Comparison of Low Frequency Sound Insulation Field Measurement Methods

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Abstract

The reliable field measurement of airborne sound insulation between rooms in the very low frequency range (20 Hz – 100 Hz) presents a substantial challenge for several reasons. Sound source and microphone placement can have a strong effect on the transmission, and diffuse field conditions are usually not possible to establish in medium-sized rooms. In this study we compare three methods that have been proposed previously for transducer placement with each other, and with mass law theory. Our results show that substantially different values may be obtained from each method of measurement. Furthermore, we examine the influence of the test signal on the measurement, and find that non-linearities in the building fabric can also substantially affect the apparent sound reduction index in the very low frequency range. We discuss how measurement techniques might be refined to increase their reliability.

Introduction

The need for measuring low frequency sound insulation (20 Hz-100 Hz) in buildings has become increasingly necessary, as occupational and community noise has a large component of low frequency energy. Airborne sources of low frequency noise in occupational and community environments varies widely from the use of home entertainment systems with low frequency drivers, to the highly intrusive noise of aircraft, traffic and construction works. However, currently, airborne sound insulation is usually only specified for 1/3-octave band frequencies from 100 Hz to 3.15 kHz.

In recent years, the Building Code of Australia (BCA) has recognised the need to improve sound insulation ratings particularly in the low frequency range. A specification for field measurements has been implemented as a means of evaluating sound insulation in buildings. A minimum weighted standardised level difference with spectrum adaptation term ($D_{nTw} + C_{tr}$) of 45 is specified for walls and floors between sole occupancy units, as well as a wall separating a sole occupancy unit from a plant room, lift shaft, stairway, public corridor or public lobby. The spectrum adaptation term (C_{tr}) is a negative correction added to quantify the low frequency performance of a wall or floor, but which does not take level differences below 100 Hz into account in its implementation for the BCA.

Hence, while the spectrum adaptation term sensitises the measurement to the lower frequency range, the degree of sound insulation in the very low frequency range remains unassessed.

Nevertheless common sources of low frequency noise, such as building services, home entertainment systems and environmental noise often have substantial energy below this range, making an important contribution to background noise quality for people (Berglund et al. 1996). Furthermore, since sound insulation is typically weakest in the low frequency range, such frequency content is likely to be transmitted well within a building, possibly causing annoyance for transmission even between non-adjacent rooms.

The problem is that the assumptions behind methods that are used for measuring sound insulation at and above the 100 Hz band are unlikely to apply in the very low frequency range in typical rooms (and indeed in reverberation room suites of laboratories).

In particular, diffuse field conditions

are not practical to achieve in small and medium rooms, and instead the sound field is likely to be dominated by room modes, which become sparser at lower frequencies. Since free field conditions are also unlikely to be achievable (eg. through temporary installation of sound absorbing material), free field methods (including sound intensity) are unlikely to succeed.

In this paper we test three field measurement methods that have been proposed for the low or very low frequency range.

Sound Transmission Theory

The mass law relates the surface density of a single leaf barrier to its sound reduction index at a given frequency (Ver and Holmer 1988).

$$R_0 = 10\log\left[1+\left(\frac{\omega\rho_s}{2\rho c}\right)^2\right]dB \qquad (1)$$

R_0 is the normal incidence sound reduction index

ω is the angular frequency in radians per second

ρ_s is the surface density kg/m^2

ρc is the characteristic impedance of air

For diffuse field incidence, the sound reduction is modified to:

$$R_{diffuse} = R_0 - 10\log(0.23R_0)dB \qquad (2)$$

Results for this expression can be a little low due to the non-diffuse nature of practical sound fields in field measurement. Hence a modification for 'field' incidence may be applied instead:

$$R_{field} = R_0 - 5dB \qquad (3)$$

For normal incidence in the mid and high frequency range, the mass law states that a doubling in the surface density of a panel corresponds to a 6 dB increase in the sound reduction index, and doubling the frequency under consideration also corresponds to a 6 dB increase.

However, in the mid and high frequency range, phenomena such as coincidence (at and above the critical frequency) and panel resonance also contribute to sound transmission. In the low frequency range coincidence may have little or no effect, leaving the mass law, at least for an infinite panel. However, the effects of resonance depend on panel dimensions and material properties. Bies and Hansen (1996) indicate that the sound reduction index of a panel is controlled by stiffness for low frequencies. According to Fahey (1987), boundaries can shift $R_{diffuse}$ values to above R_0.

In field measurements, flanking may affect the apparent sound reduction index (R'), and it is conceivable that significant flanking can occur in the very low frequency range in typical buildings.

For the purposes of this study, there are too many unknowns to theorise beyond the diffuse field mass law, so we use this as a comparison with our measurements, acknowledging that this theory does not fully represent the situation.

Measurement Methods

Three methods for field measurement of low frequency sound insulation have been trialled in this study:

- Method 1, from AS ISO 140-4 (Annex D);
- Method 2, proposed by Hopkins and Turner (2005); and
- Method 3, proposed by Fothergill (1980).

