Proceedings of the Institute of Acoustics

SOUND INSULATION OF OPEN WINDOWS: NOVEL MEASURES TO ACHIEVE VENTILATION AND SOUND INSULATION

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1. INTRODUCTION

This paper describes novel measures of achieving ventilation and sound insulation. In other words, how to allow air into a building, but keep noise out. Specifically, the development of a window system which features an openable window but also provides sound insulation of up to 25 R_w is reported.

Our interest in this arose from an office development - unfortunately still not realised - which was to be sited at Milton Park close to the Great Western Railway Line. On this line Intercity 125 trains run from Paddington to Cardiff and Bristol. For the project, the architect David Lloyd Jones, in conjunction with services engineers SVM hit upon an exciting new concept in the design of a building facade - the openable window! However as acoustic consultants for the project we knew that a normal open window would transmit high levels of train noise.

Earlier in the 1980's, during the building boom, the solution would have been simple. Sealed glass boxes were fashionable and a fully airconditioned building was regarded as a benefit to the prospective tenants. For this development, however, the decision was taken to build a green building, using natural resources as far as possible. The building would therefore have natural ventilation.

Of course these ideas are not new - proprietary ventilation packages have been available for many years. Some of these, mostly for domestic use, were tested for their sound insulation by S.Jorro[1]. There are also noise attenuating ventilation packages for houses near roads, which are designed to fulfil the requirements of the Noise Insulation Regulations[2]. These mostly feature holes in the building facade containing noise reducing elements. However many arrangements are possible in principle and Figure 1 shows some that could have been adopted for the Milton Park building. One of the designs - the Amsterdam Screen - was used with some success to reduce train noise in a large housing complex in Amsterdam[3].

For the project at Milton Park another approach was adopted - that of combining an external noise shield with external solar shading elements to produce a unique window design. The eventual window design is shown in Figure 2. It features a standard subframe into which the window elements are fitted. The standard elements include a fixed lower light, a middle openable light (for which no acoustical performance is claimed) and an upper openable light. Optional elements in the design include louvre elements for solar shading and, where noise is a factor an external glass barrier to shield the upper openable light. Acoustic absorption at the reveals and on the lightshelf reduces noise levels further. The development and testing of the window system is described below.

2. DEVELOPMENT

Development of the window system was carried out in two separate phases.

2.1 Site Feasibility Tests

The first phase involved feasibility tests for the office project at the proposed site at Milton Park - known as site 9. It involved the construction of a mock-up closed cell office on the site allowing experimental window designs to be assessed. The trial window designs were made from plywood and many arrangements were tried including the Amsterdam Screen. The effectiveness of a barrier around the site was also tested.

2.2 Development of the Lansdown Window System

For the second phase, funding was obtained from the Energy Efficiency Office to develop the window system for commercial use based on the ideas developed in phase 1. This led to the window system described above. It is known as the Lansdown Window System and is now available from Colt International[4].

At this stage, the form of the noise baffle was largely decided. However testing was required to confirm that the sound insulation could be achieved in a prototype unit and to determine the extent of some details, not least the form of the upper openable light. Two arrangements were tested: an aluminium window, bottom hung, opening inwards and a timber window which was top hung and opened outwards. The development of the window system involved three series of tests:

1. Sound insulation tests using Intercity 125 trains as a source with the aluminium prototype window installed in the mock-up office unit at Milton Park Site 9;

2. Sound insulation tests using a loudspeaker source with the aluminium window installed in Colt's acoustic test facility which comprised a semi-anechoic test chamber adjacent to a reverberant room with an opening in between.

3. Sound insulation tests using a loudspeaker source with the timber window installed in Colt's acoustic test facility.

The tests are now described below:

3. TESTS WITH TRAIN NOISE AT SITE 9

The first part of the program was to test the prototype window in a real situation; that is using train noise as a source and with the aluminium window installed in the mock-up office unit constructed at Milton Park Site 9. A section through the mock-up office unit is shown in Figure 3.

3.1 Test Method

The test method involved measuring the noise of trains simultaneously inside and outside the office cell. The mock-up office unit had a volume of $38m^3$ and a reverberation time of 0.3 seconds to simulate a typical cellular office. A microphone was placed inside the test office unit, to record the internal noise level and a microphone was placed outside the prototype office unit, in line with the facade but 10 metres from it, to measure the noise outside the test unit away from reflecting objects. The difference between the two noise levels recorded yields the dB(A) insulation to train noise.

