Proceedings of The Institute of Acoustics

THE DEVELOPMENT OF A SHORT TEST METHOD FOR THE MEASUREMENT OF AIRBORNE SOUND INSULATION IN BUILDINGS.

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INTRODUCTION

This paper describes the progress to date by the International Standards Organisation to produce a short test method for the measurement of airborne sound insulation in buildings.

A working group was set up within T.C. 43/SC2 during 1982 with the brief to produce a draft International Standard setting down the procedure and criteria for accuracy for a simplified test method. During the same year the S.E.R.C. provided the Heriot-Watt University with a major grant in order to assist with research in this area.

The research has now been completed and a draft Standard is now being prepared.

Basic Concepts

The basic concept underlying the simplified test procedure requires that the method should be as follows:-

FAST — Requiring less than 5 minutes from start to completion of the test.

SIMPLE — Meaning that a person with no specific knowledge of acoustics could be trained to carry out the test reliably within a few hours.

PLAUSIBLE — It must be possible to relate the result to the Building Standards Regulations requirements with a quantifiable degree of confidence and repeatability.

The requirements underlying the commercial development of the test equipment have been defined as follows:-

SIMPLE — The noise source in its simplest form shall comprise of a loudspeaker/amplifier and associated circuitry but with a single switch ON/OFF. Advanced versions will have additional binary circuits and corresponding switches involving FURNISHED/UNFURNISHED conditions, TRADITIONAL/TIMBER constructions, and perhaps WALL/FLOOR location.

ERGONOMIC — One person should be able to carry all the equipment in one journey without difficulty. The equipment should be capable of mains/battery operation and remote control for ON/OFF.

ECONOMIC — The cost should be approximately 10%-20% of the cost of the sophisticated equipment required for the Building Regulations test.

RELIABLE — The equipment should not be sensitive to rough handling nor should it require frequent calibration.

PROGRAMME OF RESEARCH AND DEVELOPMENT

A programme of research and development has been carried out as follows:-

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(A) DEVELOPMENT OF THE NOISE SOURCE

Analysis of Raw Data
Spectrum of Noise Source

(B) EFFECTS OF ROOM ABSORPTION UPON RESULT

(C) STUDY OF REPEATABILITY AND RELIABILITY

Temporal and Spatial Averaging of Sound Field
Effect of Operator
Conversion of Simple Result into Regulation Result

(D) MEASUREMENT PROCEDURE

Instrument for Measurement of Noise Level
Max/Min Volumes of Room, Max/Min Areas of Walls
Addition of Absorption
Calibration
Ergonomics

DEVELOPMENT OF THE NOISE SOURCE

Analysis of Raw Data

In order to develop an 'ideal' spectral shape for the noise source a considerable amount of field data was assembled and processed.

The data used in this study came from the random survey of the sound insulation in dwellings which was undertaken by the U.K. Building Research Establishment during the 1970s. Since the aims of this survey were to provide information on the typical performance of modern dwellings and on the implementation of the Building Regulations, the data gathered were ideal for the purposes of this research. The database covered some 1800 field tests involving most forms of construction and from a statistical viewpoint constituted a significantly large sample. A number of important factors have been identified during the processing of the raw data and one such result has been to establish the relationship between sound insulation according to frequency for different levels of overall insulation. The results, which are shown in Figure 1, clearly indicate that the transmission loss curves are broadly parallel, a factor which hitherto was unknown, but, more important, means that the device being developed may be used for all grades of wall regardless of insulation value. A further important relationship to be gained from the analysis of the field data is shown in Figure 2 and indicates that the average wall has a very similar insulation to the average floor. This is an important factor in deciding whether or not to have different circuits, one for walls and one for floors. Since sound insulation tests are carried out in both furnished and unfurnished houses, consideration must be given to the influence of the absorption of sound by the furnishings. The results in Figure 3 show that there is a very significant difference in spectrum shape between the two categories which can be interpreted as meaning that the test procedure must take cognisance of this factor. In summary, the analysis of field data alone has established a new set of relationships, hitherto unpublished, which should be able to stimulate new approaches to the treatment of sound insulation in dwellings.

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DEVELOPMENT OF THE SPECTRUM SHAPE

This activity has involved by far the greatest proportion of time in the overall programme of research. The work has involved, in the first instance, a computer simulation of a spectrum shape which has in turn been applied to all 1800 sets of field measurements or to various groups of data, as required. As a datum, for analysis of the performance of different spectra, 'pink-noise' has been used. Over 300 different spectra have been produced in order to test various theories and the results compared as shown in Figure 4. Each data point is defined by the simulated simple rating (abcissa) and the actual regulations rating (ordinate) derived from the same set of measurements. A best fit straight line has been matched to the data by the method of least squares and the standard deviation of the ordinates from the line used as an indicator of spread. The first set of spectra analysed involved a systematic variation of the spectrum shape (See Figure 5). This gave an indication of the optimum shape of the noise source, but did not define the logic behind the geometry. Five additional spectra were examined in detail in order to further reduce the statistical spread of results and also to examine the sensitivity of the correlation to specific spectral forms as follows:- (See Figure 6).

