Improving sound insulation measurements in homes and other buildings

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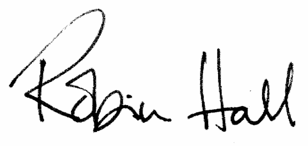

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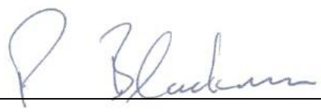

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Executive Summary

The intention of the work was to improve sound insulation measurements in buildings. This was achieved by reviewing appropriate standards to identify any inconsistencies or ambiguities; by identifying alternative methods of complying with the standards, determining whether these affected measurement results and by investigating new measurement methods. The results of this investigation suggested that the different approaches to field measurements of sound insulation allowed by the standards used do not result in systematic differences in measured sound insulation values. Therefore, the conclusion from this research was that the alternative methods of complying with the measurement standards were unlikely to affect the reproducibility of measured sound insulation values adversely.

To confirm this conclusion and to determine the range of sound insulation values that were likely to be obtained from measurements by different consultants on the same walls and floors, a round robin series of measurements was organized. The round robin exercise was supported by 45 UKAS accredited or ANC registered acoustics consultancies who routinely conduct pre-completion sound insulation tests for Building Regulations compliance. All who took part in used their own equipment and preferred measurement techniques.

The results from the tests showed that the reproducibility of the sound insulation values was good and confirmed that there was no significant difference between the different methods of complying with the measurement standards adopted by different organizations.

The general conclusion from this study is that it is reasonable to adopt methods that minimise time on site and investment in equipment so long as compliance with the relevant measurement standards is maintained and risks to personal safety are not incurred. The exercise also demonstrated the importance of robust data handling procedures and organization and, hence, the benefit of testers being accredited by third party bodies.

Two new measurement methods described in ISO 18233 were assessed as part of this study. These use deterministic Swept Sine and the Maximum Length Sequence signals respectively instead of the pseudo random signals used in conventional sound insulation measurements. The investigation was relevant because both systems reduce the adverse effect of high levels of background noise on airborne sound insulation measurements between rooms. This raised the prospect that sound insulation measurements could be conducted without suspending works in the vicinity of the rooms where measurements were being conducted. There are obvious advantages for practical methods of measuring airborne sound insulation that allow work to continue.

Measurements with the Swept Sine system were completed more quickly in high levels of measurement noise. However, measurements with both systems require considerably more time to complete than conventional measurements and require more costly equipment. Therefore, at present it is felt that neither system is appropriate for routine field measurements of airborne sound insulation.

Contents

Introduction

This report contains the results of the work described in BRE Bid number 121012. The intention of the work was to improve sound insulation measurements in buildings. Four interim reports have already been produced and are included in the appendices.

The current performance standards for sound insulation in dwellings and rooms for residential purposes required for compliance with the Building Regulations of England and Wales are contained in Approved Document E (2003 Edition). When the current version of Approved Document E came into force, sound insulation measurements between dwellings were required to demonstrate compliance. It was recognised that sound insulation measurements had to be of a consistently high standard across the whole of England and Wales and initially, UKAS accreditation for field measurement of sound insulation was required for pre-completion testing. In the 2004 Amendments to Approved Document E, it was declared that “The ODPM also regards members of the ANC Registration Scheme as suitably qualified to carry out pre-completion testing”.

Holding UKAS accreditation for field measurements of sound insulation means that testers’ measurement procedures, data handling and record keeping are fully traceable and robust. At the time of writing, the ANC Registration Scheme Committee are in the process of acquiring UKAS accreditation for their scheme and have issued a “Good Practice Guide” for field measurements. However, a range of different methods are used for complying with the standards for measuring sound insulation that are cited in Approved Document E by UKAS accredited and ANC registered testers.

To improve sound insulation measurements in buildings, the work identified ambiguities in the standards for field measurements of sound insulation and examined results from alternative methods of complying with the standards. In addition, the suitability of new methods of measuring airborne sound insulation was assessed for use in the field.

If systematic differences between different methods of complying with the relevant standards should be identified from the research, the intention was to make recommendations to improve consistency in and help ensure good measurement practice on site.

The work was supported by the NHBC Foundation, the BRE Trust, Robust Details Limited and the Association of Consultant Approved Inspectors (ACAI). In addition, the work was supported by acoustics professionals from 45 different companies who took part in a round robin series of sound insulation measurements in a building on the BRE Garston site.

Description of the project

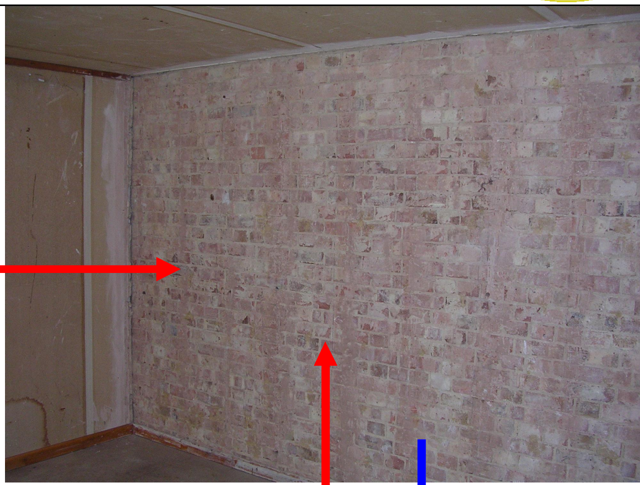
The intention of the work was to improve sound insulation measurements in buildings by:

1. reviewing the standards for measuring airborne and impact sound insulation in the field to identify any inconsistencies or ambiguities and alternative methods of complying with the standards;
2. conducting a series of measurements shaped by the conclusions from the review of the standards;
3. investigating new measurement methods that reduce the effect of background noise levels in receiver rooms and allow airborne sound insulation measurements to be made where these noise levels are relatively high;
4. examining the reproducibility of field measurements;
5. producing conclusions and recommendations, where possible, from an analysis of the results of this investigation.

Items 1 to 3 above were conducted by BRE staff. Item 4 was achieved with the help of acoustics professionals registered under the ANC Registration Scheme and those with UKAS accreditation for field sound insulation measurements who took part in a round robin series of sound insulation measurements at BRE. The round robin measurements began on 2 May 2008 and continued until 21 August 2008.

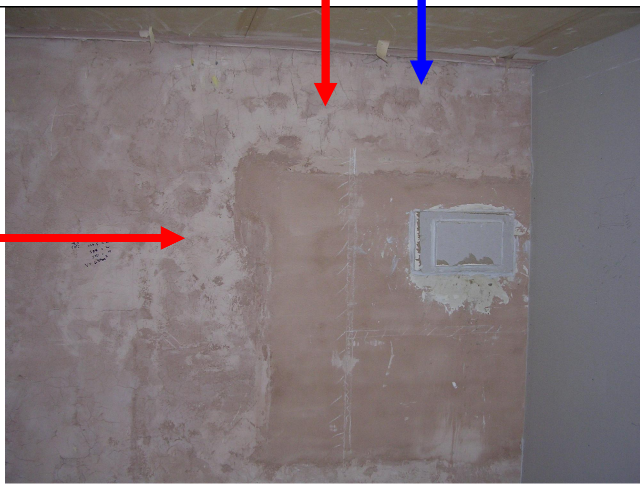
The building used for the round robin measurements had four rooms laid out as illustrated in Figure 1. The red arrows in Figure 1 indicate the rooms used for airborne sound insulation measurements and the blue arrow the rooms for impact sound insulation measurements. The walls that separated the pairs of rooms were solid masonry walls approximately 220 mm thick. In rooms 1 and 2, on the ground floor, the separating wall was plastered. In rooms 3 and4 the wall was fair faced. Rooms 4 and 2 were separated by a timber joist floor with a plasterboard ceiling fixed directly to the joists and tongue and groove chipboard walking surface.

Room 3, 1st floor (showing stud partition); volume ≈ 48 m^3



Room 4, 1st floor; volume ≈ 48 m^3

Room 1, ground floor; volume ≈ 30 m^3



Room 2, grwound floor; volume ≈ 27 m^3

Figure 1: the rooms used for the round robin measurements and their relationship to each other in Building 68A on the BRE Garston site

Findings

The results from the initial investigation of the standards for measuring airborne[1] and impact[2] sound insulation in the field, ISO 140-4 and ISO 140-7 respectively, were given in Report number 241 615; the first of four interim reports produced and produced in Annex A of this report. The report identified those parts of the guidance in the standards that would be investigated in this study. These are listed below.

1. Measurements to determine whether placing sound sources in the corners of rooms in the same planes relative to room surfaces for airborne sound insulation measurements affects sound insulation measurement results.

2. Measurements to determine whether the guidance for locating sound sources used for airborne sound insulation measurements in rooms is appropriate for both omnidirectional and cabinet loudspeakers.

3. An investigation of the requirement in ISO 140-4 that source room levels in adjacent 1/3 octave bands should not differ by more than 6 dB for airborne sound insulation measurements.

4. Measurements to determine the effect of using the smaller room as the source room for measurements of airborne sound insulation.

5. Measurements to assess the effect of dust on floors used for impact sound insulation measurements and to determine whether it should be recommended that ISO 140-7 provide additional guidance for these measurements.

6. Measurements to determine whether using the minimum number of tapping machine positions can produce significantly different values than more measurements with one different microphone position for each different tapping machine position.

7. Measurements to compare values of airborne sound insulation derived from classical measurements (ISO 140-4) and MLS and SS methods described in ISO 18233.

8. Round robin measurements to assess the reproducibility of sound insulation measurements.

Investigations of the guidance on loudspeaker positions for airborne sound insulation measurements in ISO 140-4 were conducted in rooms 1 and 2 of Building 68A. The measurements to assess the effects of different approaches to complying with the guidance for tapping machine positions and number of microphone measurements were conducted in the controlled environment of the BRE laboratories. These investigations and its results were presented in BRE report number 245877. Also included in this report was the background to the investigation of the ISO 140-4 requirement that that source room levels in adjacent 1/3 octave bands should not differ by more than 6 dB. BRE report number 245877 is in Appendix C of this report.

Airborne sound insulation

The investigations into the effect of locating different types of loudspeakers in corners and other positions when measuring airborne sound insulation showed that, where the separating wall was not directly excited by sound, the loudspeaker position had no significant effect on the single number quantity $D_{nT,w}+C_{tr}$. Nor was measured airborne sound insulation affected by using a cabinet or an omnidirectional loudspeaker as the sound source. In all, 43 measurements were made with a cabinet loud speaker and 58 measurements with an omnidirectional loudspeaker. Therefore, although it is accepted that sound pressure levels in rooms can be significantly affected by slight movements of loudspeaker[3], from the measurements it is reasonable to conclude that the location and type of loudspeaker do not affect measured standardized sound level differences.

The results from measurements with and without differences between adjacent 1/3 octave bands in source rooms greater than 6 dB are given in BRE report 245877 in Appendix C of this report. They showed no significant difference in measured values of $D_{nT,w}+C_{tr}$ when 6 dB differences were introduced between adjacent frequency bands. As discussed in report 245877, questions have recently been raised within the acoustics profession concerning the 6 dB criterion: whether it is a “left over” from the time when only analogue filters were available in sound level meters or whether level differences greater than 6 dB increase the risk of driving resonances hard and, as a consequence of this, affecting sound insulation measurement results. Attempts to drive suspected resonances in floors by introducing 6 dB spikes in the source spectrum in appropriate 1/3 octave bands were made but no consistent effect on measured airborne sound insulation was identified.

It has been shown that levels in frequency bands adjacent to a band with a level that is 6 dB greater can be affected by this higher level. If the reason for the 6 dB criterion is not related to driving resonances, then a question remains: why are level difference greater than 6 dB in adjacent bands in receive rooms ignored? More investigation of this is required perhaps although it is difficult to see what measures could be taken to remove 6 dB differences in receive rooms since these may be related to the properties of the element under test. A possibility may be to generate sound and measure level differences in individual 1/3 octave frequency bands but this method is not appropriate for routine field measurements.

Impact sound insulation

ISO 140-7 states that the minimum number of tapping machine positions for impact sound insulation measurements is 4 and the minimum number of microphone measurements is 6. No evidence was found that using the minimum number of tapping machine positions or different combinations of microphone measurements and tapping machine positions significantly affected measured impact sound insulation. Nor did locating the tapping machine positions closer together in different parts of the floor in this measurement series. However, sawdust beneath the tapping machine hammers did affect measured impact sound insulation.

Sawdust beneath the tapping machine hammers had a greater effect on the measured impact sound insulation of the concrete floor than the timber floor. Ten measurements on the concrete floor, with and without sawdust beneath the hammers, showed that sawdust reduced the average value of the weighted normalised impact sound pressure level ($L_{n,w}$) by 8 dB.

Impact sound insulation measurements are conducted with a standard impact source that has five steel hammers that strike the floor under test in a specified manner. It is described in ISO 140-7. A standard impact source is used so that the same amount of sound power is put into all floors that are tested. However, the sound power put into floors is reduced in all frequency bands that are higher than a particular frequency known as the “cut-off” frequency. This cut-off frequency depends on the relative impedances of the tapping machine hammers and the surface that the hammers strike.

The graphs of normalized impact sound level versus frequency shown in figures 3 and 4 of BRE report 245877 illustrate the characteristic difference in the response to excitation with the standard impact source on timber and concrete floors respectively. The driving point impedances of timber based floor coverings, such as chipboard, are considerably lower than those of concrete floors or concrete floors with sand-cement screeds. The power input to chipboard surfaces by the tapping machine is generally reduced in 1/3 octave bands higher than 500 Hz. With surfaces such as concrete, the cut-off frequency is usually in a frequency band higher than the limit of Building acoustics measurements (5,000 Hz).

Dust and debris beneath the tapping machine normally reduce the power input to floors. However, because the power is also reduced due to the cut-off frequency, the results from impact sound insulation tests on the timber floor were not significantly affected when dust was placed beneath the tapping machine hammers. With the concrete floor, dust beneath the tapping machine hammers had a significant effect. Therefore, particular care should be taken to ensure concrete floors or floors with sand cement screeds are clean when impact sound insulation is measured with the standard tapping machine.

Although locating tapping machines close together in different positions on the floors tested had no significant result on measured impact sound insulation, it makes sense to choose tapping machines carefully so that they are distributed appropriately on the floor under test. Therefore, it is worth revisiting the guidance in ISO 140-7 that tapping machine positions be “randomly distributed on the floor” when possible. This guidance could result in the tapping machine being placed inappropriately for some situations. For example, acousticians take care that with timber or steel joist floors, an appropriate number of measurements are made with a hammer striking the floor directly above a representative number of joists rather than risk skewing the results by not having any joists “directly” excited.

New methods of measuring airborne sound insulation

ISO 18233[4] describes the Swept Sine and Maximum Length Sequence measurement methods. Two measurement methods that reduce the adverse effect that high receive room background noise levels have on the usual ISO 140-4 measurements. Both the methods enabled airborne sound insulation to be measured in terraced houses on the BRE site in which background noise levels were high due to their close proximity to the M1 motorway. Because of the high background noise, the sound level difference between rooms in two houses could not be measured in the 1/3 octave bands 500 Hz – 3,150 Hz with the ISO 140-4 method and an omnidirectional loudspeaker. In this frequency range the measured receive room values were within 6 dB of background levels which means that the limits of measurement have been reached and that the maximum adjustment of 1.3 dB is made to receiver room levels. Not surprisingly, both the ISO 18233 methods produced higher values of $D_{nT,w}+C_{tr}$ than the classical ISO 140 method.

When the two new methods were compared with the classical ISO 140 method in the absence of high background noise, both new methods produced the same $D_{nT,w}+C_{tr}$ value as the ISO 140 method. However, at the time of writing, the ISO 18233 methods require more complex and relatively expensive equipment than is required for the ISO 140 method. In addition, they take more time to complete than the ISO 140 method because, with both, the effect of background noise is reduced by averaging a number of measurements. The greater the background noise level and variability, the greater the number of averages required. Additionally results from these averages can only be relied on if conditions in both source and receiver rooms remain constant and fixed microphone positions used. This can be difficult to achieve outside a laboratory.

To measure airborne sound insulation on site using fixed microphone positions, measurements at a minimum of five microphone positions in source and receiver rooms for each of at least two loudspeaker positions are required. Therefore, neither of the ISO 18233 methods is suitable for normal field sound insulation measurements at the moment. However, the Swept Sine system appears to be the better of the ISO 18233 two systems because the measurements take less time to complete than MLS measurements; particularly where background levels are very high.

Round robin measurements at BRE

All who took part in the round robin exercise carried out the measurements required to derive the single number quantities used to describe airborne and impact sound insulation in Approved Document E of the Building Regulations of England and Wales. These are, $D_{nT,w}+C_{tr}$ and $L'_{nT,w}$ for airborne and impact sound insulation respectively. Both $D_{nT,w}+C_{tr}$ and $L'_{nT,w}$ are produced by shifting reference curves in a specified manner in 1 dB steps. Therefore, it is accepted that the precision of these descriptors is no better than ±1 dB and it is reasonable to consider the uncertainty in their values to be at least ±1 dB. The average airborne and impact sound insulation results from the two groups of testers (ANC registered and UKAS accredited) are given in Table 1 below taken from BRE report 245878, which can be seen in Appendix D of this report. In this report, the values are given to the nearest whole number in accordance with Section 5.1 of ISO 717-1[5] and Section 4.3 of ISO 717-2[6]. The average values for airborne sound insulation produced by the two groups differ by 1 dB for each of the three pairs of rooms with the average from the ANC testers consistently producing the higher values. Both groups produced the same average value for impact sound insulation.

No significant differences were identified between the results from airborne sound insulation measurements conducted with fixed or moving microphones or occupied or unoccupied rooms. Nor were there significant differences between results from impact sound insulation measurements with different numbers of tapping machine and microphone positions. All measurements were conducted by acoustics professionals who were registered with the ANC Registration Scheme or who held UKAS accreditation. That is, by professionals qualified to conduct pre-completion testing (pct) to demonstrate compliance, or otherwise, with Building Regulations.

Statistical analysis showed that there was a difference in the $D_{nT,w}+C_{tr}$ values produced by the two groups of testers that was significant at the 5% level in rooms 1 and 2. This was also the case for rooms 2 and 4 when measurements that used the smaller of the two rooms (Room 2, 27 m^3) as the source room and Room 3 (48 m^3) as the receiver room were included. However, this is at odds with the guidance in ISO 140-4 which requires the source room to be the larger of the two rooms. Therefore, it is reasonable to examine only the results from measurements conducted in accordance with ISO 140-4. (It is believed that most, if not all of the measurements using the smaller room as the source room were conducted as part of a parallel investigation by some who took part in this round robin exercise.)

Table 1: comparison of results from ANC registered and UKAS accredited testers who took part in the round robin exercise

Rooms	ANC tests		UKAS tests	
	$D_{nT,w}+C_{tr}$ dB	$L'_{nT,w}$ dB	$D_{nT,w}+C_{tr}$ dB	$L'_{nT,w}$ dB
1 and 2	52		51	
3 and 4	47		46	
2 and 4	37	67	36	67

The results of the comparison using only airborne sound insulation results from measurements in accordance with ISO 140-4 are shown in Table 2. Statistical analysis showed that there is no significant difference in the $D_{nT,w}+C_{tr}$ values produced at the 5% level.

It is of note that rounding to integer values has exaggerated the difference between the two calculated mean values from this comparison which, to two places of decimals, were 37.52 dB and 36.46 dB. When the calculated average $D_{nT,w}+C_{tr}$ values produced by the two groups of testers from measurements in rooms 1 and 2 are compared using two places of decimals, these are 51.45 dB and 51.97 dB.

Therefore, although the statistical analysis conducted demonstrated that there were significant differences between some of the sets of data produced by the ANC and UKAS testers from airborne sound insulation measurements, these have no practical significance.

The average values for impact sound insulation produced by ANC and UKAS testers were identical but both sets of data contained $L'_{nT,w}$ values that were significantly higher than all others. Conversations with the testers responsible for the data showed that:

- an $L'_{nT,w}$ of 81 dB was the result of a calculation error;
- two identical values of $L'_{nT,w}$ = 78 dB were the result of conducting measurements on the wrong floor.

The fact that the three values of impact sound that were considerably different from the other results improves confidence in the reliability of the measurement method and the skill of the testers. However, it also highlights the importance of good preparation for site visits (at least one of the testers came to site without the instructions that were sent out) and good data handling and checking procedures. Both of these support the need for testers to be accredited by an appropriate third party and for that third party to conduct regular audits.

When these values for impact sound insulation are removed from the statistical analysis, the values of $L'_{nT,w}$ in Table 2 are produced.

Table 2: measurement results using rooms 2 and 4 with Room 4 as the source room

Rooms	Average values from ANC tests		Average values from UKAS tests	
	$D_{nT,w}+C_{tr}$ dB	$L'_{nT,w}$ dB	$D_{nT,w}+C_{tr}$ dB	$L'_{nT,w}$ dB
2 and 4	38	66	36	66
Number of measurements	25	29	28	28

Room 3 contained a partition (shown in Figure 1) that extended from floor to ceiling and halfway across the room parallel to the separating wall between rooms 3 and 4. It was located halfway between the separating wall and the wall opposite. The intention of installing the wall was to see if it affected people's choice of source and receiver rooms or affected airborne sound insulation values. For 15 out of 30 tests ANC tests and 19 out of 30 UKAS tests Room 3 was used as the source room. There was no significant difference between the ANC and UKAS test results nor was there a difference between results from measurements using rooms 3 and 4 as the source room.

When the results from all the tests conducted in accordance with the relevant standard and the round robin measurement programme are analysed, the values in Table 3 are produced.

Table 3: collated values from all tests conducted in accordance with the relevant standard and the round robin measurement programme

Rooms	$D_{nT,w}+C_{tr}$ dB	$L'_{nT,w}$ dB	St. Deviation in SNQ* dB	Number of tests
1 and 2	51		1	61
3 and 4	46		1	61
4 and 2	37		2	53
4 and 2		66	1	57

* Single Number Quantity

The values in Table 3 suggest that the procedures used on site by those who took part in the exercise are robust. Given that the single number quantities are given integer values derived by moving a reference curve insteps of 1 dB, values in their standard deviations cannot realistically be expected to be lower than

1 dB from the number of tests conducted and nature of this exercise. The 2 dB standard deviation value for rooms 2 and 4 is also evidence that tests were conducted with high levels of care and competence.