For some events the train noise inside and outside the test office unit was tape recorded so that results could be subsequently analysed and the insulation found across the frequency range in line with the methods of BS 2750 Part 5 "Field measurements of the airborne sound insulation of facade elements and facades"[5]. This allowed the performance of the window system to be compared with the laboratory results in terms of the sound reduction index, R_w in 1/3-octave frequency bands.

3.2 Test Configuration of the Window

Part of the Lansdown Window System was installed in the test office unit as the sub-frame and the upper openable light only. The external noise baffle was fitted but was of perspex instead of glass. The louvre elements were omitted. Instead of thermal double glazing, the openings for the lower and middle lights were filled with 37.5mm plywood and sealed. The upper light was the bottom hung, opening inwards aluminium unit.

The internal light shelf was not fitted, however some tests were carried out with a 40mm thick layer of acoustic absorption attached to a simulated area of suspended ceiling in the office unit which was arranged to be at the same level as the head of the sub-frame extending back 1 metre. Tests were also carried out with this absorption removed to establish its effect.

The angle of incidence for the train noise tests was approximately 0° with respect to the horizontal plane. In regard to the vertical plane perpendicular to the facade, the train noise was incident over a range of angles. However as the results were always determined as the maximum level L_{AMax} during a train pass-by, the results would have been largely determined when the train is nearest - that is at 0° to the vertical plane.

Seven tests were carried out using train noise as a noise source as described above. These were:

1. The window closed;
2. The window open at approximately 7° with absorption;
3. The window open at approximately 7° without absorption;
4. The window open at approximately 13° with absorption;
5. The window open at approximately 13° without absorption;
6. The window fully open (27°) with absorption;
7. The window fully open (27°) without absorption.

For each test one representative measurement was selected and analysed to obtain the sound level difference in frequency bands and the sound reduction index.

3.3 Results

The results of the tests are summarised in the table below. Figure 4 shows also a graph of the sound insulation in frequency bands with the train noise tests compared to the loudspeaker tests.

Summary of Train Noise Tests on Aluminium Window				
Configuration	Average dB(A) Level Difference	Number of Results	Standard Deviation	R_w (from tape recordings)
Window closed	35.2	8	0.51	-
7° opening + *a*	27.1	10	0.47	25
7° opening no *a*	25.2	8	0.58	21
13° opening + *a*	25.1	6	0.76	21
13° opening no *a*	22.5	10	1.12	19
Fully open + *a*	23.8	10	0.95	22
Fully open no *a*	20.1	5	0.59	15

Notes

1. *a* denotes acoustic absorption added in simulate suspended ceiling as described above.
2. The R_w measurements are the analysed results of a single measurement whereas the dB(A) difference represents the result of an average of several results.

3.4 Discussion

The results show that when closed, a 35dB(A) level difference is obtained. With the window open, the performance varies from 20 to 25dB(A) without absorption and from 22 to 27dB(A) with absorption. See section 6.3 for a comparison of the results with those obtained from the laboratory tests.

4. LABORATORY TESTS

For the laboratory tests, the window was installed in the opening between the reverberant and semi-anechoic rooms which form Colt's acoustic test facility.

The reverberant room was used to measure the amount of sound energy entering the room through the window. The semi-anechoic room simulated outdoor conditions in the absence of any reflecting objects.

Noise was generated in 1/3-octave bands by a loudspeaker placed in the semi-anechoic room. And, by measuring the level difference obtained between the two rooms, the performance of the window could be evaluated across the frequency range. In this way the test method followed the principles of BS 2750.

4.1 Configuration of the Test Rooms

The window system was placed in the opening between the two rooms. Because the window did not completely fill the area of the opening, the remaining area was boxed in with 25mm of plywood and sealed. Unfortunately measurements with plasterboard added to the entire subframe determined that some sound was transmitted through the plywood. This flanking transmission affected most of the measurements and the results were corrected to allow for this.

As the wall surrounding the opening in the semi-anechoic room was absorptive, aluminium sheets were taped over the wall extending one metre beyond the window and baffle. This simulates the effect of a normal building facade, which would reflect sound.