(A) Inverse A - Weighting Curve

(B) Inverse Source Room Absorption Curve

(C) Inverse Transmission Loss Curve

(D) Standard Deviation Function

(E) Failure Probability Function

Mathematically, the relationships are rather complex and an exact treatment has not yet been produced. However, it would appear that, whilst several factors are affecting the correlation simultaneously, the influence of Failure Probability and Standard Deviation are clearly predominant. A third refinement of the spectral shape has been carried out on a smaller sample (N = 100) of walls and floors. This exercise was carried out to produce the final shape of the spectra which will serve as the basis for commercial production.

EFFECT OF ROOM ABSORPTION UPON THE RESULT

Since the simplified test is just as likely to be carried out in furnished dwellings as in unfurnished ones, consideration has to be given to the effects of room absorption upon the result. The analysis of correlations between simplified measurements and regulation test results, as shown in Figure 4 shows a significant effect to be caused by room absorption. The standard deviation of results involving furnished rooms is approximately 30% superior to those obtained from unfurnished rooms. Unfurnished rooms provide greater variance in acoustical terms which reflects in any subsequent attempt at correlation of the results. There are a number of options available to counteract the adverse effects of empty room conditions. These include:-

(A)- ADDING ABSORPTION TO THE RECEIVING ROOM

(B)- ADDING ABSORPTION TO THE SOURCE ROOM

(C)- ADDING ABSORPTION TO BOTH ROOMS

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(D) - APPLYING A SPECTRAL BIAS TO THE NOISE SOURCE

(E) - APPLYING A NORMALISATION

(F) - USING A COMBINATION OF (A) AND (D)

(G) - APPLYING NO CORRECTION FOR ROOM CONDITION

The permutations are, in fact, much more extensive than it would appear from the above list. For example, there are eight different recognised methods of applying a normalisation factor, as described in (E) above. It is not appropriate to discuss the pros and cons of each form of correction factor here except to say that a substantial improvement in accuracy can be achieved by employing some of the above methods. For example, the use of normalisation (E) will produce a 100% improvement in accuracy, but will increase the complexity of the test, increase the time to undertake the test and require additional equipment to carry out the test. For the latter reasons, the most likely form of correction is the addition of absorption to the source and receiving rooms.

STUDY OF REPEATABILITY AND RELIABILITY

The existing British and International Standards already recognise the requirements for repeatability and reliability in acoustic testing as follows:-

REPEATABILITY - The closeness of agreement between successive results obtained with the same test procedure on the same specimen, under the same conditions (same operator, equipment and short intervals of time).

RELIABILITY - The closeness of agreement between individual results obtained with the same method on identical test specimens, but under different conditions (different operator, equipment and different times). In order to quantify these factors a programme of field tests was conducted involving 100 pairs of rooms. (See Figure 7.) The tests here show that the mean results of the hand monitored simple test measurements are within 0.1 dB of the machine monitored equivalent measurements. The operator's body and clothes add absorption, but that can be taken into account in the same way as for room furnishings. The standard deviation of the differences about the mean were significantly higher, 1.2 dB, for furnished rooms than for unfurnished rooms, 0.64 dB. The exact reason for this effect is, as yet, not fully understood and requires separate investigation. However, initial results would tend to indicate that the reason lies mainly in the spread of results from the Regulations test rather than the simplified measurement. Spatial averaging of the sound field has been studied and results would indicate that four 360° rotations of the sound level meter around the operator at arm's length gives as accurate a result as the B.S. 2750:1980 method. Temporal averaging of the sound source has been studied and there would appear to be little advantage in integrating the signal for periods over eight seconds per rotation. Continuous integration of the signal gives a slightly more accurate result, under steady sound field conditions, than with eyeball averaging of an analogue meter scale. However, since sound fields in buildings often tend to be non-steady and affected by background noise, the ideal measuring device would be an integrating sound level meter with a digital display plus an instantaneous reading of sound pressure level on an analogue meter. Such meters are now widely available although they are somewhat more expensive than single function devices.

