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Noise Reduction and Ventilation System: A Design of a New Intelligent Window

Keming Ye[1] and Hanbin Luo[2]

[1] *Huazhong University of Science & Technology, Wuhan, China, 302618456@qq.com*
[2] *Huazhong University of Science & Technology, Wuhan, China, luohbcem@hust.edu.cn*

Abstract

In order to enable people to have a more comfortable living environment, a new type of intelligent window has been invented to solve the problem that traditional windows cannot meet the people's need for noise reduction and natural ventilation simultaneously. This intelligent window system uses light and environment-friendly materials, and equips with circuit system which can control the hardware to achieve the optimal opening size by scientific calculation method and monitoring real-time environmental parameters through multi-factor sensors, so that users can get the best acoustic environment experience and air-breathing quality. This system can also consider the residents' different living environment and surrounding sound field conditions, and make personalized adjustment according to the individual sensitive interval of different environmental parameters. The system is also installed a laboratory to test the ventilation and noise reduction performance. The experimental data showed the noise reduction and ventilation system performance was effective, and it could avoid the interference caused by noise and airflow disturbance to residents.

Keywords: natural ventilation, noise reduction, self-adjusting system, sick building syndrome

1. Introduction

Most people spend 80% of their time indoors. Due to the pollution of the indoor environment, the cases of physical and mental injuries of human beings gradually increase, which is also known as sick building syndrome. The objects that cause sick buildings are all kinds of pollution in the surrounding environment, including ventilation system pollution, lighting pollution, heat pollution and noise pollution. Therefore, in order to protect people's physical and mental health, we need to improve the indoor environment.

Up till now, more than 250 studies have shown negative effects of noise on humans, and studies with a median difference of 10-30 dB have suggested that combining acoustic interventions with other noise reduction strategies may yield positive results. A good sound environment should help people keep a good state.

There are successful cases and excellent technical schemes for the reconstruction of mechanical ventilation components, window groups and window ventilation and noise reduction functions in buildings. For example, an intelligent noise-reduction window invented by professor Kang Jian belongs to the technical fields of architecture, building technology, architectural physics, acoustics, noise control and ventilation, etc. It forms a ventilation passage through a digital interlaced glass and adds micro-perforated sound absorber into the glass to reduce noise.

Although these inventions can well solve the problem of noise reduction and ventilation, due to the complexity of forms and the way of up-down opening and closing is not in line with common habits, and the hardware cannot be flexibly adjusted to cope with the changes of various environmental parameters. Therefore, based on meeting the requirements of noise reduction and ventilation, we added sound level meter and air quality monitoring system, combined with the sensors to achieve automatic adjustment, which increased the flexibility of this intelligent system to cope with different scenarios and make the application prospect broader.

2. Related research

In 1983, the World Health Organization (WHO) defined a series of symptoms as sick building syndrome [1]. According to the preliminary statistics of the WHO, about 30 percent of the new and reconstructed buildings are considered to have sick building symptoms. Besides, there are some studies on sick building syndrome in residential buildings [2, 3]. The awareness of impacts that are posed by poor indoor environmental conditions has been studied across various research areas such as health and building sciences [4, 5, 6]. And Indoor Environment Quality (IEQ) refers to the acceptable levels of thermal, visual and acoustic comfort in addition to Indoor Air Quality (IAQ). Here are some aspects of solutions to improving IEQ:

2.1. Noise reduction in dwelling system

Building space design usually requires quiet rooms, through the design of key technical components such as partition wall and window, the purpose of noise reduction can be achieved [7]. Once Yang, Cho etc. suggested a new low-noise window under natural ventilation should be developed [8]. Also, some window systems have already been designed by Kang and Brocklesby [9] and Tang [10].

2.2. Ventilation in dwelling system

As we all know, for indoor space, ventilation is closely related to air quality and thermal comfort. In some circumstances, natural ventilation can provide a higher ventilation rate compared to mechanical ventilation, thus improving the air quality of indoor space, which can improve occupant health by reducing building-related health problems such as sick building syndrome. And a study in Singapore [11] also proved that ventilation problem led to higher CO2 concentration and lower relative humidity which was contributed to SBS. There was a study suggested that the vital predictor of sick building syndromes is ventilation within the indoor environment [12].

2.3. Automation in dwelling system

Building intelligence could have significant impacts on the energy saving of hybrid ventilation buildings. In a study, different building intelligence leads to typically 5%–15% difference in the average energy saving percentage in different climates [13]. And automation was shown to enable the practices from routines and can be regarded as an effective solution to influence resource use at home [14].