Conclusion and recommendations

- The results from the round robin tests support that the conclusions from BRE report 245877 that different types of loudspeaker and choices of loudspeaker positions do not adversely affect measurement results when the guidance in ISO140-4 is complied with. Also that different selections of tapping machine positions and numbers of measurements do not affect measured impact sound insulation values adversely.
- No systematic differences in airborne or impact sound insulation results were identified from the different approaches to measuring sound pressure levels on site in the round robin measurement programme. Therefore, it is reasonable to conclude from this exercise that the current standard of measurement practice is sufficiently robust for pre-completion testing.
- No advantage was observed from using more time consuming measurement methods over those that required less time to complete was identified. Therefore, there appears to be no reason why the methods that minimise time on site and disruption to the construction process should not be encouraged.
- The results suggest that the statement in the 2004 amendments to the 2003 Edition of Approved Document E that; "The ODPM also regards members of ANC Registration Scheme as suitably qualified to carry out pre-completion testing" is justified.
- It is good practice to ensure that floors are clear and free from dust and debris before commencing impact sound insulation measurements. This is particularly the case with concrete floors. Special care should be taken to ensure that concrete floors are clean and free from dust and debris for impact sound insulation measurements.
- Robust data handling, checking procedures, organization and planning for field measurements are essential. It is of no help to clients or building control bodies if measurements are conducted well on site and calculations are conducted incorrectly. The current requirement in Approved Document E (2003 Edition) is for testers to be accredited by a third party. This is justified. Regular auditing of measurement practice and data handling procedures is an essential requirement of such accreditation if the quality of measurements is to be maintained and improved upon.
- The reproducibility of sound insulation measurement results from acoustics professionals conducting pre-completion testing for compliance Building Regulations who took part in this exercise is good.
- The measurement methods described in ISO 18233 are inappropriate for routine field measurements of airborne sound insulation at the time of writing. They are more appropriate measurements in laboratories, where it is easier to maintain constant conditions when high sound insulation reduces transmitted receive room levels to close to background levels for classical measurements. However, the Swept Sine measurement method appears to be more appropriate than MLS measurements when background levels are particularly high.

References

1 BS EN ISO 140-4, Acoustics – Measurement of sound insulation in buildings and of building elements – Part 4: Field measurements of airborne sound insulation between rooms, 1998, BSI.
2 BS EN ISO 140-7, Acoustics – Measurement of sound insulation in buildings and of building elements – Part 4: Field measurements of impact sound insulation between of floors, 1998, BSI
3 L. C. Fothergill, Building Research Establishment, Recommendations for the measurement of sound insulation between dwellings, Applied Acoustics,13, 171-187. (1980)
4 BS EN ISO 18233, Acoustics – Application of new measurement methods in building and room acoustics, 2006, BSI
5 BS EN ISO 717-1:1997, Acoustics – rating of sound insulation in buildings and of building elements, Part 1 Airborne sound insulation
6 BS EN ISO 717-2:1997, Acoustics – rating of sound insulation in buildings and of building elements, Part 2 Impact sound insulation

Appendix A – Interim report 1; revue of measurement standards

Improving sound insulation measurements in homes and other buildings: initial report with review of measurement standards

Prepared for: NHBC Foundation

23 November 2007

Client report number 241615

1 Improving sound insulation measurements in homes and other buildings: initial report with review of measurement standards

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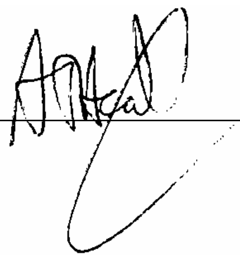

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Executive Summary

This report is the first in a series examining the measurement of sound insulation in buildings. The research was commissioned because the guidance for the measurements given in the relevant British and international standards is ambiguous in places and many acoustics professionals believe that the guidance fails to take sufficient account of conditions found in the field. Because of this and the importance of the measurements for demonstrating compliance with Building Regulations, an evaluation of the effects of different interpretations of the standards on measurement results is needed.

The work is timely because a reorganisation of the standards covering laboratory measurement of sound insulation is currently in progress. When this work is complete, a reappraisal of the standards for field measurement of sound insulation will begin. It is intended that the guidance produced from the work undertaken will be of assistance in improving the reproducibility of field sound insulation measurements and provide guidance for acoustics professionals.

This initial report:

- identifies those parts of the guidance in the standards that will be investigated;
- describes the research programme that will be adopted;
- states how the information gathered will be disseminated.

Contents

Introduction

Approved Document E (2003 Edition) (ADE) requires airborne and impact sound insulation in dwellings to be measured as part of a process of pre-completion testing unless Robust Details are used on developments registered with Robust Details Limited. ADE requires the measurements to be conducted in accordance with ISO 140-4[1] (airborne sound insulation) and ISO 140-7[2] (impact sound insulation). These standards have been criticised by acoustics professionals for taking insufficient account of conditions for testing on site. It is felt by some that the guidance is more suited for controlled laboratory conditions and it is widely accepted that some of the guidance in the standards is ambiguous.

This report is the first of a series of outputs from a research project undertaken on behalf of the NHBC Foundation and also sponsored by Robust Details Limited (RDL) and the Association of Consultant Approved Inspectors (ACAI). It identifies ambiguities and instances where there is lack of clarity in the guidance contained in ISO 140-4 and ISO 140-7. It describes the work that will be undertaken in this project and states how the knowledge gained will be disseminated.

The research programme, of which this report is a part, was described in BRE/NHBC proposal number 07/010, Proposal (amended): improving sound insulation measurements in homes and other buildings.

Review of guidance for field measurements of sound insulation

The results of the review of the relevant standards along with proposals for investigative work are given below. Airborne and impact sound insulation are discussed in turn.

Airborne sound insulation

6 dB difference in adjacent 1/3 octave bands in the source room.

ISO 140-4 requires differences between sound pressure levels in adjacent 1/3 octave frequency bands in source rooms to be ≤ 6 dB and there has been discussion concerning the relevance of this requirement amongst acoustics consultants. Some consider this requirement to be a 'left over' from the time when only analogue filters were available for use in equipment used for measuring sound pressure levels. Filters in sound level meters have limited roll-off which means that measured sound pressure levels in a 1/3 octave frequency band can be affected by levels in the adjacent bands if those levels are significantly higher. However, differences in adjacent bands > 6 dB can indicate that some room modes are driven harder than others and this may lead to the single number quantity used to describe airborne sound insulation ($D_{nT,w}$ and/or $D_{nT,w}+C_{tr}$) being dominated by measured sound pressure levels in a few 1/3 octave bands. The data obtained by BRE as part of this research and that sponsored by ANC and RDL will be analysed to determine whether results suggest that modern digital filters with greater roll-off mean suggest that differences of more than 6 dB between adjacent 1/3 octave bands affect the single number quantity for airborne sound insulation.

Location of sound source

Annex A of EN ISO 140-4 states that:

1. the distance between different loudspeaker positions shall not be less than 0.7 m;
2. at least two loudspeakers shall be not less than 1.4 m apart;
3. the distance between the sound source and the room boundaries shall be not less than 0.5 m;
4. different loudspeaker positions shall not be located within the same planes parallel to the room boundaries;
5. "is often of advantage" to use loudspeaker positions in the corners of the source room.

Point 5 above suggests that in some circumstances, practical considerations mean that points 3 and 4 above need not be adhered to. Investigations will be conducted to determine whether locating the sound source in the same plane in corners of the source room affects the measurement of airborne sound insulation.

ISO 140-4 states that the larger of two rooms should be the source room when measuring the standardized level difference (D_{nT}). However, Annex A of ISO 140-14[3] states that the lower room should be the source room for vertical measurements of airborne sound insulation. This can conflict with the guidance that the larger room should be the source room. The effect of using the smaller room as the source room for vertical measurements of airborne sound insulation will be investigated.

Hemisphere polyhedron loudspeakers are designed to be used on the floor. Therefore, with this type of loudspeaker, it is difficult not to have both source positions in the same plane relative to the source rooms boundaries (the floor and ceiling). Polyhedron loudspeakers are used because they are designed to produce omnidirectional sound (like hemisphere polyhedron loudspeakers) and are often favoured because their use should be advantageous for producing a diffuse sound field in rooms. However, it is not clear whether the guidance for locating loudspeakers in ISO 140-4 is useful for both omnidirectional and non-omnidirectional sound sources; particularly in small rooms. Therefore, this will be investigated.

Impact sound insulation

Location of impact sound source

The method for measuring impact sound insulation is contained in ISO 140-7. A standard tapping machine that is placed in different positions on the floor under test is used for the measurements. Using a standard tapping machine that meets the specification described in Annex A of ISO 140-7 should ensure that a constant quantity of sound power is put into all test floors. However, there is evidence that dust beneath the tapping machine hammers can significantly reduce the power put into floors. Measurement results on concrete and timber floors will be used to assess this to determine whether additional guidance on the condition of floors to be tested is needed.

The guidance for locating the tapping machine to generate the sound field states: “The tapping machine shall be placed in at least four different positions randomly distributed on the floor under test”. A random distribution means that for some tests the tapping machine positions could be located close together in one area of the floor rather than spread over the whole floor area. In addition, there is no guidance on the minimum separation between tapping machine positions. Measurements will be conducted on timber floors to determine whether the guidance in the standard should be modified.

The minimum number of tapping machine positions required by ISO 140-7 is four. The minimum number of measurements using fixed microphones is six. The minimum number of fixed microphone positions is four. If four tapping machine positions are used, for two of these tapping machine positions measurements must be conducted at two microphone positions if the minimum number of microphone positions are to be used. If six tapping machine positions are used, a different fixed microphone position can be used for each tapping machine position. That is, the impact sound pressure level is measured at six different positions within the receive room. There is a possibility that when only four tapping machine positions are used, the measured impact sound pressure level might be dominated by the two pairs of measurements related to two tapping machine positions. This will be investigated and recommendations made if necessary.

ALTERNATIVE METHODS FOR AIRBORNE SOUND INSULATION AND ROUND ROBIN MEASUREMENTS

Alternative methods for measuring sound insulation that might have advantages for measurements in buildings where background noise levels can be high are now available. Results from these and round robin measurements involving UKAS accredited testers and those registered under the ANC Registration Scheme could provide useful information for acoustics professionals and the building industry.

Maximum Length Sequence (MLS) and Swept Sine (SS) measurements

Currently the performance standards in the Building Regulations for the UK and Eire refer to airborne sound insulation performance standards in dwellings when measured in accordance with ISO 140-4. These measurements can be adversely affected by high levels of noise in receiving rooms and this can mean that work in rooms adjacent to those being used for measurements has to stop or that measurements have to be conducted at night when noise levels outside the test rooms are low.

MLS measurements reduce the influence of background noise levels in receive rooms on measurements enabling sound insulation to be quantified where reliable ISO 140-4 measurements might not be possible. With the publication of ISO 18233[4], two new methods for measuring airborne sound insulation have been described: the MLS method and the SS method. Both methods will be compared with the classical method of measuring airborne sound insulation. It is intended that these measurements will take place in late April 2008.

Round robin measurements

Measurements conducted by different testers in rooms that have a complex layout can produce a range of measured values. The new guidance for “special situations in the field” in ISO 140-14 is intended to reduce the spread of results from measurements in rooms with unusual layouts. Therefore, there is value in inviting a number of different testing organisations to measure the sound insulation between the same rooms where the rooms are not simple box shaped rooms.

Building 68A (B68A) at BRE has been used by members of the Association on Noise Consultants (ANC) and BRE staff to investigate the effect of operators in rooms used for field measurements of sound insulation. Currently B68A has two rooms of approximately 30 m^3 and 20 m^3 on each side of a masonry wall on the ground floor. On the first floor there are two box shaped rooms of approximately 50 m^3. The floor between the ground and first floors is a timber joist floor. BRE intends to conduct a round robin series of measurements in B68A to examine the spread of results from measurements of airborne and impact sound insulation of the walls and floors in the building. It is intended that at least one pair of rooms will have a feature intended to make knowledge of the guidance in ISO 140-14 relevant for measurements of airborne sound insulation.

The round robin is being organised with the help of NHBC Acoustics Services and a series of measurements has been proposed. Currently, UKAS accredited testers are primarily interested in taking part in the measurements but an invitation to other organisations involved in testing will be made at the Institute of Acoustics Spring Conference in April 2008.

The round robin programme of sound insulation measurements conducted at BRE will enable reproducibility to be quantified. Additionally, if sufficient numbers of ANC registered testers and UKAS accredited testers take part, there is an opportunity to determine whether there is any significant difference between the values produced by those conducting pre-completion tests in England and Wales registered under the ANC scheme and those with UKAS accreditation.

Conclusion and recommendations

This research programme is intended to determine whether recommendations to amend the guidance in ISO 140-4 and ISO 140-7 should be made. The research is timely because these standards will be reviewed following the revision of the standards for laboratory measurements of sound insulation. Ambiguities in the standards cited in Approved Document E (2003 Edition) of the Building Regulations have been identified. If applied literally, the guidance for locating the tapping machine for impact sound insulation measurements appears to be incorrect. Therefore, it is concluded that an investigation of the effect of ambiguities and guidance that appears to be inconsistent in ISO 140-4 and ISO 140-7 is justified.

The following test programme will be implemented

- Measurements to investigate the necessity of the guidance related to differences in sound pressure level between adjacent 1/3 octave bands (6 dB requirement).
- Measurements to determine whether placing sound sources in the corners of rooms in the same planes relative to room surfaces for airborne sound insulation measurements affects sound insulation measurement results.
- Measurements to determine whether the guidance for locating sound sources used for airborne sound insulation measurements in rooms is appropriate for both omnidirectional and cabinet loudspeakers.
- Measurements to determine the effect of using the smaller room as the source room for measurements of airborne sound insulation.
- Measurements to assess the effect of dust on floors used for impact sound insulation measurements and to determine whether it should be recommended that ISO 140-7 provide additional guidance for these measurements.
- Measurements to determine whether using the minimum number of tapping machine and microphone positions can produce significantly different values of impact sound pressure level than more positions with one different microphone position for each different tapping machine position.
- Measurements to compare values of airborne sound insulation derived from classical measurements (ISO 140-4) and MLS and SS methods described in ISO 18233.
- Round robin measurements to assess the reproducibility of sound insulation measurements.

References

[1] BS EN ISO 140-4, Acoustics – Measurement of sound insulation in buildings and of building elements – Part 4: Field measurements of airborne sound insulation between rooms, 1998, BSI

[2] BS EN ISO 140-7, Acoustics – Measurement of sound insulation in buildings and of building elements – Part 7: Field measurements of impact sound insulation between of floors, 1998, BSI.

[3] BS EN ISO 140-14, Acoustics – Measurement of sound insulation in buildings and of building elements – Part 14: Guidelines for special situations in the field.

[4] BS EN ISO 18233, Acoustics – Application of new measurement methods in building and room acoustics, 2006, BSI.

Appendix B – Interim report 2; new methods for airborne sound insulation measurements

bre

Comparison of Swept Sine, Maximum Length Sequence and classical airborne sound insulation measurement methods in buildings

Prepared for: NHBC

11 July 2008

Client report number 245876

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Executive Summary

This report is the second interim output from an NHBC sponsored research project concerned with improving sound insulation measurements in homes and other buildings. It contains analysis and results from comparisons of the classical method for measuring airborne sound insulation in buildings with methods designed to facilitate airborne sound insulation measurements where high background noise levels limit the usefulness of the classical method. Classical ISO 140-4 measurement methods were compared with Maximum Length Sequence and Swept Sine measurements described in ISO 18233.

The investigations suggest that:

- the three methods produce results that are insignificantly different where background noise levels are low;
- Swept Sine measurements produced values of airborne sound insulation with high background noise values where Maximum Length Sequence measurements did not;
- the ISO 18233 measurements are unlikely to be widely used for field measurements of airborne sound insulation because;
    - measurement times are significantly longer than with the ISO 140-4 method,
    - the methods require conditions to remain constant for the duration of measurements and this is likely to be difficult to achieve in the field,
    - the instrumentation required for ISO 18233 methods is more complex and less widely used than that used for the ISO 140-4 method;
- the ISO 18233 measurements are more suited to laboratory measurements than field measurements;
- Swept Sine measurements appear to be better suited to the field measurement of airborne sound insulation than Maximum Length Sequence measurements but more investigation is needed.

Contents

Introduction

This report contains the results of comparisons of sound insulation measurements of airborne sound insulation using the classical method, referenced in the Building Regulations of England and Wales, and two new methods that are useful for measuring airborne sound insulation in the presence of high background noise levels. The research programme, of which this report is a part, is described in BRE/NHBC proposal number 07/010, Proposal (amended): improving sound insulation measurements in homes and other buildings.

The performance standards for sound insulation between dwellings in England and Wales are contained in Approved Document E (2003 Edition) of the Building Regulations 2000 (ADE). The regulatory performance standards for airborne sound insulation between new build houses and flats, rooms for residential purposes and dwellings formed by a material change of use are given in terms of the single number quantity $D_{nT,w}+C_{tr}$. $D_{nT,w}$ is the weighted standardized sound level difference and C_{tr} is a correction term that makes the low frequency sound insulation performance of separating walls and floors more significant when it is added to $D_{nT,w}$. Both $D_{nT,w}$ and C_{tr} are defined in ISO 717-1[1].

Annex B of ADE states that measurements to determine $D_{nT,w}+C_{tr}$ must be done in accordance with ISO 140-4[2]. This requires pseudo random sound to be generated in one room, the source room, and the sound pressure level to be measured in this room and in the receive room that is separated from the source room by the wall or a floor of interest. However, where there are high background noise levels in the receive room, high airborne sound insulation between source and receive rooms or both, measurements in accordance with ISO 140-4 can be compromised.

ISO 140-4 states that if measured receive room levels with the sound source operating are less than 10 dB greater than the receive room background noise levels with no sound generated in the source room, then corrections must be made to the measured receive room sound pressure level with the sound source operating. If receive room levels with the sound source operating are within 6 dB of receive room background levels then the limits of measurement have been reached and the measured receive room level is adjusted by 1.3 dB. That is, 1.3 dB is added to the measured sound level difference between source and receive rooms.

Noise from traffic or from activities within buildings can both contribute to high background levels in receive rooms. On new build sites, this can mean that construction or other work in the vicinity of sound insulation measurements to has to be suspended during the measurements. Alternatively, measurements may have to be conducted out of daytime working hours or at night when traffic noise is generally lower than in the daytime. Neither solution is ideal because both have cost implications.

ISO 18233[3] was published in 2006 and describes two measurement procedures that are particularly useful for measuring airborne sound insulation when background noise levels in rooms are high. These are the maximum length sequence (MLS) method and the swept sine (SS). Therefore, it is appropriate that the methods are assessed in terms of their usefulness for field measurement of airborne sound insulation. Both methods have been known for some time but advances in technology and the availability of instrumentation systems with the necessary computational power means that such measurement systems have only recently become more widely available.

The MLS and SS methods for measuring sound insulation use deterministic signals rather than the pseudo random signal in the ISO 140-4 method. The deterministic signals are exactly repeatable and it is this property that enables the suppression of background noise levels. The signal to noise ratio can be increased by increasing the number of measurements and averaging them without the need to increase the sound pressure level of the excitation. As might be expected, this means that the MLS and SS methods require longer measurement times than the ISO 140-4 method.

Long measurements times are not advantageous for site measurements unless work that might have to be stopped for ISO 140-4 measurements can continue whilst ISO18233 measurements are conducted. Therefore, this research investigated the usefulness of the ISO 18233 methods in the presence of high background noise levels.

Description of the project

The main aim of this comparison of the classical method of measuring airborne sound insulation with the new methods described in ISO 18233 was to asses the usefulness of the new methods for measuring airborne sound insulation in the field. Therefore, measurements were conducted between two bedrooms on each side of a masonry separating wall in a row of houses on the BRE site at Garston.

Measurements during normal working hours in the houses had shown that airborne sound insulation was difficult to quantify in many 1/3 octave bands because of high levels of background noise in the receive room. These high background noise levels were due to the proximity of the M1 motorway; hence the rooms offered an excellent opportunity to assess MLS and SS measurements of airborne sound insulation in furnished rooms in real houses with high background noise levels. Both cabinet and omnidirectional loudspeakers were used for the measurements and the same loudspeaker and fixed microphone positions were used for all the measurements. Fixed microphone positions rather than continuously moving microphones were used because the MLS and SS methods cannot be used with moving microphones. However, field measurements with fixed microphone positions are perfectly acceptable. There is guidance in ISO 140-4 for measurements with fixed microphone positions and fixed microphone positions are normally used for BRE's UKAS accredited measurements of field sound insulation.

It was not possible to compare measurement results from the three methods using the houses in the absence of high receive room noise levels during working hours. Therefore, measurements were also carried out between two rooms separated by a timber floor in the BRE vertical transmission suite where background noise levels are very low. This allowed comparison of the three measurement methods in the absence of high background noise levels and with different types and levels of steady background noise generated in the receive room during measurements. Pink noise and sound from the standard tapping machine placed on a layer of resilient foam on a section of wood based board were generated in the receive room for the measurements with high background noise levels using MLS measurements. With the SS measurements, music with a regular pounding base beat was also used to produce background noise in the receive room.

The ISO 140-4, ISO 18233 (MLS) and ISO 18233 (SS) measurements in the BRE vertical laboratory were conducted using two timber floors constructed with metal web joists. Floor 1 was used for the MLS measurements and Floor 2 used for the SS measurements. These floors varied only slightly in the configuration of the metal web and measurements in accordance with ISO 140-3 had shown that the weighted sound reduction index (R_w) for both floors to be approximately 40 dB.

Although the MLS and SS methods suppress the effects of high background noise levels, the higher the noise levels are, the longer the measurements take because the number of averages required to suppress the effects of background noise increases. Therefore, measurements were conducted to quantify the difference between different numbers of averages with the MLS measurement system.

This exercise is relevant to this research because normally when sound insulation is measured on site, the time period for measurements is limited. Therefore, it is useful to know whether there is any advantage to be derived from increasing the number of averages and, hence, the measurement time. Because of the time taken to complete a full airborne sound insulation test with different numbers of averages (5 fixed microphone positions for each of two loudspeaker positions), the sound level differences between just two fixed microphone positions were used for this exercise. Unfortunately, this exercise could not be repeated with the SS measurement system because it was available only for a limited period of time.

The laboratory measurements are useful because, here, background noise levels are very low and this allowed comparison of ISO 140-4 and ISO 18233 measurement results in a controlled environment.