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STUDY OF MEASUREMENT PROCEDURE

Design of noise source

It was stated as one of the design objectives that the operation of the measuring equipment should be as simple as possible. The research programme has identified a number of variables which affect the accuracy of the result. A number of these variables are more sensitive than others and cannot be ignored without an unacceptably high degree of error being introduced. By designing to take account of some of the less critical variables, the cost and complexity of the instrument will be increased, but there may be justification for a more sophisticated version. An instrument with a fixed spectrum shape and a simple ON/OFF switch could be considered to be the basic version, but the accuracy would be unacceptably low,

$$P_{95\%} \approx \pm 4.0 \text{ dB } (D_{ntw})$$

in unfurnished rooms.

In order to compensate for the spectral imbalance caused by the lack of absorption in unfurnished receiving rooms, consideration has been given to a procedure involving the use of added absorption. The additional cost will be negligible, but will mean two items of equipment instead of one to carry. The result will, however, mean an improved accuracy of

$$P_{95\%} \approx \pm 3.0 \text{ dB } (D_{ntw})$$

The accuracy may be improved even further by adding a further weighting circuit to take account of source room absorption effects. This will improve the accuracy to approximately

$$P_{95\%} \approx \pm 2.0 \text{ dB } (D_{ntw})$$

Further improvements may be brought about by applying a weighting to take account of the construction of the wall or floor, e.g. Timber or Traditional. Indeed, circuits could be included to take account of the different insulation values of walls and floors, but these would only produce a very minor improvement in accuracy. It is unlikely for the variance to drop much below $\pm$ 1.75 dB at the 95% confidence level regardless to how many circuits are added to take account of all possible variables. The noise source, therefore, is likely to comprise of an amplifier and loudspeaker in one cabinet together with an 'ON/OFF' switch, and an optional 'UNFURNISHED/FURNISHED' switch. In addition a set of nomograms will require to be supplied to allow conversion of the simplified test result to the ISO 717 result.

Calibration procedure

The calibration method devised for the measurement of sound insulation and described in ASTM E 597 - 77T has been found to be most appropriate to this test and there would appear to be no reason to develop an alternative method.

Max/Min Volume, Max/Min Wall/Floor Area

The research has shown that the simplified method of testing is no more and no less sensitive to changes in room volume or wall/floor area than that of the B.S. 2750:1980 test method. Accordingly, no recommendations specific to this test method are envisaged and those already in existence for the more complex test should apply here also.

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Ergonomics

It is envisaged that the noise source shall be contained within a cabinet with dimensions not exceeding 500mm (Height) x 400mm (Width) x 250mm (Depth). The absorbent pack shall be contained in a plastic case with dimensions 1000mm (Length) x 500mm (Breadth) x 300mm (Depth). The weight of the combined equipment should be kept within 20 kg. both for ease of movement about building sites and also to comply with maximum carriage limits for travel by aircraft. The power supply should be mains, 100 V - 240 V, 50/60 Hz with the option of Ni Cd rechargeable battery operation. The maximum broadband sound power output should be 120 dB re 10^{12} watts.

Acknowledgement

I should like to acknowledge the significant contribution made to this work by Mr. Michael Wawro. The research was financed by the Science and Engineering Research Council and the Scottish International Educational Trust.

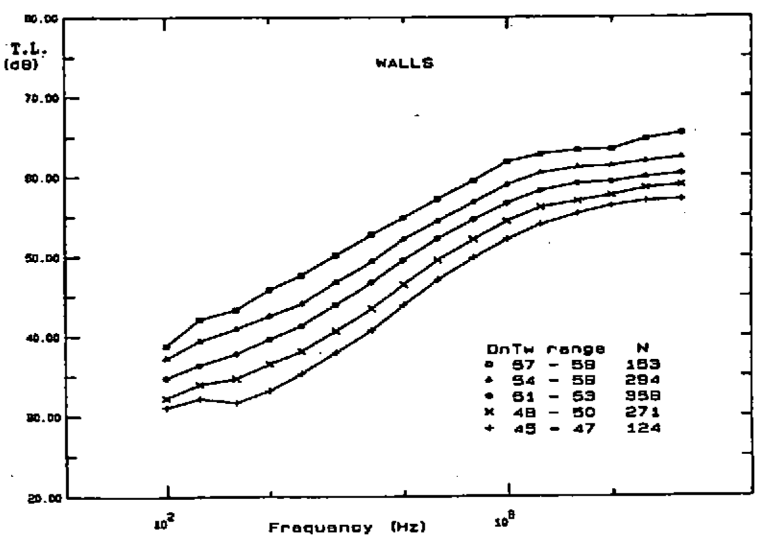

FIG. 1 THE TRANSMISSION LOSS OF WALLS ACCORDING TO INSULATION RANGE

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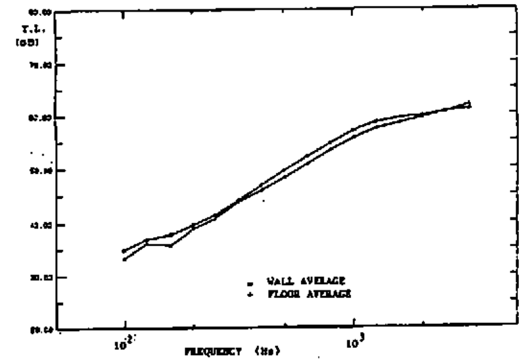

