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SOUND INSULATION MEASUREMENTS WITH INTENSITY TECHNIQUES: FLANKING TRANSMISSION

C Hopkins

Acoustics Centre, Building Research Establishment, Garston, Watford WD2 7JR

1.0 INTRODUCTION

Sound intensity techniques in building acoustics can be used as a diagnostic tool when flanking transmission is suspected to be the cause of poor sound insulation between dwellings. The ability to quantify sound transmission through the separating element and through the flanking elements allows informed decisions to be made regarding remedial measures to improve the sound insulation. It also allows the potential improvement in sound insulation to be calculated and therefore aids the choice of remedial measure to be used.

This paper looks at field sound insulation measurements using sound intensity with reference to the Nordtest laboratory method NT ACOU 084[1]. This method is currently being used as a basis for a draft ISO standard (ISO Working group TC43/SC2 WG23) for the measurement of sound insulation in buildings and of building elements using sound intensity under laboratory conditions. This methodology is transferable to sound intensity measurements in the field to quantify direct and flanking transmission.

2.0 SOUND INTENSITY MEASUREMENTS IN REVERBERANT ROOMS

The ability to accurately measure sound intensity in enclosed spaces is affected by the reactivity of the sound field. This is described by the pressure-intensity indicator or field indicator F_{pI} which is defined as 'the difference between the time and surface averaged sound pressure level, L_P, and the normal sound intensity level, L_I on the measurement surface'. To give an indication of potential problems obtaining accurate intensity measurements in a reverberant room, the following equation[2] can be used which relates reverberation times to an average value of the field indicator F_{pI},

$$F_{pI} = 9 + 10\lg(\tfrac{S}{A}) = 9 + 10\lg(\tfrac{ST}{0.16V})$$

where
S is the element surface area (m^2)
A is the absorption area of the receiving room (m^2)
V is the room volume (m^3)
T is the reverberation time (s)

In the above expression it is assumed that there is a doubling of mean square pressure approximately 150mm from the radiating surface where the intensity probe is commonly placed. Waterhouse[3] quotes the increase in the sound pressure level at a perfectly reflecting surface to be 2.2dB in a reverberant field hence the assumption used in the above equation gives worst case values. (N.B. The rule of thumb to achieve F_{pI}<10dB with S/A <1.25 is inferred from the above equation.)

The draft European Standard describing a survey method for field measurements of sound insulation (also referred to as the 'short test method')[4] contains average reverberation times in octave bands (125Hz - 2kHz) for common room constructions using European measurement data. These data can be used to indicate when the average field indicator F is likely to exceed 10dB in typical rooms in dwellings, leading to potential intensity measurement problems. Average values of field indicator F_{pI} have been calculated[5] assuming an average room dimension of 3.5m perpendicular to the separating wall for measurement of the sound power radiated by the separating wall. The data indicate that unfurnished rooms will often present measurement problems in the building acoustics frequency range without the introduction of absorbent material into the room. In furnished rooms, accurate measurements without additional absorbent are more likely to be feasible. The average reverberation times all have values greater than or equal to 0.4s whereas a value of 0.3s, which is common in many furnished living rooms in the UK would give an average field indicator of 6.2dB.

3.0 SOUND PRESSURE, SOUND INTENSITY AND THE WATERHOUSE CORRECTION

The apparent sound reduction index R' is determined from the sound power incident on a separating element W_1, the sound power transmitted by that separating element W_2 and the sound power transmitted by flanking elements W_3 using:

$$R' = 10\lg\left(\frac{W_1}{W_2 + W_3}\right) \text{ (dB)}$$

In the BS2750/ISO 140[6] method of measuring airborne sound insulation, both the incident and transmitted sound power are determined from sound pressure level measurements. When sound intensity is used to determine sound insulation, the incident sound power is determined from sound pressure level measurements, but the transmitted sound power is obtained by measuring the sound intensity radiated by the element or elements.

It is not strictly correct to compare sound insulation measurements using the sound pressure method to sound insulation measurements made using sound pressure and sound intensity. The sound pressure level method underestimates the sound power radiated into the receiving room due to the sampling of sound pressure in the centre of the room. The energy density in enclosed spaces is not uniformly distributed as assumed in the diffuse field model. At the boundaries of a room, the phase relationships between waves at a single point are no longer random which causes an increase in the energy density near the boundaries. Waterhouse[3] introduced a correction term for sound pressure measurements made in the central region of a reverberant room to calculate the total sound energy in the room. Whenever sound pressure measurements made in the centre of a reverberant room are to be related to radiated sound power or vice versa, the Waterhouse correction should be considered.