Findings

Sound insulation measurements between houses

The measured single number quantities for airborne sound insulation between two bedrooms in adjacent terraced houses at the BRE site, Garston are given in Table 4. The measurements with the two different types of loudspeaker were conducted on different days and the ISO 140-4 measurements with the two different types of loudspeaker used were conducted by different pairs of testers. It can be seen that the $D_{nT,w}+C_{tr}$ values derived using the MLS and SS methods are between 1 dB and 4 dB greater than those derived from the classical ISO 140-4 method. Table 4 also shows that the $D_{nT,w}+C_{tr}$ values derived using the dodecahedron loudspeaker are between 1 dB and 2 dB greater than those measured using the same method with the cabinet loudspeaker. The airborne sound insulation versus 1/3 octave band frequency curves are shown in Figure 2 and Figure 3.

Table 4: single number quantities for airborne sound insulation using classical, MLS and SS methods with two different loudspeakers

Cabinet loudspeaker			**Dodecahedron loudspeaker**		
$D_{nT,w}$ (C,C_{tr}) (dB)			**$D_{nT,w}$ (C,C_{tr}) (dB)**		
ISO 140-4	ISO 18233 (MLS)	ISO 18233 (SS)	ISO 140-4	ISO 18233 (MLS)	ISO 18233 (SS)
60 (-2:-8)	61 (-2:-8)	62 (-2;-8)	61 (-3;-8)	62 (-2;-7)	63 (-2;-7)
$D_{nT,w}+C_{tr}$ (dB)			**$D_{nT,w}+C_{tr}$ (dB)**		
ISO 140-4	ISO 18233 (MLS)	ISO 18233 (SS)	ISO 140-4	ISO 18233 (MLS)	ISO 18233 (SS)
52	53	54	53	55	56

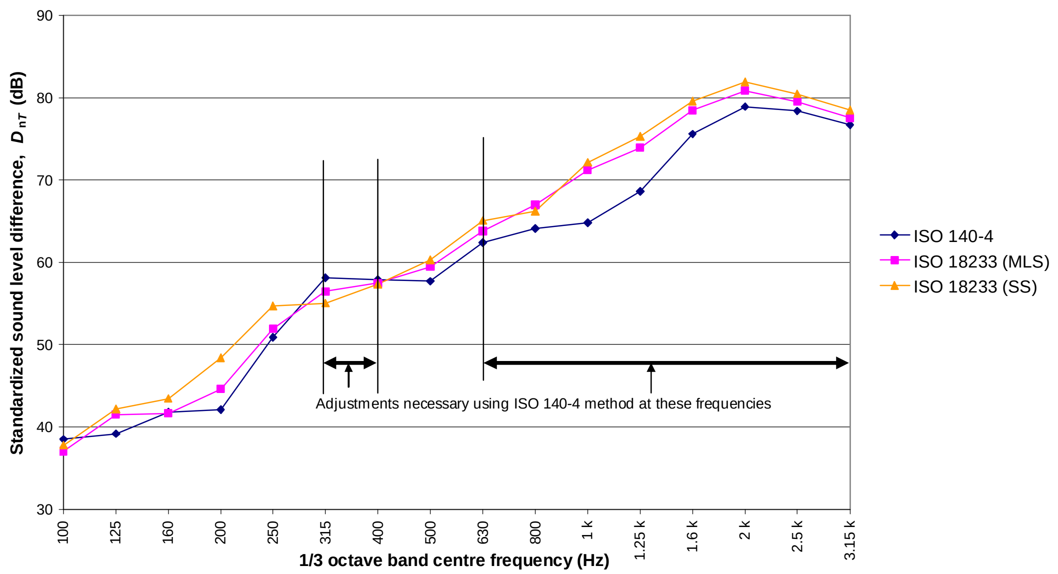

Figure 2: comparison of classical, MLS and SS sound insulation results with cabinet loudspeaker

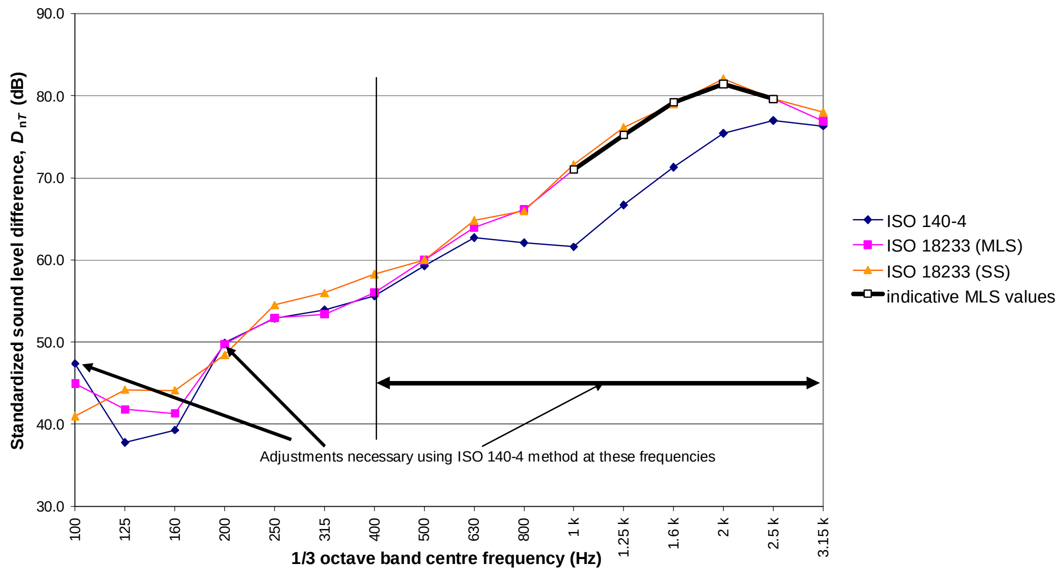

Figure 3: comparison of classical, MLS and SS sound insulation results with dodecahedron loudspeaker

The 1/3 octave band frequencies at which receive room levels were within 10 dB of background levels when the ISO 140-4 measurements were conducted are indicated on Figure 2 and Figure 3. With the cabinet loudspeaker, the measured transmitted sound levels were so close to background levels that sound insulation could not be quantified properly using the classical method. Instead, the measured sound level difference between the two rooms was increased by, the maximum, 1.3 dB in the 1/3 octave bands 400 Hz and 800 Hz – 3,150 Hz. With the dodecahedron loudspeaker, the maximum adjustment was needed in the 500 Hz – 3,150 Hz 1/3 octave bands.

Figure 3 shows indicative values over part of the sound insulation versus frequency curve derived from the MLS measurement. These are called “indicative” because it was not possible to achieve the desired signal to noise ratio of 10 dB in all 1/3 octave bands for all microphone positions. However, from measurements where the signal to noise criterion was achieved it was possible to derive indicative values. It can be seen that these values lie very close to the curve produced from the SS measurements.

The effect of increasing the number of averages used to determine the difference between source and receive room levels is shown in Table 5. Here, and in the rest of this report, L_S is the sound pressure level in the source room and L_R the level in the receive room.

Table 5: measured sound level differences between source and receive rooms in the houses with 1 and 5 averages

No. averages	1 average	5 averages
Frequency Hz	L_S - L_R dB	L_S - L_R dB
100	44.7	44.7
125	41.8	41.8
160	40.9	40.8
200	42.5	42.4
250	48.0	47.9
315	56.2	56.3
400	57.9	57.9
500	61.6	61.6
630	64.5	64.5
800	67.7	67.9
1000	69.8	70.2
1250	72.2	72.4
1600	76.8	76.9
2000	80.4	80.5
2500	80.1	80.2
3150	78.7	78.7

Sound insulation measurements in the laboratory

ISO140-4 and ISO 18233 (MLS) measurements

The measured standardised sound level differences versus 1/3 octave band frequency for Floor 1 using ISO 140-4 and ISO 18233 (MLS) measurements in the absence of significant background noise are shown in graphical form in Figure 4.

It can be seen that there is good agreement between the values produced by the two methods in the frequency range 100 Hz – 3,150 Hz, used to determine the single number quantity $D_{nT,w}+C_{tr}$, and that the two curves are indistinguishable above the 500 Hz 1/3 octave frequency band. For both methods the single number quantities were identical being $D_{nT,w}(C;C_{tr})$ = 40(-2;-6) dB.

Figure 5 shows the high levels of background noise levels generated in the receive room using pink noise and the standard tapping machine, placed on a resilient foam layer. The measured D_{nT} values using the ISO 140-4 and MLS methods with pink noise and the tapping machine to generate background noise are illustrated in Figure 6 and Figure 7 respectively. These figures show that the measured sound insulation of the floor using the ISO 140-4 method was substantially lower than that measured in the absence of significant background noise and that MLS measurements did not produce sound insulation values in 1/3 octave bands higher than 315 Hz.

The effects of increasing the number of averages on the measured difference in sound pressure levels in the source and receive rooms with MLS with A-weighted receive room background noise levels of 16 dB, 38 dB and 77 dB are shown in Table 6, Table 7 and Table 8. The measured source and receive room sound pressure levels with five different levels of background noise are shown in the tables in Appendix A. Tables 3 to 5 show that where the receive room signal to noise ratio exceeds 10 dB there is little advantage derived from increasing the number of averages. With the highest levels of background noise used for the measurements, where it was possible to measure source and receive room levels, even when the receive room signal to noise ration was significantly less that 10 dB there was little significant difference in the values of sound level difference between source and receive rooms.

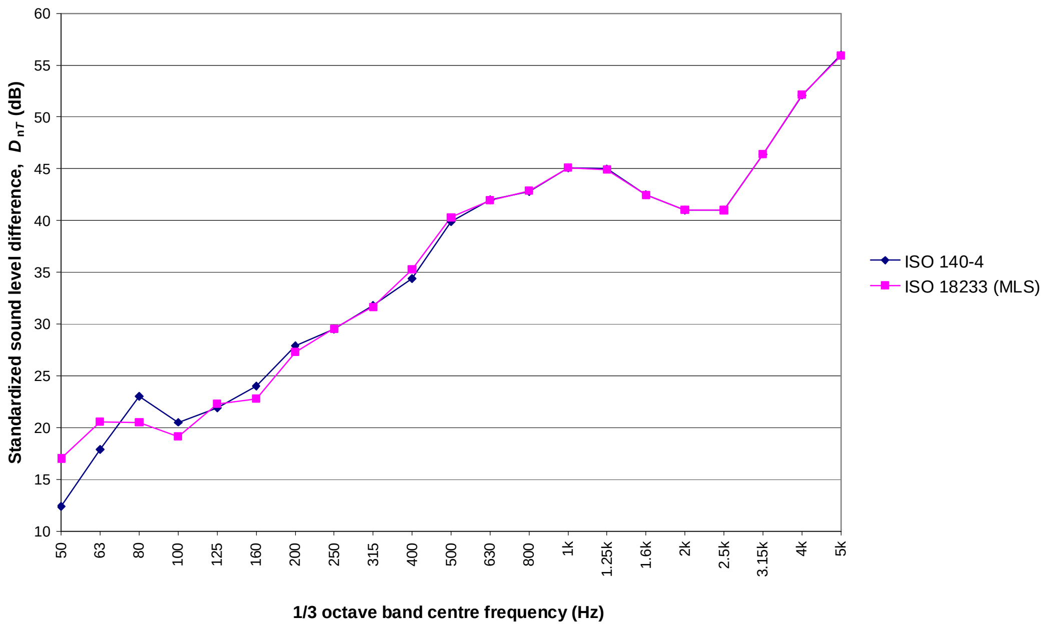

Figure 4 : measured D_{nT} versus 1/3 octave band frequency using ISO 140-4 and ISO 18233 (MLS) measurement methods with low background noise levels in the receive room

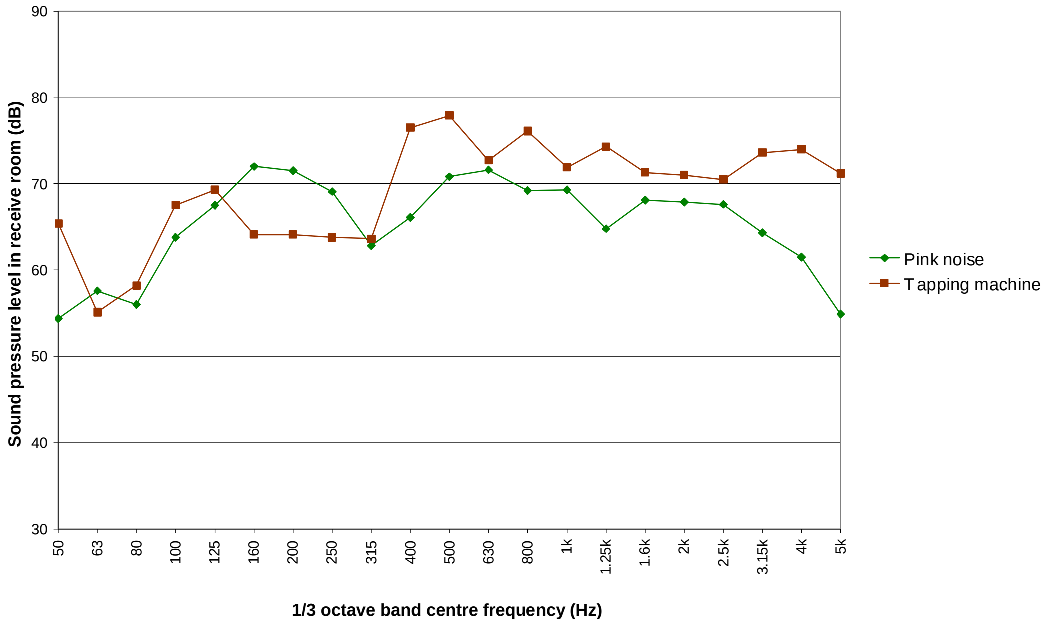

Figure 5 background noise levels generated in receive room for ISO 140-4 and ISO 18233 (MLS) measurements

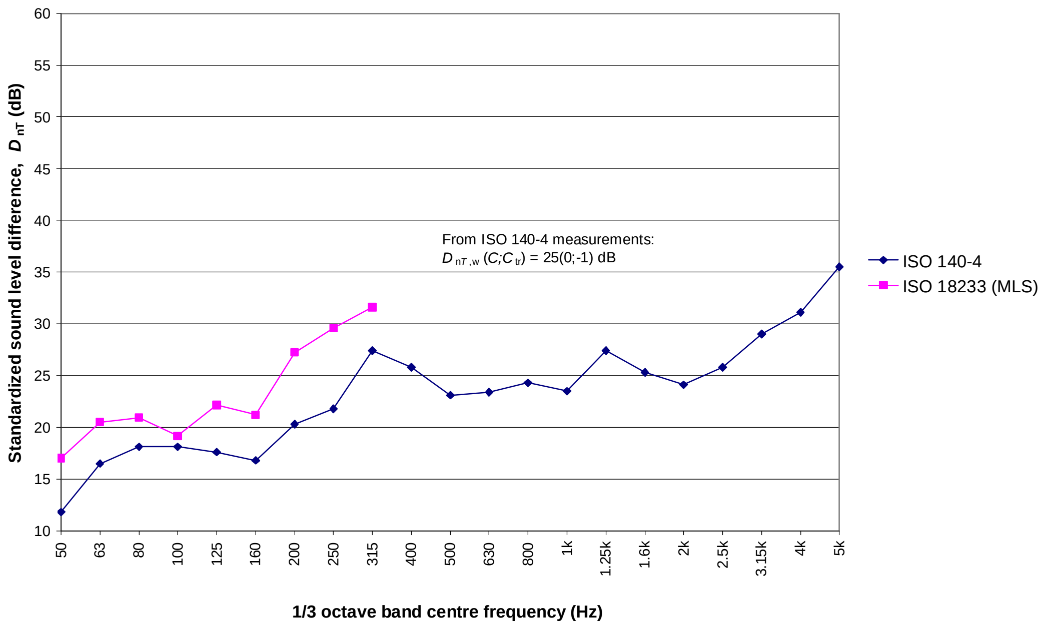

Figure 6: 18233 (MLS) and140-4 measurement results with pink noise generated in receive room

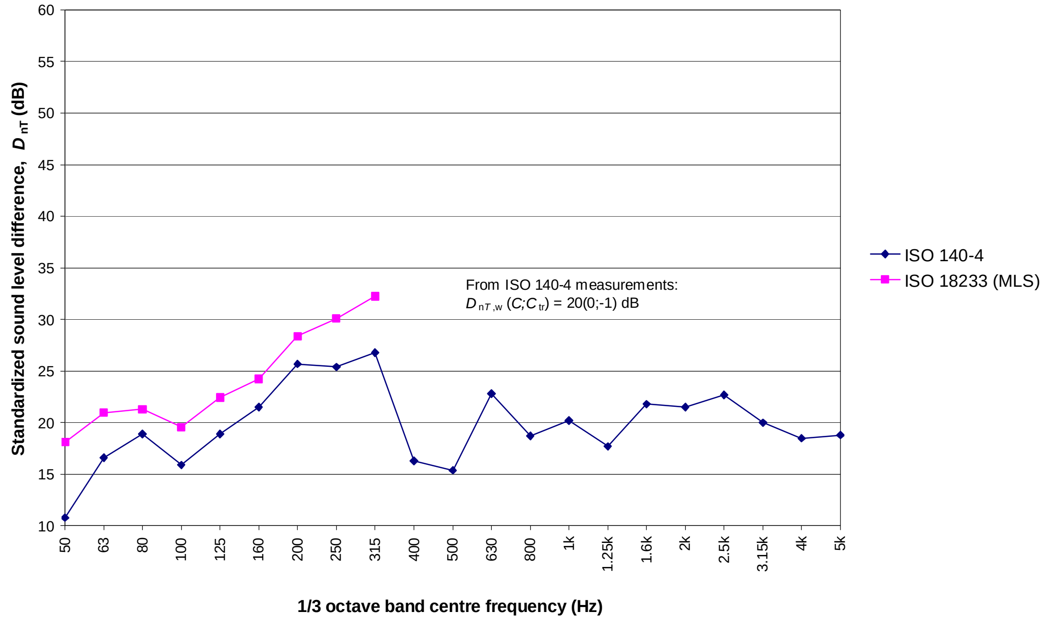

Figure 7: 18233 (MLS) and140-4 measurement results with tapping machine generated noise in receive room

Table 6: measured sound level difference (L_S-L_R), Signal/Noise ratio (S/N) and time taken for measurements with background noise level of 16 dBA

No. averages (time)		1 (55 s)		5 (90 s)		10 (130 s)		20 (205 s)	
Frequency Hz	Background noise level dB	L_S - L_R dB	S/N dB	L_S - L_R dB	S/N dB	L_S - L_R dB	S/N dB	L_S - L_R dB	S/N dB
100	6.8	13.2	37.5	13.1	37.6	13.1	37.6	13.1	37.6
125	-2.7	18.9	35.9	18.8	36.0	18.8	36.0	18.9	35.9
160	-1.4	23.5	33.6	23.4	33.8	23.4	33.9	23.4	34.1
200	11.7	23.6	30.8	23.7	30.8	23.7	30.8	23.7	30.8
250	-2	19.3	34.3	19.3	34.5	19.2	34.5	19.3	34.8
315	2.9	26.6	37.5	26.5	38.0	26.6	38.1	26.6	38.1
400	9.7	27.3	41.7	27.3	42.1	27.3	42.1	27.3	42.1
500	6.4	34.8	39.6	34.9	40.0	34.8	40.1	34.9	40.1
630	-0.2	34.9	39.7	34.8	40.4	34.9	40.5	34.9	40.6
800	1	37.1	38.0	37.1	38.8	37.1	38.9	37.0	38.9
1000	5.1	39.7	35.8	39.6	36.7	39.6	36.8	39.6	37.0
1250	0.7	39.3	38.4	39.3	39.4	39.3	39.5	39.2	39.7
1600	1.4	35.6	38.1	35.6	30.4	35.6	39.4	35.7	39.7
2000	2.1	33.8	37.5	33.8	30.4	33.8	39.0	33.8	39.3
2500	2.7	36.5	37.0	36.5	28.6	36.5	38.5	36.5	38.7
3150	3.2	43.4	31.6	43.4	26	43.3	33.6	43.4	33.9

Table 7: measured sound level difference (L_S-L_R), Signal/Noise ratio (S/N) and time taken for measurements background noise level of 38 dBA

No. averages (time)		1 (55 s)		5 (90 s)		10 (130 s)		20 (205 s)	
Frequency Hz	Background noise level dB	L_S - L_R dB	S/N dB	L_S - L_R dB	S/N dB	L_S - L_R dB	S/N dB	L_S - L_R dB	S/N dB
100	29.9	13.2	37.0	13.1	37.6	13.1	37.6	13.1	37.6
125	27.7	18.9	35.0	18.9	35.7	18.9	35.7	18.9	35.9
160	36.8	23.1	30.6	23.2	33.3	23.0	33.8	23.0	33.9
200	27.2	23.8	29.1	23.8	30.4	23.8	30.6	23.8	30.7
250	30.5	19.4	33.9	19.4	34.9	19.4	35.1	19.4	35.0
315	25.9	26.9	32.6	26.9	35.7	26.9	36.5	26.9	36.8
400	29.5	27.4	29.6	27.3	35.1	27.4	37.6	27.4	39.5
500	28.2	35.0	23.3	34.9	29.6	35.0	31.9	35.0	34.4
630	27.4	35.1	21.0	34.9	28.2	35.0	31.2	34.9	33.3
800	29.9	37.2	21.9	37.2	28.6	37.1	31.5	37.2	33.6
1000	26.3	39.7	19.3	39.6	25.2	39.7	27.9	39.6	30.5
1250	24.6	39.4	24.7	39.4	31.2	39.4	33.4	39.3	35.6
1600	26.2	35.6	24.3	35.6	30.4	35.7	32.9	35.6	35.2
2000	24.2	33.8	23.9	33.8	30.4	33.8	33.1	33.8	35.1
2500	22.5	36.5	21.9	36.5	28.6	36.6	31.5	36.6	33.6
3150	21.3	43.3	19.8	43.4	26.0	43.3	28.3	43.3	30.6

Table 8 : measured sound level difference (LS-LR), Signal/Noise ratio (S/N) and time taken for measurements background noise level of 77 dBA

No. averages (time)		1 (55 s)		5 (90 s)		10 (130 s)		20 (205 s)	
Frequency Hz	Background noise level dB	L_S - L_R dB	S/N dB	L_S - L_R dB	S/N dB	L_S - L_R dB	S/N dB	L_S - L_R dB	S/N dB
100	61.7	13.2	23.7	13.1	29.8	13.1	33.2	13	34.3
125	63.3	18.9	17.2	19.1	23.3	19.1	25.8	19.1	28.4
160	70.8	23.2	7.7	22.7	15.3	22.8	17.9	22.7	20.4
200	71.3	23.4	8.4	23.8	14.8	23.7	18.4	23.8	20.7
250	66.9	19.6	18	19.5	23.8	19.5	26.4	19.5	28.5
315	64.8	26.7	10.2	26.7	16.8	26.8	18.8	26.8	20.9
400	69.2	26.8	5.3	27.4	12.1	27.6	14.3	27.4	17.1
500	69.7	?	?	35.3	3.2	35.8	8.5	35.4	10.8
630	70.1	?	?	?	?	34.7	5.6	34.8	9.7
800	66.7	?	?	37.3	4.1	37.3	6.2	37.2	9.7
1000	66.1	?	?	?	?	?	?	39.6	4.7
1250	62.9	?	?	39.6	7.2	39.4	9.9	39.3	12
1600	65.6	?	?	35.7	6	35.8	9.4	35.7	12.4
2000	66.7	?	?	33.7	7.3	33.7	8.5	33.8	11.7
2500	66.2	?	?	36.4	4.6	36.5	7.7	36.4	10.5
3150	62.1	?	?	?	?	?	?	43.3	6.7

ISO140-4 and ISO 18233 (SS) measurements

The SS measurements were carried out on Floor number 2. Figure 8 shows that with this floor, the SS measurements gave lower values of D_{nT} than the ISO 140-4 measurements in the 1/3 octave bands with frequencies greater than 250 Hz except for the 2,500 Hz band. The single number quantity $D_{nT,w}$ calculated from the SS measurements was 1 dB lower than with the ISO 140-4 measurements but the single number quantity $D_{nT,w}+C_{tr}$ was 31 dB with both methods.

