The sound transmission loss across ventilation window under active noise cancellation

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ABSTRACT

An experimental investigation on the use of active noise cancellation to improve the sound transmission loss across a ventilation window was carried out in this study. This experiment series was conducted inside a building acoustic test chamber consisted of two isolated rooms. One of these rooms was reverberant and was used as the receiver room, while the other was made semi-anechoic and it was where the sound source was located. The ventilation window was installed on a brick wall separating these two rooms. Active control with one reference signal, one error microphone and maximum three secondary sources was implemented using the EZ-ANC II MIMO controller. Six well separated microphones which spanned over the whole volume of the receiver room were used to capture the average sound pressure level inside the receiver room. The average sound pressure levels in the receiver room with and without the active control were used to describe the improvement of sound transmission loss by the active control. Among the various control combinations tested, sound transmission loss improvement was found at frequencies below 550Hz. The highest improvement was ~5dB and was found at ~200 Hz. The improvement decreased as frequency increases in general, but there was a dip at ~300 Hz. This dip was believed to be due to a longitudinal resonance in the ventilation window cavity.

Keywords: Sound Insulation, Active Control   I-INCE Classification of Subjects Number(s): 51.4

1. INTRODUCTION

Hong Kong is a hilly city with a high population density. There has been fast growing demand by the local residents for residential areas within the urbanized regions in the territory because of daily live convenience, job and business opportunities and easy access to community facilities. This has long been a big challenge to the local government. Making urban lands available for this purpose by urban re-development is certainly a way forward. However, this has already ended up with many new residential buildings erected nearby noisy trunk roads. A recent study by the Environmental Protection Department, the HKSAR Government indicates that about 1/7 of the Hong Kong population is exposed to excessive traffic noise (1). The growing demand for urban residential areas will certainly worsen such situation unless a careful planning and effective noise mitigation measures can be derived.

In some less congested urbanized parts of Hong Kong where lands are available and the population density is not so high, conventional noise mitigation measures, such as the road side noise barriers (2), noise enclosures, setback and adjustment of building orientation (3) and etc., appear effective. However, they are nearly all inapplicable during urban re-developments because there are not enough spaces for their implementation in the already very congested and expensive urban areas. Orientations of buildings have also been dictated by the road settings and the possible views from the buildings. Besides, setbacks and extended podium structures are not easy because of the congested but expensive urban land spaces. In order to reduce noise from intruding into the living environments

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inside buildings, noise screening devices attached to the building façades are attractive alternatives to the abovementioned conventional measures.

Balconies, as well as horizontal canopies, on the building facades have been considered as possible noise screening devices by a number of researchers in the past few decades (for instance, May (4) and Mohsan and Oldham (5)). However, there are evidences showing the ineffectiveness of these structures as noise screening devices unless sound absorptions are installed within the balcony structures (5-7). Ishizuka and Fujiwara (8) studied the use of reflectors within the balcony for improved screening efficiency. Tong et al. (9) investigated the performance of sound absorption and the effects of acoustic modes inside a balcony void. However, the installation of sound absorption is not preferred as there will be consequences of maintenance and health issues. The use of reflectors is also not preferred as it largely reduces the functionality of the balcony and a larger head room is required. Acoustic fins have also been adopted in practice, but they can only offer limited protection. Double and triple glazing windows are effective noise attenuation devices (10), but they cannot be opened such that the indoor ventilation has to rely on mechanical means which will consume large amount of energy and thus not desirable in view of sustainability. There have been studies in which these multi-glazing windows are set partially opened and mechanical fans are used to draw outdoor air into the indoor environment through the window cavity (11). However, this type of design also suffers from the same drawback as the closed double glazing window. Energy is used to power the fans.

A ventilation window consists of at least two parallel glass panes and is basically an elongated plenum chambers without mechanical fans but with openings on two sides. The acoustical performance of a preliminary version of such window type in term of sound transmission loss was first studied by Ford and Kerry (11). While high sound insulation was measured, their setup was not practical as their window opening sizes were less than 10% of the corresponding window spans. However, this window design has then attracted the attention of many researchers and engineers as it can allow natural ventilation even by the induced air movement due to the heat plume of indoor occupants (12).

