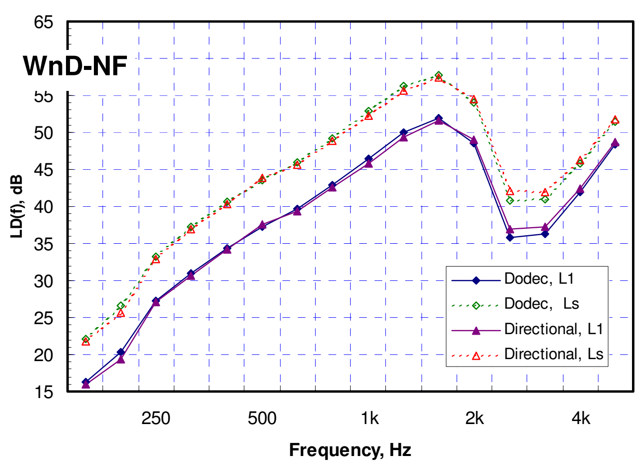


Fig. 36. Comparison of measured LD(f) using either the source room levels L_s or the average level at 1 m, L_1 for both the dodecahedron and the directional loudspeaker. Wall-with-no-door construction (WnD), no foam (NF) absorption case.

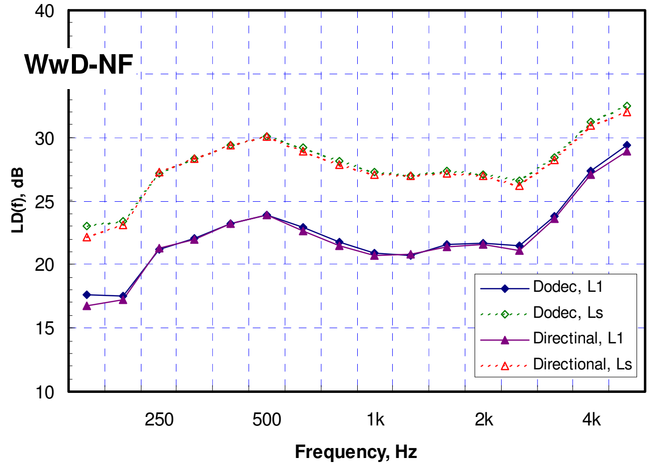


Fig. 37. Comparison of measured LD(f) using either the source room levels L_s or the average level at 1 m, L_1 for both the dodecahedron and the directional loudspeaker. Wall-with-a-door construction (WwD), no foam (NF) absorption case.

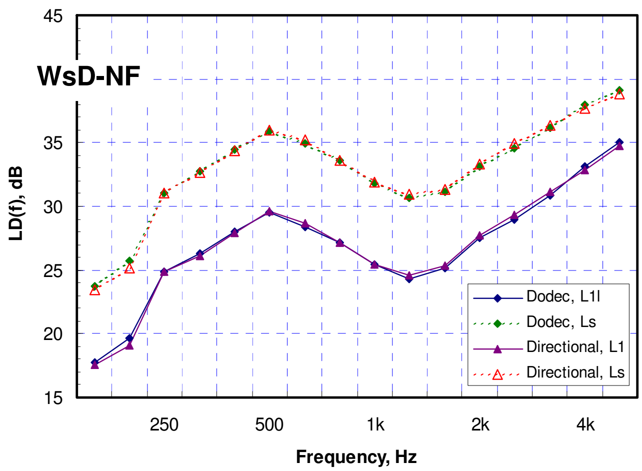


Fig. 38. Comparison of measured LD(f) using either the source room levels L_s or the average level at 1 m, L_1 for both the dodecahedron and the directional loudspeaker. Wall-with-sealed-door construction (WwD), no foam (NF) absorption case.

In all three plots above the two loudspeakers lead to similar results. However, using the average source room levels, L_s, and the average level at 1 m lead to quite different results. The difference between the two methods also varies with frequency as shown in Fig. 39. As the two loudspeakers led to very similar results, Fig 39 shows only results for the dodecahedron loudspeaker. The figure shows the differences between the LD(f) values obtained using the two methods and for the 9 combinations of 3 constructions and 3 absorption cases.

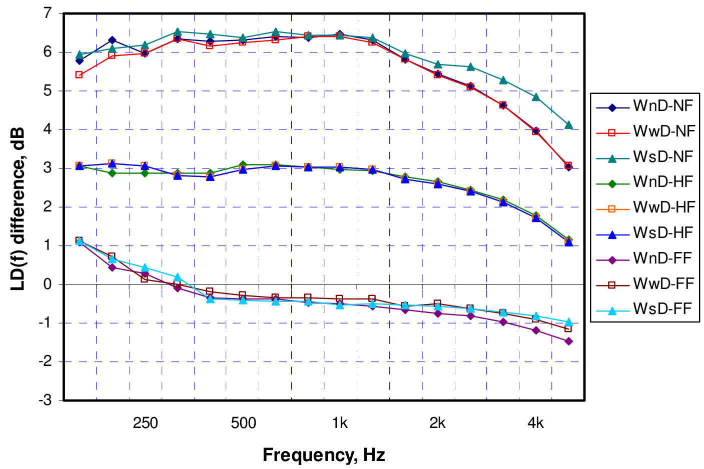


Fig. 39. Differences in measured LD(f) relative to either the source room average levels, L_s or the average source level at 1 m L_1 for the 9 combinations of 3 constructions and 3 absorption cases.

The differences in Fig. 39 vary with frequency because when the average source room levels are used, they are influenced by the total sound absorption in the particular test room. Although these data are all from the same room there were variations in the total sound absorption between tests because of changes in the temperature and humidity of the test room.

One could use the average 1m level and correct for the effects of room absorption. However, this would require reverberation time measurements to determine exactly how the test room absorption varies with frequency. This would have to be repeated for every room tested. Because it would be simpler to measure to actual source room levels than the room reverberation times, the proposed alternative method was rejected.

6. Comparison of Quick Test and Full Test Results

6.1 Parameters varied in the comparisons

The Quick Test procedure is intended to provide results that are approximately the same as those from the full speech security test but require less time and effort. The proposed quick test procedure was evaluated by comparing measured level differences obtained using the quick test procedure with values of the same conditions using the full speech security test. These comparisons were made for a number of conditions obtained by varying the 6 key variables listed in Table 1.

Variable	Values
Microphone height in receiving space	1.2 and 1.5 m
Position along the test wall	Positions #1, 5, 9, 13, 14, 18, 22 and 26 (see Fig. 3)
Source-to-wall distance	0.5, 0.75, 1.0 and 1.5 m
Room absorption	No foam (NF), half foam (HF) and full foam (FF)
Wall construction	Wall-with-no-door (WnD) and Wall-with-a-door (WwD)

Table 1 Quantities varied in comparisons of full speech security test and the quick test and the values included for each variable.

For the quick test the microphone in the receiving space was located at 8 of the positions used in the full test and indicated on Fig. 3. The receiving microphone was either 1.2 m or 1.5 m above the base of the wall. In all cases for both test procedures the microphone in the receiving space was located 0.25 m from the test wall and for the quick test the source loudspeaker was always at the same height as the receiving microphone.

For the quick test results, the source was at one of 5 distances from the test wall (0.5, 0.75, 1.0 or 1.5 m). The intent was to determine an optimum source-to-wall distance that would make possible the best agreement between the results of the two test procedures.

These comparisons are shown for two constructions: the wall-with-no-door (WnD) and for the wall-with-a-door (WwD). For each construction, comparisons were made for three different amounts room absorption: full foam (FF), half foam (HF) and no foam (NF). The same absorption conditions were maintained in both of the two rooms. The resulting reverberation times were described in Section 3.1.

6.2 Effects of receiver height on quick test results

The effect of microphone height at the spot receiver positions was first examined. As for the full test results, only small differences in measured LD(f) values were seen and mostly at lower frequencies in the 250, 315 and 400 Hz 1/3-octave bands. Figure 40 shows a comparison of measured LD(f) values averaged over the 4 positions along the wall at 1.2 and 1.5m heights and for the wall-with-no-door construction obtained using the dodecahedron source and the quick test procedure. Similar results obtained using the directional source are shown in Fig. 41.

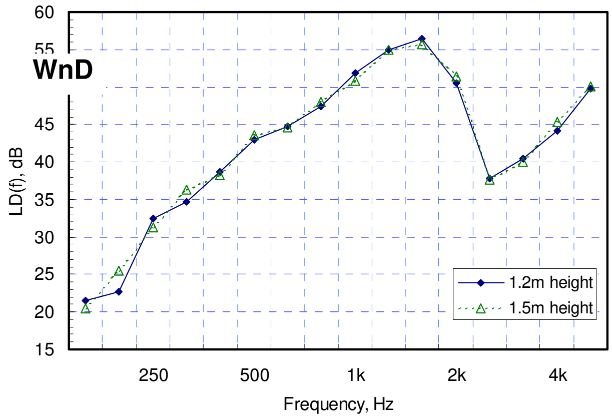


Fig. 40. Comparison of measured level differences of the wall-with-no-door (WnD) averaged over the 4 positions at each receiver microphone height using a dodecahedron source and the full foam (FF) absorption case. (see Table 1 and Fig. 3 for information on the positions).

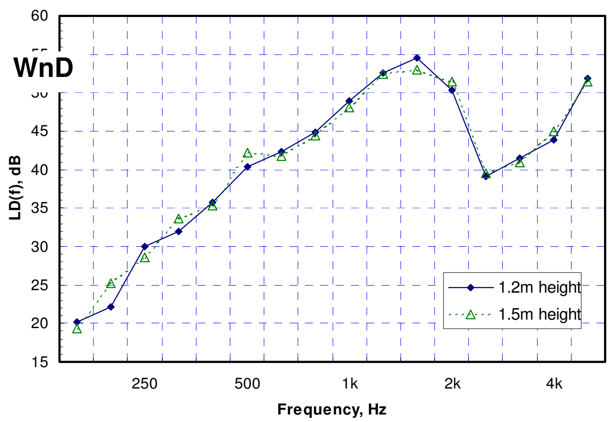


Fig. 41. Comparison of measured level differences of the wall-with-no-door (WnD) averaged over the 4 positions at each receiver microphone height using a directional source and the full foam (FF) absorption case. (see Table 1 and Fig. 3 for information on the positions).

Fig. 42 and 43 compare measured LD(f) values averaged over the 4 receiver positions at each of the two microphone heights for the wall-with-a-door construction.

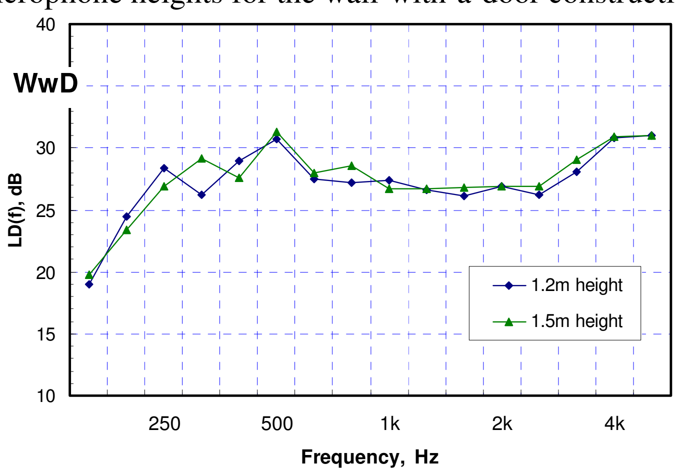


Fig. 42. Comparison of measured level differences of the wall-with-a-door (WwD) averaged over the 4 positions at each receiver microphone height using a dodecahedron source and the full foam absorption (FF) case. (see Table 1 and Fig. 3 for information on the positions).

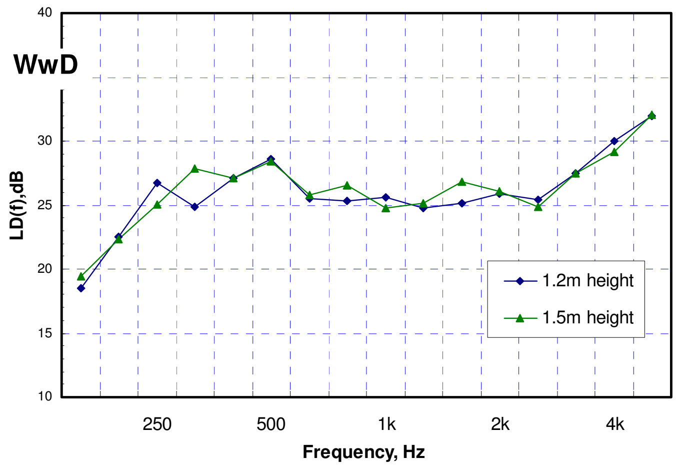


Fig. 43. Comparison of measured level differences of the wall-with-no-door (WwD) averaged over the 4 positions at each receiver microphone height using a directional source and the full foam absorption (FF) case. (see Table 1 and Fig. 3 for information on the positions).

For both the wall-with-no-door and the wall-with-a-door constructions, there were small differences in the measured LD(f) values at the two microphone heights. Similar differences were found for the full speech security test in section 4.1. As discussed in section 4.1 for the full test results, these small differences may be due to vertical resonances in the niche where the wall constructions were located. They could cause measured transmitted levels to vary with microphone height at positions 0.25 m from the test wall. However, the differences are small and mostly at lower frequencies which would be less important for the intelligibility of speech. In many of the following results, the LD(f) values are averaged over measured values at both microphone heights to give a clearer picture of the more important effects.

6.3 Effects of source-to-test-wall distance on LD(f) values

The effects of the loudspeaker-to-test-wall distance were larger and more complex than the effects of receiver height. LD(f) values measured for 4 different source-to-wall distances were compared with LD(f) values obtained from the full speech security test procedure. Results were averaged over the two microphone heights and these comparisons were repeated for constructions with and without a door and for both types of loudspeaker, for the 3 different room absorption cases and for both source loudspeaker types.

Fig. 44 shows comparisons of LD(f) values for the wall-with-no-door and using the dodecahedron loudspeaker source. The LD(f) values were obtained by averaging results at positions horizontally along the wall and at both microphone heights. For the quick test, the source was positioned at: 0.5, 0.75, 1.0 and 1.5 m from the test wall and at the same height as the microphone, which was located on the other side of the test wall. The measured average level differences are seen to vary systematically with the source-to-wall distance and the variations tended to be of similar magnitude for most included frequencies. The level differences from the quick test results were largest for the largest source-to-wall distance (1.5 m) indicating that this condition led to the lowest transmitted sound levels.

Fig. 44 also plots the measured sound transmission loss values for each absorption case. It is seen that the FSST (Full Speech Security Test) results agreed best with the TL(f) values for the most absorptive conditions (FF) in the two rooms. The LD(f) values obtained using the quick test procedure varied most with the source-to-wall distance, for the full foam absorption case.

Although there are differences between the quick test and full test results, and further variations in the quick test results with source-to wall-distance, the resulting LD(f) values follow approximately parallel trends.

Fig. 45 shows similar comparisons of LD(f) values for the same construction and measurement positions but using the directional loudspeaker source. When using the directional loudspeaker source, the variations of measured LD(f) values with source-to-wall distance were less but the range of variations varied more with frequency. In both Fig 44 and 45 the level differences from the quick test procedure were smaller than those from the full test results by the order of 5 dB for the full foam and half foam cases.

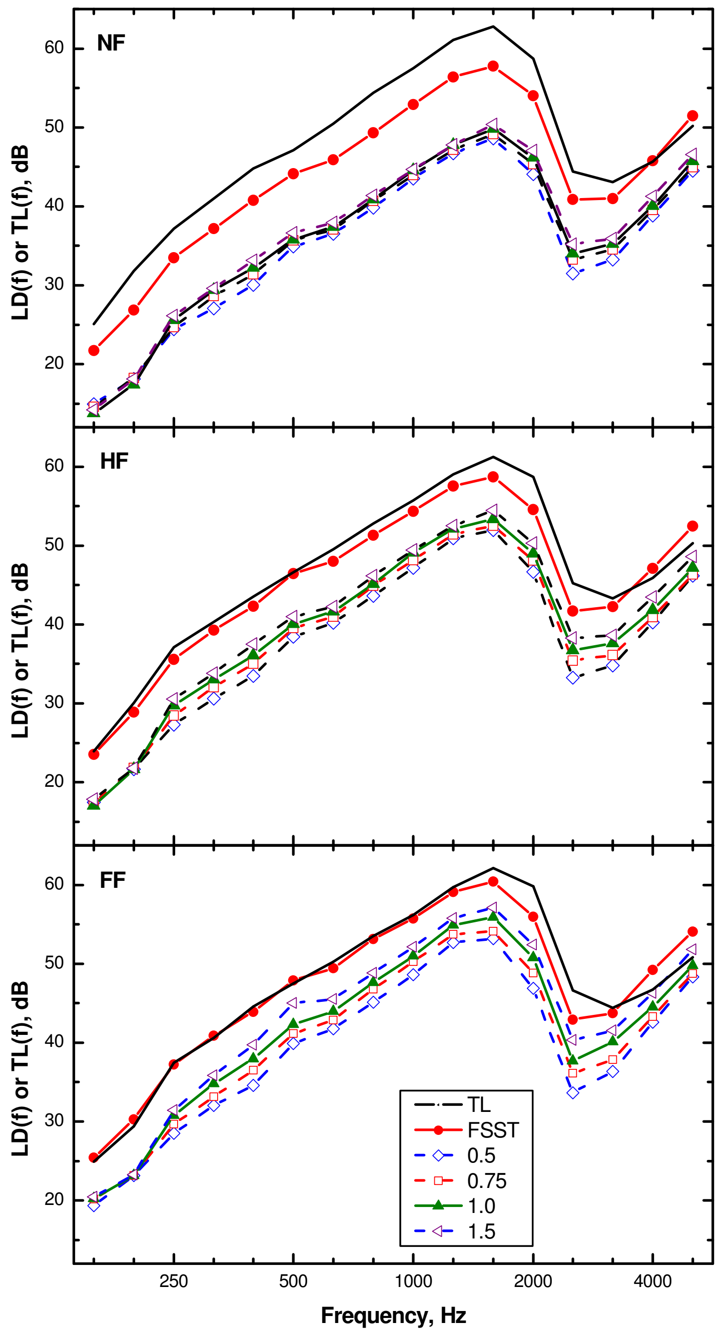


Fig. 44. Comparison of measured level differences using the full test (FSST) and quick test (QT) procedures with standard TL values for the wall-with-no-door (WnD) construction and using the dodecahedron source. For the quick test results the source-to-wall distance was varied (0.5, 0.75, 1.0 and 1.5 m) and all results are averages over the 8 microphone positions in the receiving space. Upper panel, no added foam absorption (NF); middle panel, half added foam absorption (HF), and bottom panel full foam absorption (FF).

