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Article

Experimental Study on Sound Insulation of Ventilation Partitions

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ABSTRACT

Plenum windows that ensure noise reduction and natural ventilation at the same time have been studied by many researchers. Without sacrificing the window transparency and ventilation, limited acoustical treatments could be implemented in the cavity between two glass panes to enhance noise reduction performance of plenum windows, and accordingly the sound insulation performance by plenum windows hits a bottleneck. Ventilation partition with a similar configuration to plenum windows and consisting of two opaque partition panels with staggered openings is proposed. The paper experimentally studies the sound transmission loss of six ventilation partitions with different acoustical treatments. The measurement results show that their sound transmission class (STC) ratings can be up to 21 STC points higher than that without any acoustical treatment, and the sound transmission losses are even higher than that of a closed single-layered partition at middle and high frequencies with respect to specific designs. The STC of the six ventilation partitions with acoustical treatments investigated in the present study is between STC 22 and STC 32, more than 11 STC points higher than that without any treatment.

KEYWORDS: ventilation partition; sound transmission loss; sound transmission class

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INTRODUCTION

Singapore as a country near the equator has a tropical climate, the temperature record from the Year 1981 to Year 2010 displays that 24-h mean temperatures over 12 months are between 26.4 °C to 28.3 °C [1]. A study based on the field measurement reveals that 28.5 °C is observed as an indoor operative temperature ensuring thermal neutrality for naturally ventilated apartments in Singapore [2]. Such indoor operative temperature is even 0.2 °C higher than the maximum 24-h mean temperature, which means that the residents in naturally ventilated apartments could enjoy thermal comfort. However, numerous apartments are enclosed and air-conditioned in Singapore due to high traffic noise levels. The survey conducted by the Housing and Development Board of Singapore in 2013 shows that 21.7% of Singaporeans in public housing considered their apartments noisy and 39.3% among the samples cited traffic noise as disturbing [3]. To block the outdoor noise, the easy way is to close the windows or doors, which simultaneously prevents natural ventilation. To ensure noise reduction and nature ventilation simultaneously, various solutions have been proposed and some of them are discussed below.

Ventilation window which provides noise reduction and natural ventilation attracts a lot of attention nowadays. The ventilation window, firstly conceived by Ford and Kerry [4], is comprised of two staggered glass panes. It has been found in Ref. [4] that, with respect to traffic noise, the sound reduction index of ventilation windows is about 9 dBA higher than that of open single-layered sliding window. Based on such design, Tong *et al.* [5] compared the sound insertion loss with ventilation and conventional side-hung casement windows installed in two mock-up apartments near a busy traffic road. It has shown that the acoustical benefit from ventilation windows is 7.1–9.5 dBA. Additionally, the insertion loss of ventilation windows depends on the relative direction of windows and roads [6].

During the past decades, many studies turn to the improvement of noise reduction performance by ventilation windows. Both active and passive noise control (ANC and PNC) techniques have been implemented and studied. In terms of the ANC technique, the sound out-of-phase to an incident sound could be generated by secondary noise sources between two glass panes, so that the incident sound can be cancelled and then the noise radiation through ventilation windows could be mitigated. Huang *et al.* [7] analytically and experimentally investigated the feasibility of applying the ANC technique to reduce noise radiation through ventilation windows. The extra noise attenuation by the ANC system is about 10–20 dB at a prescribed frequency band. Recently, Mirshekarloo *et al.* [8] designed and fabricated transparent piezoelectric film speakers as secondary area sound source for the noise cancellation in both conventional open and ventilation windows. Generally, the extra noise attenuation by ANC systems is limited at low frequencies [9].

