THE FIELD PERFORMANCE OF PARTIALLY OPEN DUAL GLAZING

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SUMMARY

The insulation of partially open dual glazing has already been measured in the laboratory. During an extensive programme of sound insulation tests on a house near Manchester Airport the opportunity was taken to measure the field performance. The results show an increase in insulation of up to 3 dB(A) when compared with predictions based upon laboratory SRIs.

An assessment was also made of the ventilation by comparing the rate of air change when the dual windows were open with that due to a mechanical ventilator operating with the windows closed. Under typical weather conditions it was found that there was little difference, a rate of 2–3 air changes/hour being measured.

INTRODUCTION

In order to assess the possibility of obtaining a moderate insulation from dual glazing with staggered openings, a series of sound reduction index tests was carried out in a reverberation suite.[1] By relating the results to the more practical situation of insulation against traffic or aircraft noise it was concluded that open dual windows are about 9 dB(A) better than open single windows for traffic noise and 11 dB(A) better for aircraft noise.

However, the tests were conducted using diffuse noise whereas in practice the sound is incident at a particular angle. Further, in the laboratory no measurements were made to assess the likely ventilation rate—an important factor when considering the viability of open dual glazing as against sealed glazing and mechanical ventilation.

In order to research further into the practical use of dual glazing with staggered openings, the opportunity was taken to include some tests during an extensive programme of sound insulation on a house near Manchester Airport.[2]

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TEST SITE

The tests were carried out in the two upstairs bedrooms of a semi-detached house near Manchester Airport. The house faces south and under prevailing wind conditions take-off noise strikes the front of the house and noise from landing aircraft on the approach strikes the rear. Occasionally the conditions are reversed and the rear of the house is subjected to noise from aircraft climbing away after take-off. In addition, a minor road passes the front of the house approximately 8 m from the façade. This road carries some traffic to and from the airport and also feeds the M56 airport motorway spur.

HOUSE CONFIGURATION

The house is semi-detached and was built in 1928. For some months prior to the open-glazing measurements a series of tests had been carried out to establish effective ways of sound-proofing the house against aircraft noise, particular attention being paid to the scheme laid down in the Manchester insulation grant scheme.[3] As a result, the house was in the following condition prior to the start of the current tests:

1. The house was completely dual-glazed using the Crittall-Hope Warmlife system.
2. The front and back doors were weather-stripped and led into a porch and utility room, respectively. There was a mechanical room ventilator fitted in the back living-room.
3. 75 mm Fibreglass Crown 75 was laid between the joists and 25 mm Fibreglass Flanged Building Roll inserted between rafters with 12·7 mm plasterboard nailed to the rafters.
4. Both bedroom chimneys were blocked.

WINDOW CONFIGURATION

Each bedroom primary window had the original timber frame replaced with a wooden surround to which was fastened a pair of Luminair aluminium-framed vertical sliding windows, type VS2A, with a standard centre mullion. The inner windows were Crittall-Hope Warmlife Mk 4 horizontal sliders. The inner surface of the reveals was lined with acoustic tiles, but in order to simulate more closely the laboratory tests, some measurements were made with a 25 mm layer of flexible polyurethane foam pinned across the face of the tiles.

Twin horizontal sliding units performed best in the laboratory, but this combination could not be used because of supply difficulties. Consequently a compromise was made and a mixed combination of vertical sliding outers and horizontal sliding inners had to be used. The outer window further from the noise source was opened in combination with the diagonally opposite inner to give the longest 'sound-path' through the system (Fig. 1). The same combination was used in the measurements using traffic noise as the source.

For single-glazing tests the inner Warmlife units were completely removed and the same outer window opened.

