Acoustical insertion loss of plenum window at different sound incidence angles

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ABSTRACT

Natural ventilation and acoustic protection are two conflicting issues. In densely populated cities, open window is nearly not possible because it can provide a path for noise to break-in from external into the buildings. A special window system, namely the plenum window, was investigated in this study for its acoustical insertion loss when the window was not parallel to the road in the urban environment whilst allowing a certain degree of natural ventilation. The acoustic performance of plenum window was studied using a 1:4 scale model and a 5m long source array consisted of 25 six-inch aperture loudspeakers. The positions of sound source from the window are found to be significant in protecting transportation noise based on the trend of insertion loss spectra. The insertion loss of the device was defined by the difference of the average noise level inside the receiver room between opened window and plenum window. There was around 7dBA variation in the insertion loss over the range of source angle studied. The highest insertion loss was about 11dBA and was obtained when the window was nearly parallel to the simulated line source. Plenum window was believed to be a good acoustic window with high practicality in the densely populated urban environment.

INTRODUCTION

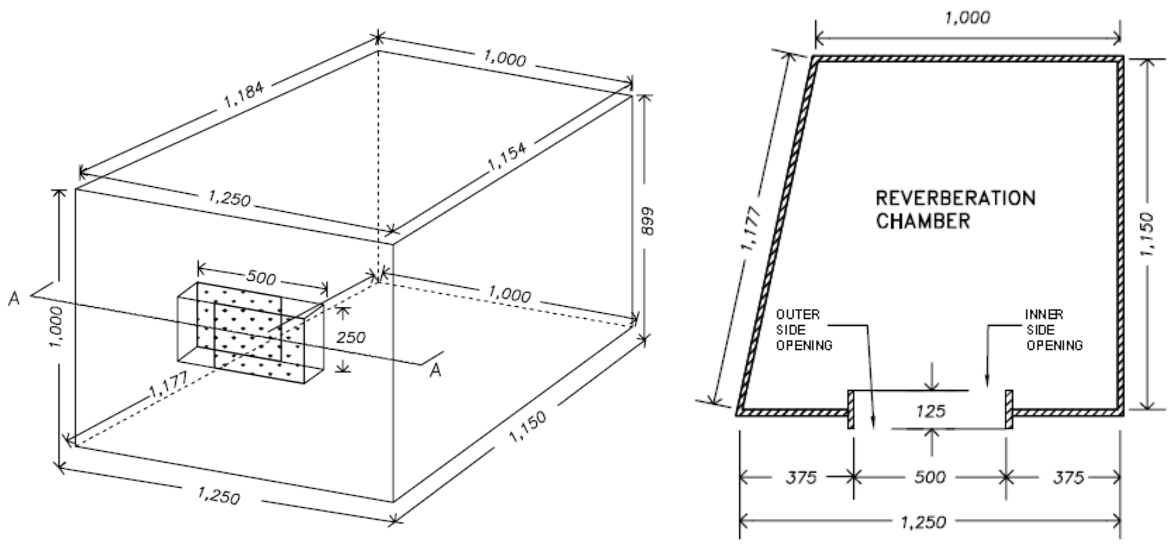
Rapid growth of economy and population in the cities have caused many buildings were built close to traffic roads. Thus, traffic noise becomes one of the importance sources of nuisance in urban areas. Traffic noise that emitted into buildings may influence daily life of nearby residents.

In buildings, windows are often the weak link in protecting the interior from ingress of outside noise. Consequently, sound insulation of window becomes significant study to overcome this environmental noise. Double glazed windows by far are well-known devices that improved acoustical performances of the windows [1, 2]. However, the drawback of these windows was not effectively at low frequencies because of the large wavelength compared to the panes thickness. There have been a numerous studies on active noise treatments to improve acoustic performance of glazed windows [3-6]. In addition, the investigation of using fins/eaves on building façade also has been studied to increase sound insulation [7].

Many of the proposed noise control solutions do not concern about natural ventilation. When natural ventilation is provided across the facade, windows will become the main noise transmission path for external noise ingress into buildings. In such circumstance, the way to reduce the noise transmission is to close all the windows, resulting in the problem of ventilation. Mechanical ventilation can be used, but this increases the energy demand of the whole city which is against the principle of sustainability.

Buratti has evaluated indoor noise reduction using open window condition [8, 9]. However, these papers deal with the noise reduction due to the addition of sound absorption materials inside the receiver room. An alternative approach concerning the concept of plenum chamber in duct silencing practice [10] is proposed to be used at the window area [11, 12]. Thin micro-perforated panel also introduced in the design. This acoustic window system was proved to be effective on acoustical protection and at the same time allowing some natural ventilation. The ventilated plenum window has received attention recently because of its strong sound transmission loss and its allowance of natural ventilation. Kang shows 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. However, the installation of micro-perforated panel inside the window is still not desirable in practice because of maintenance issue. The different angles of sound incidences and various configurations of façade devices may affect the effectiveness of window in term of acoustic and ventilation.

