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NOISE REDUCTION OF DWELLINGS AGAINST TRAFFIC NOISE

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INTRODUCTION

The main path by which external noise enters a room in a dwelling is usually the window. This is the case even where double windows are fitted except when the facade is of lightweight construction or there is some weak point such as a door or an air brick (1). For aircraft noise, transmission via chimneys and roofs may also be significant (2). A considerable amount of data has been published on the sound insulation of glass and windows in the laboratory (eg 3, 4), but field data are scarce. Laboratory conditions differ in many respects from those found in practice, and it is important to study the extent to which laboratory studies can be used to assess the performance of window systems in practice.

This paper presents noise reduction data obtained for dwellings subject to noise from road traffic. The dwellings were fitted with a range of types of window including single casements, replacement thermal double glazing and double windows formed by adding a secondary inner pane to the existing window. The results are presented over the frequency range 63 Hz to 3150 Hz and also in terms of three single figure descriptors which are often used to rate sound insulation performance. The advantages and disadvantages of each single figure descriptor are discussed.

The use of laboratory data to predict performance in practice has a number of problems. Some of these problems are associated with differences in the test environment and with the normalisation for room conditions. The field data are compared with published data obtained in the laboratory for similar types of window construction and an attempt is made to explain the differences observed.

THE FIELD DATA SET

The field data set consists of noise reduction measurements for a total of 234 windows. Of these, 50 are for single windows, 50 are for replacement windows and 134 are for double windows with a secondary inner pane. The sample of single windows further sub-divides into 20 metal casement, 20 wooden casement and 10 wooden sash windows. 42 of the replacement windows are thermal double glazing types installed in the last 10 years and these form the sample for subsequent analysis. The majority of windows were in two storey houses with the sample roughly equally divided between ground floor and first floor rooms. A small number of the double windows were in flats. Other information in the data set includes dimensions of windows and rooms and, for the single windows, measurements of reverberation times.

The noise reduction data were obtained by simultaneously recording levels of traffic noise inside and outside the dwelling on a high quality twin track tape recorder. The external microphone was situated at 1 metre from the facade while three positions near the centre of the room were used for the internal microphone. Five minute recordings were made for each of the internal positions. The special technique used when measuring the noise reduction of the double windows to overcome problems of electrical background noise in the recording system at high frequencies has been described elsewhere (1). In the case of the double windows it was usually necessary to have an external noise level (L_{A10}) of 70 dB to overcome the internal acoustic background noise. Reverberation time measurements were made using an impulse source and a Norwegian Electronics Analyser type 823 to determine reverberation times in $^1/_3$ octave bands. A minimum of three decays were analysed at each frequency.

The noise recordings were analysed through a system consisting of real time spectrum analyser and mini-computer to yield level differences in $^1/_3$ octave bands over the range 31.5 Hz to 4000 Hz.

Although no attempt was made to determine the construction of the wall in which the window was situated, any feature of the facade likely to adversely affect noise reduction such as air gaps, doors opening directly into the room behind the facade and the obvious presence of lightweight facades were noted. As a result of this information the results for two of the wooden sash windows were excluded from subsequent analysis.

RESULTS

The average noise level differences in $^1/_3$ octave bands are shown in Figure 1 and Figure 2. Only the uncorrected level differences have been considered. In theory, when comparing the noise insulation performance of one window with another the results should be normalised to take account of the window area, the room volume and the reverberation time. In practice the normalisation factor varies only within a small range for windows in dwellings and can reasonably be ignored when making comparisons on the basis of the average performance of a number of windows. It can be seen from Figure 1 that although the double windows with a wide cavity give the highest noise reduction over most of the frequency range, the replacement double glazed windows give the greatest reduction at 100 Hz and below. A resonance associated with double leaf constructions and known as the mass-air-mass resonance has a major influence on the noise reduction at low frequencies. For the double windows the frequency of this resonance is about 70 Hz and at that frequency the noise reduction is no better than for the single windows. For the double glazed windows the resonance frequency is much higher, about 280 Hz, because of the narrower cavity between the panes. At the resonance frequency the noise reduction is only slightly above that of the single windows but at low frequencies the level difference remains constant which eventually leads to the double glazed windows having the greatest noise reduction as the mass-air-mass resonance frequency for the double windows is reached.

The results for the three different types of single window are shown in Figure 2. At frequencies below 1000 Hz there is little difference in the noise reduction performance. At higher frequencies both wooden and metal casement windows show dips in the insulation curve though at different frequencies. It has been shown (5) that these dips arise from a Helmholtz resonator effect associated with the cavities around the edge of the opening casements when they are closed. The sash window frames which do not have these cavities have an insulation without dips at high frequencies.