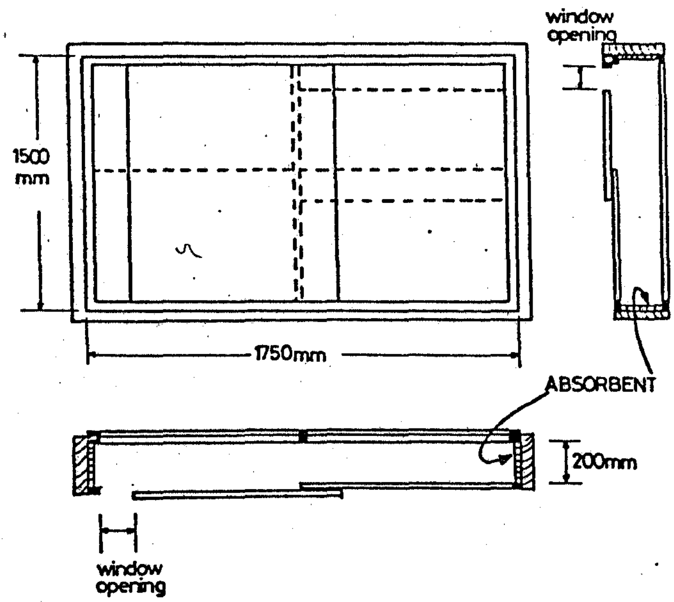

Fig. 1. Layout of back bedroom windows (viewed from inside).

METHOD OF MEASUREMENT

Measurements were made by tape-recording the noise inside and outside the house simultaneously during aircraft or traffic movements. The inside microphone was mounted on a tripod positioned approximately in the centre of each room. The external levels were measured with the microphone at the end of a 1 m pole, clamped under the eaves at either the front or the back of the house adjacent to the respective windows.

The recordings were analysed into the octave bands centred on 125, 250, 500, 1000, 2000 and 4000 Hz. These analyses were produced on paper charts and the internal and external levels were noted at the time of maximum external noise level.

Traffic noise measurements were made at the front of the house only. The internal/external levels were simultaneously recorded for a 10 minute period for each configuration. These were then analysed using the standard techniques to obtain both the internal and external L_{10} levels.[4] Further details on the method of measurement are given by Ford and Kerry.[2]

EXTERNAL NOISE LEVELS

The external noise level has been measured at either the front or the back of the house, as appropriate. There is, of course, variation between different types of aircraft and between aircraft of the same type with different loads, wind speeds, etc. The average noise spectra (calculated as a straight arithmetic average from the measurements) are shown in Table 1. Only medium and large jet aircraft have been included.

TABLE 1
AVERAGE EXTERNAL NOISE SPECTRA

Position	*Aircraft movement**	*Runway*	*No. of aircraft*	*Octave band level (dB)*						
				125	250	500	1000	2000	4000	*dB(A)*
Front of house	TO	24	162	78·5	84·4	85·6	79·9	71·1	59·4	85·1
Back of house	L	24	109	81·4	81·8	81·6	79·3	76·8	71·7	84·3
Back of house	TO	06	54	97·3	100·5	98·0	94·9	89·4	80·2	99·5
Front of house	Traffic	L_{10} (10 min sample)		71·0	71·0	69·0	68·0	64·0	56·0	72·0

* L = landing, TO = taking off.

External traffic noise levels have been measured at the front of the house only and are expressed in terms of the L_{10} level (*i.e.* the level exceeded for 10 per cent of the time). The level can vary throughout the day depending upon the number of vehicles passing; a proportion of these are heavy goods vehicles. The figures given in Table 1 are typical levels produced during the daytime.

DETAILS OF BEDROOMS

The overall dimensions of the bedrooms and windows are shown in Table 2.

The reverberation times in the rooms have been obtained by measuring the rate of decay of a recorded acoustical impulse. The results are shown in Table 3.

TABLE 2
DIMENSIONS OF ROOMS AND WINDOWS (METRES)

	Room			*Window*	
	Length	*Width*	*Height*	*Width*	*Height*
Front bedroom	3·80	3·70	2·60	1·80	1·50
Back bedroom	3·40	3·30	2·60	1·75	1·50

TABLE 3
REVERBERATION TIMES OF ROOMS (SEC)

	1/1 octave band centre frequency (Hz)					
	125	250	500	1000	2000	4000
Front bedroom	0·32	0·43	0·39	0·45	0·48	0·44
Back bedroom	0·27	0·33	0·35	0·35	0·38	0·37

WINDOW INSULATION

The insulation is defined as the difference in sound level between the interior of the room and the outside level at either the front (for aircraft taking off on runway 24 and traffic noise) or the back (for aircraft landing on runway 24 or taking off on runway 06).