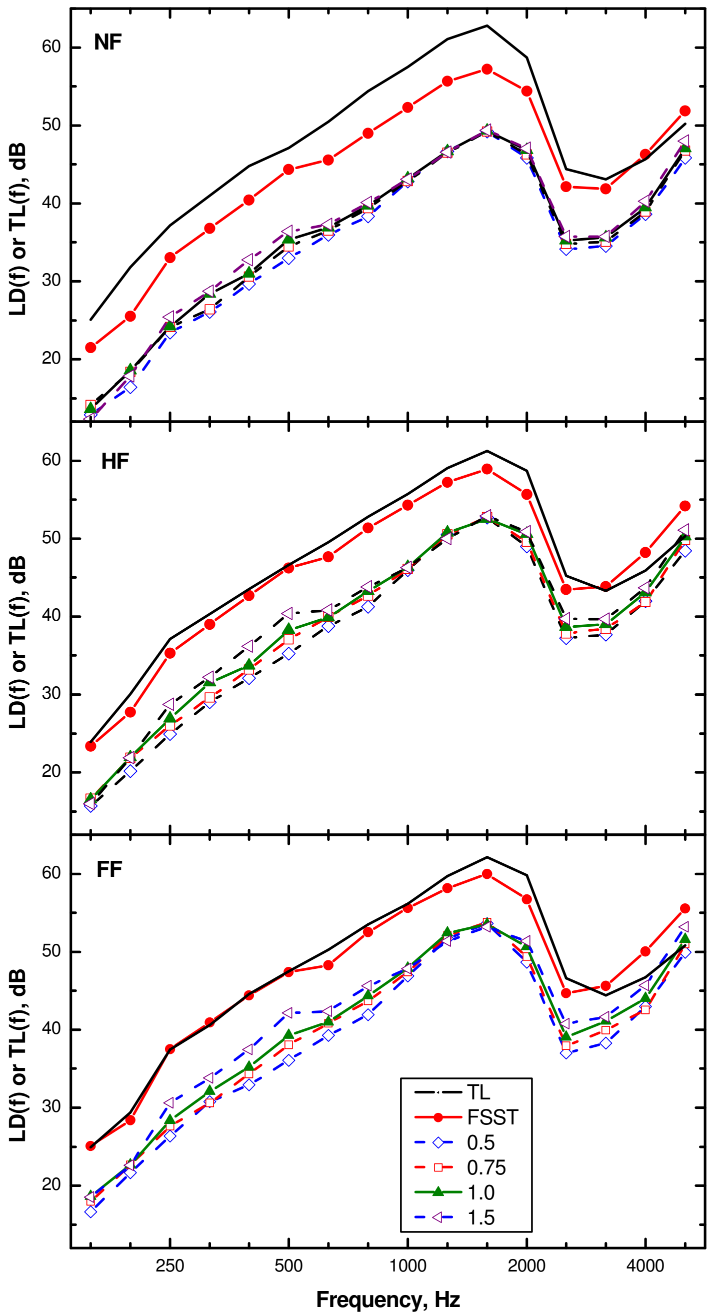


Fig. 45. Comparison of measured level differences using the full test (FSST) and quick test (QT) procedures with standard TL values for the wall-with-no-door (WnD) construction and using the directional source. For the quick test results, the source-to-wall distance was varied (0.5, 0.75, 1.0 and 1.5 m) and all results are averages over the 8 microphone positions in the receiving space. Upper panel, no added foam absorption (NF); middle panel, half added foam absorption (HF), and bottom panel full foam absorption (FF).

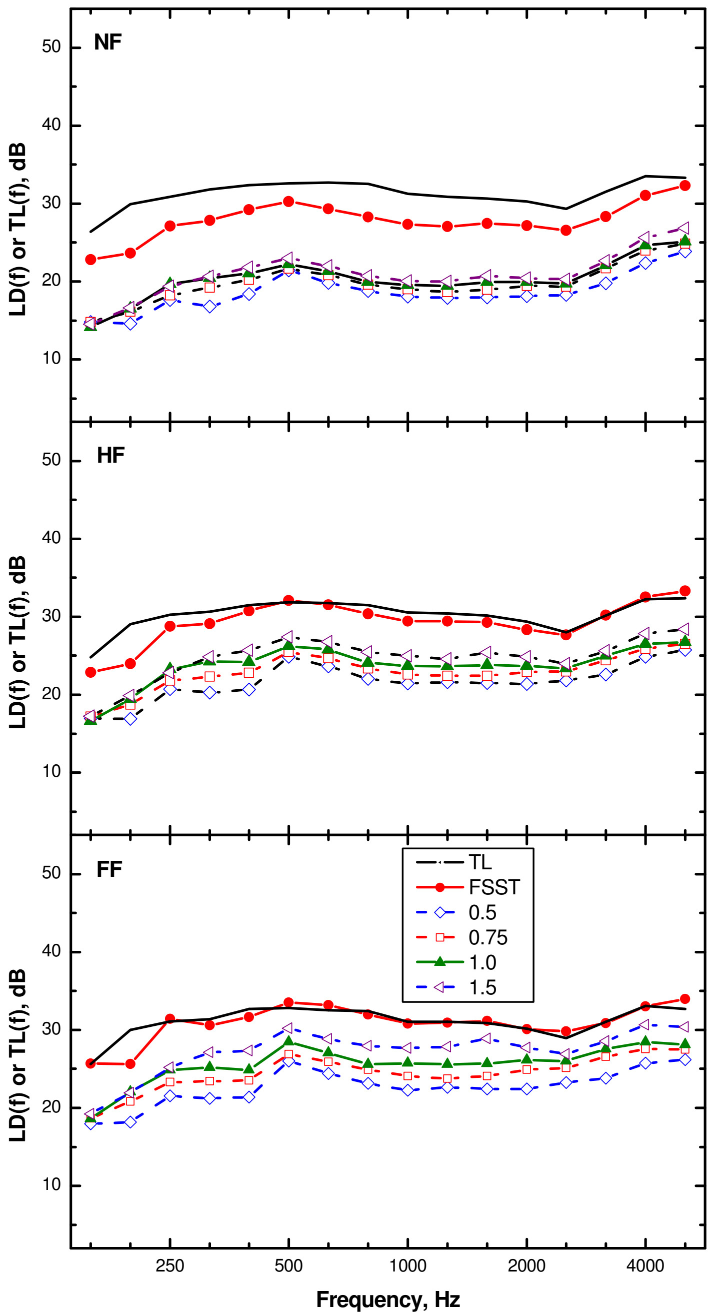


Fig. 46. Comparison of measured level differences using the full test (FSST) and quick test (QT) procedures with standard TL values for the wall-with-a-door (WwD) construction and using the dodecahedron source. For the quick test results, the source-to-wall distance was varied (0.5, 0.75, 1.0 and 1.5 m) and all results are averages over the 8 microphone positions in the receiving space. Upper panel, no added foam absorption (NF); middle panel, half added foam absorption (HF), and bottom panel full foam absorption (FF).

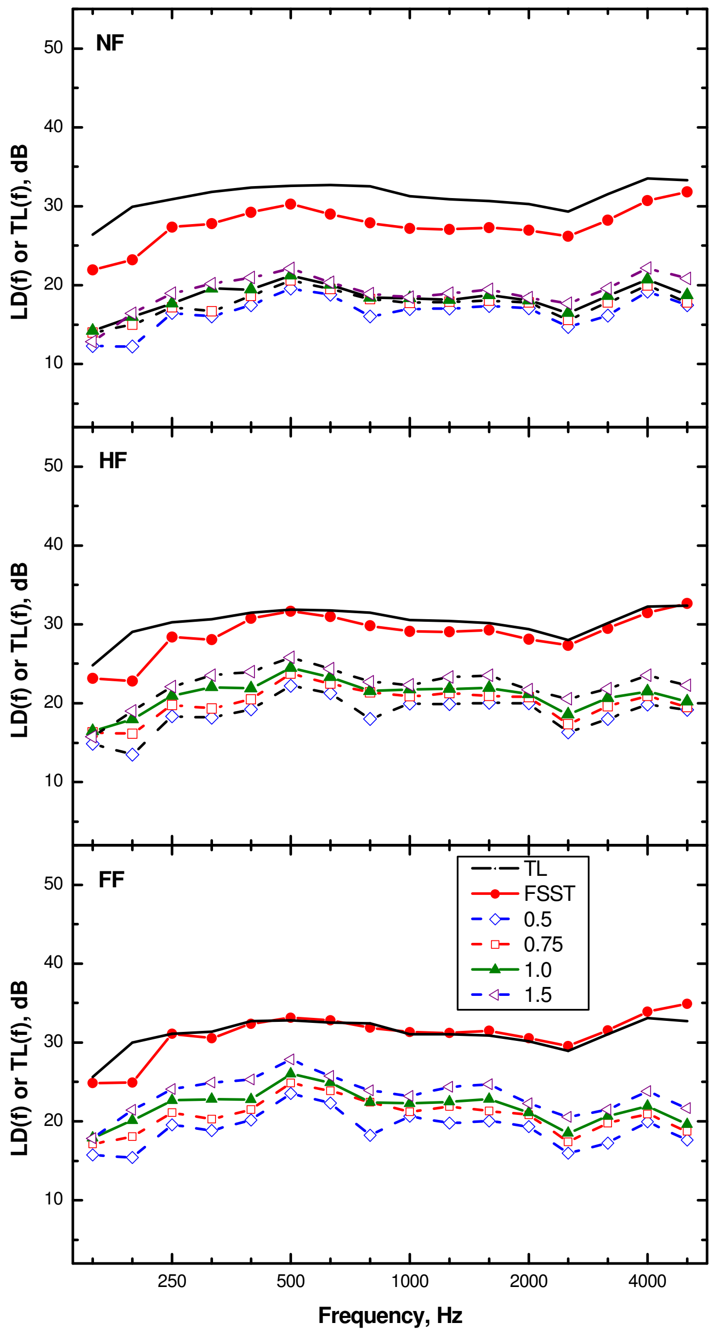


Fig. 47. Comparison of measured level differences using the full test (FSST) and quick test (QT) procedures with standard TL values for the wall-with-a-door (WwD) construction and using the directional source. For the quick test results, the source-to-wall distance was varied (0.5, 0.75, 1.0 and 1.5 m) and all results are averages over the 8 microphone positions in the receiving space. Upper panel, no added foam absorption (NF); middle panel, half added foam absorption (HF), and bottom panel full foam absorption (FF).

Fig. 46 and Fig. 47 show similar comparisons of LD(f) values for the wall-with-a-door obtained using the dodecahedron and directional loudspeakers respectively. Although the LD(f) versus frequency characteristics are quite different than for the wall-with-no-door construction, the differences between the two measurement approaches are quite similar to those in the previous two figures. In both cases the LD(f) values from the quick test procedure are lower in value than those from the full test procedure. When using the dodecahedron loudspeaker, the results in Fig. 46 again show systematic variations of the quick test LD(f) values with source-to-wall distance and with the highest LD(f) values at the largest distance from the wall. For the directional source results in Fig. 47, the quick test level differences vary a little less with source-to-wall distance than do the results using the omni-directional source.

Although there was a systematic variation in measured LD(f) with varied source-to-wall distance, there was no clear reason to pick one distance over another from these measurement results. A source-to-wall distance of 1.0 m was chosen as acceptable and further analyses focussed on using this distance and confirming its suitability. It was thought that a closer distance could lead to problems with reflections between the test wall and some sources and possible less accurate positioning of the source. On the other hand, larger distances would lead to results that are more influenced by room acoustics and the 1.0 m distance seemed a reasonable compromise. (The 1 m source-to-wall distance is also the same as used in ASTM E336-05 standard for the special case of a very large receiving room with a non-diffuse sound field).

It is important to examine the differences between the LD(f) values from the full test and the quick test results because we would like to be able to adjust the quick test results to be approximately equal to the full test results. For example, differences that did not vary significantly over frequency would make it easier to correct the quick test results to more closely equal the full test LD(f) values. Fig 48 plots the differences between the measured LD(f) values obtained using the quick test and full test procedures for the wall-with-no-door construction. The differences between the two methods are plotted for the 6 combinations of 3 absorption conditions and 2 loudspeaker types. In this plot the differences for the full foam and half foam cases when using the dodecahedron loudspeaker tend to be smaller and vary less with frequency than those for the directional loudspeaker.

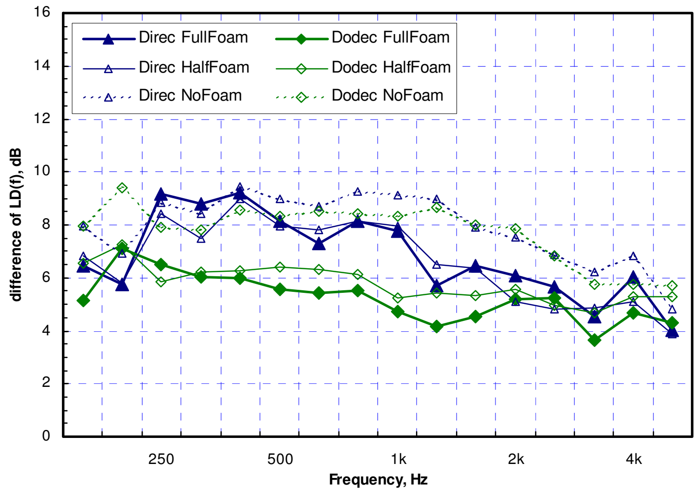


Fig. 48. Difference in measured level differences between the results of the full test and the quick test procedures (i.e. QT-FSST differences) for the 6 combinations of 3 absorption cases and 2 loudspeaker types. Results are for the wall-with-no-door (WnD) construction.

Fig. 49 plots a similar set of 6 differences between pairs of LD(f) values for the wall-with-a-door construction. Again for this construction with either the full foam or half foam cases, the differences between the two methods are smaller when using the dodecahedron source and tend to vary less with frequency than when using the directional source. For this construction, the quick test results seem to deviate most from the full test LD(f) values at high frequencies when using the directional source. This was due to the effects of transmission through the leaky door. Increased levels of higher frequency sound propagated through at the location of the edge of the door, which had no seals. The amount of increased high frequency sound varied with the type of loudspeaker as well as the position of the source loudspeaker and receiver microphone along the wall. The average results in Fig. 49 are most influenced by the higher levels transmitted when the directional source was at position #5 and #18 near the edge of the door.

Comparing the results of Fig. 48 and Fig 49 suggests that the quick test results obtained using the dodecahedron source could provide more accurate estimates of the corresponding full test results because the differences between the quick test and full test results vary much less over frequency when using the dodecahedron source.

The differences plotted in Fig. 48, and to a lesser extent in Fig. 49, for the dodecahedron source tend to decrease with increasing frequency. This suggests that it might also be possible to correct for this effect when adjusting quick test results to provide approximate predictions of full test results. However the differences for the directional source in these two figures vary differently with frequency between the two constructions.

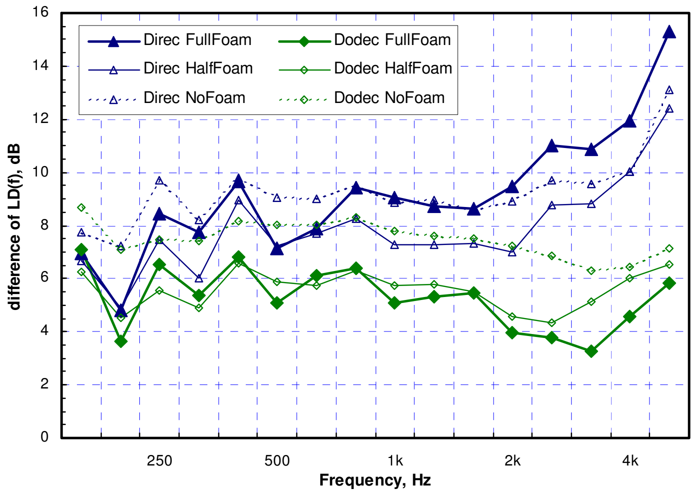


Fig. 49. Difference in measured level differences between the results of the full test and the quick test procedures (i.e. QT-FSST differences) for the 6 combinations of 3 absorption cases and 2 loudspeaker types. Results are for the wall-with-a-door (WwD) construction.