A sound reduction index R_I determined using sound intensity measurements can be adjusted with the Waterhouse correction W in order to compare the result with a sound reduction index measured using sound pressure through use of a corrected sound reduction index $R_{I,SPL}$.

$$R_{I,SPL} = R_I + W \text{ (dB)}$$

The Waterhouse correction W is defined as:

$$W = 10\lg\left(1+\frac{S_T\lambda}{8V}\right) \text{ (dB)}$$

where
S_T is the total area of all the boundary surfaces in the receiving room (m^2)
V is the receiving room volume (m^3)
λ is the wavelength of sound in air (m)

Waterhouse corrections are shown in Figure 1 for $15m^3$ and $35m^3$ rectangular rooms assuming an average room dimension of 3.5m perpendicular to the separating wall with a room height of 2.3m. The size of the correction term for rooms in typical dwellings is found to be greater than 0.5dB below 1kHz which is an important frequency range as it often determines the single number rating.

4.0 SOUND INTENSITY MEASUREMENTS

4.1 Spatial average sound intensity using the scanning technique

In building acoustics, sound intensity measurement using a scanning procedure is preferable to individual point measurements. The measurement surfaces are often large and due to the imprecise nature of building constructions it is necessary to make sure that the variations in sound radiation that occur over the surface have been adequately described in the average value of sound intensity.

The Nordtest method requires that the time and space integrated sound intensity level be measured by scanning the intensity probe across the measurement surface with a scanning pattern of parallel lines. The arithmetic average of two scans are taken; one carried out horizontally and one vertically. The difference between the two measurements should be less than 1.0dB for every frequency band. The results may still be used if the requirement cannot be met, having attempted to change the scanning pattern or sound field, but the deviation must be stated in the test report. The Nordtest method also requires that the field indicator F_{pI} shall be no greater than 10dB.

4.2 Practical considerations for scanning sound intensity measurements

Small elements can often be treated as a single area and scanned with a single sweep of the intensity probe across the surface. However, due to the large surface area of most walls/floors, or in cases where a box-shaped surface is used, it is generally more convenient and practical to split the wall surface into sub areas to be scanned individually. Scanning a large area requires physical repositioning of the operator and probe during the scan, which increases the chance of operator movement noise causing negatively signed intensity or overload.

If a single scan area is used for the whole surface, a straightforward check on the measurement validity can be made by ensuring that F_{pI}<10dB for each scan. If F_{pI} is too high, attempts can then be made to reduce it by increasing the distance of the probe from the wall surface, or adding extra absorbent to the room and repeating the scans. If multiple subareas are used, the field indicator is calculated from all sub area measurements. The average sound intensity level L_{In} for the surface area S (m^2) consisting of i subareas each of area S_i (m^2) is

$$L_{In} = 10\lg(\tfrac{1}{S}\sum_{i=1}^{n} S_i 10^{L_{Ini}/10}) \quad \text{(dB)}$$

(Negative direction intensity for a subarea is accounted for by multiplying the S_i value by -1.)

L_{In} (dB re $1\text{x}10^{-12}\text{Wm}^{-2}$) and the sound pressure level L_P (dB re $2\text{x}10^{-5}$Pa) can then be used to determine the field indicator for the entire surface from

$$F_{pI} = 10\lg(\tfrac{1}{S}\sum_{i=1}^{n} S_i 10^{L_{Pi}/10}) - L_{In} \quad \text{(dB)}$$

The field indicator value for the complete measurement surface is therefore not instantly available to be checked in the field unless the measurement equipment is computer controlled. This may mean that a judgement has to be made on the basis of individual subarea measurements, whether attempts need to be made to reduce F_{pI}. In the field, the time available on site effectively sets the limit on the amount of repeat data that can be gathered to try and improve the field indicator.

Time constraints in the field also restrict the ability to meet the requirement of achieving less than 1.0dB difference between the horizontal and vertical scans. Practically it is often difficult to satisfy this requirement, especially at the upper and lower limits of the building acoustics frequency range. To be certain of meeting the requirement, scans must be compared as the measurements are carried out, so that repeat scans can be made until the requirement is satisfied. This is too time-consuming in the field, and a practical solution is to carry out two horizontal scans and two vertical scans for each sub area and take the average of the horizontal and vertical scans with the smallest difference in each frequency band[7].