The results are shown in Figs. 2 to 8. For the sake of clarity the results obtained using polyurethane foam around the reveals have been plotted separately for each type of aircraft movement, the 'dual closed' case being plotted on each graph to aid comparison. Only two traffic noise measurements have been frequency analysed and these are shown in Fig. 8.

Table 4 summarises the insulation in dB(A) and provides a more readily comprehensible version of the results. Values obtained for the three types of aircraft movement (taking off on runways 24 and 06 and landing on runway 24) have been averaged to provide more typical figures for comparison with the traffic noise insulation and the effect of different linings on the reveals.

VENTILATION RATE MEASUREMENTS

In an attempt to obtain some indication of the amount of natural ventilation possible with partially open staggered windows, a series of ventilation rate measurements was made at the same time as the acoustic tests. No pretence is made that the resultant figures indicate the whole story because natural ventilation is dependent upon a number of factors. In particular, the pressure differential across the windows is important and this is caused either by the wind, in which case air enters the building through cracks and openings on the windward side and leaves through similar openings on the leeward side, or it may be caused by the stack effect due to indoor/outdoor temperature differences. The pressure differential is also governed by the areas and resistances offered by openings to the air flow. The main factor to be studied was the influence of open window area upon ventilation rate. Therefore, the effect of other variables was minimised by making the measurements consecutively in each bedroom with all other doors and windows closed. The measurements were made on days when the wind was in the typical quadrant for the area, namely between south and west.[5]

TABLE 4
SUMMARY OF INSULATION IN dB(A)

Window	*Opening*	*Back bedroom: aircraft taking off on runway 06*	*Front bedroom: aircraft taking off on runway 24*	*Back bedroom: aircraft landing on runway 24*	*Average for aircraft movements*	*Front bedroom. Traffic*
Acoustic tiles on reveals:						
SG Luminair type VS2A	Closed	30	29	31	30	—
SG Luminair	100	20	24	23	22	21
DG Luminair + Mk 4 Warmlife	Closed	40	39	40	40	40
	25 mm	31	30	30	30	29
	50 mm	30	28	27	28	28
	100 mm	29	26	26	27	28
	200 mm	26	23	25	25	24
25 mm polyurethane foam on reveals:						
DG Luminair + Mk 4 Warmlife	25 mm	—	32	33	32	—
	50 mm	—	29	31	30	—
	100 mm	30	29	30	30	28
	200 mm	—	26	26	26	—

An infra-red gas analyser was used to measure the rate of disappearance of a nitrous oxide tracer gas which had previously been mixed with the air in the room. Fans were used to ensure thorough mixing. The concentration of N_2O was measured at 1 minute intervals continuing for about 20 minutes. The rate of decay of the tracer gas is given by:

$$C_t = C_0 \exp(-Nt) \qquad (\textit{see}\ \text{ref. } 5)$$

where C_t = concentration of tracer gas after time t in ppm
C_0 = initial concentration of tracer gas in ppm
N = ventilation rate in room volume/unit time
t = elapsed time in minutes.

This equation may be rewritten in the form:

$$N = \frac{60}{t}(\ln C_0 - \ln C_t) \quad \text{air changes/hour}$$

So N is most easily found from the slope of a graph of $\ln C_t$ against t.

The measured ventilation rates are detailed in Table 5.

TABLE 5
VENTILATION RATES

Window type	*Opening*	*Ventilation rate*		*Wind**	
		Air changes/hr	*m^3/sec*	*Direction (degrees)*	*Speed (m/sec)*
Back bedroom:					
SG Luminair	100 mm	5·6	0·045	200	4
DG Luminair	25	2·4	0·019	180	4
	50	3·6	0·029	190	4
	100	4·8	0·039	190	4
	200	8·0	0·072	190	3
Front bedroom:					
SG Luminair	100 mm	2·1	0·021	210	3
DG Luminair + Mk 4 Warmlife	25	0·5	0·005	290	7
	50	0·9	0·009	290	5
	100	2·5	0·025	290	5
	200	1·5	0·015	230	3

* Details of the wind speed and direction were obtained at the time of the ventilation measurements from Ringway Air Traffic Control (departure information) and therefore refer to free air conditions.

