SCALE MODEL STUDY ON ACOUSTICAL BENEFITS OF PLENUM WINDOW AT VARIOUS AZIMUTHAL SOUND INCIDENCES

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ABSTRACT

Noise problem due to traffic roads has become more and more serious in densely populated cities. As the noise level keeps on increasing, opening the windows for natural ventilation has become nearly not possible. A staggered inlet and outlet openings design window, called as plenum window which can provide a good sound insulation as well as allow some natural ventilation passing through window itself was investigated in the present study. The acoustical insertion losses offered by plenum windows under the exposure to traffic noise when windows were not parallel to the line source was investigated using 1:4 scale down model and a 5m long loudspeaker array. The influence of sound incident angles onto plenum windows are found to be significant in protecting traffic noise because of its staggered design. There was about 6dBA to 8dBA variation of insertion loss over the studied angle range. Higher insertion loss obtained when the devices placed nearly normal incidence to the line source.

KEYWORDS

Acoustical benefits, plenum window, sound incidences.

INTRODUCTION

Traffic noise is likely to continue as a major issue in congested where large number of residential estates, both private and government aided, are built close to or nearby main transportation networks. Hong Kong is a dense high rise city which faces to this environmental problem. The previous survey shown that 1/7 of the Hong Kong population are living in the areas where the highest traffic noise levels exceed 70dBA (HKSAR 2006). This urban noise annoyance produces a number of effects to the human daily activities and health. In several studies, traffic noise is found to be the most critical effects on human sleep disturbances (Berglund *et al.* 2000; Öhrström and Skånberg 2004; Öhrström *et al.* 2006). The situations were even worse when the façade buildings are faced to noisy traffic networks and this make open windows are not possible in urban area.

Over the past few decades, there are many conventional noise mitigation measures has been taken to tackle the road traffic noise problem. Setbacks and extended podia are suggested in some highly problematic cases(HKSAR 1993). Many urban areas used roadside barriers to reduce the noise exposure from the noisy road networks to the residential areas. A guideline of designing noise barrier has been issued by the Hong Kong government to address this community noise (HKSAR 2003). However, these structures must be designed at the time when the whole built environment is planned and also are not adoptable in many urban retrofitting cases due to limitation of space. Façade treatment therefore is an alternative method to deals with traffic noise. Balconies are one of the self-protective building forms which attracted the attention of many professionals (Mohsen and Oldham 1977; Hothersall *et al.* 1996; Hossam El Dien and Woloszyn 2004, 2005). However, this treatment is proved to be not effective for the high rise environments (Tang 2005).

Double glazing windows are well known devices that can be used as a mitigation measure (Harris 1979). Previous studies have been carried out to provide an effectively sound insulation of the window not only the passive design of the window but also active noise control (Tadeu and Mateus 2001; Kim *et al.* 2002; Jakob and Möser 2003a; Jakob and Möser 2003b). Nevertheless, the works mentioned were not designed for the natural ventilation applications. Natural ventilation has become an increasingly important and prominent aspect of building design as an alternative way to reduce the use of mechanical ventilation systems. The principle of sustainability has been concerned in many new urban development areas in recent years(De Salis *et al.* 2002). Natural ventilation and acoustic protection are two conflicting issues. Therefore, the need of provide a better sound insulation for buildings in cities with concern about natural ventilation was increased. When natural ventilation is provided across the facade, windows will become the main noise transmission path for external noise ingress.

Recently, the concept of plenum chamber in duct silencing practice (Sharland 1979) is proposed to be used overcome this problem (Kang and Brocklesby 2005; Kang and Li 2007). This alternative window system not only allows natural ventilation ingress into indoor environment but it is also offer an effective acoustical protection of the device. Kang and Brocklesby (Kang and Brocklesby 2005) show that the plenum windows of the right dimensions lined with micro-perforated panels can produce an acoustical protection better than closing a single glazing window. The different angles of sound incidences and various configurations of façade devices may affect the effectiveness of window in term of acoustic and ventilation.

The acoustical benefits of plenum windows when the devices are placed at difference orientations from the traffic road were evaluated in the present study using 1:4 scale down model. The acoustical protection offered by plenum windows are compared with conventional opened window. The normalized traffic noise spectrum of the standard EN 1793-3 (1998) was used to express insertion losses in terms of a single rating (dBA).

