Edinburgh, Scotland
EURONOISE 2009
October 26-28

Sound insulation measurements in buildings

Robin Hall[a]
BRE, Bucknalls Lane, Garston, Hertfordshire, WD25 9XX, UK.

ABSTRACT

This paper presents the results of research that examined methods for measuring sound insulation in buildings. The work began with a review of ISO 140-4 and ISO 140-7 which defined a measurement programme conducted by BRE staff. Following this, a round robin series of measurements was conducted that was supported by acoustics professionals involved in measuring sound insulation to demonstrate compliance with regulatory performance standards. Measurements of airborne and impact sound insulation were conducted in the same rooms by all taking part using their normal measurement methods. The numbers involved in the exercise meant that typically, results from around 60 measurements of sound insulation could be compared for each pair of rooms. It was concluded that the alternative methods of complying with the measurement standards used by experienced testers are unlikely to affect the reproducibility of measured sound insulation values in buildings. Perhaps the most significant conclusion from this study is that, for comparison with Building Regulations performance standards in England and Wales, 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, a well organized approach to field measurements and, hence, the benefit of third party accreditation.

1. INTRODUCTION

Approved Document E (2003 Edition) of the Building Regulations 2000 of England and Wales (ADE) contains the minimum regulatory performance standards for sound insulation between new dwellings, rooms for residential purposes and dwellings created by modifying buildings. With the introduction of this document, measuring airborne and impact sound insulation in accordance with ISO 140-4[1] and ISO 140-7[2] respectively to demonstrate compliance with Building Regulations became compulsory.

Initially, ADE required that those conducting sound insulation measurements held UKAS, or equivalent third party, accreditation for their measurement procedures. However, to ensure sufficient numbers of qualified testers were available for sound insulation measurements, the Association of Noise Consultants (ANC) set up their Registration Scheme for pre-completion testing (PCT) and the guidance on suitable testers in ADE was changed in the 2004 amendments to include those registered with the Scheme. At the time of writing, UKAS accreditation for the ANC Registration Scheme is being sought.

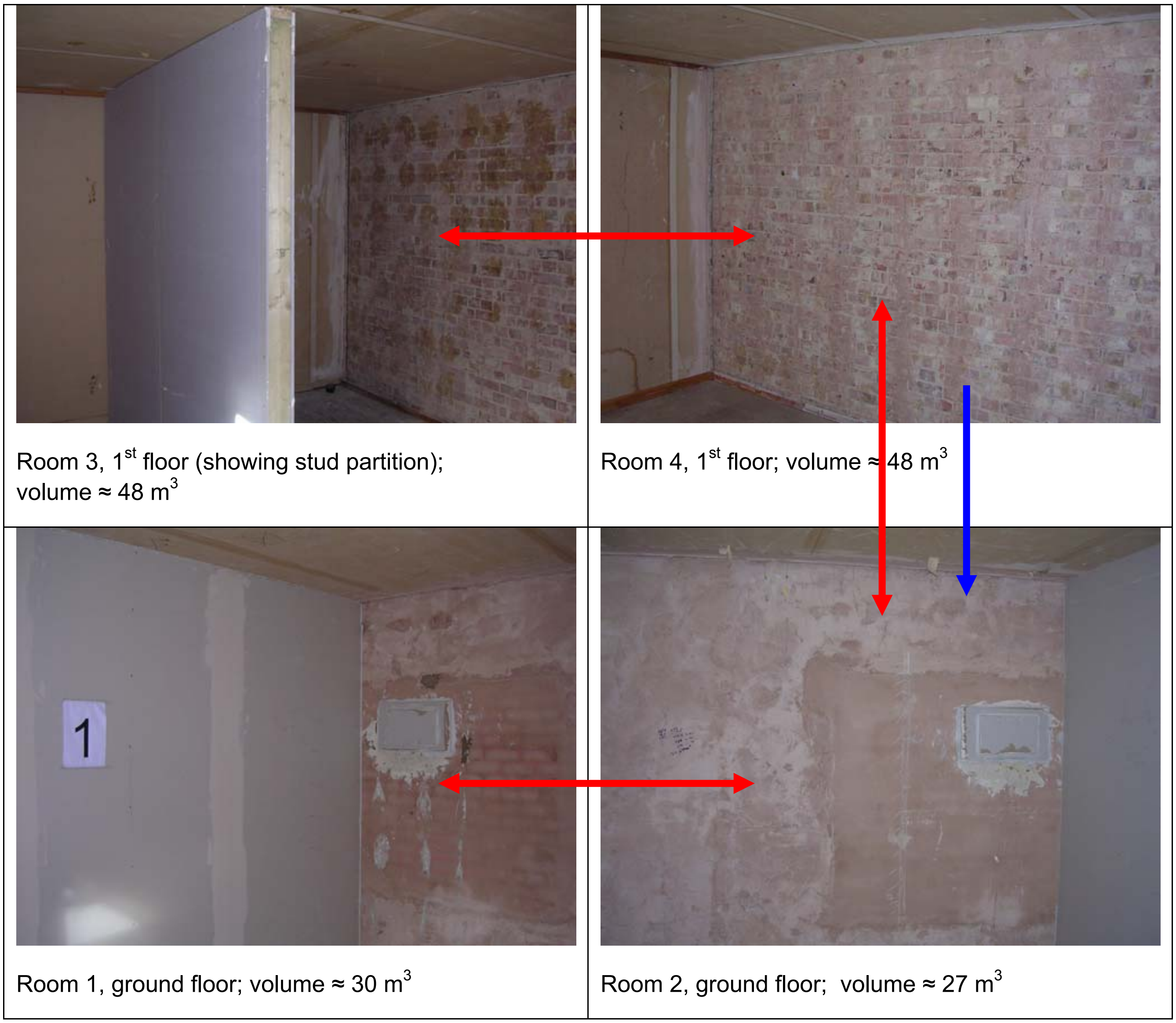
So many companies and individuals involved in sound insulation measurements in dwellings means a range of approaches are used to comply with the relevant standards. Earlier research by BRE[3] concluded that different approaches to measuring airborne and impact sound insulation had no significant affect on measurement results. However, to test this conclusion, a round robin series of measurements, supported by UKAS accredited and ANC Registered