A key factor in achieving healthy environments in buildings is the provision of a high level of Indoor Environmental Quality (IEQ) [15]. The factors of thermal comfort, acoustic and IAQ define indoor environment quality [16, 17, 18]. And because of these factors, we could improve the sick building environment via these parts.

3. Window system design

3.1. Technical background

Designing green building envelopes is often associated with acoustic issues. For instance, double or multi-glazed windows are advantageous for both energy savings and noise reduction. On the other hand, encouraging natural ventilation is one of the important topics of green building, but opening windows often cause noise problems. Therefore, the development of a window system that ensures natural ventilation and efficient use of natural daylighting while reducing noise requirements can improve the overall sustainability of the building envelope. The main object of the invention is to develop a new type of window system through acoustic, daylighting and ventilation techniques.

3.2. Design content

The intelligent window is a new type of window system which is suitable for natural ventilation and can effectively reduce noise. The double-layer hollow glass structure of the digital staggered model is used to form a narrow and long ventilated space, and a micro-perforated sound absorption film is added to the inside of the glass to weaken the sound transmission, to achieve the effect of noise reduction. Motor sliding rails are installed on the top of two double-glazed Windows, which can adjust the opening and closing sizes of the Windows freely, so as to control the length of the noise reduction space, balance the ventilation and noise reduction functions, and adapt environmental parameters under special noise or climatic conditions. In this system, the glass and it is sound absorption film are almost completely transparent, which does not affect the daily exposure of natural light, and its size can be installed on the facade of existing buildings without affecting the appearance.

The window system is equipped with two sensors to meet the function of self-adaptation. The sound level meter is used to monitor indoor sound pressure level, and a digital anemometer is used to monitor wind speed in the ventilated space. This design can meet the needs of different people. For example, people's tolerance for sound is completely different during daytime activities and sleeping at night, and residents living close to the road area need to reduce the indoor sound pressure level, and residents living in quiet villa area need to increase the ventilation volume for better breathing experience. This system can adjust the proportion of its own parameters according to local conditions and personal preferences, which is the best distance for Windows to get the best living experience.