FIG. 2 WALL AND FLOOR AVERAGE TRANSMISSION LOSS

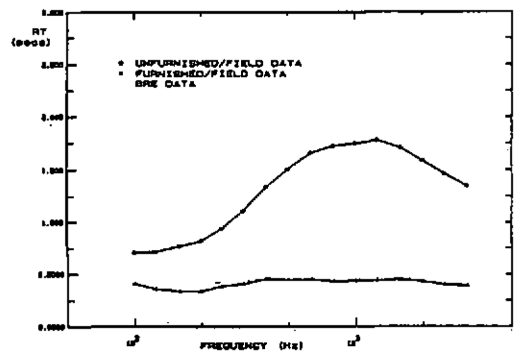

FIG 3 THE RELATIVE ABSORPTION OF FURNISHED AND UNFURNISHED DWELLINGS IN TERMS OF REVERBERATION TIME.

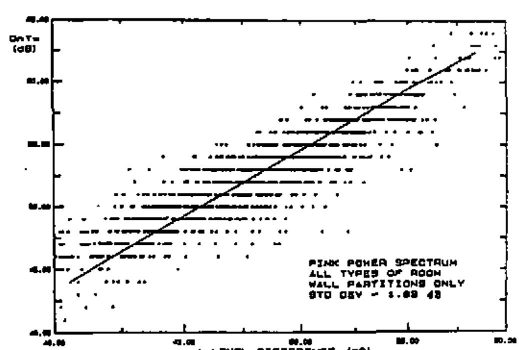

FIG. 4 THE CORRELATION OF THE 1985 BUILDING REGULATION RESULTS WITH THE SIMPLE TEST RESULTS.

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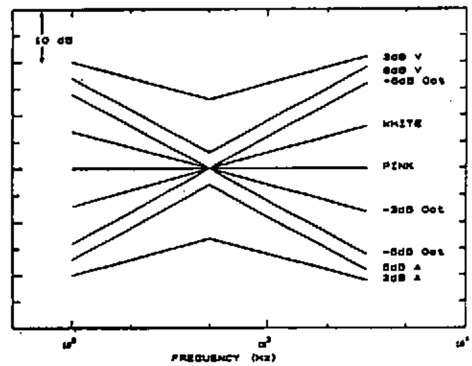

FIG 5 SYSTEMATIC VARIATION OF SPECTRUM SHAPE

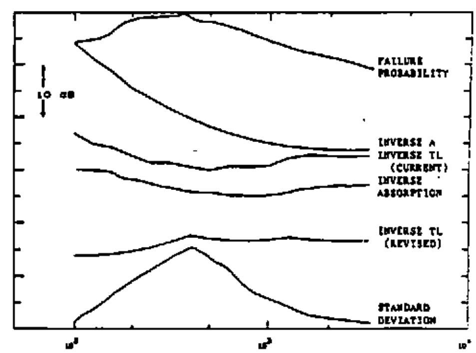

FIG 6 VARIATION OF SPECTRUM SHAPE ACCORDING TO SPECIFIC CRITERIA

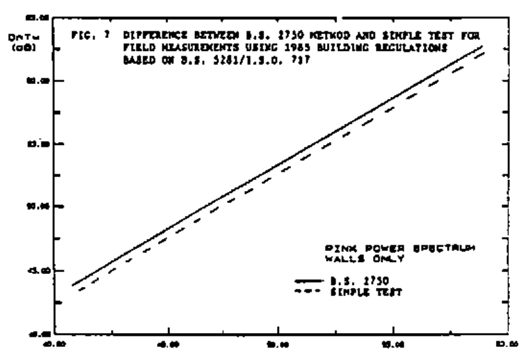

FIG. 7 DIFFERENCE BETWEEN B.S. 2750 METHOD AND SIMPLE TEST FOR FIELD MEASUREMENTS USING 1985 BUILDING REGULATIONS BASED ON B.S. 5281/I.S.O. 717

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IN SITU MEASUREMENTS OF SOUND INSULATION USING A PORTABLE SOUND INTENSITY ANALYZER

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Introduction

Several methods have been developed to investigate the way sound is transmitted between rooms; a review is given in [1]. The recently developed sound intensity method has been used to find the contributions from the individual radiating surfaces to the total field within the receiving room e.g. [2] [3] [4]. This paper presents a small, battery operated intensity analyzer which enables in situ measurements to be conveniently performed. To illustrate the use of this analyzer in practice, the direct and flanking sound insulation between two newly built terraced houses were measured and the results compared with classical insulation measurements. The effect of discrete point and sweep measurement techniques on the results was also investigated.