The samples of single and of double glazed replacement windows were subjected to more detailed analysis to examine the effect of various parameters on the level difference. It was found that almost identical results were obtained for ground floor and first floor windows. However when the samples were sub-divided between flat and bay windows statistically significant differences were found over the frequency range 400-2000 Hz. For single glazing the bay windows gave, on the average, approximately 2 dB more noise reduction than the flat windows but the effect was reversed for the double glazed windows. At present there is no explanation of these apparently inconsistent results.

SINGLE FIGURE DESCRIPTORS OF INSULATION

An alternative method of describing the noise reduction performance is by means of a single figure index of which there are three in common usage, D_A - the difference in A weighted sound levels, D_W - obtained by using the rating method in BS 5821: 1980 and D_{AV} - the arithmetic mean of the noise reductions in $^1/_3$ octave bands usually over the range 100-3150 Hz. The results for the three types of window whose average noise reductions are shown in Figure 1 are given in Table 1. In all cases the figures are based on unnormalised level differences.

Table 1 Average single figure insulation values (dB)
[Standard deviations in brackets]

Window Type	Single	Double Glazed	Double Window
D_A	28.6 (2.9)	33.3 (3.0)	34 (3.0)
D_W	30.2 (3.1)	35.1 (3.3)	40.6 (2.8)
D_{AV}	28.3 (2.7)	33.6 (3.0)	37.1 (2.6)

Each of the single figure descriptors of noise reduction has advantages and disadvantages. D_W and D_{AV} are similar in that they do not depend on the incident noise spectrum. An analysis of the data for double windows showed a high correlation (r = 0.97) between these two descriptors, but it seems unlikely that such a high correlation would be maintained across all window types. The main advantage of D_{AV} is its simplicity of calculation together with the fact that for many windows its value is approximately equal to D_A for road traffic noise. Its main disadvantage is that it can give undue credit to high values of insulation at frequencies where there is relatively little incident noise. The rating method used to derive D_W overcomes this problem because values above the rating curve cannot be traded against shortfalls at other frequencies. Unfortunately it is not clear that the shape of the rating curve is the optimum one for reducing road traffic noise or any particular source of external noise. In fact the shape of the curve was based on an early German standard which was in turn based on laboratory tests on a 225 mm brick brick wall (6). Neither D_W nor D_{AV} take into account the noise reduction performance below 100 Hz.

The major difference with D_A is that the value of D_A depends on the spectrum of the incident sound. Because of the dependence of D_A on the incident spectrum, any quoted value of D_A should include details of this spectrum. For the mean insulation curves for double glazing and double windows in Figure 1 the values of D_A are higher for an aircraft noise spectrum than road traffic noise. Furthermore the difference in D_A for the double windows (4 dB) is more than twice that for the double glazing (1.5 dB). Since the main objective when considering values of external insulation is often to obtain the correct internal noise level (A weighted) it follows that D_A will be the best descriptor of insulation performance.

When using D_A however it is as well to be aware of the fact that in individual situations it can lead to confusing results. For example for one dwelling where measurements were made on double windows the value of D_A on the ground floor was 5 dB below that on the first floor despite both windows having a similar overall performance. The difference in D_A values was due to screening at ground floor level by a wall which resulted in an incident noise spectrum heavily biassed towards the low frequencies. For the double window sample as a whole insulation values were, on average, 1 dB higher on the first floor than on the ground floor and this may be attributed to shielding effects on the ground floor.

The use of D_A for comparing the noise reduction performance of different constructions would be improved if standardised spectra were available. The standardised spectra would cover the range of spectra commonly found (at the very least average spectra for road traffic noise and aircraft noise). For critical situations and where it is known that the incident noise spectrum differs significantly from the standardised spectra it would still be necessary to determine D_A from the actual measured or predicted incident spectrum.

PREDICTION OF FIELD PERFORMANCE FROM LABORATORY STUDIES

Much of the available data on the sound insulation of windows have been obtained in the laboratory and involve measurements between reverberant rooms. While the data are useful in indicating how various parameters influence sound insulation there is some uncertainty in converting the laboratory data to level differences in the field. The uncertainty arises from two factors, the differences in the incident sound field and the normalisation for receiving room conditions.

(i) Incident Sound Field

In the laboratory, measurements are usually made between reverberant rooms so that the sound reduction index (SRI) is related to the difference between sound pressure levels in the source and receiving rooms. In the field the relationship between the incident sound intensity and the sound pressure level measured in front of the facade will be different from that in a reverberant room. When the incident sound is a plane wave and the sound pressure level is measured without reflections from the facade then 6 dB must be added to the measured level difference. In practice it is not clear that the incident sound from a road constitutes a simple plane wave and the position of the microphone at 1 metre from the facade will mean that reflected sound will be included. The reflected sound results in an increase of about 2.5 dB (A) in the measured level. When measurements are made in frequency bands some variation about this figure could be expected.

