ROUND ROBIN ON UNCERTAINTY IN SOUND INSULATION MEASUREMENTS.

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Background

The most recent version of Approved Document E of the Building Regulations 2000 in England and Wales came into force on the 1st July 2003. The most significant changes in the 2003 version of the Approved Document were, firstly, the introduction of the spectrum adaptation term C_{tr}, designed to reflect the greater importance of low-frequency in determining the overall airborne sound insulation performance of separating walls and floors. Secondly the introduction of mandatory pre-completion testing for all newly-built and newly-converted dwellings.

In response to the statement in the original draft of the Approved Document which said that all test bodies which carry out pre-completion testing should be third party accredited through UKAS, the Association of Noise Consultants (ANC) put together as an alternative approach, a registration scheme that identified certain ANC member companies, and within them particular test engineers, that fulfilled criteria of competence in sound insulation measurement. The intention was that these Test Engineers would be authorised to undertake sound insulation measurements, airborne and impact, on separating walls in accordance with the Approved Document. The ANC Registration Scheme was subsequently approved by the Office of the Deputy Prime Minister (ODPM) and included in the 2004 Amendment to the Approved Document.

There are currently over 90 ANC member organisations, of which 63 have, after careful consideration, been allowed to join the ANC Registration Scheme for pre-completion testing. This has resulted in 260 test engineers undertaking typically 3000 individual tests per month. To date (February 2007) over 60,000 tests have so far been carried out, on over 10,000 sites.

On 1 July 2004, the Robust Details (RD) scheme was given full approval in the 2004 Amendment to ADE, as an alternative to pre-completion testing, for house builders who are prepared to build to a higher standard of construction as detailed in the RD Handbook. These construction forms are based upon combinations of separating wall and floors which have been extensively field-tested and shown to give results which are typically 5 dB better than required for compliance with ADE. Construction sites which are registered with Robust Details Ltd consent, as a part of their contract, to make their plots available for spot inspections (amounting to ca 1% of all registered plots) and for spot check field tests (at a rate of 2% of all registered plots). Inspection and testing is carried out on behalf of Robust Details Ltd by a team of specially appointed inspectors who are acknowledged experts in building acoustics. They also have to be either UKAS Accredited or Registered on the ANC Scheme.

The procedures for sound insulation testing in the field, under the ANC Scheme and by RD inspectors, are based upon, and must fully comply with, International Standards ISO 140:1998 Part 4 (for airborne tests), ISO 140:1998 Part 7 (for impact tests) and also Approved Document E (2003) Annex B. Although the ISO 140 test procedure is quite prescriptive in its requirements for minimum room size, direction of testing and the positions of sound source and microphone with respect to the room boundaries, there is still scope for minor variations in technique from one test engineer to another. Engineers have a choice, for example, between cabinet and polyhedron-type loudspeakers, and between using several fixed microphone positions as opposed to a moving microphone when sampling the diffuse field in source and receiving rooms.

Given this scope for variability in technique, even within the constraints of the ISO standards and ADE Annex B, there is bound to be some uncertainty in the reproducibility of sound insulation values obtained from a particular separating element in a building by a number of test engineers.

Previous studies have attempted to quantify this uncertainty, frequently with particular emphasis on measurements at low frequencies. The authors of this report are unaware of any recent studies that have involved a significant number of test engineers on different types of building construction under practical site conditions.

The Round Robin

The purpose of this investigation was to identify the factors that can influence the accuracy of field measurements of the airborne sound insulation of separating walls and floors in (i) a typical masonry construction and (ii) in a typical lightweight timber-frame construction. The aim was to use the data obtained to produce a form of 'Good Practice Guide' for test engineers and consequently improve measurement reproducibility.

Two apartment developments were selected for the study. A site in Liversedge was identified as representing a typical masonry construction with blockwork cavity walls and concrete plank floors. A site in Doncaster was chosen to act as a typical timber-frame construction. They were selected on the basis of availability for the four consecutive days of the study.
Twenty-one test engineers, all of whom are registered with the ANC Registration Scheme for pre-completion testing, volunteered their time to carry out measurements on one floor and one wall at each site.