COMPARISON WITH LABORATORY WORK

In order to see how the measured insulation compares with that which would be expected theoretically, some results from the laboratory work, carried out during the spring of 1972, and reported by Ford and Kerry,[1] have been applied to the real situation at Ringway Road.

Owing to supply difficulties it was not possible to duplicate exactly in the field a particular window arrangement previously tested in the laboratory. Accordingly a compromise was made and horizontal sliding inner units were mated with vertical sliding primaries. The laboratory tests thought to resemble the combination most closely were the two horizontal sliders for dual glazing and single open, and the vertical sliders for the single closed. The choice was made on the basis of total open area and air path length. Since windows with acoustic tiles on the reveals were not tested in the laboratory, the comparisons were made for the foam reveals.

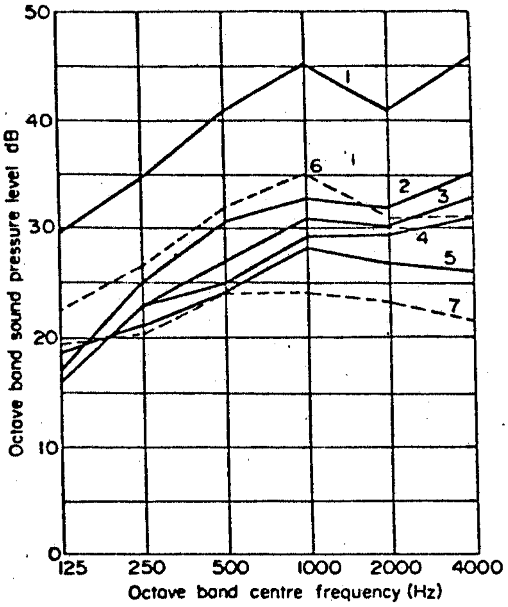

Fig. 2. Back bedroom window insulation with aircraft landing on runway 24. Acoustic tiles on reveals. (1) Dual closed. (2) Dual open 25 mm. (3) Dual open 50 mm. (4) Dual open 100 mm. (5) Dual open 200 mm. (6) Single closed. (7) Single open 100 mm.

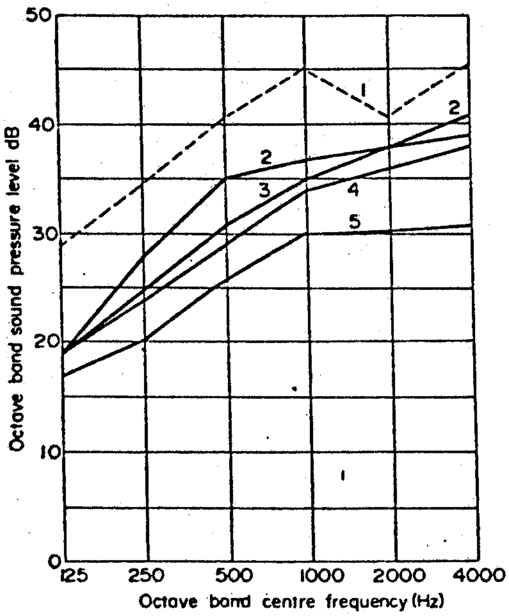

Fig. 3. Back bedroom window insulation with aircraft landing on runway 24. Foam on reveals. (1) Dual closed. (2) Dual open 25 mm. (3) Dual open 50 mm. (4) Dual open 100 mm. (5) Dual open 200 mm.