Figure 9 shows the same data as those shown in Figure 8 with measurement data with high levels of background noise generated in the receive room. The receive room background noise levels were similar to those generated for the MLS measurements but in this case, music with a steady pounding base beat was used in addition to pink noise and the tapping machine as a background noise source. The single number quantities for airborne sound insulation derived from the SS measurements are shown in Table 9.

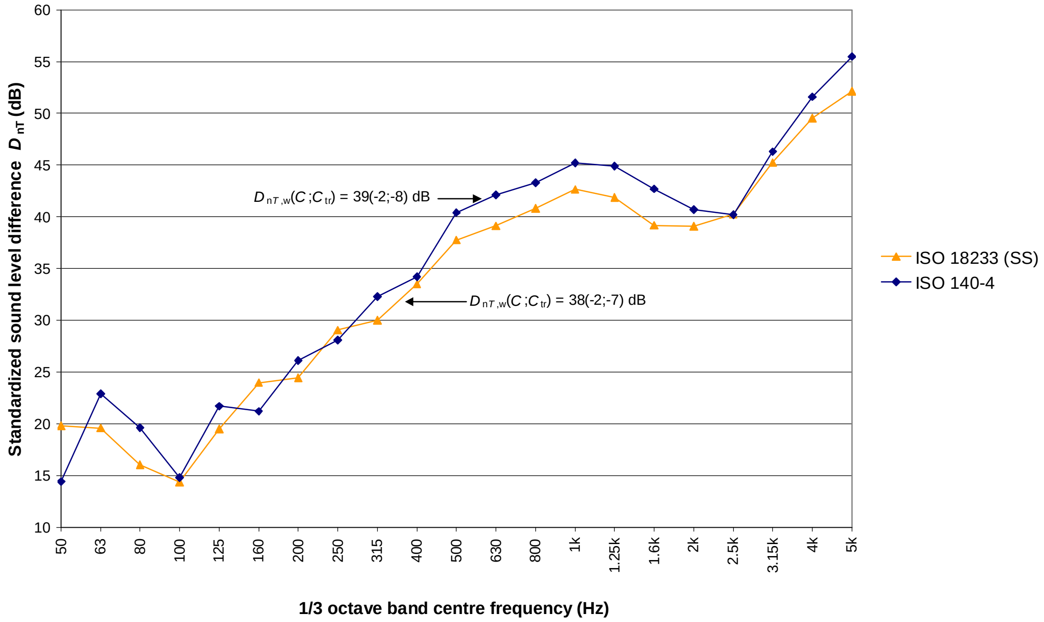

Figure 8: measured D_{nT} versus 1/3 octave band frequency using ISO 140-4 and ISO 18233 (SS) measurement methods with low background noise levels in the receive room

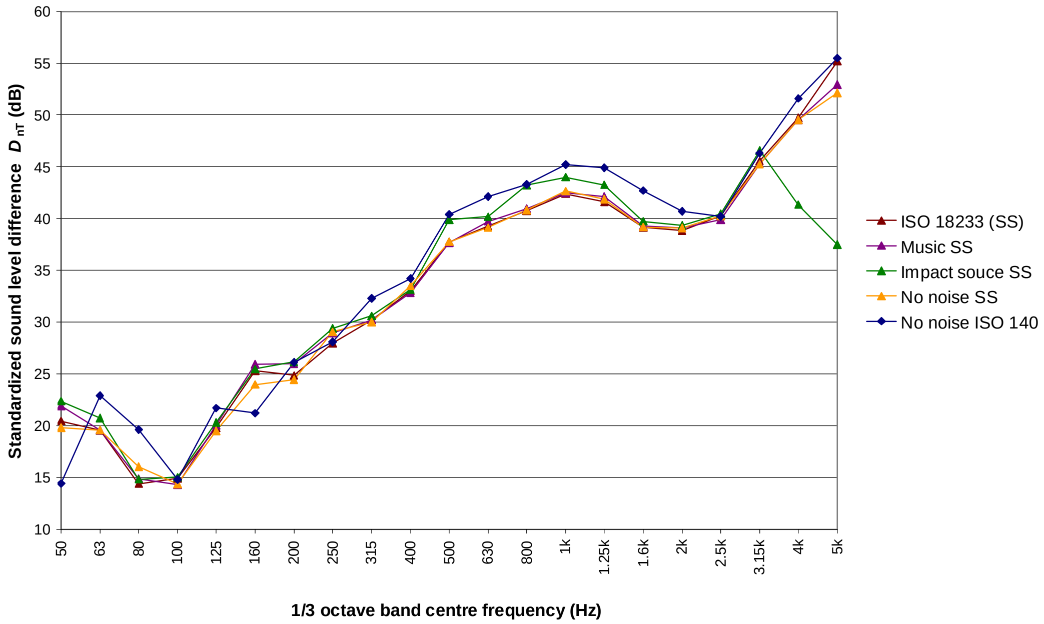

Figure 9: comparison of measured D_{nT} values with and without different types of noise in the receive room

Table 9: $D_{nT,w}+C_{tr}$ values with different sources of background noise in the receive room

Background noise source	**$D_{nT,w}(C;C_{tr})$ dB**
None	38 (-2;-7)
Pink noise	38 (-2;-7)
Music	38 (-2;-7)
Tapping machine	38 (-1;-6)

Discussion

Figure 2 and Figure 3 show that measured airborne sound insulation using the MLS and SS methods are generally greater than those derived from the ISO 140-4 measurements in the frequency ranges significantly affected by receive room background noise levels. It is not surprising that the measured values of sound insulation in the mid to high frequency ranges should be higher with the ISO 18233 methods because these suppress the effect of background noise. Clearly, if the sound pressure level in the source room in a 1/3 octave band is 90 dB, even if the wall between them reduces the transmitted level by 60 dB in the same frequency band, it is not possible to measure a sound level difference with the classical method greater than 50 dB if the background level in the receive room is 40 dB.

Table 4 shows that $D_{nT,w}$ values from the ISO 18233 methods range from 61 dB to 63 dB and that $D_{nT,w}+C_{tr}$ values range from 53 dB to 56 dB. However, $D_{nT,w}$ is determined by shifting a reference curve in steps of 1 dB towards the measured D_{nT} versus frequency curve so a difference in $D_{nT,w}$ of 2 dB from measurements on different days conducted by different testers is not significant. Rather, a range of measurement results of this order might be expected from consideration of previous work conducted by ANC (Association of Noise Consultants) members[4] in a masonry building which showed a 3 dB range in $D_{nT,w}$ values as did an earlier investigation by Lang[5]. Therefore, from the number of measurements made, it cannot be concluded that there is a significant difference between the MLS and SS measurements or between results from the two loudspeakers used. However, as would be expected, Figure 2 and Figure 3 indicate that the MLS and SS methods produce higher values of sound insulation where ISO 140-4 measurements are significantly affected by receive room background noise levels.

The comparison of the results from ISO 140-4 and ISO 18233 methods shown in Figure 4 and Figure 8 show that closer correlation was achieved between MLS and ISO 140-4 methods than between the SS and ISO 140-4 methods. However, there was no significant difference between the single number quantities produced by the ISO 140-4 and ISO 18233 methods. Indeed $D_{nT,w}+C_{tr}$ values produced by the different methods on each floor were identical. The SS method did produce values for sound insulation in the presence of high background noise levels where the MLS method did not. In addition, the SS technique produced identical $D_{nT,w}$ values with and without high background noise levels. This suggests that, for measurements in the presence of particularly high background levels, the SS technique may be better than MLS; particularly if the time available for measurement is limited.

A disadvantage with using both MLS and SS measurements for field sound insulation measurements is that they are more time consuming than the classical method. The measurement results in Table 6, Table 7, Table 8 and the tables in Appendix A show that the time taken to measure a sound level difference between one set of fixed microphone positions varied depending on the number of averages used. To measure airborne sound insulation between rooms, at least five measured level differences are required for each of at least two loudspeaker positions. A minimum of ten measurements when one loudspeaker is used. Even if only one average were used, this means a total measurement time of over nine minutes to measure sound level differences. In addition to this time, there is the time to move microphones and loudspeakers and the time to measure reverberation times in receive rooms. The minimum time specified in

ISO 140-4 for measurements to measure source and receive room levels in the 100 Hz – 3,150 Hz frequency range is six seconds.

The number of averages required when using the ISO 18233 methods depends on receive room background levels although the level differences using MLS in Table 6 and Table 7 show that the measured differences in source and receive room levels using just one or twenty averages is never more than 0.2 dB even with a background noise level of 38 dBA. Table 8 shows that in high levels of background noise, the number of averages and the time taken to measure airborne sound insulation using MLS must be increased.

For these laboratory measurements, background was generated using pink noise. In the houses on the BRE site, the dominant source of background noise was traffic on the nearby M1 motorway. The measured source-receive room sound pressure level differences in Table 5 show that here too there was no significant advantage in using five averages rather than just one.

There is another disadvantage inherent in the MLS and SS measurements. Because these measurements use deterministic signals that are exactly repeatable, conditions in both source and receive rooms must remain unchanged during the measurements[6,7]. Therefore moving microphone measurement techniques cannot be used and differences in temperature and humidity and air movement that result in changes of the speed of sound in the air can all have a detrimental effect on MLS and SS measurements. Currently there is little available information on the effects of changes in atmospheric conditions on SS measurements although it appears that these are less sensitive to changes than MLS measurements[3].

The SS measurement system was provided free of charge by Campbell Associates for a limited period of time. This meant that there was insufficient time to investigate the effects of increasing measurement times as had been done with the MLS technique.

Conclusions

The measurements conducted suggest that, in the absence of significant receive room background noise levels, the ISO 140-4 and MLS methods for measuring airborne sound insulation produce results that are indistinguishable from each other. In the mid to high frequency building acoustics frequency range there was a greater difference between results from the ISO 140-4 and SS measurement methods but these two methods still produced identical values of $D_{nT,w}+C_{tr}$.

The MLS and SS measurement methods take significantly more time than ISO 140-4 measurements and require equipment that is more expensive and less commonly used than that used for ISO 140-4 measurements. Therefore, use of the ISO 18233 methods is unlikely to be widely used in the field.

The ISO 18233 methods might offer advantages if noisy work could be continued adjacent to rooms where airborne sound insulation is being measured. However, the deterministic nature of the signals used with the techniques means that conditions in both source and receive rooms would have to remain constant for what could be long periods of time to conduct the measurements. This is unlikely to occur on site and the ISO 18233 methods are likely to be more useful for laboratory measurements of high values of airborne sound insulation where conditions are more controlled.

The measurements conducted suggest that SS measurements are better suited to field measurement of airborne sound insulation than MLS measurements but further investigation of this is required.

Acknowledgement

BRE are grateful to Campbell Associates for the loan of their Swept Sine sound airborne sound insulation measurement system for this research.

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Appendix B

Effect of increasing the number of averages for MLS measurements on measured sound pressure level values with different receive room background noise levels

	Background	age (55 seconds)			5 averages (1 min 30 secs)			10 averages (2 mins 10 secs)			20 averages (3 mins 25 secs)		
Frequency	level	Source	Receive	S/N	Source	Receive	S/N	Source	Receive	S/N	Source	Receive	S/N
Hz	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB
50	7.6	80.3	71.3	39.7	80.3	71.3	39.7	80.2	71.3	39.8	80.2	71.2	39.8
63	6.7	83.2	67.3	35.9	83.2	67.2	36	83.1	67.2	36.1	83.1	67.1	36.1
80	-0.2	80.5	69.2	37.1	80.5	69.2	37.2	80.5	69.1	37.2	80.4	69.1	37.3
100	6.8	90.5	77.3	37.5	90.4	77.3	37.6	90.4	77.3	37.6	90.4	77.3	37.6
125	-2.7	90.8	71.9	35.9	90.7	71.9	36	90.7	71.9	36	90.7	71.8	35.9
160	-1.4	92.5	69	33.6	92.4	69	33.8	92.4	69	33.9	92.4	69	34.1
200	11.7	93.5	69.9	30.8	93.5	69.8	30.8	93.5	69.8	30.8	93.5	69.8	30.8
250	-2	95.1	75.8	34.3	95.1	75.8	34.5	95	75.8	34.5	95	75.7	34.8
315	2.9	93.6	67	37.5	93.5	67	38	93.5	66.9	38.1	93.5	66.9	38.1
400	9.7	92.9	65.6	41.7	92.8	65.5	42.1	92.8	65.5	42.1	92.8	65.5	42.1
500	6.4	94.5	59.7	39.6	94.5	59.6	40	94.4	59.6	40.1	94.4	59.5	40.1
630	-0.2	93.6	58.7	39.7	93.5	58.7	40.4	93.5	58.6	40.5	93.5	58.6	40.6
800	1	93.3	56.2	38	93.3	56.2	38.8	93.3	56.2	38.9	93.2	56.2	38.9
1000	5.1	91.9	52.2	35.8	91.8	52.2	36.7	91.8	52.2	36.8	91.8	52.2	37
1250	0.7	93.5	54.2	38.4	93.5	54.2	39.4	93.5	54.2	39.5	93.4	54.2	39.7
1600	1.4	92.1	56.5	38.1	92.1	56.5	39.2	92.1	56.5	39.4	92.1	56.4	39.7
2000	2.1	91.1	57.3	37.5	91.1	57.3	38.8	91.1	57.3	39	91	57.2	39.3
2500	2.7	90.9	54.4	37	90.8	54.4	38.3	90.8	54.3	38.5	90.7	54.2	38.7
3150	3.2	91.1	47.7	31.6	91.1	47.7	33.5	91	47.7	33.6	91	47.6	33.9
4000	3.7	89.3	41	24	89.3	41	25.6	89.2	40.9	25.9	89.1	40.8	26.2
5000	4.1	87.8	35	17	87.8	35	18.4	87.8	35	18.8	87.7	34.9	19.1

	Background	1 average (0 min 55 s)			5 averages (1 min 30 s)			10 averages (2 min 10 s)			20 averages (3 min 25 s)		
Frequency	level	Source	Receive	S/N	Source	Receive	S/N	Source	Receive	S/N	Source	Receive	S/N
Hz	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB
50	22.2	80.2	71.3	39.8	80.2	71.2	40	80.1	71.2	40	80.1	71.2	40
63	11.1	83.2	67.2	36	83.2	67.1	36.2	83.2	67.1	36.1	83.2	67.1	36.2
80	27.7	80.5	69.2	36.9	80.5	69.1	37.2	80.5	69.1	37.2	80.4	69.1	37.3
100	29.9	90.5	77.3	37	90.4	77.3	37.6	90.4	77.3	37.6	90.4	77.3	37.6
125	27.7	90.8	71.9	35	90.7	71.8	35.7	90.7	71.8	35.7	90.7	71.8	35.9
160	36.8	92.5	69.4	30.6	92.5	69.3	33.3	92.4	69.4	33.8	92.4	69.4	33.9
200	27.2	93.5	69.7	29.1	93.5	69.7	30.4	93.5	69.7	30.6	93.5	69.7	30.7
250	30.5	95.1	75.7	33.9	95.1	75.7	34.9	95	75.6	35.1	95	75.6	35
315	25.9	93.6	66.7	32.6	93.5	66.6	35.7	93.5	66.6	36.5	93.5	66.6	36.8
400	29.5	92.9	65.5	29.6	92.8	65.5	35.1	92.8	65.4	37.6	92.8	65.4	39.5
500	28.2	94.5	59.5	23.3	94.4	59.5	29.6	94.4	59.4	31.9	94.4	59.4	34.4
630	27.4	93.6	58.5	21	93.5	58.6	28.2	93.5	58.5	31.2	93.4	58.5	33.3
800	29.9	93.3	56.1	21.9	93.3	56.1	28.6	93.2	56.1	31.5	93.2	56	33.6
1000	26.3	91.9	52.2	19.3	91.8	52.2	25.2	91.8	52.1	27.9	91.8	52.2	30.5
1250	24.6	93.5	54.1	24.7	93.5	54.1	31.2	93.5	54.1	33.4	93.4	54.1	35.6
1600	26.2	92.1	56.5	24.3	92.1	56.5	30.4	92.1	56.4	32.9	92	56.4	35.2
2000	24.2	91.1	57.3	23.9	91.1	57.3	30.4	91.1	57.3	33.1	91	57.2	35.1
2500	22.5	90.8	54.3	21.9	90.8	54.3	28.6	90.8	54.2	31.5	90.7	54.1	33.6
3150	21.3	91	47.7	19.8	91.1	47.7	26	91	47.7	28.3	90.9	47.6	30.6
4000	20.8	89.3	41	15.9	89.2	41	21.1	89.2	40.9	22.8	89.1	40.8	24.2
5000	21.1	87.8	35	14.3	87.8	35	17.7	87.8	35	18.4	87.7	34.9	19.1

	Background	1 average (0 min 55 s)			5 averages (1 min 30 s)			10 averages (2 min 10 s)			20 averages (3 min 25 s)		
Frequency	level	Source	Receive	S/N	Source	Receive	S/N	Source	Receive	S/N	Source	Receive	S/N
Hz	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB
50	28.2	80.2	71.3	39.3	80.2	71.2	39.8	80.1	71.2	39.8	80.1	71.2	39.7
63	33.4	83.3	67.1	35	83.2	67.1	36.1	83.2	67.1	36	83.2	67.1	36.2
80	36.9	80.5	69.1	35	80.5	69.1	36.3	80.5	69.1	36.7	80.4	69.1	36.7
100	45.5	90.4	77.4	35.4	90.4	77.3	37.1	90.4	77.3	37.1	90.4	77.3	37.4
125	47.4	90.8	71.9	31	90.7	71.8	34.5	90.7	71.8	34.9	90.7	71.8	35.4
160	55.1	92.5	69.4	22.6	92.4	69.4	28.3	92.4	69.4	30.7	92.4	69.4	32.1
200	54.9	93.6	69.7	22.9	93.5	69.7	27.4	93.5	69.7	28.7	93.5	69.7	29.9
250	50.8	95.1	75.7	30.8	95	75.6	33.7	95	75.6	34.3	95	75.6	34.6
315	48.3	93.5	66.7	24.6	93.5	66.6	30.7	93.5	66.6	32.5	93.5	66.6	33.9
400	52.8	92.8	65.4	20.2	92.8	65.4	26.2	92.8	65.4	29.4	92.8	65.3	32.2
500	53.9	94.5	59.3	14.3	94.4	59.4	19.5	94.4	59.4	22.7	94.4	59.3	25.7
630	53.8	93.5	58.7	13	93.5	58.5	18.5	93.4	58.6	21.2	93.4	58.6	24.3
800	50.6	93.3	56.1	13.1	93.3	56	19.7	93.2	56.1	21.6	93.2	56	24.7
1000	49.8	91.8	52.2	8.9	91.8	52.2	16.2	91.8	52.1	19	91.7	52.1	21.5
1250	46.5	93.5	54.1	16	93.5	54.1	21.9	93.5	54.1	24.6	93.4	54	27.5
1600	49.3	92.1	56.4	15.4	92.1	56.4	21.4	92.1	56.4	24.1	92	56.4	26.8
2000	50.6	91.1	57.3	15.1	91.1	57.3	21.1	91.1	57.2	23.8	91	57.2	26.7
2500	50.2	90.8	54.3	13.1	90.8	54.2	19.3	90.7	54.2	21.8	90.7	54.1	24.7
3150	46	91	47.6	10.3	91	47.7	17.3	91	47.7	19.8	90.9	47.6	22.5
4000	43.5	89.3	40.9	5.5	89.2	41	13.2	89.2	40.9	15.8	89.1	40.8	18.2
5000	38.1	87.8	35	6.1	87.8	34.9	12.7	87.8	34.9	15.2	87.7	34.9	16.9