PNC techniques, which employ sound absorbers, seem to be an efficient way to improve noise reduction performance of ventilation windows at a wider frequency range. Without playing any influence on the window transparency or light penetration, the transparent micro-perforated absorber was placed on one of the glass panes [10]. Due to its low sound absorption coefficient, the improvement in noise reduction is not significant. On the contrary, the non-transparent sound absorbers of good sound absorption performance would help to significantly increase noise reduction levels of ventilation windows if the light penetration is not taken into account. The ventilation windows with various configurations have been tested by Sondergaard *et al.* [11]. The non-transparent sound absorbing sheets were placed either on the glass panes, along with the window frames or on the vents. The laboratory measurement conducted in Ref. [11] shows that the weighted sound reduction index (R_w) can reach 22 dB to 30 dB, which depends on the configurations, as a reference that the weighted sound reduction index (R_w) of an open single top hung window of the same size is 8 dB. Besides, the perforated plates with back cavities installed along the window frame are able to enhance the noise reduction performance, where the improved noise reduction level depends on the perforation rate and the depth of cavities [12]. Moreover, Tang [13] numerically investigated the potential improvement of noise reduction by installing rigid circular cylinder arrays into the window cavity between two partition panels. For the simple cylinder arrangements considered in the study, the traffic noise reduction enhancement observed can be as high as 4–5 dB.

In order to not sacrifice window transparency, besides of using transparent devices, another way to achieve better noise reduction performance is leaving as much as possible space between two glass panes, so that more acoustical treatments could be implemented along the window frame. This is probably the reason that most ventilation windows are much thicker than conventional windows in the mentioned references [5,11,12]. Thick windows might not be accepted by the residents in practice, not only because thicker windows are heavier and need more manpower to be installed, but also thicker windows will take more living space. Considering continuously increased housing prices in high-density cities like Singapore and Hong Kong, thinner windows would be more popular from a cost perspective. To overcome the disadvantage, ventilation partitions with similar configurations, *i.e.*, consisting of two staggered and opaque panels, are proposed in the paper. Ventilation partitions could be built flushed with a bearing wall with conventional windows, therefore will not take extra living space. In this way, transparency is still provided by conventional windows. More importantly, more acoustical treatments could be implemented in the cavity of the ventilation partitions without taking light penetration into account, in this way better noise reduction performance could be achieved. This paper tests the noise reduction performance of six ventilation partitions with different acoustical treatments in the laboratory environment. Also, the noise distribution in the cavities with different configurations will be discussed to clarify how acoustical treatments help to enhance the noise reduction by ventilation partitions.

MEASUREMENT SET-UP

The sound transmission loss (TL) was employed to characterize the noise reduction performance of ventilation partitions. Two reverberation rooms (volumes: 115.4 m^3 and 107.2 m^3) are coupled through a wall with a rectangular opening, as shown in Figure 1. The opening of width 1 m and height 1.8 m was used to accept partitions of the same size. The measurement was carried out complied with ASTM E90-09 [14]. The noise generator CESVA AP 600 and omnidirectional sound source CESVA BP012 were used to generate and play pink noise in the source room. The use of pink noise is to improve the signal to noise ratio of the measurement at low frequency. The sound pressure levels at 6 points in the source and receiver rooms, respectively, were measured by the sound level meter B&K type 2250 with 1/2 inch microphone B&K 4189. Then the averaged sound pressure levels, L_s and L_r, in the source and receiver rooms can be obtained for computing the TL, that is $\mathrm{TL} = L_s - L_r - 10\log\frac{S}{A}$, where S represents the area of the test specimen, A is the equivalent sound absorption area of the receiver room measured according to ASTM E2235-04 [15].

Figure 1. Measurement set-up.

VENTILATION PARTITIONS

As mentioned earlier, ventilation partitions consist of two partition panels with two staggered openings. This section will present the TLs of ventilation partitions with 6 different configurations of acoustical treatments. As a baseline, the TLs of a ventilation partition without any acoustical treatment and a closed single-layered partition were tested as well. In total, the TLs of 8 partitions were measured and compared.