In the present study, scale model measurements were taken to investigate the acoustical performance of an acoustic window system, namely plenum window. It is believed that the performance of the plenum window will depend on difference incidence of angles. Since façade windows are often not parallel to the traffic roads, the insertion losses of plenum windows when the devices are not facing to the traffic were evaluated.



(a) **(b)**

Figure 1. (a) Isometric view and **(b)** section A-A of scale model

METHODOLOGY

Experiment facilities

All measurements were carried out in the test chamber at acoustic lab of the Department of Building Services Engineering. The reverberation room originally was emission room of coupled reverberating rooms which used for ISO 140-3 tests [13] for sound transmission loss of building materials. Similar to Kang's set-up [14], walls and ceiling of chamber were covered by 2 layers of 2 inches fibreglass in order to reduce the diffuse field condition in the room. The chamber was converted into a semi-anechoic chamber with a volume of about $100m^3$ and workable concrete floor area of approximately $24m^2$.

Scale model

A 1:4 scale model was selected to investigate the acoustical performance of plenum window at different incidence 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 by 250mm height was presented at the front side of the model. Figure 1 shows the dimensions of present scale model and the openings of the plenum window. Two 5mm thick plastic panes were staggered at the window with air gap of 125 mm between both panes to allow ventilation across it. There are two openings of plenum window which defined as outer side opening and inner side opening as shown in Figure 1 (b). Outer side opening of window was faced to sound source while another opening was faced to simulated chamber.

Reverberation times inside the receiver room (scale model) were measured to determine the sound field condition of simulated chamber. Twelve points were irregularly spaced within the receiver room were chosen to measure the average reverberation time inside the chamber. The reverberation time was tested using DIRAC system with MLS signal. All reverberation times inside the scale model were less than 3.5 second throughout the 1/3 octave band frequency. As model was a 1:4 scale down model, this implies that the simulated receiver chamber was reverberant; ~ 0.8 second if model was compared to the full scale reverberation room.

Experiment set-up

Environment noise caused by road traffic was adopted in the present investigation. A 5 meter long line source consisted of 25 six-inch aperture loudspeaker was used to simulate road traffic noise. The loudspeakers were capable to produce a continuous broadband noise in one-third octave bands from 20 Hz to 20 kHz, which corresponds to the range of 100 Hz to 5kHz for the full scale window. A constant magnitude of white noise signals were supplied by Brüel & Kjær 1405 Noise Generator and connected to power amplifier to drive loudspeakers array.

Model was placed at 3m away from the line source. Sound intensity falling onto the plenum window on the emission side was measured using six 1/4" microphones (Brüel & Kjær Type 4935) while nine microphones were spanned within the reverberation chamber to capture the different sound level when sound transmitted into the chamber. Microphones inside the receiver room were placed at least 375 mm away from the window to capture the sound energy. The signals of 12 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.

Plenum window tested

Refer to the Table 1, scenarios S1 and S2 were setup to test the acoustical performance of plenum windows. However, scenarios S3 and S4 were controlled cases to facilitate the direct comparison between particular window designs with opened and closed window. The scenario of fully closed window was tested by sealing a 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
S1	250	250
S2	125	125
S3	Fully opened window	
S4	Fully closed window	

In practice, building facades are not always facing to traffic road. The performance of window may change due to the different incidence of angles and reflections, which have been developed by some researchers [12, 15]. In order to investigate effect of source orientation relative to the performance of plenum window, model was adjusted for various positions. Figure 2 shows the different sound incidence angles of sound source to the window system. 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 line source.

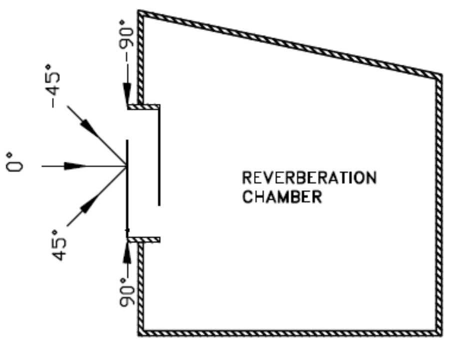


Figure 2. Different angles of sound incidence

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 [16] 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 [8, 9]. For this purpose, the difference between acoustical levels before and after installation of plenum window was evaluated. The opened window case is used as the reference. The insertion loss can be expressed as:

$$R_i = L_{i,S3} - L_{i,Sj} \tag{1}$$

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

where *i* represent the *i*th one-third octave band data, from 100 Hz to 5kHz, L_{Sj} the level obtain in receiver chamber in scenario *Sj* and N_i the normalized noise band level.

RESULTS AND DISCUSSIONS

Figure 3 illustrates the insertion losses for studied windows at different positions from the sound source which Scenario S3 was the reference case. The scale model results give a good indication for the acoustical insertion loss compared to the open window condition. The result implies that plenum windows (S1 & S2) offered a good acoustical protection when exposed to traffic noise. The highest road noise weighted insertion loss for the plenum window of both scenarios S1 and S2 are ~ 10 dBA and ~ 10.5 dBA respectively. A different acoustic level of about 10 dBA for an orientation parallel to traffic road is enough to make plenum window as acceptable alternative window in term of acoustic and natural ventilation. From the comparison of test scenarios with a closed window, it can be observed that the closed window condition results about 4.5dBA larger insertion loss than plenum windows.

