# The application of scale models to predict the acoustical performance of screens attached directly to vented facades

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**Reducing environmental noise break-in to naturally ventilated buildings**

## Introduction

In modern architecture, natural ventilation is a key design feature. Because of the nature of these buildings, vented facades with low levels of air resistance and in turn, low levels of acoustical resistance are typically required. Acoustical barriers have been used for many years to control noise from roads and other environmental noise sources. These barriers are not particularly effective at protecting buildings when placed at some distance from the building. This article, the first in an occasional series, presents a method of assessing the acoustical performance of vented facades which incorporate acoustic barriers as part of the facade. It is demonstrated that scale models can be used to assess the acoustical performance of these facades.

It should be noted that the terms 'screens', 'baffles', and 'barriers' are used interchangeably in the following.

The importance of increasing the acoustical attenuation provided by vented facades is becoming of great importance, owing to the desire to develop green buildings on noisier sites. The acoustical performance of a vented facade can principally be increased by two means; by including some form of acoustical attenuator into the air inlet vent of a vented facade or alternatively and more unconventionally, to incorporate acoustic barriers in front of the air vents within vented facades. This paper focuses on this latter form of acoustic attenuation and how to assess the acoustical performance of acoustic screens/barriers incorporated within a vented facade.

A paper written by Gavin Irvine[1] shows the effects of adding acoustic barriers directly to the side of a building. This paper describes how the 'Lansdown' window shown in Figure 1 still achieves 22dB $R_w$ of sound insulation when open. This is estimated to be some 7 to 12 dB better than that of a conventional window.

The Lansdown window was developed using a mock-up office placed near the noise source in question (in this case a railway line). The prototypes used for the development work were made from plywood. Once the final design had been optimised, it was built from aluminium and tested in a laboratory which gave similar results to the models tested. The final conclusion of the report was:

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

Reference[2] provides the results of a range of tests undertaken on opening windows. The investigation included seven popular domestic window models, and tested for the effects of degree of opening and the angle of incident noise. The range of measured insulation ratings for windows with a free open area of $0.05m^2$ was (in terms of $D_w$) 14 to 20 dB.

The results indicated that no one particular opening style provided significantly better insulating characteristics over others. Nevertheless, the report stated that in general the set of windows with an outward-opening light performed well. Rotation of source incidence away from the normal within a non-diffuse acoustical environment is found consistently to improve the resulting open window façade insulation.

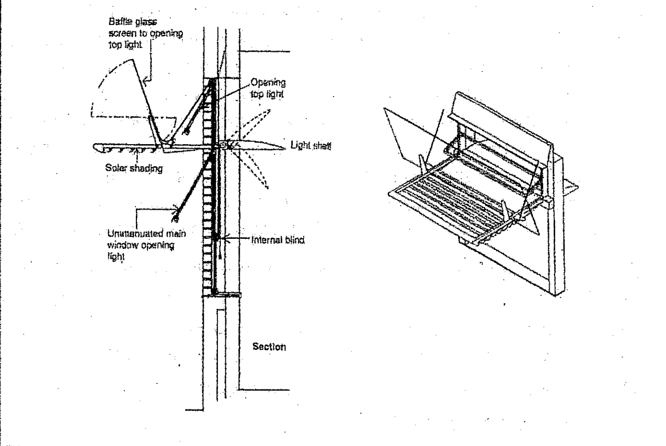


**Figure 1**

*The Lansdown window system*

There is a direct relationship between a windows area of opening and its characteristic level of acoustical insulation: larger openings reduce the degree of acoustical protection. This relationship does not however correlate with a logarithmic ratio of relative opening sizes. Measured weighted insulation differences in opening areas are limited to 1dB for open area increases from $0.05m^2$ to $0.1m^2$ and 2dB for increases from $0.1m^2$ to $0.2m^2$.