4.2 Test Method

The test method was designed to follow the recognised procedures of BS 2750 as closely as possible.

4.2.1 Measurements in the Reverberation Chamber. For the internal measurements the reverberation chamber was used to determine the sound energy entering a room through a window. Traditional methods of determining the energy were followed such that the measurements in the reverberation chamber complied with BS 2750.

4.2.2 Measurements in the Semi-anechoic Room. The sound energy incident on the window was determined in accordance with the principles of the latest draft revision to BS 2750: Part 5. This allows the sound pressure incident on a facade element to be determined by fixing the microphone to the facade itself. This procedure allows the energy incident on the window to be calculated and avoids strong (and variable) reflections from the facade influencing the measurements.

Before the noise baffle was added, the microphone was taped to the window and the results of six different positions were averaged. The result obtained was used for all successive tests for each type of window. The sound source for the measurements was a large loudspeaker which was powered by a 100 Watt amplifier. The loudspeaker was placed 3.1 metres from the facade in line with the centre line of the window. The loudspeaker was titled backwards to obtain an angle of incidence to the horizontal of 36°. The 36° incidence differs from the train noise tests where the angle of incidence was approximately 0° to the horizontal.

The angle of incidence with regard to the line perpendicular to the facade was 0° for most of the tests. However some tests were carried out at other angles of incidence with the same distance from the loudspeaker to the facade and the same 36° incidence with respect to the horizontal plane.

4.3 Test Configuration

The general principle of the tests for both the aluminium and timber windows was to start with a basic arrangement and then progressively add acoustic treatment. At each stage the performance for different opening angles was tested. Once the optimum arrangement was found the loudspeaker was moved to test other angles of incidence with respect to the line perpendicular to the facade. Therefore the test program followed was generally as described below:

1. Test window with no baffle for different opening angles;
2. Add external baffle and test for difference opening angles;
3. Add internal light shelf and test for different opening angles;
4. Add reveal absorption and test for different opening angles;
5. Test different angles of incidence, with respect to the line perpendicular to the facade, for an window opening angle of 15°;
6. Test at different angles of incidence with extended baffle.

For the aluminium window stages 3 and 4 were combined in one stage. Stages 5 and 6 were analysed for the aluminium window only.

4.3.1 Aluminium Window. The aluminium window had a bottom hung, inward opening upper light which was openable to a maximum of 27°. The upper, middle and lower lights were glazed with thermal double glazing consisting of two 6mm panes separated by a 12mm airgap. The middle light was fully openable but kept closed for all the tests. Subsequent weather tests indicated that the window tested was poorly sealed at the mitred joints. This may have affected the acoustic performance of the window when closed but is unlikely to make a significant difference to the tests on the open window.

4.3.2 Timber Window. The timber window was fitted with a top hung, opening out upper light. For openings greater than approximately 10°, the hinge location moved down the frame so that a gap appeared at the top of the window as well as the bottom. The gap increased in size with the opening angle. As with the aluminium window, the lights were glazed with 6/12/6 thermal double glazing and the middle light was openable but kept closed.

4.3.3 Light Shelf. For some of the tests the light shelf was added to the window. The upper (ie., light reflecting) surface of the light shelf was constructed of perforated metal covering mineral fibre so that it was acoustically absorptive. For the timber window the light shelf was tested in one of three positions: horizontal, inclined upwards at 45° to the horizontal and lastly folded down where it would have had a negligible effect.

4.3.4 Reveal Absorption To obtain a further improvement, acoustic absorption was added to the head and side reveals of the upper opening light for some tests. The acoustic absorption used in this case was some cut sections of a fissured mineral fibre ceiling tile approximately 15mm thick.

4.3.5 Extended Baffle. To test the effect of an extended baffle, the baffle width was extended by one metre each side for some of the tests with the aluminium window. The extension pieces were made up of aluminum sheets. The horizontal tray between the baffle and the window lights was also extended by one metre on each side.

5. RESULTS

The results are summarised in Figures 5 & 6. The legend on the graph shows the single figure rating of sound insulation, R_w (shown simply as R) and the configuration. LS on the graphs indicates the light shelf and Ab indicates the absorption was included around the reveals. The table below also summarises the results for 0° incidence with respect to the vertical plane perpendicular to the facade.