The three methods are described below. One situation was tested, with the larger, non-rectangular, room (188 m^3) used as the source room. The receiving room was rectangular (123 m^3).

For each of the three methods tested, three signals were used: white noise of 15 seconds duration, sine sweep of 15 seconds duration, and sine sweep of 60 seconds duration (for impulse response-based measurements). The white noise was filtered to remove energy below 16 Hz and above 120 Hz.

Both sine sweep signals were linear from 16 Hz to 120 Hz. This frequency range was chosen so as to allow the natural roll off of the loudspeaker (Whise 319A subwoofer) to occur. The sweep signals were deconvolved to yield impulse responses. This loudspeaker has an internal driver, with sound radiated entirely via a rectangular port.

Different signals are susceptible to different types of distortion. White noise may be subject to intermodulation distortion.

While on the other hand, a pure tone signal such as a swept sine signal may be vulnerable to harmonic distortion; however this may be separated by converting the signal to an impulse response – as long as the difference in frequency is not small (this effect is most obvious for a logarithmic sine sweep because harmonic distortion products form distinct pseudo-impulse responses (Farina 2000), but also occurs for a linear sine sweep, with the harmonic distortion smeared across time).

While both types of signal are susceptible to background noise, the sine sweep technique in general has a very high immunity to random background noise, but measurement results can be affected by steady state tonal noise.

Satoh et al (2004, 2005) address the influence of background noise in sound insulation measurements. By measuring with a sine sweep or MLS signal to obtain an impulse response, the influence of background noise (assumed to be random phase) can be suppressed.

In their study, the influence of the duration of the signal was investigated by comparing linear sine sweep signals with four durations ranging from 0.17s to 87.38s, and a reference signal of white noise with 10s duration. The results show that as duration increases, variation with the reference signal decreases with an increase in frequency.

A 10 minute duration sine sweep signal was used to compare a number of signal-to-noise ratio conditions with a reference signal (without noise) at low frequencies. Under adverse signal to noise ratio conditions (less than 0 dB), variation with the reference signal increases as the signal to noise ratio decreases.

The joining partition in our study is a single leaf partition 6.48 m x 3.96 m. It

is made up of two plasterboard panels, 10 mm thick with a surface density of 13 kg/m^2. Between the two panels is a steel stud frame. Benches are located on the receiving room side of the wall. Vibrometer measurements suggest that the lowest wall resonance is in the vicinity of 14 Hz.

Background Noise

The background noise of the source and receiving rooms was measured over a 5 minute period and the average taken from three positions. The sound pressure level in the receiving room was tested to ensure that the signal was at least 10 dB higher than the background noise in all 1/3-octave bands.

Reverberation time

Each measurement method that was tested specified different methods for the measurement of reverberation time. Trialling methods for reverberation time measurement were not addressed with this paper.

Thus it was decided that the reverberation time would be measured once, and used to calculate the sound reduction index for all methods of measuring sound insulation.

A logarithmic sine sweep was generated from 16 Hz to 120 Hz. The loudspeaker was positioned in a corner of the receiving room to excite the maximum number of room modes.

Nine different microphone positions were selected in an area around the centre of the room which allowed accurate measurement of the lowest modal frequency which was calculated to be 27 Hz.

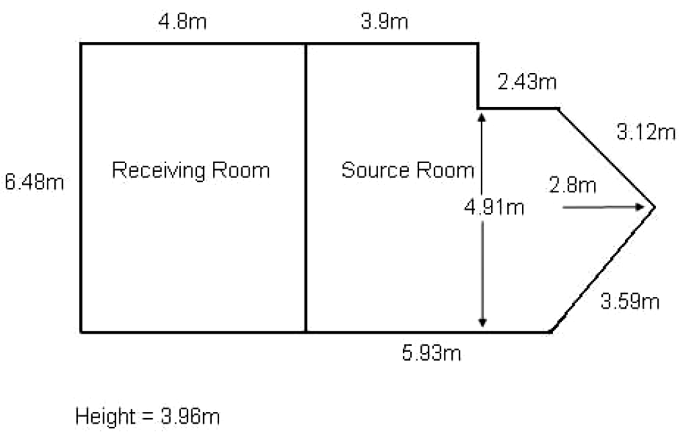


Figure 1. Source and Receiving Room Dimensions

Freq. (Hz)	20	25	31.5	40	50	63	80	100
T_{20} (s)	2.6	3.5	2.2	1.6	2.5	1.9	2.0	2.0

Table1: 1/3 Octave Band Reverberation Times of the Receiving Room

Two measurements were made at each of the nine positions within the restricted area, and the reverberation time obtained from the impulse responses. Reverberation times from T_{20} were spatially averaged for 1/3-octave band frequencies from 20 Hz to 100 Hz, and are shown in Table 1.

Reverberation time in the source room was not specifically measured for this project, but previous measurements in this room yielded octave band reverberation times of between 1.2 s and 1.3 s.

