## IOA Spring Conference.

# An empirical study of the effects of occupied test rooms and a moving microphone when measuring Airborne Sound Insulation

A joint research project by the Association of Noise Consultants (ANC), Robust Details Ltd (RDL) and the Building Research Establishment (BRE).

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## 1 Introduction

It is acknowledged by many practitioners in building acoustics that the current test Standard for airborne field sound insulation testing in the UK, i.e. ISO 140:1998 Part 4 [1] is an imperfect document, containing ambiguities which allow scope for variations in equipment, test arrangement and test procedure, while still being compliant with the Standard.

Concerned by the effect this may have on repeatability and reproducibility of field tests, the ANC and Robust Details Ltd, sponsored a round robin between 21 different ANC Registered testers, at two different test sites in the early part of 2006, using four different test procedures [2]. There were no further instructions given about the test procedure except to advise the testers that their tests must be fully complaint with BS EN ISO 140:1998 Part 4 and Annex B of Approved Document E (2003) [3].

Although the results of the round robin showed levels of reproducibility which were comparable with other studies [4], there were differences in results, between testers, which appeared to be completely random and did not appear to correlate with the different test methods. In other words, there was no evidence, from the round robin data, that any particular test arrangement or procedure was inherently ‘better’or ‘worse’ than another. Or, that the data samples obtained were insufficient to show a significant effect.

One aspect of the test procedure which is mentioned neither in ISO 140-4 nor ISO 140-7 is whether or not the tester should be present in the test rooms while undertaking the tests. It is fair to say that at the time of drawing up the ANC Registration Scheme and the Robust Details Protocol, this was not considered either by the ANC Committee or by the RD Inspectorate because it simply did not occur to the consultants representing these bodies that testing from outside the room could be considered a realistic option, due to the need to hear any changes in ambient noise, particularly in the receiver room, when working on a typical building site. The field test standards (ISO 140-4 and 140-7) were, on the other hand, drawn up by people more familiar with laboratory test procedures in which intrusive noise is not a problem and where tests are invariably taken with the rooms unoccupied.

Another variation in test method included in the round robin study and which also raises eyebrows amongst laboratory-based acousticians is the ‘manual moving microphone’ technique. This has been labelled by some as the “Tai Chi” method, for reasons which are obvious when the technique is observed in action, and is preferred by many ANC testers and by the Robust Details inspectorate [5] as it provides space-averaging over an infinite number of points rather than the 5 points allowed using fixed microphones. Again, ISO 140 offers no specific guidance, simply referring to a ‘moving microphone’ and describing the trajectory of the sweep in some detail. The ‘manual moving microphone’ test procedure, when correctly implemented, complies fully with ISO 140-4 and ISO 140-7 and has been considered acceptable by the ANC Registration Scheme committee and by DCLG (formerly the ODPM). The test method is not accepted by BRE for Ecohomes tests, however, and the Ecohomes protocol required for ANC testers is currently as follows :

> *To be accepted by the assessor, reports prepared by ANC registered consultants must clearly confirm compliance with one of the following methods:*
>
> *1) Unattended source and receiver room measurements, using static microphone positions (as defined in ISO 140:4 Section 6.3.2.).*
>
> *2) Unattended source and receiver room measurements using a mechanical rotating boom microphone system (sweep radius as defined in ISO 140:4 Section 6.3.2.)*
>
> *3) Attended source and receiver room measurements using static microphone positions (as defined in ISO 140:4 Section 6.3.2) provided that the tester remains still during each measurement and provided that the tester remains in the room throughout the measurements.*

This project was therefore devised by the ANC and RDL, in close collaboration with BRE and DCLG, to investigate possible errors in the accuracy and repeatability of test results as a result of these two variables. The study is concerned with the field measurement of airborne sound insulation only.

In summary, the objective of this study is to investigate the possible differences in test results produced by the presence or absence of the tester in the test rooms and also any difference produced by a ‘manual moving microphone’ as compared to measurements traditionally obtained using fixed microphone positions.

In order that each of these two variables could be examined separately, a programme of measurements was undertaken between February and July 2007, at one of the test facilities at BRE in Watford, known as Building 68.

Figure 1 - Building 68 at BRE Watford


**Update – tests in small rooms.**

The main body of this paper refers to tests carried out between rooms of approximately 50m$^3$ volume. On modern housing developments, room sizes are typically much smaller than this, especially in bedrooms and rooms of around 20m$^3$ volume are commonplace. It was therefore agreed between the three sponsors of the project, that each of the pair of larger rooms should be subdivided into two rooms of approximately 30 m$^3$ and 20 m$^3$, in order to test the validity of the test methods under a full range of test conditions.

This work was completed in October 2007 and the results of the tests are reported in section 7.4 of this report, as an update.

## 2. Description of test arrangement (50 m$^3$ rooms).

The ground floor of building 68 comprises two rooms either side of a 215 mm brick separating wall which is plastered on both sides. The dimensions of the rooms are approximately 5m x 4m x 2.5m high i.e. 50 $m^3$, arranged so that the separating wall is the longest wall with an area of 12.5 $m^2$. The floor is a solid concrete slab and the ceiling is a timber joist floor with one layer of plasterboard fixed directly to the joists. The flanking walls are of lightweight construction and do not cross the separating wall so that flanking transmission is low. The edges of the separating wall can be seen in the photograph above. The construction is therefore reasonably representative of the test arrangement for a pair of semi-detached houses.

Initial tests carried out by the author in February 2007, using three different test methods, showed that the airborne sound insulation of the wall was 50 dB DnTw+Ctr (+ 1 dB) with the DnTw value typically 55 dB and the spectrum adaptation term, Ctr, typically -5 dB. The RT of the rooms (unoccupied) was found to be in the range of 1 to 1.5 second across the frequency range of 50 Hz to 5 kHz.

The floors of the test rooms were marked out in a 1 metre grid to give 20 intersecting points (diagram Figure 1) These would form the X and Y coordinates for the fixed microphone positions. At each X,Y coordinate, four different heights were obtained at .5 metre intervals using a graduated marker. In this way, 80 different mic positions could be identified for later analysis, all within the permitted area defined in ISO 140 Part 4 (no closer than 0.5 metres from any boundary).

Two source positions were used with the loudspeaker(s) placed at the corners of the source room, but no closer than 0.5 m from any room surface to comply with ISO 140. The loudspeakers were placed on stands so that they were 0.5 m from the floor and at two different heights. This effectively reduced the number of available mic positions in the source room (see photos).

Figure 2

Source position 1 | Source position 2

**Microphone positions (static measurements)**

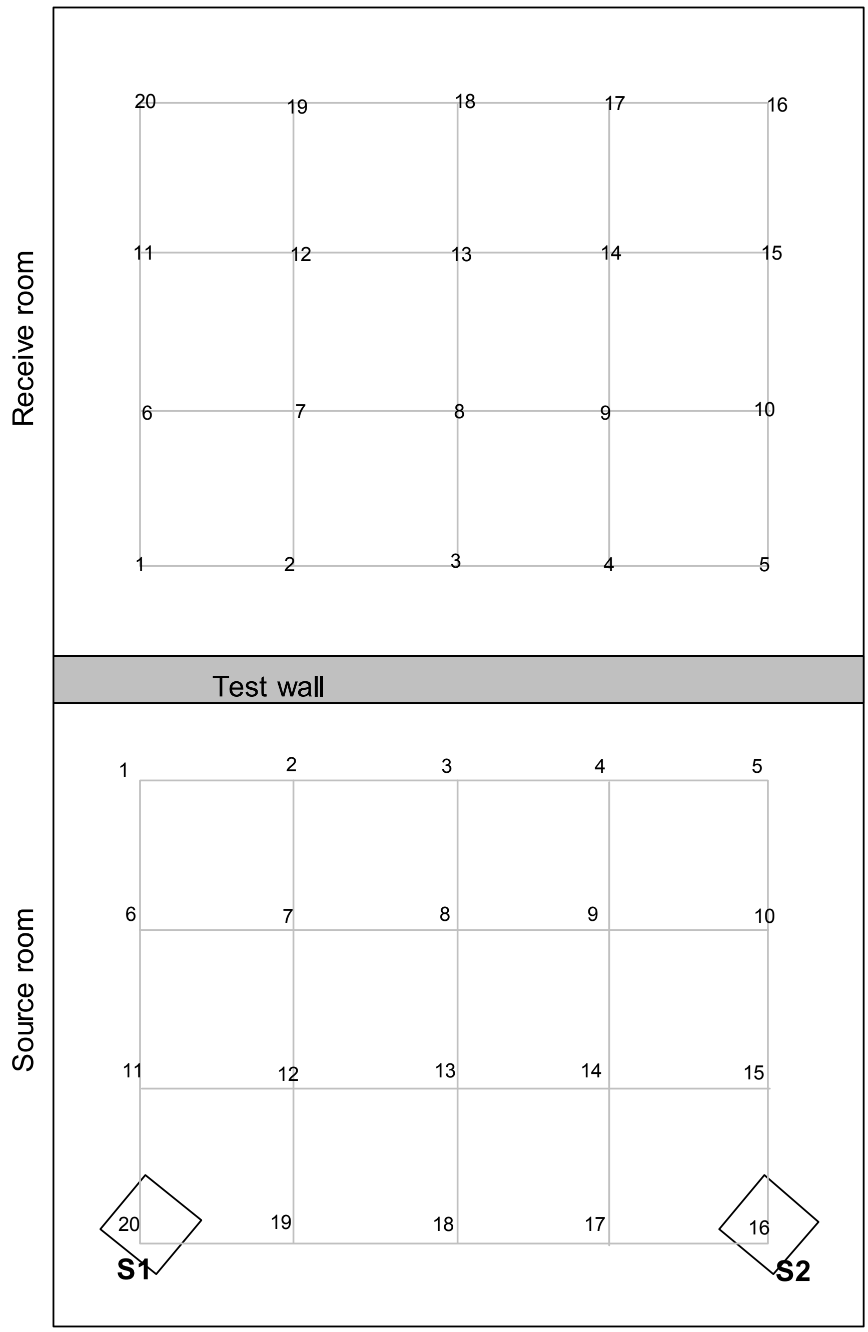



Figure 3. (50m$^3$ rooms)

Five different experimental methods are described in the following paragraphs. These follow the common field test procedures employed by test bodies conducting airborne pre-completion sound insulation testing but essentially vary only according to;

a) the presence or absence of the tester in the rooms and
b) the spatial sampling method (moving or fixed microphones) .

The variables a) and b) were tested on different dates with different personnel and/or different test equipment, including mechanical rotating booms, and under widely varying weather conditions. In all, 20 sets of measurements were compiled over the project period as summarised in Table 1.

**Table 1 – summary of tests in chronological sequence.**

| Test No. | Date | Test condition | Instrumentation |
|---|---|---|---|
| 1 | 22nd Feb | MMM (Method 4) | Nor 118 |
| 2 | 22nd Feb | Static - both rooms unoccupied (Method 1) | Nor 118 |
| 3 | 22nd Feb | Static - both rooms occupied (Method 2) | Nor 118 |
| 4 | 22nd Feb | Static - source unoccupied/receiver occupied (Method 3) | Nor 118 |
| 5 | 16th March | Rotating Booms - both rooms unoccupied (Method 5a) | NRA-840 |
| 6 | 16th March | Rotating Booms - both rooms unoccupied (Method 5b - different direction) | NRA-840 |
| 7 | 16th March | Static - both rooms unoccupied (Method 1) | NRA-840 |
| 8 | 16th March | Static - both rooms occupied (Method 2) | NRA-840 |
| 9 | 16th July | Static - both rooms unoccupied (Method 1) | Nor 118 |
| 10 | 16th July | Static - source unoccupied/receiver occupied (Method 3) | Nor 118 |
| 11 | 16th July | MMM (Method 4) | Nor 118 |
| 12 | 26th July | Static - both rooms unoccupied (Method 1) | Nor 140 |
| 13 | 26th July | Static - source unoccupied/receiver occupied (Method 3) | Nor 140 |
| 14 | 26th July | MMM (Method 4) | Nor 140 |
| 15 | 26th July | Static - both rooms unoccupied (Method 1) | Nor 140 |
| 15 | 26th July | Static - both rooms unoccupied (Method 1) | Nor 140 |
| 17 | 26th July | Static - both rooms unoccupied (Method 1) | Nor 140 |
| 18 | 26th July | Static - both rooms unoccupied (Method 1) | Nor 140 |
| 19 | 26th July | MMM (careless handling of instrument) (Method 4) | Nor 140 |
| 20 | 26th July | MMM (rapid scanning of microphone) (Method 4) | Nor 140 |

## 3. Description of Test Methods.

Test Method 1 - Static mic positions - source and receiver rooms unoccupied.

This is the reference test method which was repeated on each test date as part of the test programme and as a control. Microphone positions are fixed, according to the grid positions shown in Figure 3, with the microphone remotely connected by an extension cable to the sound level meter which is located, with the operator, outside of the rooms being measured. The tests carried out by BRE staff on the 16$^{th}$ March used a dual channel measurement system and the source and receiver room measurements were carried out simultaneously. The tests carried out by the author for all the controls used a single channel measurement system, requiring measurement of the source room, followed by the receiver room, relocating the measurement equipment after each set of measurements.

This test configuration is summarised by the diagrams Figures 4 and 5.

Figure 4 – Test Method 1 (ANC)

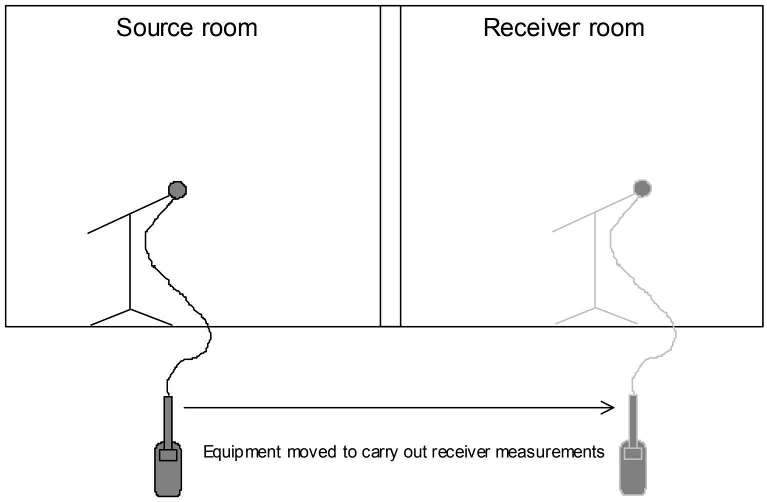
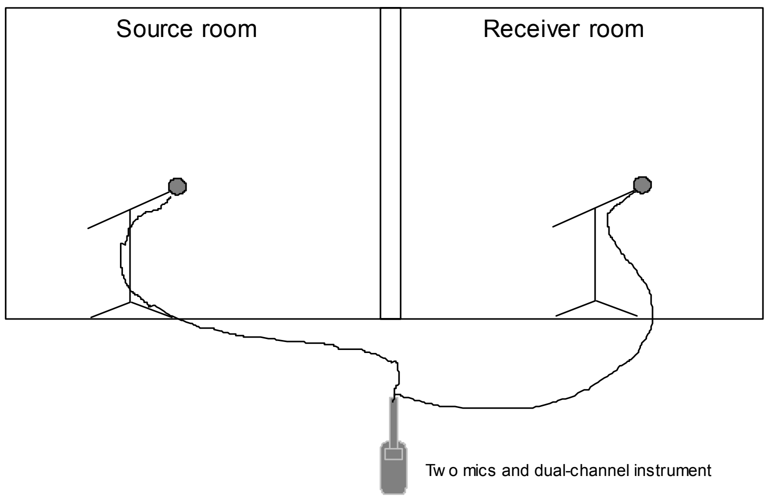



Figure 5 – Test Method 1 (BRE)




<u>Test Method 2 - Static mic positions - source and receiver rooms occupied.</u>

This procedure requires at least two testers, one to remain in the source room whilst the receiver room measurement is taken by the second tester (see Figure 6). For the dual-channel measurements three personnel were required, one to remain in source room, one in the receiver room and one to operate the equipment. This test will examine the effect of the human body on the sound field in both rooms.

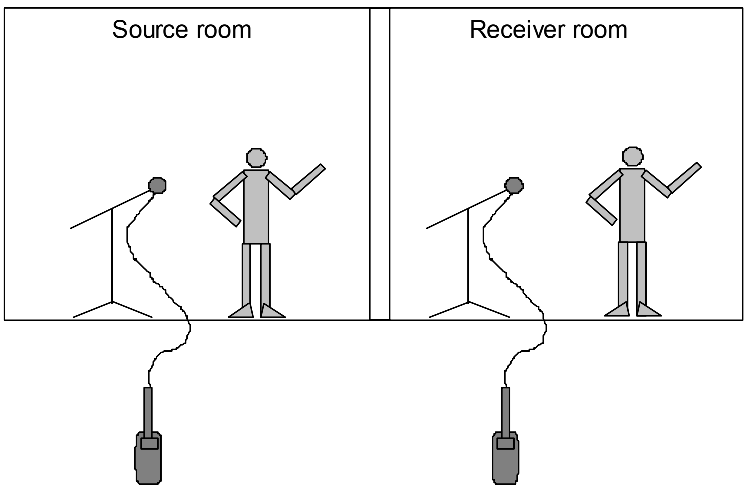
Test Methods 1 and 2 were carried out sequentially by taking 1 measurement with the tester in the room and than taking the 2nd measurement with the tester out of the room, *without moving the microphone*. The sequence was repeated for each of the mic positions on the three-dimensional grid.

The same procedure was repeated for the receiver room measurements, *without moving the sound source*. Background noise in the receiver room was monitored regularly throughout the sequence of measurements.

The process was repeated for the 2nd source position.

For all the body-in-room measurements, care was taken to ensure that the measurement microphone had a clear 'line of sight' to the sound source at each position, to avoid any screening effects caused by the tester's body

Figure 6 – Test Method 2.

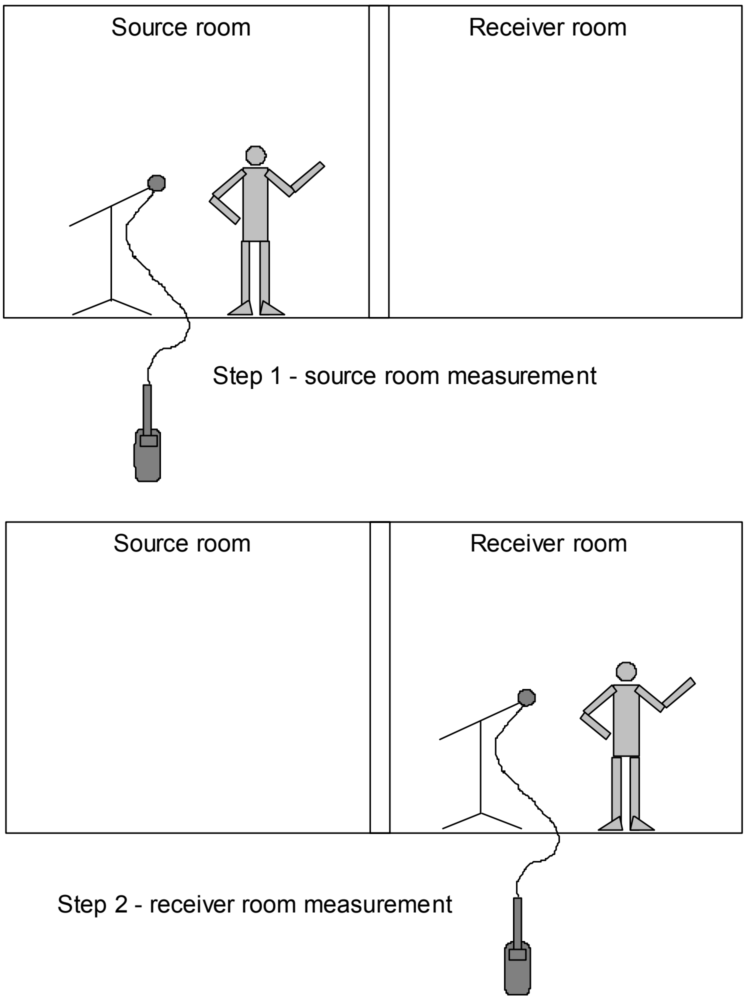



Test Method 3 – Static mic positions - Source room unoccupied while receiver room is occupied.

This test examines the effect of what happens when the tester takes the source room measurement while present in the source room, then leaves the source room and enters the receiving room to take the receiving room measurements. This test also uses fixed mic positions on a stand. This is the favoured procedure adopted by many testers when working on sites single-handed. The only difference between test methods 2 and 3 is the removal of the tester from the source room while the receiving room measurements are taken. Theory predicts that a very small increase in the source room level is to be expected due to the change in the absorption characteristics of the source room.

This test arrangement is illustrated by Figure 7.

Figure 7 – Test Method 3.




Test Method 4 - Moving microphone - Source room unoccupied while receiver room is occupied.