6.4 Spectral variations along the test wall

The variations of the transmitted sound with frequency can be more clearly understood with plots of the spectrum of the measured level differences obtained using the quick test procedure. Fig. 50 (upper panel) plots the measured LD(f) values obtained using the quick test (QT) procedure at each of the 8 measurement positions using the dodecahedron source and for the full foam condition. The lower panel of this figure shows the corresponding measured LD(f) values obtained when using the full speech security test (FSST) procedure at the same positions. Both of these results were for the wall-with-no-door construction. Although some small systematic variations along the wall were found for the complete full test results in the previous section, there are other larger variations in the results among the 8 positions for the quick test results than for the full test results.

Fig 51 shows LD(f) values for the same conditions and both test procedures obtained using the directional loudspeaker source. Again there is greater variation in LD(f) values among the 8 positions for the quick test results than for the full test results.

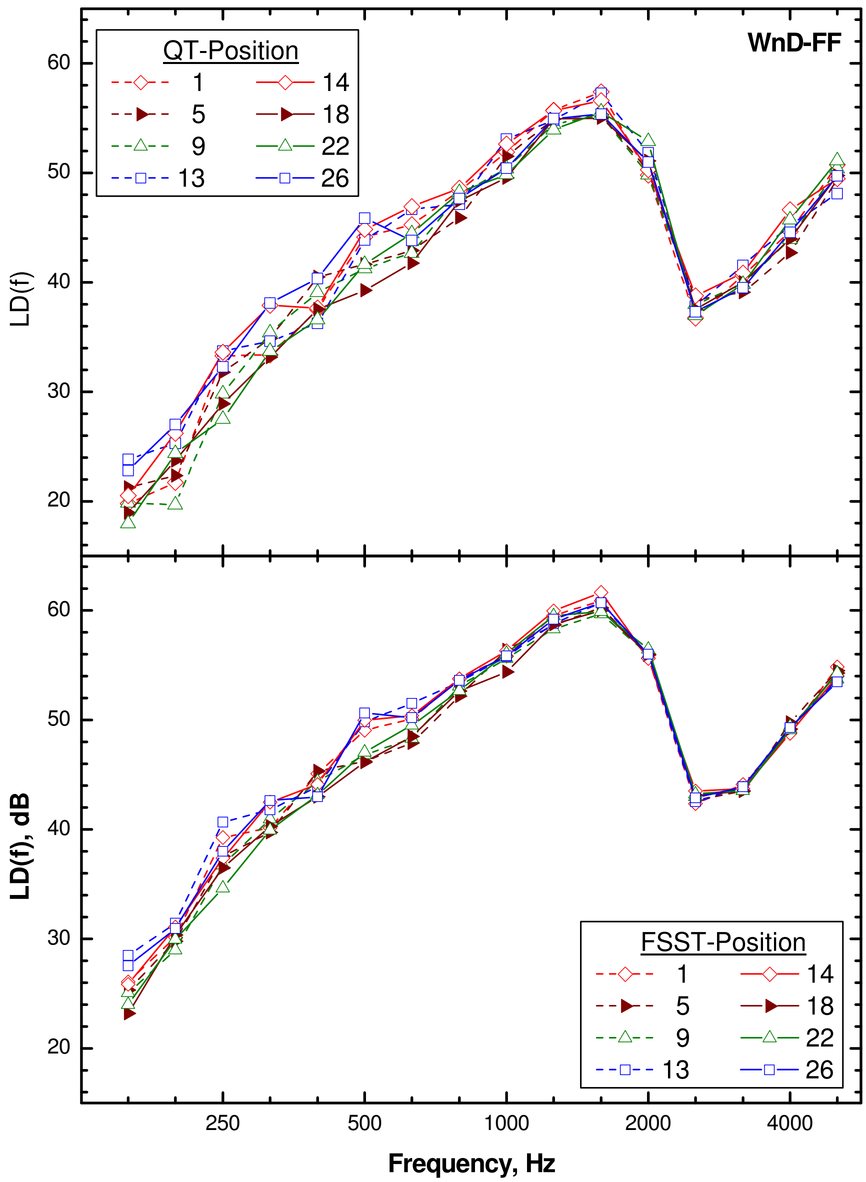


Fig. 50. Measured level differences versus frequency at the 8 positions used for the quick test results for the wall-with-no-door (WnD) construction and the full foam (FF) absorption case obtained using the dodecahedron source. The upper panel results were obtained using the quick test(QT) procedure and the lower panel using the full test(FSST) results.

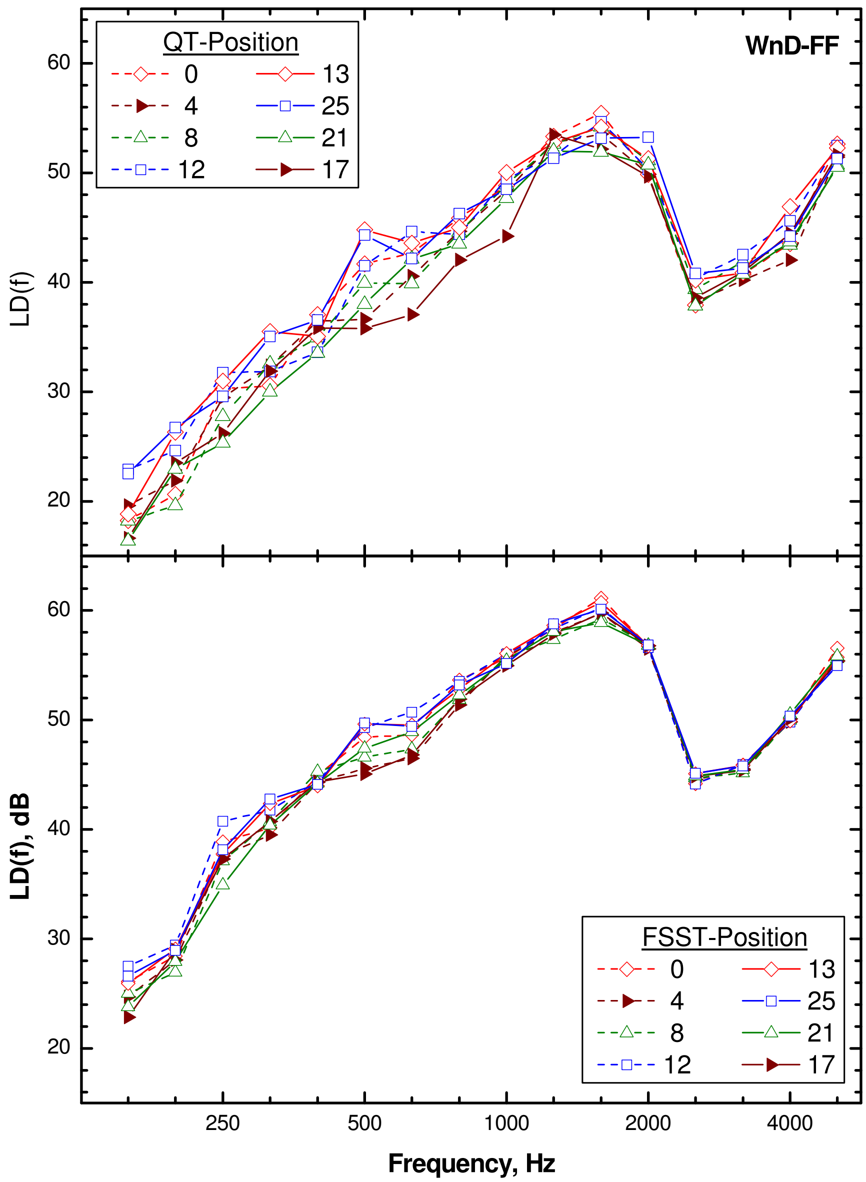


Fig. 51. Measured level differences versus frequency at the 8 positions used for the quick test results for the wall-with-no-door (WnD) construction and the full foam (FF) absorption case obtained using the directional source. The upper panel results were obtained using the quick test(QT) procedure and the lower panel using the full test(FSST) results.

The results for the construction consisting of a wall-with-a-door are shown in Fig 52 and Fig 53 for the dodecahedron source and directional source respectively. For these results there are larger variations among the results at the different microphone positions because the transmission characteristics of the wall vary along the wall due to the presence of the door. The LD(f) values at positions #5 and #18 are usually the lowest values at each frequency because these positions were at the location of the leaky door. However, the full test results still indicate less variation in LD(f) values with microphone position than do the quick test results.

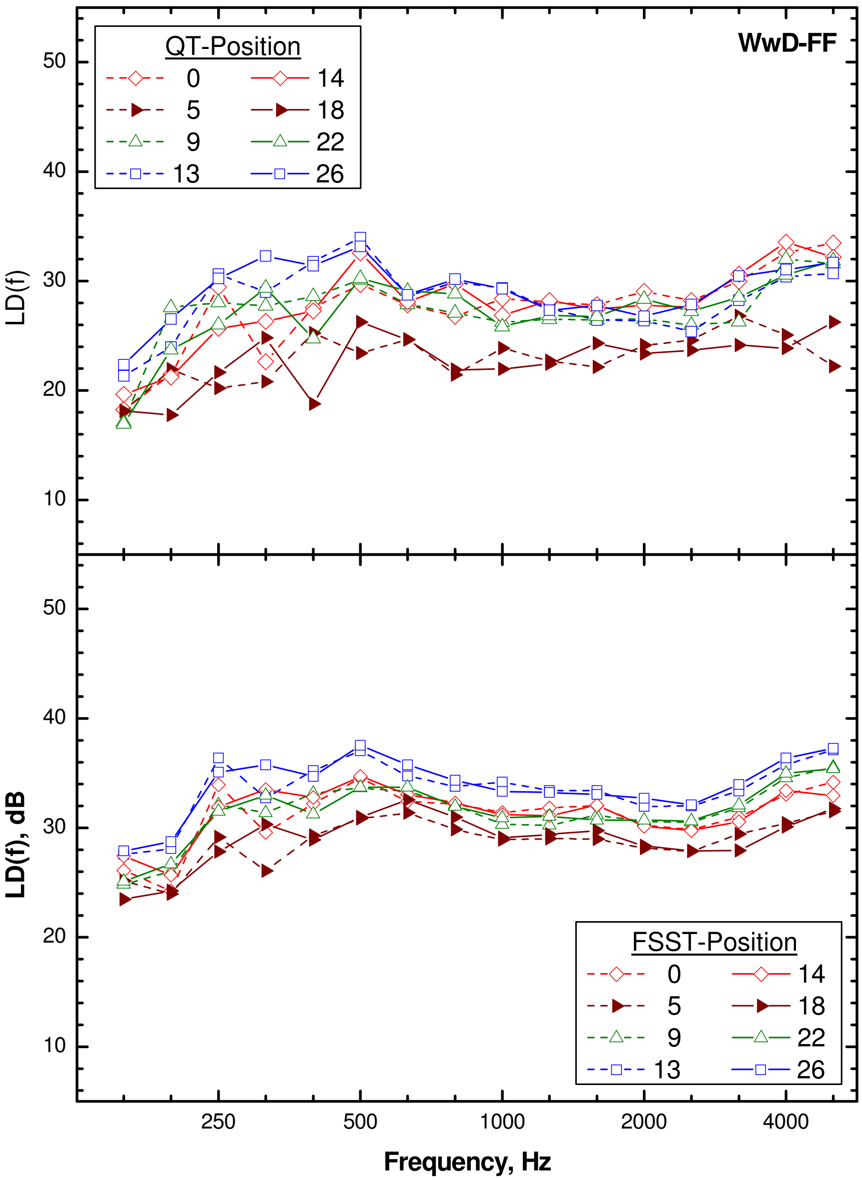


Fig. 52. Measured level differences versus frequency at the 8 positions used for the quick test results for the wall-with-a-door (WwD) construction and the full foam (FF) absorption case obtained using the dodecahedron source. The upper panel results were obtained using the quick test (QT) procedure and the lower panel results using the full test (FSST) results.

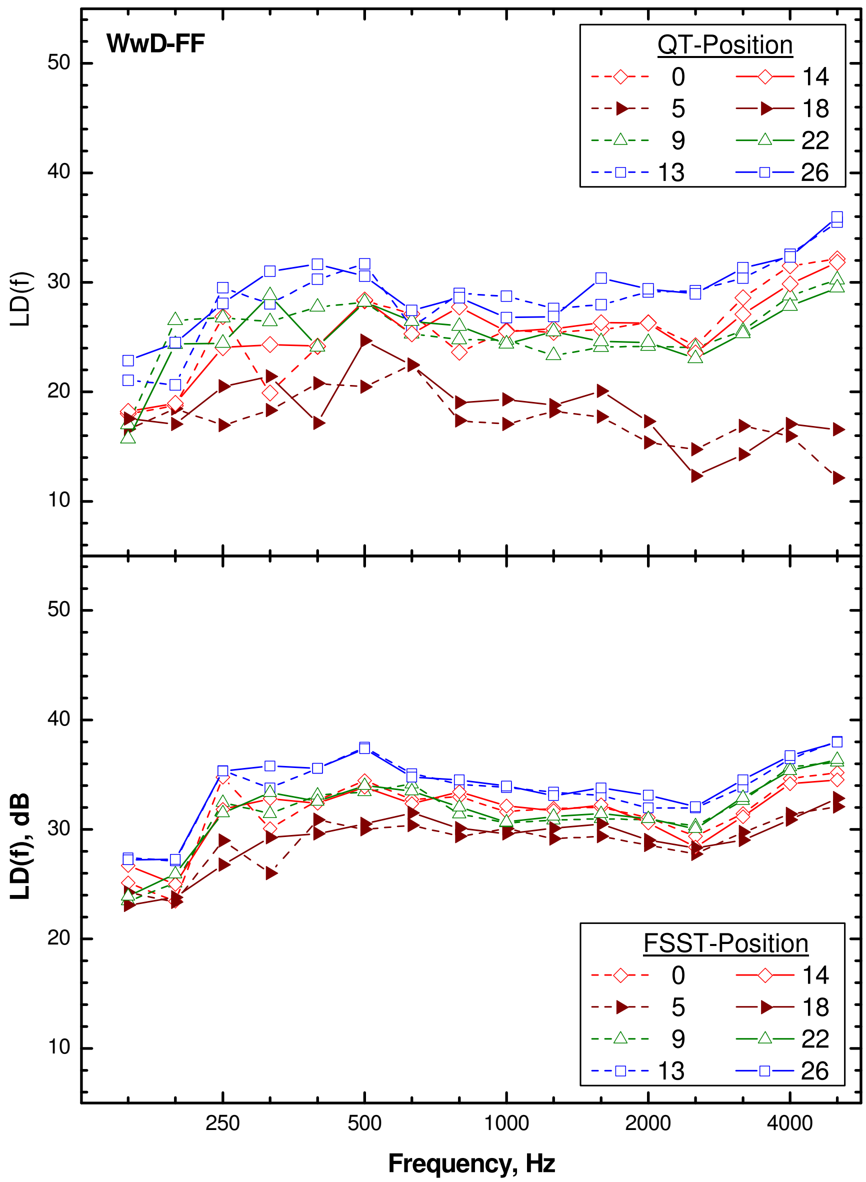


Fig. 53. Measured level differences versus frequency at the 8 positions used for the quick test results for the wall-with-a-door (WwD) construction and the full foam (FF) absorption case obtained using the directional source. The upper panel results were obtained using the quick test (QT) procedure and the lower panel results using the full test (FSST) results.

These results help to explain the pattern of the differences between the two methods in Fig. 49. Although the full test results in Fig 52, obtained using the directional source, are similar to those using the dodecahedron source for the full test results, the quick test results show much larger variations with microphone position. Using the directional source and the quick test procedure provides results that better define the variations in the transmission characteristics of the wall-with-a-door but consequently agrees less well with the full test procedure.

6.5 Effect of source-to-wall distance on LD(avg) values

The differences between the quick test and full test results were further considered in terms of averages over speech frequencies from 160 to 5k Hz. Fig. 54 plots the differences between pairs of level differences, LD(avg), values versus source-to-wall distance for the wall-with-no-door construction. Results are shown for the 6 combinations of 2 loudspeaker types and 3 added foam absorption cases. All differences in LD(avg) values decrease with increasing source-to-wall distance. That is, when the source is farthest from the test wall, the results are most similar to the full test results. The variations with source-to-wall distance are more rapid for the cases with the most added foam absorption present for both the dodecahedron source and the directional source.

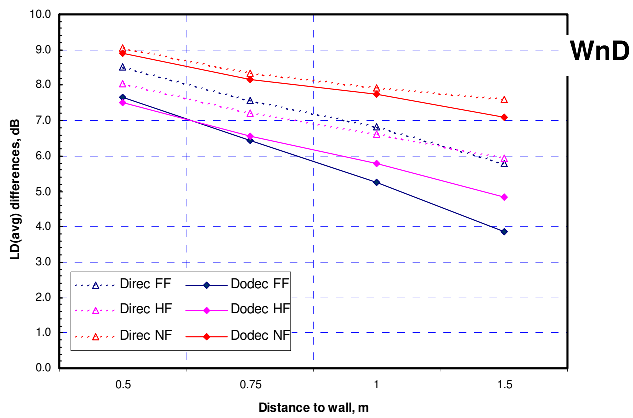


Fig. 54. Differences between LD(avg) values from the quick test and the full test for the wall-with-no-door (WnD) construction, (i.e. QT-FSST differences).