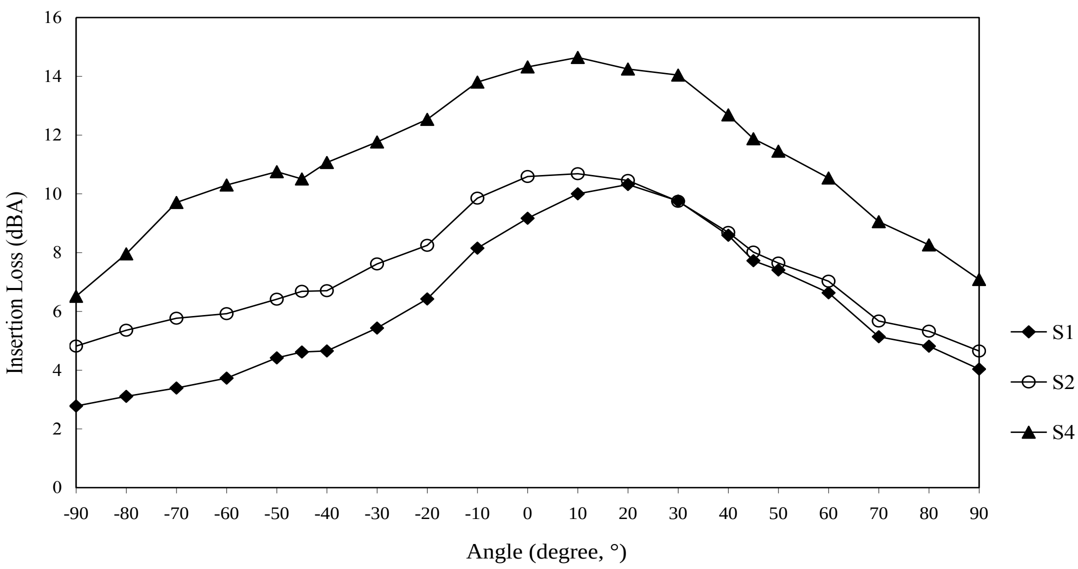


Figure 3. Insertion loss of devices at different sound incidence angles

The angles of sound incidence onto the tested devices are found to be significant in affecting the performance of devices. Based on the trend of insertion loss spectra as shown in figure 3, there were about 6 dBA to 7.5 dBA variation in the insertion loss of tested devices over the range of studied angles. The acoustical insertion loss of windows were higher when windows were at parallel orientations to the sound source compared to when windows were placed perpendicular to the road. The highest insertion loss of plenum window was obtained when the window was nearly parallel to the sound source.

There are different positions of insertion loss peaks for the tested windows. The insertion loss peaks are observed at around 20° and at around 10° of sound incidence angles of S1 and S2 respectively. In the case where the openings of plenum window were 250 mm for both sides (S1), higher acoustic benefits obtained when the incident angles of sound wave onto window were between 15° to 25°. However, the trend of insertion loss for the scenario S2 when the openings are 125 mm shows higher insertion loss slightly shift to the left side of the studied angles range which around 5° to 15°.

When the window of S1 turning perpendicular to line source, results shows a small changes in sound insertion of about 1 dBA for two different positions (-90° and 90°). The sound insulation of S1 was better when the angle of sound incidence is 90° was reasonable because the sound wave may be blocked or reflected by the outer pane of devices. At this position, the outer side opening of devices was faced far away from sound source.

The difference insertion loss of tested plenum windows indicated that changes of opening sizes will influence the acoustic behavior of the devices. A significant sound insulation is found for the sound incidence angles where the outer side opening faced close to that sound source. Higher variations of acoustic benefits at the incidence angle of sound wave between -90° to 0° onto the tested devices were as expected because the direct sound waves may ingress into indoor environment through the outer side openings.

CONCLUSION

The acoustical protections of plenum windows were tested using scale model. Source room in the present study was changes to semi-anechoic room to reduce the strong reverberation field inside the room. The normalized traffic noise spectrum of the standard EN 1793-3 was used to estimate the insertion loss of studied devices in term of single rating.

The effects of source orientations relative to the devices are discussed. The influence of angles of sound incidence onto façade devices are found to be significant in protecting traffic noise. There was around 6 dBA – 7.5 dBA variation in the insertion loss over the range of studied source angles. When devices placed nearly parallel to traffic roads, higher insertion losses were obtained.

In the present experiment, the performance of plenum window also affected by the opening sizes of the devices. Other configurations of devices such as the depth of air gaps and traffic distance may influence the protection performance of plenum window. The effect of sound source distance and plenum dimensions to the acoustical protection is still not clear. Further experiments on variation of source distance and as well as other window configurations are suggested.

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