Instrumentation

The Sound Intensity Analyzer used for these measurements is a small (138 × 215 × 300 mm), robust, instrument weighing less than 6 kg. It is capable of measuring sound intensity, sound pressure and particle velocity in the eight octave bands with centre frequencies from 63 Hz to 8 kHz as well as the linear and A-weighted values (see block diagram Fig.1). For a complete sound intensity analysing system, the analyzer must be equipped with a sound intensity probe. A new Sound Intensity probe has been specially developed for use with the portable analyzer. This probe is based on the two microphone technique as is the widely used Type 3519 but it employs phase matched ½" prepolarised condenser microphones of modified design [5]. The frequency ranges over which the various microphone pairs may be used to measure intensity are shown in Fig.2.

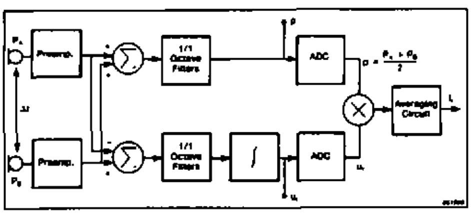

Fig. 1. Block diagram of portable, octave band intensity analyser.

The analyzer is a serial analyzer that is the measurements are performed in the octave bands consecutively and stored in the internal memory. The internal memory can contain a complete measurement that is a sound intensity spectrum, a particle velocity spectrum, and two pressure spectra. The automatic facility of the analyzer enables a complete spectrum to be measured in all frequency bands with autoranging of attenuators and initiation of output over the interface bus to a peripheral device such as a printer. The LCD displays the measured levels and error codes and also gives an analogue indication of the magnitude and direction of the intensity level. When measuring sound power, the area of the control surface can be entered into the analyzer so that the measured intensity is weighted accordingly and the resulting sound power level is displayed on the LCD.

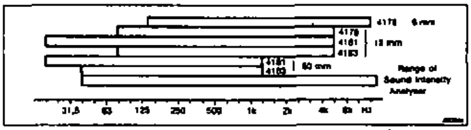

Fig. 2. Usable frequency range of phase matched microphone pairs for an error of less than 1 dB under free field conditions. Pair 4178 consists of two ¼" 4135 microphones. Pair 4181 consists of two ½" 4133 microphones. Pair 4183 consists of two ½" 4176 microphones. Pairs 4181 & 4183 are fitted with phase correctors

A remote control unit to which the probe may be attached enables the analyzer to be operated without having to remove one's eyes from the probe. This is an important consideration when using the sweeping technique for spatial averaging where the traversing speed of the probe has to be kept constant to yield reproducible results.

Mass storage of data may be done either by sending spectra to a programmeable PC or to a Digital Cassette Recorder Type 7400. If spectra are stored on the Type 7400 then they may be processed using the Sound Intensity Application Package BZ 7004 originally developed for the third octave Sound Intensity Analysing system Type 3360.

Amplitude calibration

The complete system may calibrated by applying a known sound pressure level at each microphone in turn by means of a pistonphone. Once any attenuator adjustments have been made, changes in temperature and pressure do not necessitate a recalibration. The actual values of temperature and pressure may be keyed into the analyzer and the results are weighted accordingly.

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Phase calibration
The actual phase calibration of the system is performed at the factory. In situ a phase verification may be performed by inserting the probe into a small acoustic coupler connected to a pistonphone or other sound source. When the same signal is received by both microphones, the measured intensity on an ideal intensity analyzer would be zero. This measurement on a practical intensity analyzer measures the "residual intensity" of the instrument. The difference between the residual intensity level, $L_{I,R}$, and the corresponding pressure level $L_{p,R}$ in the coupler is known as the residual intensity index of the system $L_{K,0}$ which is directly related to the dynamic capability of the system [6]. The residual intensity index $L_{K,0}$ as measured for two systems is shown in Fig.3.