	Background	1 average (0 min 55 s)			5 averages (1 min 30 s)			10 averages (2 min 10 s)			20 averages (3 min 25 s)		
Frequency	level	Source	Receive	S/N	Source	Receive	S/N	Source	Receive	S/N	Source	Receive	S/N
Hz	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB
50	36	80.2	71.3	38.7	80.2	71.2	39.6	80.1	71.2	39.4	80.2	71.4	39.9
63	39.8	83.2	67.2	31.5	83.2	67.2	34.8	83.2	67.1	35.6	83.2	67.1	36.3
80	44.1	80.5	69.2	32	80.4	69.1	35.3	80.4	69.1	36.4	80.4	69	36
100	51.6	90.4	77.3	32	90.4	77.3	34.8	90.4	77.3	36.6	90.3	77.3	36.8
125	54.2	90.8	71.9	26.3	90.7	71.9	31.3	90.7	71.8	32.6	90.7	71.6	33.6
160	61.9	92.5	69.5	16.5	92.4	69.4	22.5	92.4	69.4	26.1	92.4	69.6	27.5
200	61.2	93.5	69.7	17.5	93.5	69.7	22.6	93.5	69.7	26.2	93.5	69.8	27.7
250	57.7	95.1	75.7	25.6	95	75.6	31.1	95	75.6	32.4	95	75.5	33.5
315	55.4	93.6	66.7	18.7	93.5	66.6	25	93.5	66.6	27.4	93.5	66.6	29.1
400	59.7	92.8	65.5	13.9	92.8	65.3	19.9	92.8	65.4	22.7	92.7	65.3	25.2
500	60.4	94.5	59.3	4.4	94.4	59.3	14.3	94.4	59.2	16.8	94.3	59.3	18.9
630	60.7	93.5	58.9	6.4	93.5	58.5	12.6	93.4	58.5	15.4	93.4	58.4	17.5
800	57.1	93.3	56	4.3	93.2	56.1	13	93.2	56	16.1	93.2	56	17.8
1000	56.4	91.8	"-"	0.0?	91.8	52.2	9.4	91.8	52.2	12.4	91.7	52	14.6
1250	53.3	93.5	54.1	9.1	93.5	54	15.9	93.4	54	18.5	93.4	54	20
1600	56	92.1	56.5	8.7	92.1	56.4	15.7	92.1	56.4	18.2	92	56.3	20.1
2000	57.4	91.1	57.3	8	91.1	57.2	15.3	91	57.2	17.8	91	57.2	19.9
2500	57	90.8	54.2	6.6	90.7	54.2	13.6	90.7	54.2	16	90.6	54.1	18.5
3150	52.8	91	"-"	0.0?	91	47.6	10.8	91	47.6	13.9	90.9	47.5	16
4000	50.2	89.3	"-"	0.0?	89.2	40.9	7	89.2	40.9	9.7	89.1	40.8	11.9
5000	44.6	87.8	"-"	0.0?	87.8	34.9	6.6	87.8	34.9	9.5	87.7	34.8	11.7

	Background	1 average (0 min 55 s)				5 averages (1 min 30 s)				10 averages (2 min 10 s)				20 averages (3 min 25 s)			
Frequency	level	Source	Receive		S/N	Source	Receive		S/N	Source	Receive		S/N	Source	Receive		S/N
Hz	dB	dB	dB		dB	dB	dB		dB	dB	dB		dB	dB	dB		dB
50	22.2	80.2	71.4	8.8	39.8	80.2	71.4	8.8	40	80.2	71.4	8.8	40	80.1	71.4	8.7	39.3
63	11.1	83.3	67.2	16.1	36	83.2	67.2	16	36.2	83.2	67.1	16.1	36.1	83.2	67.1	16.1	34.7
80	27.7	80.5	69.1	11.4	36.9	80.5	69.1	11.4	37.2	80.4	69.1	11.3	37.2	80.4	69.1	11.3	34.5
100	29.9	90.4	77.2	13.2	37	90.4	77.3	13.1	37.6	90.4	77.3	13.1	37.6	90.3	77.3	13	34.3
125	27.7	90.7	71.8	18.9	35	90.7	71.6	19.1	35.7	90.7	71.6	19.1	35.7	90.7	71.6	19.1	28.4
160	36.8	92.5	69.3	23.2	30.6	92.4	69.7	22.7	33.3	92.4	69.6	22.8	33.8	92.4	69.7	22.7	20.4
200	27.2	93.5	70.1	23.4	29.1	93.5	69.7	23.8	30.4	93.5	69.8	23.7	30.6	93.5	69.7	23.8	20.7
250	30.5	95.1	75.5	19.6	33.9	95	75.5	19.5	34.9	95	75.5	19.5	35.1	95	75.5	19.5	28.5
315	25.9	93.5	66.8	26.7	32.6	93.5	66.8	26.7	35.7	93.5	66.7	26.8	36.5	93.5	66.7	26.8	20.9
400	29.5	92.8	66	26.8	29.6	92.8	65.4	27.4	35.1	92.8	65.2	27.6	37.6	92.7	65.3	27.4	17.1
500	28.2	94.4	?	?	23.3	94.4	59.1	35.3	29.6	94.4	58.6	35.8	31.9	94.4	59	35.4	10.8
630	27.4	93.5	?	?	21	93.4	?	?	28.2	93.4	58.7	34.7	31.2	93.4	58.6	34.8	9.7
800	29.9	93.3	?	?	21.9	93.2	55.9	37.3	28.6	93.2	55.9	37.3	31.5	93.2	56	37.2	9.7
1000	26.3	91.8	?	?	19.3	91.8	?	?	25.2	91.7	?	?	27.9	91.7	52.1	39.6	4.7
1250	24.6	93.5	?	?	24.7	93.5	53.9	39.6	31.2	93.4	54	39.4	33.4	93.4	54.1	39.3	12
1600	26.2	92.1	?	?	24.3	92.1	56.4	35.7	30.4	92	56.2	35.8	32.9	92	56.3	35.7	12.4
2000	24.2	91.1	?	?	23.9	91.1	57.4	33.7	30.4	91	57.3	33.7	33.1	91	57.2	33.8	11.7
2500	22.5	90.8	?	?	21.9	90.7	54.3	36.4	28.6	90.7	54.2	36.5	31.5	90.7	54.3	36.4	10.5
3150	21.3	91	?	?	19.8	91	?	?	26	91	?	?	28.3	90.9	47.6	43.3	6.7
4000	20.8	89.3	?	?	15.9	89.2	?	?	21.1	89.2	?	?	22.8	89.1	"-"	?	?
5000	21.1	87.8	?	?	14.3	87.8	?	?	17.7	87.8	?	?	18.4	87.7	35.2	52.5	3.2

Appendix C – Interim report 3; effect of different interpretation of the guidance in ISO 140-3 and ISO 140-7

Interim Report 3: the effect of different interpretations of the guidance in ISO 140-3 and ISO 140-7 on measured sound insulation

Prepared for: NHBC Foundation

3 September 2008

Client report number 245877

1 Interim Report 3: the effect of different interpretations of the guidance in ISO 140-3 and ISO 140-7 on measured sound insulation

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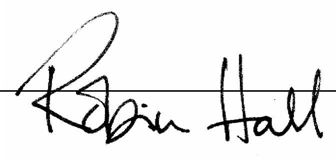

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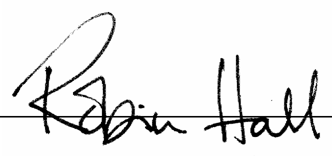

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Executive Summary

This is the third interim report in the NHBC sponsored project named “Improving sound insulation measurements in homes and other buildings”. The project is concerned with the effects that ambiguities in or different interpretations of the standards can have on measured values of airborne and impact sound insulation.

This report contains the results of the measurements designed to investigate aspects of the guidance in the standards that were identified in the first report produced as part of this project. The results presented will be supplemented by those from the round robin measurement of airborne and impact sound insulation that have been conducted by ANC registered and UKAS accredited testers at BRE. The results of the round robin measurements will be the subject of the next interim report scheduled as part of this research.

The findings from the measurements conducted are given below.

No evidence was found that differences in source room sound levels greater than 6 dB affected single number quantities for airborne sound insulation more significantly than the expected variation in field sound insulation measurements due to; normal measurement repeatability and reproducibility and lack of diffusivity in rooms, particularly at low frequencies.

No evidence was found that using a cabinet loudspeaker instead of an omnidirectional dodecahedron loudspeaker or vice versa affected measured sound insulation significantly. Nor was there any evidence that the locations used for the loudspeakers significantly affected measured airborne sound insulation.

No evidence was found that using the minimum number of tapping machine positions or different combinations of microphone measurements and tapping machine positions significantly affected measured impact sound insulation.

Sawdust beneath the tapping machine hammers had a greater effect on the measured impact sound insulation of the concrete floor than the timber floor. Sawdust beneath the hammers significantly reduced the single number quantity for impact sound insulation of the concrete floor. Particular care should be taken to ensure that floors are free of dust and debris when the impact sound insulation of concrete floors or floors with sand cement screeds is measured.

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Contents

Introduction

This report is the third interim report in the NHBC sponsored project “Improving sound insulation measurements in homes and other buildings”. It contains the results of the measurements to determine the effect of different interpretations of the guidance in the measurements specified in Approved Document E for measuring sound insulation in dwellings.

Approved Document E (2003 Edition) (ADE) requires airborne and impact sound insulation in dwellings to be measured as part of a process of pre-completion testing unless Robust Details are used on sites registered with Robust Details Limited. ADE requires the measurements to be conducted in accordance with ISO 140-4[1] (airborne sound insulation) and ISO 140-7[2] (impact sound insulation). These standards have been criticised by acoustics professionals for taking insufficient account of conditions for testing on site. It is felt by some that the guidance is more suited for controlled laboratory conditions and it is widely accepted that some of the guidance in the standards is ambiguous.

Despite criticism of ISO 140-4 and ISO 140-7, the importance of optimizing reproducibility of field measurement results is recognized by acoustics professionals and others with an interest in the built environment. The current version of Approved Document E gives minimum values of airborne sound insulation and maximum values of impact sound insulation between dwellings that must be achieved for compliance with Building Regulations. This, along with credits awarded for sound insulation performance in the Code for sustainable homes (CSH), means that the importance of reliable field sound insulation measurements is greater now than when the 1992 version of ADE was in force. Then, average values of measured sound insulation were used to decide whether performance standards for sound insulation had been achieved. Also failure to meet the performance standards in the 1992 Edition of ADE did not itself mean a failure to comply with the Building Regulations 1991. Under the current ADE, in England and Wales compliance with Building Regulations is considerably less ambiguous. Sound insulation performance has to be demonstrated. If minimum regulatory performance standards are not achieved in buildings they do not comply.

The laboratory standards in the ISO 140 series are currently being reviewed and, when this review is complete, the field standards for sound insulation measurements will be considered. Therefore, a review of the guidance in ISO 140-4 and ISO 140-7 is timely. It is anticipated that results from this research and other work conducted by members of the Association of Noise Consultants (ANC) will be used to inform the review when it takes place.

Efforts to improve the reproducibility of sound insulation measurements in buildings are not new. In the 1970s a working group comprising seven leading UK test organizations devised a test procedure to minimize differences in measurement results from different testers[3]. The new measurement protocol was used by all participants, along with their normal procedures, to measure airborne and impact sound insulation in a building located at the BRE Garston site. The protocol specified the locations of sound sources and six fixed microphones in the rooms. It resulted in slight reductions in the variability of measurements compared with individual testers’ normal methods. However, it was noted that all participants had considerable experience of testing in buildings so dramatic improvements could not reasonably have been expected.

More recent work at BRE investigated field measurements of low frequency airborne sound insulation between rooms[4]. Particular attention was paid to airborne sound insulation in the 50 Hz, 63 Hz and 80 Hz 1/3 octave bands and the $C_{50\text{-}3150}$ and $C_{tr50\text{-}3150}$ single number quantities.

This research is primarily concerned with optimising the reproducibility of the single number quantities used for regulatory purposes. The single number quantities currently used in ADE are derived from measurements in the 1/3 octave frequency bands 100 Hz to 3,150 Hz inclusively. The aspects of the sound insulation measurements to be investigated were identified in the first interim report[5] produced as part of this research and are listed below.

1. Measurements to investigate the necessity of the guidance related to differences in sound pressure level between adjacent 1/3 octave bands (6 dB requirement).
2. Measurements to determine whether placing sound sources in the corners of rooms in the same planes relative to room surfaces for airborne sound insulation measurements affects sound insulation measurement results.
3. Measurements to determine whether the guidance for locating sound sources used for airborne sound insulation measurements in rooms is appropriate for both omnidirectional and cabinet loudspeakers.
4. Measurements to determine the effect of using the smaller room as the source room for measurements of airborne sound insulation.
5. Measurements to assess the effect of dust on floors used for impact sound insulation measurements and to determine whether it should be recommended that ISO 140-7 provide additional guidance for these measurements.
6. Measurements to determine whether using the minimum number of tapping machine and microphone positions can produce significantly different values of impact sound pressure level than more positions with one different microphone position for each different tapping machine position.

- Round robin measurements to assess the reproducibility of sound insulation measurements.

It is anticipated that information from the round robin measurements will provide information on using the smaller of two rooms as the source room when measuring the airborne sound insulation because some testers taking part use hemi-dodecahedron loudspeakers. These are intended to be placed on the floor to generate sound for measurements but it is not advisable to place them on floors whose sound insulation is being measured. Therefore, it is likely that some participants will use the lower room as the source room when measuring the airborne sound insulation of the floor as part of this exercise. The lower room is approximately 20 m^3 smaller than the upper room. Also, the document; Method Statement 1, Spot-check field-testing produced by Robust Details Ltd. (RDL) states that the lower room should be the source room when measuring the airborne sound insulation of floors and RDL testers have taken part in the round robin exercise. Because of this and because it is accepted that using the smaller of two rooms can result in higher measured values of sound insulation than using the larger room as the source room, Point 4 above has not been investigated in the measurement programme discussed here.

Description of the project

The method for measuring airborne sound insulation of walls and floors in buildings is described in ISO 140-4. The method for measuring impact sound insulation of floors is described in ISO 140-7. ISO 140-4 specifies the requirements for the sound field in source rooms (where sound is generated), the method of generating sound and the method of measuring sound pressure level. Similarly, ISO 140-7 specifies the methods for generating and measuring impact sound pressure levels. Therefore, this research is concerned with the effects that ambiguities in the standards or different interpretations of the standards may have on measured values of airborne and impact sound insulation.

Measurements were conducted at the BRE Garston site in building B68A which was used for the round robin measurements that will be the subject of the next interim report and in the BRE vertical transmission suite. Using B68A meant that more measurements could be conducted than would be possible on sites away from BRE with the rooms remaining unaltered throughout the measurement programme. The BRE laboratories were used for some of the measurements in this research project because it meant that the measurements could be conducted in a more closely controlled environment than can be found on site.

Airborne sound insulation

6dB criterion for adjacent 1/3 octave bands

ISO 140-4 requires differences between sound pressure levels in adjacent 1/3 octave frequency bands in source rooms to be ≤ 6 dB and there has been discussion concerning the relevance of this requirement amongst acoustics consultants. Some consider this requirement to be 'left over' from the time when only analogue filters were available for use in equipment used for measuring sound pressure levels. Filters in sound level meters have limited roll-off which means that measured sound pressure levels in a 1/3 octave frequency band can be affected by levels in the adjacent bands if those levels are significantly higher. However, filters in modern equipment have greater roll-off than was available in the past and has been argued that, when using modern equipment, the guidance is not relevant.

To date, the basis of the 6 dB criterion has not been identified. It may be historical and due to the limited roll-off of analogue filters. It could be that differences in adjacent 1/3 octave bands in source rooms greater than 6 dB indicate that a particular room mode or group of modes is being driven harder than others and that this may, in turn, drive resonances that affect measured airborne sound insulation. If this is the case the requirements for the source spectrum in ISO 140-4 can be justified and still have relevance.

A research programme that took place in B68A prior to this research involved making fixed microphone measurements on a virtual three dimensional grid in the source and receive rooms. It was intended to use groups of five measurements in the source room which resulted in the 6 dB criterion being exceeded between adjacent 1/3 octave bands to assess the resultant effect on calculating the single number quantity for airborne sound insulation. However, insufficient groups of measurements with differences greater than 6 dB in adjacent 1/3 octave bands were identified. Therefore, to investigate the effects of not satisfying the 6 dB criterion, measurements were conducted in the BRE laboratories with differences greater than 6 dB deliberately generated.

Measurements of airborne sound insulation were carried out using a substantial timber floor with an independent ceiling installed in the BRE vertical transmission suite. The spectrum in the source room was adjusted to ensure that there were differences between adjacent 1/3 octave bands greater than 6 dB. Measurements were also conducted on a timber floor with a construction similar to that used in internal floors in dwellings and which had much lower airborne sound insulation. With both floors attempts were made to “drive” suspected resonances as hard as possible using the equipment available.

For the measurements on the floors, airborne sound insulation was determined in accordance with the method specified in Annex B of ADE (2003 Edition). The apparent weighted sound reduction index, R'_{w}, values are shown in addition to $D_{nT,w}$ values for the substantial floor. Although significant flanking sound transmission is unlikely in the laboratory (flanking limit 70 dB R_{w}), R'_{w} is used because the measurements were not conducted using the three preferred source positions identified from the laboratory commissioning process. Instead two corner loudspeaker positions were used as might be the case in the field. R' was calculated in accordance with Annex B of ADE (2003 Edition).

Loudspeaker position and type

Annex A of EN ISO 140-4 states that:

1. the distance between different loudspeaker positions shall not be less than 0.7 m;
2. at least two loudspeakers shall be not less than 1.4 m apart;
3. the distance between the sound source and the room boundaries shall be not less than 0.5 m;
4. different loudspeaker positions shall not be located within the same planes parallel to the room boundaries;
5. “it is often of advantage” to use loudspeaker positions in the corners of the source room.

Point 5 above means that where necessary, points 3 and 4 above need not be adhered to. In addition, placing loudspeakers on the floor in corners means that the two positions are in the same plane relative to the floor and ceiling in most rooms. Therefore, measurements to determine whether or not using different loudspeaker positions that complied with the guidance in ISO 140-4 affected measured sound insulation. Loudspeaker positions that were not in accordance with the guidance in ISO 140-4 were also conducted. A cabinet loudspeaker and omnidirectional dodecahedron loudspeaker were used for the measurements.

Figure 15 in Appendix A shows the layout of the rooms used for the measurements. The corners used to reference the loudspeaker positions in the source room are identified as 1 and 2. The separating wall is opposite the wall labelled W. The measurements were conducted using a B&K 4224 cabinet loudspeaker and the locations used for the measurements are identified in Table 18 in Appendix A.

The loudspeaker locations for each measurement are given along with the single number quantities derived. The mean and standard deviations values of the single number quantities are also given.

Impact sound insulation

The standard tapping machine is used for generating impact sound and its requirements are specified in Annex A (normative) of ISO 140-7. The standard states:

1. the tapping machine shall be placed in at least four positions randomly distributed on the floor (to generate impact sound);
2. on floors with joists, the tapping machine should be placed at 45^{o} to the joists;
3. the minimum number of measurements of impact sound pressure level using fixed microphone positions is six, a combination of at least four microphone positions and at least four tapping machine positions shall be used.

The standard gives an example to clarify the guidance in Point 3 above. “For two microphone and two tapping machine positions, make measurements for all possible combinations. For the other two microphone and two tapping machine positions make the measurements on a one to one basis”. To some acoustics professionals, including the author of this report, the example is difficult to understand. The result of the guidance is that if only four tapping machine positions are used to generate impact sound, some tapping machine positions will have more measurements of impact sound pressure level measured than others. Therefore the effect of using the minimum four tapping machine positions was investigated.

ISO 140-7 gives no guidance on the minimum separation of tapping machine positions and the use of the word “randomly” in Point 2 above is unfortunate. “Evenly” or “uniformly” might be better choices because a random distribution might lead to all tapping machine positions being in virtually the same position. Therefore, the effect of locating the groups of tapping machine positions differently was investigated.

Findings

Airborne sound insulation

6 dB criterion

The results of the measurements on the timber joist floor with an independent ceiling are shown in Table 10. Single number quantities and the sum of the unfavourable differences are given. It can be seen that both *R'* and $D_{nT,w}$ are unaffected by differences greater than 6 dB between the 1/3 octave bands listed and the bands adjacent to them. When C_{tr} was added to $D_{nT,w}$ to give the single number quantity used for regulatory purposes in Approved Document E, the mean value for airborne sound insulation was 49.3 dB $D_{nT,w}+C_{tr}$ with a standard deviation in this value of 0.5 dB.

Table 10: comparison of measurement results with and without differences greater than 6 dB in adjacent 1/3 octave bands

Single number quantity	ISO 140-4 measurement	1/3 octave band with level > 6dB greater than in adjacent bands					
		125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	3150 Hz
	(dB)	(dB)	(dB)	(dB)	(dB)	(dB)	(dB)
R'_w	57	57	57	57	57	57	57
C	-3	-3	-3	-3	-3	-3	-3
C_{tr}	-8	-8	-8	-8	-8	-8	-8
$R'_w + C_{tr}$	49	49	49	49	49	49	49
SumUDiff	29	31	31.6	30.7	29.5	31	30.9
$D_{nT,w}$	57	57	57	57	57	57	57
C	-2	-3	-3	-3	-3	-3	-3
C_{tr}	-7	-8	-7	-8	-7	-8	-8
$D_{nT,w} + C_{tr}$	50	49	50	49	50	49	49
SumUDiff	27	29.3	29.6	28.7	27.7	29.4	29.3

The sound reduction index versus 1/3 octave band centre frequency for the floor is shown in Figure 10. Also shown are the source room sound pressure levels generated in the three 1/3 octave bands centred on 160 Hz. Source and receive room sound pressure levels were measured using rotating booms and sound was generated using two loudspeakers and two similar but uncorrelated filtered pink noise sources (filtered so that sound was generated only in the 160 Hz 1/3 octave band).

The values for *R'* in these three bands are compared with those derived from measurements where these bands were unaffected by differences greater than 6 dB in Table 11. There appear to be significant differences between the 125 Hz and 160 Hz 1/3 octave bands with and without the level difference greater than 6 dB but the 200 Hz 1/3 octave band value appeared to be unaffected. It proved impossible to conduct a measurement which resulted in a change in $D_{nT,w}+C_{tr}$ greater than 1 dB. Table 10 shows the changes occurred only in the C_{tr} value when $D_{nT,w}$ was used in its calculation.