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5.0 EXAMPLE MEASUREMENT OF DIRECT AND FLANKING TRANSMISSION BETWEEN DWELLINGS

Intensity measurements made in the BRE flanking laboratory can be used to demonstrate measurement analysis in a situation where sound is radiated by two flanking surfaces and a separating surface. A wide band noise source was placed in one of the first floor rooms with intensity measurements taken in the adjacent first floor room. The two flanking surfaces included a 100mm aerated concrete flanking wall leaf ($70kgm^{-2}$) and a 12.5mm plasterboard ceiling ($10kgm^{-2}$) supported by a wooden lattice. The separating surface was a 100mm concrete separating wall leaf ($166kgm^{-2}$). Radiation into the receiving room was dominated by the plasterboard ceiling with a predicted critical frequency in the 2.5kHz third octave band. Below the critical frequency, non-resonant transmission across the plasterboard between the room and roof void is dominant, whereas above the critical frequency, resonant transmission between room and plasterboard as well as roof void and plasterboard dominates.

Measured sound power levels for each of the three surfaces are shown in Figure 2. The primary check on this data is made using the field indicator values for each measurement surface shown in Figure 3. The field indicator is dependent upon the position of the probe in the sound field and is non-zero if the sound field is not that of a plane progressive wave or inter-channel phase mismatch exists. The normalised error due to phase mismatch can be quantified using the difference between the residual pressure-intensity index and the measurement field indicator. The Nordtest method specifies that the residual pressure-intensity index is greater than (F_{pI}+10)dB so that the maximum error in the intensity measurement due to phase mismatch is less than 0.45dB. Assuming that the phase mismatch is known to be negligible compared to the actual phase difference that exists in the sound field, the field indicator for a measurement made in a reverberant field can only indicate that the sound intensity value may not be accurate because it is not a progressive plane wave field. The Nordtest method requires that F_{pI}<10dB which in this example is only satisfied for all surfaces between 400Hz and 1.25kHz although the separating and flanking walls had field indicators below 10dB between 160Hz and 1.6kHz. The reason for higher field indicator values with the ceiling measurements is partly due to the difficulty in damping the room modes between the ceiling and the floor without the operator standing on absorbent material whilst scanning the ceiling. Intensity measurements on walls are simplified by the fact that absorbent material can be strategically placed near the room surfaces or stacked behind the operator to damp the room modes. (N.B. Measurement problems are also encountered when scanning a floor surface where it is awkward to hang absorbent material above the operator and operator footfall noise that radiates from the floor must be avoided.)

If field indicator values greater than 10dB can not be resolved on site, a secondary check should be made to ensure that the measured receiving room sound energy corresponds to the predicted sound energy from the intensity measurements using all the significant radiating surfaces in the receiving room. The measured receiving room sound energy is found from sound pressure measurements in the centre of the room with the addition of the Waterhouse correction. The difference ΔE between the calculated energy from the intensity measurements and the measured energy using sound pressure is calculated as shown in the equation below.

$$\Delta E = 10\lg(\sum_{i=1}^{n} 10^{L_{Wi}/10}) + 10\lg(\tfrac{4}{A}) - L_p - 10\lg(1 + \tfrac{S_T \lambda}{8V}) \quad \text{(dB)}$$

where
L_{Wi} are the measured sound power levels for each of the i radiating surfaces (dB re $1\times10^{-12}Wm^{-2}$)
L_p is the average sound pressure level in the receiving room (dB re $2\times10^{-5}Pa$)

Zero values for ΔE indicate the inclusion of all significant radiating surfaces and accurate sound intensity measurements for the dominant radiating surfaces. The use of intensity measurements with $F_{pI}\geq10dB$ in rank ordering of the sound power rating for different surfaces can with caution be justified by referring to values of ΔE.

Figure 4 shows the energy level difference ΔE using measured receiving room sound energy with and without the Waterhouse correction. The receiving room volume V was $51.2m^3$ with a total surface area S_T of $87.6m^2$. These room parameters give rise to Waterhouse corrections that cause a significant increase in the accuracy of the receiving room sound energy at low frequencies. Between 400Hz and 1.25kHz where $F_{pI}<10dB$ for all three surfaces, ΔE is seen to be less than 1.1dB.

6.0 CONCLUSIONS

- Sound intensity is useful in the quantification of flanking transmission.

- Sound intensity measurements in unfurnished dwellings will often require absorbent material to be used to reduce the room reverberation time and hence provide satisfactory field indicator values.

- Scanning sound intensity measurements are the most practical method of determining the spatial average intensity radiated by walls and floors in the field.

- The Waterhouse correction is needed to:
  a) compare sound insulation data measured using sound pressure for comparison with data measured using sound intensity and sound pressure.
  b) check that all significant radiating surfaces in a room have been measured.

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REFERENCES

1. **Nordtest method NT ACOU 084** Approved 1992-03. Building elements: Sound insulation, intensity scanning under laboratory conditions. ISSN 0283-7145.

2. **F J Fahy.** Sound Intensity. Elsevier Science Publishers Ltd.