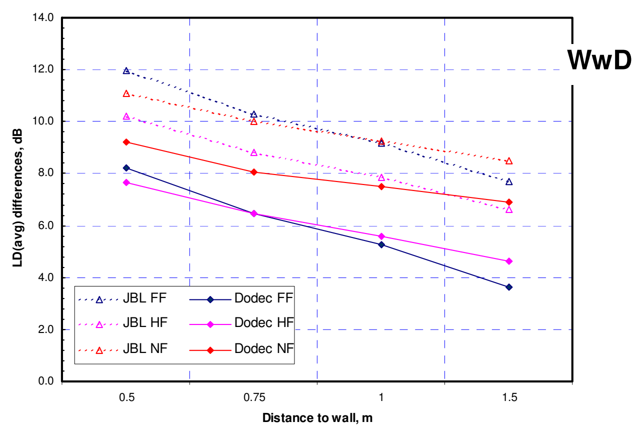


Fig. 55. Differences between LD(avg) values from the quick test and the full test for the wall-with-a-door (WwD) construction, (i.e. QT-FSST differences).

Fig. 55 plots the differences between the quick test and full test LD(avg) values for the wall with a door construction. These results are very similar to those for the other construction in Fig. 55. Neither plot suggests any reason for choosing one of the source-to-wall distance over another.

Fig. 48 and Fig. 49 showed some considerable variation in the differences between the two test methods over frequency. These can be evaluated by calculating the standard deviations of LD(f) values over the speech frequencies from 160 to 5k Hz. Less variation over frequency would result in lower standard deviation values and would make it easier to get better agreement between the two test procedures. Fig. 56 plots standard deviations over frequency for differences in LD(f) values from the quick test and full test for the wall-with-no-door construction. The standard deviations were smaller when the dodecahedron source was used. For the results obtained using the dodecahedron source, the standard deviations are smallest for the intermediate distances of 0.75 and 1.0 m, suggesting these are more suitable source-to-wall distances for the quick test.

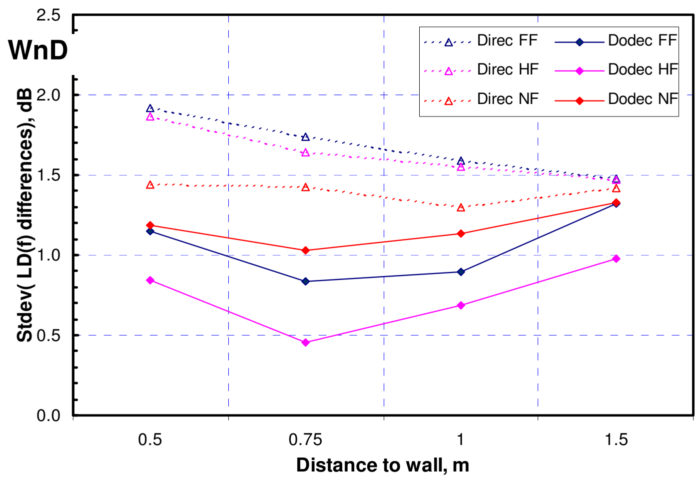


Fig. 56. Standard deviations over speech frequencies of the differences between LD(avg) values from the quick test and the full test for the wall-with-no-door (WnD) construction.

Fig. 57 plots standard deviations of the differences in LD(f) values between the two test procedures for the wall-with-a-door construction. Again the standard deviations are almost always larger when the directional source was used. Similar to Fig. 56, using the dodecahedron source and one of the intermediate source-to-wall distances (0.75 and 1.0 m) tended to lead to lower standard deviations.

The results in Fig. 56 and Fig 57 demonstrate clearly that the dodecahedron would make possible more accurate estimates of the full test LD(f) values from the quick test results and that using a 1.0 m source-to-wall distance leads to results that were among the lowest standard deviations of the differences between the two methods.

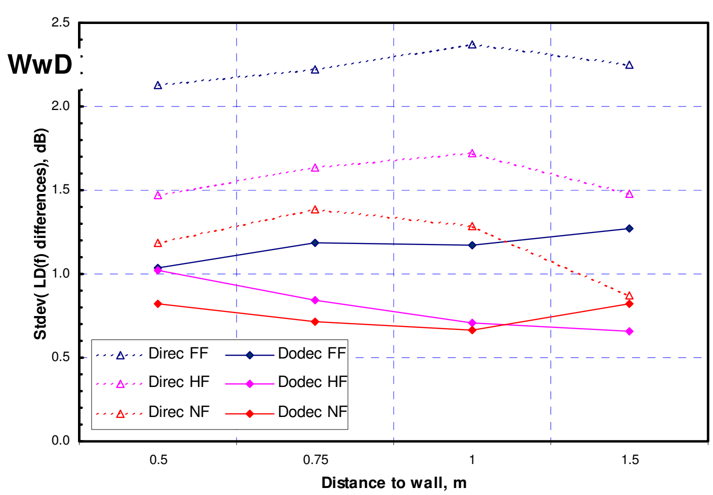


Fig. 57. Standard deviations over speech frequencies of the differences between LD(avg) values from the quick test and the full test for the wall-with-a-door (WwD) construction.

7. Predicting Full Test Level Differences from Measured Quick Test Level Differences

7.1 Quantifying Effects of varied room absorption

Although the measured level differences using the quick test are different than those obtained using the full speech security test, the results in the previous section suggest that the two sets of results are closely related. In this section a procedure for adjusting or correcting the quick test results so that they are approximately equal to the full test results will be evaluated. Only the results for a 1.0 m source-to-wall distance will be used.

In the previous section it was seen that the main systematic differences between quick test and full test level differences were caused by the variations in room absorption. It is therefore first necessary to show how the differences between the quick test and full test LD(avg) values vary with the variations in room absorption. The room absorption was varied from: no foam (NF), to half foam (HF) and to full foam (FF). The actual amounts of absorption were determined from the measured reverberation times and the room volumes using the Sabine reverberation time equation. The total room absorption as an equivalent area of perfect absorber is given by,

$$A = 0.161\ V/T_{60},\ m^2, \qquad (3)$$

where A is the total sound absorption in m^2, V is the room volume in m^3, and T_{60} is the reverberation time in s. Measured reverberation times were averaged over the speech frequencies from 160 to 5k Hz. These frequency averaged T_{60} values were used to calculate the total room absorption values for each of the 3 absorption conditions.

Commonly used simple diffuse field theory relates the reverberant sound level in a room to $10\log\{4/A\}$, where again A is the total sound absorption in m^2. The room absorption conditions were described in terms of this expression where the absorption values were based on average reverberation times over the speech frequencies.

The differences between the LD(avg) values obtained using the quick test (QT) and those using the full speech security test (FSST) were then plotted versus the $10\log\{4/A\}$ values for the 3 absorption cases. Fig. 58 plots the QT-FSST differences versus $10\ \log\{4/A\}$ values of the receiving room for results using the dodecahedron source and the 6 combinations of 3 absorption conditions and two wall constructions. Each data point is the average of measured LD(avg) values at the 8 microphone positions used in comparing the two test methods. The plot shows a small difference between the results for the two different constructions and larger variations with varied room absorption. Regression lines were fitted to the data for each construction and to the average of both sets of data. This average regression line for both constructions was,

$$y = -0.0612 \cdot x^2 - 1.1298 \cdot x - 10.109,\ dB \qquad (4)$$

Here y = the difference in LD(avg) values and $x = 10\log\{4/A\}$.

This equation can be used for predicting the variation of the QT-FSST differences of the LD(avg) values with varied room absorption when using a dodecahedron loudspeaker source.

For the FF and HF conditions, which are more representative of conditions found in meeting rooms, there are only small variations in the LD(avg) differences. The average difference for these conditions was 5.2 dB ±0.5 dB. In many cases it would be acceptable to use this mean difference to predict the full test results corresponding to the measured quick test results in most meeting room situations rather than using the more complicated but more precise regression equation.

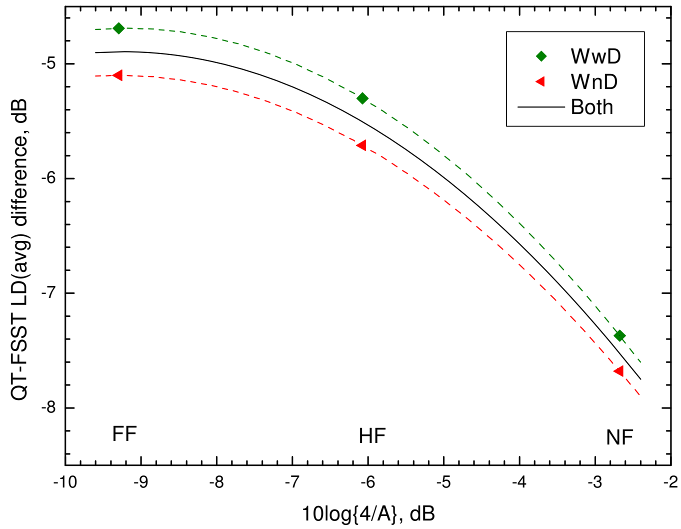


Fig. 58. Differences between LD(avg) values obtained using the quick test (QT) and the full speech security test (FSST), using the dodecahedron source, for the 6 combinations of two constructions WwD and WnD and 3 room absorption cases FF, HF and NF.

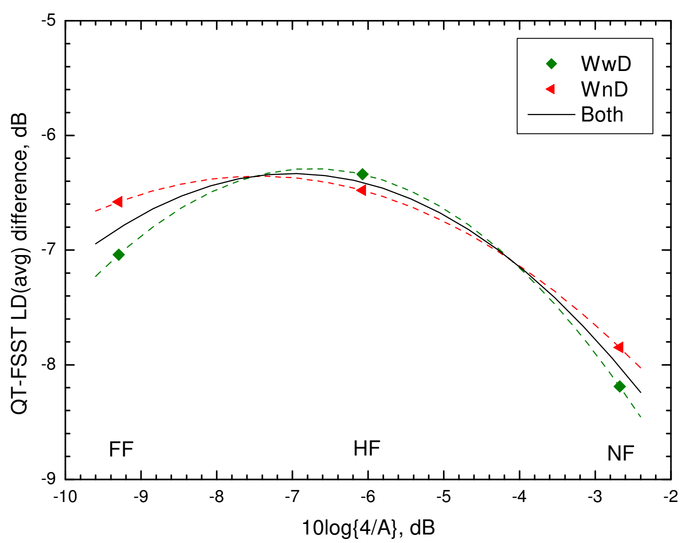


Fig. 59. Differences between LD(avg) values obtained using the quick test (QT) and the full speech security test (FSST), using the directional source, for the 6 combinations of two constructions WwD and WnD and 3 room absorption cases FF, HF and NF.

Fig. 59 shows the differences between LD(avg) values obtained using the QT and the FSST when using the directional sound source for the same 6 combinations of 2 wall constructions and 3 room absorption cases. The best-fit regression line to the combined data was,

$$y = -0.0902 \cdot x^2 - 1.1259 \cdot x - 10.742. \quad (5)$$

The variables y and x are the same as in equation (4).

Again, for the FF and HF conditions there are only small variations in the LD(avg) differences. The average difference for these conditions was 6.6 dB ±0.4 dB. In many cases this mean difference could be used to predict the full test results from quick test results rather than use the more complicated but more precise regression equation.

7.2 Predicting full test LD(avg) values from quick test LD(avg) values

LD(avg) values were measured for the 48 combinations of 8 microphone positions, 2 wall constructions and 3 absorption cases using both the quick test and full test procedures. The expected LD(avg) values for the full test were predicted using the measured LD(avg) values obtained using the quick test plus a correction for the effects of room absorption using either equation (4) or (5). These predicted FSST LD(avg) values are plotted versus the measured FSST LD(avg) values in Fig. 60 for measurements using the dodecahedron source. The data are seen to cluster close to the y = x line and the RMS error about this line was only 0.56 dB for these data.

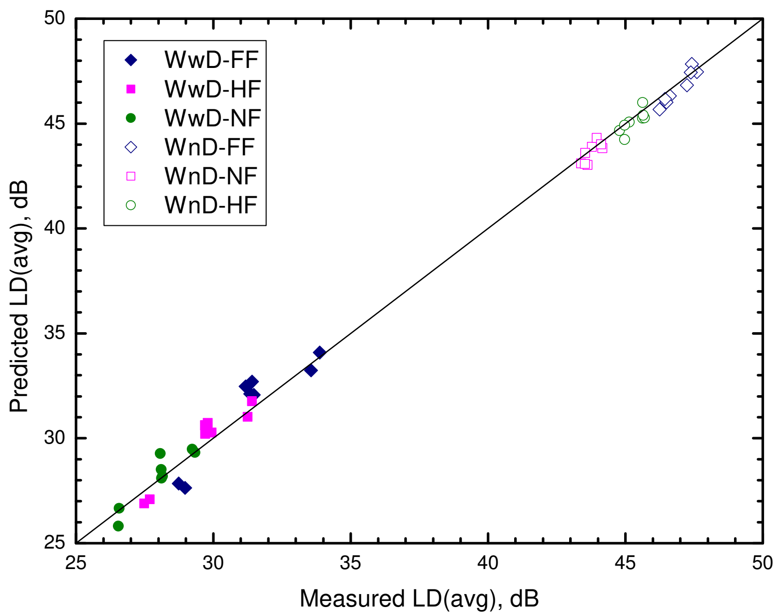


Fig. 60. Predicted full test LD(avg) values from quick test LD(avg) values plotted versus measured full test LD(avg) values for measurements using the dodecahedron source. (RMS difference between measured and predicted = 0.56 dB).

A similar comparison of measured and predicted full test LD(avg) values for measurements using the directional source is shown in Fig. 61. This figure shows greater scatter than the previous plot for the dodecahedron source and the RMS error about the y = x line was 1.46 dB for these data. The increased scatter is largely caused by the measurements at positions #5 and #18 near the door for the wall-with-a-door construction, where distinctly lower LD(avg) values were obtained when using the directional source. Using the directional source better identifies the increased sound transmission at the door but leads to results that differ from the measured full test results.

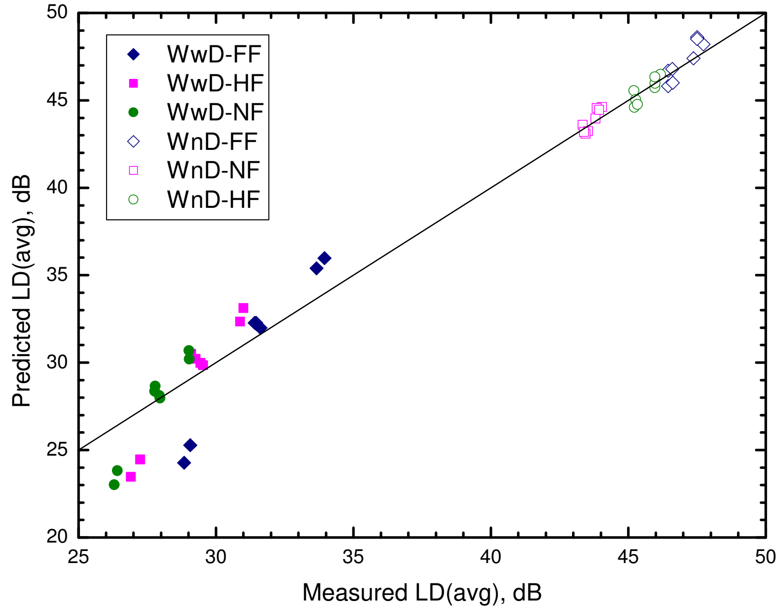


Fig. 61. Predicted full test LD(avg) values from quick test LD(avg) values plotted versus measured full test LD(avg) values for measurements using the directional source. (RMS difference between measured and predicted = 1.46 dB).

The errors in the predictions of full test LD(avg) values from quick test measurements were also calculated separately for the 6 combinations of 2 constructions and 3 room absorption cases. Fig. 62 plots these calculated RMS differences between the measured and predicted full test LD(avg) values. These RMS differences tend to increase with increased room absorption and are larger for the directional source than for the dodecahedron source. The RMS differences are also lower for measurements of the wall-with-no-door construction because the transmission properties of this construction do not vary greatly with position along the wall. Because of the door in the wall-with-a-door construction, the transmission properties do vary significantly with position along the wall and the two test procedures do not indicate exactly the same variations with position.

These results suggest that if one uses a dodecahedron source to make quick test measurements, the full test LD(avg) values can usually be predicted within less than ±0.5 dB for homogeneous constructions such as the wall-with-no-door and within less than ±1.0 dB for more complex constructions such as the wall-with-a-door. Using a directional source will lead to results that agree less well with the full test results.