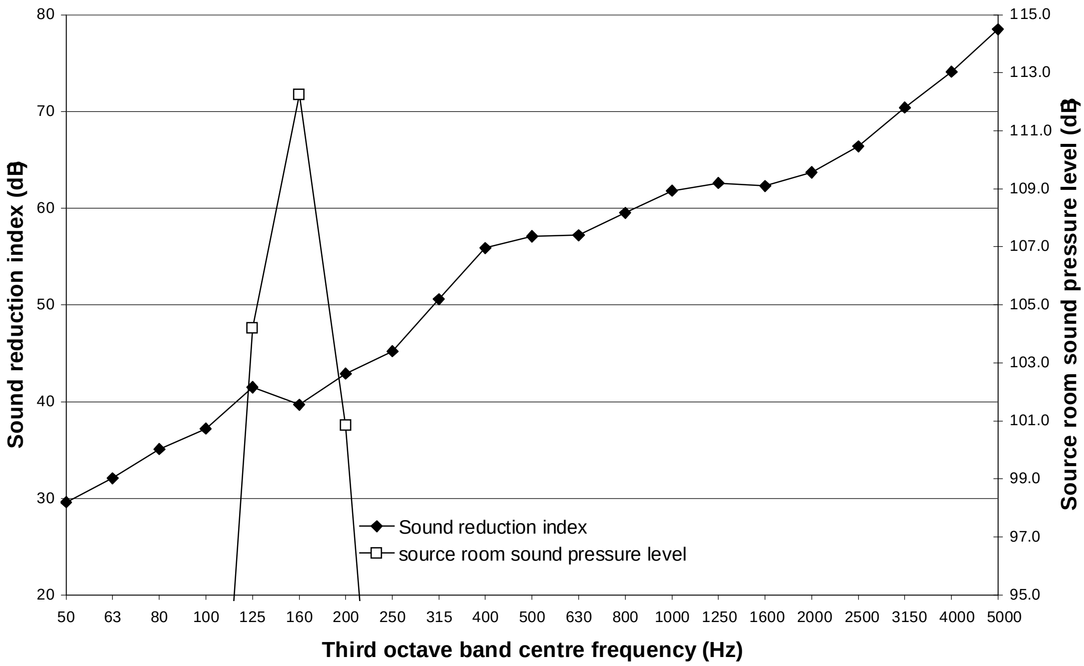

Figure 10: sound reduction index versus 1/3 octave band centre frequency with source room levels generated at a suspected resonance frequency

Table 11: comparison of *R'* in the 125 - 160 Hz 1/3 octave bands with and without differences greater than 6 dB

1/3 octave band centre frequency (Hz)	*R'* (dB)	Results from 4 measurements	
		Mean *R'* (dB)	St. dev. in *R'* (dB)
125	41.1	35.2	0.4
160	40.7	37.4	0.6
200	40.6	41.3	0.4

Table 12: comparison of measurement results with and without differences greater than 6 dB in adjacent 1/3 octave bands (ADE internal type floor)

Type of test	$D_{nT,w}$ (dB)	C (dB)	C_{tr} (dB)	$D_{nT,w}+C_{tr}$ (dB)
ISO 140 test	38	-2	-7	31
>9 dB at 2 kHz	38	-2	-7	31
>6 dB at 100 Hz	38	-2	-7	31
>8 dB at 125 Hz	38	-1	-6	32
>10 dB at 2 kHz	38	-2	-7	31
>10 dB at 100 Hz	38	-2	-6	32
>12 dB at 1.6 kHz	38	-1	6	32
>10 dB at 2.5 kHz	38	-1	6	32
Average	38	-1.6	-6.5	31.5
Std. dev.	0.0	0.5	0.5	0.5

Similar measurements were carried out using a timber floor similar to an internal floor used in dwellings resulted in the single number quantities shown in Table 12. The sound reduction index versus 1/3 octave band centre frequency for the floor is shown in Figure 11. This floor was also driven as hard as possible at 100 Hz and 2000 Hz due to evidence of a resonances in these 1/3 octave bands. The results of these measurements are shown in Table 13. There was no significant difference in the measurement values of airborne sound insulation with or without differences in levels greater than 6 dB.

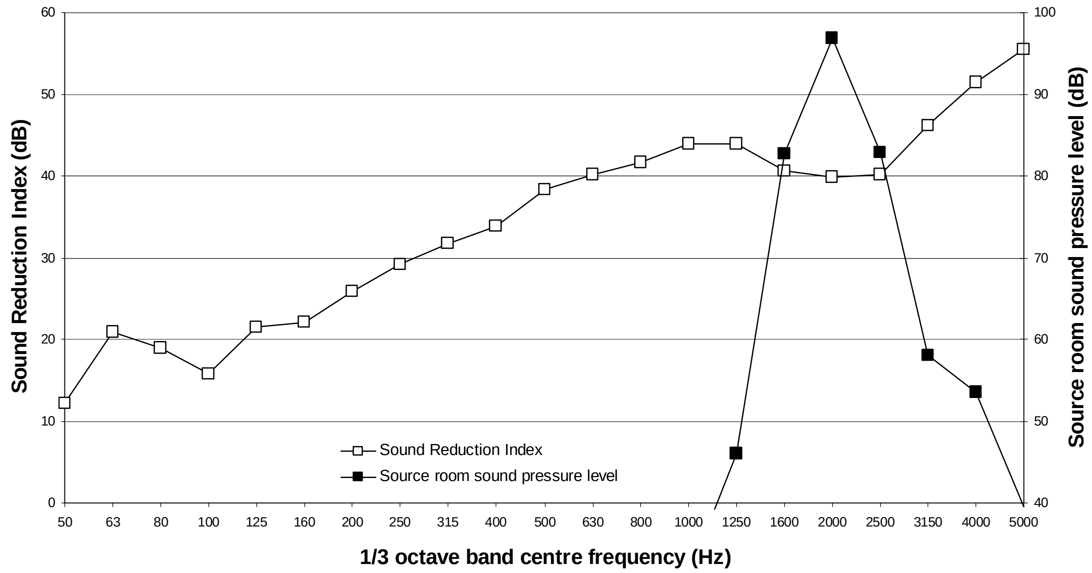

Figure 11; sound reduction index versus 1/3 octave band centre frequency with source room levels generated at 2000 Hz

Table 13: comparison of *R*' in the 80 - 125 Hz and 1,600-2,500 Hz 1/3 octave bands with and without levels differences more than 6 dB greater in the 100 Hz and 2000 Hz bands than in adjacent bands

1/3 octave band frequency (Hz)	*R'* (dB). > 6dB level difference		Average *R'* (dB)	Std deviation in *R'* (dB)	Number of tests
	Test 1	Test 2			
80	17.4	15.7	19.6	0.6	4
100	14.2	13.8	14.6	0.5	
125	21.4	19.6	20.9	1.4	
1600	38.8	38.4	38.9	0.2	5
2000	38.5	38.0	38.4	0.3	
2500	39.2	38.8	39.7	0.4	

loudspeaker positions

Table 14 contains the collated results from the measurements that examined the effect of loudspeaker locations and type on measured airborne sound insulation. Results for loudspeakers in corners, loudspeaker positions that comply with ISO 140-4 but are not in corners and other positions where loudspeaker positions might, for example, be in the same plane relative to the room surfaces (this is contrary to the guidance in ISO 140-4). The loudspeaker locations for each measurement are given along with the single number quantities derived in Table 19, Table 20 and Table 21 of Appendix A.

Table 14: results of measurements with cabinet loudspeaker

	Cabinet loudspeaker in corner					Number of tests
	$D_{nT,w}$ (dB)	C (dB)	C_{tr} (dB)	$D_{nT,w}+C_{tr}$ (dB)	SumUDiff (dB)	
Mean	56.3	-1.3	-4.9	51.3	26.2	24
Std. dev.	0.4	0.5	0.5	0.5	2.6	
Cabinet loudspeaker not in corner						
Mean	56.3	-1.4	-4.9	51.4	27.0	12
Std. dev.	0.5	0.5	0.5	0.5	2.9	
Non-ISO 140-4 compliant loudspeaker positions						
Mean	56.4	-1.3	-4.9	51.6	25.9	7
Std. dev.	0.5	0.5	0.4	0.5	2.6	

The results from the airborne sound insulation measurements with the omnidirectional loudspeakers are given in Table 15. The results for each loudspeaker position are given in Table 22 and Table 23 in Appendix A.

Table 15: results of measurements with omnidirectional loudspeaker

	Dodecahedron in corner					Number of tests
	$D_{nT,w}$ (dB)	C (dB)	C_{tr} (dB)	$D_{nT,w}+C_{tr}$ (dB)	SumUDiff (dB)	
Mean	56.0	-1.7	-5.3	50.8	28.1	24
Std. dev.	0.2	0.5	0.5	0.4	2.1	
Dodecahedron not in corner						
Mean	55.9	-1.8	-5.6	50.3	28.3	34
Std. dev.	0.3	0.4	0.5	0.6	1.8	

Impact sound insulation

The results of the measurements on the timber joist floor that investigated the effect of using the minimum four tapping machine positions and different combinations of pairs of impact sound pressure level measurements to achieve the minimum six measurement positions are shown in Table 16. The table also shows the results with the four tapping machine positions all in corners, the centre of the floor and directly above and in lone with the joists (that is all tapping machine hammers impacting the floor directly above the joists). The results from the first set of tests are illustrated in graphical form in Figure 12.

Table 16: measured normalized impact sound pressure level of a timber joist floor

Test	ISO 140		Corner		Centre		Joists		Sawdust	
	L_{nw} (dB)	C_I (dB)	L_{nw} (dB)	C_I (dB)	L_{nw} (dB)	C_I (dB)	L_{nw} (dB)	C_I (dB)	L_{nw} (dB)	C_I (dB)
1	82	-1	81	0	82	-1	82	-1	81	0
2	81	0	81	-1	82	-1	82	-1	80	0
3	82	-1	81	0	82	-1	82	-1	81	0
4	81	0	81	0	82	0	82	-1	81	-1
5	82	0	81	0	82	-1	82	-1	81	0
6	81	0	81	-1	82	-1	82	0	80	0
7	82	0	81	-1	82	-1	82	-1	81	0
8	81	0	81	0	82	-1	82	-1	81	0
9	82	-1	81	-1	82	0	82	-1	81	0
10	82	-1	81	-1	82	0	82	-1	81	0
Mean	81.6	-0.4	81.0	-0.5	81.8	-0.7	82.0	-0.9	80.8	-0.1
St. dev.	0.5	0.3	0.0	0.5	0.4	0.5	0.0	0.3	0.4	0.3

The results from the same types of tests on a heavyweight concrete floor are given in Table 17 and Figure 13. Figure 14 shows how sawdust was used in the impact sound insulation tests.

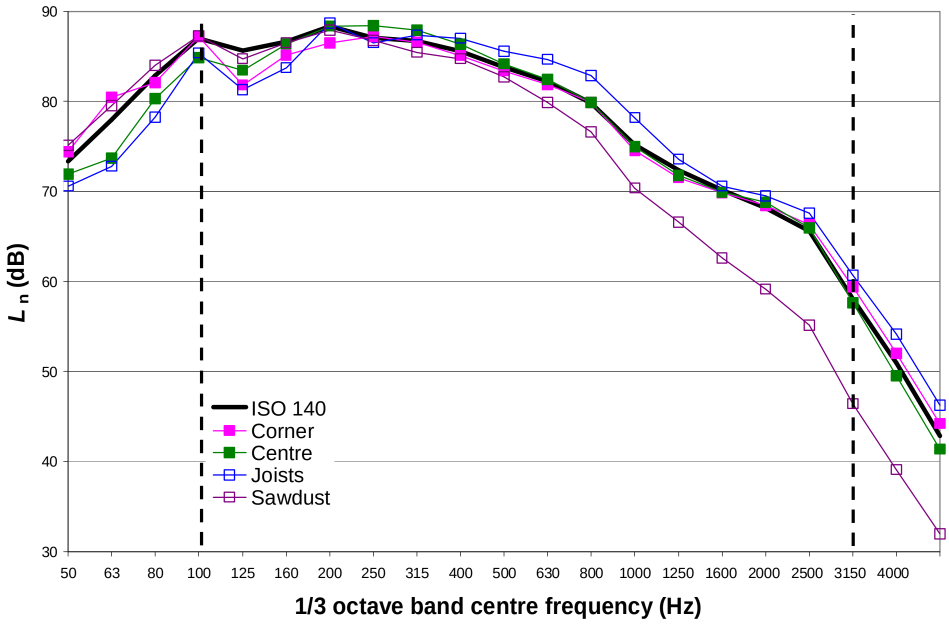

Figure 12: normalized impact sound pressure level versus 1/3 octave band centre frequency of timber joist floor

Table 17: measured normalized impact sound pressure level of a heavyweight concrete floor

Test	ISO 140		Corner		Centre		Sawdust	
	L_{nw} (dB)	C_I (dB)	L_{nw} (dB)	C_I (dB)	L_{nw} (dB)	C_I (dB)	L_{nw} (dB)	C_I (dB)
1	79	-12	79	-12	79	-11	70	-7
2	79	-12	79	-12	79	-12	71	-7
3	79	-12	79	-12	79	-12	71	-7
4	79	-12	79	-12	79	-11	71	-7
5	79	-12	79	-11	79	-11	71	-7
6	79	-12	79	-12	79	-12	71	-7
7	79	-12	79	-12	79	-11	71	-7
8	79	-12	79	-12	79	-11	71	-8
9	79	-12	79	-12	79	-12	71	-7
10	79	-12	79	-12	79	-12	71	-8
Mean	79.0	-12	79.0	-11.9	79.0	-11.5	70.9	-7.2
St. dev.	0.0	0.0	0.0	0.3	0.0	0.5	0.3	0.4

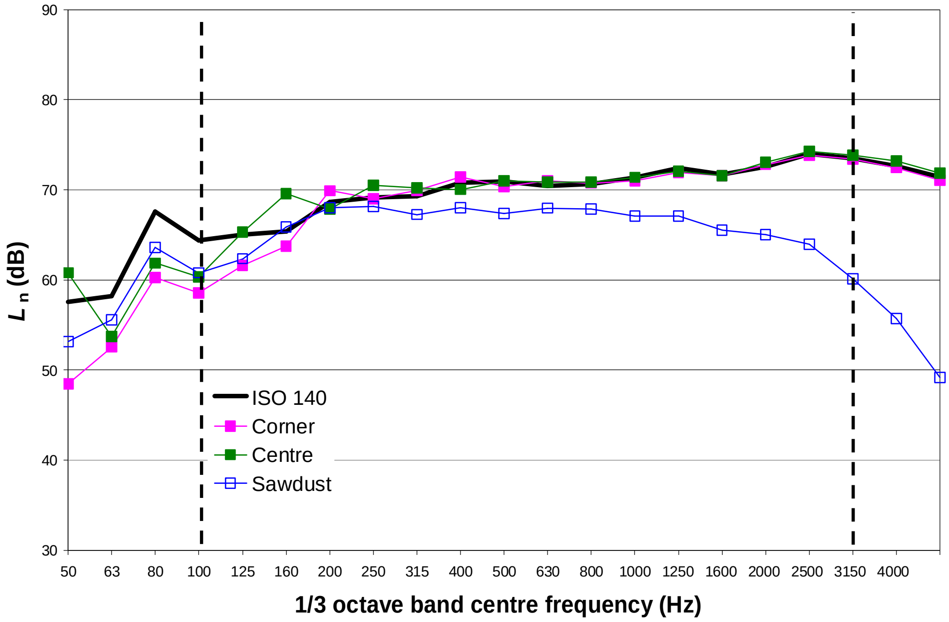

Figure 13: normalized impact sound pressure level versus 1/3 octave band centre frequency of heavyweight concrete floor

Figure 14: sawdust on timber floor for impact sound insulation measurements

Discussion

6 dB criterion

There is evidence to demonstrate that imposing a signal in a frequency band that is more than 6 dB greater than the level in adjacent bands can affect the measured levels in the adjacent bands. However, the measurements conducted as part of this research were intended to investigate the effect of differences greater than 6 dB on measured airborne sound insulation. The measurements conducted produced no evidence that failure to comply with the ISO 140-4 requirement that differences in adjacent 1/3 octave bands in the 100 Hz – 3,150 Hz should be no greater than 6 dB affects the single number quantities derived from measurement data. No differences in R'_{w} or $D_{nT,w}$ were observed and differences in the C_{tr} term did not change by more than 1 dB in the measurements conducted. Hence $D_{nT,w}+ C_{tr}$ and $R'_{w}+ C_{tr}$ did not change by more than 1 dB.

Table 10and Table 12 show that there is no evidence that the value ofC_{tr} is affected by the 6 dB criterion being exceeded at low or high frequencies. Therefore, it is reasonable to conclude that measured differences in C_{tr} are no more likely to be caused by differences greater than 6 dB in adjacent 1/3 octave bands than by other measurement issues (such as; longer sound wavelengths, fewer room modes and a less diffuse sound field in rooms at low frequencies.

Table 11 shows that the measured airborne sound insulation in the 160 Hz 1/3 octave band was more than 3 dB greater when sound was generated only at 160 Hz than when measured using broadband sound. There is no obvious explanation for this. Background noise levels were not high and ISO 140 allows both broadband and individual 1/3 octave band measurements. However, when conducting individual 1/3 octave band measurements it is usual to generate sound in 1/3 octave band and filter the signal from microphones so that a measurement is made only in the same frequency band in which sound is generated. This did not occur here and may be partly responsible for the unexpected difference in measured sound insulation at 160 Hz.

Loudspeaker position and type of loudspeaker

It has been shown that moving the position of loudspeakers by a few centimetres can change source room sound pressure levels by several decibels. ISO 140-3 requires preferred loudspeaker positions to be identified when commissioning laboratories for measuring airborne sound insulation. However, no evidence was produced that differences in loudspeaker position or type affected the measured airborne sound insulation in the 30 m^2 rooms used for this investigation. It should be noted that none of the loudspeaker positions used was in a position that an acoustics professional is unlikely to use. None was more than 0.9 m from a wall and no measurements of sound pressure level were taken at a distance less than 1 m from the loudspeaker.

Impact sound insulation

The measured weighted normalized impact sound pressure level of the timber joist floor was not affected by more than 1 dB by placing the tapping machine in a corner, in the centre of the floor or on top of joists.

Nor was it affected by different combinations of impact sound pressure level measurements and tapping machine positions. Figure 12 shows that significant amounts of sawdust beneath the tapping machine hammers affected the impact sound insulation in the 1/3 octave bands above 500 Hz. However, because impact sound insulation was not significantly affected in the important low frequency region, $L_{n,w}$ was unaffected.

The timber floor used for the impact sound insulation measurements was similar to internal floors in dwellings and had low impact sound insulation. It is accepted that measured sound insulation can be affected by the inappropriate location of the tapping machine. Therefore, although with this floor, no differences related to tapping machine location greater than 1 dB were observed, it would be irresponsible to propose changing the guidance in ISO 140-7 on the basis of these results.

Table 17 shows that the concrete floor was unaffected by different combinations of impact sound pressure level measurements and tapping machine positions and by the location of the tapping machine. For this type of resonantly reacting floor it is not surprising that the position of the tapping machine on the floor is not critical. However, Figure 13 shows that sawdust beneath the tapping machine hammers reduced impact sound insulation significantly above the 250 Hz 1/3 octave band. Table 17 shows that $L_{n,w}$ was reduced by 8 dB by sawdust beneath the tapping machine hammers.

The significant difference in $L_{n,w}$ with the concrete floor is due to the characteristic impact sound transmission of the concrete floor at high frequencies. Comparison of Figure 12 and Figure 13 illustrates the difference in the typical impact sound insulation characteristics of timber floors and concrete floors. With concrete floors, impact sound transmission at high frequencies tends to be similar to or greater than that at low frequencies. With timber floors, impact sound transmission is usually reduces at high frequencies. The shape of the reference curve in ISO 717-2 used to determine $L_{n,w}$ and $L'_{nT,w}$ means that significant impact sound transmission at high frequencies will result in relatively high values for these descriptors. Here, the sawdust beneath the hammers acted like and reduced the power input to the concrete floor at high frequencies and resulted in the significant observed improvement in impact sound insulation.

Conclusions

No evidence was found that differences in source room sound levels greater than 6 dB affected single number quantities for airborne sound insulation more significantly than the expected variation in field sound insulation measurements due to; normal measurement repeatability and reproducibility and lack of diffusivity in rooms, particularly at low frequencies.

No evidence was found that using a cabinet loudspeaker instead of an omnidirectional dodecahedron loudspeaker or vice versa affected measured sound insulation significantly. Nor was there any evidence that the locations used for the loudspeakers significantly affected measured airborne sound insulation.

No evidence was found that using the minimum number of tapping machine positions or different combinations of microphone measurements and tapping machine positions significantly affected measured impact sound insulation.

Sawdust beneath the tapping machine hammers had a greater effect on the measured impact sound insulation of the concrete floor than the timber floor. Sawdust beneath the hammers significantly reduced the single number quantity for impact sound insulation of the concrete floor. Particular care should be taken to ensure that floors are free of dust and debris when the impact sound insulation of concrete floors or floors with sand cement screeds is measured.

References

1 BS EN ISO 140-4, Acoustics – Measurement of sound insulation in buildings and of building elements – Part 4: Field measurements of airborne sound insulation between rooms, 1998, BSI

2 BS EN ISO 140-7, Acoustics – Measurement of sound insulation in buildings and of building elements – Part 7: Field measurements of impact sound insulation between of floors, 1998, BSI

3 L. C. Fothergill, Building Research Establishment, Recommendations for the measurement of sound insulation between dwellings, Applied Acoustics,13, 171-187. (1980)

4 C. Hopkins, P Turner, BRE, Field measurement of airborne sound insulation between rooms with non-diffuse sound fields at low frequencies, Applied Acoustics,66, 1339-1382. (1980)

5 Mlestone 1, BRE report number 241615, Improving sound insulation measurements in homes and other buildings: initial report with review of measurement standards

Appendix C

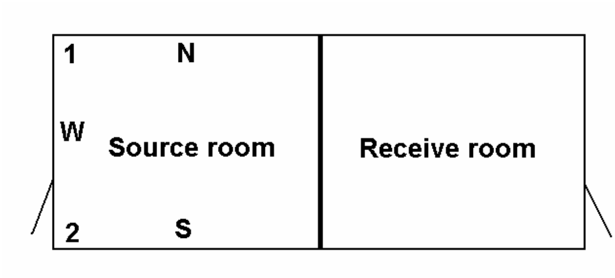

Figure 15: layout of rooms used for measurements

Source room volume = 30 m^3

3.95 m x 3.01 m x 2.49 m

Receive room volume = 27 m^3

3.90 m x 2.74 m x 2.49 m

Plastered solid brick separating wall ≈ 230 mm thick.