Kang and his co-workers (13) did tests on ventilation windows and studied the improvement of acoustical insertion loss after installing perforated panels inside these windows. The authors, in collaboration with local authorizes, have carried out further analysis on the acoustical performance of the ventilation windows through in-situ site tests (14). The use of sound absorption materials for performance improvement was also investigated. The orientation of the window relative to the noise source has also important influence on the acoustical performance of the window (15). The acoustical benefit of installing the ventilation window, which is defined as the increase in noise reduction above that of the corresponding conventional opened single glazing prescribed façade window (14), is about 8 dBA in practice. However, such performance is still found not good enough in some housing projects. A stronger ventilation window in term of acoustical protection is thus practically in need.

The active control method, which uses a secondary source system to interfere destructively with the original sound field, is certainly an important add-in for improving the acoustical performance of the ventilation windows because such destructive cancellation can theoretically result in very low sound level overall (16). This method has been tried out in an attempt to reduce the standing wave resonance effect within a double glazing window (17) and for improving the insertion loss of a vertical noise barrier (18). Huang et al. (19) studied the sound attenuation across an ventilation window with active control system using a scale model with planar incident wave. The major objective of the present study is to investigate experimentally the effectiveness of active sound cancellation using a full scale model.

2. EXPERIMENTAL SETUP

All the experiments in the present study were carried out inside the acoustic testing chambers in the Hong Kong Polytechnic University. The test chambers are two coupled but isolated chambers originally used for the ISO 140-3 tests for sound transmission loss of building materials. They are isolated from the building structure. The bigger chamber has a volume of about 240 m^3 and a height of 5 m, while the smaller one, usually used as the receiver room, has a floor area of ~21 m^2 and a volume of ~84 m^3. Figure 1 shows the floor layout of the chambers. Throughout the experiment, the source room was made semi-anechoic, while the reverberation inside the receiver room could be adjusted by using fiberglass. The investigation was started with a less reverberant receiver room.

The ventilation window was installed on the wall separating these two chambers. Figure 2 illustrates its structure and essential dimensions. The height of the window was 1350 mm.