This article highlights the complexities in predicting the acoustical performance of an open window. Reference[1] shows that baffled windows can be used to increase significantly the attenuation of a vented facade. The drawback here is that a combination of a number of acoustical factors makes calculating the performance of baffled windows difficult to predict accurately. This is mainly due to the complexity of the sound field within a localised and confined space, along with the complexities of predicting the effects of diffraction around screens. In addition, it is exceptionally difficult to assess and predict the effects of the sounds' angles of incidence, an important factor on open windows or a baffled opening.

A second major difficulty in assessing the acoustical performance of vented facades and bespoke screened facades is that of cost and practicality. Owing to the nature of these facades, it is not seen as possible to use the methods given within ISO140-10:1992[3], since acoustic barriers and screens only work in free-field conditions. It is therefore necessary to build a room and a facade to assess the acoustical performance of these types of systems, which is extremely costly and highly impractical.

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**The application of scale models** - *continued from page 31*

This article goes on to discuss how scale models are already used in acoustics and what advantages they offer in the prediction of the acoustical performance of vented facades. In order to demonstrate the accuracy of such models, the results of tests undertaken by MACH Acoustics are presented. These first provide a comparison between three facades at full size, half and quarter scales. From there, a detailed analysis of performance levels is provided.

## Theory of scale models

Scale models have been used for some decades in order to predict the behaviour of concert halls. One of the main reasons why scale models are used today is to assess diffraction, resonance and other complex acoustical properties which cannot as yet be computer simulated. The basic reason for using scale models is one of practicality: it is simply not possible to test and 'tweak' a full-scale auditorium before construction. The scale model of an auditorium therefore provides a practical and accurate method of assessing the acoustical performance of these spaces. On the same principles, it is seen that scale models could be used to assess the acoustical performance of open or baffled windows.

Scale models can also be used to model the airborne sound insulation of glazing. Reference[4] concluded that:

*'The results of this study have demonstrated that it is possible to model the sound transmission characteristics of windows by means of using scale models'*

We shall now consider how by building a scale model of a façade, an identical sound reduction index is measured.

The principles behind scale models are relatively simple: a test object is reduced in size to a given scale and is then tested conventionally. The resulting frequency response is shifted in frequency by the same factor as that of the scaling ratio, and the result is an accurate prediction of the system's performance taken from a manageable model. This principle is shown in Figure 2: in this case the model scale is one-quarter. In the case of vented facades, the hole within the facade is also reduced by a scaling factor, so the acoustic attenuation of this facade is increased. To correct for this, the magnitude of the frequency response has o be adjusted by 10 times the logarithm of the scale, so as to represent the full-scale model.

The frequencies are multiplied by the scaling factor [1]

10 times the logarithm of the scaling factor is added to the original amplitude [2]

| Window diameter | Scaling factor | Frequency | Amplitude |
|---|---|---|---|
| 200mm | 1 | times 1 | plus 10 log(1) |
| 100mm | ½ | times 0.5 | plus 10 log(2) |
| 50mm | ¼ | times 0.25 | plus 10 log(4) |

**Table 1**

*Scaling effects*

## Feasibility of using scale models to assess the acoustical performance of vented facades

The aim of the first set of feasibility tests was to establish whether it was possible to predict the same acoustical performance from three facades at three different scales, at full size, half scale and one quarter scale. To do this, three different models were built as shown in Figure 4. The dimensions and screen size used, as shown in Figure 3, were chosen so as to maximise resonant behaviour, standing waves and any other acoustical effects which may occur. The reason for doing this was to determine whether all three scale models would predict the same performances.

In all cases, the screen was formed using 18mm medium density fibreboard (MDF). The solid section of the facade was formed from an 18mm MDF panel, lined on the back with 32mm of dense plasterboard. The expected resistance to the passage of sound through the solid part was at least 10dB greater than that through the opening.