METHODOLOGY

Laboratory Facilities

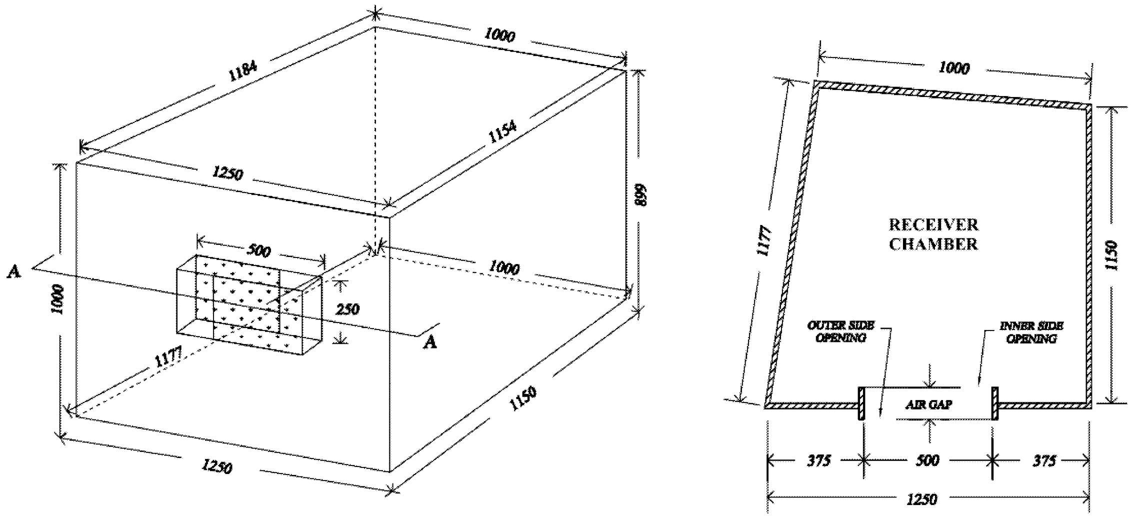
The measurements are performed in the chamber at acoustic laboratory of the Department of Building Services Engineering. This chamber originally was used as emission room for the coupled reverberating rooms which was built according to ISO 140-3 standard of sound transmission loss test. In order to reduce the diffuse field condition in the chamber, the chamber was converted into a semi-anechoic chamber by putting up two layers of 2-inch fiberglass curtains to all walls and ceiling of the chamber, which similar set-up has been adopted in other experiments (Kang 2006). The chamber has a volume of about $100m^3$ and workable concrete floor area of approximately $24m^2$.

Sound Source

Since traffic noise is the most serious source of noise pollution in a congested high-rise city, the sound source adopted in the present study has to have similar characteristics as this noise. Traffic noise is regarded as a line source formed by many incoherent point sources of the same strength. In the present study, a 5m long linear loudspeaker array consisted of 25 six-inch aperture loudspeakers was adopted. The loudspeakers were capable to generate sound up to 20kHz in 1/3 octave band which corresponds to 5kHz for the full scale window. The loudspeaker array was located on the chamber floor at 3m horizontally away from the scale model. A constant magnitude of white noise signals were supplied by Brüel & Kjær 1405 Noise Generator and connected to power amplifier to drive loudspeakers array.

Scale Model

In the present study, a 1: 4 scale down model was placed inside the semi-anechoic chamber to investigate the acoustical performance of plenum window at different incident angles. Model was made of 18mm thick varnished plywood which simulated receiver room of the coupled reverberant chambers in acoustic laboratory. A window with dimension of 500mm wide, 250mm height and 125mm deep was presented at the front side of the model. Model was placed on a portable platform for ease movement. Window sill was at 0.5m height from the concrete floor. Two 5mm thick plastic panes were staggered at the window with air gap between both panes to allow certain degree of natural ventilation. Figure 1 shows the dimensions of present scale model and the openings of the plenum window. There are two openings of plenum window which defined as outer side opening and inner side opening, which outer side opening was faced to sound source while another opening was faced to simulated chamber.

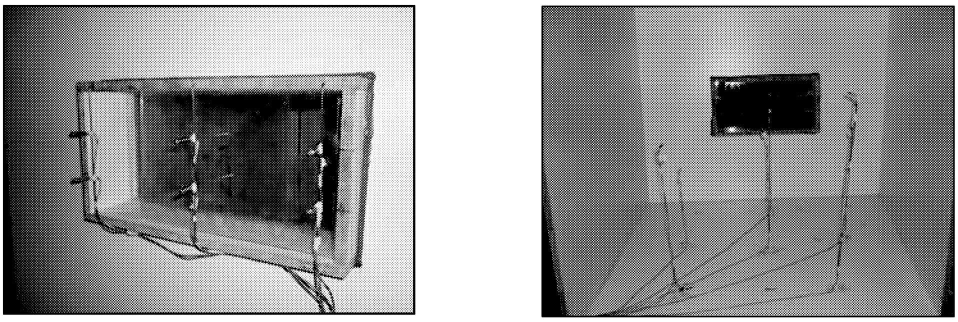


Isometric view **Section A-A**

Figure 1 Dimension of simulated receiver chamber

Experiment Set-up

At the emission side of the tested window, a measurement array consists of six 1/4" microphones (Brüel & Kjær Type 4935) as shown in figure 3(a) was adopted to estimate the sound intensity falling onto the plenum window. Figure 3 (b) shows another nine microphones which are spanned within the chamber to capture the different sound level when sound transmitted into the simulated reverberation chamber. The signals of all microphones and an output of noise generator were recorded using a data acquisition system (Brüel & Kjær 3506D PULSE). Air temperature and relative humidity inside both source room and receiver room (scale model) were remained at 26.4 °C; 55.7% and 26.7 °C; 53%, respectively throughout the measurements.