Method 1: AS ISO 140—4 (Annex D)

The loudspeaker is placed in such a position as to ensure a diffuse sound field, and so that direct radiation does not interfere with flanking elements or the partition.

A minimum of three loudspeaker positions is required, with the following conditions on their placement:

1. There is to be at least 0.7 m between positions with two positions not less than 1.4 m apart;
2. There is to be at least 0.5 m between source centre and boundaries (note that we were unable to achieve this with respect to the floor because of the weight of the loudspeaker).

The microphone positions in the source and receiving room are to be out of the direct field. A minimum of six microphone positions are required, with the following conditions on their placement:

1. There is to be at least 1.4 m between microphone positions;
2. There is to be at least 1 m between microphones and boundaries; with an ultimate limit of 1.2 m;
3. There is to be at least 2 m between microphones and the source.

The sound pressure level is then measured at each microphone position in 1/3-octave bands with centre frequencies of 50 Hz, 63 Hz, and 80 Hz (for this study we extended this approach to 20 Hz, without modification).

From these measurements, calculations of spatially averaged sound pressure level, level difference between rooms, and *R’* are performed in the conventional manner (using diffuse field assumptions).

R’ is used instead of the measured level difference *(D)* or standardised level difference (D_{nT} used in the BCA takes into account the 0.5s reverberation time of furnished dwellings) in order to compare each measurement methods with diffuse field mass law theory.

Annex D (which is ‘informative’) is not recommended for room volumes below 50 m^3, as diffuse-field conditions are not possible for frequencies below 50 Hz. However, this method has been used here in order to assess its applicability to medium sized room for frequencies down to 20 Hz.

It differs from the standard method for higher frequencies by (i) increasing the number of loudspeaker and microphone positions; (ii) increasing the minimum separating distances between microphone positions, boundaries and the sound source; and (iii) increasing the averaging time for

measurements.

By increasing the number of loudspeaker positions, the non-diffuse field can be partly compensated for by exciting numerous sound fields. The increase in microphone positions is necessary to obtain a reliable spatially averaged measurement.

Method 2: Hopkins and Turner

Hopkins and Turner (2005) propose that in the source room, the loudspeaker be placed in the corner farthest from the partition, and the sound pressure level in the four corners furthest from the loudspeaker be measured.

In the receiving room, the four corners opposite the partition should be measured. The microphone should be placed between 0.3 m and 0.6 m from the corner, along the x, y and z axes.

The proposed procedure estimates the room average sound pressure level from measurements made in the corners of the room and measurements made in the centre region of the room (obtained according to AS ISO 140—4).

The maximum measured value of the corner positions in each 1/3-octave band (50, 63 and 80 Hz) is averaged with the measurements made according to AS ISO 140—4 which have a weighting factor of two, to give the average sound pressure level of the room:

$$L = 10\log\left(\frac{2\times10^{L_{ASISO140-4}/10} + 10^{L_{corner}/10}}{3}\right) dB \qquad (4)$$

where

$L_{ASISO140-4}$ is the average sound pressure level obtained from AS ISO 140—4

L_{corner} is the maximum sound pressure level in the 1/3-octave band

To determine the *R'*, the same calculation process is followed as for Method 1.

This method was originally developed to allow measurement of rooms below 50 m^3 in the 50 Hz, 63 Hz and 80 Hz 1/3-octave bands. In the current project, the method proposed by Hopkins and Turner was implemented for two medium sized rooms, with the intention of measuring frequencies below 50 Hz for which the sound field is not diffuse.

Accounting for room modes in low frequency sound insulation measurements is important to domestic environments, as most seating and sleeping positions are located close to walls and corners.

With the Hopkins and Turner method, measuring in the corners of a room will ensure that low frequency sound insulation measurements are not overestimated and are relevant to domestic environments.

In their report, Hopkins and Turner show the new procedure to be more reliable, when compared with AS ISO 140—4. Three dimensional surface plots of the sound pressure level data in each measurement plane were used to calculate the room average sound pressure level.

The difference between this average and the average from the two measurement methods was then calculated.

The proposed method showed a lower difference, within ±1 dB of the room average sound pressure level calculated from the three dimensional surface plots.

In addition, field tests were carried out on 37 wall and floor constructions, of two different lightweight materials: timber and steel. The standardised level difference for the 50 Hz, 63 Hz, and 80 Hz 1/3-octave bands were for the AS ISO 140—4 and the proposed method. The new method was found to produce lower results.

Method 3: Fothergill

Fothergill (1980) proposed that in the source room, the loudspeaker be positioned in a corner opposite the partition at a 45 degree angle to the walls to ensure maximum excitation of room modes. The front of the loudspeaker is to be a minimum of 0.7 m from the corner.

There are to be six microphone positions, using two different heights

at three defined points in each room.

The positions are to be:

1. A and B: Halfway along the wall opposite the partition, 1m from the partition and normal to it;
2. C and D: Halfway along the wall between the loudspeaker corner and the partition, 1 m away from this wall and normal to it;
3. E and F: In the corner opposite the loudspeaker, 1 m from the partition and 1m from the adjacent wall.