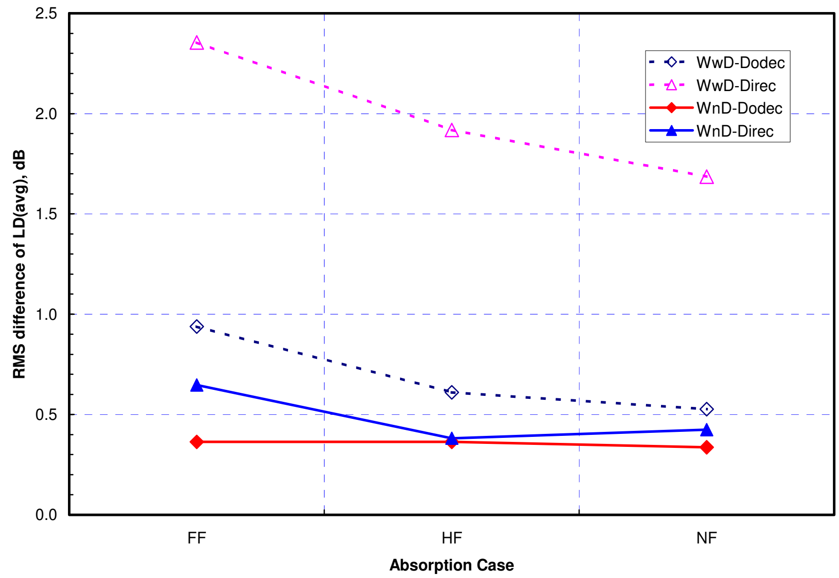


Fig. 62. RMS differences between measured and predicted LD(avg) values using the full speech security test and predicted values from the quick test procedure. WwD, wall-with-door; WnD, wall-with-no-door constructions. FF, full foam absorption; HF, half foam absorption and NF, no foam absorption cases.

7.3 Predicting full test LD(f) values from quick test LD(f) values

The corrections for the effects of room absorption produced by equations (4) and (5) are based on the frequency-averaged effects of room absorption. One would expect that when examined in more detail the effects of room absorption would vary with frequency. In spite of this, they were also used to correct measured LD(f) values obtained using the quick test procedure to predict the LD(f) values that were obtained using the full test procedure. The agreement between measured and predicted 1/3-octave band LD(f) values was examined for the 6 combinations of 2 constructions and 3 absorption cases using both loudspeaker types.

Fig. 63 compares measured and predicted LD(f) values for the wall-with-no-door construction (WnD). Results at positions #5 and #26 are shown because these tended to show the worst and best agreement respectively between measured and predicted values. For the results using the dodecahedron source in the upper panel of Fig. 63, the agreement is very good at both microphone positions. The results in the lower panel show that when the directional source was used, there were some larger differences between the measured and predicted full test LD(f) values. The RMS differences calculated over frequency from 160 to 5k Hz between the measured and predicted LD(f) values at each position are included in the figure caption.

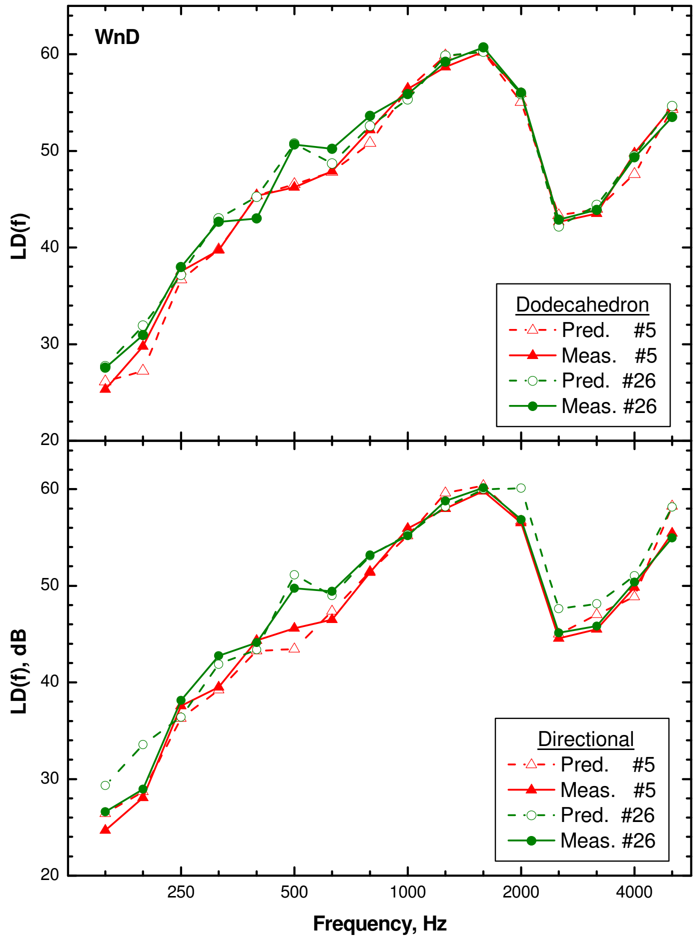


Fig. 63. Comparison of measured and predicted full test LD(f) values at position #5 and #26 for the wall-with-no-door (WnD) construction. Upper panel results: using the dodecahedron source; lower panel results: using the directional source. The RMS differences over the speech frequencies (160-5k Hz) between the predicted and measured LD(f) values are included in the table below.

RMS differences, dB		
Position	Dodecahedron	Directional
#5	1.05	1.29
#26	0.91	2.07

The predicted and measured full test LD(f) values are compared for the wall-with-a-door (WwD) construction in Fig. 64 for the same two positions as in Fig. 63. For this construction there are larger differences between measured and predicted full test LD(f) values than for the wall-with-no-door construction in Fig. 63. The differences are largest when the directional source was used as illustrated in the lower panel of this figure. At position #5 close to the door the predicted LD(f) values are different than the measured full test LD(f) values by several decibels. The RMS differences calculated over frequency from 160 to 5k Hz between the measured and predicted LD(f) values at each position are included in the figure caption.

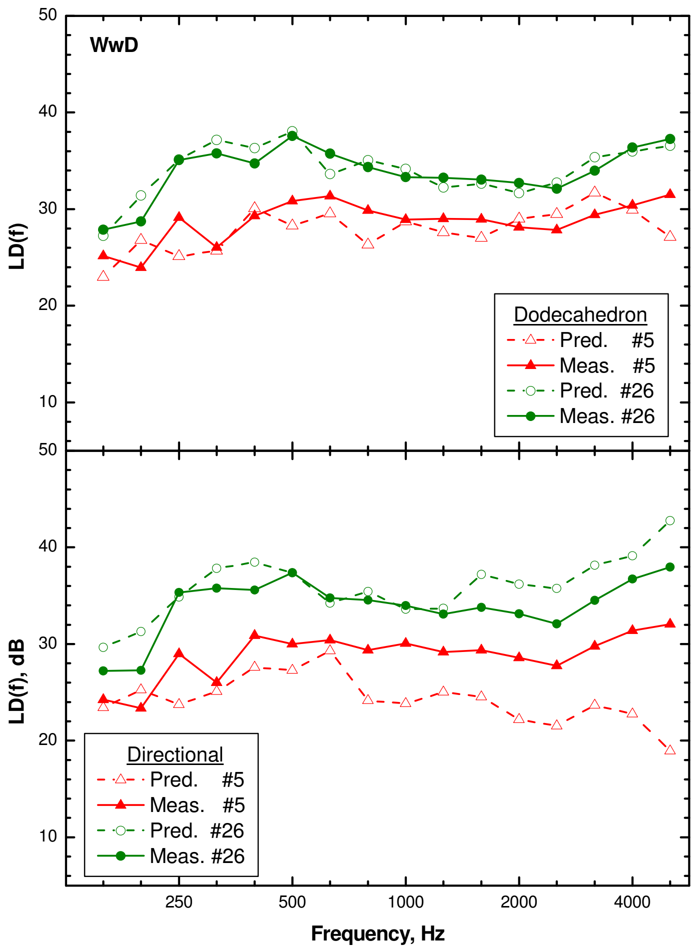


Fig. 64. Comparison of measured and predicted full test LD(f) values at position #5 and #26 for the wall-with-no-door (WnD) construction. Upper panel results: using the dodecahedron source; lower panel results: using the directional source. The RMS differences over the speech frequencies (160-5k Hz) between the predicted and measured LD(f) values are included in the table below.

RMS differences, dB		
Position	Dodecahedron	Directional
#5	2.32	5.71
#26	1.21	2.66

Fig. 63 and 64 illustrate the range of agreement between measured and predicted LD(f) values. The RMS differences over frequency from 160 to 5k Hz were calculated for all combinations of the 2 constructions and 3 room absorption cases as well as for the two different loudspeaker types and are plotted in Fig. 65. These results show a trend for increased prediction errors for LD(f) values with increasing room absorption and larger RMS differences when using the directional source. By considering the RMS errors for LD(avg) values in Fig 62 and the RMS errors for LD(f) values in Fig. 65, the relative success of the predictions can be evaluated for the different constructions, absorption cases and loudspeaker type. For example, when using the decahedron source to test the wall-with-no door, Fig. 62 indicates RMS errors in LD(avg) values of about 0.35 dB, suggesting quite accurate predictions of the average properties of the construction. However, for this case Fig. 65 indicates that there will be differences at individual 1/3-octav band frequencies of 1 to 1.5 dB. For the dodecahedron source and the wall with a door, the errors in LD(avg) predictions could approach 1.0 dB (Fig. 62), but considering differences over individual 1/3-octave band frequencies RMS differences suggestions further differences of as much as 2 dB (Fig. 65).

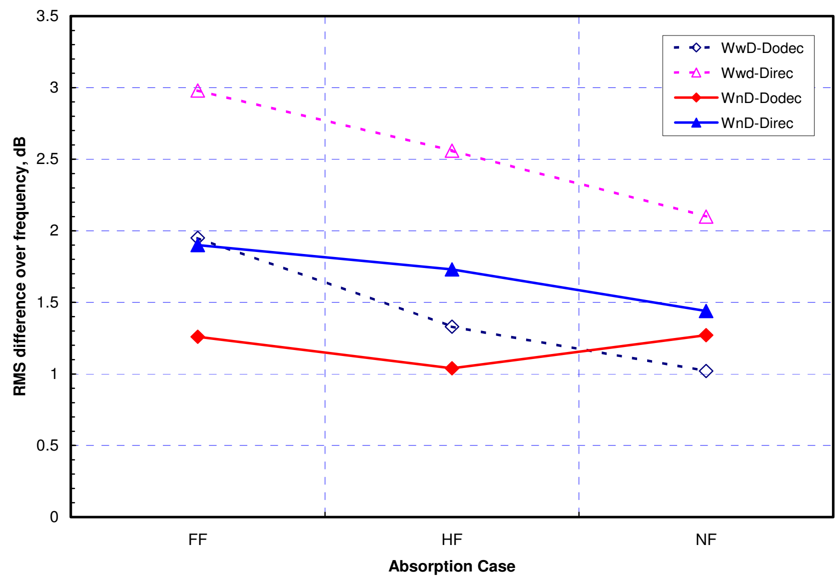


Fig. 65. RMS differences over frequency between measured and LD(f) values using the full speech security test and predicted values from the quick test procedure. WwD, wall-with-door; WnD, wall-with-no-door constructions. FF, full foam absorption; HF, half foam absorption and NF, no foam absorption cases.

Although the corrections were only based on frequency-averaged effects of varied room absorption, they are seen to work quite well for results obtained using the dodecahedron source. However, for the results using the directional source, it is not possible to accurately predict the full test LD(f) values for the wall-with-a-door construction. In many meeting rooms, walls with doors are the major source of speech privacy problems. Not being suitable for assessing this condition is a serious disadvantage to using a directional sound source and a strong argument for using a more omni-directional source such as the dodecahedron source, when the goal is to closely approximate the full test results.

8. An Alternative Quick Test Procedure

The quick test procedure is based on assessing the output of the source at a reference distance of 1 m prior to measuring a test condition. The level at one meter could be measured on axis in free field conditions such as in an anechoic room or it could be calculated from sound power measurements of the source in a reverberation chamber. The latter approach would give an output level equivalent to the average over all directions from the source at a distance of 1 m. For an approximately omni-directional source such as the dodecahedron the two methods should result in approximately the same source levels. However, for the directional source the two approaches will result in quite different source spectra for the same source.

The results in the previous two sections for various measurements using the quick test procedure were made using a directional average level at 1 m to represent the source levels. The current section shows the difference that result when the source levels are obtained from on-axis measurements. Results are only given for the directional source because the two approaches are expected to lead to quite different results for this source but not for the dodecahedron.

Fig. 66 compares plots of LD(f) values from 3 different procedures all using the directional source and for measurements of the wall-with-no-door construction for the full foam case (FF). One procedure was the full speech security test procedure (FSST). The other two were quick test (QT) results using either on-axis anechoic room measurement of the source levels at 1 m or other using a directional average level at 1 m. The procedure using a directional average source level leads to results that are closer to being parallel to the FSST LD(f) values in this figure.

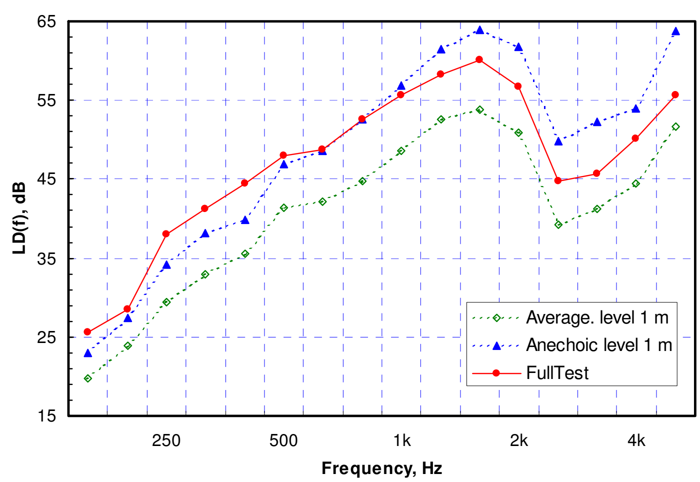


Fig. 66. Comparison of LD(f) values from the FSST procedure with two approaches to the QT procedure for the wall-with-no-door (WnD) construction and the full foam absorption.

The differences between the FSST LD(f) values and the LD(f) values from the two quick test procedures are plotted in Fig. 67. The differences for the QT procedure using the on-axis anechoic room measurements of the source level vary much more over frequency than the differences for the QT procedure using a directional average source level at 1 m. This large variation over frequency is due to the directionality of the loudspeaker varying with frequency, which leads to differences between the on-axis spectrum and the directional averaged spectrum. It would be more difficult to predict the FSST results from the QT results using the on-axis source levels at 1 m because of this large variation in the differences over frequency. Because of this serious disadvantage this approach was not considered further.

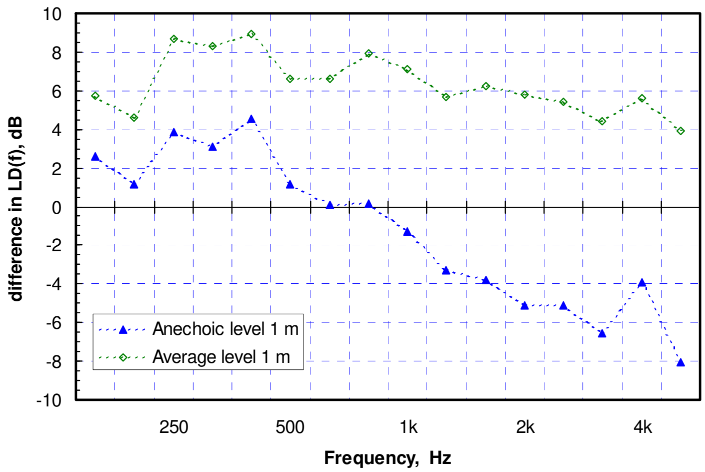


Fig. 67. Differences between LD(f) values obtained using the FSST procedure and QT procedures using either an on axis anechoic source level at 1m or a directional average source level at 1 m.

9. Investigation of Impulse Response Measurements for the Quick Test

The quick test consists of measuring attenuations between the output of a calibrated source and the measured levels of the transmitted test sounds at spot receiver positions 0.25 m from the other side of the test wall. This requires quite loud test signals in the source room, a 1/3-octave band analyser and further processing to obtain speech privacy measures from the measured LD(f) values. The transmitted sounds must be significantly above the level of the ambient noise at the receiver to obtain accurate measurements of the LD(f) values.

We have recently developed new measurement software (SPMSoft) that uses impulse response techniques to measure speech privacy between positions in open-plan offices [9, 10]. SPMSoft measures attenuations from a calibrated source to receiver positions in nearby workstations using a calibrated source. This is the same principal as the proposed speech security quick test procedure. However, the measured level differences for closed offices and meeting rooms are much larger than those encountered in open-plan offices. It is therefore important to first determine whether the transmitted signals will be significantly above the ambient noise at the receiver position when using the impulse response procedure.

This section describes the results of exploratory tests, carried out using the SPMSoft program, to evaluate the success of this approach for measuring the speech privacy of meeting rooms according to the proposed quick test procedure. Measurements of the level differences through the 'patched' wall were measured using the SPMSoft program and compared with the results of the conventional approach of using steady state pink noise signals. The noise rejection of the impulse response measurements can be improved by using longer sine sweep test signals and by increasing the number of repeats of the sine sweep signal that are synchronously averaged. Fig. 68 Compares the measured level differences obtained using a steady state pink noise signal, with 5 combinations of sine sweep length and number of repeats for the impulse response measurements.