(ii) Normalisation for Receiving Room Conditions

The normalisation correction applied in the laboratory is 10 log S/A where S is the area of the test specimen and A is the absorption area of the receiving room. In domestic rooms reverberation times are currently very low (7) so the sound field may not be reverberant and the average absorption coefficient is not small. In this type of situation Beranek (8) has derived a normalisation $10 \log (^1/_4 + S/R)$ for the near field of the window where $R = A/(1 - \alpha)$ and α is the average absorption coefficient for the room. In the far field the normalisation would be 10 log S/R.

(iii) Comparison of Laboratory and Field Data

In order to assess the actual difference between laboratory and field measurements the field data reported here were compared to laboratory measurements of sound reduction index (9). In order to try to match the degree of sealing the average of the upper quartile of field results were compared to laboratory results for weatherstripped wooden and metal casement windows. The comparison was made at mid-frequencies thus further removing the effect of differences in sealing and also removing low frequency effects.

The difference (ΔL) between the laboratory sound reduction index and the unnormalised level difference in the field was found to be about 4 dB. The relationship may be considered in the form:

$$SRI = \Delta L + K_1 + 10 \log S/A + K_2$$

where K_1 is the correction required to determine the incident sound energy from the sound pressure level at 1 metre from the facade and K_2 the correction to the normalisation which is required to take account of the differences in sound fields in the receiving room. The empirical result given above shows that:

$$K_1 + K_2 + 10 \log S/A = -4$$

By using average room parameters to determine a typical value of 10 log S/A it can be shown that $K_1 + K_2 = 4$. Values for K_1 range from approximately zero if the external field is considered quasi-reverberant to + 3 dB for a plane wave. For K_2 the range could be from − 1 dB for the normalisation 10 log S/R to + 4 dB if the normalisation $10 \log (^1/_4 + S/R)$ is used. It can be seen that there are a number of values for K_1 and K_2 which could satisfy the empirical equation which has been derived. Therefore the observed difference between laboratory and field data can be explained in terms of the external noise field and room normalisation. Further detailed examination of these factors is required to determine actual values for K_1 and K_2 in a particular situation.

CONCLUSIONS

The average reduction in traffic noise levels for dwellings with closed single windows is 28.6 dB(A) compared to 34 dB (A) for double windows with a secondary inner pane. Replacement double glazed windows gave an average A weighted traffic noise reduction only slightly below that for the double windows and gave the highest insulation at frequencies below 125 Hz.

Despite some problems when evaluating measurements of individual windows, it is concluded that the A weighted level difference D_A is the best single figure measure of noise insulation. The use of D_A would be improved if standardised incident noise spectra were available for calculating values of D_A from frequency band noise reduction data.

NOISE REDUCTION OF DWELLINGS AGAINST TRAFFIC NOISE

It has been found that for the reduction of traffic noise in dwellings the laboratory sound reduction index is 4 dB less than the unnormalised level difference. Further research is required to support this empirical correction and to enable appropriate corrections to be derived for other situations, for example aircraft noise incident on schools. The availability of these corrections will enable much greater use to be made of the considerable amount of laboratory data which has been published.

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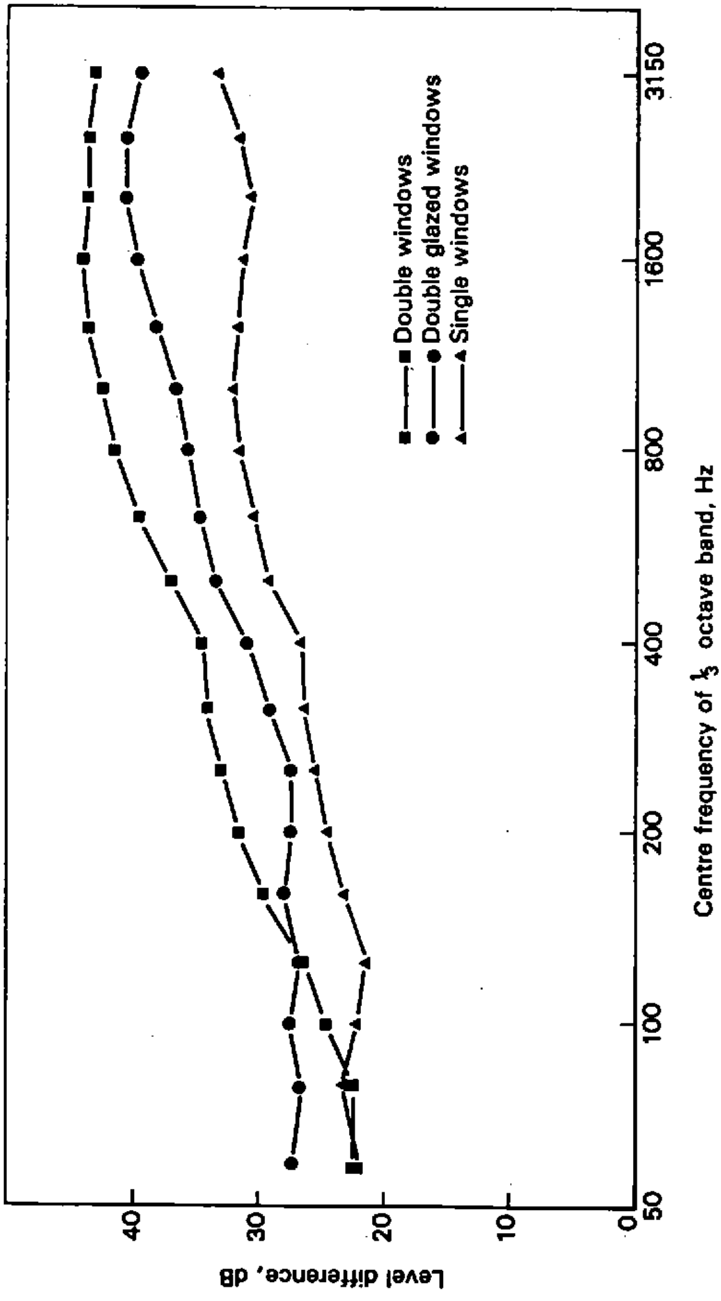