The microphones are to form a vertical plane through points 1, 2 and 3 which is at a 45 degree angle to the walls and parallel to the front face of the loudspeaker.

The distances between A and B, C and D, E and F are to be 0.7 m. The microphone nearest to the loudspeaker is to be at a height of 1.5 m, with each other microphone being at alternate heights of 0.7 m and 1.5 m.

The microphone positions in the receiving room are to be a mirror image of those in the source room.

For non-rectangular rooms, measurements are to be restricted to a rectangular area of the room, which must include at least 7 m^2 of the partition area and substantial floor area.

To determine the *R'*, the same calculation procedure was followed as for Method 1.

Fothergill (1980) addresses the issues of interpretation and reproducibility of the measurement technique described in ISO 140–4.

Results show an improved reproducibility with the new method, however, as each method was carried out in a test facility with rectangular rooms, the measurement conditions were favourable and thus only a small improvement on results was expected.

The method described by Fothergill (1980) is not specifically specified for low frequencies, and no indication is given as to whether the method can be implemented for a lower frequency range.

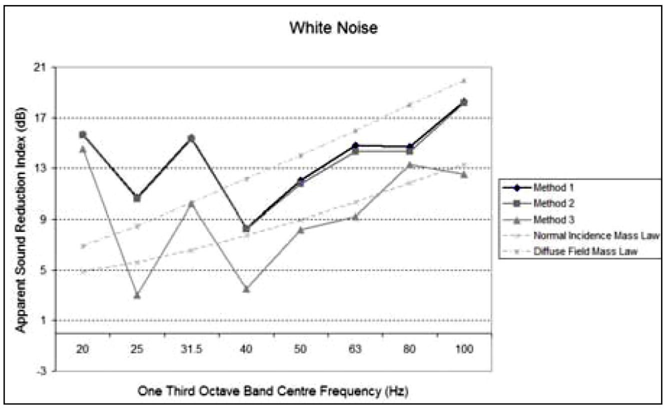


Figure 3: White Noise Method Comparison

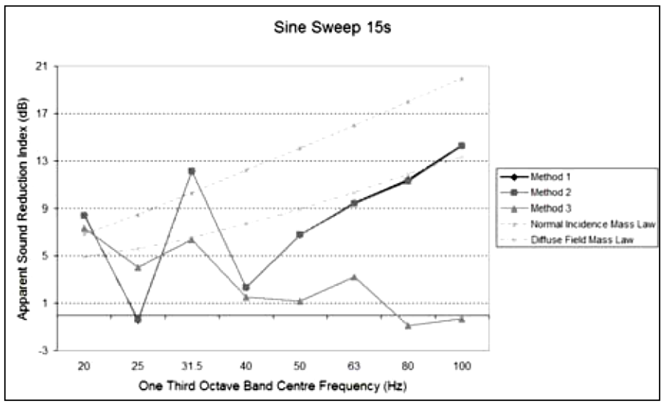


Figure 4: Sine Sweep 15 s Method Comparison

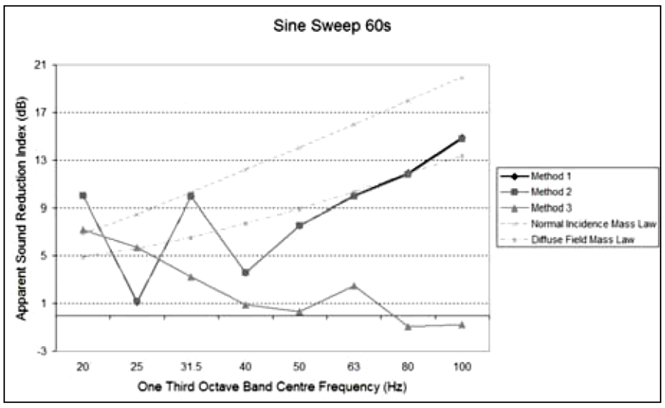


Figure 5: Sine Sweep 60 s Method Comparison

Results

Background Noise

The spatially averaged background noise sound pressure level spectra in the source and receiving rooms exhibit similar patterns from 20 Hz to 63 Hz. In the receiving room, the sound pressure level is above that found in the source room for most 1/3-octave band centre frequencies. The maximum level occurs at 25 Hz with 42 dB; similar levels are seen at 40 Hz, 50 Hz and 80 Hz.

