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The acoustic performance of ventilated window with quarter-wave resonators and membrane absorber

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ABSTRACT

Noise and air pollution problems become significantly in a busy city such as Hong Kong since buildings usually located close to the heavy traffic lines. Traditional openable window cannot fulfill all the functions of noise reduction, lighting and natural ventilation. A new ventilated window combines the multiple quarter-wave resonators (silencer) and the new wing wall designs aim to make a balance between acoustic and ventilation performances at the same time. Furthermore, the use of multiple-wave resonators and membrane absorber which made plexi-glass plastic sheet replace absorption material can improve the durability; avoid small particle emission and light transparency.

The acoustic and ventilation performance of new ventilated window were examined in this study. Noise attenuation of the new ventilated window design has improved significantly by combine flexible absorber and quarter-wave resonator effects. Transmission loss of 10–22 dB can be achieved in the frequency range of 500 Hz–4 kHz band. Outlet air flow velocity of ventilated window design is higher than that of "an open window". Thus, both the acoustics and ventilation performance of the new ventilated window is essential. Wind-driven natural ventilation is an effective strategy in maintaining the comfort and health of the indoor environment.

1. Introduction

Both the noise and air pollution problems become significant because many buildings in a busy city such as Hong Kong closed to heavy traffic lines. Complaints about traffic noise have increased in the past years. The major frequency range of traffic noise is in the frequency range of 500 Hz–4 kHz. Windows have to be securely closed to mitigate noise most of the time; even though people usual prefer to open windows for fresh air. Consequently, residents cannot enjoy the fresh air induced by natural ventilation all the year round. Mitigation measures to reduce the impact from the noise and air pollution become a hot topic. The conceivable benefits will be the reduction of building energy consumption by air conditioning and artificial lighting by using more natural resources.

Air conditioning provides cooling to meet the thermal comfort requirement. An alternative approach to achieve acceptable thermal conditions inside the building is to utilize natural ventilation to decrease or raise up the indoor air temperature. However, external wind speed in Hong Kong unevenly distributes all year round especially in summer time. Sometimes there is no wind at all whereas at times of typhoons arrive with extreme high wind velocity. In hot summer time, a large amount of air conditioning has to use to fulfill the demands of fresh air exchange; and to reduce the indoor temperature at Hong Kong.

Design of a sustainable building becomes crucial in Hong Kong. Sustainable building is defined as "the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a property's life-cycle: from siting to design, construction, operation, maintenance, renovation, and deconstruction. This practice expands and complements the classical building design concerns of economy, utility, durability, and comfort" [1]. The natural ventilated window introduced in this paper aims to reduce noise and enhance natural ventilation to maintain human comfort. This can reduce the use of air-conditioning which is the most energy consumption in Hong Kong.

In designing a natural ventilation system, there is always a conflict between ventilation and acoustic requirements. Larger openings are always required in enhancing the effectiveness of natural ventilation; conversely. At the same time, it may also generate higher noise levels.

Field and Fricke [2] investigated the use of multiple quarter-wave resonator system in noise attenuation. The result indicates that the effectiveness of the noise attenuation of the multiple resonator system is feasible with the resonator system in its normal position. The costs are lowest compared to other sound insulation devices and maintenance is less. Salis et al. [3] reviewed a few

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noise control techniques and assessed the variation of airflow characteristics with sound insulation to road traffic noise of facades incorporating ventilation openings. Their findings show that natural ventilation openings offer little resistance to the noise passage. Ventilation openings incur large flow constraints.

Gao and Lee's work [4]explained abundant natural ventilation performance has to be controlled strictly by specific opening positions. Yin et al. [5] considered the interaction between wind and heat is one of the principal reasons for affecting natural ventilation, but they did not consider the noise pollution.

Low frequency waves entering buildings through ventilation ducts can cause symptoms such as nausea, headaches, fatigue, insomnia and vibration in internal organs. Ballagh [6] proved that reactive attenuators using expansion chamber can overcome the drawback of using porous acoustic materials. The expansion chamber design, however, achieves a promising attenuation at high frequencies only but has poor noise reduction at low frequency below 250 Hz. Asdrubali and Buratti [7] designed a high sound insulation ventilating windows allowed airflow through the window itself. It is applicable for medium and high frequency but not for low frequency sound waves. Cox and Antonio [8] and Takahashi et al. [9] also showed that the thin membrane can be used to absorb noise at the frequency below 250 Hz. Huang [10] suggested using a flexible membrane in duct noise control. He predicted that the wave dissipation by flexible materials like rubber could outperform typical fibrous duct lining. Both flexural and sound waves diminish with distance for panels with ample structural damping, b. The combination of wave reflection and dissipation allows broadband, low-frequency noise reduction over a short distance. The acoustic behavior of a vibrating metal membrane system has investigated by Frommhold et al. [11]. The metal membrane absorber showed two resonance points, which can be related to a Helmholtz resonance and a plate resonance and can achieve satisfactory sound absorption at low and medium frequencies over more than one octave. Ballagh [6] has also designed a silencer using a panel resonator which constructed of a stiff lightweight foam cored board with airspace behind. The results showed that the panel resonator achieved better low frequency noise reduction than the expansion chamber. A similar silencer made of wood panel suggested by Wang et al. [12]. Unlike a thin membrane, the resonance frequency of the panel is easier to be controlled. However, no panel absorber with transparent material had studied.