[a] Email address. hallr@bre.co.uk

testers, was conducted in a building (B68A) at the BRE Garston site. All who took part in the round robin undertook commercial measurements of sound insulation in buildings.

2. ROOMS USED FOR THE MEASUREMENTS

Building 68A has four rooms arranged in relation to each other as illustrated in Figure 1 which meant that both airborne and impact sound insulation measurements could be conducted. The red arrows in Figure 8 indicate the rooms used for airborne sound insulation measurements and the blue arrow the rooms for impact sound insulation measurements.



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, ground floor; volume ≈ 27 m^3

Figure 1: the rooms used for round robin measurements

The walls separating the pairs of rooms were solid masonry approximately 220 mm thick. In rooms 1 and 2, on the ground floor the separating wall was plastered. In rooms 3 and 4 the wall was fair faced. Rooms 4 and 2 were separated by a timber joist floor with a plasterboard ceiling fixed directly to the underside of the joists. Tongue and groove chipboard was screwed to the top the joists.

3. DATA PROVIDED AND APPROACH TO ANALYSIS

All who took part in the round robin exercise were required to derive the single number quantities used to describe airborne and impact sound insulation in ADE. These are, $D_{nT,w}+C_{tr}$ and $L'_{nT,w}$ for airborne and impact sound insulation respectively. The sets of data produced using, for example, fixed and moving microphones were then compared to determine whether the two approaches produced significantly different results.

Where two sets of data were compared, a statistical two-tailed F test was conducted to determine whether there was a significant difference in the variances of the sets. The results of these tests allowed the appropriate two-tailed students t-tests to be conducted to determine whether the mean values of the data sets were significantly different at the 5% level.

Both $D_{nT,w}+C_{tr}$ and $L'_{nT,w}$ are produced by shifting reference curves in a specified manner in 1 dB steps and are given as integer values in accordance with ISO 717-1[3] and 717-2[4]. Therefore, mean values of the single number quantities are given as integer values here. However, where integer values exaggerate differences in means, this is indicated and the values are also given to one or two places of decimals.

All the statistical analysis was conducted using the statistical functions in Microsoft Excel although some results were checked using a dedicated statistical analysis application. This means that the analysis assumes that the distribution of the results is a normal distribution; usually represented by the familiar bell-shaped curve centered on the mean value. Since the measurements were made in the same rooms by all those taking part, this approach is justified. There is also 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[6] where all the measurements were conducted in the same rooms.

4. MEASUREMENT PROCEDURES AND RESULTS

There is pressure to minimise the amount of time spent on commercial measurements of sound insulation on site. Therefore, measures to speed up the process of testing are widely adopted for pre-completion testing in dwellings. Whereas in laboratories it is extremely unusual for people to be present in rooms during measurements of sound pressure level, it is not uncommon for site measurements. The comparison of the results from the different approaches to measurements adopted by those who took part in the exercise is presented below.