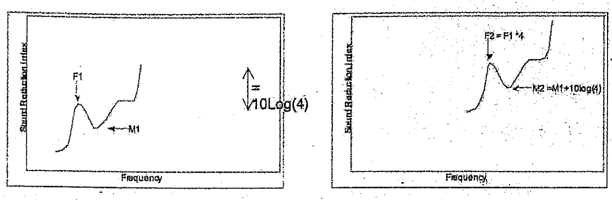


**Figure 2**

*Scale model effect*

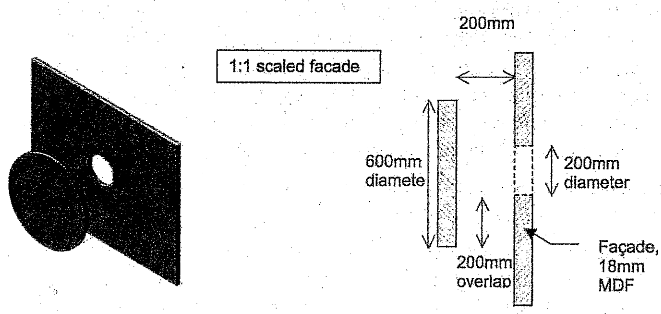


**Figure 3**

*The window studied*

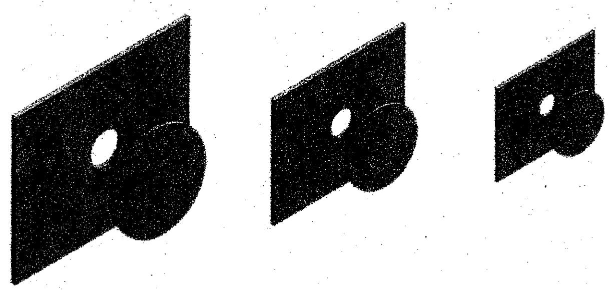

**Figure 4**

*Full-size model, half scale model and quarter scale model*

### Measurement set up

The measurement setup is shown in Figure 6. The noise source was situated in free field conditions outside the test room. The receiving microphone was positioned inside the room, which was made acoustically as 'dead' as possible with soft finishes.

Tests were conducted to conform as closely as possible to BS EN ISO 140-5:1998[5]. This standard advises placing the loudspeaker with an angle of sound incidence of 45° to the facade (±5°), however in order to drive as many resonances as possible within the screened

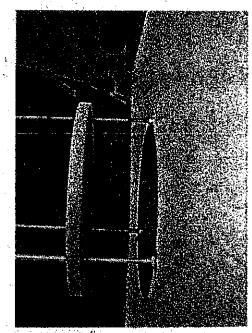

**Figure 5**

*Window with a baffle*

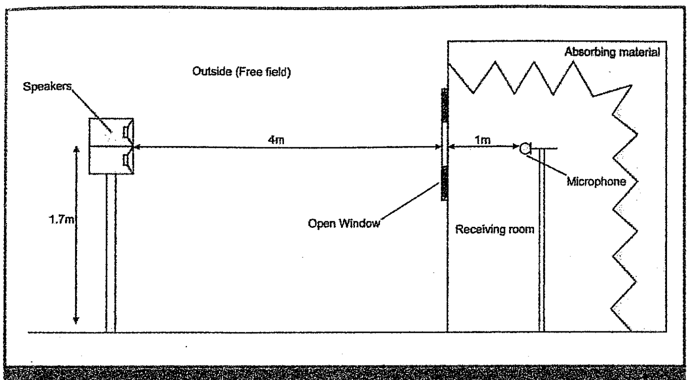


Figure 6

*Measurement setup*

window, normal incidence sound waves are desirable. The loudspeakers were therefore placed on-axis with the test specimen.

**Results relating to the feasibility of using scale models**

Figures 7, 8 and 9 present the sound pressure levels for the three facades at full size, half and quarter scales. Figure 7 presents the FFT results without scaling of any sort. As can be seen, there is no obvious correlation between the results for the three facades.