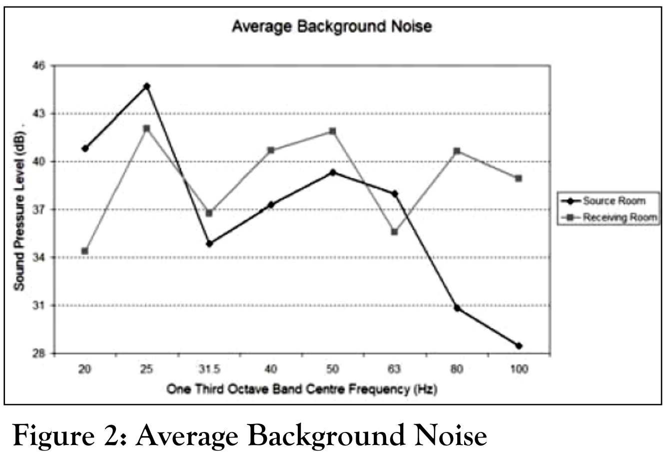


Figure 2: Average Background Noise

The spatially averaged background noise sound pressure level in the source room has a distinctive peak of almost 45 dB at 25 Hz. At 20 Hz, the sound pressure level decreases to approximately 41 dB. There is a significant decrease of 10 dB at 31.5 Hz, followed by a linear increase to 39 dB at 50 Hz. Minimum values are seen at 80 Hz and 100 Hz, with the sound pressure level dropping below 30 dB.

Test Method Comparison

Comparison of the three test methods using white noise as the source signal yielded very similar results for methods 1 and 2. Method 3 follows a similar trend as methods 1 and 2; which is approximately 4 dB lower than methods 1 and 2. In the range of

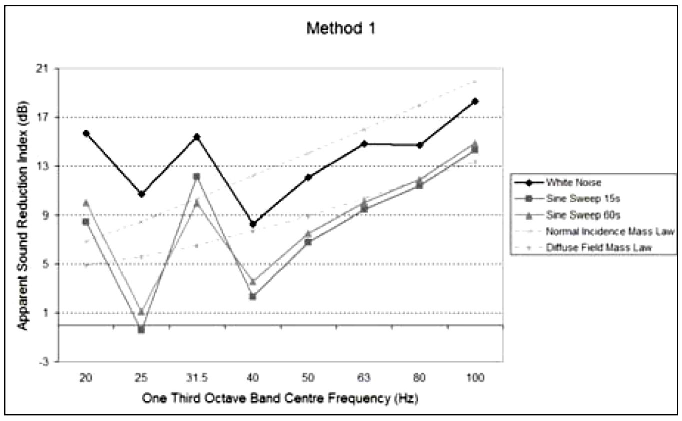


Figure 6: Method 1 Signal Comparison

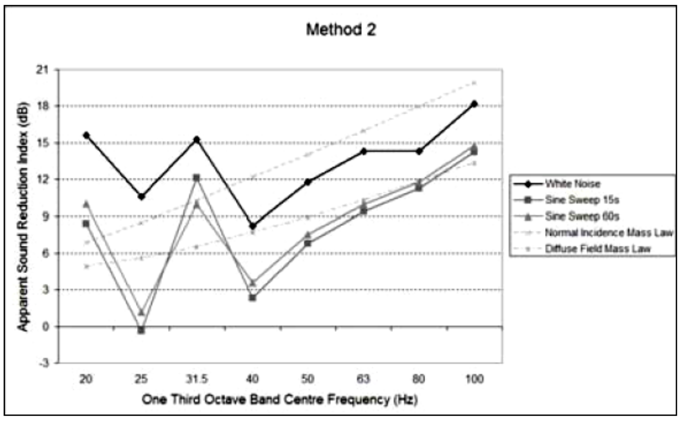


Figure 7: Method 2 Signal Comparison

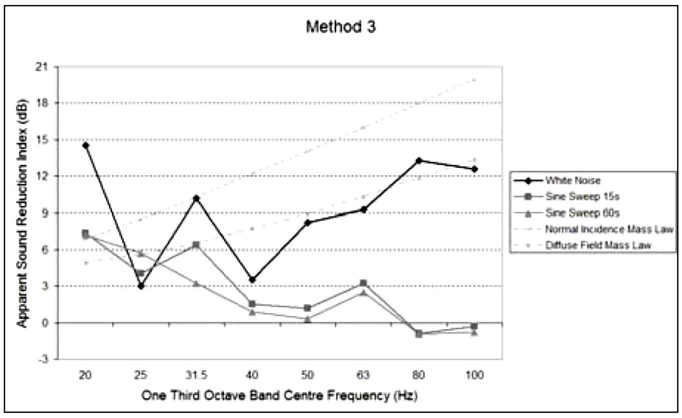


Figure 8: Method 3 Signal Comparison

20 Hz to 40 Hz, peaks in *R'* occur at 20 Hz and 31.5 Hz. Above 40 Hz, all methods show an increasing R'.

Comparison of the three test methods using the 15 s sine sweep as the source signal showed the same result for Methods 1 and 2. However, similar to the results seen with white noise, frequencies in the range of 20 Hz up to 40 Hz do not appear to be plausible i.e. not closely related to mass law theory.

Method 3 exhibits a general reduction in *R'* as frequency increases. There are two exceptions, with peaks occurring at 31.5 Hz and 63 Hz. Above 80 Hz, *R'* is negative. The 60 s sine sweep source signal yields similar results to that seen with the 15 s sine sweep signal. The peak at 31.5 Hz for all methods, seen in both the white noise and 15 s sine sweep signals, is reduced.