Participants were asked to measure using the following variables:

1. Sampling the fields in the source and receiving rooms.

    Several fixed microphone positions are to be used for each source position, and
    The measurements to be repeated using a manual, moving microphone, technique broadly as described in ISO 10052:2004.
    A calculation of the single number index to be made for each set of measurements.

2. Measuring the reverberation time in the receiving room.

    Interrupted loudspeaker decays were to be used, and
    Impulse decays to be used e.g. balloon bursts or starting pistol
    Separate calculations of the single number indices to be made from each set of measurements.

The combination of all the measurement variables described therefore resulted in a total of four separate sets of calculations for each wall and floor at each of the two test sites, sixteen sets of calculations in all, per engineer.

The test engineers were not given any further instructions about the tests or the use of their equipment. They were only asked to follow their normal test procedure (this should, in any case, be in full accordance with ISO 140:1998 Part 4 and with Annex B of Approved Document E (2003)). The test engineers were allowed one hour at each site to perform one wall test and one floor test as described. This was in order to accommodate the number of volunteers within reasonable time limits and also to reflect typical site conditions, where time on any 'live' construction site could be at a premium.

Statistical analysis of the results returned by individual test engineers suggested, however, that variations traceable to microphone technique and the two types of RT measurement were of zero or very low significance. This was taken to indicate that there is no preference for one technique over another. This would suggest that there is no automatic reason to produce a 'Good Practice Guide' on this basis and that test engineers should be encouraged to carry on in their normal way.

The smallness of the variation in results based on the different microphone techniques and the different RT measurement, for each test engineer, has been used as a justification for averaging the complete results for each engineer and for each partition. The intention being to use the availability of the data to explore the sensitive issue of variation from one test engineer to another.

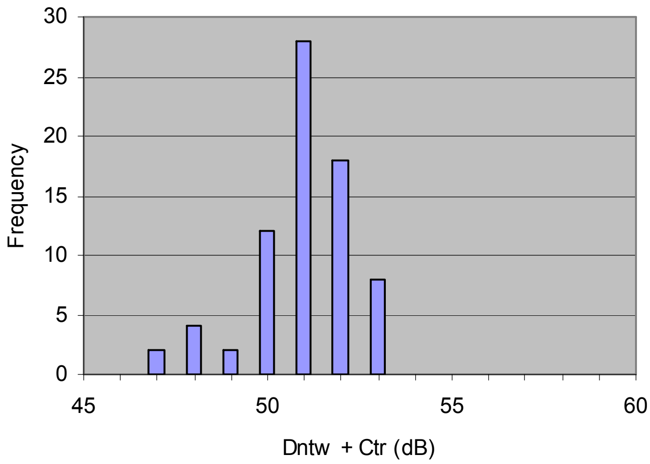
The Data Analysis.

This section considers the statistical variations among different engineers, for each of the four partitions tested.

Masonry Wall.

For the masonry wall tests at Liversedge, the adjacent rooms were of different volumes and all tests were correctly carried out from the large space to the smaller space, thus avoiding any variation due to test direction. Taking D_{nTw} as the primary reference, the test results ranged from 57 dB D_{nTw} to 60 dB D_{nTw} i.e. a range of 3 dB with a standard deviation of 0.7 dB. Considering the possible procedural variations from one engineer to another, this set of results is remarkable and the reproducibility returned is comparable with laboratory-derived data. Introducing the spectrum adaptation term, C_{tr}, into the single-number index widens the range of values from 47 dB D_{nTw} + C_{tr} to 53 dB D_{nTw} + C_{tr} i.e. a range of 6 dB with a standard deviation of 1.37 dB. These results compare well with the conclusions of the study by J Lang [1], which showed a range of 3 dB for D_{nTw} and a range of 5 dB for D_{nTw} + C_{tr}, albeit with fewer testers and presumably, under more controlled conditions.