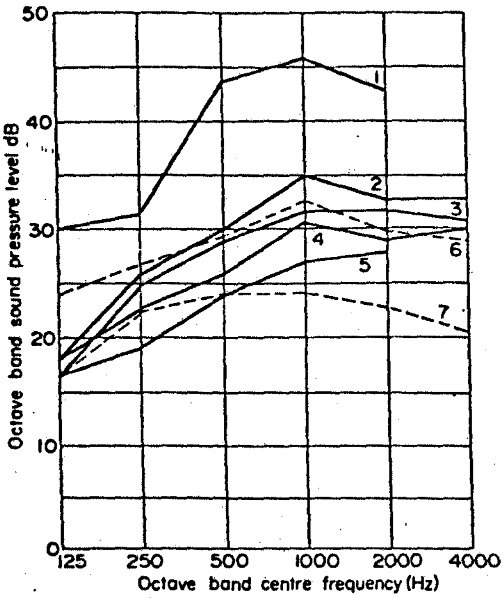

Fig. 4. Front bedroom window insulation with aircraft taking off on runway 24. Acoustic tiles on reveals. (1) Dual closed. (2) Dual open 25 mm. (3) Dual open 50 mm. (4) Dual open 100 mm. (5) Dual open 200 mm. (6) Single closed. (7) Single open 100 mm.

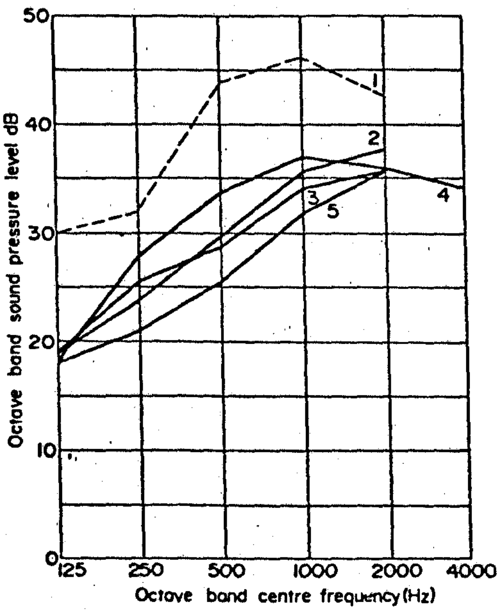

Fig. 5. Front bedroom window insulation with aircraft taking off on runway 24. Foam on reveals. (1) Dual closed. (2) Dual open 25 mm. (3) Dual open 50 mm. (4) Dual open 100 mm. (5) Dual open 200 mm.

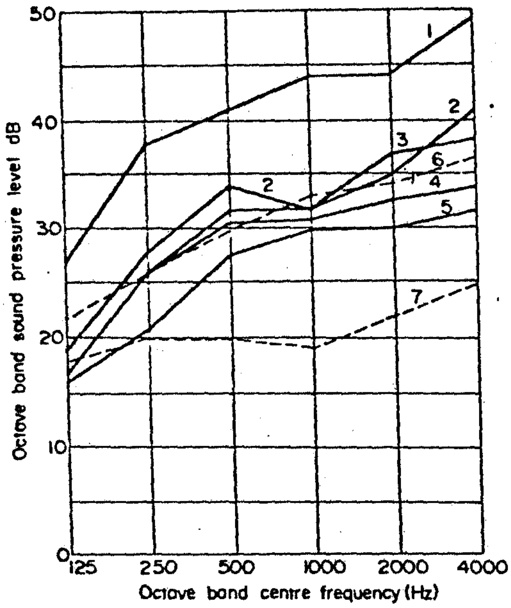

Fig. 6. Back bedroom window insulation with aircraft taking off on runway 06. Acoustic tiles on reveals. (1) Dual closed. (2) Dual open 25 mm. (3) Dual open 50 mm. (4) Dual open 100 mm. (5) Dual open 200 mm. (6) Single closed. (7) Single open 100 mm.