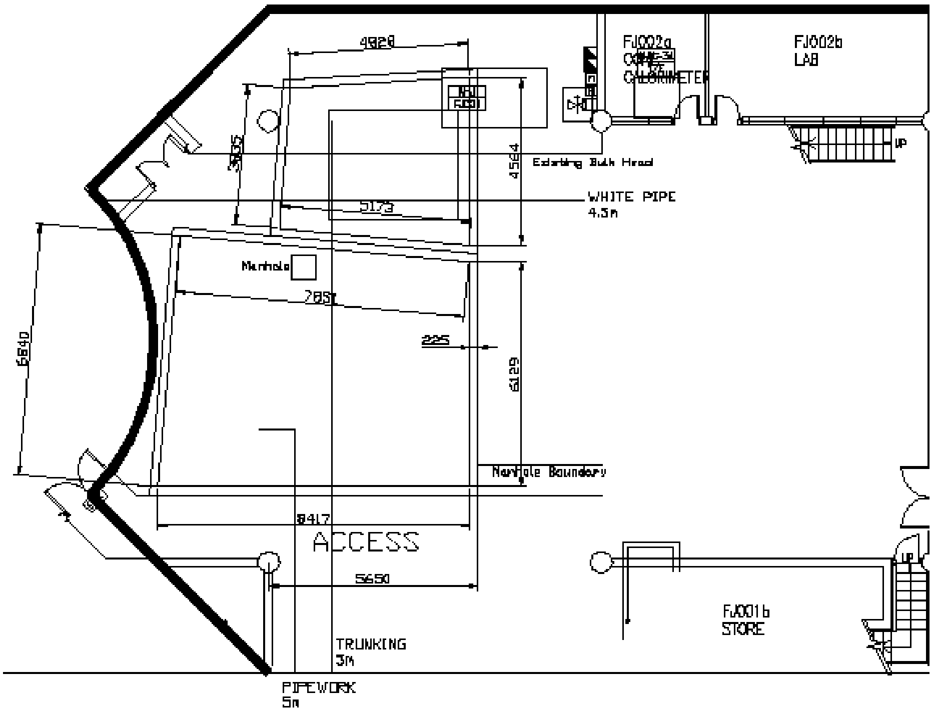


Figure 1 – The test chambers

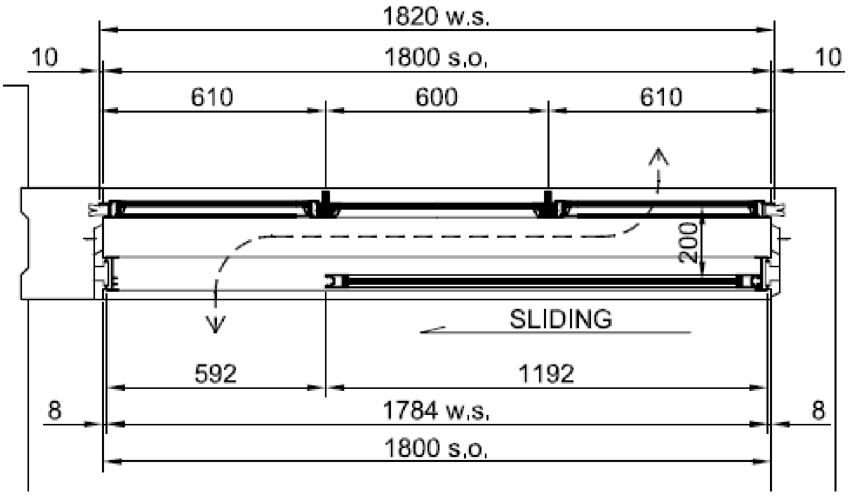


Figure 2 – The ventilation window used and its dimensions (arrows : direction of air movement)

Six Brüel & Kjær 4935 microphones, which spanned over the volume of the receiver room, were used to capture the average sound level inside the room with and without the active sound cancellation. The effectiveness of the active cancellation in the present study is defined as the reduction of average sound level inside the receiver room after the active noise control was turned on. A 6-inch aperture loudspeaker located on the floor of the source chamber was used as the sound source.

The active control was implemented using the MIMO active noise controller (ANC) EZ-ANC II with adaptive feedforward FXLMS algorithm. The present ANC system consisted of one reference signal, three error signals and up to three secondary sources (10 cm aperture VISATON FR 10 HMP) located at the inlet of the ventilation window. Figure 3 shows the schematic of the measurement system. Each error signal was utilized as the adaptive feedback control signal to calculate the output signal for the secondary sound source mounted at the same height of the error microphone.

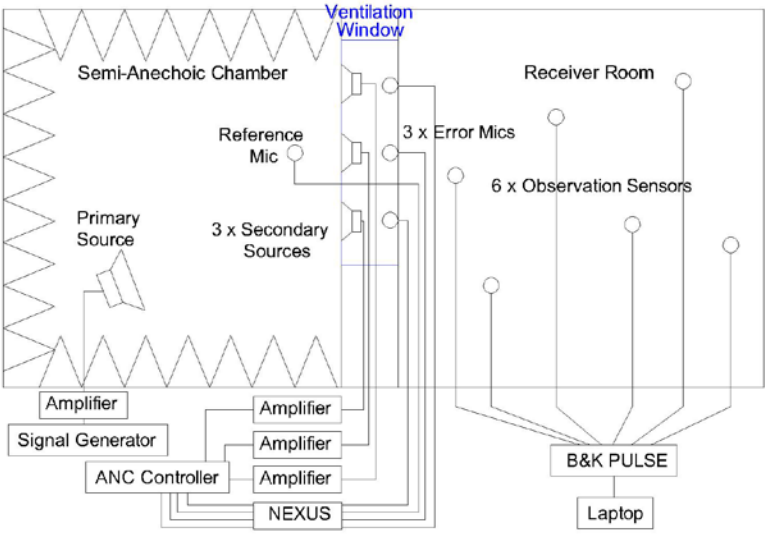
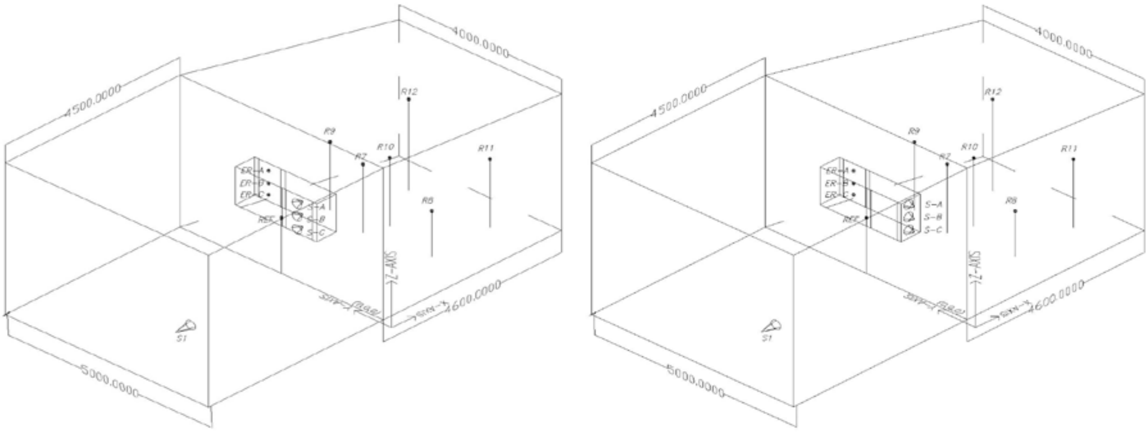