Table 18: loudspeaker locations in B68A

Loudspeaker position identifier	Loudspeaker location
1a	On floor facing corner 1, cabinet touching walls
1b	On floor facing corner 2, cabinet touching walls
2a	On floor facing corner 1, cabinet 0.5 m from walls N and W
2b	On floor facing corner 2, cabinet 0.5 m from walls S and W
3a	0.5 m high facing corner 1, cabinet 0.5 m from walls N and W
3b	0.5 m high facing corner 2, cabinet 0.5 m from walls S and W
4a	0.7 m high facing corner 1, cabinet 0.7 m from walls N and W
4b	0.7 m high facing corner 2, cabinet 0.7 m from walls S and W
5a	0.9 m high facing corner 1, cabinet 0.7 m from walls N and W
5b	0.9 m high facing corner 2, cabinet 0.7 m from walls S and W
6a	0.7 m high facing N, 0.5 m from N, 0.5 m from W
6b	0.7 m high facing S, 0.5 m from S, 0.5 m from W
7a	0.7 m high facing N, 0.5 m from N, 0.9 m from W
7b	0.7 m high facing S, 0.5 m from S, 0.9 m from W
8a	0.7 m high facing W, 0.9 m from N, 0.5 m from W
8b	0.7 m high facing W, 0.9 m from S, 0.5 m from W

Table 19: measurement results with cabinet loudspeaker in corners

Loudspeaker positions	$D_{nT,w}$ (dB)	C (dB)	C_{tr} (dB)	$D_{nT,w}+C_{tr}$ (dB)	SumUDiff (dB)
1a+1b	57	-2	-5	52	29.6
1a+2b	57	-2	-5	52	28.3
1a+3b	57	-2	-6	51	29.8
1a+4b	57	-2	-6	51	29.4
1a+5b	56	-1	-5	51	22.1
1b+2a	56	-1	-4	52	24.3
1b+3a	56	-1	-4	52	24.5
1b+4a	56	-1	-4	52	23.6
1b+5a	56	-1	-5	51	26
2a+2b	57	-2	-5	52	32
2a+3b	56	-1	-5	51	24.4
2a+4b	56	-1	-5	51	24.2
2b+3a	56	-1	-4	52	24.4
2b+4a	57	-2	-5	52	31.6
2b+5a	56	-1	-5	51	26.1
3a+3b	56	-1	-5	51	25.1
3a+4b	56	-1	-5	51	24.7
3a+5b	56	-1	-5	51	25.9
3b+4a	56	-1	-5	51	24.2
3b+5a	56	-2	-5	51	26.8
4a+4b	56	-1	-5	51	23.8
4a+5b	56	-1	-5	51	24.9
4b+5a	56	-1	-5	51	24.9
5a+5b	56	-2	-5	51	27.5
Mean	**56.3**	**-1.3**	**-4.9**	**51.3**	**26.2**
Std Deviation	**0.4**	**0.5**	**0.5**	**0.5**	**2.6**

Table 20: measurement results with cabinet loudspeaker and ISO 140-4 compliant loudspeaker positions

Loudspeaker positions	$D_{nT,w}$ (dB)	C (dB)	C_{tr} (dB)	$D_{nT,w}+C_{tr}$ (dB)	SumUDiff (dB)
3a+6b	56	-1	-5	51	24.7
3a+7b	57	-2	-5	52	30.4
3a+8b	56	-1	-5	51	26.5
3b+6a	56	-1	-5	51	24.1
3b+7a	57	-2	-5	52	29.4
3b+8a	56	-1	-4	52	23.5
5a+6b	56	-1	-5	51	26.3
5a+7b	57	-2	-6	51	31.8
5a+8b	56	-2	-5	51	28
5b+6a	56	-1	-5	51	24.9
5b+7a	57	-2	-5	52	30.4
5b+8a	56	-1	-4	52	24.5
Mean	**56.3**	**-1.4**	**-4.9**	**51.4**	**27.0**
Std Deviation	**0.5**	**0.5**	**0.5**	**0.5**	**2.9**

Table 21: measurement results with cabinet loudspeaker and non-ISO 140-4 compliant loudspeaker positions

Loudspeaker positions	$D_{nT,w}$ (dB)	C (dB)	C_{tr} (dB)	$D_{nT,w}+C_{tr}$ (dB)	SumUDiff (dB)
4a+6b	56	-1	-5	51	23.8
4a+7b	57	-2	-5	52	29.3
4a+8b	56	-1	-5	51	25.5
4b+6a	56	-1	-5	51	23.8
4b+7a	57	-2	-5	52	29.1
4b+8a	56	-1	-4	52	23.1
1a+7b	57	-1	-5	52	26.6
Mean	**56.4**	**-1.3**	**-4.9**	**51.6**	**25.9**
Std Deviation	**0.5**	**0.5**	**0.4**	**0.5**	**2.6**

Table 22: measurement results with dodecahedron loudspeaker and ISO 140-4 compliant loudspeaker positions – no corner positions

Loudspeaker positions	$D_{nT,w}$ (dB)	C (dB)	C_{tr} (dB)	$D_{nT,w}+C_{tr}$ (dB)	SumUDiff (dB)
3a+4b	56	-2	-6	50	29.4
3a+5b	56	-2	-6	50	30.8
3a+8b	56	-2	-6	50	30.6
3a+9b	55	-1	-5	50	25.5
3a+10b	56	-2	-6	50	29.7
3a+11b	56	-2	-5	51	29.6
3b+4a	56	-2	-5	51	29
3b+5a	56	-2	-6	50	30.5
3b+8a	56	-2	-6	50	27.5
3b+9a	56	-2	-6	50	30.5
3b+10a	56	-2	-6	50	29.1
3b+11a	56	-2	-5	51	28.5
4a+5b	56	-2	-5	51	28.9
4a+6b	56	-2	-6	50	28.4
4a+7b	56	-2	-5	51	28.8
4a+10b	56	-2	-5	51	27.4
4a+11b	56	-1	-5	51	28
4b+5a	56	-2	-5	51	28.6
4b+6a	56	-2	-6	50	31.8
4b+7a	56	-1	-5	51	27
4b+10a	56	-2	-6	50	27.2
4b+11a	56	-1	-5	51	26.6
6a+8b	55	-2	-6	49	25.2
6a+9b	55	-2	-6	49	27.7
6a+10b	55	-1	-5	50	24.1
6a+11b	56	-2	-6	50	31.8
6b+8a	56	-2	-6	50	26.9
6b+9a	56	-2	-6	50	29.9
6b+10a	56	-2	-6	50	28.5
6b+11a	56	-2	-6	50	27.9
8a+10b	56	-2	-6	50	26.3
8a+11b	56	-1	-5	51	26.2
8b+10a	56	-2	-6	50	28.4
8b+11a	56	-2	-5	51	27
Mean	**55.9**	**-1.8**	**-5.6**	**50.3**	**28.3**
Std Deviation	**0.3**	**0.4**	**0.5**	**0.6**	**1.8**

Table 23: measurement results with dodecahedron loudspeaker in corners - including same height pairs

Loudspeaker positions	$D_{nT,w}$ (dB)	C (dB)	C_{tr} (dB)	$D_{nT,w}+C_{tr}$ (dB)	SumUDiff (dB)
1a+1b	56	-1	-5	51	24.9
1a+2b	57	-2	-6	51	31.6
1a+3b	56	-1	-5	51	25.8
1a+4b	56	-1	-5	51	23.9
1a+5b	56	-1	-5	51	25.6
1b+2a	56	-2	-5	51	26.8
1b+3a	56	-2	-6	50	29.8
1b+4a	56	-2	-5	51	28.2
1b+5a	56	-2	-6	50	29.6
2a+2b	56	-1	-5	51	25.3
2a+3b	56	-2	-5	51	27.6
2a+4b	56	-1	-5	51	25.8
2b+3a	56	-2	-5	51	28.4
2b+4a	56	-1	-5	51	26.7
2b+5a	56	-2	-5	51	28.2
3a+3b	56	-2	-6	50	31.1
3a+4b	56	-2	-6	50	29.4
3a+5b	56	-2	-6	50	30.8
3b+4a	56	-2	-5	51	29
3b+5a	56	-2	-6	50	30.5
4a+4b	56	-2	-5	51	27.2
4a+5b	56	-2	-5	51	28.9
4b+5a	56	-2	-5	51	28.6
5a+5b	56	-2	-5	51	30.3
Mean	**56.0**	**-1.7**	**-5.3**	**50.8**	**28.1**
Std Deviation	**0.2**	**0.5**	**0.5**	**0.4**	**2.1**

Appendix D – Interim report 4; results of round robin measurements at BRE

Results of field sound insulation round robin measurements at BRE

Prepared for: NHBC

23 October 2008

Client report number 245878

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Executive Summary

45 acoustics professionals took part in a round robin series of tests in a building at the BRE Garston site. All were qualified to conduct pre-completion testing to demonstrate compliance with the performance standards for sound insulation between dwellings. Sound insulation was measured between two pairs of rooms separated by a masonry wall and one pair of rooms separated by a timber joist floor. Airborne and impact sound insulation measurements were conducted as appropriate.

The single number quantities for airborne and impact sound insulation, $D_{nT,w}+C_{tr}$ and $L'_{nT,w}$ respectively, are integer numbers. Therefore, the significance of differences in results from the different methods adopted and from UKAS accredited and ANC registered testers was analysed using statistical techniques. Two tailed F-tests and two tailed t-tests were used which assume that the measurement data are normally distributed.

No consistent differences between different techniques were identified although a difference in the average values of $D_{nT,w}+C_{tr}$ (airborne sound insulation) of a masonry wall that was significant at the 5% level was found between ANC and UKAS tests. However this difference in the averages was only 1 dB and the spread of results from the 61 tests on each walls was not greater than 5 dB.

The spread of $D_{nT,w}+C_{tr}$ values from measurements on the timber joist floor was 10 dB and the spread of $L'_{nT,w}$ values was 17 dB. Therefore, confidence in the measured sound insulation values of this floor is lower than those of the walls.

Contents

Introduction

This is the fourth interim report for the NHBC sponsored project “Improving sound insulation measurements in homes and other buildings”. It contains the results of measurements by individuals qualified to undertake pre-completion testing in dwelling to demonstrate compliance with Building Regulations. The main objective of the round robin measurements was to examine the spread of the values of the single number quantities for airborne and impact sound insulation used to describe sound insulation in Approved Document E. Therefore, the following descriptors for sound insulation provided by the participants were examined:

- the weighted standardized level difference ($D_{nT,w}$);
- the correction term C_{tr};
- the weighted standardized impact sound pressure level ($L'_{nT,w}$).

This exercise is important because different approaches to measurements in buildings are “allowed” by the relevant standards and different interpretations of the standards lead to different practices being adopted by those regularly undertaking pre-completion tests.

$D_{nT,w}$ and $L'_{nT,w}$ are derived in accordance with ISO 717-1 and 717-2 respectively by shifting reference curves in relation to the measured D_{nT} and L'_{nT} values, as appropriate, in steps of 1 dB. Therefore, it is generally accepted that the limits of accuracy of $D_{nT,w}$ and $L'_{nT,w}$ values are no better than ± 1 dB.

Previous research at BRE[1] has shown that the numerical spread of results from experienced testers working in the same rooms is not great. Therefore, statistical analysis techniques were used to determine whether different techniques or groups of testers produced significantly different values of sound insulation from others. Comparing results from different the methodologies used by testers is useful because:

- some methods adopted by testers result in measurements being conducted considerably more quickly than others;
- equipment to allow concurrent measurements in two rooms (for airborne sound insulation) is more complex and expensive than that used for subsequent measurements in source and receive rooms.

An investigation into whether techniques requiring more time on site and more expensive equipment are significantly better than quicker measurements with cheaper equipment may help professionals’ approach to pre-completion testing. This, in turn, may result in benefits to industry.

Description of the project

Measurements of airborne and impact sound insulation were conducted in Building 68A, on the BRE Garston site, by representatives of organisations having UKAS accreditation for the tests or being registered under the scheme run by the Registration Committee of the Association of Noise Consultants (ANC). Therefore, all those who took part in the exercise are demonstrably qualified to conduct the pre-completion tests required in Approved Document E (2003 Edition).

The rooms used for the measurements are illustrated in Figure 16.

Room 3 (showing stud partition); volume ≈ 48 m^3

Room 4; volume ≈ 48 m^3

Room 1; volume ≈ 30 m^3

Room 2; volume ≈ 27 m^3

Figure 16: rooms in Building 68A used for the measurements

Airborne sound insulation was measured between rooms 1 and 2 on the ground floor and rooms 3 and 4 on the first floor of Building 68A. These are separated by a 215 mm solid brick wall which is plastered on both sides on the ground floor and fair faced on the first floor. The airborne and impact sound insulation of the timber joist floor between Room 4 on the first and Room 2 on the ground floor were also measured.

45 different companies took part in the tests and each was given access to Building 68A for one day. Some of the participants used the exercise to examine their in-house measurement procedures by having tests done by different members of their team. Where this took place, the measurement data have been treated

as independent data sets. That is, they have been treated in the statistical analysis in the same manner as data from different companies.

All those taking part in the exercise used their own equipment and working practices. In some cases these were practices accredited by UKAS and in others they were practices approved by the ANC Registration Scheme Committee. Individuals who conduct tests for Robust Details Limited undertook additional experiments using diffusers in rooms. Some of those involved in this exercise submitted their results to BRE. These have not been treated as a separate group because there were insufficient results provided to justify it. However, using furniture of building materials to improve diffusivity in rooms is not uncommon so not separating these out is justified.

Results from the following “groups” were examined:

- measurements using moving microphones and fixed microphone positions;
- measurements with rooms occupied and unoccupied;
- the number of tapping machine positions used for the measurement of impact sound insulation;
- using different source rooms, where this is justifiable;
- UKAS accredited testers and testers registered under the ANC Registration Scheme.

The spread of results produced by two different groups, such as moving or fixed microphones, was examined using the two tailed F-test. This tests whether there is a significant difference in the variances of the two sets of results. The results of this analysis enabled a two tailed t-test to be done on the same data to determine whether there is a significant different difference in the means of the two sets of results. This is because the type of t-test that should conducted is affected by whether or not the variances of the two sets of result are significantly different.

All the statistical analysis was conducted using the statistical functions in Microsoft Excel. This means that the analysis assumes that the distribution of the results is a normal distribution; usually represented by the familiar bell-shaped curve centred around the mean value. Since the measurements were made in the same rooms by all those taking part, this approach is justified. There is a precedent for this approach. A two tailed F-test was used to examine the spread of results from different techniques in earlier research at BRE[1] where all the measurements were conducted in the same rooms.

Findings and analysis

The results of the analysis of the measurement results are given are given in the following order:

- airborne sound insulation measurements of the wall between rooms 1 and 2;
- airborne sound insulation measurements of the wall between rooms 3 and 4;
- airborne sound insulation measurements of the floor between rooms 4 and 2;
- impact sound insulation measurements of the floor between rooms 4 and 2.

The results from ANC registered testers using different measurement techniques are given first, then those from UKAS accredited testers. After this the results from the ANC and UKAS testers are compared. Analysis of the results from the different methods adopted by different testers within the ANC and UKAS groups determines whether a direct comparison of the results from these two groups of testers is justified.

Where it is possible and useful, the same analysis has been conducted on measurement results from both ANC and UKAS testers. Sometimes this was not done. For example; only one of the ANC group conducted measurements with both source and receive rooms unoccupied. 13 of the UKAS group conducted the measurements in this manner. Therefore, no sensible comparison of measurement results from the two groups with the rooms unoccupied could be done.

The results of each of the F-tests is given in terms of the two-tailed probability that the variances in the two arrays of interest are not significantly different. The value returned is called the P value. Where the P value is less than 0.05, there is a 95% probability that the two variances are significantly different. In statistical terms; there is a significant difference at the 5% level.

Similarly the t-test returns the P value for the hypothesis that there is no difference in the arithmetic means of the two sets of values being compared. Again, where the P value is less than 0.05, there is a significant difference at the 5% level.

Where the P values for the F-tests and the t-tests identify a significant difference at the 5% level, they are given in Bold type.

Airborne sound insulation

Rooms 1 and 2 ANC

Comparison of the results from the ANC group using fixed and moving microphones is shown in Table 24. Table 25 compares the results of measurements when the source room levels were measured with a person in the source room and receive room levels were measured with the source room unoccupied and receive room occupied. Only two ANC testers did not hold the sound level meter or microphone by hand. Neither table show any significant differences in the variances or the arithmetic means of the single number quantities examined.

Table 24: comparison of results using fixed and moving microphones (ANC rooms 1 and 2)

Measurement method	Fixed	Moving	Fixed	Moving	Fixed	Moving
Single number quantity	$D_{nT,w}+C_{tr}$ dB	$D_{nT,w}+C_{tr}$ dB	C_{tr} dB	C_{tr} dB	$D_{nT,w}$ dB	$D_{nT,w}$ dB
Number of measurements	16	14	16	14	16	14

Average	51.8125	52.14286	-4.750000	-4.35714	56.5625	56.5
Variance	0.5625	0.285714	0.466667	0.247253	0.395833	0.423077
F-test P value	0.227064		0.256929		0.892633	
t-test P value	0.181490		0.086376		0.791264	

Table 25: results from measurements with receive rooms occupied and unoccupied for measurements. Source room occupied for all measurements (ANC rooms 1 and 2)

Both rooms occupied?	Yes	No	Yes	No	Yes	No
Single number quantity	$D_{nT,w}+C_{tr}$ dB	$D_{nT,w}+C_{tr}$ dB	C_{tr} dB	C_{tr} dB	$D_{nT,w}$ dB	$D_{nT,w}$ dB
Number of measurements	12	16	12	16	12	16
Average	52.15385	51.8125	-4.53846	-4.625	56.69231	56.4375
Variance	0.641026	0.295833	0.435897	0.383333	0.397436	0.395833
F-test P value	0.122424		0.791025		0.923208	
t-test P value	0.184595		0.833487		0.232219	

Rooms 1 and 2 UKAS

The results from UKAS testers using fixed and moving microphones are given in Table 26. There is a difference at the 5% level in the variances of the C_{tr} values derived from the fixed and moving microphone methods. However, there was no difference in the mean values from the two types of measurement.

Table 26: comparison of results using fixed and moving microphones (UKAS rooms 1 and 2)

Measurement method	Fixed	Moving	Fixed	Moving	Fixed	Moving
Single number quantity	$D_{nT,w}+C_{tr}$ dB	$D_{nT,w}+C_{tr}$ dB	C_{tr} dB	C_{tr} dB	$D_{nT,w}$ dB	$D_{nT,w}$ dB
Number of measurements	26	5	26	5	26	5
Average	51.38462	51.8	-3.96154	-4.8	56.26923	56.6
Variance	1.126154	0.2	8.918462	0.2	0.604615	0.3
F-test P value	0.104309		**0.002099**		0.522716	
t-test P value	0.401573		0.186042		0.373935	

Table 27 shows the results of the analysis of the results from UKAS testers using fixed and moving microphone methods. Here there is no significant difference at the 5% level in $D_{nT,w}+C_{tr}$ values. Because $D_{nT,w}+C_{tr}$ is of primary importance for comparison with Building Regulations targets, differences in $D_{nT,w}$ and C_{tr} values were not examined separately. Also, some UKAS testers used rotating booms for moving microphone measurements and a significant number of UKAS testers used tripods for fixed microphone positions. Therefore, there is no benefit in making the same comparisons with the UKAS data as were made with the ANC data.

Table 27: results from measurements with receive rooms occupied and unoccupied for measurements. Source room occupied for all measurements (UKAS rooms 1 and 2)

Both rooms occupied?	Yes	No
Single number quantity	$D_{nT,w}+C_{tr}$ dB	$D_{nT,w}+C_{tr}$ dB
Number of measurements	6	10
Average	51.16667	51.8
Variance	2.566667	0.622222
F-test P value	0.063378	
t-test P value	0.303228	

Comparisons between measurements with both source and receive rooms occupied and both rooms unoccupied are shown in Table 28. The data in Table 28 are derived from measurements using fixed and moving microphones.

Table 28: comparison of results in occupied and unoccupied room (UKAS rooms 1 and 2)

Room occupation	Not Occupied	Occupied
Single number quantity	$D_{nT,w}$+C_{tr} dB	$D_{nT,w}$+C_{tr} dB
Number of measurements	13	18
Average	51.38462	51.5
Variance	0.75641	1.205882
F-test P value	0.415738	
t-test P value	0.755841	

Rooms 1 and 2: comparison of UKAS and ANC test results

Table 29 compares the arithmetic means and variances of $D_{nT,w}$+C_{tr}, C_{tr} and $D_{nT,w}$ for the ANC and UKAS testers. Table 30 shows the results of the statistical analysis of the mean and variance values in Table 29. The analysis shows that there is a difference at the 5% level in the average $D_{nT,w}$+C_{tr} values from the ANC and UKAS testers. Also that there is a difference at the 5% level in the variances of the C_{tr} and $D_{nT,w}$+C_{tr} values produced by the two groups.

Table 29: arithmetic mean, standard deviation and variance from UKAS and ANC testers for $D_{nT,w}+C_{tr}$, C_{tr} and $D_{nT,w}$

	UKAS			ANC		
Single number quantity	$D_{nT,w}+C_{tr}$ dB	C_{tr} dB	$D_{nT,w}$ dB	$D_{nT,w}+C_{tr}$ dB	C_{tr} dB	$D_{nT,w}$ dB
Number of measurements	31	31	31	30	30	30
Average	51.45161	-4.09677	56.32258	51.96667	-4.56667	56.53333
Variance	0.989247	7.556989	0.55914	0.447126	0.391954	0.395402

Table 30: P values for comparisons of the ANC and UKAS data (rooms 1 and 2)

Single number quantity	Test	P value
$D_{nT,w}+C_{tr}$ (dB)	F	**0.0353341**
	t	**0.02131062**
C_{tr} (dB)	F	**4.1315E-12**
	t	0.36051983
$D_{nT,w}$ (dB)	F	0.35360769
	t	0.23903759

The maximum $D_{nT,w}+C_{tr}$ value from UKAS testers was 53 dB

The minimum $D_{nT,w}+C_{tr}$ value from UKAS testers was 48 dB

The maximum $D_{nT,w}+C_{tr}$ value from ANC testers was 53 dB

The minimum $D_{nT,w}+C_{tr}$ value from ANC testers was 51 dB

Rooms 3 and 4 ANC

Comparison of the results from the ANC group using fixed and moving microphones is shown inTable 31. Table 32 compares the results of measurements when the source room levels were measured with a person in the source room and receive room levels were measured with the source room unoccupied and receive room occupied. There is no difference at the 5% level between moving and fixed methods of measuring sound pressure level in the rooms nor between results when the occupancy of the source room changed for the receive room measurements.