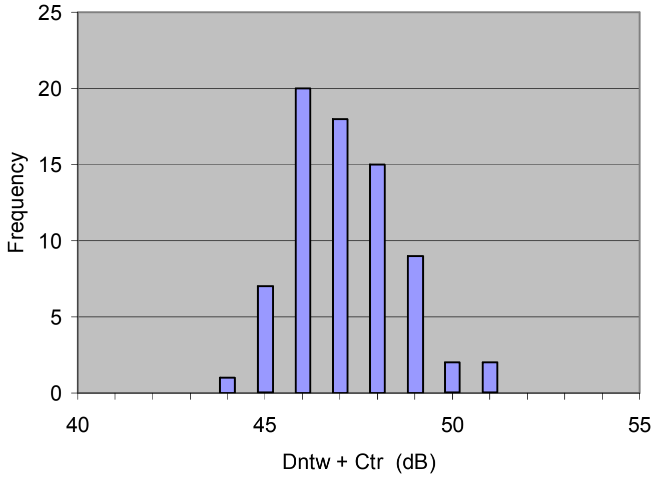
Figure 1 – Spread of results (D_{nTw} + C_{tr}) for the Masonry Wall.



Concrete Floor.

Test results for the concrete floor (Liversedge) ranged from 53 dB D_{nTw} to 56 dB D_{nTw} i.e. a range of 3 dB with a standard deviation of 0.73. Introducing the spectrum adaptation term, C_{tr}, into the single-number index gives a range of values from 44 dB D_{nTw} + C_{tr} to 51 dB D_{nTw} + C_{tr} i.e. a range of 7 dB with a standard deviation of 1.46. It should be noted that this pair of rooms were of identical size and shape (L-shaped) although it is too early to draw any direct conclusions from this.

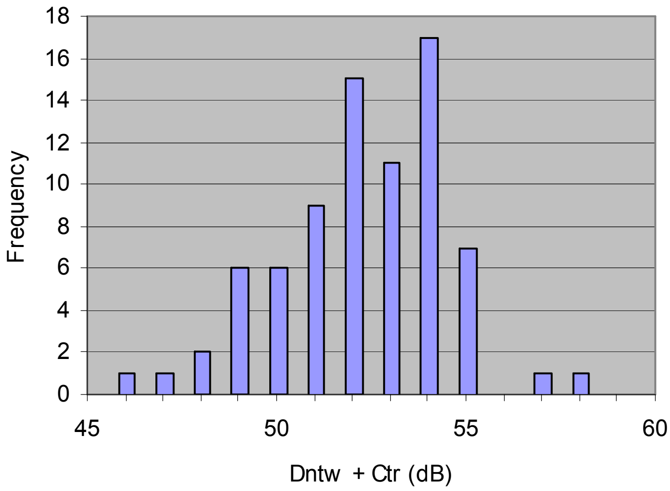
Figure 2 – Spread of results ($D_{nTw} + C_{tr}$) for the Concrete Floor.



Timber-joist floor.

For the tests on the timber-joist floor in the timber frame building at Doncaster, the results range from 61 dB D_{nTw} to 66 dB D_{nTw} i.e. a range of 5 dB with a standard deviation of 1.13. Introducing the spectrum adaptation term, C_{tr}, into the single-number index gives a range of values from 46 dB $D_{nTw} + C_{tr}$ to 58 dB $D_{nTw} + C_{tr}$ i.e. a range of 12 dB with a standard deviation of 2.23. This is a greater range of test results than in any of the masonry/concrete partitions and requires further consideration.

Figure 3 – Spread of results ($D_{nTw} + C_{tr}$) for the Timber Floor.