In this paper, the panels of all the partitions are the same Calcium Silicate Board (CSB) of thickness 9 mm and mass density 1050 kg/m^3 to mimic the acoustical hard wall partitions. In terms of ventilation partitions, the spacing between the two panels is 0.082 m, therefore the total thickness of ventilation partitions is 0.1 m. Figure 2 shows the front view of ventilation partitions. Figure 3 shows the cross-section view of the ventilation partition without any acoustical treatment (Case B0), in specific, the left opening of height 0.225 m faces to the source room while the right one of the same size faces to the receiver room. Figure 4 displays the configurations of 6 different configurations of acoustical treatments (Cases

C1–C6) implemented in the cavity between the two panels. The detailed description of the 6 cases is presented in Table 1. The sound absorbers are made up of fiberglass of density 80 kg/m^3. The sound absorption coefficient of the fiberglass with thickness 25mm and surface area 8.64 m^2 was measured in a reverberation chamber referring to [15] and as listed in Table 2.

Figure 2. Front view of a tested ventilation partition from the receiver room.

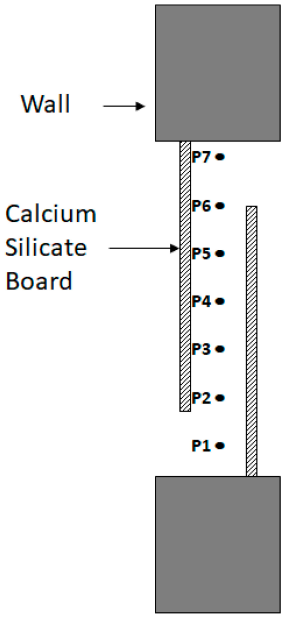

Figure 3. The cross-section view of Case B0: Ventilation partition without any acoustical treatment.