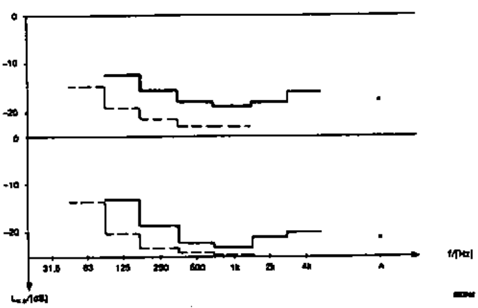

Fig. 3. Residual intensity index $L_{K,0}$ measured for 2 intensity systems using the portable intensity analyzer and various microphone pairs.
Upper curves: —4183, Δr = 12 mm
---4183, Δr = 50 mm
Lower curves: —4181, Δr = 12 mm
---- 4181, Δr = 50 mm
A-weighted values measured with Δr = 12 mm

Measurement conditions
The sound insulation measurements were performed in two adjacent terraced houses. The party wall separating the two houses had an area of 14 m^2 on the receiving room side of which only 10 m^2 was common to both the transmitting and receiving rooms. The common area was made of 230 mm concrete. The remaining area, made of lighter materials, (wood clad breezeblock) extended beyond the outer wall of the transmitting house and faced out into the garden. The volume of the receiving room was 80 m^3. Its reverberation time was approximately 1,5 seconds in the frequency range 100 Hz to 3150 Hz which on applying sabines equation yields a total absorption of 8,7 m^2.

As a control, the apparent sound reduction index R' was measured according to ISO 140. The value for the area used in the formula for R' was the common party wall area as prescribed by ISO 140, that is 10 m^2. The remaining 4 m^2 of the party wall thus represented a flanking transmission path.

Consideration of measurement difficulties
Before intensity measurements were performed, the need for reducing the reverberation time in the receiving room was evaluated. The factors which influence the measurement accuracy of the intensity estimates (ignoring for the time being errors due to under sampling, varying sweep rate and the like) are

1. The reactivity index L_K of the sound field in front of the radiating surface.
2. The absorption of the radiating surface.

The greater the reactivity index, the greater the averaging time which must be employed for the same statistical accuracy in the measured intensity. If the reactivity index exceeds the dynamic capability of the system then the measurement will be subject to a bias error [6].

An intensity analyzer measures the net intensity in the probes direction at a given point, therefore the net intensity measured over a wall is equal to the desired radiated intensity only if the oppositely directed intensity absorbed by the wall is negligible [7]. The absorbed intensity will be negligible when the absorption coefficient for the wall is far less than 1 and/or the incident intensity is relatively small.

In reference [7] a set of formulae has been derived which enables one to calculate the relative error in the intensity measurement caused by wall absorption α and the reactivity index L_K during measurement of the partial power contribution of a wall segment.

For a receiving room with N surfaces the apparent intensity I radiated into the room by the partition is given by:

$$I = \sum_{n=1}^{N} I_{t,n}\, S_n / S \qquad \text{eq.1}$$

where $I_{t,n}$ is the intensity transmitted by the n^{th} surface of area S_n and S is the surface area of the partition.

For the n^{th} wall the relative error ϵ_n is given by:

$$\epsilon_n\,(I) = 10 \log \left(1 - \frac{S\, I\, \alpha_n}{A\, I_{t,n}}\right) \text{dB} \qquad \text{eq.2}$$

where α_n is the absorption coefficient of the n^{th} wall, and A is the total absorption of the receiving room.

The reactivity index for the n^{th} wall is given by

$$L_{K,n} = 10 \log \left[\left(1 - \frac{S\, I\, \alpha_n}{A\, I_{t,n}}\right) / \left(1 + \frac{8\, S\, I}{A\, I_{t,n}}\right) \right] \text{dB} \qquad \text{eq.3}$$

Another way of expressing these quantities is given in [9]

$$\epsilon_n = 10 \log (1 - A_n W / A W_n) \qquad \text{eq.4}$$

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$$L_{K,n} = 10 \log [(1 - A_n W/AW_n)/(1 + 8WS_n/AW_n)] \quad \text{eq.5}$$

where A is the total absorption of the receiving room A_n is the absorption of the n^{th} wall, W is the total sound power injected into the room, W_n is the sound power injected by the n^{th} wall.

The last formula can be simplified [9] if one can assume that A_n is negligible and that in front of the wall the pressure due to the reverberant field is far greater than the pressure due to the direct field. This gives:

$$L_{K,n} \simeq -10 \log [8WS_n/AW_n] \quad \text{eq.6}$$

Setting n = 1 into these formulae reduces them to the case of 1 radiating surface e.g. the case of a laboratory transmission suite with little or no flanking transmission. These formulae were used to estimate how much extra damping was required to reduce $|L_K|$ and ϵ. Examples of the calculated ϵ_n and $L_{K,n}$ are given in Table 1 for two values of α, firstly on the party wall of area 10 m² assumed to be the only radiator and secondly on a flanking wall of the same area assumed to radiate a fifth of the total intensity entering the room.