The main differences between the two sine sweep signals are at 25 Hz and 31.5 Hz. For the 60 s sine sweep signal, R' for Method 3 at 25 Hz increases; at 31.5 Hz, R' of all methods decreases, giving Method 3 a more even decline.

Test Signal Comparison

For Method 1, results for each of the signals follow the same trend, except at 80 Hz, where the white noise signal shows the same *R'* as at 63 Hz. The 15 s sine sweep and 60 s sine sweep show very good agreement at most frequencies (less than 1 dB difference),

with an exception at 31.5 Hz, where the 15 s sine sweep is 3 dB higher.

Results for Method 2 show that all signals to have the same result as for Method 1.

Results for Method 3 show significant differences for the white noise signal and both sine sweep signals. Below 40 Hz, no trend is set with the white noise signal; however, above 40 Hz, *R'* is increasing. Both sine sweep signals show the trend of a decreasing *R'* with increasing frequency. The signals are in good agreement with less than 2 dB differences at most frequencies, except at 31.5 Hz, where the 15 s sine sweep has a 3 dB peak above the 60 s sine sweep.

Test Signal Level Comparison

As the results from each method were assessed, it was found that more questions had arisen than had been answered.

Discrepancies between the methods using different transducer positions might be expected to an extent. However, there should be very little difference between results for different measurement signals if the system under test is linear and time-invariant.

Therefore we investigated whether this was the case. Comparison of the test signal level was conducted to help explain the results obtained for the test method comparison and test signal comparison.

It was thought that non-linearities, due to the sound power level of the source, were having a confounding effect on the sound insulation measurements.

The purpose of this test was not to do a spatial average between the two rooms, but simply to examine changes in level differences for one fixed source position and one fixed receiver position in each room.

Four different settings were used with Setting 1 having the lowest sound power level and each setting increasing by 3 dB. Setting 4 had the closest sound power level to that used for all measurements comparing the three methods for measuring sound insulation.