Summary of Laboratory Test Results (R_w) for different Opening Angles (0° incidence)						
Opening Angle	No Baffle		Add Baffle		Add Light Shelf and Reveal α (Light Shelf Horizontal)	
	Aluminium	Timber	Aluminium	Timber	Aluminium	Timber
5°	18	16	22	24	25	25
10°	14	11	21	21	24	21
15°	12	11	20	20	22	21
20°	11	9	20	19	21	20
27°	10	8	19	18	20	19

6. DISCUSSION

6.1 Closed Performance

From Figure 5 the range in performance of the window system can be seen. The performance ranges from a simple open window with no baffle (R_w = 8 for the timber window) to the fully closed window (R_w = 31). Here the timber window performs better than the maximum obtained for the aluminium window (R_w = 27) which indicates the poor sealing of the aluminium prototype. A well-sealed aluminium window would have a performance similar to the timber window. It is also interesting to note the slight increase in performance for the closed window without and then with the noise baffle.

6.2 Open Performance

The performance when open can be seen in the table above. Figure 6 shows the performance of the aluminium window for a range of opening angles. For small window openings, the performance approaches that of the closed window.

The cumulative effect of each window element can be seen in the table above and in Figure 5. When the baffle is added there is a marked increase in performance above 630Hz. The subsequent addition of absorption around the reveals and the light shelf give a further small improvement of 1 to 3dB.

At low frequencies the baffle had less of an effect and therefore the baffle is more suitable at reducing the noise of sources with a significant high frequency effect - for example trains and fast-flowing traffic. At low frequencies there are sharp peaks and troughs in the sound insulation. This is a result of a complex interaction of resonances and the small slit openings employed.

6.3 Comparison with Train Noise Tests

When the tests are compared (as in Figure 4) it can be seen that generally, a good agreement was found between the laboratory loudspeaker test and the train noise tests and that the performance of the timber window is lightly worse than the aluminium window for the equivalent opening area. This is probably because the timber window has an opening at the top and the bottom and a larger effective open area for the same angle of opening.

6.4 Performance at other angles of incidence.

The performance of the window system at angles of incidence other than 0° with respect to the vertical plane perpendicular to the facade was also measured by moving the loudspeaker. As expected, the performance dropped markedly at angles of incidence more than 40° with respect to the vertical plane perpendicular to the facade. For the aluminium window with a 15° opening, the lightshelf and reveal absorption the R_w falls from 22 at 0° to 20 at 40° and 13 at 80°. The effect of widening the baffle brought a typical 1 dB improvement at wide angles of incidence.

7. SUMMARY

A window design has been developed which can provide up to 25 R_w from an open window. The baffle works best at high frequencies and is therefore most suitable for train noise and fast-flowing traffic.