The upper room was slightly larger than the lower and some engineers chose (correctly) to use the upper room as the source room, while others chose to ignore the difference and used the lower room as the source room. This could partially explain the wider range of test results. The differences in the test results do not appear to be systematic, however, and there is not enough evidence to conclude that the variations in the results are any more than normal experimental variations, possibly traceable to the generally poorer performance of lightweight structures at low frequency. There were some particularly low and high values not seen in the masonry results and as the reason is not known, they were included in the above statistical analysis anyway.

<u>Timber-framed wall.</u>

The tests on the timber-framed wall at Doncaster showed a wide range of results in terms of both D_{nTw} (16 dB) and $D_{nTw} + C_{tr}$ (21 dB). The main reason for this is one of interpretation of the test arrangement i.e. how to deal with a room arrangement which consists of two coupled volumes, a kitchen and dining room, connected by an arched opening with the separating wall at the kitchen end as indicated in Photograph 1. Some engineers chose to test from kitchen to kitchen and this understandably produced a lower set of insulation values, while some engineers chose to test from dining room to dining room, ignoring the kitchen, producing the higher values. Yet more engineers chose to sample both volumes more or less equally. No guidance on this was given prior to the tests and no guidance on how to test under these conditions is given in either the ISO standard or in ADE.

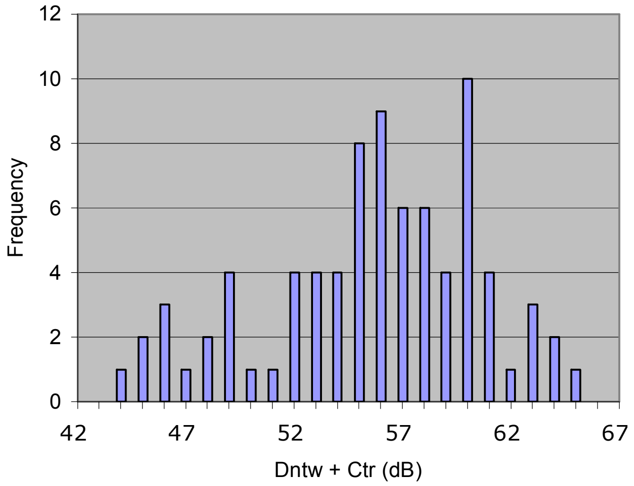
Photograph 1 – Doncaster, Plot 34 looking into the kitchen area.

For this reason, the test results from the timber-framed wall are unhelpful in terms of the primary objective of this investigation which was to determine variations in test procedure from one engineer to another, rather than to test the variation imposed by different interpretations of the room layout. The test results are effectively the combination of at least three different test arrangements and should be viewed in that context. They are worthy of closer analysis solely as an opportunity to study the effects of unusual room geometry.

It should be evident from the distribution graph (Figure 4) that the statistical relationship within the data set is non-existent or random, or that the data comes from different measurement exercises.

Notwithstanding the above, while it is inappropriate to draw any conclusions from the timber wall tests, the test results from this set of tests are included in this paper for interest. This test situation does occasionally arise in practice and is a case where some clear guidance is required, either from reference to other Standards, or perhaps through an eventual 'ANC Good Practice Guide'.

Figure 4 – Spread of results (D_{nTw} + C_{tr}) for the Timber Wall.



Conclusions

The analysis shows that the test results obtained from the masonry wall and floor at the Liversedge site indicate that the measurement practices adopted by the test engineers are capable of producing test results that show an acceptable degree of variation.

The conclusions drawn from the tests on the timber-framed structure at Doncaster, however, are more complicated. The test results on the timber floor show a marked variation in low frequency performance which is not unreasonable as the sound insulation of these structures is relatively poor at low frequencies resulting in large negative values for C_{tr}.

The accuracy of sound insulation measurements in timber structures is therefore very dependent upon reliable measurement at low frequencies and yet this is known to be notoriously difficult, even under ideal conditions. The variation in test results in these partitions can, at least partly, be accounted for by the inherent uncertainties involved in real-world acoustic measurements in small spaces and attention is drawn to Annex D of ISO140:1998 Part 4, which advises caution when measuring at frequencies below 400Hz.