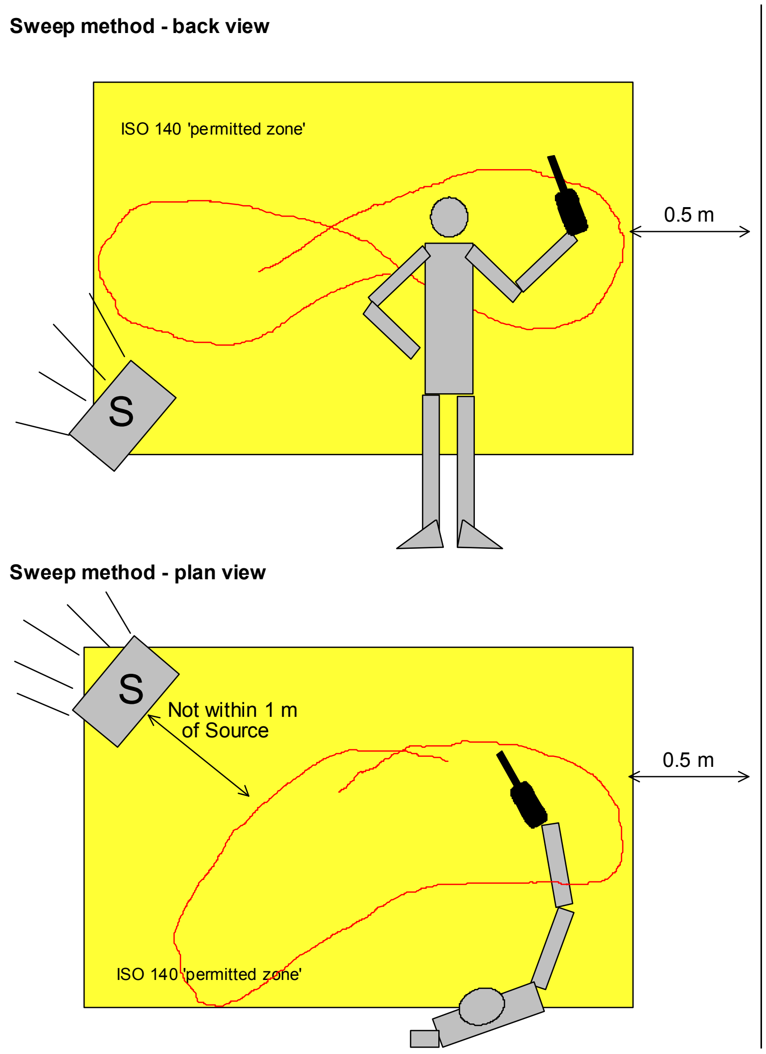
This is variously known as ‘Tai Chi’ method, or the ‘manual moving microphone’ method or MMM! For this experiment, the acoustic conditions are identical to Test 3 but this time the only difference is the method of sampling the sound field. The sweep method was carefully defined for this study to enable repetition by others and is worthy of a detailed description.

The procedure is a slightly refined version of the technique described in the Robust Details Method Statement [5] and is NOT the ‘survey method’ as described in BS EN ISO 10052:2004 [6]. The technique described involves holding the sound level meter (SLM) at arms length and slowly and deliberately moving the SLM to describe a loop, without moving from the spot. The sweep trajectory should form a circle or ellipse according to the description in ISO 140 Part 4, 6.3.2 (b) and yet should try to sample as much of the permitted space as possible without passing too close to a room boundary or the sound source. Examination of the author’s sweep technique shows that there is a natural tendency to 'distort' the trajectory so that in plan the sweep is 'kidney' shaped while in section, the sweep is slightly 'figure-of-eight' shaped. Although the sweep technique was agreed upon by all parties prior to the commencement of the project, it was later realised that this may not be strictly in accordance with the description given in 6.3.2b of ISO 140 [1].

For this test procedure, 16 individual sweeps were recorded for each source position, in both the source room and the receiver room, with the tester moved to a different position for each sweep so that the sweep trajectory passes through different points in the room.

Great care was taken to ensure that the measurement microphone had a clear 'line of sight' to the sound source at all points of the sweep trajectory, to give equivalence to the unattended measurements by avoiding any screening effects caused by the tester's body. Similar care was taken to try to include at least two points on each sweep which were approximately 0.5 metres from two room boundaries, to give equivalence to the fixed measurements.

Figure 8 – Manual sweep technique.



Test  Method 5 - Moving microphone – using a mechanical rotating boom.

This is actually two separate tests, carried out by BRE staff, duplicating the acoustic conditions of Test Method 1, but using a pair of mechanical rotating booms, one in the source room and the other in the receiver room, rather than a series of fixed mic positions.  Test Method 5a was a test in the same direction as all other tests and Test Method 5b was with the test direction reversed.

The measurement equipment was the same dual-channel arrangement to enable source and receiver room measurements to be carried out simultaneously.

## 4.  Source Types, Location and Measurement equipment.

Of the five test methods described in Section 3, three were repeated on different dates, using different source equipment, different instrumentation and under different weather conditions.  Two different testers were used.  In this way, the data analysis can look at reproducibility as well as repeatability, although the test rooms and test direction were the same throughout.

16th March 2007.

| | |
|---|---|
| Test Team | BRE |
| Sound Source | B&K 4224 |
| Instrument | Norsonic Nor 840 (2 channel) |
| Weather | Warm and dry |
| | |
| Test Methods | 1, 2 and 5. |

Brief Description:

The sound source was set on a stand facing into a corner and angled back so as to create a diffuse field.  The source spectrum was generated from within the instrument and adjusted via a third octave graphic equaliser to give a uniform spectrum.  80 microphone positions for each variable, with height increments of 0.5 m

Norsonic 840 used by BRE team


B&K 4224 sound source

16th July 2007

| | |
|---|---|
| Test Team | Iain Critchley (ANC/RDL) |
| Sound Source | JBL Eon 1500 + Norsonic Nor 250 power amplifier |
| Instrument | Norsonic Nor 118 (single channel) |
| Weather | Extremely wet and windy |
| | |
| Test Methods | 1, 3 and 4. |

Brief Description.

The sound source was set on a stand facing into a corner and angled back so as to create the best diffuse field.  Pink noise was generated within the amplifier but has limited electronic adjustment so the spectrum was 'adjusted' by moving the loudspeaker.  40 fixed microphone positions were used and 16 MMM sweeps, with height incremented in 100 mm steps.

Norsonic Nor 250 power amp


JBL ‘Eon’ 1500 loudspeaker

26th July 2007

| | |
|---|---|
| Test Team | Iain Critchley (ANC/RDL) |
| Sound Source | 2, JBL Eon 1500’s + 2, Norsonic Nor 250 power amplifiers |
| Instrument | Norsonic Nor140 (single channel) |
| Weather | Warm and dry but windy. |
| Test Methods | 1, 3 and 4. |

Brief Description.

Tests were carried out using 2 identical sound sources fed with non-coherent signals as required by ISO 140. The sound sources were set on stands facing into the corners and angled back so as to create the best diffuse field. Pink noise was generated within the amplifiers but having limited electronic adjustment so the spectrum was ‘adjusted’ by moving the loudspeakers. 40 fixed mic positions were used, with height incremented in 100 mm steps.


Amps doubled up!

Further tests (tests 15 to 18) were carried out using different loudspeakers (B&K dodecahedron and Norsonic hemi-dodecahedron mounted on the floor) and different orientations of the cabinet loudspeaker (on the floor, facing into the room etc.) For these tests the sampling method was a normal random placement of 5 fixed mic positions as would be used for field tests, rather than the grid positions, with each test repeated three times.

Although the moving microphone method has been carefully described in this report, some tests (tests 19 and 20) were also carried out using a deliberately 'sloppy' technique e.g. creating handling noise in the instrument and scanning the microphone up and down rapidly, to see what affect this has.

These additional variables will not be discussed in detail as they are outside the main remit of the study, but they are included in the summary results for interest.

Dodecahedron loudspeaker

Hemi-dodecahedron loudspeaker

Verification and Calibration of Sound Sources.

ISO 140-4:1998 Para 6.2 requires that the sound generated in the source room shall be steady and have a continuous spectrum in the frequency range considered and that the sound spectrum shall not have differences in level greater than 6 dB between adjacent one-third-octave bands. ADE clarifies this by saying that; "the difference between the *average* sound pressure levels in adjacent one-third-octave bands should be no more than 6 dB".

The BRE test equipment included a graphic equaliser which was used to produce a reasonably flat sound spectrum. Possible drift in output of the sound source over time was checked by taking a periodic reference measurement at a known fixed position. No significant drift was found.

The equipment used by the author did not include a graphic equaliser and used two methods of adjusting the source spectrum;

a) The Norsonic Nor 280 amplifier has selectable spectra composed of ‘pink noise’, ‘white noise’ and combinations thereof. There is a further correction available in this equipment which boosts the LF and the HF energy, designed to compensate for the fall in frequency response at both ends of the audible spectrum which is a characteristic of the compact polyhedron loudspeakers available from this manufacturer. The HF boost also helps overcome background noise.

b) Placing the sound source in a corner as is common practice by most testers for pre-completion sound insulation testing, tends to excite all room modes equally. However, small movements of the sound source relative to the room boundaries can make significant differences to the average sound spectrum in the room.

The author used a combination of methods a) and b) to produce a reasonably flat spectrum. The spectrum was checked by taking one 30 second sweep and moving the sound source slightly until the 6 dB criteria was achieved. The technique is not perfect, however, and differences of greater than 6 dB between adjacent frequency bands are evident in some of the individual measurements due to inevitable pressure level variations in the room due to modal effects.

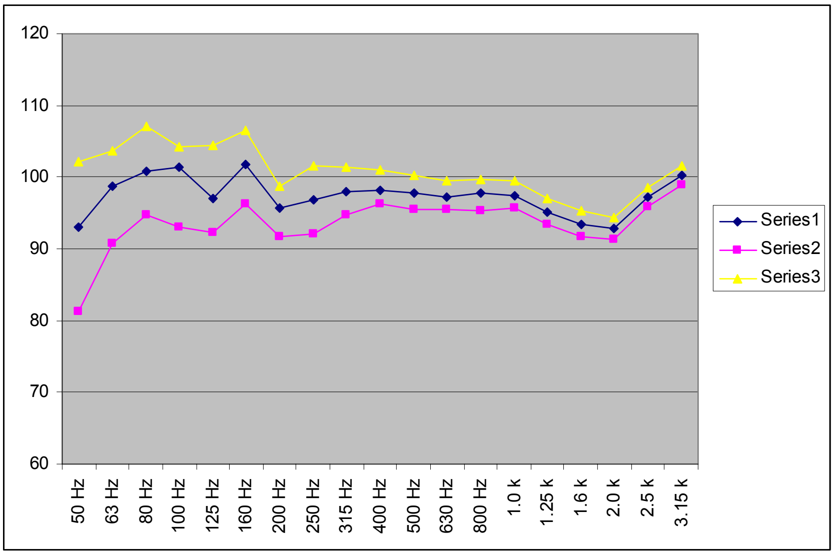
The data analysis upon which this report is based used all of the available test groups and no attempt was made to filter out the 6 dB ‘errors’.

For reference, the average source room spectra for the 16$^{th}$ July and the 26$^{th}$ July are shown in Figures 9 to 12 for comparison, measured using the fixed microphone method and the manual moving microphone method. Note that the average source spectrum on the 16$^{th}$ July has only just met the 6 dB criteria between 160 Hz and 200 Hz in spite of care during initial calibration.

The output of the sound source and amplifier was checked for drift by ‘soak testing’ which involved five, 30 second bursts of pink noise, at full power, with a 20 second cool down period between bursts – without moving the reference microphone. No significant drift was observed between the first and last measurements obtained.

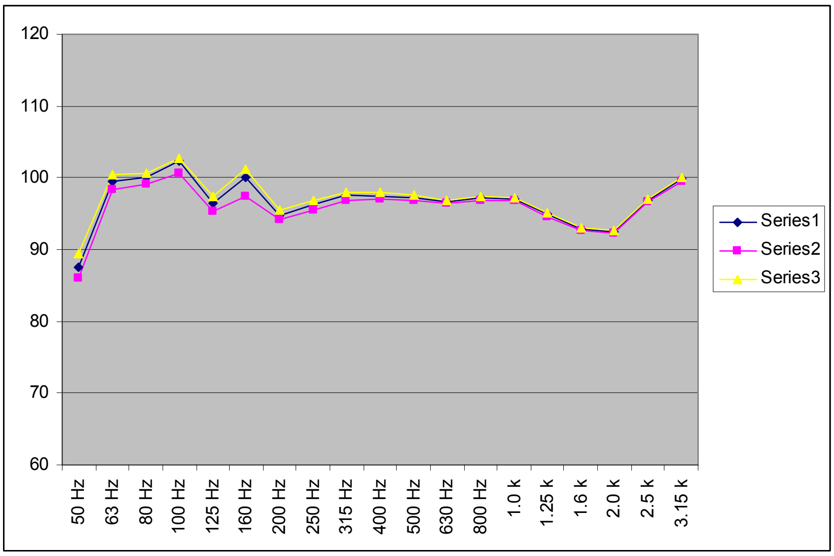
The weighted sound pressure level in the source room measured typically between 110 dBA and 113 dBA - necessary in order to overcome background noise in the receiver room. This clearly carries a risk of hearing damage. High performance ear defenders were worn at all times during exposure to these high noise levels.

Figure 9 – Source Spectra 16th July – single source – position 1 – fixed microphone positions.




Series 1 – Mean value of 40 individual spot measurements.
Series 2 – Lowest value per third octave band at any position
Series 3 – HIghest value per third octave band at any position.

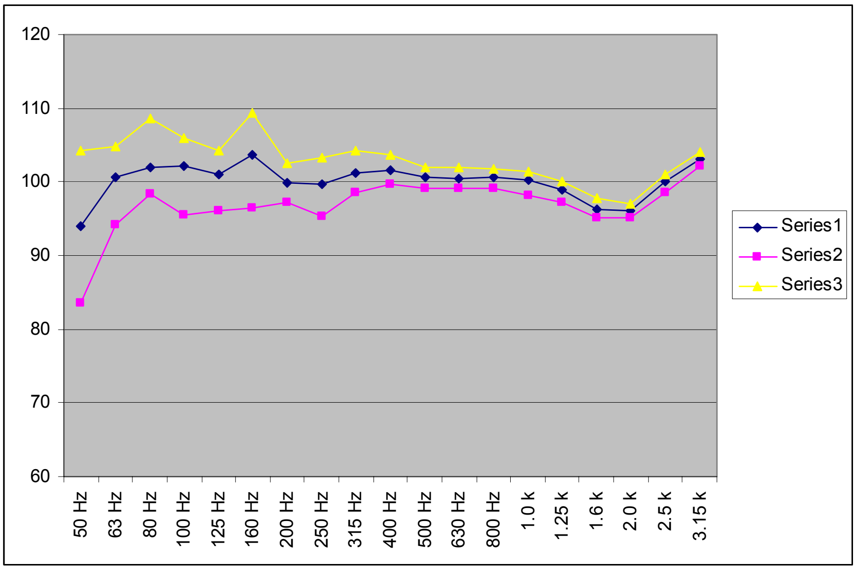
Figure 10 – Source Spectra 16th July – single source – position 1 – manual moving microphone.




Series 1 – Mean value of 16 full sweeps from different centres.
Series 2 – Lowest value per third octave band in any sweep.
Series 3 – Highest value per third octave band in any sweep

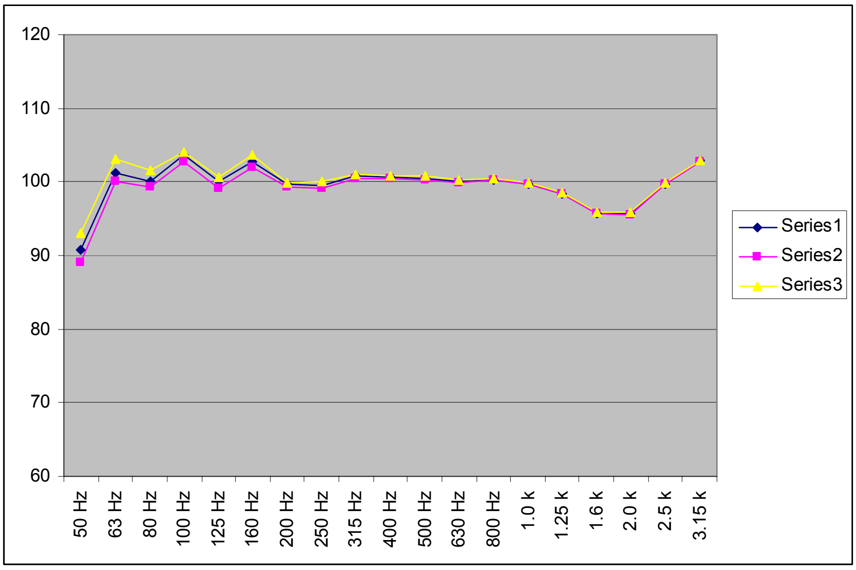
Note that the mean spectra are virtually identical for the two sampling methods but there is a much greater possible range of values for the fixed microphone measurements.

Figure 11 – Source Spectra 26th July – two sources operating simultaneously – fixed microphone positions.




Series 1 – Mean value of 40 individual spot measurements.
Series 2 – Lowest value per third octave band at any position
Series 3 – Highest value per third octave band at any position.

Figure 12 – Source Spectra 26th July – two sources operating simultaneously – manual moving microphone.




Series 1 – Mean value of 10 full sweeps from different centres.
Series 2 – Lowest value per third octave band in any sweep.
Series 3 – HIghest value per third octave band in any sweep

Note the similarity of the mean spectra for the two sampling methods but there is a much greater possible range of values for the fixed microphone measurements.

## 5. Summary test results (50m3 rooms).

Table 2 – mean test results in chronological order

| Test No. | Date | Test Method | Test condition | Mean Test result dB | Range dB | Rounded | SD |
|---|---|---|---|---|---|---|---|
| 1 | 22nd Feb | Method 4 | MMM | 50.4 | 0.2 | 50 | n/a |
| 2 | 22nd Feb | Method 1 | Static - both rooms unoccupied | 50.6 | 0.4 | 51 | n/a |
| 3 | 22nd Feb | Method 2 | Static - both rooms occupied | 50.2 | 0.4 | 50 | n/a |
| 4 | 22nd Feb | Method 3 | Static - source unoccupied/receive r occupied | 50.8 | 0.5 | 51 | n/a |
| 5 | 16th March | Method 5a | Rotating Booms - both rooms unoccupied | 50 | n/a | 50 | n/a |
| 6 | 16th March | Method 5b | Rotating Booms – as 5a but direction reversed | 51 | n/a | 51 | n/a |
| 7 | 16th March | Method 1 | Static - both rooms unoccupied | 50.23 | 1.96 | 50 | 0.38 |
| 8 | 16th March | Method 2 | Static - both rooms occupied | 50.38 | 1.89 | 50 | 0.35 |
| 9 | 16th July | Method 1 | Static - both rooms unoccupied | 51.01 | 1.86 | 51 | 0.34 |
| 10 | 16th July | Method 3 | Static - source unoccupied/receive r occupied | 50.91 | 1.94 | 51 | 0.37 |
| 11 | 16th July | Method 4 | MMM | 50.19 | 1.02 | 50 | 0.19 |
| 12 | 26th July | Method 1 | Static - both rooms unoccupied | 51.06 | 1.63 | 51 | 0.33 |
| 13 | 26th July | Method 3 | Static - source unoccupied/receive r occupied | 50.77 | 1.58 | 51 | 0.29 |
| 14 | 26th July | Method 4 | MMM | 50.55 | 0.71 | 51 | 0.16 |
| 15 | 26th July | Method 1 | Static - both rooms unoccupied | 50 | 0.3 | 50 | n/a |
| 15 | 26th July | Method 1 | Static - both rooms unoccupied | 50.4 | 0.2 | 50 | n/a |
| 17 | 26th July | Method 1 | Static - both rooms unoccupied | 50.4 | 0.4 | 50 | n/a |
| 18 | 26th July | Method 1 | Static - both rooms unoccupied | 50.2 | 0 | 50 | n/a |
| 19 | 26th July | Method 4 | MMM (careless handling of instrument) | 50.4 | n/a | 50 | n/a |
| 20 | 26th July | Method 4 | MMM (rapid scanning of microphone) | 50.5 | n/a | 51 | n/a |

Table 3 – mean test results ranked according to DnTw+Ctr value

| Test No. | Date | Test Method | Test condition | Mean Test result | Range dB | Rounded | SD |
|---|---|---|---|---|---|---|---|
| 5 | 16th March | Method 5a | Rotating Booms - both rooms unoccupied | 50 | n/a | 50 | n/a |
| 15 | 26th July | Method 1 | Static - both rooms unoccupied | 50 | 0.3 | 50 | n/a |
| 11 | 16th July | Method 4 | MMM | 50.19 | 1.02 | 50 | 0.19 |
| 3 | 22nd Feb | Method 2 | Static - both rooms occupied | 50.2 | 0.4 | 50 | n/a |
| 18 | 26th July | Method 1 | Static - both rooms unoccupied | 50.2 | 0 | 50 | n/a |
| 7 | 16th March | Method 1 | Static - both rooms unoccupied | 50.23 | 1.96 | 50 | 0.38 |
| 8 | 16th March | Method 2 | Static - both rooms occupied | 50.38 | 1.89 | 50 | 0.35 |
| 1 | 22nd Feb | Method 4 | MMM | 50.4 | 0.2 | 50 | n/a |
| 15 | 26th July | Method 1 | Static - both rooms unoccupied | 50.4 | 0.2 | 50 | n/a |
| 17 | 26th July | Method 1 | Static - both rooms unoccupied | 50.4 | 0.4 | 50 | n/a |
| 19 | 26th July | Method 4 | MMM (careless handling of instrument) | 50.4 | n/a | 50 | n/a |
| 20 | 26th July | Method 4 | MMM (rapid scanning of microphone) | 50.5 | n/a | 51 | n/a |
| 14 | 26th July | Method 4 | MMM | 50.55 | 0.71 | 51 | 0.16 |
| 2 | 22nd Feb | Method 1 | Static - both rooms unoccupied | 50.6 | 0.4 | 51 | n/a |
| 13 | 26th July | Method 3 | Static - source unoccupied/ receiver occupied | 50.77 | 1.58 | 51 | 0.29 |
| 4 | 22nd Feb | Method 3 | Static - source unoccupied/ receiver occupied | 50.8 | 0.5 | 51 | n/a |
| 10 | 16th July | Method 3 | Static - source unoccupied/ receiver occupied | 50.91 | 1.94 | 51 | 0.37 |
| 6 | 16th March | Method 5b | Rotating Booms – as 5a but direction reversed | 51 | n/a | 51 | n/a |
| 9 | 16th July | Method 1 | Static - both rooms unoccupied | 51.01 | 1.86 | 51 | 0.34 |
| 12 | 26th July | Method 1 | Static - both rooms unoccupied | 51.06 | 1.63 | 51 | 0.33 |

The results for tests 7 through to 14 in Tables 2 and 3 are the result of independent, detailed statistical analysis by CMMS, which is fully explained in the next section. Only the test results for Test Methods 1, 2, 3 and 4 have been statistically analysed for this study.