3.3. Conceptual drawing

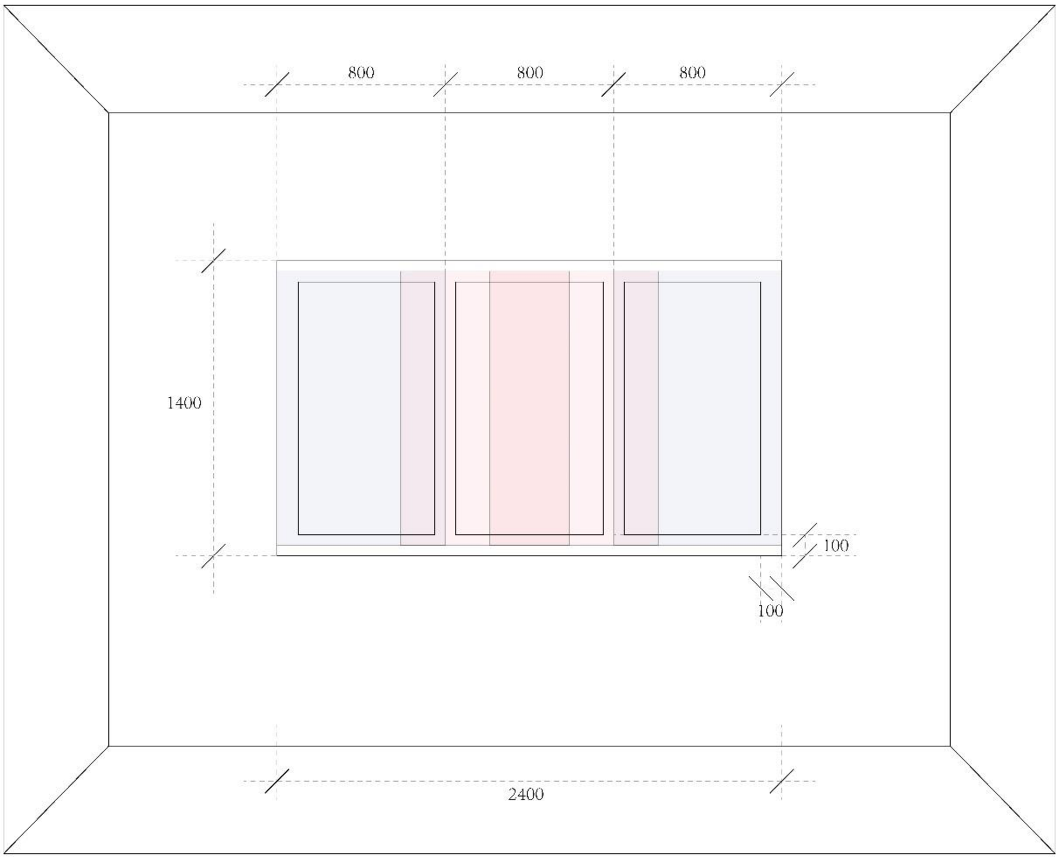

Fig. 1. Front view of the window system.

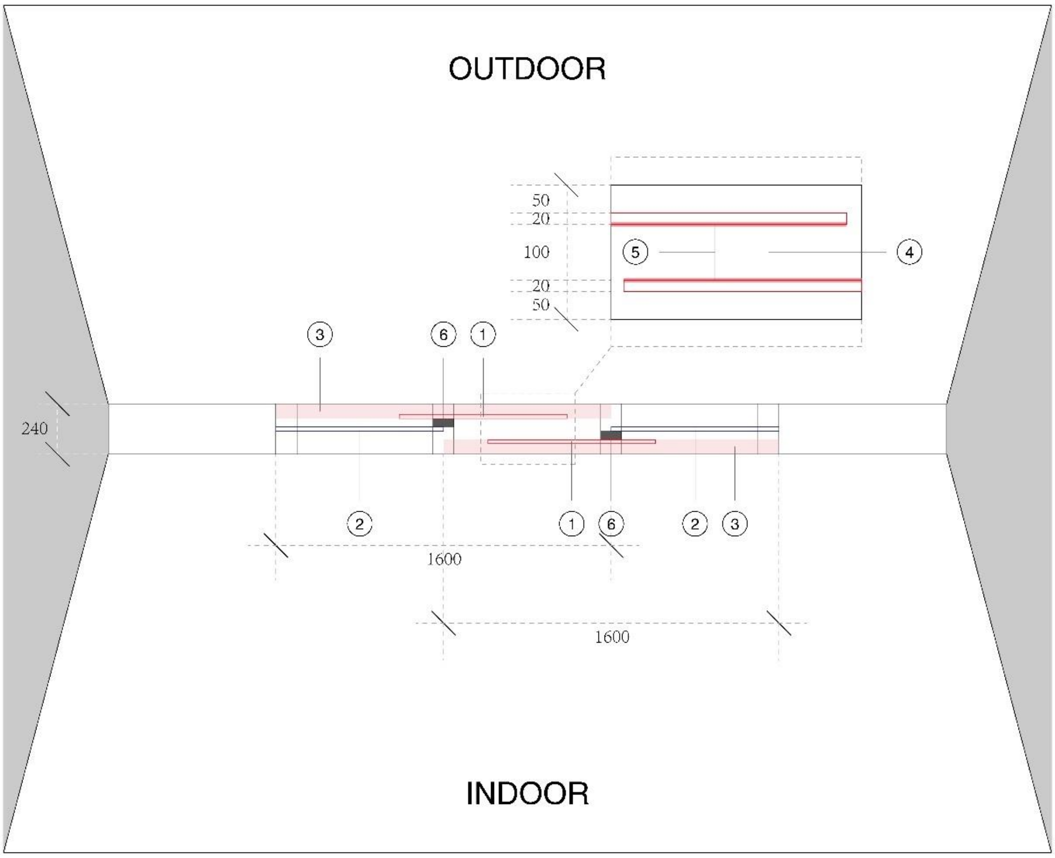

Fig. 2. Top view of the window system.

The main form is shown in the above (Fig.1). The entire outer frame is made of a lightweight aluminium alloy structure of 2400 mm wide multiply 1400 mm high. An equal width structure is set in each third of the middle for support. The metal frame structure of the main form is 100 mm thick. The entire window system uses four hollow double glazing (800 mm multiply 1400 mm), of which two blue ones are fixed position isolation glazing. The two red pieces are movable sliding glass.