Figure 3 – Schematic of the ANC system

There are two secondary source orientations included in this study (Figure 4). The first case is when these loudspeakers are facing the incoming sound directly. The second case is when the loudspeakers are facing the cavity towards the window outlet (which was adopted by Huang et al. (19)). These two cases are hereinafter referred to as ‘F’ and ‘C’ respectively. The six microphone signals in the receiver room were also recorded using a PULSE system. In the foregoing discussions, ‘1-channel’ ANC refers to the case where only the middle secondary speaker is operated, ‘2-channel’ ANC the case where only the middle speaker is disabled and ‘3-channel’ ANC the case where all the secondary control sources are in operation.



(a) Orientation ‘F’ (b) Orientation ‘C’

Figure 4 – Secondary source orientations

3. RESULTS AND DISCUSSIONS

Figure 5 illustrates the noise attenuation inside the receiver room under the ‘2-channel’ ANC with pure tone excitation. The performance of the ‘F’ secondary source orientation appears better especially at low frequencies and at frequencies higher than 900 Hz. The latter is also the frequency range where sound amplification is observed. The width of the ventilation window gap is 200 mm and thus one can expect the cut-on frequency of the first asymmetric mode across the gap width is ~860 Hz. Therefore, the amplification (or uncontrollable situation) at high frequency is probably due to the asymmetric mode propagation along the gap.

There are two dips of sound attenuation. The first one is found at ~315 Hz and the other at ~630 Hz. These frequencies are near to those of the longitudinal resonance across the length of the ventilation window flanked by the sliding panel. Since the ‘C’ type secondary source orientation is not performing very well, the foregoing discussion will be focused on the ‘F’ type secondary source orientation.