Table 31: comparison of results using fixed and moving microphones (ANC rooms 3 and 4)

Measurement method	Fixed	Moving	Fixed	Moving
Single number quantity	$D_{nT,w}+C_{tr}$ dB	$D_{nT,w}+C_{tr}$ dB	C_{tr} dB	C_{tr} dB
Number of measurements	16	14	16	14
Average	46.5	46.85714	-5.125	-5.14286
Variance	1.0666667	1.208791	0.25	0.43956
F-test P value	0.8084523		0.294894	
t-test P value	0.3669875		0.93371	

Table 32: results from measurements with receive rooms occupied and unoccupied for measurements. Source room occupied for all measurements (ANC rooms 3 and 4)

Both rooms occupied?	Yes	No	Yes	No
Single number quantity	$D_{nT,w}+C_{tr}$ dB	$D_{nT,w}+C_{tr}$ dB	C_{tr} dB	C_{tr} dB
Number of measurements	13	16	13	16
Average	46.61538	46.8125	-5.15385	-5.125
Variance	1.25641	0.9625	0.307692	0.383333
F-test P value	0.756268		0.724096	
t-test P value	0.563863		0.71863	

Rooms 3 and 4 had insignificantly different dimensions but Room 3 had a partition located halfway between the separating wall and the wall facing it. Some testers used Room 3 as the source room and some Room 4. The results from the two sets are shown in Table 33. There is no difference at the 5% level in results from the two sets of data.

Table 33: results with Room 3 and Room 4 as the source room

Source room	3	4
Single number quantity	$D_{nT,w}+C_{tr}$ dB	$D_{nT,w}+C_{tr}$ dB
Number of measurements	15	15
Average	47.06667	46.26667
Variance	0.495238	1.495238
F-test P value	0.051849	
t-test P value	0.062868	

Rooms 3 and 4 UKAS

Comparison of the results from the ANC group using fixed and moving microphones is shown in Table 34. Table 35 compares the results of measurements when the source room levels were measured with a person in the source room and receive room levels were measured with the source room unoccupied and receive room occupied. There is no difference at the 5% level between moving and fixed methods of measuring sound pressure level in the rooms nor between results when the occupancy of the source room changed for the receive room measurements.

Table 34: comparison of results using fixed and moving microphones (UKAS rooms 3 and 4)

Measurement method	Fixed	Moving	Fixed	Moving	Fixed	Moving
Single number quantity	$D_{nT,w}+C_{tr}$ dB	$D_{nT,w}+C_{tr}$ dB	C_{tr} dB	C_{tr} dB	$D_{nT,w}$ dB	$D_{nT,w}$ dB
Number of measurements	26	5	26	5	26	5
Average	46.03846	47	-4.57692	-4.6	51.38462	51.6
Variance	0.998461	1	8.253846	0.3	0.726154	0.3
F-test P value	0.850639		0.005397		0.40502	
t-test P value	0.058411		0.970295		0.593382	

Table 35: results from measurements with receive rooms occupied and unoccupied for measurements. Source room occupied for all measurements (UKAS rooms 3 and 4)

Both rooms occupied?	Yes	No
Single number quantity	$D_{nT,w}+C_{tr}$ dB	$D_{nT,w}+C_{tr}$ dB
Number of measurements	6	12
Average	46	46.166667
Variance	0.8	1.7878788
F-test P value	0.386581	
t-test P value	0.787534	

Table 36 shows that there is no significant difference at the 5% level between the results from measurements when rooms were occupied or unoccupied. Table 37 shows that there is no significant difference at the 5% level between the results from measurements using Room 3 or Room 4 as the source room.

Table 36: results from measurements with receive rooms occupied and unoccupied for measurements. Source room occupied for all measurements (UKAS rooms 3 and 4)

Room occupation	Not Occupied	Occupied
Single number quantity	$D_{nT,w}+C_{tr}$ dB	$D_{nT,w}+C_{tr}$ dB
Number of measurements	19	12
Average	46.10526	46.33333
Variance	1.321637	0.787879
F-test P value	0.383405	
t-test P value	0.563296	

Table 37: results from measurements using different source rooms (UKAS rooms 3 and 4)

Source room	3	4
Single number quantity	$D_{nT,w}+C_{tr}$ dB	$D_{nT,w}+C_{tr}$ dB
Number of measurements	19	11
Average	46.21053	46
Variance	1.064327	1
F-test P value	0.955556	
t-test P value	0.590389	

Rooms 3 and 4: comparison of UKAS and ANC test results

Table 38 compares the arithmetic means and variances of $D_{nT,w}+C_{tr}$, C_{tr} and $D_{nT,w}$ for the ANC and UKAS testers. Table 39 shows the results of the statistical analysis of the mean and variance values in Table 38. The analysis shows that there is a difference at the 5% level in the average $D_{nT,w}$ values from the ANC and UKAS testers. Also that there is a difference at the 5% level in the variances of the C_{tr} values produced by the two groups.

Table 38: arithmetic mean, standard deviation and variance from UKAS and ANC testers for $D_{nT,w}+C_{tr}$, C_{tr} and $D_{nT,w}$

	UKAS			ANC		
Single number quantity	$D_{nT,w}+C_{tr}$ dB	C_{tr} dB	$D_{nT,w}$ dB	$D_{nT,w}+C_{tr}$ dB	C_{tr} dB	$D_{nT,w}$ dB
Number of measurements	31	31	31	30	30	30
Average	46.19355	-4.58065	51.41935	46.66667	-5.13333	51.8
Variance	1.094624	6.91828	0.651613	1.126437	0.326437	0.441379

Table 39: P values for comparisons of the ANC and UKAS data (rooms 3 and 4)

Single number quantity	Test	P value
$D_{nT,w}+C_{tr}$ (dB)	F	0.93685014
	t	0.08476019
C_{tr} (dB)	F	**1.1803E-12**
	t	0.26152314
$D_{nT,w}$ (dB)	F	0.29726031
	t	**0.04931346**

The maximum $D_{nT,w}+C_{tr}$ value from UKAS testers was 48 dB

The minimum $D_{nT,w}+C_{tr}$ value from UKAS testers was 44 dB

The maximum $D_{nT,w}+C_{tr}$ value from ANC testers was = 49 dB

The minimum $D_{nT,w}+C_{tr}$ value from ANC testers was 45 dB

Rooms 2 and 4 ANC

Comparison of the results from the ANC group using fixed and moving microphones is shown in Table 40. The F-test shows that there is a significant difference in the arithmetic means of the $D_{nT,w}+C_{tr}$ values produced using fixed and moving microphones. Table 41 compares the results of measurements when the source room levels were measured with a person in the source room and receive room levels were measured with the source room unoccupied and receive room occupied. There is no difference at the 5% level between results depending on whether the occupancy of the source room changed for the receive room measurements.

Table 40: comparison of results using fixed and moving microphones (ANC rooms 2 and 4)

Measurement method	Fixed	Moving	Fixed	Moving	Fixed	Moving
Single number quantity	$D_{nT,w}+C_{tr}$ dB	$D_{nT,w}+C_{tr}$ dB	C_{tr} dB	C_{tr} dB	$D_{nT,w}$ dB	$D_{nT,w}$ dB
Number of measurements	16	13	16	13	16	13
Average	36.5	38.35714	-10.875	-10.1429	47.375	47.92857
Variance	2.533333	3.631868	2.516667	1.824176	2.116667	1.302198
F-test P value	0.500181		0.566285		0.385202	
t-test P value	**0.007028**		0.187737		0.260999	

Table 41: results from measurements with receive rooms occupied and unoccupied for measurements. Source room occupied for all measurements (ANC rooms 2 and 4)

Both rooms occupied?	Yes	No	Yes	No
Single number quantity	$D_{nT,w}+C_{tr}$ dB	$D_{nT,w}+C_{tr}$ dB	C_{tr} dB	C_{tr} dB
Number of measurements	13	16	13	16
Average	38	36.88235	-10.2308	-10.7647
Variance	4.5	2.985294	1.525641	2.816176
F-test P value	0.437155		0.286834	
t-test P value	0.122797		0.343629	

Table 42 examines the effect of using rooms 2 or 4 as the source room for the measurements. The analysis shows that there is no significant difference at the 5% level between the two sets of measurements.

Table 42: results from measurements using different source rooms (ANC rooms 2 and 4)

Source room	3	4
Single number quantity	$D_{nT,w}+C_{tr}$ dB	$D_{nT,w}+C_{tr}$ dB
Number of measurements	5	25
Average	36.6	37.52
Variance	1.8	4.176667
F-test P value	0.430331	
t-test P value	0.34592	

Rooms 2 and 4 UKAS

Table 43 compares the values for the single number quantities of interest from measurement by the UKAS group using fixed and moving microphones. Only in the variances of the C_{tr} values is there a difference that is significant at the 5% level.

Table 43: comparison of results using fixed and moving microphones (UKAS rooms 2 and 4)

Measurement method	Fixed	Moving	Fixed	Moving	Fixed	Moving
Single number quantity	$D_{nT,w}+C_{tr}$ dB	$D_{nT,w}+C_{tr}$ dB	C_{tr} dB	C_{tr} dB	$D_{nT,w}$ dB	$D_{nT,w}$ dB
Number of measurements	26	5	26	5	26	5
Average	36.03846	36.6	-9.38462	-10.8	46.96154	47.4
Variance	4.838462	1.3	35.20615	2.2	6.198462	2.3
F-test P value	0.209363		**0.015329**		0.346057	
t-test P value	0.585636		0.604597		0.708635	

Table 44 shows that changing the occupancy of the source room during the measurement had no significant effect on the results.

Table 44: results from measurements where the occupancy with receive rooms occupied and unoccupied for measurements. Source room occupied for all measurements (UKAS rooms 2 and 4)

Both rooms occupied?	Yes	No
Single number quantity	$D_{nT,w}+C_{tr}$ dB	$D_{nT,w}+C_{tr}$ dB
Number of measurements	19	12
Average	35.78947	36.66667
Variance	5.619883	1.878788
F-test P value	0.06802	
t-test P value	0.255237	

Table 45 shows that there is no significant difference at the 5% level between the arithmetic means of the $D_{nT,w}+C_{tr}$ values where rooms were occupied or unoccupied.

Table 45: results from measurements with rooms occupied or unoccupied for measurements. (UKAS rooms 2 and 4)

Room occupation	Not Occupied	Occupied
Single number quantity	$D_{nT,w}+C_{tr}$ dB	$D_{nT,w}+C_{tr}$ dB
Number of measurements	19	12
Average	36.31579	35.83333
Variance	2.005848	8.151515
F-test P value	**0.008472**	
t-test P value	0.594336	

Rooms 2 and 4: comparison of UKAS and ANC test results

Table 46 compares the arithmetic means and variances of $D_{nT,w}+C_{tr}$, C_{tr} and $D_{nT,w}$ for the ANC and UKAS testers. Table 47 shows the results of the statistical analysis of the mean and variance values in Table 46. The analysis shows that there is a difference at the 5% level in the average $D_{nT,w}+C_{tr}$ and $D_{nT,w}$ values from the ANC and UKAS testers. Also that there is a difference at the 5% level in the variances of the C_{tr} and $D_{nT,w}$ values produced by the two groups.

Table 46: arithmetic mean, standard deviation and variance from UKAS and ANC testers for $D_{nT,w}+C_{tr}$, C_{tr} and $D_{nT,w}$ (rooms 2 and 4)

	UKAS			ANC		
Single number quantity	$D_{nT,w}+C_{tr}$ dB	C_{tr} dB	$D_{nT,w}$ dB	$D_{nT,w}+C_{tr}$ dB	C_{tr} dB	$D_{nT,w}$ dB
Number of measurements	31	31	31	30	30	30
Average	36.12903	-9.6129	47.03226	37.36667	-10.5333	47.63333
Variance	4.249462	29.91183	5.498925	3.826437	2.257471	1.757471

Table 47: P values for comparisons of the ANC and UKAS data (rooms 2 and 4)

Single number quantity	Test	P value
$D_{nT,w}+C_{tr}$ (dB)	F	0.779415
	t	**0.019387**
C_{tr} (dB)	F	**5.26E-10**
	t	0.373028
$D_{nT,w}$ (dB)	F	**0.002853**
	t	0.222002

The maximum $D_{nT,w}+C_{tr}$ value from UKAS testers was 39 dB

The minimum $D_{nT,w}+C_{tr}$ value from UKAS testers was 29 dB

The maximum $D_{nT,w}+C_{tr}$ value from ANC testers was = 43 dB

The minimum $D_{nT,w}+C_{tr}$ value from ANC testers was 34 dB

Impact sound insulation

Rooms 2 and 4 ANC

All ANC tests were done with the receive room occupied when impact sound pressure levels were measured. Table 48 shows that there was a significant difference in the variances at the 5% level in the $L'_{nT,w}$ values produced but significant difference in the average values. However, the P value (the probability that the variances are the same) includes one value of $L'_{nT,w}$ = 81 dB. If this value were to be excluded there would be no significant difference in the variances. Since this $L'_{nT,w}$ result is 15 dB greater than the average value of the other results, its removal may be justified.

There is no significant difference in the arithmetic means of the two sets of results in Table 48.

Table 48: comparison of results using fixed and moving microphones (ANC rooms 2 and 4)

Measurement method	Fixed	Moving
Single number quantity	$L'_{nT,w}$ dB	$L'_{nT,w}$ dB
Number of measurements	22	8
Average	67.13636	66
Variance	10.59957	0.857143
F-test P value	**0.002277**	
t-test P value	0.150113	

The number of tapping machine positions used for the measurements was either 6 or 4. Therefore, Table 49 compares the results from these two methods. There is no significant difference in the arithmetic means of the two sets of data but there is a significant difference at the 5% level in the variances. However, one value of $L'_{nT,w}$ was 81 dB. When this value is excluded there is no significant difference in the variances. Since this $L'_{nT,w}$ result is 15 dB greater than the average value of the other results, its removal is justified.

Table 49: comparison of results with 4 and 6 tapping machine positions (ANC rooms 2 and 4)

No. tapping machine positions	4	6
Single number quantity	$L'_{nT,w}$ dB	$L'_{nT,w}$ dB
Number of measurements	25	5
Average	66.88	66.6
Variance	9.776667	0.3
F-test P value	**0.003891**	
t-test P value	0.679929	

Rooms 2 and 4 UKAS

Table 50 shows that there was no significant difference in the average values of $L'_{nT,w}$ whether fixed of moving microphones were used although there was a significant difference at the 5% level in the variances. However, two values of $L'_{nT,w}$ = 78 dB were recorded. If these were to be excluded there would be no significant difference in the variances. Since these $L'_{nT,w}$ results are 12 dB greater than the average value of the other results, there removal may be justified.

Table 50: comparison of results using fixed and moving microphones (UKAS rooms 2 and 4)

Measurement method	Fixed	Moving
Single number quantity	$L'_{nT,w}$ dB	$L'_{nT,w}$ dB
Number of measurements	25	5
Average	66.96	66.8
Variance	11.70667	0.2000
F-test P value	**0.001232**	
t-test P value	0.82411	

Table 51 shows that there was no significant difference in the results with the receive room occupied or unoccupied. However, two values of $L'_{nT,w}$ = 78 dB were recorded. When these are excluded the values for the variance with the receive room occupied and not occupied become 0.500 and 0.690 respectively. Since these $L'_{nT,w}$ results are 12 dB greater than the average value of the other results, there removal is justified.

Table 51: comparison of results with receive room occupied and unoccupied (UKAS rooms 2 and 4)

Receive room occupied?	Yes	No
Single number quantity	$L'_{nT,w}$ dB	$L'_{nT,w}$ dB
Number of measurements	20	10
Average	66.95	66.9
Variance	7.418421	15.6556
F-test P value	0.163363	
t-test P value	0.967831	

Table 52 shows that there was a significant difference in the variances of the results produced using 4 or 6 tapping machine positions. However, two values of $L'_{nT,w}$ = 78 dB were recorded. When these are excluded there is no significant difference in the variances. Since these $L'_{nT,w}$ results are 12 dB greater than the average value of the other results, their removal is justified. There is no difference in the arithmetic means of the values of $L'_{nT,w}$.

Table 52: comparison of results with 4 and 6 tapping machine positions (UKAS rooms 2 and 4)

No. tapping machine positions	4	6
Single number quantity	$L'_{nT,w}$ dB	$L'_{nT,w}$ dB
Number of measurements	26	4
Average	67.07692	66
Variance	11.03385	0.6667
F-test P value	**0.038449**	
t-test P value	0.50418	

Comparison of UKAS and ANC test results (impact sound insulation, rooms 2 and 4)

Table 53 and Table 54 show that there was no significant difference in the average values of impact sound insulation produced by the ANC and the UKAS testers. When the unusually high values for $L'_{nT,w}$ are excluded, the values in italics in the fourth and fifth columns of Table 53 are produced.

Table 53: arithmetic mean, standard deviation and variance from UKAS and ANC testers for $L'_{nT,w}$ (rooms 2 and 4)

	UKAS	ANC	*UKAS*	*ANC*
Single number quantity	$L'_{nT,w}$ dB	$L'_{nT,w}$ dB	$L'_{nT,w}$ dB	$L'_{nT,w}$ dB
Number of measurements	30	30	*28*	*29*
Average	66.93333	66.83333	*66.14286*	*66.34483*
Variance	9.71954	8.143678	*0.719577*	*1.019704*

Table 54: P values for comparisons of the ANC and UKAS data (rooms 2 and 4)

Single number quantity	Test	P value
$L'_{nT,w}$	F	0.636987
	t	0.897337

The maximum $L'_{nT,w}$ value from UKAS testers was 78 dB

The minimum $L'_{nT,w}$ value from UKAS testers was 65 dB

The maximum $L'_{nT,w}$ value from ANC testers was 81 dB

The minimum $L'_{nT,w}$ value from ANC testers was 64 dB

With the unusually high values of impact sound insulation removed these maximum and minimum values are given below.

The maximum $L'_{nT,w}$ value from UKAS testers was 68 dB

The minimum $L'_{nT,w}$ value from UKAS testers was 65 dB

The maximum $L'_{nT,w}$ value from ANC testers was 68 dB

The minimum $L'_{nT,w}$ value from ANC testers was 64 dB

Summary

When rounded to integer values as required by the measurement standards and Approved Document E (2003 Edition) of the Building Regulations the average values shown in Table 55 were produced from the ANC and UKAS tests.

Table 55: average single number quantities produced from ANC and UKAS tests

Rooms	ANC tests		UKAS tests	
	$D_{nT,w}+C_{tr}$ dB	$L'_{nT,w}$ dB	$D_{nT,w}+C_{tr}$ dB	$L'_{nT,w}$ dB
1 and 2	52		51	
3 and 4	47		46	
2 and 4	36	67	37	67

When the ANC tests and UKAS tests are considered separately, there is no statistically significant consistent difference in the arithmetic mean values of the results from measurements with:

- rooms occupied or unoccupied;
- changing the occupation of the source room when conducting receive room measurements;
- fixed or moving microphones;
- hand held sound instruments or the use of stands or rotating booms.

However, there was a difference that was significant at the 5% level in:

- the mean $D_{nT,w}+C_{tr}$ values produced by the ANC and UKAS tests between rooms 1 and 2;
- the mean $D_{nT,w}+C_{tr}$ values produced by the ANC and UKAS tests between rooms 2 and 4;
- the mean $D_{nT,w}$ values produced by the ANC and UKAS tests between rooms 3 and 4.

The range of values for $D_{nT,w}+C_{tr}$ from the measurements between rooms 1 and 2 was 5 dB. From the 30 ANC tests the range was 3 dB and from the UKAS tests 5 dB.

From the measurements in rooms 3 and 4, the range of $D_{nT,w}+C_{tr}$ values from both ANC and UKAS tests was 4 dB.

The range of $D_{nT,w}+C_{tr}$ values between rooms 2 and 4 was 10 dB. When the two sets of data produced by ANC and UKAS tests where Room 4 was used as the source room, there is no significant difference between the variances or the means from the measurements.

It is of note that there was no significant difference in the $D_{nT,w}+C_{tr}$ values between rooms 2 and 4 depending on whether the 50 m^3 or the 30 m^3 room was chosen as the source room (ISO 140-4 requires the room with the larger volume to be used as the source room). However, flanking sound transmission via the timber stud walls containing doors forming the 27 m^3 room within the 50 m^3 room on the ground floor may have reduced the effect of using the smaller of the two rooms as the source room.

There was no difference in the arithmetic mean values of $L'_{nT,w}$ produced by using fixed or moving microphones or four or six tapping machine positions. However, variances were larger with fixed rather than moving microphones.

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Although there was no significant difference in the mean values of $L'_{nT,w}$ produced by ANC and UKAS testers, three of the results were considerably higher than the others. Investigation of the reason for this may be worthwhile and will be attempted.

Conclusions

No systematic difference was identified in the single number quantities for airborne or impact sound insulation produced by the different techniques used to measure sound pressure level in the rooms in Building 68A.

The range of $D_{nT,w}+C_{tr}$ values, for airborne sound insulation, from the measurements on the timber floor was 10 dB. This is twice as great as that observed from the measurements in rooms separated by masonry walls. The large range of $D_{nT,w}+C_{tr}$ values for the timber floor cannot be attributed to the relatively small volume of room 2 because a similar spread of results was not observed when sound insulation of the wall between rooms 1 and 2 was measured. Since the range of $L'_{nT,w}$ values from the measurements on the timber joist floor was 17 dB, it is reasonable to conclude that there is more uncertainty in sound insulation results from timber joist floors like this one than from measurements on masonry walls.

The difference in the average values of $D_{nT,w}+C_{tr}$ produced from the ANC and UKAS tests between rooms 1 and 2, rooms 3 and 4 and rooms 2 and 4 was only 1 dB. Statistical analysis that assumed measurement results were distributed normally showed that this difference was significant at the 5% level in rooms 1 and 2. For the other pairs of rooms the 1 dB difference was not significant although when results of all measurements between rooms 2 and 4 including those which used Room 2 as the source room were compared, there was a difference in $D_{nT,w}+C_{tr}$ values significant at the 5% level between the two groups of testers.

There was no significant difference in the average values of $L'_{nT,w}$ produced by ANC or UKAS testers or by using 2 or 4 tapping machine positions. However the spread of the values was 17 dB.

- 22 Results of field sound insulation round robin measurements at BRE robin measurements at BRE

References

[1] L. C. Fothergill, Building Research Establishment, Recommendations for the measurement of sound insulation between dwellings, Applied Acoustics,13, 171-187. (1980)