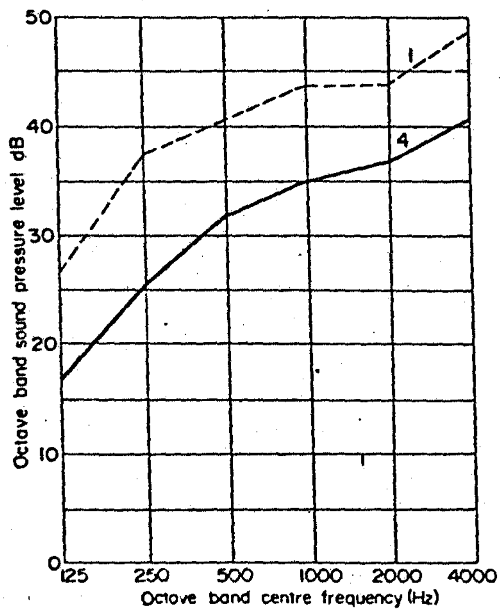

Fig. 7. Back bedroom window insulation with aircraft taking off on runway 06. Foam on reveals. (1) Dual closed. (4) Dual open 100 mm.

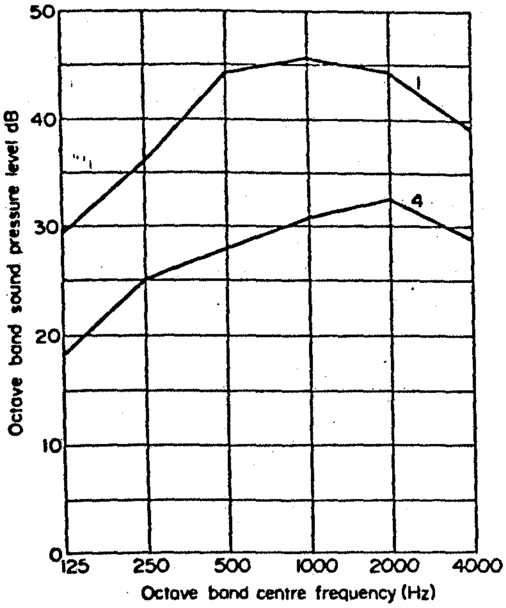

Fig. 8. Front bedroom window insulation with traffic noise as source. Acoustic tiles on reveals. (1) Dual closed. (4) Dual open 100 mm.

Table 6 shows the sound reduction indices[6] averaged into the equivalent octave bands for the horizontal sliding windows spaced 200 mm apart with foam reveals that were tested in the laboratory. Also included are the measurements made on a single-glazed vertical sliding unit fully closed. In order to apply these results to the real situation, corrections have to be applied for room size and absorption, and window size, in the following manner:

Assuming reverberant conditions, the sound level in the room, L_R, is given by:

$$L_R = L_0 - 3 - \mathrm{SRI} + 10 \log_{10}\left(\frac{4S}{A}\right) \mathrm{dB}$$

where L_0 is the level at a distance of 1 m from the building façade, S is the area of the window and A is the room absorption. Since

$$A = \frac{0{\cdot}16V}{T}$$

L_R can be expressed in terms of the room volume, V, and the reverberation time, T:

$$L_R = L_0 - 3 - \mathrm{SRI} + 10 \log\left(\frac{4ST}{0{\cdot}16V}\right)$$

TABLE 6

LABORATORY SRI'S (EQUIVALENT OCTAVE BAND VALUES) IN dB

Window	*Opening*	*Octave band SRI*						*Average*
		125	250	500	1000	2000	4000*	100-3150
Single vertical, type VS2A	Closed	18·3	19·1	23·0	24·5	25·9	27·9	22·5
Single horizontal, type HS2	100 mm open	10·1	9·9	11·3	11·6	12·2	12·7	11·0
Dual horizontal	Closed	26·8	32·9	39·0	42·0	45·6	43·5	38·0
	25 mm open	14·5	22·5	33·9	31·8	28·4	31·9	26·9
	50 mm open	10·9	19·8	31·4	27·0	30·4	32·1	24·9
	100 mm open	10·2	15·8	27·1	25·2	27·4	26·7	21·8
	200 mm open	8·5	13·4	25·1	24·2	24·0	23·3	19·5

* Since the laboratory measurements of SRI used only the frequency range to 3150 Hz it was not possible to calculate the equivalent octave band insulation for the 4000 Hz octave. The figure quoted here is the 3150 Hz one-third octave band value.