Absorption of wall α	i) Party wall		ii) Flanking wall	
	ϵ_1 dB	$L_{K,1}$ dB	ϵ_2 dB	$L_{K,2}$ dB
0,01	-0,05	-10,1	-0,25	-16,9
0,1	-0,5	-10,6	-3,7	-20,4

Table 1. Calculated ϵ and $L_{K,n}$ for $A = 8,7 m^2$
i) Party wall, area 10 m², is the only radiator
ii) Flanking wall, area 10 m², radiates a fifth of total intensity entering receiving room.

These difficult measurement conditions were ameliorated by introducing bales of rockwool into the middle of the receiving room, where they acted as an acoustic drain. The mean reverberation time was reduced from 1,5 s (A = 8,7 m²) to 0,4 s (A = 32,6 m²). Comparison of Tables 1 and 2 shows that the extra absorption reduced the anticipated error on the intensity measurements and lowered the reactivity index significantly.

Absorption of wall α	i) Party wall		ii) Flanking wall	
	ϵ_1 dB	$L_{K,1}$ dB	ϵ_2 dB	$L_{K,2}$ dB
0,01	-0,01	-5,4	-0,07	-11,3
0,01	-0,14	-5,5	-0,7	-12.0

Table 2. Caption as for table 1 except $A = 32,6 m^2$

Although a powerful sound source was employed in the transmitting room (about 110 dBA sound pressure level), the large insulation index (I_a = 58 dB) of the party wall meant that the intensity levels in the receiving room were so small that non-stationary noise from the building site and even the purring of an instrument's cooling fan interfered with the measurements. It is therefore advantageous to use a silent, battery operated instrument in the receiving room and to perform the measurements after working hours.

Intensity measurements

Intensity measurements were performed on the party wall and on the flanking building elements termed window wall, inclined wall, floor, ceiling, garden door, flanking wall, rear wall. The probe was held with the centre of the microphone spacer at 15 cm from the surface under test. This distance was chosen after preliminary investigations showed that distance had little influence on the results. All the results shown in this paper employed a 12 mm microphone spacer. The measurements were performed using the serial portable octave Sound Intensity Analyser and the results controlled by the parallel, third-octave/octave Sound Intensity Analysing System Type 3360.

Sound reduction index of building elements

The apparent sound reduction index R' of the various building elements in the receiving room were determined using the intensity method from:

$$R' = L_p - 6\text{ dB} - L_I + 10 \log \left(\frac{S}{S_n}\right) \text{dB} \quad \text{eq.7}$$

where L_p is the mean sound pressure level in the source room and L_I is the transmitted intensity measured in the receiving room over the element under test. S and S_n are the areas of the party wall and the flanking element repectively. The results are shown in

Octave centre frequency Hz	Party wall concrete	Party wall breeze block	Window wall	Inclined wall	Garden door	Total R' dB (intensity)	Apparent sound reduction index R' dB (ISO 140)
125	46,7	45,6	56,2	53,2	56,2	42,3	44,1
250	52,3	56,3	63,2	60,2	66,2	50,0	49,1
500	57,5	59,4	64,2	69,2	69,2	54,5	53,1
1 k	68,1	65,9	67,7	73,2	79,2	61,9	58,1
2 k	73,3	75,1	72,0	78,2	77,2	67,6	62,1

Table 3. Sound reduction indices of building elements

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Table 3. The results of R' for the concrete and the breeze block part of the party wall are the averages of 10 and 4 measurements respectively. The accuracy of the individual measurements is within 1 dB.

Some discrepancy between R' using the intensity method and R' using the ISO 140/IV method in Table 3 is to be expected as not all the flanking building elements were taken into account.

The sound intensity measurements on the party wall were measured using the sweep technique in 12 subareas with an averaging time of 32 s. (Fig.4). The sweep rate was about 0,5 m/s. The intensity levels at that end of the wall closest the garden were markedly higher in certain octaves. The drawings of the houses showed that the part of the party wall common to both houses was made of 230 mm concrete whereas that part facing directly into the garden was made of 150 mm breeze block clad with wood. The sound pressure level is the garden near to the breeze block wall was approximately 80 dBA indicating that the high intensity levels on this part of the wall were due to flanking transmission.

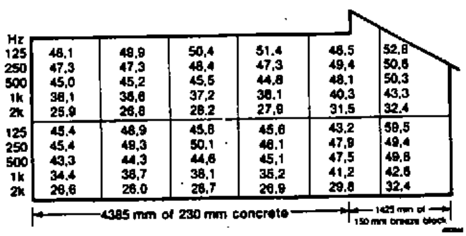

Fig. 4. Sound intensity levels on party wall in dB re 1 pW. m^{-2}

Sweep and point measurement technique
Comparison was made between sweep and point measurements of intensity over the party wall in 12 subareas using the portable octave Sound Intensity Analyzer. The resulting sound reduction indices are shown in Table 4. The sweep speed was about 0,5 m/s.