The length of the sine sweep signal is described by its order. The length in seconds is calculated as 2 to the power 'order' times the period for each sample (1/44,100 s). Multiplying this by the number of repeats gives the total test signal duration. These total signal durations are listed in the legend of Fig. 68. A longer total signal duration leads to better agreement with the result of the conventional approach using pink noise. An order 18 sweep and 32 repeats or an order 20 sweep with 8 repeats both have the same total signal duration of 190.22 s. Using either produces very good agreement over the frequencies from 100 Hz to 10k Hz. For example, when using the order 18 sine sweep with 32 repeats, the differences between the two approaches were less than ±0.4 dB in all 1/3-octave bands from 100 to 10k Hz (which is the full frequency range of the SPMSoft program). For the speech frequency range of 160 to 5k Hz, even when using an order 18 sine sweep with 8 repeats, the differences in each 1/3-octave band were always les than ±0.5 dB.

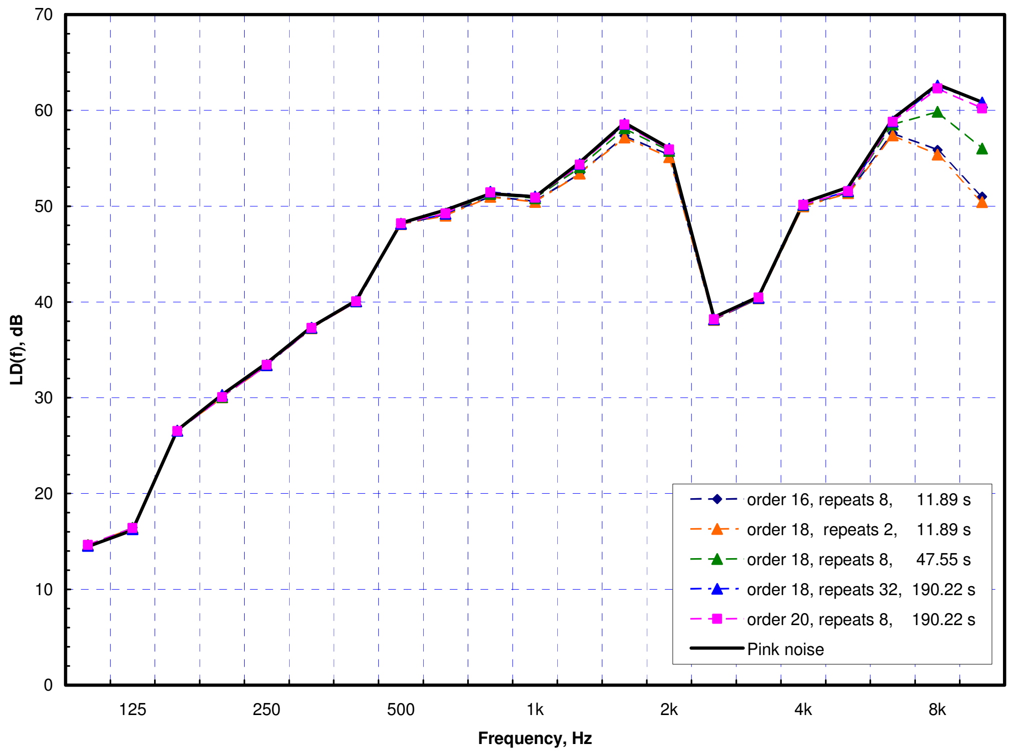


Fig. 68. Comparison of measured LD(f) values for the conventional pink noise procedure with 5 combinations of sine sweep length (order) and number of repeats of the sine sweep signal. The legend also lists the total test signal duration in seconds for each of these combinations.

The impulse response technique is seen to very accurately reproduce the results of the conventional test using a steady state pink noise signals if an appropriate total signal duration is used. The use of dedicated measurement software could make speech privacy testing of meeting rooms faster and provide immediate results to guide the user while investigating problems.

There is a need for further work to develop the impulse response approach for measuring the speech privacy of closed rooms. In particular an approach is required for determining the required combination of sine sweep length and the number of repeats to provide adequate noise rejection in the results. Although Fig. 68 indicates that it is the total signal duration that is important, using longer sine sweep signals with fewer repeats is usually more convenient. This is because there must be a wait period after each sine sweep to allow the reverberant sound in the room to die away before the next repeat can be output. The procedure should be validated for a range of conditions and the limits of its applicability determined.

10. Summary and Conclusions

This report presents a large number of results intended to provide an initial evaluation of the merits of a new quick test (QT) for evaluating the speech security of meeting rooms. The main purpose of the work was to compare results of the QT procedure with those from the previously developed full speech security test (FSST) [7]. Measured level differences, averaged over speech frequencies, LD(avg), and as a function of frequency, LD(f), were obtained from the two measurement procedures. The two sets of LD(avg) and LD(f) values from the two tests procedures were compared with each other and also with the standard sound transmission loss measures, TL(avg) and TL(f) of each construction.

The effects of various parameters on the FSST results were first explored. From the FSST test results, measured LD(f) values were always lower than the corresponding TL(f) but the variations with frequency were approximately parallel for the two quantities. Although TL(f) values do not vary with room absorption, the measured LD(f) values increased with decreasing reverberant sound levels in the receiving room. Measured LD(avg) values were seen to vary with position along a test wall. When the wall included a door, these variations increased to several decibels. For the wall-with-a-door construction LD(f) values varied with position along the wall indicating spectral changes in the transmitted sound. There were only minor differences when the receiving microphone height was varied. For the FSST test procedure, results using a dodecahedron loudspeaker (omni-directional source) and a directional loudspeaker were generally very similar.

For the QT procedure the same parameters were evaluated as well as the distance of the source to the test wall. The measured LD(f) values using the quick test procedure increased with increasing source-to-wall distance. There were again no significant effects of the receiving microphone height on the measured LD(f) values for the two heights used. (Of course, larger variations in microphone height could lead to different effects if the microphone position approached the location of a more significant sound leak). The LD(f) values from the quick test procedure were always lower values than those from the FSST procedure and the differences between the two measurement approaches were influenced by the loudspeaker type. When the dodecahedron loudspeaker was used, the differences between the QT and FSST measurement approaches were relatively constant over frequency for most conditions. Using the directional source led to larger variations over frequency for the differences between the QT and FSST measurement results. This was especially true for the constructions with a door in the wall.

The differences between the LD(avg) values from the QT and FSST measurement approaches were shown to vary with the reverberant sound level in the receiving room (i.e. $10 \log\{4/A\}$). By correcting for this effect, the LD(avg) values from the FSST test could be accurately predicted from the QT results with an RMS error of ±0.56 dB when using a dodecahedron source. The RMS error increased to ±1.46 dB when using the directional source. Larger errors were found in individual 1/3-octave band results. Although in these results using a dodecahedron loudspeaker led to more accurate predictions of FSST results, using the directional source could lead to more accurate estimates of the effects of room absorption on the differences between the two measurement approaches.

Some additional tests investigated several related issues.

The results in Section 9 demonstrated that impulse response measurement software could be adapted to efficiently obtain accurate QT results. By providing immediate results, measurement could also be a useful diagnostic tool for investigating speech security problems.

The results in Appendix II considered the effects of loudspeaker directionality on the errors in the full speech security test measures following the requirements of ASTM E2638-08 [7]. While the averaged LD(avg) values obtained using the dodecahedron source and the directional source were very similar, the uncertainty of the mean levels was larger when using the directional source. These results can give guidance as to the increased number of source room microphone positions required to achieve the same accuracy as when using the dodecahedron source.

Appendix III provides results that illustrate how another form of quick test could provide good estimates of the sound transmission loss of doors as installed in the field. As doors are the most common impediment to achieving satisfactory speech security, a convenient method of evaluating them could be of great practical value.

Further evaluations for a wider range of constructions and loudspeaker types would more completely establish the success of the QT procedure.

Appendix I. Loudspeaker Data

The speech security tests were carried out using two different types of loudspeaker. One was a dodecahedron loudspeaker, which included 12 100mm diameter drivers and is intended to be approximately omni-directional. Fig A-I-1 shows the measured directionality at 1000, 2000, 4000 and 8000 Hz. The loudspeaker is seen to be quite omni-directional at 1000 Hz and lower frequencies (not shown). However, as frequency is increased, the levels become more irregular with angle from the source. This is due to the interference of sounds from the 12 different drivers, which increases as the distance between drivers becomes large relative to the wavelength of the test sound.

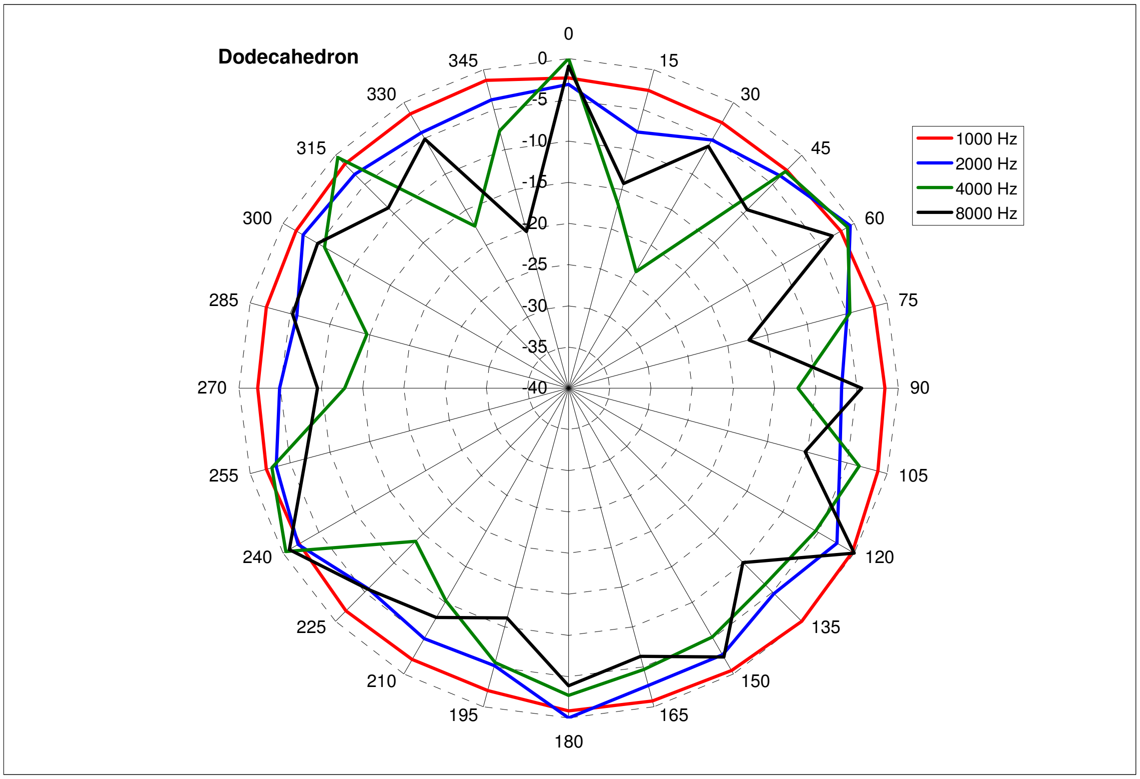


Fig. A-I-1. Directionality of the dodecahedron loudspeaker.

The other loudspeaker was a conventional more directional loudspeaker consisting of one 250 mm diameter driver (JBL E110-8) in a vented rectangular box. The internal dimensions of the box were 317.5 by 254.0 by 203.2 mm. It was constructed of 19 mm plywood and had a circular vent hole with a 21.1 mm diameter. Fig A-I-2 shows the measured directionality at 1000, 2000, 4000 and 8000 Hz. This loudspeaker was quite directional and tends to radiate most energy close to the on-axis direction and less sound energy in other directions. The on-axis levels in Fig. A-I-2 are 15 to 20 dB higher than the levels to the rear of the loudspeaker for the frequencies plotted.

These two loudspeakers are representative of the two extremes in possible test loudspeakers. Loudspeakers with larger drivers would tend to be even more directional. Dodecahedron loudspeakers are commonly used as approximations to omni-directional sources.

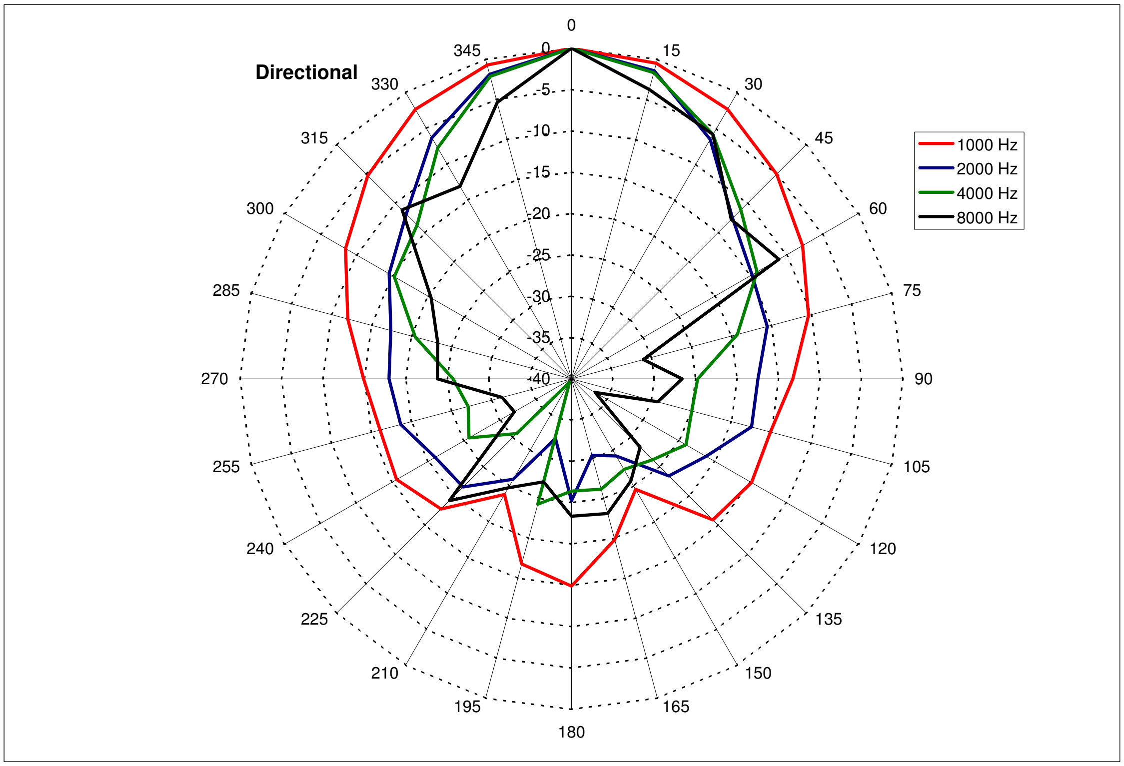


Fig. A-I-2. Directionality of loudspeaker consisting of a 250 mm driver in a vented enclosure.

Appendix II. Effect of Loudspeaker Directionality and Number of Positions on the FSST Results

The new ASTM speech privacy measurement standard [7] requires a minimum of 2 positions of the loudspeaker used to generate test sounds in the source room and a minimum of 5 microphone positions to measure the source room levels. That is, source room levels would be measured for a total of 10 combinations of source and receiver position. Data from the current evaluations of the full speech privacy/security test were used to determine how the number of source measurements and the directionality of the source loudspeaker would affect the accuracy of the measured source room levels and consequently the resulting level differences. The data included the combinations of 5 microphone positions and 2 or 5 source positions for, 2 types of loudspeaker directionality (directional and dodecahedron loudspeakers) and the 3 sound absorption cases. In addition, this combination of results was available for the 3 different constructions: (a) wall-with-no-door, (b) wall-with-a-door, and (c) wall-with-sealed-door.

The averages of the measured level differences were first compared. The results are presented in terms of LD(avg) values, which are arithmetic averages of level differences over the speech frequencies from 160 to 5k Hz. These LD(avg) values were then averaged for the various combinations of source and receiver location. Fig. A-II-1 compares average level differences for the wall-with-no-door construction plotted versus absorption cases. Three sets of data are included: (a) averages of 25 combinations of 2 source positions of the dodecahedron source and 5 microphone positions, (b) averages of 25 combinations of 2 source positions of the directional source and 5 microphone positions, and (c) averages of the 45 combinations of 5 source positions of the dodecahedron source and 9 microphone positions.

The 5 source positions were measured at 9 microphone positions in the source room giving a total of 45 measurements of the source room level. This case was taken as a reference case representing the best estimate of the actual mean value. The 2-source-position cases were each measured at 5 microphone positions in the source room as the minimum recommended by the standard [7]. A total of 25 combinations of 2 source positions and 5 receiver positions were included resulting in a total 50 source room level measurements.

With a large total number of source room level measurements for both the reference case (N=45) and the multiple two-source cases (N=50), the overall mean values for the 2-source cases for both types of loudspeaker agree quite closely with the mean values from the 5-source average case with differences of only a small fractions of a decibel. This simply indicates that with a large enough number of measurements either loudspeaker type will lead to approximately the same mean values.