8. REFERENCES

1. S.M.K. Jorro "The Sound Insulation of Passive Ventilators" Proc. IOA. Vol.12: Part 5 (1990) pp 41-53.

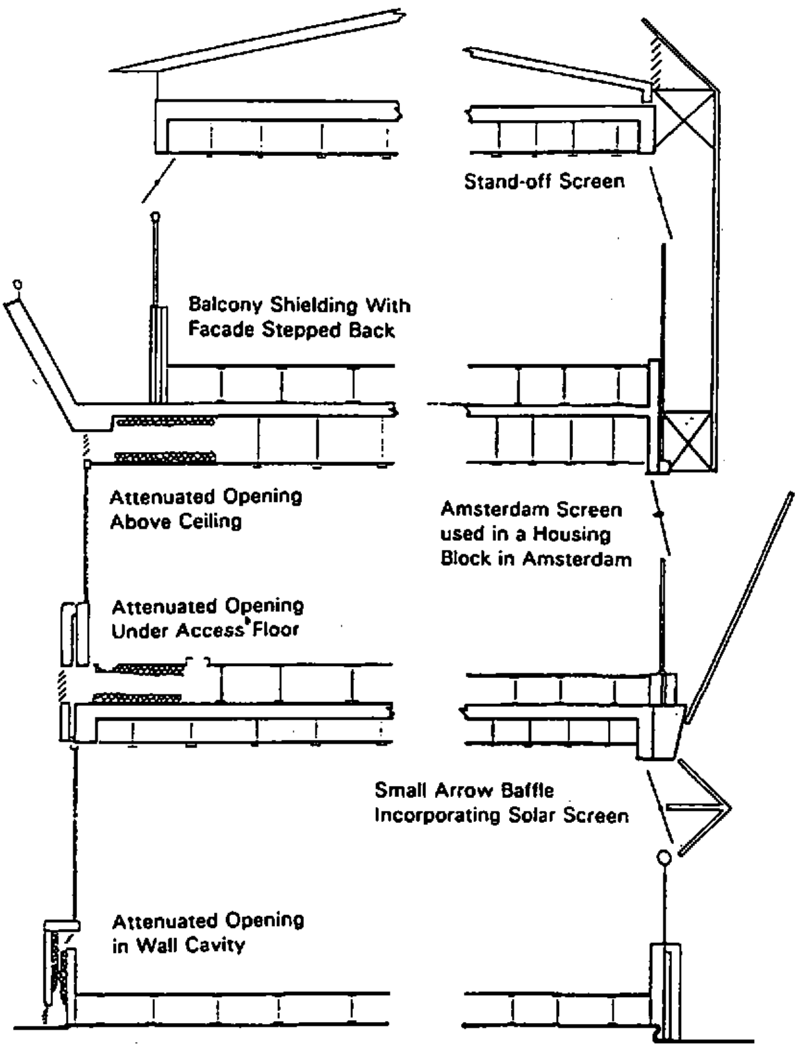
2. The Noise Insulation Regulations 1975, S.I. 1975 No.1763, HMSO

3. "Stijlvol in de Nuances - Woongebouw 'de Droogbak' van Rudy Uytenhaak" de Architekt (Holland) February 1990.

4. "Windows as Climate Modifiers" The Architect's Journal, 4 August 1993.

5. British Standard BS 2750 Part V: 1980 (ISO 140) "Field measurements of airborne sound insulation of facade elements and facades", BSI.