Figure 1 Comparison of average level differences for three window types

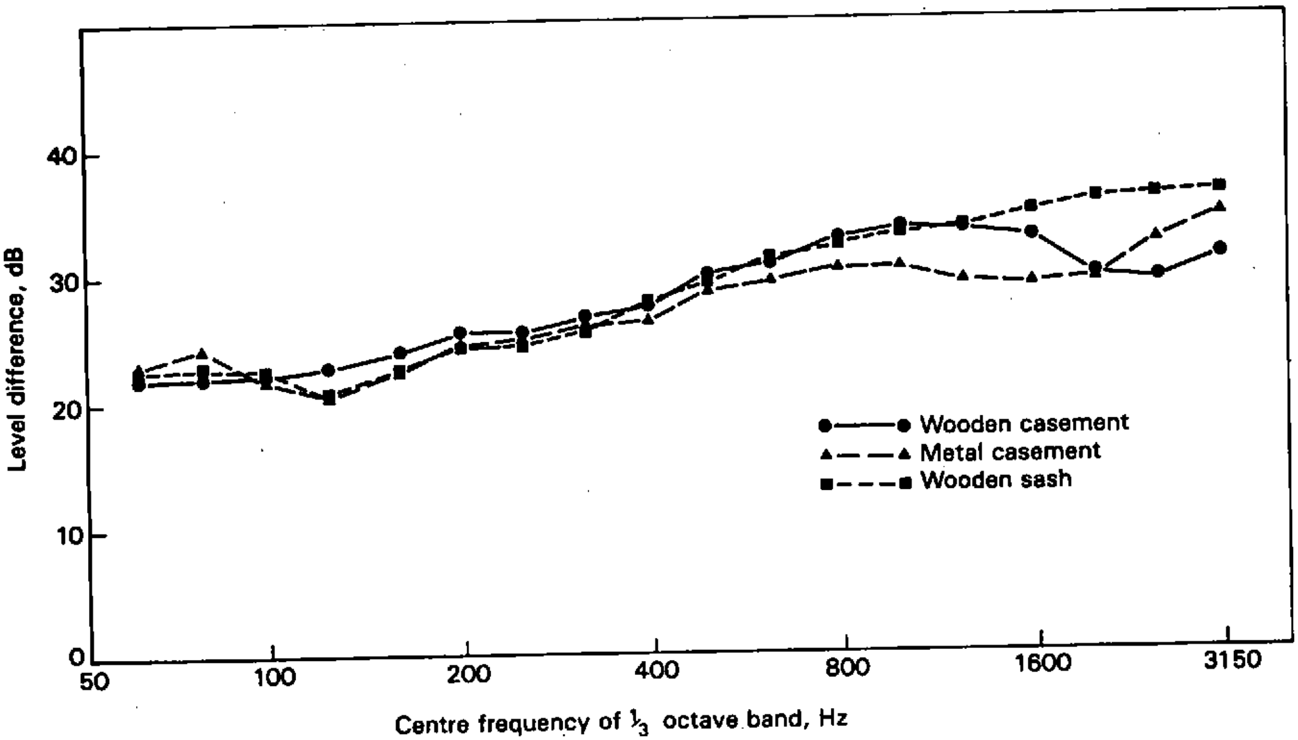

Figure 2 Comparison of average level differences for single windows with three types of frame