Analysis of the test results in terms of the contributing factors to the D_{nTw} + C_{tr} calculation show that it is the contribution at 100 Hz that is the dominant factor, to the extent that the D_{nTw} + C_{tr} value can be approximated by adding 20 to the standardised level difference at 100 Hz!

The graph in Figure 5 shows the contribution to $D_{nT,w}$ + C_{tr} of each of the terms

$$10^{(L_i - R_i)/10}$$

for the measured Standardised Level Differences.

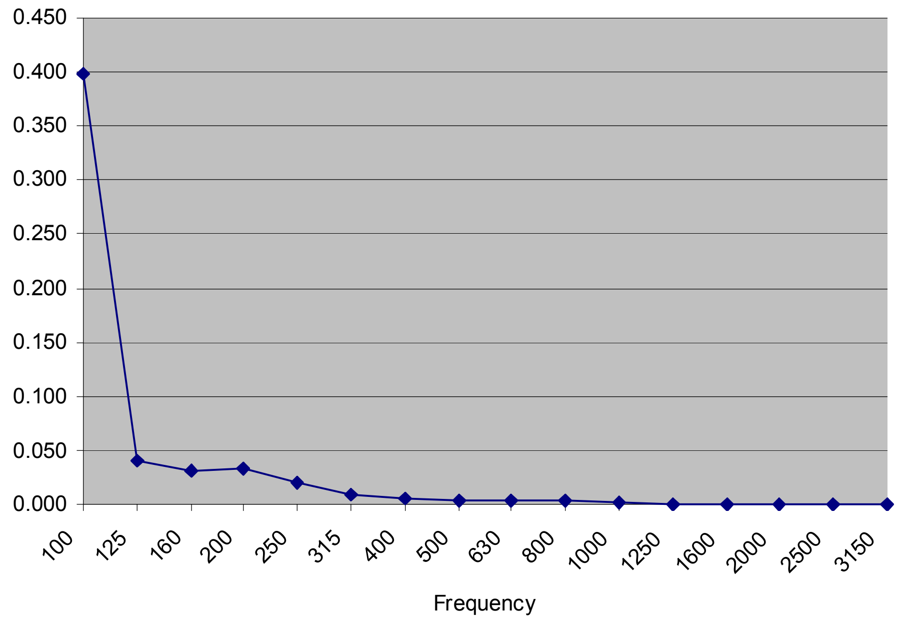
It is clear that the result is dominated by the single term at the low frequency 100 Hz. Indeed this term is so dominant that a good approximation to the value of $D_{nT,w}$ + C_{tr} is given by

$$D_{nT,w} + C_{tr} = -(L_i - R_i)$$

where, in this case, i = 1 (i.e. 100 Hz) and L_i = -20

Figure 5 - Terms contributing to the calculation of $D_{nT,w} + C_{tr.}$

$10^{(L_i - R_i)/10} \times 10^5$



The test results on the timber wall at Doncaster vary widely due to factors already discussed and it is considered prudent not to include these results in the overall statistical analysis at the present time.

We conclude that there are no significant or systematic differences resulting from the use of different microphone sampling techniques, from different methods of RT measurement or from different types of loudspeaker, at least on the basis of the relatively small sample of tests on which this study is based.

Although the above conclusions should be taken with caution, there is no evidence to suggest that any one engineer's method or technique is intrinsically more reliable than that of others.

There is clearly scope for further study, however, and the evidence suggests that this should be focussed on the measurement of lightweight structures with emphasis on reducing uncertainty at low frequencies e.g. at 100 Hz. Further studies are likely to include the use of portable diffusers and absorbers in source and receiver rooms to improve the modal response of the test rooms.

A joint research project with the ANC, Robust Details Ltd and BRE is currently in progress (March 2007) to investigate uncertainty under more controlled conditions. The results of this further research will be reported in a future paper.

Reference

[1] 'A round robin on sound insulation in buildings' Applied Acoustics Vol52 no3/4 pp225-238 (1997

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