Figures 8 and 9 present the same data as Figure 7, but with frequency and magnitude of the half-scale and quarter-scale results shifted in accordance with Equations [1] and [2]. Figures 8 and 9 now show strong agreements between the frequency responses and magnitude of all three cases. It can be seen that the peaks and troughs in the frequency response of the system are similar in frequency and in amplitude.

The information in Figures 8 and 9 reveals one of the limitations of this type of analysis: the data for the quarter-scale model with an aperture diameter of 50mm is limited to 5kHz. The fact that the measured data points need to be shifted in frequency means that the scaling of facades to less than quarter scale may not be feasible using conventional measurement equipment, assuming that it is desirable to know the frequency response of the facade above 4kHz.

**Insertion losses**

ISO 7235:2003[6] defines insertion loss as follows:

$$D_i = LW_i - Lw_{ii} \qquad [3]$$

where

$LW_i$ is the level of the sound power in the frequency band considered, propagating along the test duct or radiating into the connected reverberation room when the test object is installed, and

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$LW_{ii}$ is the level of the sound power in the frequency band considered, propagating along the test duct or radiating into the connected reverberation room when the substitution duct replaces the test object.

MACH Acoustics has used the above equation to interpret the acoustical performance of a baffle as an insertion loss. The data presented in Figure 10 is therefore the effect of adding a screen to a simple open vent within a facade. In effect, these data present the insertion loss added by a baffle in front of the open vent. Figure 10 shows all three models scaled in frequency and magnitude as in Figure 9.

This again confirms that scale models can be used to assess the acoustical performance of vented and screened facades.

## Detailed assessment

Figure 10 shows that the effects of adding a screen to an open vent can improve the acoustical performance of the vent, but can also have a detrimental effect at given frequencies. This past of the article therefore looks at a detailed assessment which investigated the factors affecting the frequency response of a baffle placed over an open window.

Figure 12(a) shows the two main vented facades modelled, one with a 100mm diameter vent and the other with rectangular vent of the same open area. Figure 12(b) shows that the measured sound pressure levels at the receiver position were almost identical for the two models.

Figure 13 presents the insertion loss for a screen with a diameter of 300mm, placed 20 metres from the facade. This screen was then moved towards the façade in increments of 40mm. It can be seen that as the screen becomes closer to the facade, the detrimental effect of the screen between 500Hz and 1.25kHz becomes amplified, starting at a 5dB detriment and increasing to 10dB. These data also show that as the distance between the screen and the facade is reduced, the dip in frequency response increased in frequency. At higher frequencies above 1.5kHz, the effects of varying the distance are not noticeable until the screen is extremely close at 20mm, but for the most part there is no additional attenuation of high frequencies achieved by moving the screen closer to the facade.

Figures 14(a) and 14(b) show the effects of adding acoustical absorption to either side of the screen. It can be seen that when the absorption is on the rear of the screen, *ie* between the screen and facade, the resonance is reduced at 3kHz. This resonance was most likely due to reflections between the screen and the facade, the absorption suppresses this behaviour.

Circular holes and screens were originally used to increase the resonant effects in the frequency response of the test specimen. This was done so as to assess the feasibility of using scale models to predict the performance of vented facades. In reality, vents and screens are more likely to be rectangular in shape than circular. A comparison of the circular and rectangular holes was therefore made, as shown in Figures 15(a) and 15(b). For comparative purposes, the areas of the screen and vents and the amount of overhang were all kept constant.

The most noticeable difference between the circular and rectangular arrangements is above a frequency of 6.5kHz. Here the rectangular screen showed improved performance levels over those of the circular screen: the rectangular screen provided significantly higher levels of attenuation. The other notable feature is that the resonances of the rectangular shaped facade are less severe and spread across more frequency bands. This is assumed to be due to the fact that there is a fixed distance between the edge of the vent and the edge of the screen when using a circular screen. This fixed distance is likely to drive a resonance or standing wave effect. Since the distance between the edge of the vent and the edge of the screen in the rectangular model is more varied, the magnitude of the response is reduced and is spread across a broader frequency range.