Hz	R point	R sweep
125	47,2	47,9
250	52,1	52,8
500	58,4	58,8
1 k	63,9	63,6
2 k	74,2	73,9
A	61,4	61,4

Table 4. Sound reduction indices point and sweep measurement techniques over 12 subareas on the party wall

Conclusion
The sound intensity technique was succesfully used to determine the contributions from a number of building elements to the total sound power radiated into the receiving room.

Formulae were given which enabled the normalised error and the reactivity index to be estimated before the intensity measurements were commenced. Despite low intensity levels and high reactivity indices, problems which are unavoidable when performing sound insulation measurements in situ, reproducible results were obtained using a portable, battery operated, octave intensity analyser with both the sweep and point measurement technique.

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APPLICATIONS OF TIME DELAY SPECTROMETRY (ISOLATION AND ABSORPTION)

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The T.D.S. (time delay spectrometry) technique was originally developed by Richard C. Heyser in 1967 (1), although it was 1983 before a dedicated portable system was commercially available.

The technique enables measurements to be made in the time or frequency domains and the information very easily manipulated between these two domains. The resolution obtained in one domain depends on the width of the window in the other domain. Time resolution T.R.=

$$\frac{B \text{ - Bandwidth of tracking filter}}{S \text{ - Sweep rate}} = \frac{1}{F}$$

Frequency resolution F.R.=

$$\frac{S \text{ - Sweep rate}}{B \text{ - Bandwidth of tracking filter}} = \frac{1}{T}$$

The product F.R. x T.R. equals unity, the uncertainty principle.

Until now the technique has been mainly used for the anechoic measurement of loudspeakers (2) and the measurement of rooms and auditoria.

For the anechoic measurement of loudspeakers the only limitation for frequency resolution (particularly low frequency) is the reflection free space.

Reflection free distance = T.R. x C = D.R.
EG for F.R. = 50Hz T.R. = $\frac{1}{50}$ = 0.02 secs.

= D.R. = 0.02 x 344 = 6.88m

Therefore the dimensions of the testing room have to be the same as the anechoic room for equipment measurements, however the surfaces can be perfectly reflective.

The T.D.S. system has been used for the measurement of absorption of materials. The technique is quite straight forward to obtain the absorption of signals of normal incidence.

The basic set up is to have a perfectly reflective surface and a sound source at some distance apart. The microphone is then placed at some point directly between the source and reflective surface. The E.T.C. (energy time curve) is then obtained for this system, the specular reflection from the reflective surface will appear on the E.T.C. The frequency response of this reflection can then be obtained from the E.F.C. (energy frequency curve). The time window of this E.F.C. must be small enough to exclude the direct sound and any other reflections present in the test room, but as large as possible to get as great as possible frequency resolution.

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A direct comparison can then be made by covering the reflective surface with the absorbent material to be tested.

To obtain the oblique incidence absorption characteristics of a material a similar technique, however, the frequency resolution decreases as the angle of incidence (re:normal) increases.

As reflected path length $\rightarrow$ direct path length. Time window obtainable $\rightarrow$ 0.

Theoretically the sound isolation of barriers and partitions could be measured in a similar way. The flanking transision paths could be identified on the E.T.C. and excluded (or individually measured) in the E.F.C. measurement.

However, at this point in time, tests have failed to be conclusive, partially due to problems of reverberation in the source and receiving areas and also the large signal to noise ratio required.

Theoretically, however, the T.D.S. method should have a superior signal to noise ratio over any other analysis system (3). The signal to correlated noise ratio is greater than 60dB (using adequate time windows to provide an equivalent frequency resolution of other methods).

There is theoretically no limit to how narrow a filter we can use in T.D.S. for a specified T.R. or F.R. as long as the product of bandwidth and measuring time is kept constant. We can therefore cancel the influence of background noise, independent of it's level or frequency distribution. If the background noise has a broad spectrum then only a small part of it will be in the pass band at the time compared to the signal. Background noise consisting of pure tones will also be suppressed when the effective integration time of the filter is chosen much longer than the period for which the noise remains in the filter.

The recent advances in software (by R.C. Heyser) for the Tecron TEF10 machine have also included zero correction (for nullification of background noise)and averaging programmes (providing up to 64 sample averages).

Examples of E.T.C. and T.D.S. measurements will be shown at the presentation of this paper.

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