## 6. Statistical Data Analysis and Results.

The methodology employed for data analysis mimics the calculation procedure used in field testing under the Approved Document E (2003) [3] for Pre-Completion Testing and is in accordance with ISO 717:1996 Part 1 [7] .

### 6.1 Static microphone tests

For each loudspeaker location, ISO 140 requires that data from at least five microphone positions are logarithmically averaged in each one-third octave band for both the source room and the receive room. The receive room averages in each frequency band are corrected for background noise and subtracted from the averaged source room levels to give two sets of background-corrected-level-dfference values (D) corresponding to each of the two source positions. The two sets of level-difference values are then averaged arithmetically, according to ADE, and the reverberation time correction applied to yield the DnT values in each frequency band, from which the single number values of DnTw and Ctr and derived.

Measurements for the occupied and unoccupied rooms are processed separately and the reverberation time values employed are those corresponding to the occupied and unoccupied receive room as appropriate.

### 6.2 Procedure for enabling statistical analysis for static tests.

All calculations of the single number values for DnTw+Ctr are based upon 5 source positions and 5 receiver positions, for each of 2 source positions.

From each set of 80 source room measurements (from the coordinates shown in Figure 1), 16 groups of 5 different microphone positions are possible, for each source position. Similarly, 16 different groups of receive room positions are possible.

A Visual Basic programme was devised to select groups of data in a pseudo-random manner based upon five zones, such that each group consists of 1 mic position from each zone, resulting in a group which is evenly distributed throughout the rooms. This selection process simulates a typical tester's procedure when randomly placing the microphone. The programme also selects receive room data in the same way and the groups are then paired and the DnT values calculated according to ISO 717/1. Pairs are selected from the 2$^{nd}$ source position and the DnTw and Ctr values are calculated. There are a possible 256 different permutations and therefore 256 different DnTw and Ctr values. However, the programming is random so it is possible that some duplication could occur between groups and that two or more mic positions, within a group, could be on the same plane.

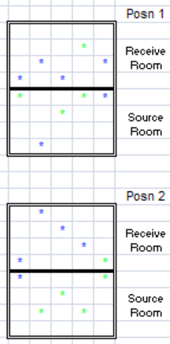
To generate a reasonable number of values for statistical analysis, 200 pairs were calculated by the programme, for each Test Method.

Figure 13 - Example of spreadsheet used to analyse static microphone data.

Body Out of Both Rooms

| | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Speaker Position 1 | Source Room 1 | 97.7 | 100.0 | 99.6 | 93.1 | 94.1 | 102.9 | 94.4 | 97.9 | 98.5 | 99.1 | 98.4 | 97.2 | 97.8 | 98.3 | 96.0 | 94.8 | 93.4 | 96.9 | 100.8 | 103.2 | 104.7 | 1 | | | |
| | | 95.3 | 99.1 | 99.3 | 104.3 | 102.3 | 103.6 | 96.2 | 98.2 | 98.1 | 100.0 | 99.9 | 99.5 | 99.5 | 98.3 | 97.0 | 93.9 | 94.3 | 97.5 | 101.3 | 103.9 | 105.5 | 39 | | | |
| | | 82.2 | 102.6 | 101.7 | 100.0 | 94.3 | 99.9 | 93.7 | 98.2 | 96.4 | 99.7 | 97.0 | 97.3 | 98.0 | 99.4 | 97.0 | 94.4 | 92.7 | 97.6 | 100.8 | 103.8 | 105.1 | 8 | | | |
| | | 98.2 | 95.0 | 99.5 | 103.1 | 99.0 | 102.3 | 95.3 | 98.8 | 100.2 | 101.0 | 99.1 | 97.6 | 98.3 | 97.6 | 96.1 | 93.8 | 92.8 | 97.7 | 100.5 | 103.5 | 104.9 | 4 | | | |
| | | 100.9 | 102.3 | 104.6 | 103.1 | 96.5 | 103.7 | 92.0 | 93.3 | 96.6 | 97.4 | 99.5 | 97.5 | 98.3 | 97.9 | 95.6 | 95.0 | 94.4 | 97.2 | 100.5 | 103.0 | 104.9 | 25 | | | |
| | dB average | 97.5 | 100.5 | 101.5 | 102.0 | 98.4 | 102.7 | 94.5 | 97.6 | 98.2 | 99.6 | 98.9 | 97.9 | 98.4 | 98.3 | 96.4 | 94.4 | 93.6 | 97.4 | 100.8 | 103.5 | 105.0 | | | | |
| | Receive Room 1 | 67.6 | 62.5 | 63.8 | 63.6 | 61.6 | 57.8 | 49.6 | 57.6 | 56.0 | 55.9 | 53.0 | 48.4 | 46.6 | 43.6 | 39.4 | 34.7 | 31.7 | 35.1 | 37.2 | 39.7 | 41.2 | 21 | | | |
| | | 62.5 | 60.0 | 65.6 | 64.3 | 58.9 | 61.9 | 50.3 | 56.1 | 55.2 | 55.2 | 52.3 | 46.9 | 45.8 | 42.2 | 38.8 | 34.0 | 31.5 | 34.8 | 36.8 | 39.2 | 40.4 | 27 | | | |
| | | 67.0 | 64.3 | 66.2 | 61.9 | 60.6 | 57.2 | 51.9 | 52.9 | 55.6 | 55.8 | 51.9 | 47.4 | 45.4 | 43.5 | 38.9 | 34.4 | 32.1 | 34.9 | 36.9 | 38.7 | 40.1 | 23 | | | |
| | | 59.2 | 59.4 | 68.4 | 62.8 | 56.6 | 58.7 | 52.2 | 57.8 | 55.0 | 54.8 | 50.8 | 48.4 | 45.4 | 41.8 | 38.6 | 34.5 | 32.2 | 35.1 | 37.2 | 39.1 | 40.7 | 14 | | | |
| | | 57.9 | 56.1 | 63.8 | 63.6 | 58.9 | 59.0 | 50.2 | 55.2 | 55.9 | 55.0 | 50.9 | 49.5 | 46.7 | 43.0 | 39.7 | 34.3 | 32.3 | 35.2 | 36.4 | 39.7 | 40.9 | 30 | | | |
| | dB average | 64.5 | 61.3 | 65.9 | 63.3 | 59.6 | 59.3 | 51.0 | 56.3 | 55.6 | 55.4 | 51.9 | 48.2 | 46.0 | 42.9 | 39.1 | 34.4 | 32.0 | 35.0 | 36.9 | 39.3 | 40.7 | | | | |
| | corrected for background | 64.5 | 61.3 | 65.9 | 63.3 | 59.6 | 59.3 | 51.0 | 56.3 | 55.6 | 55.4 | 51.9 | 48.2 | 46.0 | 42.9 | 39.1 | 34.4 | 32.0 | 35.0 | 36.9 | 39.3 | 40.7 | | | | |
| Speaker Position 2 | Source Room 2 | 98.1 | 96.7 | 98.4 | 91.1 | 93.3 | 100.3 | 97.0 | 96.3 | 97.7 | 97.1 | 97.4 | 97.5 | 96.4 | 97.9 | 95.1 | 93.5 | 92.6 | 98.0 | 99.6 | 102.6 | 104.8 | 21 | | | |
| | | 89.8 | 96.7 | 99.7 | 102.9 | 94.5 | 98.3 | 93.9 | 97.1 | 95.3 | 97.9 | 96.9 | 97.0 | 98.5 | 98.2 | 95.4 | 94.2 | 92.7 | 97.4 | 99.6 | 102.9 | 104.3 | 12 | | | |
| | | 80.7 | 101.0 | 100.8 | 100.4 | 94.0 | 96.5 | 94.2 | 95.6 | 96.5 | 97.9 | 97.6 | 97.5 | 98.9 | 97.9 | 96.0 | 93.5 | 92.8 | 97.6 | 100.3 | 102.4 | 104.3 | 8 | | | |
| | | 90.7 | 94.9 | 102.5 | 101.2 | 103.7 | 102.0 | 96.2 | 96.8 | 97.5 | 97.9 | 97.3 | 98.7 | 98.8 | 99.7 | 96.3 | 93.5 | 93.4 | 97.3 | 100.8 | 103.1 | 104.8 | 14 | | | |
| | | 99.5 | 102.2 | 105.4 | 100.4 | 95.4 | 101.7 | 97.0 | 97.5 | 100.6 | 97.1 | 97.1 | 96.8 | 98.5 | 97.2 | 94.6 | 92.7 | 92.2 | 97.1 | 100.4 | 102.6 | 104.1 | 5 | | | |
| | dB average | 95.5 | 99.2 | 102.1 | 100.5 | 98.4 | 100.2 | 95.9 | 96.7 | 97.9 | 97.6 | 97.3 | 97.6 | 98.3 | 98.3 | 95.5 | 93.5 | 92.8 | 97.5 | 100.2 | 102.7 | 104.5 | | | | |
| | Receive room 2 | 69.4 | 66.6 | 65.7 | 55.1 | 54.6 | 56.7 | 57.7 | 57.2 | 57.7 | 54.6 | 52.5 | 50.6 | 46.8 | 43.0 | 39.2 | 34.1 | 31.7 | 35.2 | 37.1 | 38.8 | 40.8 | 21 | | | |
| | | 68.4 | 65.2 | 66.1 | 64.5 | 61.3 | 57.5 | 55.8 | 54.5 | 55.1 | 56.5 | 50.1 | 49.7 | 45.9 | 43.0 | 39.5 | 34.0 | 32.0 | 34.9 | 37.6 | 39.9 | 40.7 | 39 | | | |
| | | 57.8 | 59.7 | 67.0 | 61.9 | 57.8 | 54.6 | 53.4 | 56.1 | 57.5 | 54.7 | 52.2 | 48.7 | 46.6 | 43.0 | 38.8 | 34.3 | 31.8 | 34.7 | 38.3 | 39.3 | 41.1 | 33 | | | |
| | | 60.9 | 57.5 | 67.1 | 64.9 | 57.6 | 53.1 | 55.9 | 55.6 | 58.6 | 57.3 | 51.3 | 48.9 | 45.4 | 42.7 | 39.2 | 33.8 | 32.0 | 34.9 | 37.4 | 39.5 | 40.5 | 29 | | | |
| | | 70.3 | 66.6 | 68.5 | 65.1 | 60.6 | 55.7 | 56.7 | 54.8 | 56.5 | 55.8 | 52.0 | 49.0 | 46.1 | 42.2 | 37.9 | 33.5 | 32.1 | 34.3 | 37.2 | 38.8 | 40.1 | 5 | | | |
| | dB average | 67.5 | 64.5 | 67.0 | 63.4 | 59.0 | 55.8 | 56.1 | 55.7 | 57.2 | 55.9 | 51.7 | 49.4 | 46.2 | 42.8 | 39.0 | 33.9 | 31.9 | 34.8 | 37.5 | 39.3 | 40.7 | | | | |
| | corrected for background | 67.5 | 64.5 | 67.0 | 63.4 | 59.0 | 55.8 | 56.1 | 55.7 | 57.2 | 55.9 | 51.7 | 49.4 | 46.2 | 42.8 | 39.0 | 33.9 | 31.9 | 34.8 | 37.5 | 39.3 | 40.7 | | Dntw | | Dntw + Ctr |
| | level difference 1 | 33.1 | 39.2 | 35.6 | 38.7 | 38.8 | 43.4 | 43.6 | 41.4 | 42.6 | 44.2 | 47.0 | 49.7 | 52.4 | 55.5 | 57.3 | 60.0 | 61.6 | 62.4 | 63.9 | 64.2 | 64.4 | | | | |
| | DnT1(corrected for RT) | 37.8 | 43.4 | 38.7 | 40.6 | 41.1 | 45.6 | 47.2 | 45.7 | 46.7 | 48.8 | 51.4 | 53.8 | 56.4 | 59.3 | 61.0 | 63.6 | 65.0 | 65.3 | 66.4 | 66.3 | 66.2 | | 57 | -5 | 51.94 |
| | level difference 2 | 28.0 | 34.7 | 35.1 | 37.1 | 39.4 | 44.4 | 39.7 | 41.0 | 40.7 | 41.7 | 45.6 | 48.1 | 52.1 | 55.5 | 56.6 | 59.6 | 60.8 | 62.7 | 62.6 | 63.4 | 63.8 | | | | |
| | DnT2(corrected for RT) | 32.7 | 38.9 | 38.2 | 39.0 | 41.7 | 46.6 | 43.3 | 45.2 | 44.8 | 46.2 | 49.9 | 52.2 | 56.1 | 59.3 | 60.3 | 63.1 | 64.2 | 65.6 | 65.1 | 65.6 | 65.7 | | 55 | -4 | 50.57 |
| | DnT(mean) | 35.3 | 41.1 | 38.5 | 39.8 | 41.4 | 46.1 | 45.3 | 45.4 | 45.7 | 47.5 | 50.6 | 53.0 | 56.2 | 59.3 | 60.7 | 63.3 | 64.6 | 65.4 | 65.7 | 65.9 | 65.9 | | 56 | -5 | 51.31 |
| | Background | 30.0 | 25.0 | 31.9 | 31.9 | 25.3 | 25.8 | 22.6 | 21.8 | 25.4 | 22.4 | 23.1 | 24.7 | 27.2 | 28.6 | 25.4 | 19.3 | 12.8 | 8.7 | 7.8 | 7.4 | 7.0 | | | | |
| | RT1(T30 body out) | 1.50 | 1.30 | 1.03 | 0.78 | 0.85 | 0.83 | 1.15 | 1.34 | 1.29 | 1.42 | 1.35 | 1.27 | 1.25 | 1.21 | 1.19 | 1.13 | 1.08 | 0.97 | 0.89 | 0.82 | 0.77 | | | | |
| | RT2(T30 body in) | 1.54 | 1.30 | 1.01 | 0.83 | 0.81 | 0.83 | 1.12 | 1.26 | 1.24 | 1.36 | 1.29 | 1.14 | 1.07 | 1.02 | 1.00 | 0.97 | 0.92 | 0.85 | 0.78 | 0.72 | 0.67 | | | | |

Clear Select Stats




## 6.3 Moving microphone tests

Only one sweep is required, according to ISO 140, in source and receiver rooms for each source position. Spatial-averaging is achieved by default. The receive room data in each frequency band is corrected for background noise and subtracted from the source room levels to give two sets of background-corrected-level-dfference values (D) corresponding to each of the two source positions. The two sets of level-difference values are then averaged arithmetically, according to ADE, and the reverberation time correction applied to yield the DnT values in each frequency band, from which the single number values of DnTw and Ctr are derived.

Measurements for the occupied and unoccupied rooms are processed separately and the reverberation time values employed are those corresponding to the occupied and unoccupied receive room as appropriate.

## 6.4 Procedure for enabling statistical analysis for moving mic tests.

All calculations of the single number values for DnTw+Ctr are based upon 1 source sweep and 1 receiver sweep, for each of 2 source positions.

With 16 source sweeps and 16 receiver sweeps, per source position, 256 different permutations of paired data are possible. The Visual Basic programming for the moving microphone data was simpler as there was no logarithmic averaging required.

To generate a reasonable number of values for statistical analysis, 200 pairs were used by the programme to calculate single number values, for each set of test data.

Figure 14 - Example of spreadsheet used to analyse moving microphone data

| | Moving Microphone | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LS1 | Source Sweep 1 | 86.7 | 99.2 | 99.5 | 102.5 | 95.9 | 99.6 | 94.9 | 95.9 | 97.6 | 97.5 | 97.3 | 96.9 | 97.4 | 97.1 | 94.9 | 93.0 | 92.5 | 97.1 | 100.0 | 102.7 | 104.4 | 11 | | |
| | Receive Sweep 1 | 56.6 | 58.5 | 68.0 | 64.3 | 59.6 | 57.6 | 51.5 | 55.9 | 56.0 | 55.7 | 51.8 | 47.9 | 45.7 | 42.2 | 38.2 | 33.6 | 31.6 | 34.7 | 36.7 | 38.8 | 40.2 | 9 | | |
| | corrected for background | 56.6 | 58.5 | 68.0 | 64.3 | 59.6 | 57.6 | 51.5 | 55.9 | 56.0 | 55.7 | 51.8 | 47.9 | 45.7 | 42.2 | 38.2 | 33.6 | 31.6 | 34.7 | 36.7 | 38.8 | 40.2 | | | |
| LS2 | Source Sweep 2 | 87.3 | 99.4 | 101.0 | 103.5 | 95.6 | 96.5 | 94.8 | 96.1 | 97.5 | 96.9 | 97.8 | 96.8 | 97.2 | 97.2 | 94.7 | 92.8 | 92.5 | 96.8 | 99.6 | 102.6 | 104.3 | 13 | | |
| | Receive Sweep 2 | 59.4 | 59.6 | 67.0 | 64.6 | 60.5 | 55.5 | 54.0 | 55.4 | 57.3 | 54.8 | 50.6 | 48.0 | 44.8 | 41.5 | 37.8 | 33.1 | 31.2 | 34.4 | 36.7 | 38.9 | 40.3 | 15 | | |
| | corrected for background | 59.4 | 59.6 | 67.0 | 64.6 | 60.5 | 55.5 | 54.0 | 55.4 | 57.3 | 54.8 | 50.6 | 48.0 | 44.8 | 41.5 | 37.8 | 33.1 | 31.2 | 34.4 | 36.7 | 38.9 | 40.3 | | | |
| | level difference 1 | 30.1 | 40.7 | 31.5 | 38.2 | 36.3 | 42.0 | 43.4 | 40.0 | 41.6 | 41.8 | 45.5 | 49.0 | 51.7 | 54.9 | 56.7 | 59.4 | 60.9 | 62.4 | 63.3 | 63.9 | 64.2 | | | |
| | DnT1(corrected for RT) | 35.0 | 44.8 | 34.6 | 40.4 | 38.4 | 44.2 | 46.9 | 44.0 | 45.5 | 46.1 | 49.6 | 52.6 | 55.0 | 58.0 | 59.7 | 62.3 | 63.5 | 64.7 | 65.2 | 65.5 | 65.5 | 55.0 | -5.0 | 50.41 |
| | level difference 2 | 27.9 | 39.8 | 34.0 | 38.9 | 35.1 | 41.0 | 40.8 | 40.7 | 40.2 | 42.1 | 47.2 | 48.8 | 52.4 | 55.7 | 56.9 | 59.7 | 61.3 | 62.4 | 62.9 | 63.7 | 64.0 | | | |
| | DnT2(corrected for RT) | 32.8 | 43.9 | 37.1 | 41.1 | 37.2 | 43.2 | 44.3 | 44.7 | 44.1 | 46.4 | 51.3 | 52.4 | 55.7 | 58.8 | 59.9 | 62.6 | 63.9 | 64.7 | 64.8 | 65.3 | 65.3 | 55.0 | -5.0 | 50.07 |
| | DnT(mean) | 33.9 | 44.4 | 35.8 | 40.8 | 37.8 | 43.7 | 45.6 | 44.4 | 44.8 | 46.3 | 50.5 | 52.5 | 55.4 | 58.4 | 59.8 | 62.4 | 63.7 | 64.7 | 65.0 | 65.4 | 65.4 | 55.0 | -5.0 | 50.28 |

## 6. Results (50m3 rooms)

The results of the 200 equivalent measurements in each of the various categories have been processed:

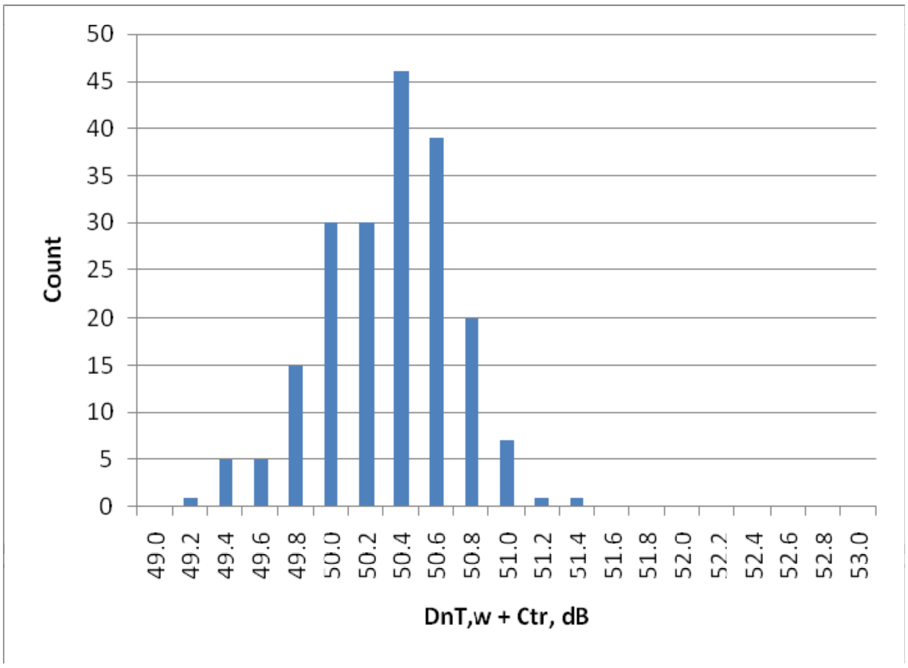
• to extract histograms showing the distribution of DnTw + Ctr values,

• to extract the descriptive statistics for each category

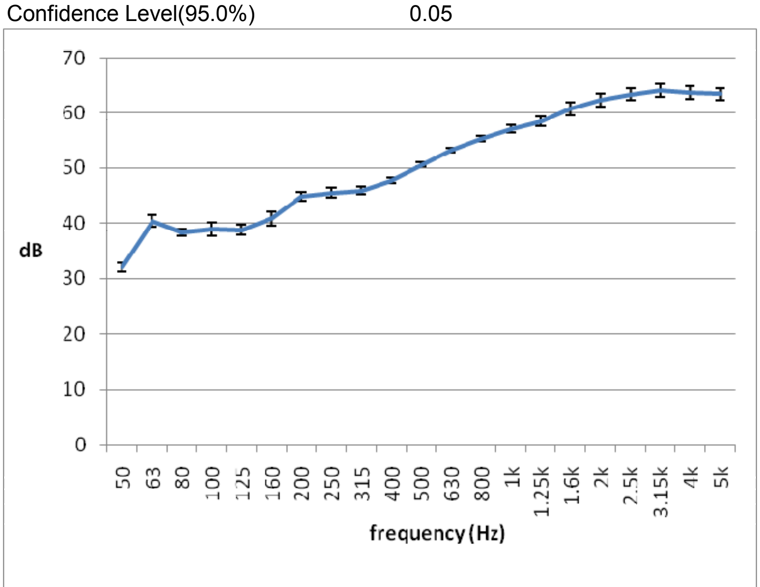
• to calculate the mean and standard deviations of the final DnT values in each of the one third octave bands calculated from all 200 equivalent tests (shown graphically with the standard deviations as error bars)

• to show the Dntw + Ctr values calculated from these means

All values have been calculated to two decimal places as the results are very close. These are shown below as Tests 7 to 14

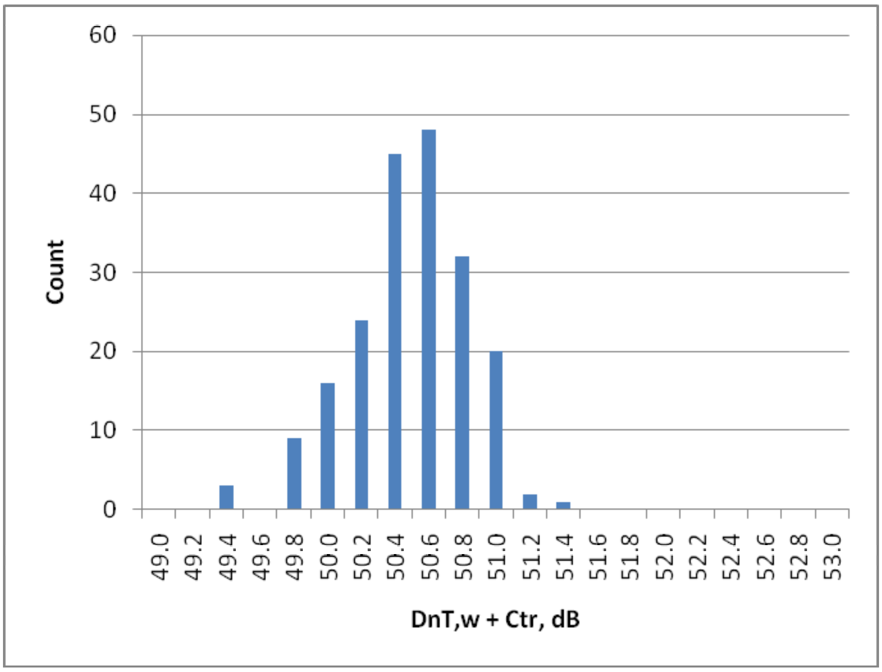



| | |
|---|---|
| Mean | 50.23 |
| Standard Error | 0.03 |
| Median | 50.26 |
| Standard Deviation | 0.38 |
| Sample Variance | 0.15 |
| Range | 2.12 |
| Minimum | 49.10 |
| Maximum | 51.22 |
| Sum | 10045.23 |
| Count | 200.00 |
| Confidence Level(95.0%) | 0.05 |

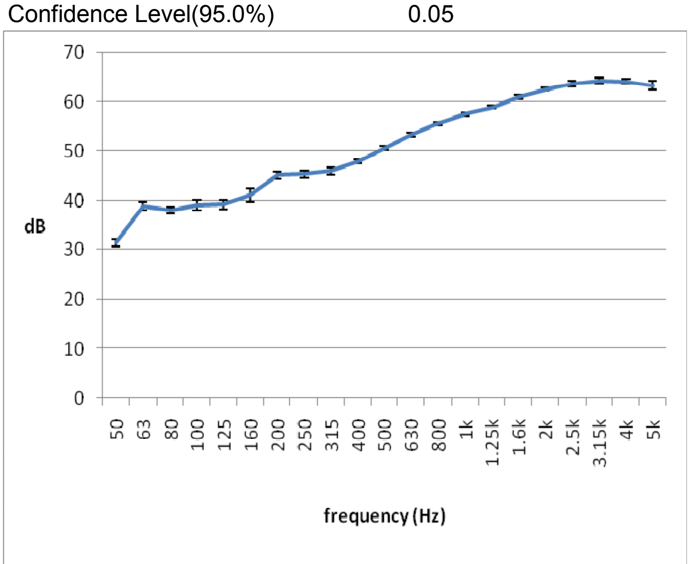



Dntw + Ctr = 50.31

Figure 15 - Test 7 16th March Static Microphones Both rooms unoccupied (Method 1)

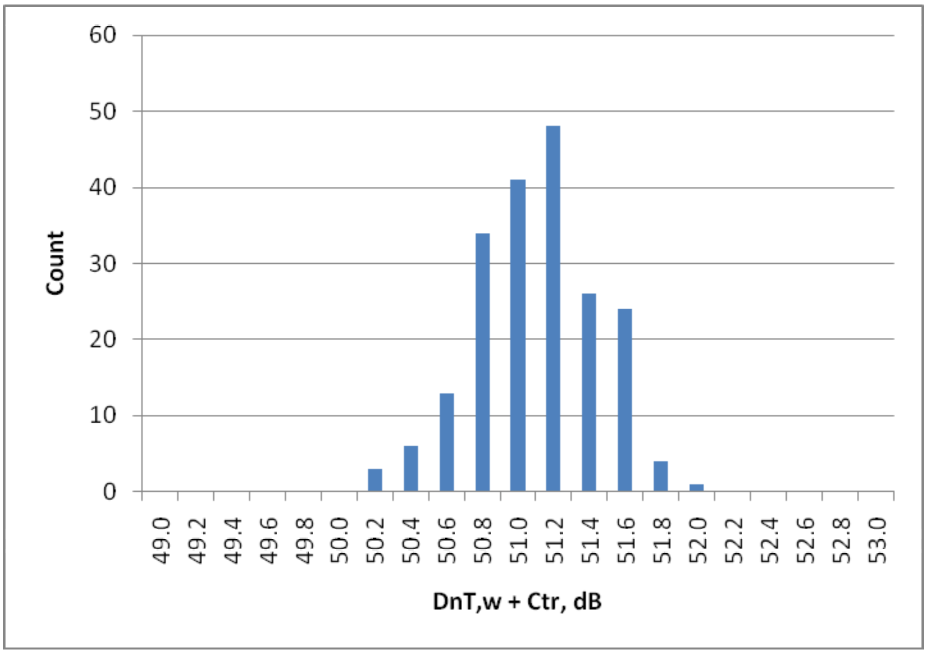



| | |
|---|---|
| Mean | 50.38 |
| Standard Error | 0.02 |
| Median | 50.43 |
| Standard Deviation | 0.35 |
| Sample Variance | 0.12 |
| Range | 2.02 |
| Minimum | 49.29 |
| Maximum | 51.31 |
| Sum | 10076.69 |
| Count | 200.00 |
| Confidence Level(95.0%) | 0.05 |

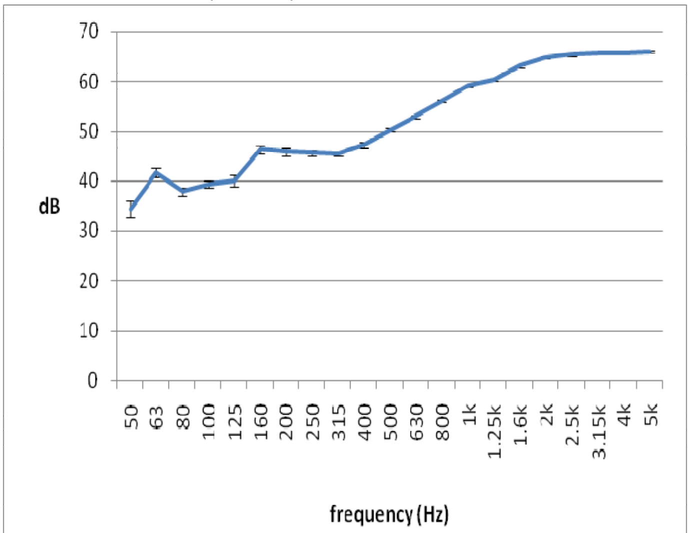



Dntw + Ctr = 50.45

Figure 16 Test 8 16th March Static Microphones Both rooms occupied (Method 2)

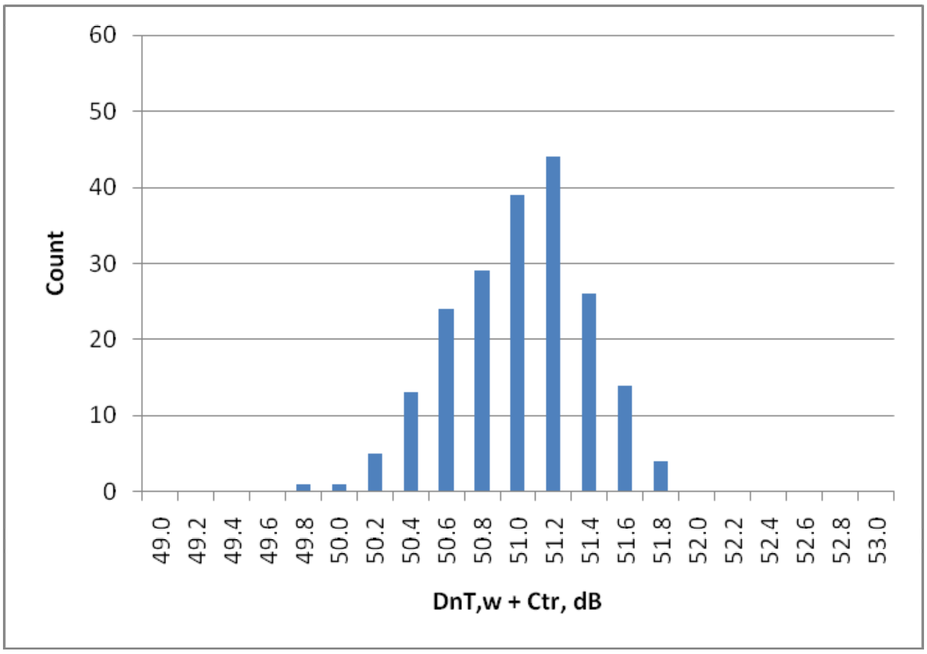



| | |
|---|---|
| Mean | 51.01 |
| Standard Error | 0.02 |
| Median | 51.00 |
| Standard Deviation | 0.34 |
| Sample Variance | 0.11 |
| Range | 1.86 |
| Minimum | 50.08 |
| Maximum | 51.94 |
| Sum | 10201.23 |
| Count | 200.00 |
| Confidence Level(95.0%) | 0.05 |

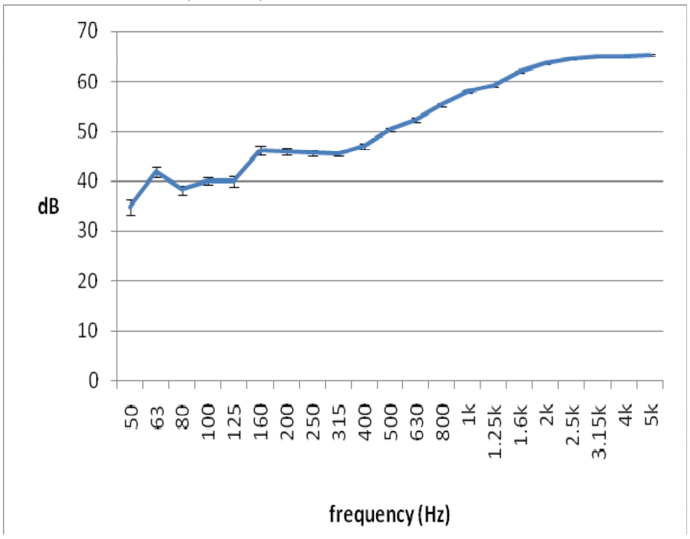



Dntw + Ctr = 51.05

Figure 17 Test 9 16th July  Static Microphones Both rooms unoccupied (Method 1)

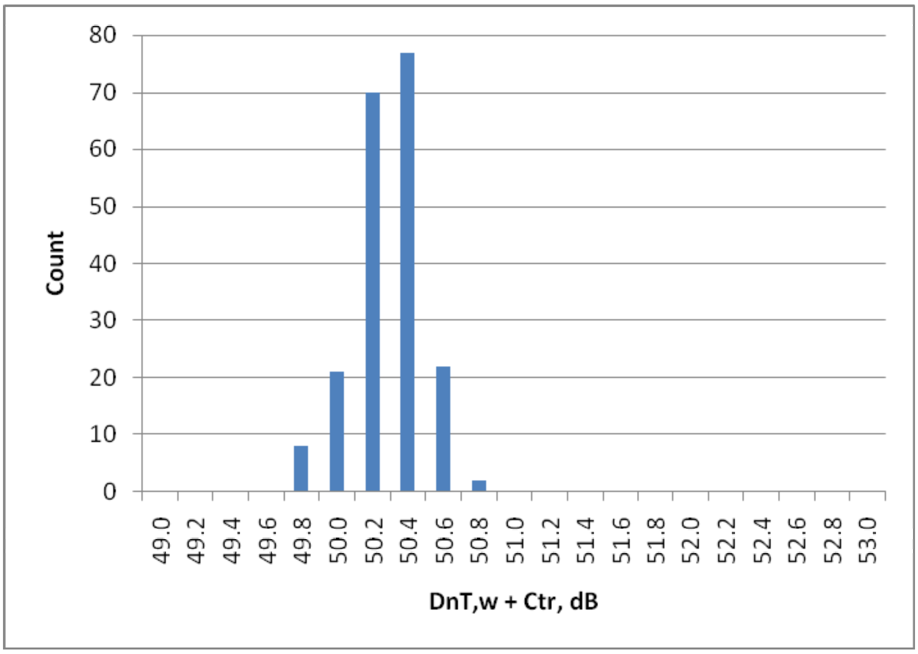



| | |
|---|---|
| Mean | 50.91 |
| Standard Error | 0.03 |
| Median | 50.92 |
| Standard Deviation | 0.37 |
| Sample Variance | 0.14 |
| Range | 1.94 |
| Minimum | 49.76 |
| Maximum | 51.70 |
| Sum | 10181.30 |
| Count | 200.00 |
| Confidence Level(95.0%) | 0.05 |

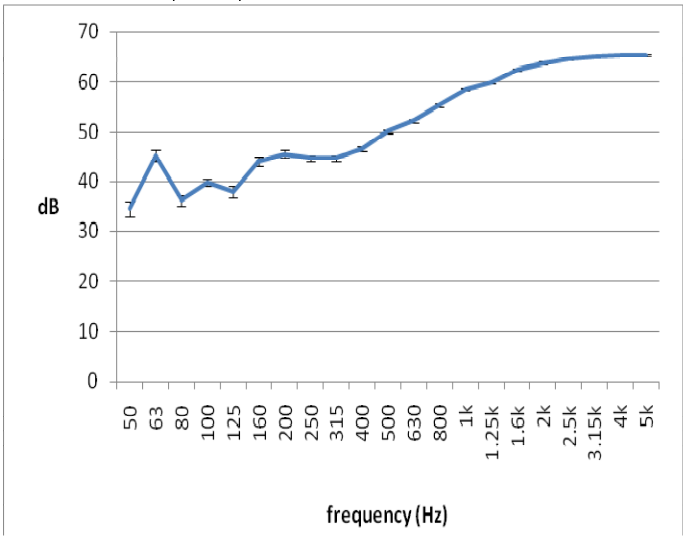



Dntw + Ctr = 50.95

Figure 18 Test 10 16th July Static Microphones Source room unoccupied Receive room occupied (Method 3)

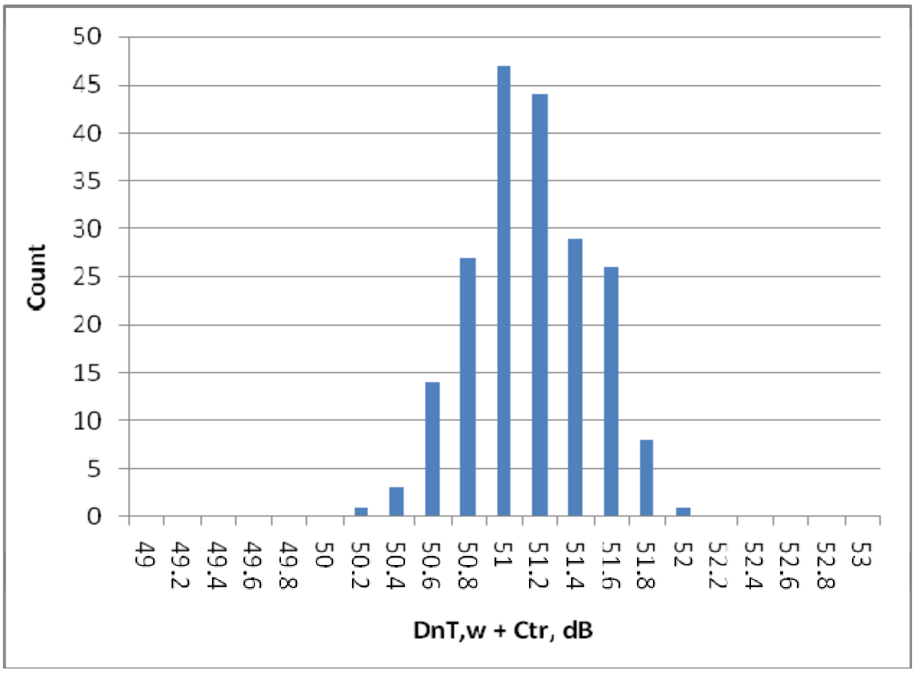



| | |
|---|---|
| Mean | 50.19 |
| Standard Error | 0.01 |
| Median | 50.20 |
| Standard Deviation | 0.19 |
| Sample Variance | 0.04 |
| Range | 1.02 |
| Minimum | 49.65 |
| Maximum | 50.67 |
| Sum | 10038.49 |
| Count | 200.00 |
| Confidence Level(95.0%) | 0.03 |