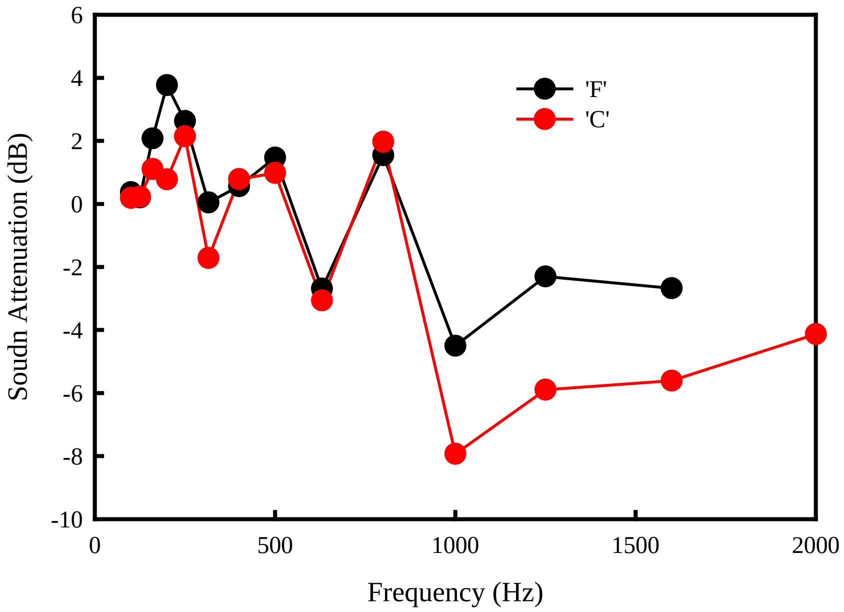


Figure 5 – Performance of ‘2-channel’ ANC under tonal excitation

The performances of ANC using different number of control channels with the ‘F’ type secondary source orientation are shown in Figure 6. It can be observed that the ‘2-channel’ ANC performs the best. The ‘3-channel’ ANC gives slightly better results than the ‘1-channel’ ANC but only before the cut-on of the abovementioned asymmetric gap mode. It is found that there is more difficult for the controller to estimate the transfer functions when the number of channels reached 3, and the controller was unable to function at frequency higher than 1 kHz.

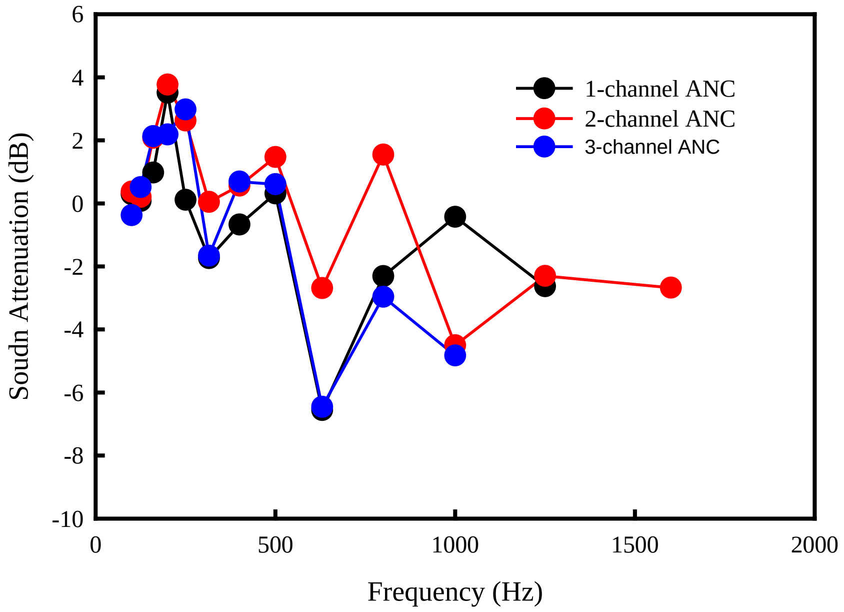


Figure 6 – ANC performance with different number of control channels under tonal excitation

The fibreglass in the receiver room was then removed and the reverberation times in the room increased drastically (Figure 7). The ANC performance was worsen when the receiver room became more reverberant as shown in Figure 8. Under the strong reverberant condition, the error microphone signals were very much contaminated by the sound field in the receiver room such that the transfer functions were not accurately estimated. A new attenuation dip is observed at ~200 Hz, which is close to that of a longitudinal resonance across the length of the ventilation window. The outlet impedance of the window, which depends on the coupling between the window and the receiver room cavity, appears to have played an influential role in the sound transmission process.