Figure 1 - Novel Measures to achieve Ventilation and Sound Insulation



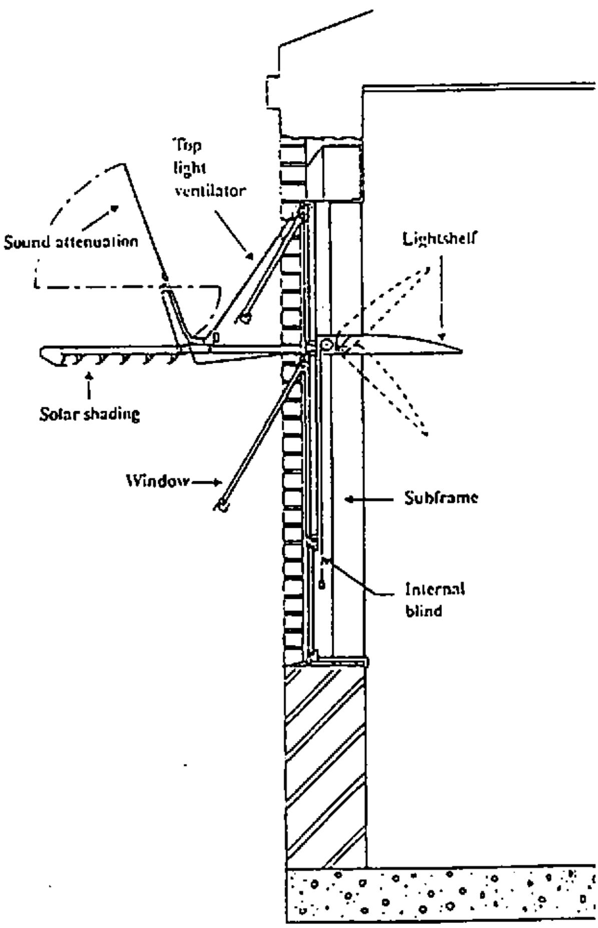


Figure 2 - The Lansdown Window System

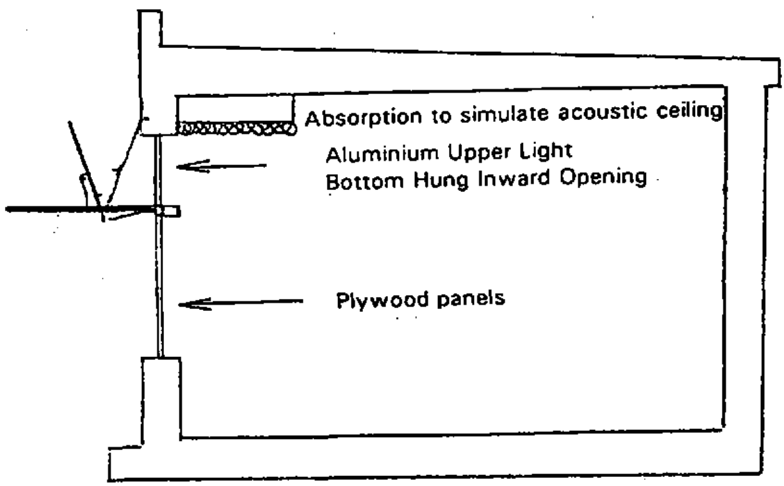


Figure 3 - Section through Mock-up Office Unit at Site 9

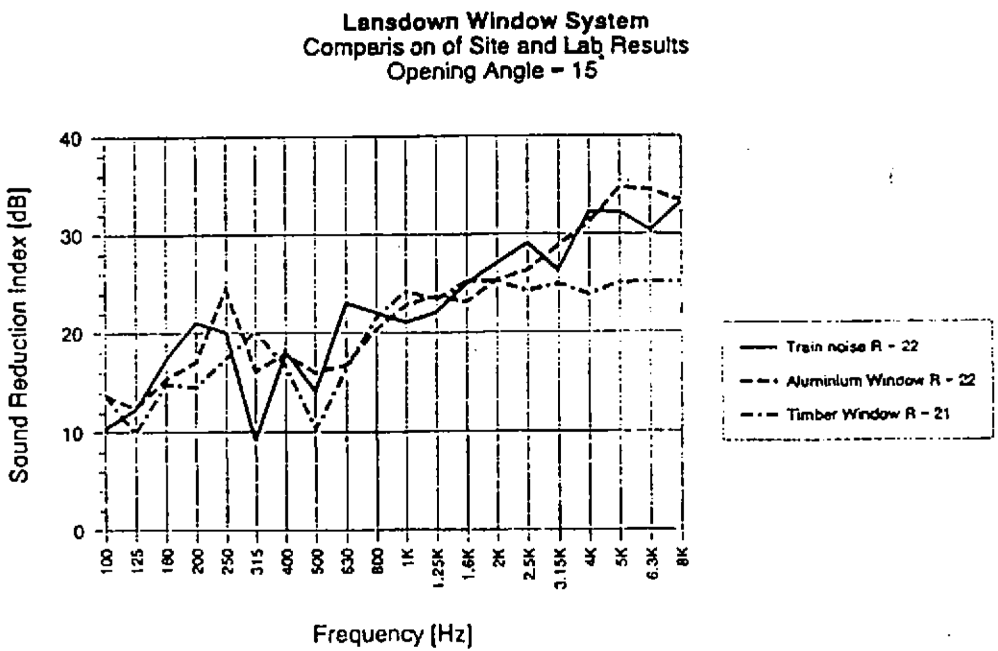