The thickness of the entire window system is 240 mm from the top view (Fig.2). The upper part is outdoor space and the lower part is indoor space. Three layers of a track are nested in the aluminium frame. The upper and lower layers are red sliding glass tracks, and the middle layer is blue insulating glass track. The thickness of all double-layer insulating glass is 20mm. Two pieces of red sliding glass are separated by 100mm and can slide freely left and right in the marked red area, thus forming a ventilated space with a length range from 0 to 800mm. Because of the difference between indoor and outdoor temperature, this space can let the air form convection, to achieve the effect of natural ventilation. When the two pieces of red sliding glass interlaced, the narrow and long channel formed will weaken the transmission of sound. In addition, the glass inner wall is affixed with micro-perforated sound absorption film, which can better play the role of noise reduction.

The numbers in the figure are as follows:

1. Sliding glass.
2. Insulating glass.
3. Glass slip range.
4. Noise reduction space.
5. Micro-perforated sound absorption film.
6. Sound insulation pipe.

4. Laboratory test

4.1. Laboratory settings

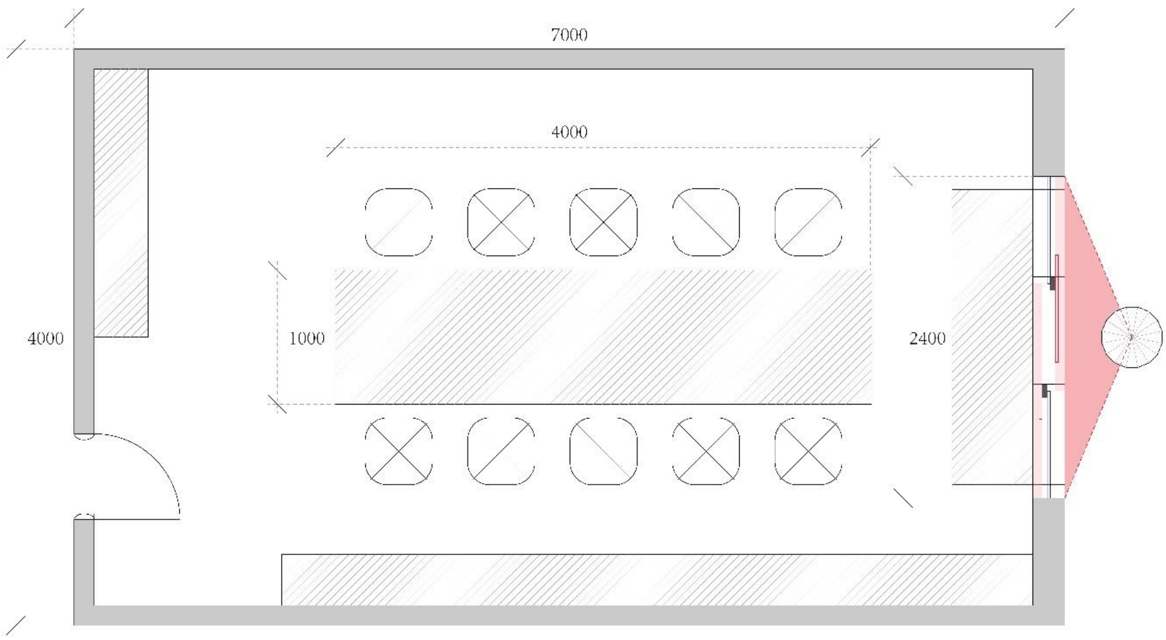

Fig. 3. Laboratory layout schematic.

The experiment was conducted in the audiometric laboratory of a university in Wuhan, China; the lab has a volume of 28 m2 and background noise of 25 dB(A). The figure above shows the layout schematic diagram of the laboratory (Fig. 3). The intelligent window is installed on the building exterior wall on the north side of the laboratory, and a dodecahedral sound source (MHY-14324) with independent power amplifier (HA12-AWA5870A) is installed on the outdoor platform opposite the intelligent window. A UNI-T digital anemometer (UT363) is used to test wind speed in the ventilated space, and a sound level meter (AWA5688) is used to test indoor acoustic data. The laboratory does not have additional noise sources and equipment to change the air quality, so the air quality and acoustic environment data obtained from the test are relatively closed and accurate.

4.2. Experimental method design

In this experiment, the noise reduction performance and ventilation effect of the Windows in five open and close states were tested. Five states correspond to the volume sizes of five noise reduction spaces respectively, with the maximum value of 0.112 m3 (Fig. 4A) and the minimum value of 0 m3 (Fig. 4E). Take the average values of upper and lower limits respectively to get 0.028 m3 (Fig. 4D), 0.056 m3 (Fig. 4C) and 0.084 m3 (Fig. 4B).