With a view to reducing reflections between the facade and screen, the effect of angling the screen was studied (with the large screen being used in these models). Tests were carried out at 10° intervals between 0 and 30°. The results in Figure 16(a) and 16(b) are for those where the base of the screen was fixed. The main effect of changing the angle of the screen occurs between 500Hz and 1.25kHz, where there is an improved level of sound reduction. The resonance within this frequency band is suppressed by angling the screen, with the best performance being obtained at 30°. However with a 30° angle the improvement at these frequencies is offset by the loss in performance at the

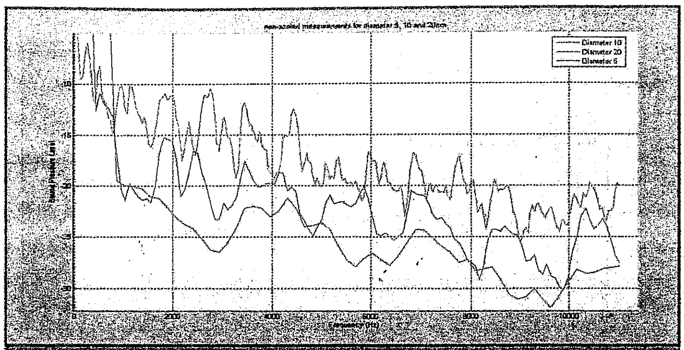

**Figure 7**

*Non-scaled frequency responses of receiving noise levels*

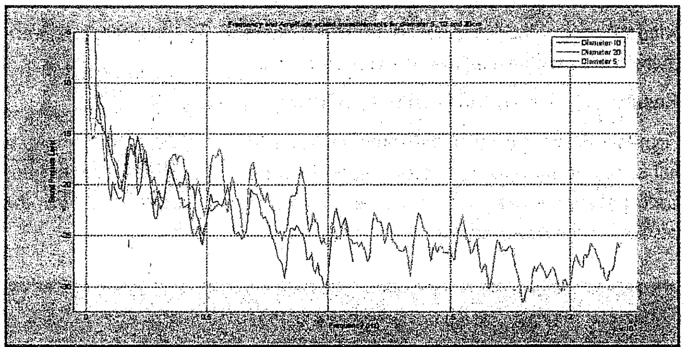

**Figure 8**

*Frequency response within the receiver room, amplitude and frequency shifted*

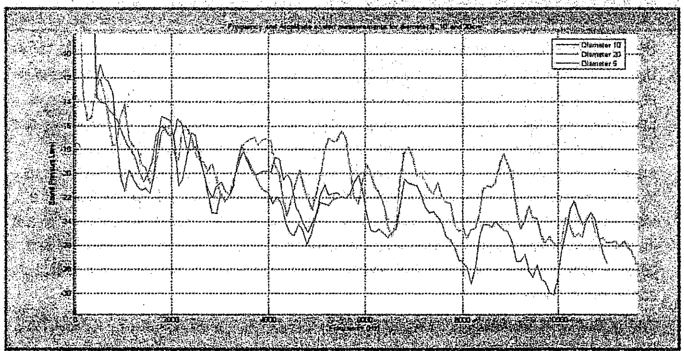

**Figure 9**

*Zoom on Figure 8 to show audible frequency range*

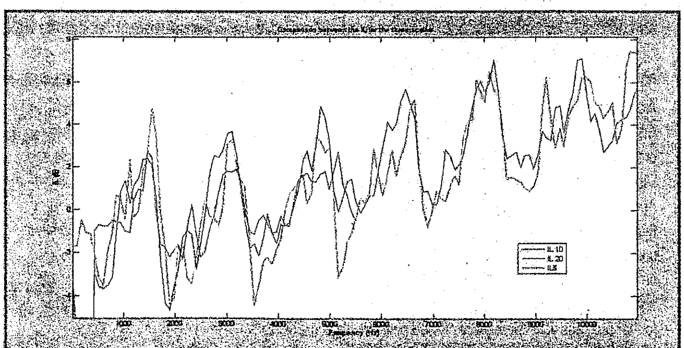

**Figure 10**

*Comparison of the insertion losses for the models at three different scales* frequencies just above, from 1.25kHz to 3.15kHz. The best compromise therefore seems to be 20°.

Again, absorption was added to the rear of the screen and then the angles tests were repeated. As might be expected, similar results were found as when testing the variation of distance: the resonance between 500Hz and 1kHz was limited to 5dB, and the performance above 2kHz was increased by an average of 5dB. In these tests, there was a strong correlation between the increase in angle and the decrease in the resonant behaviour at the mid-range frequencies. With absorption present, the difference between the barrier angles is less pronounced, and the best angle to use would be 30°. Although it offers less performance between 1.2 kHz and 2kHz, this angle has the least resonance and so is a good compromise. Figures 17(a) and 17(b) provide the results of this assessment.