Figure 9: White Noise Signal Level Comparison

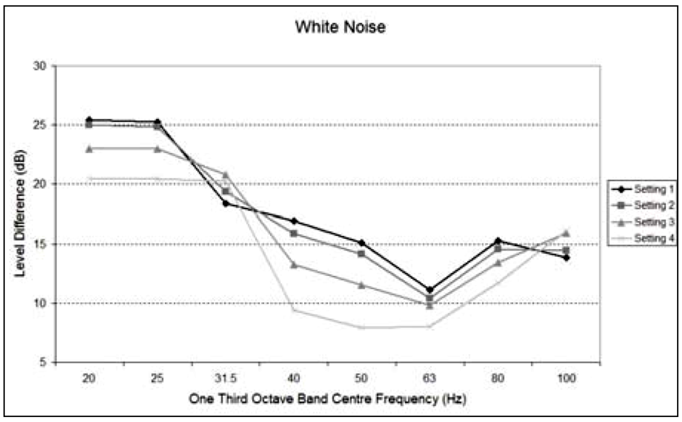


Figure 10: Sine Sweep 15 s Signal Level Comparison

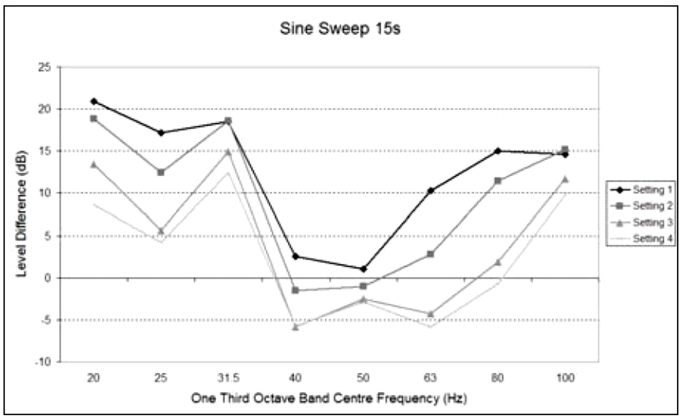


Figure 11: Sine Sweep 60 s Signal Level Comparison

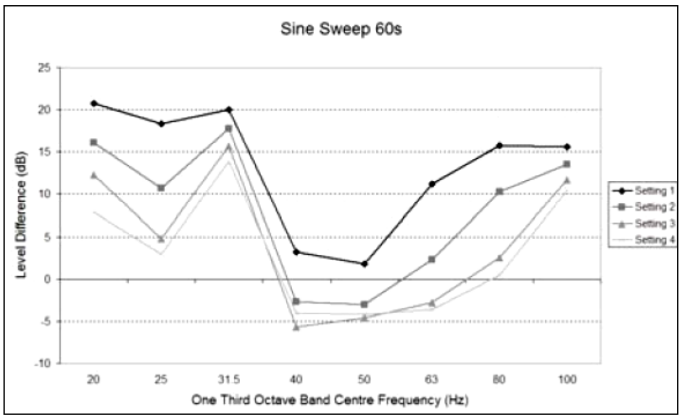
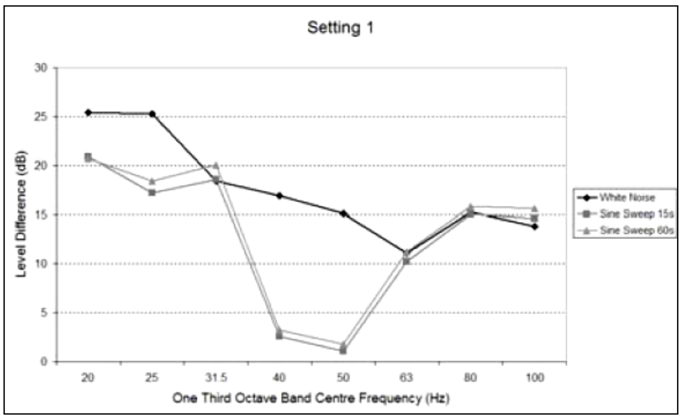


Figure 12: Setting 1 Signal Level Comparison



The signal level comparison with white noise as the source reveals that the highest level difference in general is achieved with the lowest sound power setting.

For all settings the highest level difference was found at 20 Hz and 25 Hz. After 25 Hz, the level difference decreases for all frequencies up to 63 Hz, then increases again at 80 Hz by 4 dB for Setting 1.

The signal level comparison with the

15 s sine sweep signal has shown similar results: increasing the sound power of the source increases the level difference. With this signal, the highest level difference is seen from 20 Hz and 31.5 Hz for most settings.

At these frequencies, Setting 1 ranges from approximately 21 dB at 20Hz, to 18.5 dB at 31.5 Hz. The level difference then decreases to a minimum of 2 dB at 50 Hz, followed by a sudden increase to 15 dB at 80 Hz.

The signal level comparison with the 60 s sine sweep has a very similar trend to that found with the 15 s sine sweep measurement. The main difference between them is that the longer sine sweep has a higher level difference for most settings, although the difference is minimal (maximum difference is less than 3 dB), due to the improved signal to noise ratio that is the result of a longer sine sweep.

Comparing the white noise signal with the sine sweep signals reveals significant differences at 20 Hz, 25 Hz, 40 Hz and 50 Hz for Setting 1. There is a very low level difference (less than 5 dB) for the sine sweep signals at 40 Hz and 50 Hz. At all other frequencies the level difference of each signal for Setting 1 is in very good agreement.

For each setting, as the sound power increases by 3 dB, agreement between the three signals reduces and the level difference reduces for all source signals.

Discussion

Background Noise

The most likely source of the increased background noise at 20 and 25 Hz is the air conditioning system, which remained on for all measurements taken. Associated ductwork runs along the ceiling through the partition in both the source and receiving rooms.

Other sources of noise which may contribute to the results are (i) electrical noise from the lights and, (ii) the elevator shaft, which is located directly next to the source room.

Much care was taken to eliminate variable external noise from all measurements by conducting measurements at times of minimal activity within the building.

However, as can be seen from the results of the background noise measurements, it is not possible to eliminate all noise sources, nor was it possible to eliminate variation in the noise.

Nevertheless, the contribution of background noise to any measurements that are performed should be insignificant as the sound source was more than 10 dB above the background noise in both rooms for all 1/3-octave band centre frequencies.

One point of interest is that narrow band analysis revealed the presence of some low frequency tonal components in the background noise.

The sweep method has no particular immunity to tones in the background (if they are maintained without phase shifts

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(Continued from page 30)

during a measurement). However, since the sweep signal was more than 10 dB above the background noise, it is still probable the effect of tonal background noise was negligible.

Test Method Comparison

Results within the range of 20 Hz to 40 Hz for all methods do not compare well to the diffuse field mass law. The erratic results seen below 40 Hz might be attributed to the non-diffuse sound fields, as well as other factors such as boundary effects of panel resonance and stiffness.

The decreasing *R'*, seen in Method 3, can probably be attributed to the method itself. The microphone positions detailed in Method 3 are relatively close to the room boundaries.

Four positions out of the total six are less than 1 m from a boundary or wall. Thus the sampled sound field is not balanced; a small area around the edge of the room dominates the results. This method is most meaningfully applied to a symmetric pair of rooms, and so may not be appropriate to the situation tested.

The question of room mode influence on field sound transmission measurement can be approached from various viewpoints. Hopkins and Turner's approach provides added emphasis to room modal behaviour.

Alternatively, it would be possible (but probably not practical) to completely suppress room modes in the source room and receiving rooms through synchronous averaging of a large number of modally balanced transducer positions (as demonstrated in part by Welti, 2002).

Probably for field measurements, the arguments of Hopkins and Turner are more compelling, since this means that a measurement will correspond more closely to the effective sound insulation of the situation.