The power of 70dB is stably output by the non-directional sound source to ensure the even distribution of sound frequency. A sound level meter is set up in the room to measure the data for five minutes, which is used to measure the equivalent sound pressure level of each frequency under the weight of A meter, and draw the corresponding spectrum diagram.

The anemometer is placed in the noise reduction space to measure the wind speed to correspond to the ventilation volume, and the measured data is m/s.

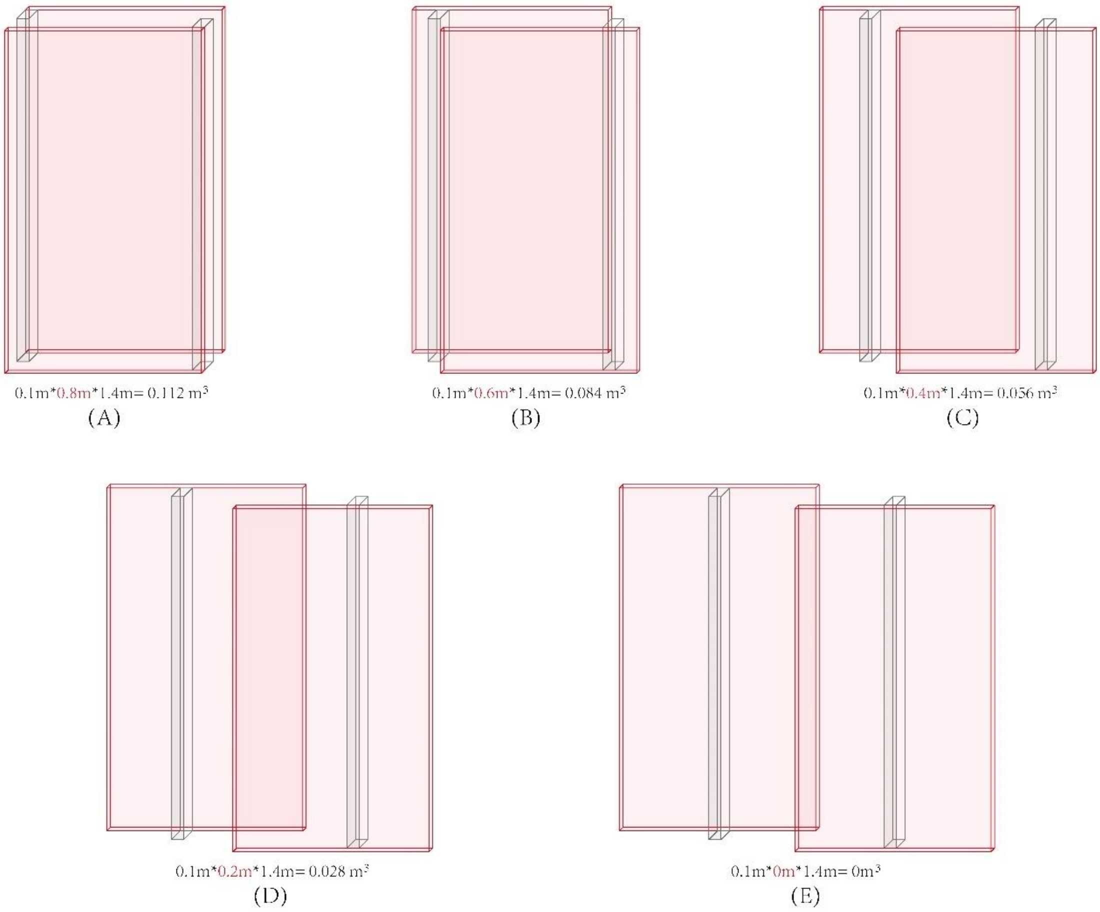

Fig. 4. Open and close gradient schematic.

4.3. Result

The spectrum diagram of corresponding states and the other sound data is shown below (Fig.5) (Table.1). Intelligent window can play a better role in noise reduction, and it can be found that the larger the noise reduction space is, the better the noise reduction performance is. As we can see the change of gradient is uniform.

Micro-perforated sound absorption film (MPA) has a good weakening effect on high frequency sound, but it is weaker than low frequency sound, The larger the volume of the ventilated space, the larger the difference in the attenuation effect of the high and low sound frequencies. With the Windows almost completely closed, sounds above 5000Hz almost faded away.

Table 1. Sound data.