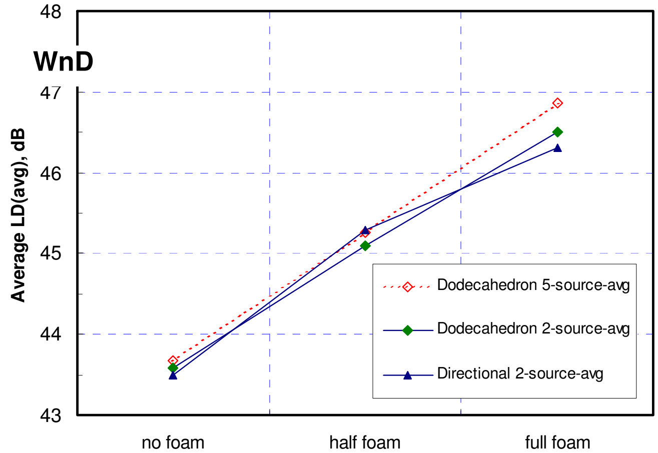


Fig. A-II-1. Average measured LD(avg) values for the wall-with-no-door (WnD) construction versus the three absorption conditions for: (a) reference case of 5 source positions and the dodecahedron source, (b) case with 2 source positions and the dodecahedron source, and (c) case with 2 source positions and the directional loudspeaker source.

Of course the standard does not require 25 different combinations of 2 source positions and 5 source-room microphone positions; only one combination of 2 source positions and 5 microphone positions is required, corresponding to a total of 10 measurements. The standard deviations from 10 measurements would be a less accurate estimate of the true values and the standard errors of the mean source room level would be increased when only 10 measurements are made instead of 50. The use of a directional loudspeaker rather than an approximately omni-directional loudspeaker (dodecahedron) is also expected to increase the variance of the measured source room levels and hence to contribute to further increasing standard errors of mean source room levels. These effects were also investigated with these data.

The standard deviations of the measured source room levels were first considered. These were calculated for the 5-sourec and the 2-source data, for each of the two source types, for the 3 added foam absorption cases and for the 3 different constructions. Figure A-II-2 plots the resulting standard deviations of the measured source room levels for the wall-with-no-door construction and the dodecahedron source. The two lines indicate how the overall average standard deviations for the 2-source results and the 5-source results increase with increasing foam absorption. For these averages of all conditions, the mean standard deviations for both numbers of sources are nearly identical.

The shaded area in Fig. A-II-2 shows the range of standard deviations that were obtained for each set of 2 sources and 5 microphones. Clearly there is a range of estimates of the standard deviations of sound levels in the source room which would lead to different LD(avg) values. Figure A-II-3 plots similar results for the directional source. For the directional source there are small differences between the overall average standard deviations for the 2-source and the 5-source data.

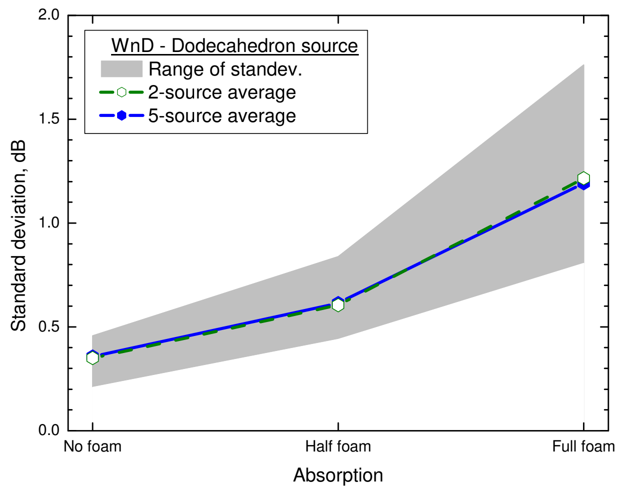


Fig A-II-2. Standard deviations of source room LD(avg) values for the wall-with-no-door (WnD) construction, using the dodecahedron source plotted versus increasing added sound absorption. The lines show the average standard deviations for data using 2 or 5 source positions. The shaded area shows the range of values for combinations of 2 source positions and 5 microphones positions.

Comparing the results in Fig. A-II-3 for the directional source with those in Fig. A-II-2 for the dodecahedron source indicates differences between the results for the two source types. The overall average standard deviations are larger for the directional source and the range of estimates from the individual combinations of 2 sources and 5 microphones is larger for the directional source results in Fig. A-II-3.

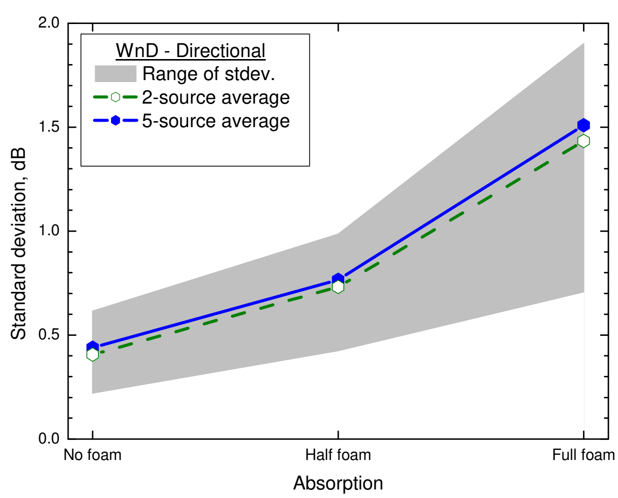


Fig A-II-3. Standard deviations of source room LD(avg) values for the wall-with-no-door (WnD) construction, using the directional source plotted versus increasing added sound absorption. The lines show the average standard deviations for data using 2 or 5 source positions. The shaded area shows the range of values for combinations of 2 source positions and 5 microphones positions.

Because the standard deviations of the measured levels using the directional source were larger than those using the dodecahedron source, we expect less precise average source room levels when using a directional source. The accuracy of the mean values is described by the standard error (SE) of the mean values. Fig. A-II-4 plots calculated standard errors for the mean values using the dodecahedron source. The line for the standard error for the 5-source position data was calculated from the levels obtained from the 45 combinations of 5 source positions and 9 microphone positions (N=45). It is plotted as a very precise reference case. The dashed line indicates the average of calculated SE values of the combinations of 2 source and 5 microphone positions. The shaded area shows the range of SE values from the individual combinations of 2 source positions and 5 microphone positions (N=10). Using the 2 source and 5 microphone position data leads to larger SE values and hence to less precise average sound level values. When only one combination of 2 source positions and 5 microphone position is used, the SE could be as large as 0.55 dB for the full foam case which had similar reverberation times to typical meeting rooms.

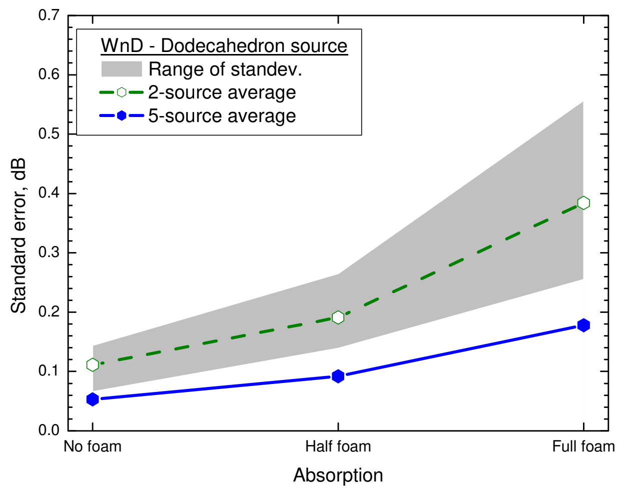


Fig A-II-4. Standard errors of mean source room LD(avg) values for the wall-with-no-door (WnD) construction, using the dodecahedron source plotted versus increasing added sound absorption. The lines show the average standard errors for data using 2 or 5 source positions. The shaded area shows the range of values for combinations of 2 source position and 5 microphones positions.

Fig. A-II-5 shows SE values for results using the directional source. All of the results for the directional source indicate larger SE values than those for the dodecahedron source in Fig. A-II-4.

These results indicate that the standard error of the mean source room levels, L_S(avg), values is unlikely to exceed about 0.6 dB. This seems like a quite small and acceptable value. However, larger spatial variations of sound levels and larger SE values may occur in many actual meeting rooms, which may be acoustically less diffuse than the reverberant test chamber (even when absorption was added). Previous results in meeting rooms using a dodecahedron source indicated spatial standard deviations of 1.5 to 2.9 dB with an average of 1.8 dB for 11 meeting rooms. Clearly spatial variations could be a little larger in some meeting rooms than in the reverberation chamber even when absorption was added.

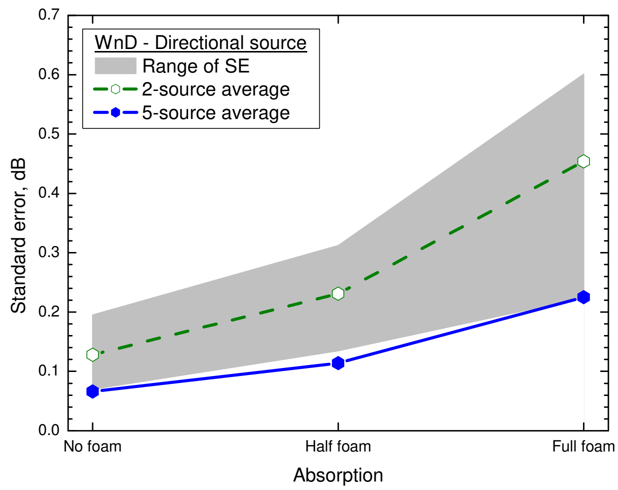


Fig A-II-5. Standard errors of mean source room LD(avg) values for the wall-with-no-door (WnD) construction and using the directional source plotted versus increasing added sound absorption. The lines show the average standard errors for data using 2 or 5 source positions. The shaded area shows the range of values for combinations of 2 source positions and 5 microphones positions.

These results were also determined for the case of the wall-with-a-door and for the wall with the sealed door. The results were very similar because the different constructions did not significantly change the acoustical conditions in the source room.

Even for the full foam absorption case and measurements using the directional loudspeaker, the standard error of mean LD(avg) were always less than 0.6 dB. Although larger values may occur in less diffuse meeting rooms, the current results indicate the requirements of the new ASTM E2638-08 standard should provide quite accurate results.

Appendix III. Adapting the Quick Test to Measure Sound Transmission Loss of Doors in the Field

Comparisons of the quick test results with those from the full speech security test suggested, that when measuring a wall-with-a-door, using the dodecahedron source led to better agreement. The directional source produced results that varied more with position along the wall than did the full test results. However, the directional source better indicated the reduced sound insulation at the position of the door. Although this approach was not in better agreement with the full test results, it did seem to provide a better assessment of the sound insulation of the door. This appendix includes an analysis of the quick test results to determine how well they can evaluate the sound transmission loss of a door to determine whether another form of quick test could provide useful estimates of the transmission loss of doors as installed in the field.

The sound insulation of a door can be measured by installing the door in a wall with very high sound transmission loss located between two reverberation chambers. If the sound transmission loss of the wall is much higher than that of the door, then it will not have a significant effect on the sound transmission loss measurement and the results will indicate only the properties of the door. It is not possible to do this in the field because the properties of the wall are not known and would not always be very much better than those of the door at all frequencies. Thus, a measurement of sound transmission through a wall-with-a-door will typically provide results that are a combination of the effects of both the wall and the door. More sophisticated techniques such as sound intensity measurements, could be used in the field but are more complex and require more expensive equipment. A quick and inexpensive procedure for evaluating the sound transmission loss of doors would be a useful tool for verifying the properties of doors in the field.

In our laboratory tests we measured the sound transmission loss of constructions that included: a wall-with-a-door and a wall-with-a-sealed-door. Since we had already measured the transmission loss of the wall without the door, we could estimate the transmission loss of the door in each case. This was only possible at frequencies for which the sound energy transmitted through the door was significantly greater than that transmitted through the wall. Because the wall was almost 6 times larger in area than the door, the required transmission loss of the wall at each frequency must be at least 18 dB greater than that of the door to make it possible to accurately determine the transmission loss of only the door. In our case we could only obtain valid measurements of the transmission loss of the door at frequencies above 200 Hz. Fig. A-III-2 includes the measured transmission loss of the wall and that of the door for frequencies above 200 Hz.

The corrections required to adjust the quick test results to approximate transmission loss values were first determined by comparing LD(avg) values with TL(avg) values. These values should be arithmetic averages of the decibel values over the speech frequencies from 160 to 5k Hz. However, the transmission loss of the door could not be determined for the 160 and 200 Hz 1/3-octave bands. Therefore TL(avg) and LD(avg) values were compared for the frequency range from 250 to 5k Hz.

Estimates of the required corrections were made from the differences of the TL(avg) values for the door and for the sealed door with the corresponding LD(avg) values. The

LD(avg) values were from the average of quick test measurements at the two positions beside the door (positions #5 and #18). The analyses were also carried out for the wall-with-no-door construction for completeness. These were repeated for all 3 absorption cases. For each construction and absorption case the constant 'C_1' required to increase the LD(avg) values to equal the TL(avg) values was determined. That is,

$$LD(avg) + C_1 = TL(avg) \quad (x)$$

The resulting corrections C_1 are plotted versus 10log{4/A} to show the variation with absorption condition in Fig. A-III-1 and are summarised in Table A-III-1. When using the directional source (left hand panel of Fig A-III-1), the corrections were very similar for the full foam and half foam absorption cases for both the wall-with-a-door and the wall-with-a-sealed-door constructions. These values are indicated by the box on Fig. A-III-1 and the shaded cells in Table A-III-1. Over these four measurement conditions for the directional source results, the corrections only varied from 5.20 to 6.50 dB, a range of 1.30 dB with an average of 5.97 dB. For the same conditions and the results using the dodecahedron source the range of corrections 2.50 dB. This is approximately double the range of corrections need when using the directional source. An average value could be used as a single correction for walls with doors and for these more common conditions. The correction term is more varied for the case of the wall-with-no-door and for the no foam absorption cases, but these are usually of less interest.

	Directional source			Dodecahedron source		
	WwD	WsD	WnD	WwD	WsD	WnD
Full foam	6.16	5.20	7.70	0.80	1.30	6.00
Half foam	6.50	5.90	8.50	2.10	3.30	7.80
No foam	8.60	8.20	11.80	4.90	6.00	11.10

Table A-III-1. Corrections 'C_1' to convert LD(avg) values to approximate TL(avg) values. Shaded cells indicate conditions commonly found in meeting rooms. WwD, wall-a-door; WsD, Wall-with-a-sealed-door; WnD, wall-with-no-door)

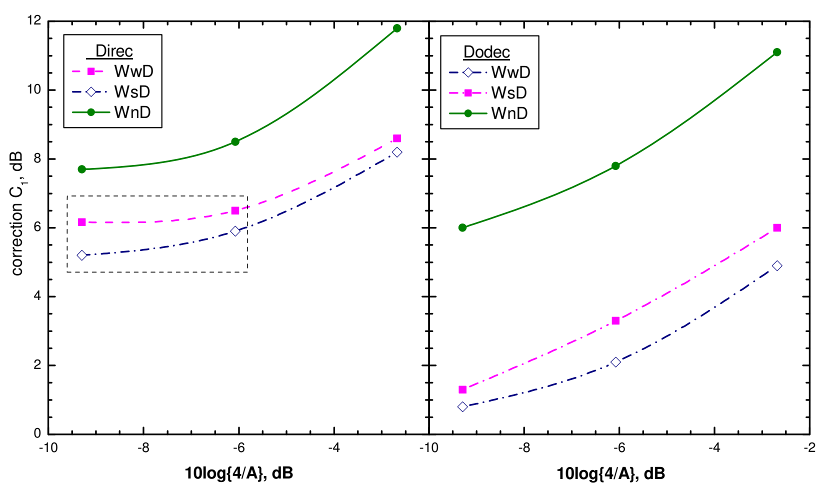


Fig A-III-1. Corrections 'C1' to convert LD(avg) values to approximate TL(avg) values plotted versus absorption conditions described by 10log{4/A}. The box in the left panel indicates more common acoustical conditions in offices for which there were only small variations in the value of C_1 for results using the directional source.

The comparison of predicted and measured transmission loss versus frequency results of the door for the 3 absorption cases are plotted in Fig. A-III-2 to A-III-4. Each of these compares predicted TL(f) values for the door obtained from the quick test level differences and adjusted using the appropriate C_1 value. The measured transmission loss of the wall-with-no-door is also included for reference.

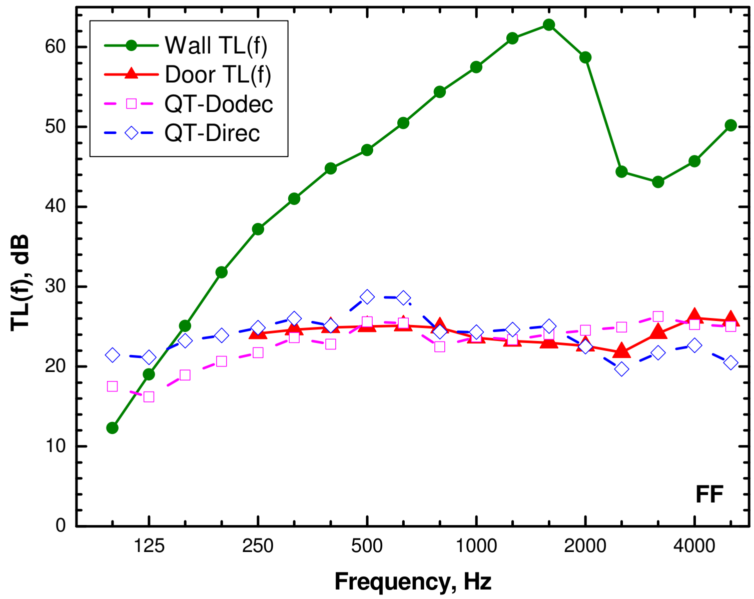


Fig A-III-2. Comparison of measured and predicted TL(f) values of the door for the full foam (FF) absorption case. Predicted TL(f) values using both the dodecahedron and directional sources obtained from quick test (QT) level differences are shown.