Figure 4 - Comparison of Site and Lab Tests
Opening Angle = 15°

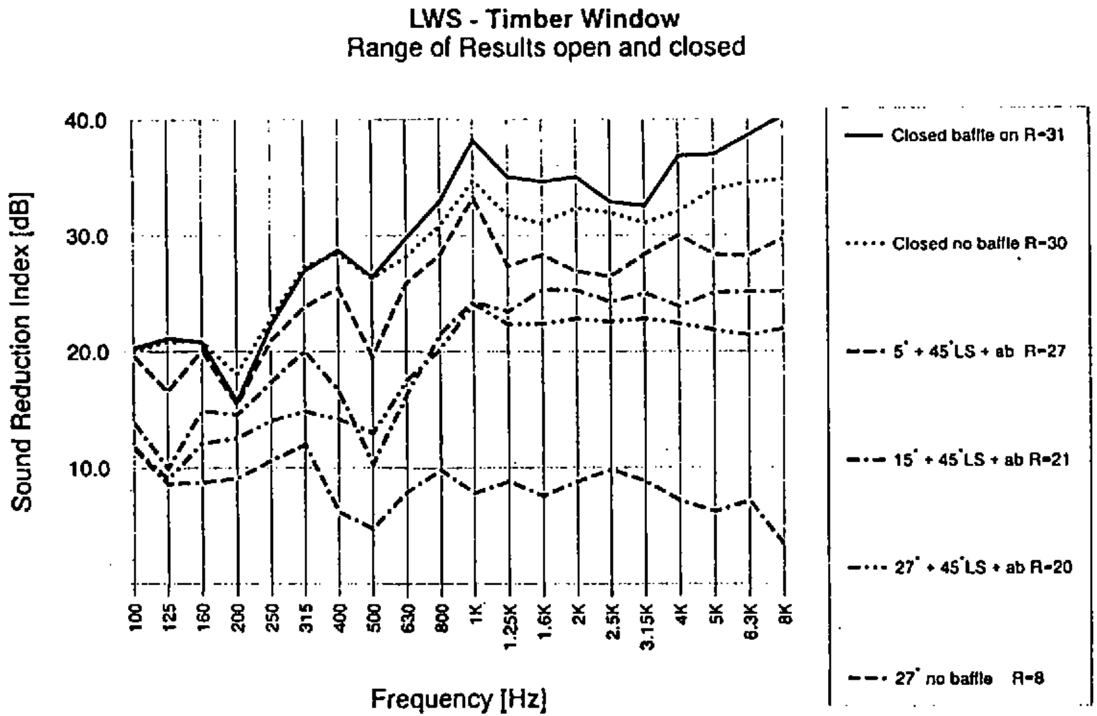


Figure 5 - Timber Window - Range of Results Open and Closed

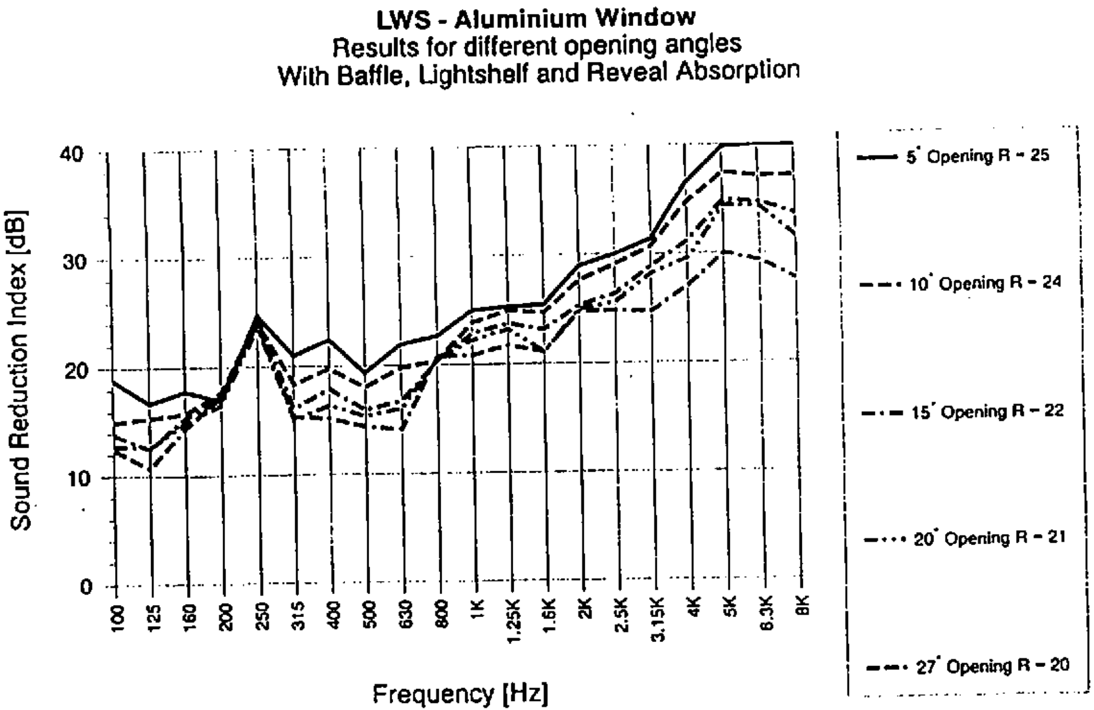


Figure 6 - Aluminium Window Results for Different Opening Angles