### Scaling results

The final point to be considered is that the models described above use air vents and screens which are fairly small compared with those used within buildings. It is therefore likely that the results will be shifted by a factor of between 2 and 10, depending upon the size of the final vents. In order to provide clear results, the data were shifted by a factor of 2 in terms of frequency only in Figure 11. This provides an indication of the possible results of using screens incorporated directly into the facade of a building.

### Conclusion

In conclusion, is can be seen that scale models of facades provide a practical and cost effective method of assessing the acoustical performance of screens incorporated directly into the facade of a development. The results of early modelling show that screened facades not only have a benefit in terms of acoustic attenuation, but can also have a negative effect on the acoustical performance of a vented facade.

Through a series of detailed testing, MACH Acoustics has studied the factors controlling resonance and other aspects influencing the acoustical performance of barriers to vented facades. The authors are therefore confident that this form of acoustical study could be used to improve the acoustical performance of vented facades.

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### References

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[2] Napier University, School of the Built Environment – NANR116.; 'Open/closed window research' Sound insulation through vented domestic windows, 2007.

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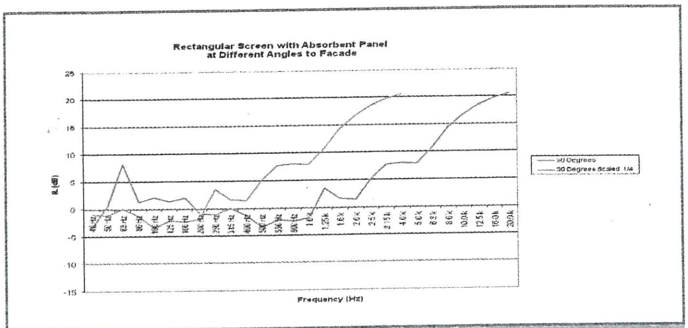


**Figure 11**

*Results of scale modelling, the data above represents the shifted results for a square hole and baffle. The inside face of the baffle is lined with acoustical absorption, and the baffle is also placed at a 30° angle.*