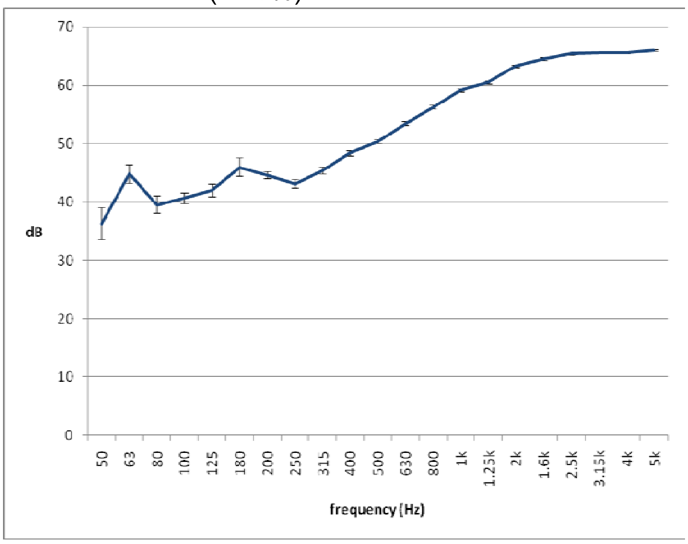



Dntw + Ctr = 50.21

Figure 19 Test 11 16th July Moving Microphones (Method 4)

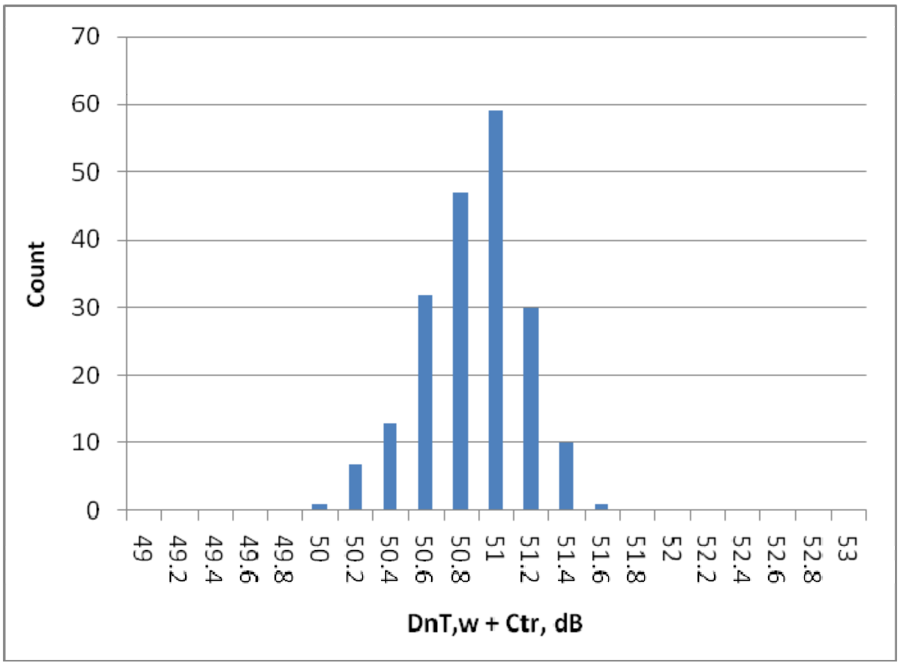



| | |
|---|---|
| Mean | 51.06 |
| Standard Error | 0.02 |
| Median | 51.05 |
| Standard Deviation | 0.33 |
| Sample Variance | 0.11 |
| Range | 1.63 |
| Minimum | 50.18 |
| Maximum | 51.81 |
| Sum | 10211.18 |
| Count | 200.00 |
| Confidence Level(95.0%) | 0.05 |

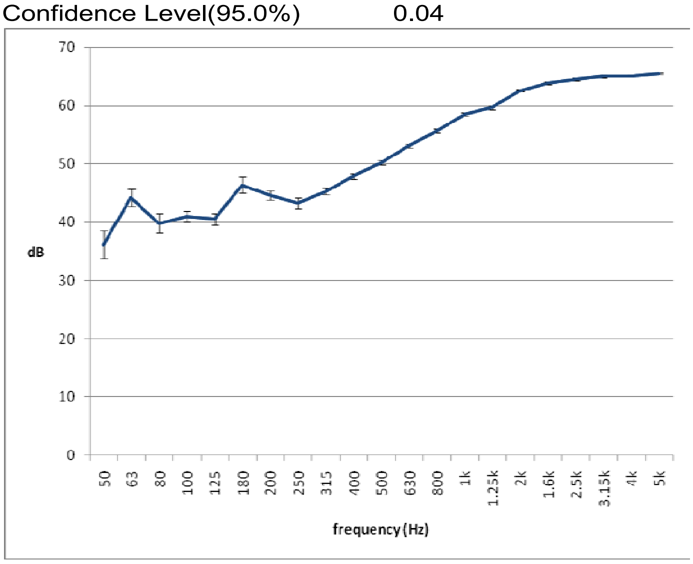



Dntw + Ctr = 51.11

Figure 20 Test 12 26th July Static Microphones both rooms unoccupied (Method 1)

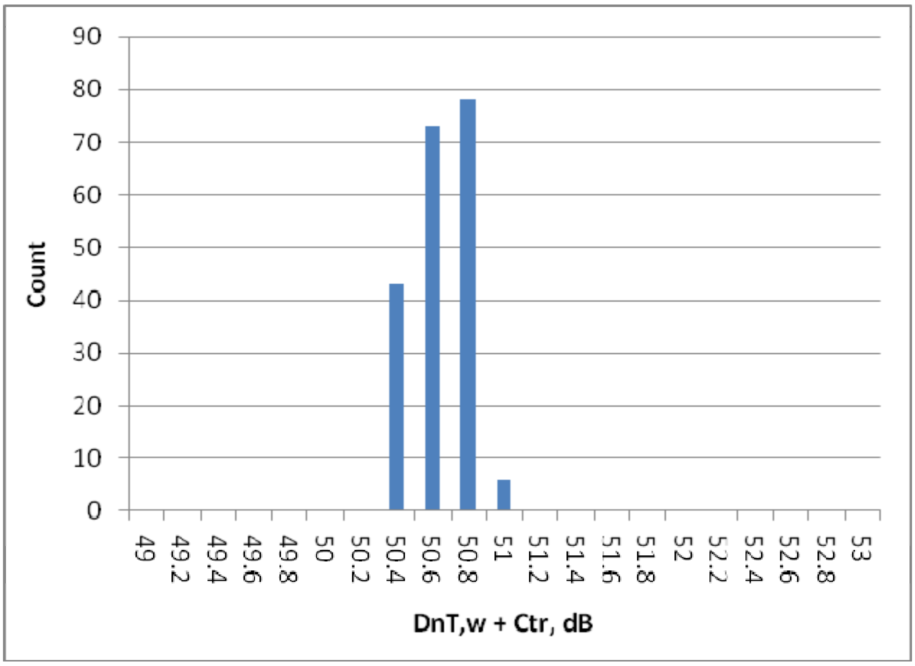



| | |
|---|---|
| Mean | 50.77 |
| Standard Error | 0.02 |
| Median | 50.80 |
| Standard Deviation | 0.29 |
| Sample Variance | 0.08 |
| Range | 1.58 |
| Minimum | 49.89 |
| Maximum | 51.47 |
| Sum | 10154.44 |
| Count | 200.00 |
| Confidence Level(95.0%) | 0.04 |

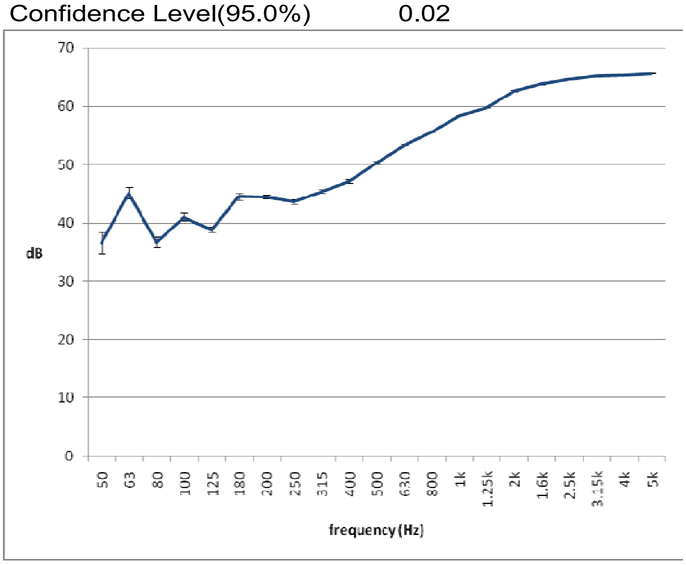



Dntw + Ctr = 50.83

Figure 21 Test 13 26th July Static Microphones Source room unoccupied Receive room occupied (Method 3)




| | |
|---|---|
| Mean | 50.55 |
| Standard Error | 0.01 |
| Median | 50.57 |
| Standard Deviation | 0.16 |
| Sample Variance | 0.02 |
| Range | 0.71 |
| Minimum | 50.24 |
| Maximum | 50.94 |
| Sum | 10110.10 |
| Count | 200.00 |
| Confidence Level(95.0%) | 0.02 |




Dntw + Ctr = 50.57

Figure 22 Test 14 26th July Moving Microphones (Method 4)

## 7. The Determination of Repeatability Values from the Test Data

### 7.1 Introduction

International Standard ISO:140-2:1991 [8] introduces the concept of Repeatability as a measure of the precision of measurements of sound insulation in buildings and building elements. Repeatability is defined as the value below which the absolute difference between two single test results obtained under repeatability conditions may be expected to lie with a probability of 95%. Repeatability conditions refer to the situation in which independent test results are obtained with the same method on identical test material in the same laboratory with the same equipment by the same operator within short intervals of time. Tentative target values of the repeatability are given in the standard.

Given the substantial amount of data generated in these tests under what clearly amount to repeatability conditions the opportunity has been taken to determine the repeatability values for each of the tests reported here by an empirical method.

The results are compared with the target values given in the standard as a means of comparing the precision of the measurements generated by the test procedures adopted for this study which are typical of the normal field procedures used for pre-completion sound insulation testing.

The repeatability values given here are for field determinations of the standardised level difference DnT in sixteen one-third octave bands. The comparison with the target values of the standard has to be made cautiously as the values quoted in the standard are for measurements of sound reduction index under laboratory conditions. The standard perhaps can be thought of as offering a useful, if severe, quantitative benchmark for measurement precision.

### 7.2 Measurement of repeatability

For each test 200 sets of DnT values are generated in each of sixteen[1] one-third octave bands. For each band absolute differences between all 200 sets of values are calculated. (19900 differences) The differences are grouped in steps of 0.2 dB and the cumulative distribution found as shown in Figure 23.

According to the definition of repeatability the absolute difference corresponding to the 95% level is the repeatability value.

This process has been carried out for 16 bands in the 8 tests (7 to 14) referred to in the body of the report.

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[1] The standard refers to the frequency range 100 Hz to 3150 Hz

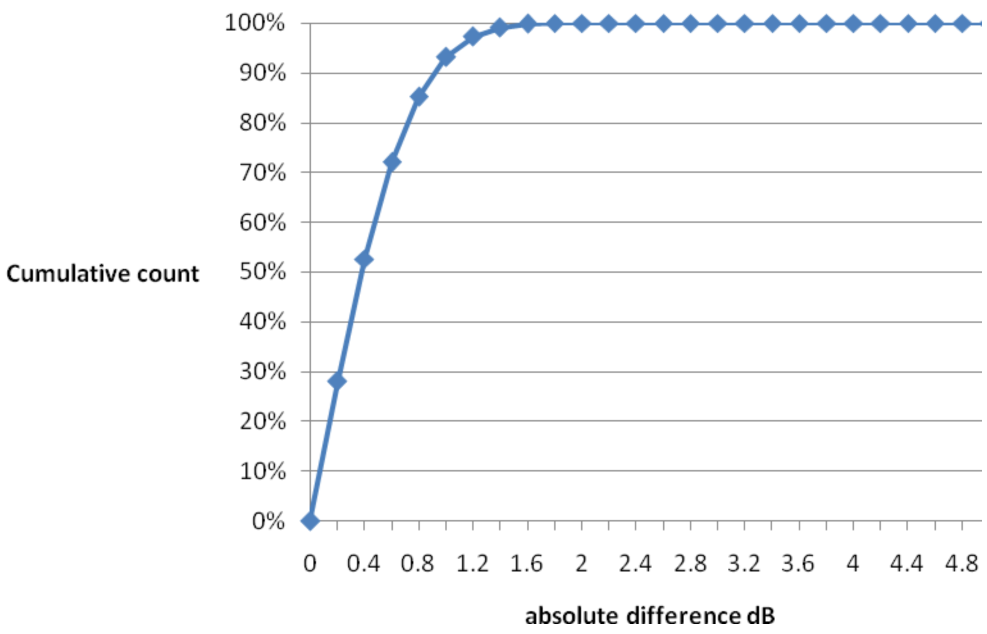


Figure 23 Cumulative count of absolute differences for the calculation of repeatability, r (Test 2 Static microphone, occupied rooms, 630 Hz)

## 7.3 Results (50m3 rooms)

The repeatability values for the eight tests are shown in the following Figures 24 to 26

The results show that for Tests 8 to 14 the repeatability values compare reasonably well with the target values of the standard although the poor repeatability at 160 Hz was more evident for tests 12 and 13 for reasons which are not obvious but which are accounted for by the wider variation in sound pressure level in the room, at 160 Hz, produced by the two simultaneous sound sources. With the single sound source, the variation was 10.4 dB but with two sources, the variation is 12.8 dB. This can be seen by looking at Figures 9 and 11, in section 4 of this paper.

The results of the repeatability tests are reassuring especially in view of the comments made in the introduction with the regard to the stringency of the standard. The repeatability values given by the moving microphone method of measurement are particularly good.

The reasons for the high values of the absolute differences shown at high frequencies in Test 1 are not fully explainable but are thought to be due to background interference during one set of unoccupied receive room measurements.

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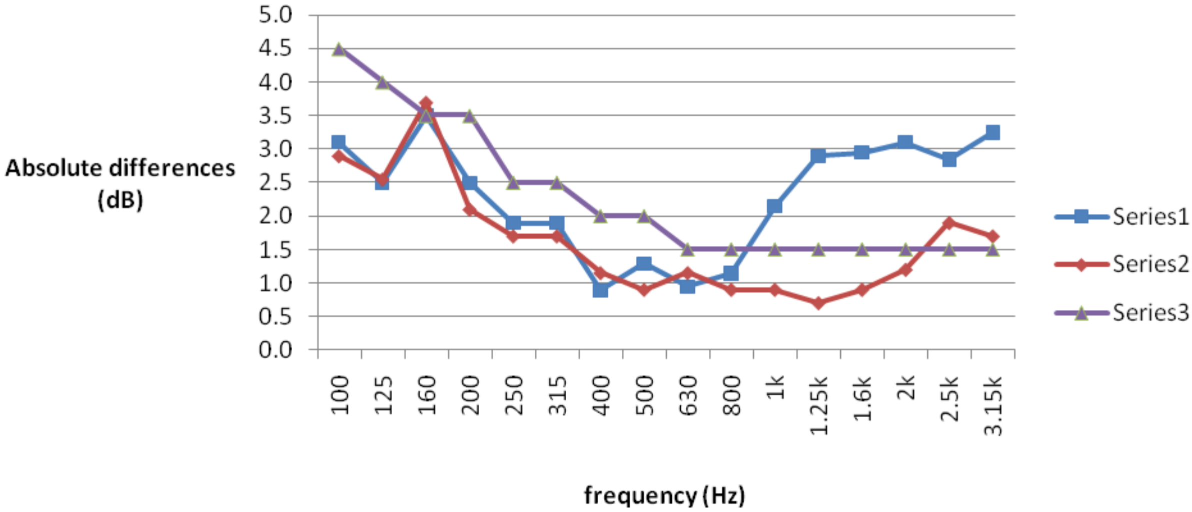
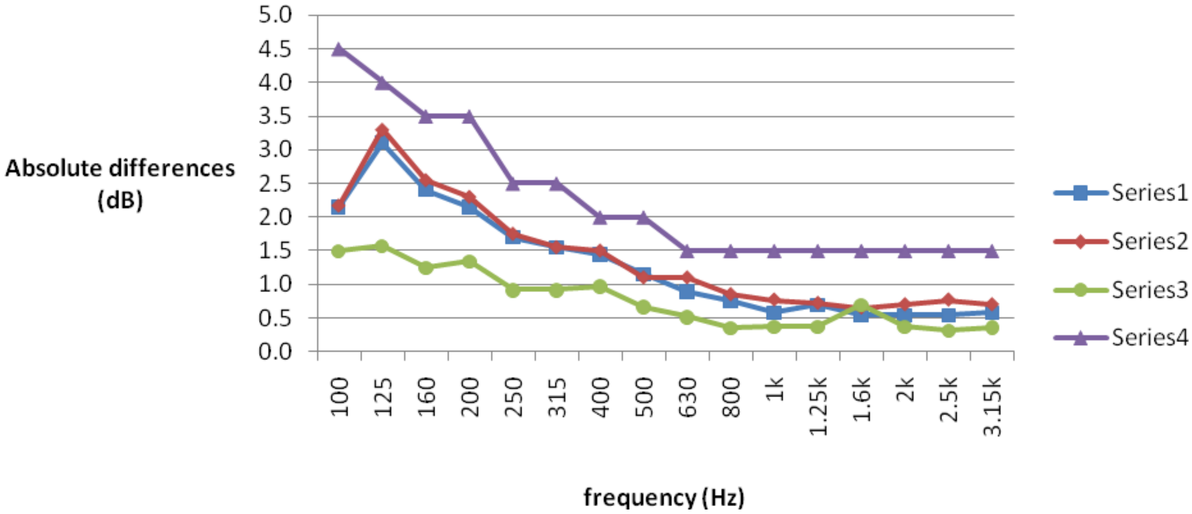


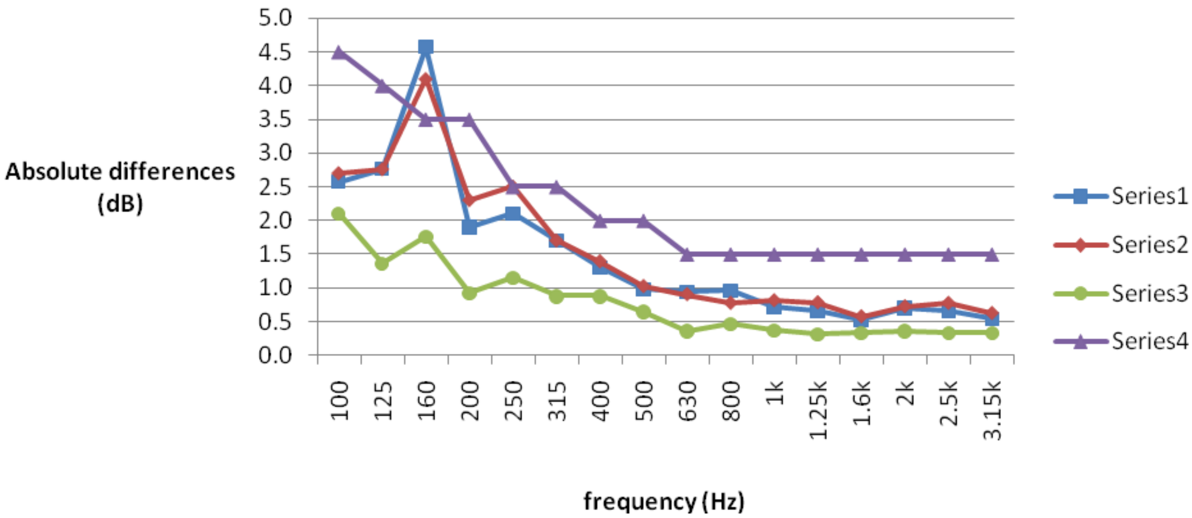

Series 1 -Static microphone, unoccupied rooms
Series 2 -Static microphone, both rooms occupied
Series 3 - ISO 140-2:1991

Figure 24 Repeatability values for Tests 7 and 8 (16th March)




Series 1 -Static microphone, unoccupied rooms
Series 2 -Static microphone, Source room unoccupied when receiver room occupied
Series 3 -Moving microphone
Series 4 - ISO 140-2:1991

Figure 25 Repeatability vaues for Tests 9, 10 and 11 (16th July)




Series 1 -Static microphone, unoccupied rooms
Series 2 -Static microphone, Source room unoccupied when receiver room occupied
Series 3 -Moving microphone
Series 4 - ISO 140-2:1991

Figure 26 Repeatability values for Tests 12, 13 and 14 (26th July)

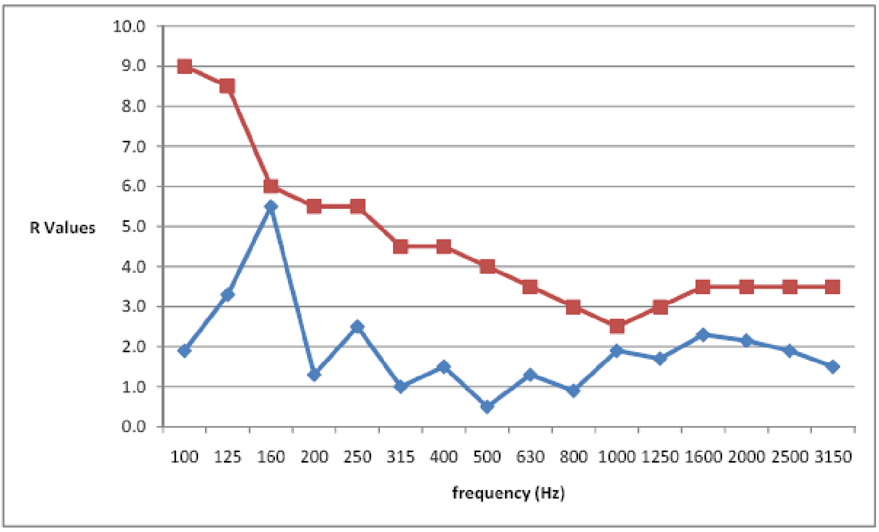



Figure 27 Reproducibility values for tests 7 to 14. ISO 140-2 R values for airborne sound reduction index – field tests.