(a) (b)

Figure 2 (a) Source side microphone array and (b) receiver side microphone locations

Plenum Window Tested

Two different window openings of 50mm and 125mm width by 250mm height were tested as shown in table 1. The test configurations are coded for the sake of easy reference. "P" denotes the opening sizes of the test windows and "A" denotes the air gap sizes of window to allow ventilation. The case of fully opened window was used as reference case to estimate the acoustical performance of plenum window. Fully closed window was also tested to compare its sound intensity different with special acoustic window system. Closed window was stimulated by sealing 5mm thick plastic pane to the window frame while the case of fully opened window was the scenario where there was absence of plastic panes.

Table 1 Plenum window tested scenarios

Scenario	Outer side opening	Inner side opening	Air gap sizes
P125A100	125	125	100
P125A075	125	125	75
P050A100	050	050	100
P050A075	050	050	75
Opened	Fully opened		
Closed	Fully closed		

In order to investigate effect of source orientation relative to the performance of plenum window, model was adjusted for various positions. Figure 4 shows the different azimuthally sound incidence angles of sound source to the window system, which the centreline of window was chosen as the axis of the rotations. The orientation of model was at -90° incidence of angle when the window was perpendicular to loudspeaker array with the outer opening (sound side opening) was close to the sound source. Model was rotated to that the incident of angle changed from -90° to 90° with every 10° increment. At 0° of incidence angle, window was parallel to the loudspeaker array which represents the scenario where the window is directly facing to the source line.

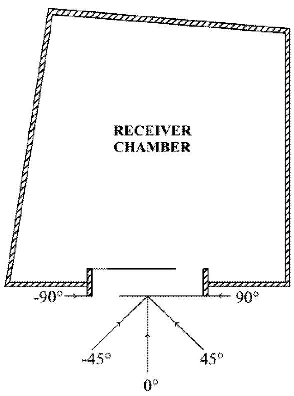


Figure 4 Different angles of sound incidence

Since the objective of the present study is to estimate the acoustical protection of the plenum window in the presence of traffic noise, the normalized traffic noise spectrum of the standard EN 1793-3 (1998) was adopted. The EN 1793-3 for traffic noise case was often used in the estimation of the insertion loss in term of a single rating (Buratti 2002, 2006). The insertion loss describes the sound pressure level drops due to installation of the plenum window. For this purpose, the opened window case is used as the reference. Room constant was included in the noise reduction calculation because the reverberation times inside the simulated receiver chamber have changed with the window opening width. The insertion loss can be expressed as:

$$R = L_{i,Opened} - L_{i,Plenum} - 10\log_{10}\left(\frac{RC_{i,Opened}}{RC_{i,plenum}}\right) \quad (1)$$

$$IL = -10\log_{10}\left[\frac{\sum_{i=1}^{18} 10^{0.1(N_i - R_i)}}{\sum_{i=1}^{18} 10^{0.1N_i}}\right] \quad (2)$$

where i represent the ith one-third octave band data, from 100 Hz to 5kHz, L_i the average noise level obtain in receiver chamber, N_i the normalized noise band level and $_{Opened}$ and $_{Plenum}$ donate data that obtained in the fully opened window case (reference case) and plenum window respectively.

RESULTS AND DISCUSSIONS

Figure 5 illustrates the effects of acoustical protection of plenum window at various sound incidence of angles. The spectrum of fully closed windows is also presented in the graph as comparison. As expected, the trend of closed window acoustic spectrum shows higher of insertion losses compared to the opened window. The results also implied that the highest acoustic performance differences obtained when the road was placed nearly parallel to the closed window.

The influence of sound incident angle onto façade devices is found to be significant in protecting traffic noise. There was around 6 dBA variation in the acoustic benefits over the range of studied source angles. The insertion losses of these special windows increase slowly when the sound wave of traffic road moved from perpendicularly (-90° or 90°) to facing directly to the windows (0°). The maximum insertion loss achieved when stimulated line source was nearly parallel to the device, which is around 14dBA.