Insulation

$$L_0 - L_R = \mathrm{SRI} - 11 + 10 \log \frac{V}{ST}$$

Using the figures given in Tables 2 and 3 for V, S and T, the factor 10 log (V/ST) can be calculated for each room at each octave frequency.

To facilitate comparisons between the measured and theoretical insulation for the different outside levels quoted in Table 1, a single figure insulation value has been calculated by computing the A-weighted levels from the external and internal spectra. The insulation in dB(A) is then defined as

$$\text{Insulation} = (L_0)_A - (L_R)_A$$

The results are shown in Table 7. Table 8 is a comparison between the average of the calculated results in Table 7 and the measured results given in Table 4. Generally there is a difference between the average SRI measured in the laboratory and the insulation in a real situation of about 7 dB because of the external facade reflection, the particular noise spectrum, the window area and the room effect.

TABLE 7

INSULATION VALUES IN dB(A), CALCULATED FROM LABORATORY MEASUREMENTS OF SOUND REDUCTION INDEX AND THE MEASURED EXTERNAL NOISE SPECTRA

Window	*Opening (mm)*	*Back bedroom: aircraft taking off on runway* 06	*Front bedroom: aircraft taking off on runway* 24	*Back bedroom: aircraft landing on runway* 24	*Average for aircraft movements*	*Front bedroom: traffic*
Single	Closed	26·7	26·9	28·1	27	28
Single	100	15·7	15·4	15·8	16	16
Dual (foam reveals)	Closed	42·0	42·2	43·4	42	43
	25	32·5	32·2	32·6	32	32
	50	28·4	30·1	29·3	29	29
	100	26·0	26·8	27·4	27	26
	200	23·4	24·7	25·2	24	24

TABLE 8

COMPARISON BETWEEN THE CALCULATED AND MEASURED INSULATION IN dB(A) (AVERAGE VALUES TAKEN FROM TABLES 4 AND 7)

Window	*Opening (mm)*	*Aircraft movements*		*Traffic movements*	
		Calculated	*Measured*	*Calculated*	*Measured*
Single	Closed	27	30	28	—
Single	100	16	22	16	21
Dual (polyurethane foam reveals)	Closed	42	40*	43	—
	25	32	32	32	—
	50	29	30	29	—
	100	27	30	26	28
	200	24	26	24	—

* Acoustic tile reveals.

CONCLUSIONS

The measurements have indicated that it is possible to obtain a moderate insulation of about 30 dB(A) using staggered dual windows opened to 100 mm. This is comparable with the insulation obtained with a single openable window fully closed. With either closed or open dual glazing a good absorbent on the reveals (*e.g.* flexible polyurethane foam with a typical absorption coefficient of 0·6) gives an insulation about 2 dB(A) higher than the materials generally used (*e.g.* acoustic tiles with typical absorption coefficient of 0·3) and it would be worth seeking a suitable commercial product which would be acceptable in practice.

Insulation of open staggered dual windows against aircraft noise is marginally better than for traffic noise, but the difference of 1 dB(A) is small and of the same order as the experimental errors.

A comparison with the laboratory work is provided in Table 8. Generally, the field measurements show an increased insulation of 1–3 dB(A) over the predictions based on laboratory experience. This is attributed not only to the more discrete angle of incidence of the sound waves experienced in practice compared with the random noise used in the laboratory, but also to the acoustic state of the measuring room. The calculations on which the figures in Table 8 are based assumed reverberant conditions in the bedroom, but this is far from true in practice and would account for a discrepancy of approximately 1 dB(A). Other discrepancies are thought to be due to the different type and layout of the windows and to the position of the measuring microphone in a semi-reverberant room.

The limited number of ventilation rate measurements have shown that the natural ventilation arising from dual glazing with staggered openings is not very different from that from single glazing opened the same distance. The absolute ventilation rate is a function of wind speed and direction, and it is thought that these factors are usually much more significant than temperature gradients. Certainly, in Manchester there are very few completely windless days. A 5 knot wind is quite typical and this gave a natural ventilation rate, when the windows were opened 100 mm, of around 2–3 air changes/hour. This compares well with mechanical room ventilators which are only required to give a maximum of about 3 air changes/hour in a room.

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