Reproducibility for field tests is defined as the difference between two independent test results found by two operators or two testing teams on the same location. The reproducibility value R (calculated as for repeatability r) should not exceed the values given in Table A3 of the standard, represented by the red reference curve in the graph.

## 8. Discussion (based on test results obtained in 50m$^3$ rooms)

Test Method 1.

All the test results obtained using Method 1 (Static mic positions and unoccupied rooms) are based upon the minimum of five mic positions and two source positions required for the ISO 140 Part 4 standard. No attempt was made to improve repeatability by selecting more positions e.g. 10 or 20, as advocated by Turner and Ramadorai [9], although this could easily be done using the present data set.

With this small number of sample points in the room, the wide variation of possible sound pressure levels between individual points means that the energy average spectrum from just five points, as permitted in the standard, is not necessarily a true representation of the average sound energy in the room. In the low frequency region, the variation from point to point in the relevant third octave band is as high as 15 dB. This is clearly illustrated in Figures 9 and 11, in section 4 of this paper. It follows that the repeatability is likely to be poor compared to multiple sample points, or a continuous sweep.

The mean test results for this method, over the different test dates, are close, however and range from 50 dB DnTw+Ctr to 51.06 dB DnTw+Ctr and represent both ends of the overall scale of results for this study. The spread of individual tests is 3 dB and it would be possible, using this measurement method, to obtain test results for this party wall ranging from 49 dB DnTw+Ctr to 52 dB DnTw+Ctr.

The large differences between tests at high frequency as revealed by the repeatability graph of Figure 24 cannot be explained at this time as these tests were not carried out by the author. This could be the result of a single rogue measurement, possibly affected by background noise, or may be a data error. This does not seem to have affected the overall mean test results in any way.

Test Method 2.

The test results with both rooms occupied show similar sensitivity to variation across the sound field as for Method 1 with no significant difference in the test results, due to the occupancy of the rooms, revealed by the statistical analysis.

The mean test results for this method over the different test dates are between 50.2 dB DnTw+Ctr and 51.38 dB DnTw+Ctr and represent both ends of the overall scale of results for this study. The spread of individual tests is less than 2 dB and it would be possible, using this measurement method, to also obtain test results for this party wall ranging from 50 dB DnTw+Ctr to 52 dB DnTw+Ctr.

Test Method 3.

For these tests, the source room measurements are taken using fixed mic positions as for Method 2, with the tester present in the source room. The tester then leaves the source room, with the measurement equipment and takes the receiver room measurements while present in the receiver room.

As fixed microphone positions are used, the limitations imposed by the small number of samples and the wide variations in pressure level across the room, also apply to this Test Method as for Methods 1 and 2.

The mean test results for this method over the different test dates are between 50.77 dB DnTw+Ctr and 50.91 dB DnTw+Ctr. The spread of results for this Method are also just below 2 dB and it would be possible, using this measurement method, to also obtain test results for this party wall ranging from 50 dB DnTw+Ctr to 52 dB DnTw+Ctr.

The removal of the tester from the source room should, in theory at least, tend to give a slightly conservative (i.e. lower) test result than the comparative tests where the test rooms are either both occupied, or both unoccupied. This effect appears to be so small as to be insignificant in the context of this phase of the study, as there is no significant difference between the test results produced by Method 3 and Method 2 (both rooms occupied). In fact the lowest individual test result of 49 dB DnTw+Ctr was produced using Test Method 1 (both rooms unoccupied).

Test Method 4.

The moving microphone measurements were taken with the tester present in the source room and then leaving the source room to perform the receiver room measurement. The acoustic conditions in respect of room occupation are therefore identical to Test Method 3. All test results are based on level differences between two sweeps, 1 source, 1 receiver, for each of two source positions.

In terms of repeatability according to ISO 140-2:1991, the moving microphone measurements give the most repeatable results. This is most notable in the low frequency region where other investigators [9] and [10] have found difficulty. The repeatability of this technique seems almost impervious to variations in sound pressure level between adjacent frequency bands caused by room artefacts, presumably because each sweep is equivalent to many hundreds of measurement samples and the pressure variations are therefore more faithfully recorded. This is clearly evident by examination of Figures 9 to 12 in section 4 of this paper.

The mean test results for this method over the different test dates are between 50.2 dB DnTw+Ctr and 50.55 dB DnTw+Ctr and are towards the middle of the scale of results for this study with two of the tests rounding to 51 dB. The spread of individual tests is 1 dB, and it would be possible to also obtain test results for the party wall, using this test method, ranging from 50 dB DnTw+Ctr to 52 dB DnTw+Ctr.

Again, the anticipated reduction in the DnTw+Ctr value resulting from the removal of the tester from the source room, is so small as to be insignificant when comparing test methods.

I has been suggested earlier in this report that if the 'manual moving microphone method' is employed, then the sweep technique itself is critical in obtaining reliable results. It is interesting to note, however, that two of the moving microphone tests were performed using a deliberately 'wrong' technique. One involved moving the microphone very rapidly in a series of up/down and side to side swings, the second involved moving the hand on the instrument to create handling noise. Neither of these tests showed any significant difference in the single figure values.

Reproducibility between test methods.

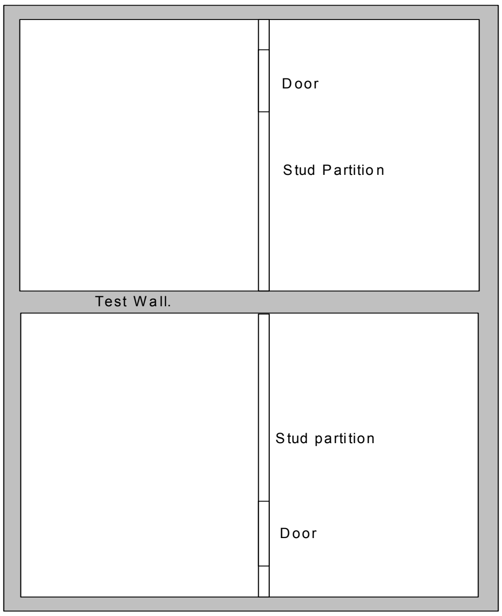
The reproducibility values for all tests are within the criteria of ISO 140-2:1991.

The 160 Hz value is closest to the reference value and this is due to the test methods based on fixed mic positions and the sensitivity to room modes.

## 9. Update October 2007 - Tests in smaller rooms.

The tests were repeated in October 2007 when the 50m3 rooms were each divided into two smaller rooms by the construction of new partition walls, as shown in Figure 28.

Figure 28 – Small room test arrangement




The tests were repeated in each pair of rooms ($30m^3$ and $20m^3$) in a similar manner as described in Section 4, for test methods 1, 3 and 4, except that a 0.7 m grid was used, rather than 1m, to obtain a sufficient number of sampling positions.

The test methods are summarised again briefly as follows:

Test Method 1 – Static microphone positions both rooms unoccupied.

Test Method 3 – Static microphone positions, source room occupied for source room measurements but unoccupied during receive room measurements.

Test Method 4 – Manually swept microphone, single sweep with source room occupied for source room measurement, but unoccupied during receive room measurements.

## 9.1 Test Results in small rooms

As for the large room data, the results of the 200 equivalent measurements for each of the test variables have been processed:

• to extract histograms showing the distribution of DnTw + Ctr values,

• to extract the descriptive statistics for each category

• to calculate the mean and standard deviations of the final DnT values in each of the one third octave bands calculated from all 200 equivalent tests (shown graphically with the standard deviations as error bars)

• to show the Dntw + Ctr values calculated from these means

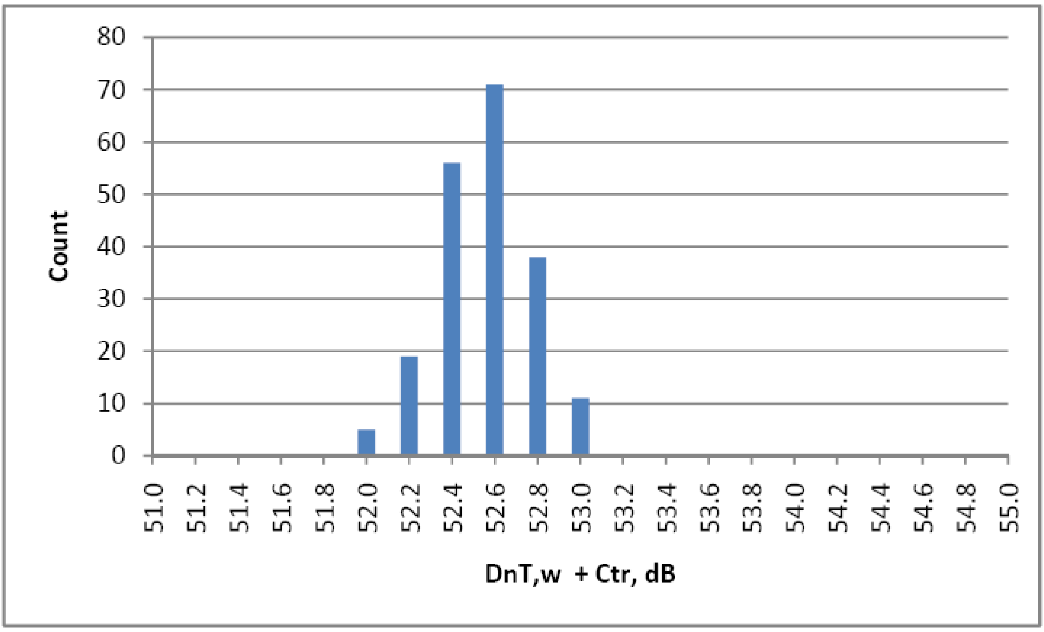
All values have been calculated to two decimal places as the results are very close. The results of each of the six tests are summarised in Tables 4 and 5 and illustrated graphically in Figures 29 to 34.

Table 4 – summary results of small room tests.

| Test | Date | Room Size | Method | Mean (rounded) | Mean (to 2dp) | SD | Min | Max | Range |
|---|---|---|---|---|---|---|---|---|---|
| 21 | 17/10/2007 | 30 | Static unoccupied | 53 | 52.67 | 0.23 | 51.92 | 53.19 | 1.260 |
| 22 | 17/10/2007 | 30 | Static, occupied | 52 | 52.37 | 0.27 | 51.63 | 53.04 | 1.400 |
| 23 | 17/10/2007 | 30 | Moving microphone | 52 | 52.11 | 0.14 | 51.8 | 52.49 | 0.690 |
| 24 | 18/10/2007 | 20 | Static unoccupied | 52 | 52.46 | 0.22 | 51.87 | 52.99 | 1.120 |
| 25 | 18/10/2007 | 20 | Static, occupied | 52 | 52.32 | 0.25 | 51.63 | 52.88 | 1.250 |
| 26 | 18/10/2007 | 20 | Moving microphone | 52 | 51.5 | 0.31 | 50.58 | 52.23 | 1.650 |

Table 5 – Comparison with $50m^3$ room data

| Test | Date | Room Size | Method | Mean (rounded) | Mean (to 2dp) | SD | Min | Max | Range |
|---|---|---|---|---|---|---|---|---|---|
| 9 | 16/07/2007 | 50 | Static unoccupied | 51 | 51.01 | 0.34 | 50.08 | 51.94 | 1.860 |
| 10 | 16/07/2007 | 50 | Static, occupied | 51 | 50.91 | 0.37 | 49.76 | 51.7 | 1.940 |
| 11 | 16/07/2007 | 50 | Moving microphone | 50 | 50.19 | 0.19 | 49.65 | 50.67 | 1.020 |
| 12 | 26/07/2007 | 50 | Static unoccupied | 51 | 51.06 | 0.33 | 50.18 | 51.81 | 1.630 |
| 13 | 26/07/2007 | 50 | Static, occupied | 51 | 50.77 | 0.29 | 49.89 | 51.47 | 1.580 |
| 14 | 26/07/2007 | 50 | Moving microphone | 51 | 50.55 | 0.16 | 50.24 | 50.94 | 0.710 |
| 21 | 17/10/2007 | 30 | Static unoccupied | 53 | 52.67 | 0.23 | 51.92 | 53.19 | 1.260 |
| 22 | 17/10/2007 | 30 | Static, occupied | 52 | 52.37 | 0.27 | 51.63 | 53.04 | 1.400 |
| 23 | 17/10/2007 | 30 | Moving microphone | 52 | 52.11 | 0.14 | 51.8 | 52.49 | 0.690 |
| 24 | 18/10/2007 | 20 | Static unoccupied | 52 | 52.46 | 0.22 | 51.87 | 52.99 | 1.120 |
| 25 | 18/10/2007 | 20 | Static, occupied | 52 | 52.32 | 0.25 | 51.63 | 52.88 | 1.250 |
| 26 | 18/10/2007 | 20 | Moving microphone | 52 | 51.5 | 0.31 | 50.58 | 52.23 | 1.650 |




| | |
|---|---|
| Mean | 52.46 |
| Standard Error | 0.02 |
| Median | 52.46 |
| Standard Deviation | 0.22 |
| Sample Variance | 0.05 |
| Range | 1.12 |
| Minimum | 51.87 |
| Maximum | 52.99 |
| Count | 200.00 |
| Confidence Level (95.0%) | 0.03 |

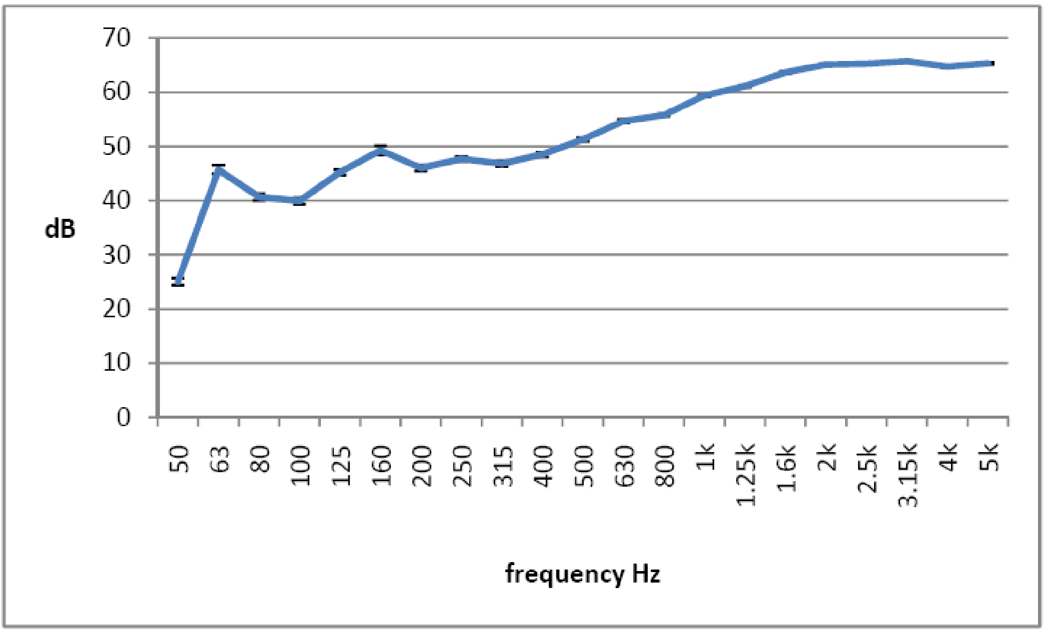
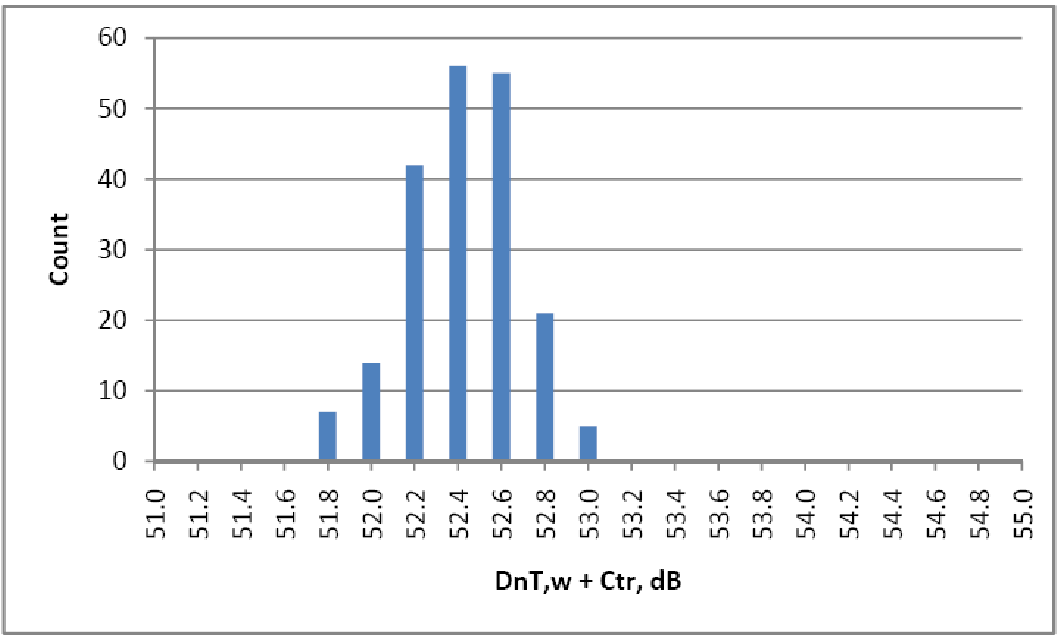



Figure 29 - 20m3 rooms - Static Microphones, both rooms unoccupied (Method 1)




| | |
|---|---|
| Mean | 52.32 |
| Standard Error | 0.02 |
| Median | 52.33 |
| Standard Deviation | 0.25 |
| Sample Variance | 0.06 |
| Range | 1.25 |
| Minimum | 51.63 |
| Maximum | 52.89 |
| Count | 200.00 |
| Confidence Level (95.0%) | 0.04 |

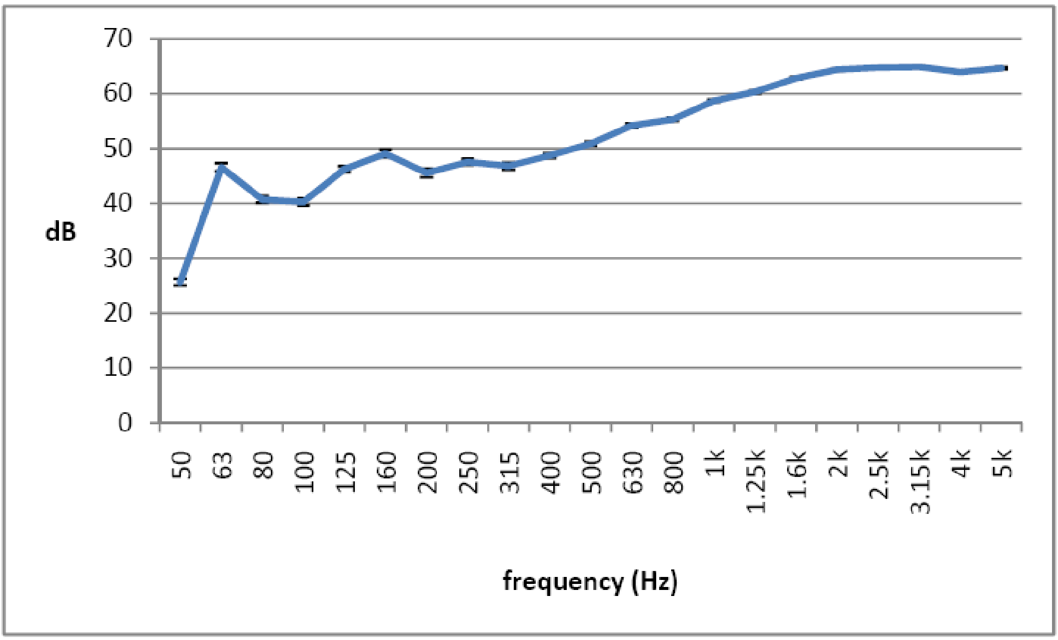
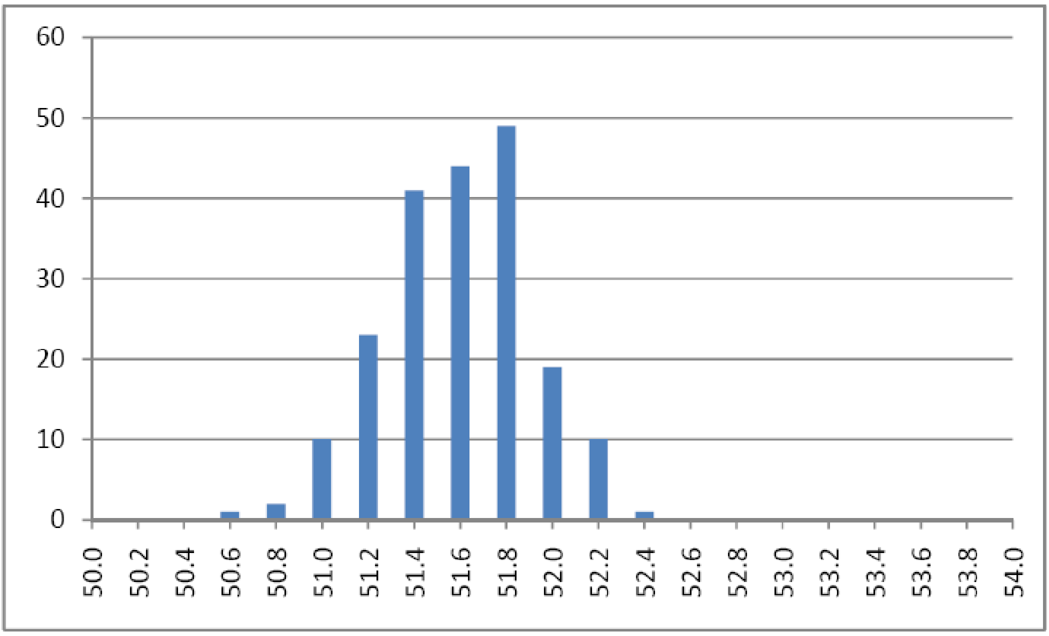