Better acoustical performance obtained when the opening sizes of plenum window were changed to smaller sizes. There was about 1dBA to 4dBA acoustical benefits when the opening size for same air gap width changed from 125mm to 50mm except those positions that window was nearly facing to line source (-10° to 20°). The peak of insertion loss was expanded to further negative angles when the opening sizes were changed from 125mm to 50mm. In the case where the openings of plenum window were 125 mm for both sides, higher acoustic benefits obtained when the incident angles of sound wave onto window were between 0° to 10°. The trends of insertion loss for smaller opening sizes observed nearly the same trend as closed window where the graphs were symmetry ~ 0°.

When changing the opening sizes of the window, larger variation of insertion loss observed at the negative side of sound incident angle (-90° to 0°) than another side. Plenum window oriented at these angles (negative side) allowed some direct sound waves go into the simulated receiver room through the outer side opening. However, the acoustic benefits obtained for all studied scenarios were not very big difference at the positive side of sound incident angles (0°to 90°). At these orientations, sound waves may be blocked or reflected by the outer pane of the tested window which the resistance of sound that transmitted into receiver room was larger compare to negative angles.

The results implied that the influence of air gap width was less significant in protecting window from the traffic noise. The insertion loss was slightly increase which was ≤ 1dBA when change the air gap sizes from 100mm to 75mm for the same opening sizes of device. The insertion loss increase more rapid when air gap width changes for the scenario where the openings of plenum window were small. Sound incident angle at positive side also were not sensitive on the changes of air gap width for the fixed opening size.

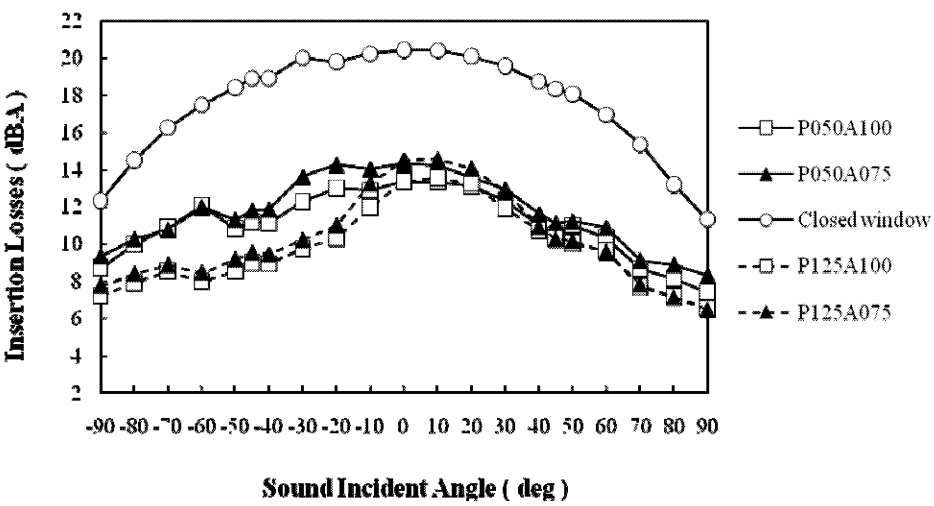


Figure 5 Insertion losses of devices at different sound incidence angles

CONCLUSIONS

A scale model measurement was carried out to investigate the acoustic performance of plenum window when the device was exposed to the traffic road. Twenty-five 6 inches of loudspeakers were used as line source in the present study. The normalized traffic noise spectrum of the standard EN 1793-3 was used to estimate the insertion losses of studied devices in term of single rating. The effects of source orientations relative to the plenum windows are discussed.

Plenum window offered a better acoustical protection when exposed to traffic noise at various incidence of angles if compare to opened window. The influence of azimuth sound incident angles onto plenum windows are found to be significant in protecting devices from the line source. There was around 6 dBA to 8 dBA variation in the acoustic benefits over the range of studied source angles. The maximum insertion loss obtained was about

14 dBA when the window was placed nearly parallel to the traffic road. Minimum acoustic benefit recorded is ~ 6dBA which was found when the window was oriented perpendicularly to the line source.

A significant sound insulation is found for the sound incident angles at negative side, where the outer side opening was faced close to the sound source. Higher variations of insertion losses obtained at the incident angle of sound wave between -90° to normal incidence. These rapid changes of acoustic benefits were caused by direct sound paths which can ingress into indoor environment through the outer side opening of the window. The insertion loss tend to be sensitive to the changes of window opening sizes and air gap width when the devices was faced to negative side sound incident angles.

In the present experiment, plenum window offered a good acoustical protection from the traffic noise and it was acceptable as alternative window in term of acoustic and natural ventilation. However, the acoustic benefits obtained in present study were less than results from Kang (Kang and Brocklesby 2005) due to absent of MPA. Other configurations of devices such as sound source distance and plenum dimensions to the acoustical protection are still not clear. Further experiments on variation of source distance and as well as other window configurations are suggested.

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