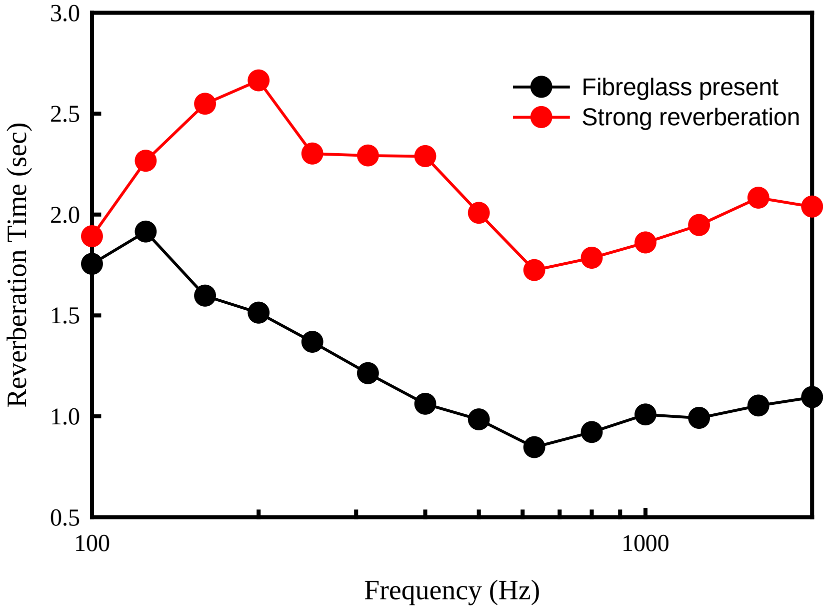


Figure 7 – Reverberation times in receiver room

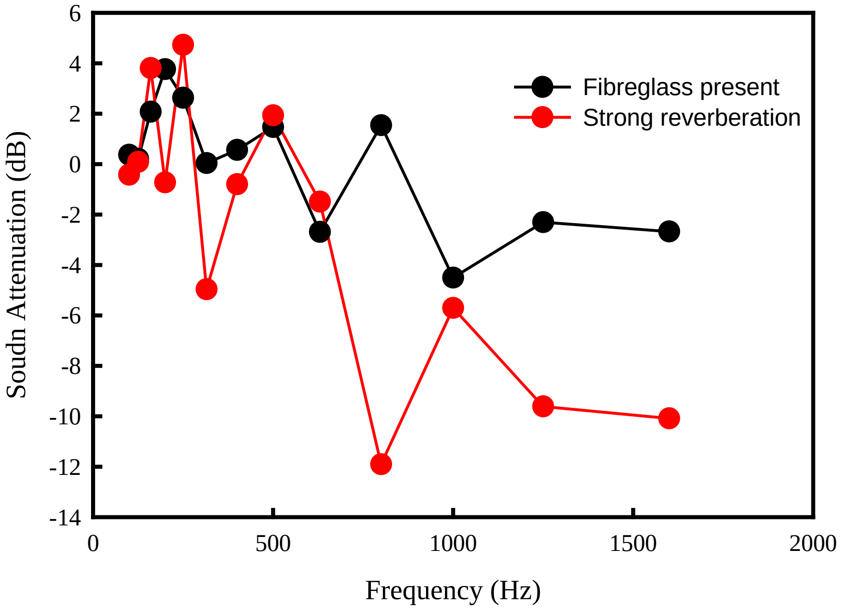


Figure 8 – Effect of receiver room reverberation on ANC performance (2-channel ANC, tonal excitation)

4. CONCLUSIONS

The effectiveness of applying active sound cancellation technique to improve the acoustic insulation of ventilation window was studied in the present investigation. A full scale window and a MIMO active controller with the adaptive feedforward FXLMS algorithm were used. Each ANC system consisted of 1 reference and up to 3 control channels (each was linked with an error signal and a secondary source).

It is found that all the ANC systems tested failed at frequency close to or exceed the first asymmetric gap mode cut-on frequency. The longitudinal resonance across the length of the ventilation window franked by the sliding panel resulted in attenuation dips or even slight sound amplification. The longitudinal resonance effect became more serious when the reverberation in the receiver room became stronger, indicating that the coupling/interaction between the sound field inside the receiver room cavity and the window cavity has large influence on the performance of active noise cancellation.

Overall, the additional noise reduction obtained by applying active sound cancellation technique to ventilation window is found very limited. The highest additional attenuation was ~4dB, while the highest operational frequency in the present test cases was ~500 Hz.

ACKNOWLEDGEMENTS

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