Figure 30 - 20m3 rooms - Static Microphones, source room unoccupied, receiver room occupied (Method 3)




| | |
|---|---|
| Mean | 51.50 |
| Standard Error | 0.02 |
| Median | 51.53 |
| Standard Deviation | 0.31 |
| Sample Variance | 0.10 |
| Range | 1.65 |
| Minimum | 50.58 |
| Maximum | 52.23 |
| Count | 200.00 |
| Confidence Level (95.0%) | 0.04 |

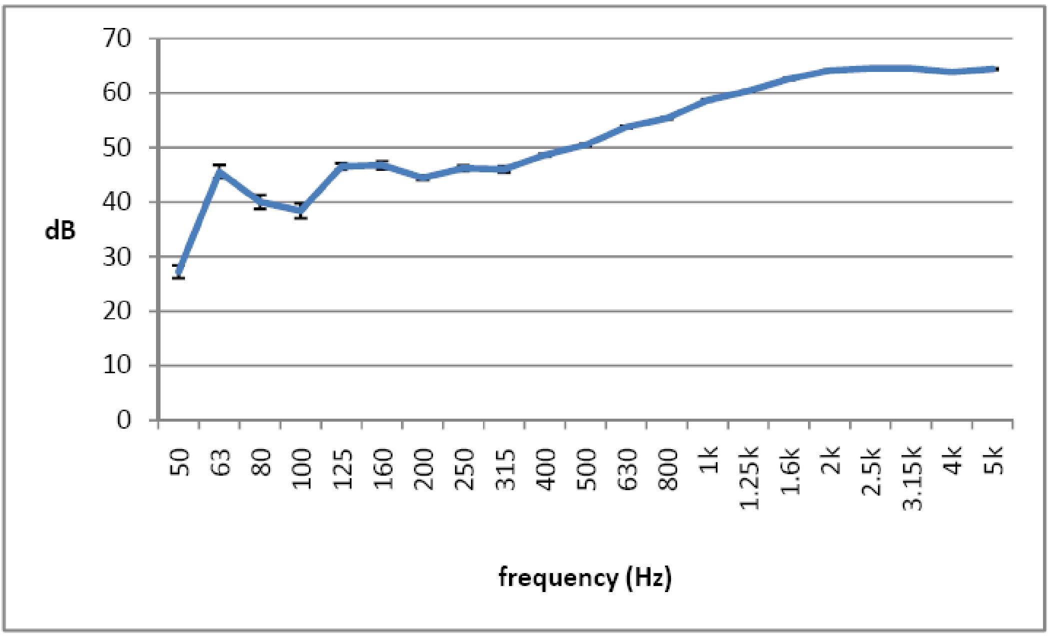
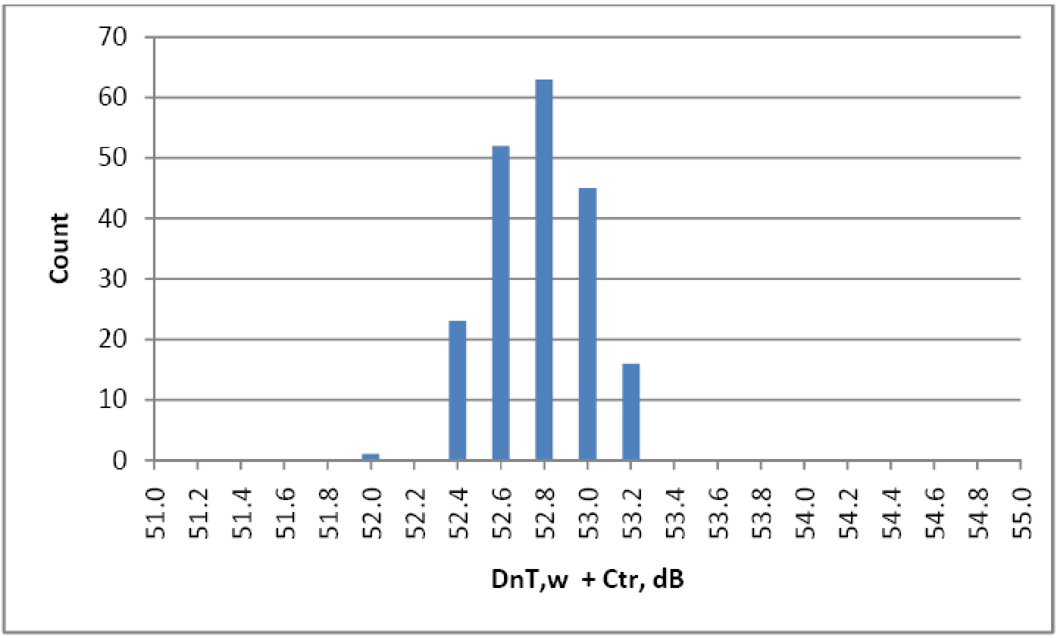



Figure 31 - 20m3 rooms - Moving Microphones, source room unoccupied, receiver room occupied (Method 4)




| | |
|---|---|
| Mean | 52.67 |
| Standard Error | 0.02 |
| Median | 52.68 |
| Standard Deviation | 0.23 |
| Sample Variance | 0.05 |
| Range | 1.26 |
| Minimum | 51.92 |
| Maximum | 53.19 |
| Count | 200.00 |
| Confidence Level (95.0%) | 0.03 |

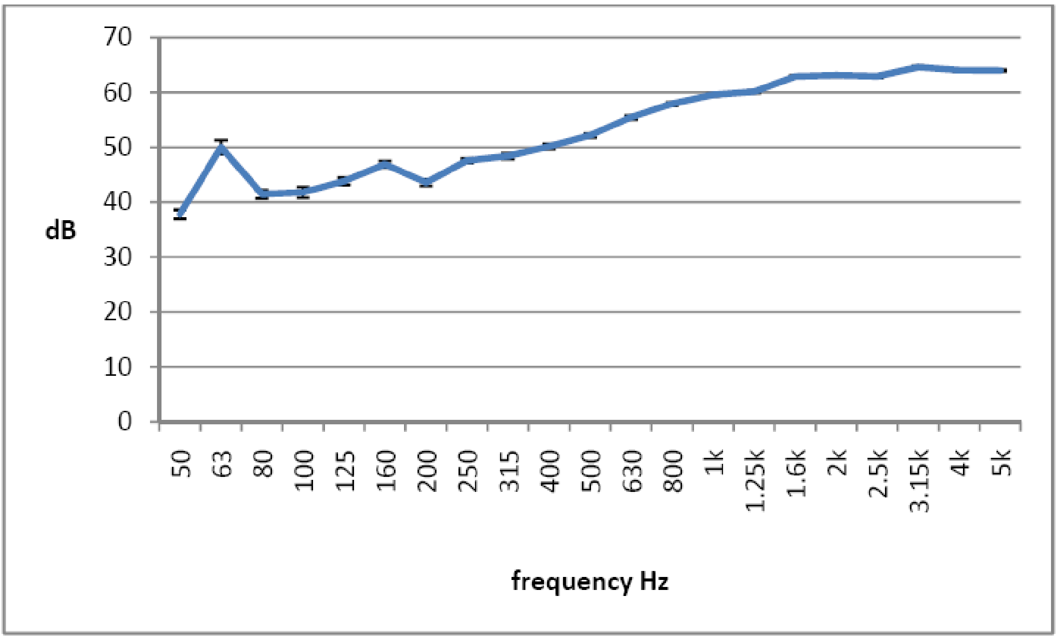
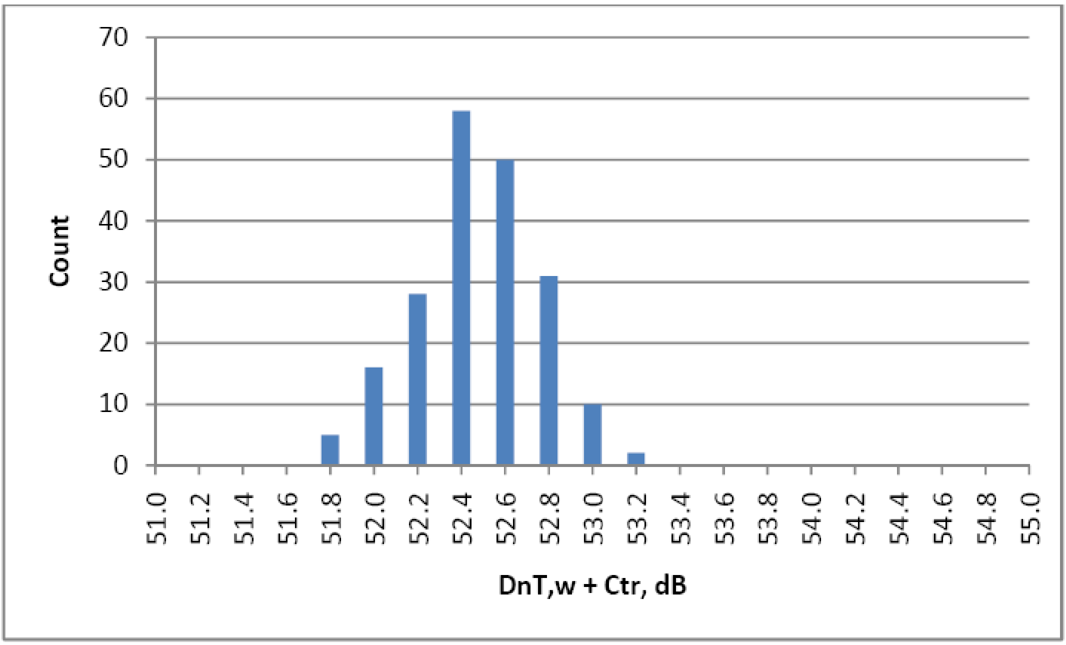



Figure 32 - 30m3 rooms - Static Microphones, both rooms unoccupied (Method 1)




| | |
|---|---|
| Mean | 52.37 |
| Standard Error | 0.02 |
| Median | 52.38 |
| Standard Deviation | 0.27 |
| Sample Variance | 0.07 |
| Range | 1.40 |
| Minimum | 51.63 |
| Maximum | 53.04 |
| Count | 200.00 |
| Confidence Level 95.0%) | 0.04 |

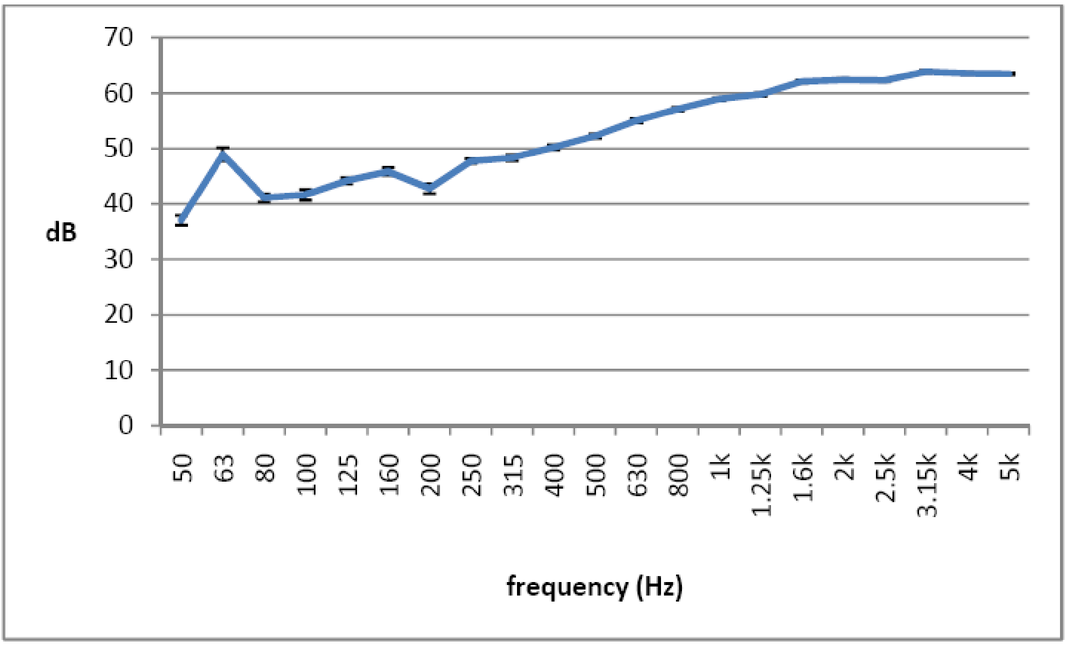
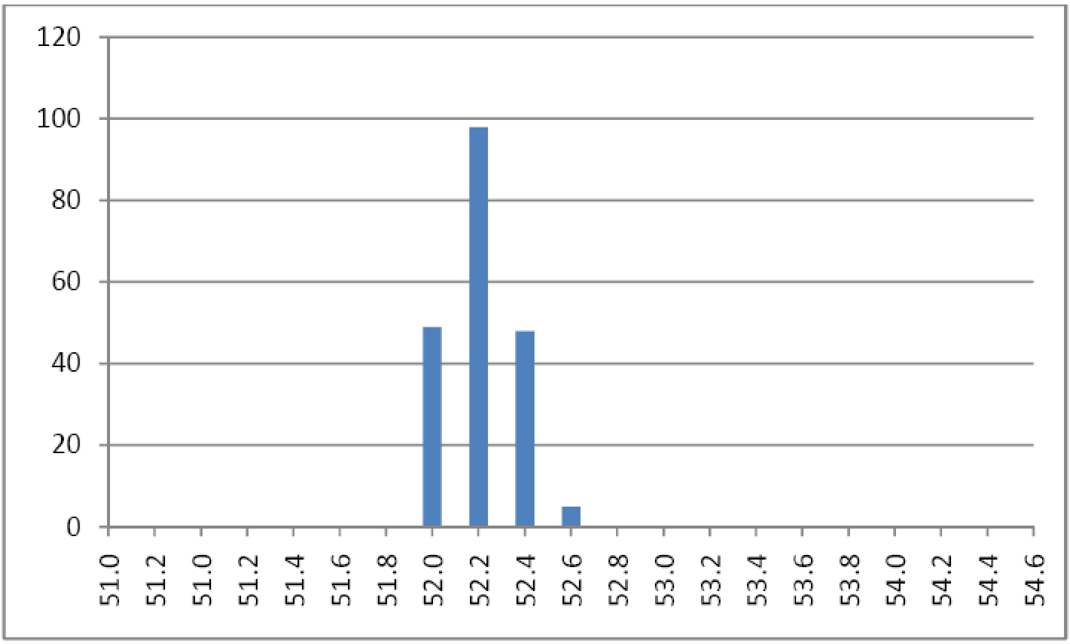



Figure 33 - 30m3 rooms - Static Microphones, source room unoccupied, receiver room occupied (Method 3)




| | |
|---|---|
| Mean | 52.11 |
| Standard Error | 0.01 |
| Median | 52.11 |
| Standard Deviation | 0.14 |
| Sample Variance | 0.02 |
| Range | 0.69 |
| Minimum | 51.80 |
| Maximum | 52.49 |
| Count | 200.00 |
| Confidence Level (95.0%) | 0.02 |

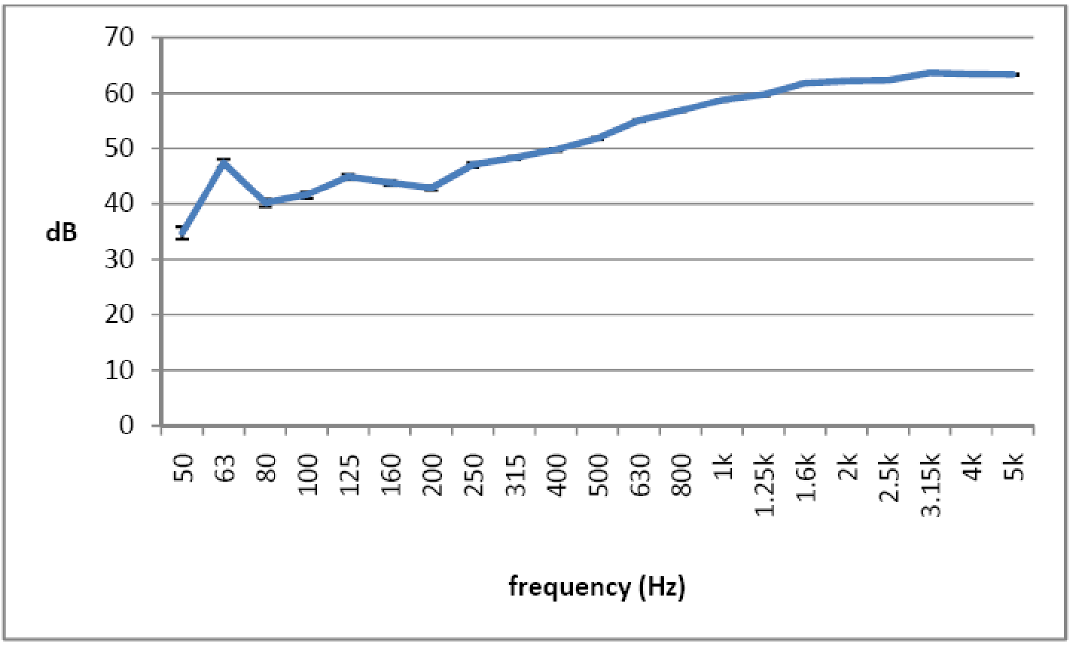


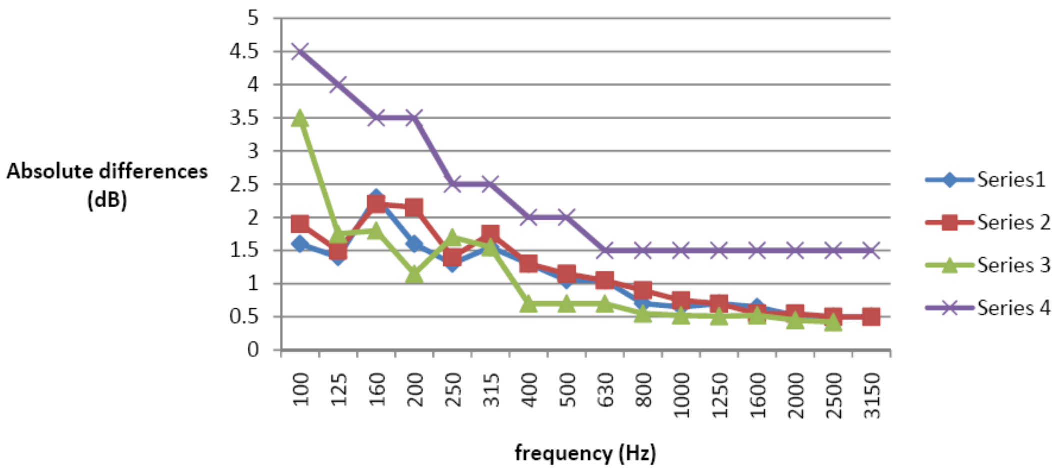

Figure 34 - 30m3 rooms - Moving Microphones, source room unoccupied, receiver room occupied (Method 4)

## 9.2 Repeatability of tests in small rooms.

Repeatability is calculated according to International Standard ISO:140-2:1991 [8], for field tests. For each test 200 sets of DnT values are generated in each of sixteen[2] one-third octave bands. For each band absolute differences between all 200 sets of values are calculated. (19900 differences) The differences are grouped in steps of 0.2 dB and the cumulative distribution found as shown in Figures 35 and 36.

According to the definition of repeatability the absolute difference corresponding to the 95% level is the repeatability value.

This process has been carried out for each of the 16 frequency bands in the 6 tests carried out in the small rooms as described in this report.