A. Fixed and moving microphones

Of 30 airborne sound insulation measurements in each of the rooms conducted by ANC members, only one test in each pair of rooms was conducted with unoccupied source and receiver rooms. For impact sound insulation measurements, all ANC measurements were conducted with the receiver room occupied. Fewer UKAS tests were conducted with occupied than with unoccupied rooms; typically 19 out of 31 UKAS airborne sound insulation tests were conducted with rooms occupied.

In laboratories, when fixed microphone positions are not used, microphones are usually moved with a fixed radius around a point with rotating booms. On site, moving microphones are usually hand held because rotating booms are expensive, take up a lot of space, take significant time to set up and may not be appropriate in small furnished rooms. Of all the tests conducted, only two airborne sound insulation measurements in each pair of rooms and two impact sound insulation measurements were conducted using rotating booms. Therefore, although results obtained using fixed microphones can be compared with those from moving microphones, there were insufficient measurements using rotating booms to assess the difference between moving microphone measurements in occupied and unoccupied rooms.

The arithmetic means of the results from all of the airborne sound insulation measurements in the rooms conducted with fixed and moving microphones are given in Table 1. Also shown are the ranges of results (maximum-minimum), the standard deviation (SD) in the mean values and the number of measurements (N). The same information for the impact sound insulation measurements between rooms 4 and 2 conducted with fixed and moving microphones is shown in Table 2.

Table 1: airborne sound insulation results with fixed and moving microphones

Rooms	Fixed microphones				Moving microphones			
	$D_{nT,w}+C_{tr}$ dB	Range dB	SD	N	$D_{nT,w}+C_{tr}$ dB	Range dB	SD	N
1 and 2	52	5	1.0	42	52	2	0.5	19
3 and 4	47	4	1.0	42	46	4	1.0	19
2 and 4	36	6	1.6	41	38	8	1.9	19

Table 2: impact sound insulation results with fixed and moving microphones

Rooms	Fixed microphones				Moving microphones			
	$L'_{nT,w}$ dB	Range dB	SD	N	$L'_{nT,w}$ dB	Range dB	SD	N
1 and 2	66	5	1.0	44	66	2	0.9	13

Table 1 and Table 2 show that the average values for the single number quantities used to describe airborne and impact sound insulation in Approved Document E are unaffected by the use of moving or fixed microphones. Although the average $D_{nT,w}+C_{tr}$ values produced by fixed and moving microphones in rooms 3 and 4 and rooms 2 and 4 each differ by 1 dB, the two-tailed t-tests conducted show that there is no significant difference in at the 5% level in the values produced by the two methods. The same is true of the impact sound insulation measurements in Table 2 although considerably fewer tests were with conducted with moving microphones than with fixed microphones.

B. Changing source room occupancy during measurements

ISO 140-4 requires the level difference between the source room and the receiver room to be determined. However, it does not require measurements in both rooms to be conducted concurrently. Therefore, relatively expensive dual channel analysers that allow concurrent measurements are not necessary for compliance with the standard. To minimise costs, often a single consultant attends site with a hand held and relatively inexpensive sound level meter for the measurements. In this situation, the acoustic absorption due to the person holding the sound level meter is removed from the source room when measurements are conducted in the receiver room. This means that there is the potential for sound levels to be higher in the source room when receiver room measurements are being conducted. Hence there is a possibility that airborne sound insulation may be underestimated in some rooms. Therefore, results from measurements with both source and receiver rooms occupied were compared with those from measurements where the source room was occupied for source room measurements but not for receiver room measurements.

Table 3 shows the results of the measurements where both rooms were occupied for source and receiver room measurements and where the occupancy of the source room changed for the receiver room measurements. Mean $D_{nT,w}$+C_{tr} values for rooms 3 and 4 are given to one place of decimals below the table.

Table 3: airborne sound insulation between rooms with source room occupied and unoccupied

Rooms	Source and receiver rooms occupied				Source room unoccupied for receiver room measurements			
	$D_{nT,w}$+C_{tr} dB	Range dB	SD	N	$D_{nT,w}$+C_{tr} dB	Range dB	SD	N
1 and 2	52	5	1.2	19	52	2	0.6	27
3 and 4	46*	4	1.1	19	47**	4	1.2	28
2 and 4	37	10	2.1	31	37	6	1.6	29

*46.4 dB, **46.5 dB

Statistical analysis confirmed that changing the occupation of the source room when receive room measurements were made had no significant effect at the 5% level in the average $D_{nT,w}$+C_{tr} values produced. The 1 dB difference in the mean values for sound insulation between rooms 3 and 4 is exaggerated due to rounding to integer values as can be seen when the average values are given to one place of decimals. The range of measured airborne sound insulation values was largest between rooms 2 and 4, separated by a timber floor. It was initially felt that this might be due to the choice of loudspeaker positions in the larger upper room. However, the lowest $D_{nT,w}$+C_{tr} value provided was 33 dB. Analysis showed that there is a likelihood of approximately 5% of this value being measured. It is reasonable to consider this a "statistical out-lier" since there is no evidence that the measurement technique was flawed. The highest value provided was 43 dB $D_{nT,w}$+C_{tr}. Examination of this result showed that the $D_{nT,w}$ and C_{tr} values had been added together incorrectly. The result should have been 35 dB. Excluding this result would have resulted in the range of results for rooms 2 and 4 being 6 dB.