From the acoustic aspects, foams or fiber layers use frequently to attenuate the noise. However, they are the sources of dust and require replacement and maintenance of ordinary. Quarter-wave resonator as showed in Fig. 1a can replace traditional absorption material because (i) it requires little maintenance and allows air to pass straightly without harming human health, and (ii) it works with devilishly acceptable noise screening effects. As presented in Fig. 1a, silencer includes ten quarter-wave resonators in series. The quarter wave resonator is constructed of rectangular cavities bounded by plastic partitions with one open end. The acoustic absorbers effect is same as open tube with resonance response when the length of tube is quarter of acoustic wavelength.

Most of the studies in recent years paid attention to its function in the industry (i.e. mufflers in engines); despite the fact that few studies concern its application in the building environment. The new wing wall design combines multiple quarter-wave resonators are a new concept compared with traditional open windows or wing wall.

In this study, the acoustics and ventilation performance of three types of silencers for ventilated window will investigate in details. Sections 2–4 are for acoustic investigation. Three types of ventilated silencer are: (i) a tube with cavity open filled with transparent absorption material of polyester (ii) a tube with cavity open installed with multiple quarter-wave resonators (iii) a tube with cavity closed with transparent plastic membrane. The theoretical formula for acoustics designs of ventilated silencer will present in Section 2, and details showed in Appendix I. The experimental and theoretical transmission losses of those ventilated silencer designs in between tubes will present in Section 3. The muffler effect corresponds to those ventilated silencer installed in the room examines showed in Section 4. The ventilation performance of those ventilated silencer designs addition to wing wall design shown in Section 5. Section 6 discusses the conflicts of noise control with ventilation and lighting function in an openable window. The innovative design of ventilated window discusses in Section 7.

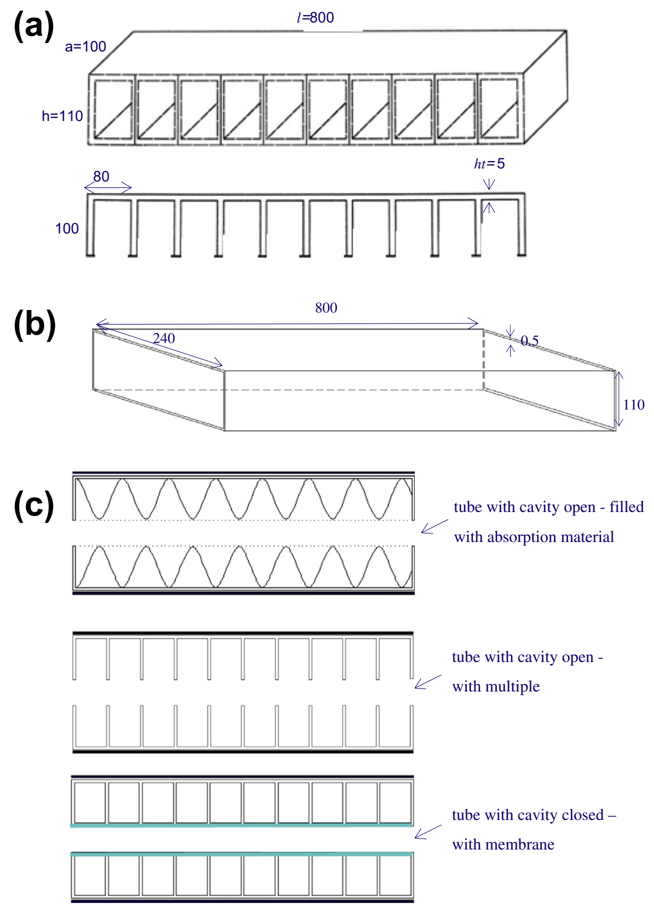

Fig. 1. (a) 3D-view and top-view of the multiple quarter-wave resonators, (b) 3D-view of the duct and (c) multiple quarter-wave resonators installed inside the duct (all dimensions in mm).

2. Theoretical formula for ventilation duct design

The simplified theoretical formulae to demonstrate the main noise insulation design principles of silencer for ventilated window present in this section. The complete deviations showed in Appendix I.

2.1. Formula of flexible absorber

The surfaces of the tube excite to be vibrated at resonances frequencies to dissipate energy when sound energy transmits in the tube of silencer. This terms as a flexible absorber.

The transmission loss (TL) corresponds to flexible absorber effect can be predicted by

$$TL = 10 \log \left(\frac{2\alpha l}{h}\right) (\mathrm{dB}) \tag{1}$$