Series 1 – Static, unoccupied rooms
Series 2 – Static, occupied room
Series 3 – Moving mics
Series 4 – ISO 140-2: 1991 field test criteria

Figure 35 –repeatability between test methods 20m3 rooms

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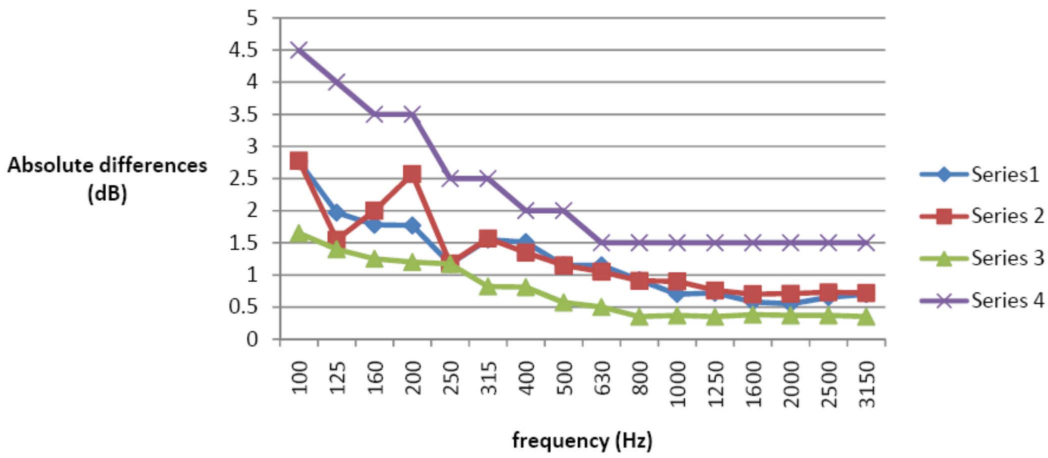
[2] The standard refers to the frequency range 100 Hz to 3150 Hz




Series 1 – Static, unoccupied rooms
Series 2 – Static, occupied room
Series 3 – Moving mics
Series 4 – ISO 140-2: 1991 field test criteria

Figure 36 –repeatability between test methods 30m$^3$ rooms

## 10. Discussion 2 – tests in small rooms

The first and most apparent observation is that the test results obtained for the smaller rooms are approximately 2 dB higher than for the large rooms. It is therefore inappropriate to make a direct comparison with the large room test data, other than of repeatability which is independent of the actual test result.

### 10.1 30m$^3$ Rooms.

Referring to Table 5, all of the tests recorded in the 30m$^3$ rooms show good repeatability with a standard deviation of 0.23 and 0.27 for the two sets of static microphone measurements and standard deviation of 0.14 for the moving microphone measurements.

Statistically, there appears to be a small but significant trend towards a lower value of DnTw+Ctr for the measurements using Test Method 3 i.e. static microphone positions, source room unoccupied during receiver room measurements. This is revealed by a 0.3 dB drop in the mean test result compared to the fully unoccupied measurements according to Test Method 1. This drop is sufficient to change the test result from 53 dB DnTw+Ctr to 52 dB DnTW+Ctr, when rounded to a whole number as required by the ISO Standards.

There is a further reduction in the mean test result produced using the moving microphone method (Test Method 4), of 0.56 dB.

This reduction is assumed to be the effect of the additional absorption in the source room due to the presence of the tester and the removal of that absorption when the tester leaves the room to take the receive room measurements. The effect is roughly the same as predicted by Sabine.

### 10.2 20m3 Rooms.

Referring again to Table 4, all of the tests recorded in the $20m^3$ rooms show good repeatability with a standard deviation of 0.22 and 0.25 for the two sets of static microphone measurements and standard deviation of 0.31 for the moving microphone measurements.

As for the $30m^3$ rooms, there is also a small but significant trend towards a lower value of DnTw+Ctr for the measurements using Test Method 3 i.e. static microphone positions, source room unoccupied during receiver room measurements. This is revealed by a 0.14 dB drop in the mean test result compared to the fully unoccupied measurements according to Test Method 1. This drop is insufficient to make any change to the test result when rounded to a whole number as required by the ISO Standards.

There is a further reduction in the mean test result produced using the moving microphone method (Test Method 4), of 0.96 dB.

There is also a noticeable increase in the range and standard deviation of tests from the moving microphone method, compared to the $30m^3$ data and the $50m^3$ data, suggesting that the presence of the body in rooms of this size (around $20m^3$) or less is of greater significance than for larger rooms.

### 10.3 Comparison with the $50m^3$ room data.

The first phase of this study was based upon measurements made by two different teams of testers and at least two different sets of test equipment.

By eliminating variables due to different testers and different equipment and using only the data, for example, produced by the ANC/RD personnel, using the same test equipment throughout, the analysis becomes more sensitive to the remaining variables.

Table 5 therefore summarises only the statistical data for tests carried out on the 16th and 26th July, in the $50m^3$ rooms and on the 17th and 18th October in the $20m^3$ and $30m^3$ rooms.

Close analysis of the $50m^3$ data, in Table 5, also reveals a small but significant downward trend in the statistical mean value of the test results due to the presence/absence of the tester's body in the source room. This was not particularly evident in the initial analysis of the full experimental data set due to the presence of other variables.

Note: The tests from the $50m^3$ rooms are re-numbered 1 to 6, the tests from the $30m^3$ room are numbered 7 to 9 and the tests from the $20m^3$ rooms are numbered 10 to 12, for clarity, in Table 5a.

Table 5a – Comparison with 50m$^3$ room data (tests renumbered)

| Test | Date | Room Size | Test Method | Mean (rounded) | Mean (to 2dp) | SD | Min | Max | Range |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 16/07/2007 | 50 | Static unoccupied | 51 | 51.01 | 0.34 | 50.08 | 51.94 | 1.860 |
| 2 | 16/07/2007 | 50 | Static, occupied | 51 | 50.91 | 0.37 | 49.76 | 51.7 | 1.940 |
| 3 | 16/07/2007 | 50 | Moving microphone | 50 | 50.19 | 0.19 | 49.65 | 50.67 | 1.020 |
| 4 | 26/07/2007 | 50 | Static unoccupied | 51 | 51.06 | 0.33 | 50.18 | 51.81 | 1.630 |
| 5 | 26/07/2007 | 50 | Static, occupied | 51 | 50.77 | 0.29 | 49.89 | 51.47 | 1.580 |
| 6 | 26/07/2007 | 50 | Moving microphone | 51 | 50.55 | 0.16 | 50.24 | 50.94 | 0.710 |
| 7 | 17/10/2007 | 30 | Static unoccupied | 53 | 52.67 | 0.23 | 51.92 | 53.19 | 1.260 |
| 8 | 17/10/2007 | 30 | Static, occupied | 52 | 52.37 | 0.27 | 51.63 | 53.04 | 1.400 |
| 9 | 17/10/2007 | 30 | Moving microphone | 52 | 52.11 | 0.14 | 51.8 | 52.49 | 0.690 |
| 10 | 18/10/2007 | 20 | Static unoccupied | 52 | 52.46 | 0.22 | 51.87 | 52.99 | 1.120 |
| 11 | 18/10/2007 | 20 | Static, occupied | 52 | 52.32 | 0.25 | 51.63 | 52.88 | 1.250 |
| 12 | 18/10/2007 | 20 | Moving microphone | 52 | 51.5 | 0.31 | 50.58 | 52.23 | 1.650 |

By using the results obtained using Test Method 1 (Static microphone positions, unoccupied test rooms) as a reference, the magnitude of the variation can be assessed according to Table 6.

Table 6 – magnitude of variation due to test method

| Test | Date | Room Size | Method | Mean (to 2dp) | Compare with reference |
|---|---|---|---|---|---|
| 1 | 16/07/2007 | 50 | Static unoccupied | 51.01 | 0 |
| 2 | 16/07/2007 | 50 | Static, occupied | 50.91 | -0.1 |
| 3 | 16/07/2007 | 50 | Moving microphone | 50.19 | -0.82 |
| 4 | 26/07/2007 | 50 | Static unoccupied | 51.06 | 0 |
| 5 | 26/07/2007 | 50 | Static, occupied | 50.77 | -0.29 |
| 6 | 26/07/2007 | 50 | Moving microphone | 50.55 | -0.51 |
| 7 | 17/10/2007 | 30 | Static unoccupied | 52.67 | 0 |
| 8 | 17/10/2007 | 30 | Static, occupied | 52.37 | -0.3 |
| 9 | 17/10/2007 | 30 | Moving microphone | 52.11 | -0.56 |
| 10 | 18/10/2007 | 20 | Static unoccupied | 52.46 | 0 |
| 11 | 18/10/2007 | 20 | Static, occupied | 52.32 | -0.14 |
| 12 | 18/10/2007 | 20 | Moving microphone | 51.5 | -0.96 |

The variations are very small and are only evident when the test results are calculated to 0.1 dB precision.  It is also evident from the repeatability graphs of Figures 35 and 36, for the small rooms, that the variation is well within the recommended limits of repeatability quoted in ISO 140-2:1992.

## 10.4 Range of test results and confidence limits.

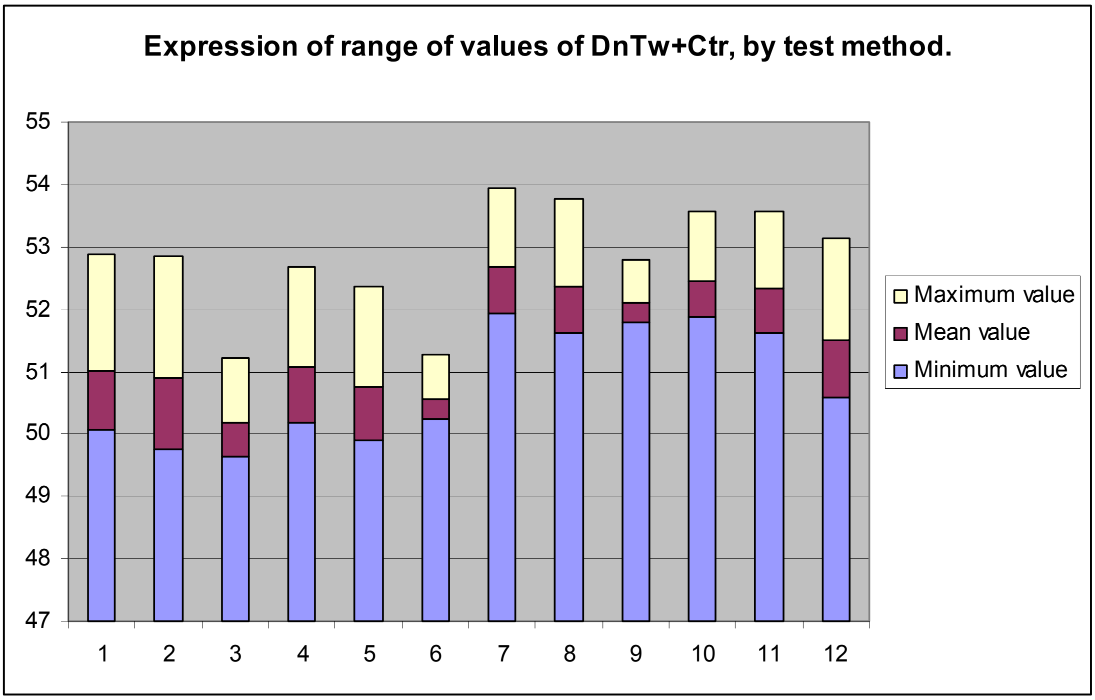
Range of values.

The chart of Figure 37 shows all of the ANC/RD test results expressed as a function of minimum value, mean value and maximum value. This simplifies and better illustrates the concept of 'repeatability' by showing the 'real –world' test results which could be expected if any of the rooms were retested, using the same tester and using the same equipment, at a future time.

It can be seen from the chart, by visual inspection alone, that the 50m$^3$ room data (tests 1 to 6) is quite different from the data obtained from the smaller rooms (tests 7 to 12), especially in terms of the mean value, even though the range is sufficient to allow the results to overlap.

Figure 37 also clearly illustrates the improvement in repeatability (reduced range of test results) when using the moving microphone method, with the exception of the results from the 20m$^3$ rooms.

Figure 37.




Confidence limits.

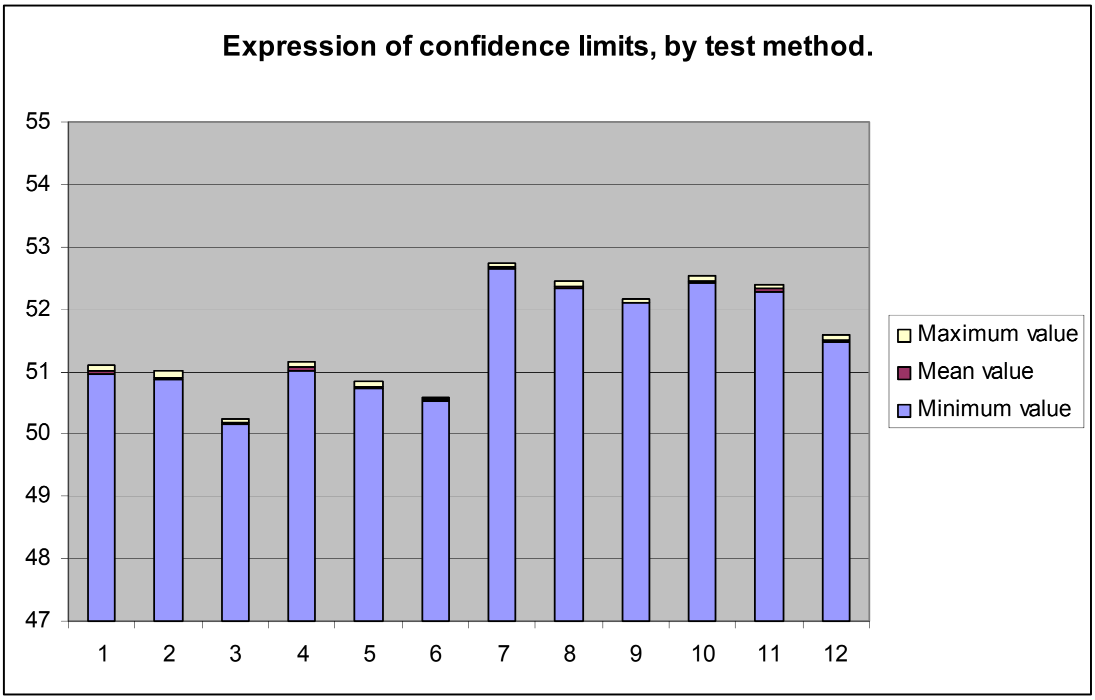
The statistical analysis includes the calculation of the 95% confidence limits for each group of tests. The confidence limit is an expression of the repeatability of each test method and enables the 'true value' of the test result to be determined from a data set, within 95%. For example, the 'true value' for test 12 (Moving microphone method, 20m$^3$ rooms) is 51.5 dB plus/minus the confidence limit of 0.04, with 95% certainty. The test result therefore lies between 51.46 dB and 51.54 dB. This example is particularly interesting when 'whole number rounding' is applied!

Confidence limits for all of the ANC/RD test results are included in Table 7 and illustrated in the chart of Figure 38.

Table 7 – confidence limits.

| Test | Date | Room Size | Method | Mean (rounded) | Mean (to 2dp) | CI | Min | Max | Range |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 16/07/2007 | 50 | Static unoccupied | 51 | 51.01 | 0.05 | 50.96 | 51.06 | 0.100 |
| 2 | 16/07/2007 | 50 | Static, occupied | 51 | 50.91 | 0.05 | 50.86 | 50.96 | 0.100 |
| 3 | 16/07/2007 | 50 | Moving microphone | 50 | 50.19 | 0.03 | 50.16 | 50.22 | 0.060 |
| 4 | 26/07/2007 | 50 | Static unoccupied | 51 | 51.06 | 0.05 | 51.01 | 51.11 | 0.100 |
| 5 | 26/07/2007 | 50 | Static, occupied | 51 | 50.77 | 0.04 | 50.73 | 50.81 | 0.080 |
| 6 | 26/07/2007 | 50 | Moving microphone | 51 | 50.55 | 0.02 | 50.53 | 50.57 | 0.040 |
| 7 | 17/10/2007 | 30 | Static unoccupied | 53 | 52.67 | 0.03 | 52.64 | 52.7 | 0.060 |
| 8 | 17/10/2007 | 30 | Static, occupied | 52 | 52.37 | 0.04 | 52.33 | 52.41 | 0.080 |
| 9 | 17/10/2007 | 30 | Moving microphone | 52 | 52.11 | 0.02 | 52.09 | 52.13 | 0.040 |
| 10 | 18/10/2007 | 20 | Static unoccupied | 52 | 52.46 | 0.03 | 52.43 | 52.49 | 0.060 |
| 11 | 18/10/2007 | 20 | Static, occupied | 52 | 52.32 | 0.04 | 52.28 | 52.36 | 0.080 |
| 12 | 18/10/2007 | 20 | Moving microphone | 52 | 51.5 | 0.04 | 51.46 | 51.54 | 0.080 |

Figure 38 – confidence limits.



## 11. Conclusions.

This investigation draws its conclusions based upon measurements in three pairs of rooms of volume 50 $m^3$, 30 $m^3$ and 20 $m^3$. Mean values quoted in this paper are the arithmetic mean of 200 separate calculations of DnTw+Ctr, with each calculation based upon 5 source room measurements and 5 receive room measurements. Each group of five measurements were selected from a set of 3-dimensional co-ordinates, in a pseudo-random manner to minimise repetition and to ensure that the group is randomly distributed throughout the room. Measurements were also made using the manual moving microphone technique.

1. All of the test results produced by all the test variants are very close and produce mean values which are within 1 dB DnTw+Ctr, when rounded to a whole number, for each pair of rooms.

2. For the 50$m^3$ rooms, the range of test results produced by individual tests across all test variants are within a range of 49 dB DnTw+Ctr to 52 dB DnTw+Ctr, when rounded to a whole number, with a standard deviation of no more than 0.38 dB.

3. For the 30$m^3$ rooms, the range of test results produced by individual tests across all test variants are within a range of 52 dB DnTw+Ctr to 53 dB DnTw+Ctr, when rounded to a whole number, with a standard deviation of no more than 0.37 dB.

4. For the 20$m^3$ rooms, the range of test results produced by individual tests across all test variants are 52 dB DnTw+Ctr, when rounded to a whole number, with a standard deviation of no more than 0.31 dB.

5. Differences between test methods only become apparent when the DnTw+Ctr values are calculated to 0.1 dB precision and when all variables are eliminated other than the ‘body in the room’ and the spatial sampling technique.

6. The variation caused by the presence or absence of a body in the source room is very small but appears to show a slight downward trend (towards an unfavourable test result) of up to 0.3 dB, compared to tests in unoccupied rooms.

7. The variation caused by the combination of body in room and moving microphone is also very small but appears to show a downward trend (towards an unfaourable test result) of up to 0.6 dB, compared to tests in unoccupied rooms and with static microphones, in the 50$m^3$ and 30$m^3$ rooms. This variation increases to 1 dB for the tests in the 20$m^3$ rooms.

8. This investigation suggests that the manual moving mic technique (MMM), which also involves taking the tester out of the source room, produces the most repeatable results in rooms of $30m^3$ or more when compared with any of the other test methods.  Most notable is the improved accuracy and repeatability of this method at low frequency, where modal variations produce well-documented inaccuracies in the other, more traditional test methods.

9. Notwithstanding 6, 7 and 8, the repeatability values for all of the results, based on the one-third octave DnT values, are within the recommended limits defined in ISO 140-2:1991.

10. There is, however, a trade-off for the improved repeatability of the moving microphone technique which is that this does appear to increase the risk, statistically, of obtaining an unfavourable test result by up to 1 dB, in rooms of less than $25m^3$.

## 12. Future Work.

The BRE team are currently investigating variables produced by source types and location and will be looking into the validity of the historical “6dB rule” taking account of modern digital filters.

Small rooms show low modal density below the Schroeder frequency and this makes accurate measurements difficult below 400 Hz due to large variations in sound pressure level within the room. This can have particular impact on the spectrum adaptation term, Ctr, as this is highly dependent on measurements below 200 Hz.   Future work will include an investigation into the effectiveness of diffusers at reducing mode-induced variations and their effect on repeatability.

## 13. References

[1] ISO140-4:1998.  Acoustics – Measurement of sound insulation in buildings and of building elements  Part 4 airborne sound insulation.
[2]  I C Critchley, P R Dunbavin, R Lawrence, D J McNeil.  Round Robin on uncertainty in sound insulation measurements, proceedings of the IOA Spring Conference April 2007.
[3] Approved Document E (2003 including 2004 amendments) – Resistance to the passage of sound.
[4]  J. Lang. A round robin on sound insulation in buildings. Applied Acoustics, Vol. 52 (3/4).
225-238. (1997).
[5]  Robust Details Ltd – Method Statement 1 – Spot Check Field Testing.

[6] BS EN ISO 10052:2004 - Acoustics. Field measurements of airborne and impact sound insulation and of service equipment sound. Survey method.
[7] BS EN ISO 717-1. Acoustics – Ratings of sound insulation in buildings and of building
elements. Part 1. Airborne sound insulation. ISO 717-1:1996/Amd 1:2006
[8] ISO 140-2:1991 Acoustics – Measurement of sound insulation in buildings and of building elements. Part 2 – Determination, verification and application of precision data.
[9] P Turner and R Ramadorai – A practical approach to improving sound insulation measurement at low frequencies, proceedings of the IOA Spring Conference April 2007.
[10] Gibbs BM, Maluski S. Airborne sound level difference between dwellings at low frequencies. Building Acoustics 2004;11(1), 61-78