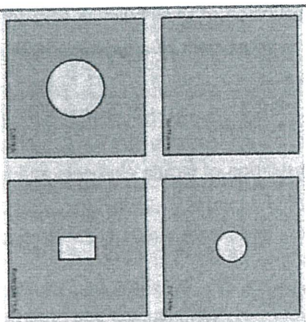

**Figure 12(a)**

*Different facade styles*

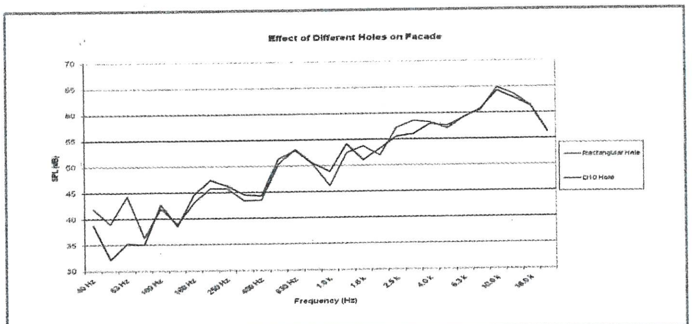


**Figure 12(b)**

*Sound pressure levels within receiver room for the two facade types modelled*

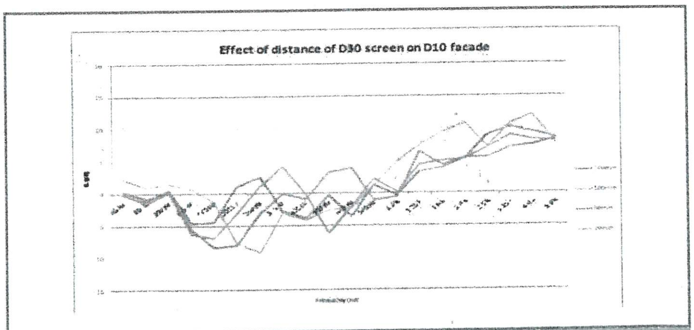


**Figure 13**

*Variation of distance between screen and facade as an insertion loss*

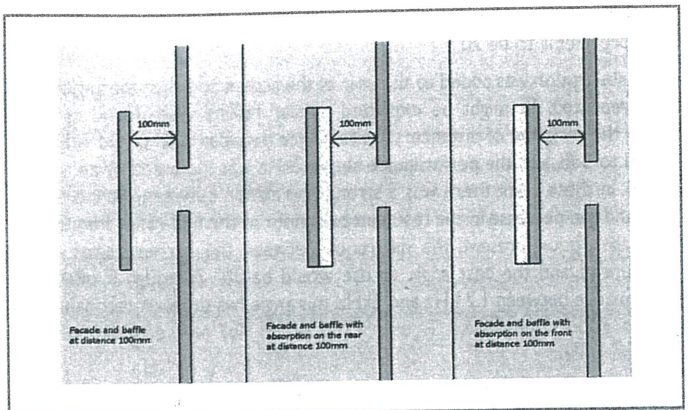


**Figure 14(a)**

*Acoustical absorption incorporated into the baffles*

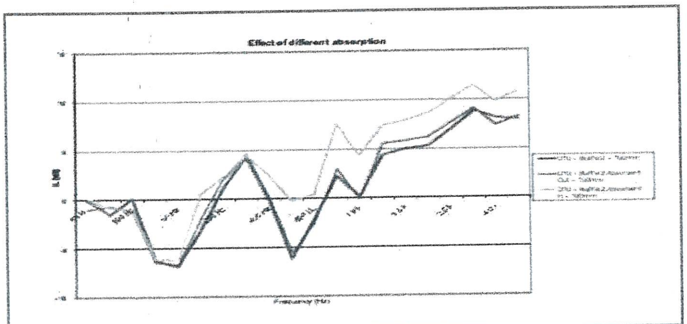


**Figure 14(b)**

*Effects of acoustical absorption incorporated into the baffles*

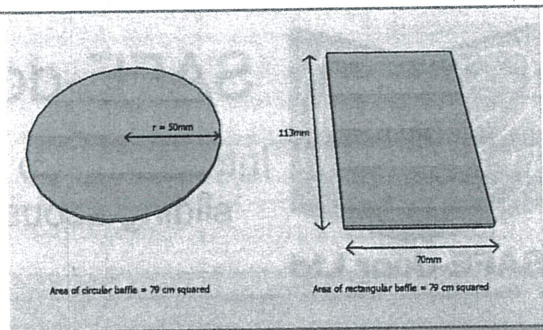