Test Signal Comparison

The slight drop in R' at 80 Hz for Method 1 corresponds to an increased background noise level in the receiving room. However, there is no indication in the test signal level comparison that verifies this.

As test signal levels of the sine sweep signals are the same for all settings and frequencies, the difference at 31.5 Hz can only be attributed to an anomaly in the background noise which occurred at the time of measurement.

The differences between the white noise signal and the sine sweep signals seen in Method 3 cannot be explained with the tests that were carried out. Further research is required to explain the unusual results.

One area to explore is how the absorption in the receiving room should be characterised, since it will appear to be different for different transducer positions (based on the degree to which various room modes are activated).

The interpretation of decay curves can be an-other area of difficulty for low frequency 1/3-octave bands in small rooms. In the present study, the absorption of the receiving room was assumed to be the same for all methods.

Test Signal Level Comparison

For white noise sound insulation measurements, the results indicate that background noise may still be a concerning factor although the signal is more than 10 dB above the background noise.

However, increasing sound power of the source results in a decreasing level difference, which may be linked to an increasing amount of rattle within the building. Inadvertently, this seems to have an even more adverse affect on sound insulation measurements than the background noise.

The signal level comparison with the sine sweep signals has shown similar results, the high level difference corresponding to the high background noise level in the source room between 20 Hz and 31.5 Hz, and above 80 Hz.

This is an indication of tonal background noise, as random phase noise has little effect on a sine sweep signal.

All results from the test signal level comparison indicate that white noise in general has an increased level difference compared to the sine sweep signals.

Setting 1 (the lowest sound power level), shows that some frequencies do not have the same level difference.

Background noise may be the cause of discrepancies at 20 Hz and 25 Hz. Between 40 Hz and 50 Hz the reason is not so clear. The high background noise in the receiving room may be the cause.

As a further analysis of this problem, we converted the white noise recordings into impulse responses (by cross-correlating the original signal with recorded signals in the rooms).

The results for Methods 1 and 2 indicate that there is a large difference between analysis methods for the white noise recordings.

The white noise impulse response produced in Method 1 shows promising signs for frequencies 40 Hz and above with the R' being closer to the diffuse field mass law than is seen with the original analysis. However, at 63 Hz there is an anomaly which breaks the trend in the R'.

The results for methods 2 and 3 show no improvement, with the results actually being worse than those for the original analysis.

Thus the original method for analysing the white noise recordings appears to be the most successful for the signal.

Conclusion

Airborne sound insulation measurements are difficult to make in the low frequency range as it is not always possible to establish a diffuse field as is required by the current standard AS ISO 140–4.

Provided in this document is an informative annex which is a guideline for the measurement of low frequencies.

The guideline is specified for rooms with a minimum volume of 50 m^3, and for 1/3-octave band centre frequencies 50 Hz, 63 Hz and 80 Hz only. In some circumstances it may be necessary to be

able to measure frequencies lower than this, since airborne noise sources extend beyond this limit.

Three different methods for measuring low frequency sound insulation were trialled which included the current standard detailed in Annex D of AS ISO 140–4 as well as two other methods previously proposed.

Each method involved a different combination of transducer placement, and three source signals tested for each method.

An additional element of varying the test signal level was added to the study in order to better assess each test method and source signal.

Different results were achieved using different source signals, even though all signals had essentially a white power spectrum. These differences might be caused by two influences:

1. the differences between nonlinear effects that occur with different signal types and
2. perhaps the susceptibility of each signal type to background noise.

With regard to the first influence, a sine sweep is likely to produce a different type of distortion to white noise.

Inter-modulation distortion cannot occur for a pure tone, but could be prominent for white noise – whereas harmonic distortion can be important for a pure tone.

Furthermore, the conversion from a sine sweep to an impulse response separates distortion frequencies from the measurement frequency.

With regard to background noise susceptibility, the sine sweep technique in general has a very high immunity to random background noise, but measurement results can be affected by steady state tonal noise.

The deconvolution analysis is unable to distinguish between a tone produced by an impeller of an air handling system or an electrical hum and the re-cording of the test signal.

The random noise immunity of the sine sweep measurement may be improved by applying a tracking band-pass filter prior to deconvolution – but this does not improve noise immunity for tonal noise.

For all tested methods of measuring sound insulation, it was found that frequencies below 40 Hz yielded unreliable results. This is due to a combination of factors including: the non-diffuse sound field, boundary effects of panel resonance and stiffness.

Method 1 proved to show more plausible results when compared to the diffuse field mass law for both sine sweep source signals. Method 3, on the other hand, showed better results for the white noise source signal.

The effect of sound power level on all three source signals was quite substantial, indicating that the system under test was non-linear.

One aspect of this non-linearity was rattling from elements within the building, which increased with an increase in sound power level, reducing the level difference.

In future, it is suggested that all source signals be at the minimum level which is necessary to make an accurate measurement sufficiently above the noise floor.

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