C. ANC and UKAS testers

The comparison of the results from ANC registered and UKAS accredited testers in shown in Table 4.

Table 4: comparison of results from ANC registered and UKAS accredited testers who took part in the round robin exercise

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
1 and 2	52		51	
3 and 4	47		46	
2 and 4	37	67	36	67

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 higher average values of airborne sound insulation. Both groups produced the same average value for impact sound insulation.

Statistical analysis suggested 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. The comparison for rooms 2 and 4 includes results from 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, using the smaller of two rooms as the source room is at odds with the guidance in ISO 140-4. 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.)

The results of the comparison using only airborne sound insulation results between rooms 2 and 4 from the measurements are shown in Table 5. Statistical analysis showed that there is no significant difference in the $D_{nT,w}+C_{tr}$ values produced by the two groups of testers at the 5% level.

Table 5: 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

It is of note that rounding to integer values has exaggerated the difference between the calculated average values from UKAS and ANC testers. To two places of decimals, the average values for $D_{nT,w}+C_{tr}$ shown in Table 5 were 37.52 dB and 36.46 dB for ANC and UKAS testers respectively. 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 for UKAS and ANC testers respectively. Such a small difference appeared unlikely to be significant and was checked using a dedicated statistical analysis application (SPSS). The result of the analysis with SPSS also suggested that the difference between the means was significant.

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 (standardizing to a figure other than 0.5 s) and 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 could be attributed to errors unrelated to measuring sound pressure levels and reverberation times improves confidence in the reliability of the measurement method. However, it 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.

When the identifiably incorrect values for impact sound insulation were removed from the statistical analysis, the values of $L'_{nT,w}$ in Table 5 were produced. It should be noted that these erroneous values were also removed from the analysis of the difference in results from measurements with fixed and moving microphones and changes in source room occupation.

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 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.

Calculating the average values from all tests conducted in accordance with the relevant standard in each of the rooms without separating different approaches to compliance produces the values shown in Table 6. These values in suggest that the procedures used on site by those who took part in the exercise are robust.

Table 6: 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	Range dB	Number of tests
1 and 2	52		1	5	61
3 and 4	46		1	5	61
4 and 2	37		2	10	53
4 and 2		66	1	4	57

* Single Number Quantity

4. CONCLUSIONS

No evidence of significant systematic differences in measured values of field sound insulation produced by different approaches to complying with ISO 140-4 and ISO 140-7 was identified. Nor was any advantage identified from measurements in empty rooms, as is normally the case in acoustics laboratories, rather than occupied rooms. Perhaps the most significant conclusion from this study is that, for comparison with Building Regulations performance standards, it is reasonable to adopt measurement 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. However, the exercise also demonstrated the importance of robust data handling procedures and a well organized approach to field measurements. The two errors identified in the calculation of single number quantities could both have been avoided by better data handling procedures. Such errors emphasize the benefit of regular audits and third party accreditation.

ACKNOWLEDGMENTS

This research was sponsored by the BRE Trust, the NHBC Foundation, Robust Details Limited and the Association of Consultant Approved Inspectors (ACAI). The author is grateful for their support and acknowledges Andrew Heath's contribution to this work when he worked at BRE.

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 of floors, 1998, BSI.
3. R Hall and A Heath, BRE, An examination of the guidance for field measurements of sound insulation in the ISO 140 series of standards; initial results, in Proceedings if IOA Spring Conference 2008, Reading 2008, pp 70-76 Vol. 30, Pt.2.

4. BS EN ISO 717-1:1997, Acoustics – rating of sound insulation in buildings and of building elements, Part 1 Airborne sound insulation.
5. BS EN ISO 717-2:1997, Acoustics – rating of sound insulation in buildings and of building elements, Part 2 Impact sound insulation.
6. L. C. Fothergill, Building Research Establishment, Recommendations for the measurement of sound insulation between dwellings, Applied Acoustics,13, 171-187, 1980.
7. K. Alvarez and M.P. Brown, Modern Physics, McGraw-Hill, London 1998, pp.20-33.