State	Leq T (dB)	Lmax (dB)	Lmin (dB)	L90 (dB)	L50 (dB)	L10 (dB)
A	37.6	44.1	33.6	35.3	36.8	42.7
B	42.4	48.9	37.4	39.3	42.7	46.6
C	46.8	52.1	42.0	44.9	46.9	50.9
D	54.3	59.8	49.8	50.4	53.9	57.1
E	61.4	67.7	56.7	58.2	61.0	64.6

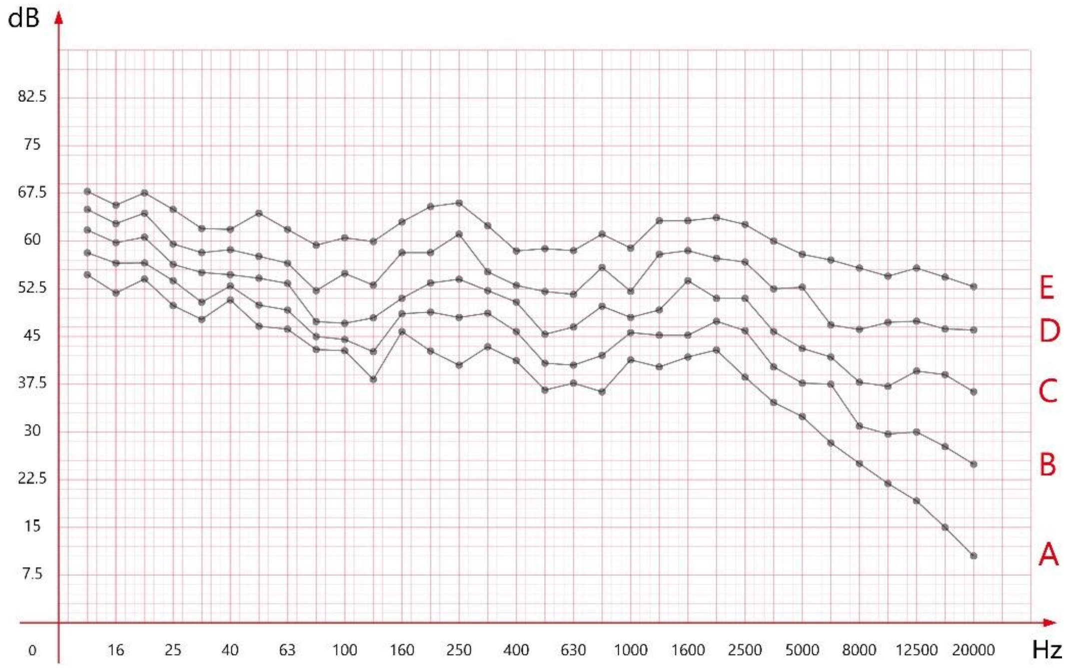

Fig. 5. Spectrum diagram of the test.

The ventilation data below (Table.2) shows that the ventilation volume increases with the reduction of noise reduction space, and the relationship is basically inversely proportional.

Table 2. Ventilation data.

State	A	B	C	D	E
Ventilation rate (m/s)	0.42	0.56	0.77	0.98	1.21

The ventilation data above (Table.2) shows that the ventilation volume increases with the reduction of noise reduction space, and the relationship is basically inversely proportional.

Therefore, the whole intelligent window system can be judged, and the effect of natural ventilation and noise reduction can be completed at the same time. With the movement of sliding glass, the noise reduction performance and ventilation effect can be deployed within a certain range, to easily cope with different environments and personal preferences.

5. Future directions and conclusion

The sound fields inside the intelligent window and their relationships with ventilation and noise reduction are examined in detail. Besides, attentions are paid on the feasibilities of using different materials of MPA. The results presented illustrate that it is effective to use this intelligent window system to reduce noise while still naturally ventilating at different opening sizes and show that reduction in noise is possible using MPA adhered to the air-tight double-glazing windows. The potential improvement of noise reduction could be made on dealing with lower frequencies of sound vibration when analysing the results which further suggest that this can be achieved using some adapted standard materials.

And that using natural ventilation during acoustic measurements suggest that, at normal air movement levels there is no negative effect on the noise reduction achieved using MPA, but a more quantitative and precise test is still required. We will use environment data sensors, such as small sound level meter, temperature and humidity sensor, rain sensor, to realize the automatic function of intelligent window for the future design. Users can set according to their own environmental comfort preferences.

The further studies about this intelligent window system need to be carried out to improve the effect of reducing lower frequencies, because the low-frequency sound has strong penetration and diffraction ability. In addition, studies for the development of low-energy and more intelligent window system and facilities will be needed through the development of modern and smart cities.

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