The results in Fig. A-III-2 are for the full foam absorption case. The graph shows quite good agreement between the predicted values from the quick test LD(f) values at all frequencies from 250 to 5k Hz. Although the quick test results make it possible to estimate TL(f) values below 250 Hz, they are probably only indicative of the combined properties of the wall and the door.

The comparisons in Fig A-III-3 and A-III-4 further illustrate that it is possible to get reasonably accurate predictions of TL(f) values by applying the described corrections to the LD(f) values obtained from the quick test measurements.

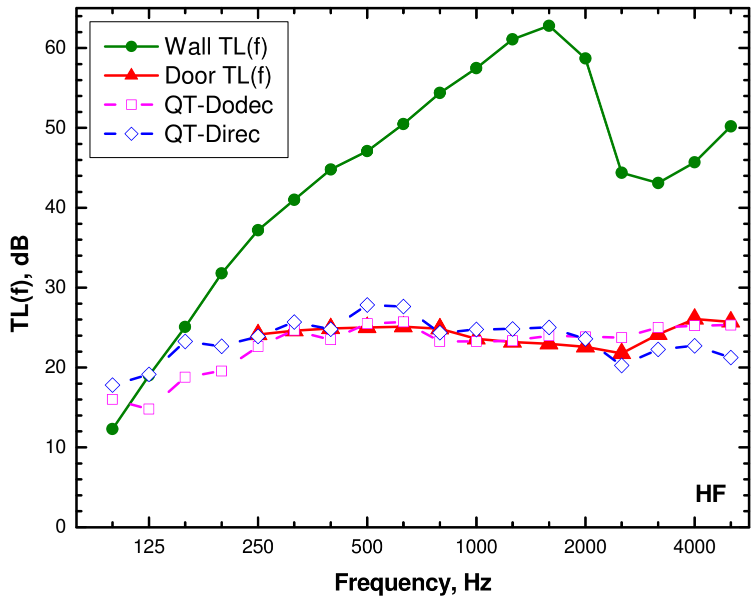


Fig A-III-3. Comparison of measured and predicted TL(f) values of the door for the half foam (HF) absorption case. Predicted TL(f) values using both the dodecahedron and directional sources obtained from quick test (QT) level differences are shown.

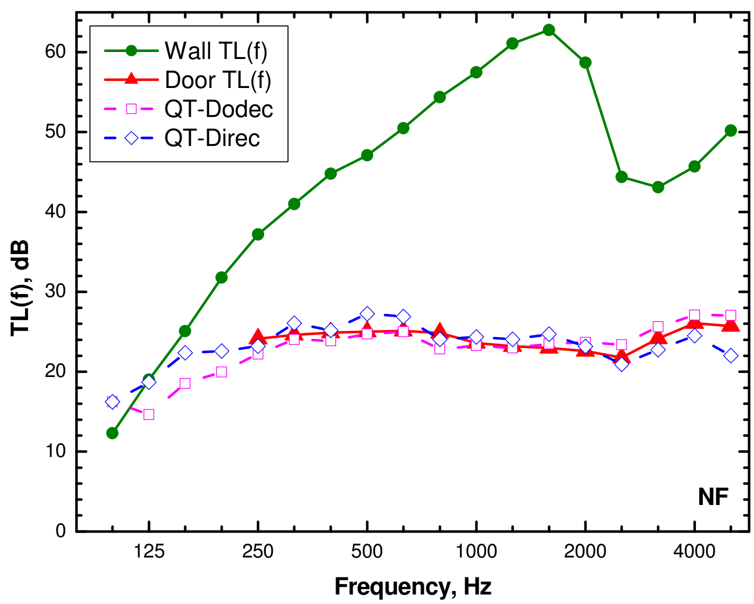


Fig. A-III-4. Comparison of measured and predicted TL(f) values of the door for the no foam (NF) absorption case. Predicted TL(f) values using both the dodecahedron and directional sources obtained from quick test (QT) level differences are shown.

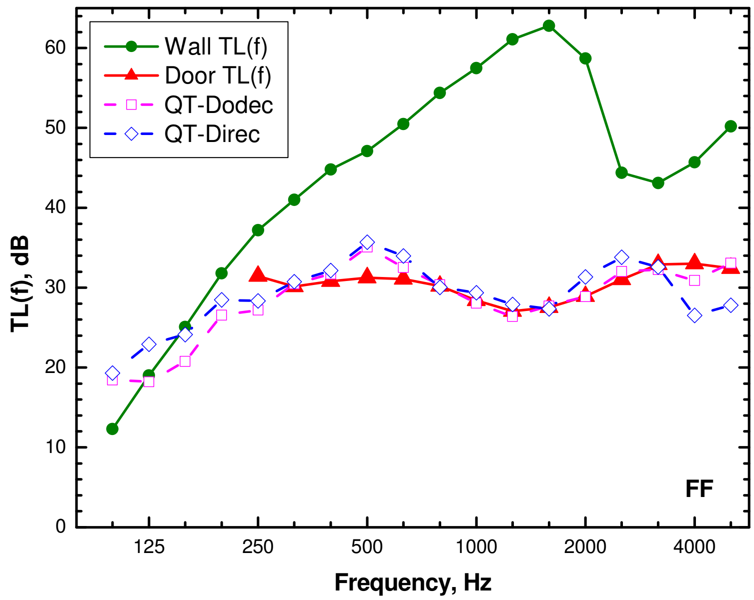


Fig. A-III-5. Comparison of measured and predicted TL(f) values of the sealed door for the full foam (FF) absorption case. Predicted TL(f) values using both the dodecahedron and directional sources obtained from quick test (QT) level differences are shown.

The same comparisons were plotted for the sealed door case and are shown in Fig. A-III-5 to A-III-7. This was the same door but with its periphery sealed with adhesive metal tape and consequently it had somewhat higher TL(f) values.

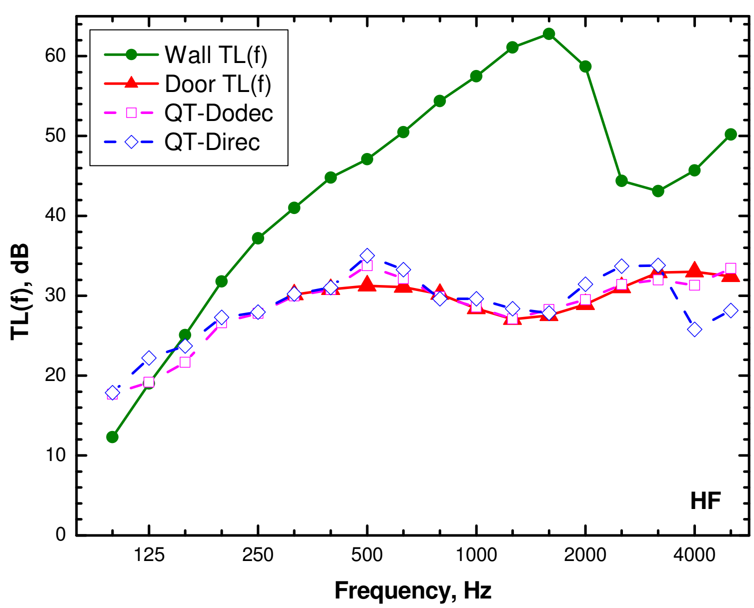


Fig A-III-6. Comparison of measured and predicted TL(f) values of the sealed door for the half foam (HF) absorption case. Predicted TL(f) values using both the dodecahedron and directional sources obtained from quick test (QT) level differences are shown.

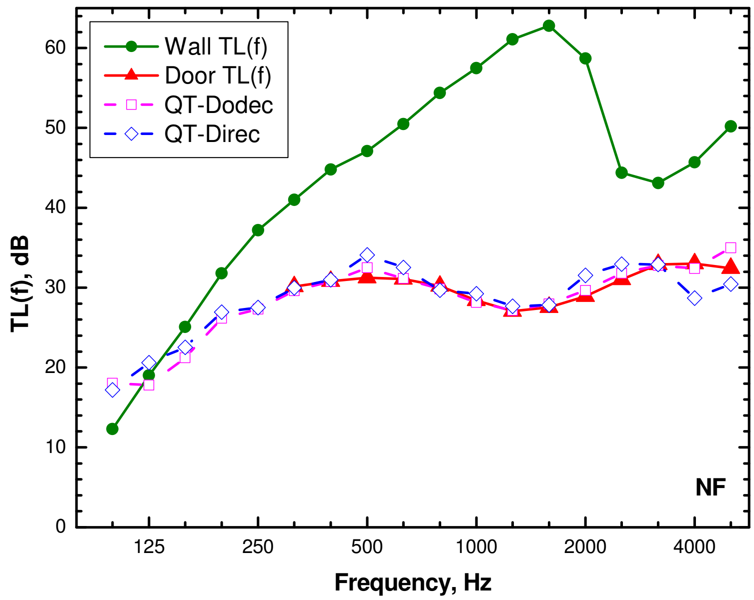


Fig. A-III-7. Comparison of measured and predicted TL(f) values of the sealed door for the no foam (NF) absorption case. Predicted TL(f) values using both the dodecahedron and directional sources obtained from quick test level differences are shown.

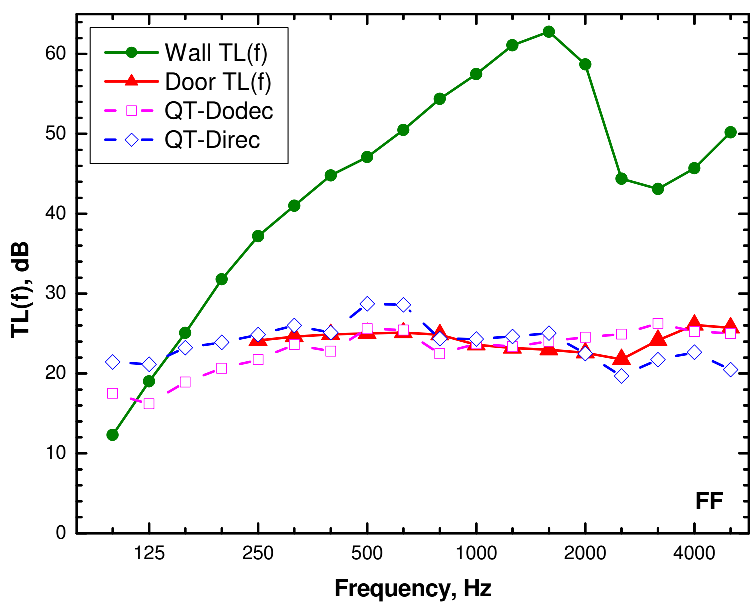


Fig A-III-8. Comparison of measured and predicted TL(f) values of the wall-with-no-door for the full foam (FF) absorption case. Predicted TL(f) values using both the dodecahedron and directional sources obtained from quick test level differences are shown.

For completeness the same comparisons of measured and predicted TL(f) values were produced for the wall-with-no-door construction and are included in Fig. A-III-8 to A-III-10. The predictions were based on the measured LD(f) values using the quick test procedure at the same two positions as used for the doors.

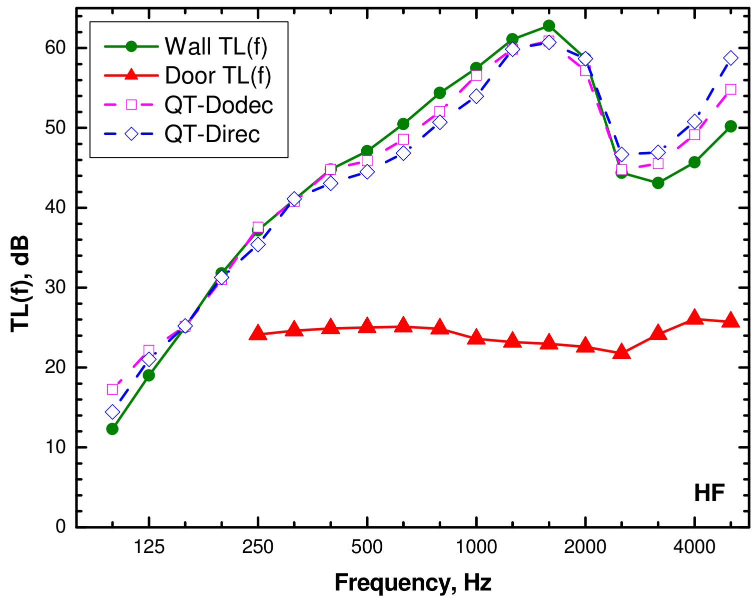


Fig A-III-9. Comparison of measured and predicted TL(f) values of the wall-with-no-door for the half foam (HF) absorption case. Predicted TL(f) values using both the dodecahedron and directional sources obtained from quick test (QT) level differences are shown.

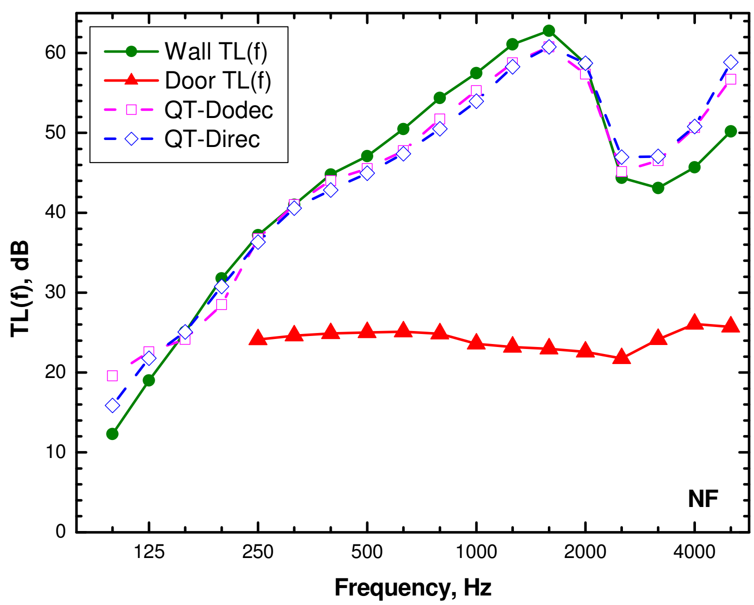


Fig. A-III-10. Comparison of measured and predicted TL(f) values of the wall-with-no-door for the no foam (NF) absorption case. Predicted TL(f) values using both the dodecahedron and directional sources obtained from quick test (QT) level differences are shown.

The differences between the predicted and measured TL(f) values were evaluated by calculating the RMS differences between each pair of predicted and measured results over the frequency range from 250 to 5k Hz. For the wall-with-no-door construction, the RMS differences between predicted and measured TL(f) values were also calculated over the frequency range from 100 to 5k Hz. The calculations were carried out for the combinations of the 3 foam conditions, 3 constructions and 2 loudspeaker types. The RMS differences between the predicted and measured results, using the dodecahedron source, are included in Table A-III-3 and those using the directional source in Table A-III-4. The variations of the differences between measured and predicted values over frequency are seen to be larger when using the directional source than when using the dodecahedron source. That is, for these data we can predict the variations with frequency more accurately from the quick test results using the dodecahedron results.

Absorption case	250 – 5k Hz			100 - 5k Hz
	WwD	WsD	WnD	WnD
FF	1.65	1.75	2.17	2.66
HF	1.06	1.38	2.05	2.52
NF	1.15	1.39	2.85	3.57

Table A-III-3. RMS differences in decibels between measured and predicted TL(f) values for 3 absorption cases (FF, full foam; HF, half foam; NF, no foam) and 3 constructions (WwD, wall-with-door; WsD, wall-with-sealed-door; WnD, wall-with-no-door) using the dodecahedron source. Shaded cells indicate conditions commonly found in meeting rooms.

Absorption case	250 – 5k Hz			100 - 5k Hz
	WwD	WsD	WnD	WnD
FF	2.47	2.91	2.78	3.33
HF	2.11	2.92	3.56	3.22
NF	1.59	2.07	3.61	3.41

Table A-III-4. RMS differences in decibels between measured and predicted TL(f) values for 3 absorption cases (FF, full foam; HF, half foam; NF, no foam) and 3 constructions (WwD, wall-with-door; WsD, wall-with-sealed-door; WnD, wall-with-no-door) using the directional source. Shaded cells indicate conditions commonly found in meeting rooms.

This method of predicting the sound transmission loss of a door in the field is first dependent on choosing the appropriate C_1 value to correct for the effects of room absorption in the test rooms. The C_1 values in Table A-III-1 suggest that it is easier to estimate an accurate C_1 value when using a directional source because the corrections vary less with room absorption than when using the dodecahedron source. On the other hand, the RMS differences over frequency are lower when using the directional source. Of course the variations over frequency would not matter if only and estimate of TL(avg) is required.

These results are based on measurements of only 2 variations of 1 door in one wall construction. They suggest differences between results obtained using a dodecahedron source and a directional source but only one type of directional source was used. Although these results are based on a limited range of constructions, they strongly suggest that it is possible to get reasonable estimates of the sound transmission loss characteristics of doors as installed in the field using the proposed variation of the quick test level difference measurements. However, before this approach can be more generally adopted, these results must be further validated with measurements of a broader range of door, wall and loudspeaker characteristics.

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