3. **R V Waterhouse.** Interference patterns in reverberant sound fields. Journal of the Acoustical Society of America (1955) 27(2) 247-258.

4. **CEN/TC 126/WG 1 N181.** Building Acoustics: Field measurements of airborne and impact sound insulation and of sound pressure level from equipment - Survey method. 10th draft October 1995.

5. **C Hopkins and T Emmanuel.** Sound intensity measurements for building acoustics. Institute of Acoustics Bulletin (Internoise 96 issue) 21(4) July-August (1996).

6. **BS 2750: Part 4 : 1980 ISO 140/IV-1978** Measurement of sound insulation in buildings and of building elements Part 4. Field measurements of airborne sound insulation between rooms.

7. **T Emmanuel.** Measurement of the sound insulation of facades and facade elements - A comparison of the intensity technique with the traditional method. Proceedings of the Institute of Acoustics Vol. 15: Part 8 (1993).

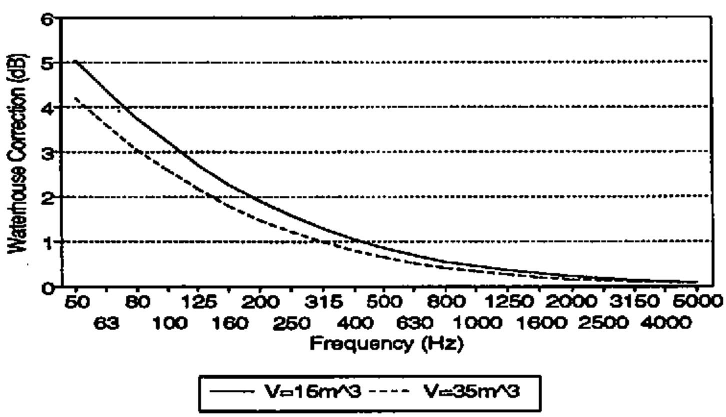

Figure 1: Waterhouse correction for typical rooms of volume V (m^3)

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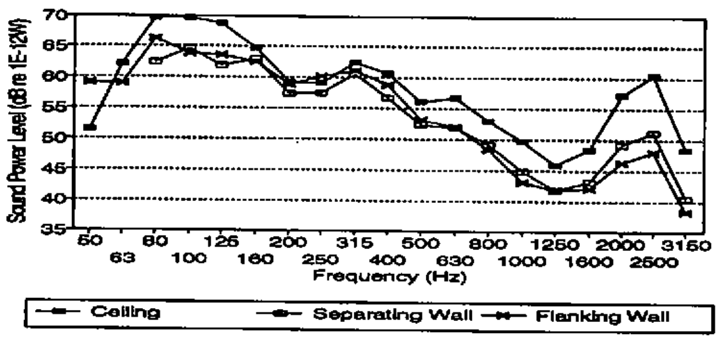

Figure 2: Sound power measurements in the BRE flanking laboratory

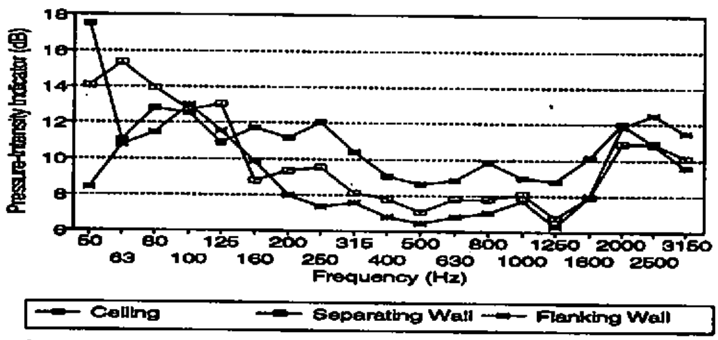

Figure 3: Field Indicator F_{pI} for each measurement surface

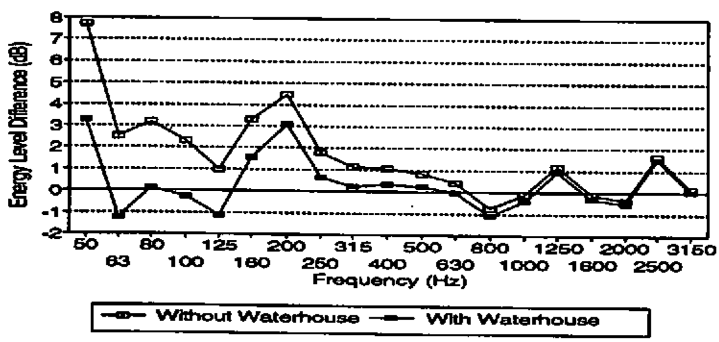

Figure 4: Energy Level Difference ΔE (dB)