**Figure 15(a)**

*Comparison between circular and rectangular baffles*

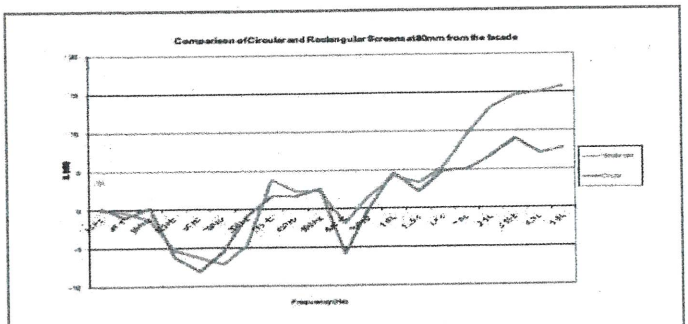

**Figure 15(b)**

*Results showing the difference in performance between circular and rectangular baffles*

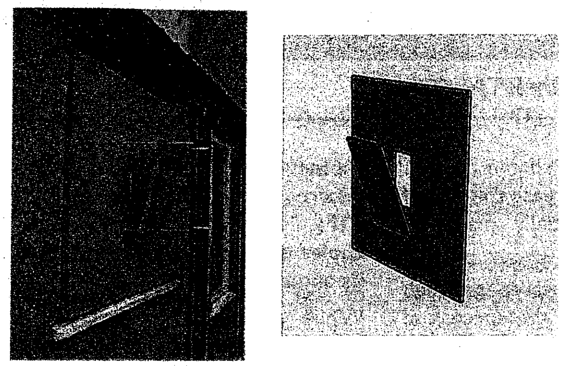

**Figure 16(a)**

*The effect of angling the baffle*

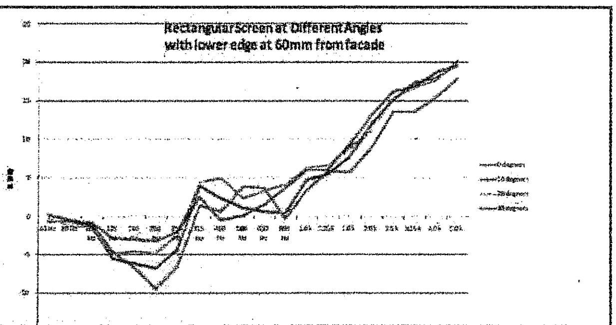


**Figure 16(b)**

*The results of angling the baffle*

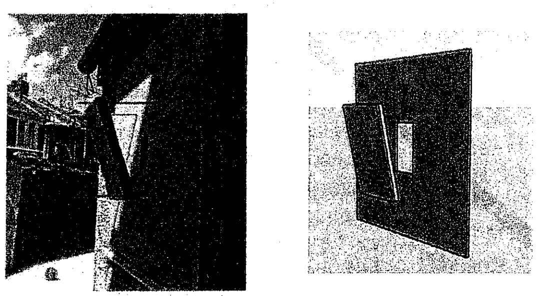

**Figure 17(a)**

*The effect of adding acoustical absorption to the inside face of an angled baffle*

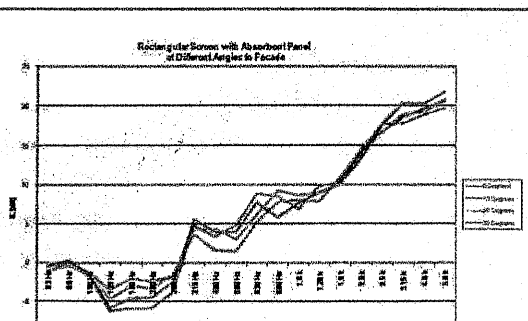


**Figure 17(b)**

*Result of placing acoustical absorption on the inside face of an angled baffle*