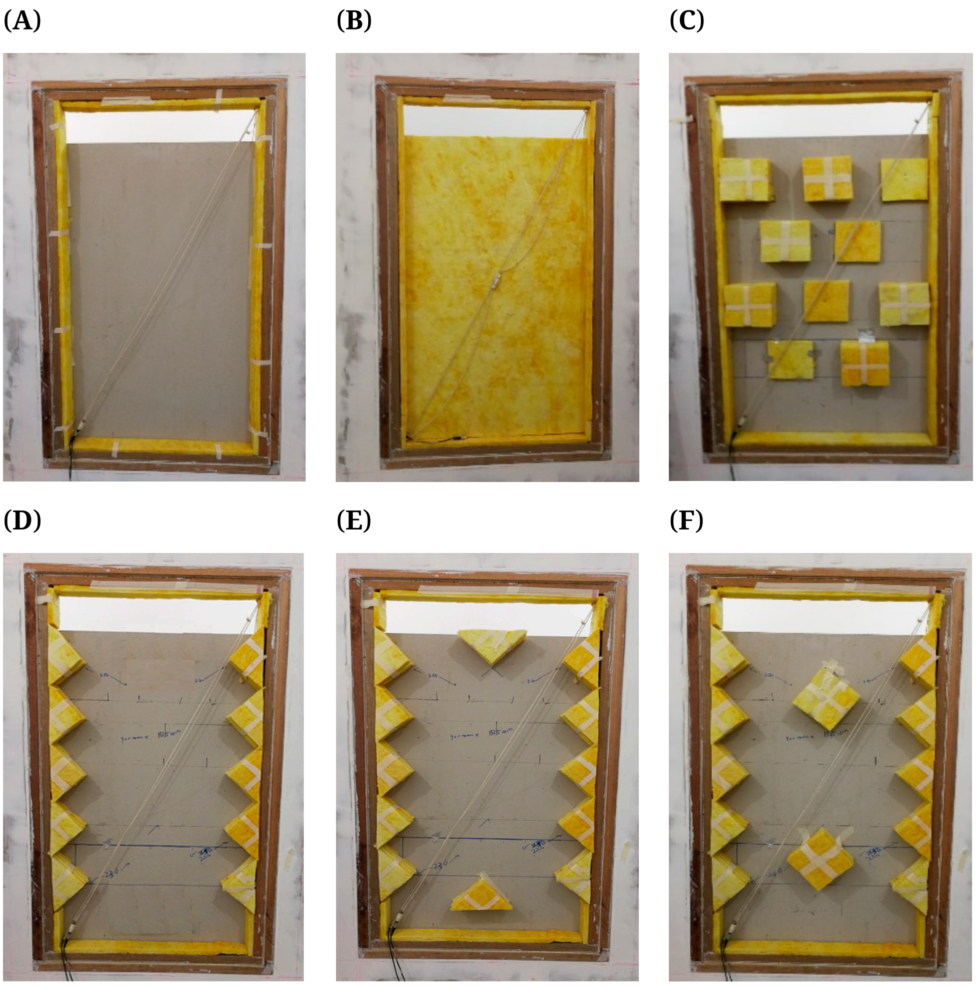

Figure 4. Six ventilation partitions with acoustical treatments. **(A)** Case C1, STC 22; **(B)** Case C2, STC 31; **(C)** Case C3, STC 32; **(D)** Case C4, STC 26; **(E)** Case C5, STC 29; **(F)** Case C6, STC 32.

Table 1. Descriptions and STC of ventilation partitions with 9 different configurations.

Cases	Description	STC
B0	Ventilation partition without any acoustical treatment	11
B1	Fully closed single layered partition	31
C1	The fiberglass of thickness 25 mm is placed along the partition frame.	22
C2	The fiberglass of thickness 25 mm is placed along the partition frame and layered on one panel.	31
C3	On the base of C1, 6 rectangular blocks of size 200 mm and thickness 82 mm as well as 4 rectangular sheets of size 200 mm and thickness 25 mm placed between the two panels. 4 rectangular sheets are layered along the diagonal line of the cavity to balance the performance of the noise reduction and air supply.	32
C4	The fiberglass of thickness 25 mm covers the top and bottom sides of the frame, 10 triangle blocks of side size 200 mm and thickness 82 mm are placed along the left and right sides of frame.	26
C5	On the base of C4, two triangular blocks of side size 200 mm and thickness 82 mm are fixed between two panels and avoid the staggered openings.	29
C6	On the base of C4, two rectangular blocks of side size 200 mm and thickness 82 mm are fixed between two panels.	32
C6-1	On the base of C6, the perforated metal sheet is used to cover the sound absorbers.	30

Table 2. Sound absorption coefficient of fiberglass.

Frequency [Hz]	Sound absorption Coefficient
100	0.02
125	0.05
160	0.08
200	0.19
250	0.18
315	0.37
400	0.41
500	0.57
630	0.65
800	0.81
1000	0.83
1250	0.85
1600	0.84
2000	0.73
2500	0.72
3150	0.70
4000	0.74

In Figure 5, the dash-dotted line presents the TL of Case B0 while the dashed line shows the TL of Case B1, *i.e.*, Closed single-layered partition. The curves with different markers correspond to the TLs of Cases C1 to C6. The comparison of Cases B0 and C1 demonstrates that the sound absorber placed along the window frame significantly increases the sound transmission loss, especially at the middle and high octave-band frequencies. For instance, compared to Case B0, the maximum improvement of the sound transmission loss is 11 dB at the frequency 2 kHz using the configuration of Case C1. Compared to Case C4, the additional triangular or square blocks placed in the centre of the cavities (Cases C5 and C6) help to further increase the sound transmission loss, and the sound transmission loss of Case C6 is higher than that of Case C5 probably due to the larger area of sound absorbers exposed to the cavity. Moreover, the TLs of Cases C2, C3, C6 at the middle and high frequencies are close to or even higher than that of Case B1, which means that ventilation partitions with specific designs can help to isolate the noise as well as a closed partition.

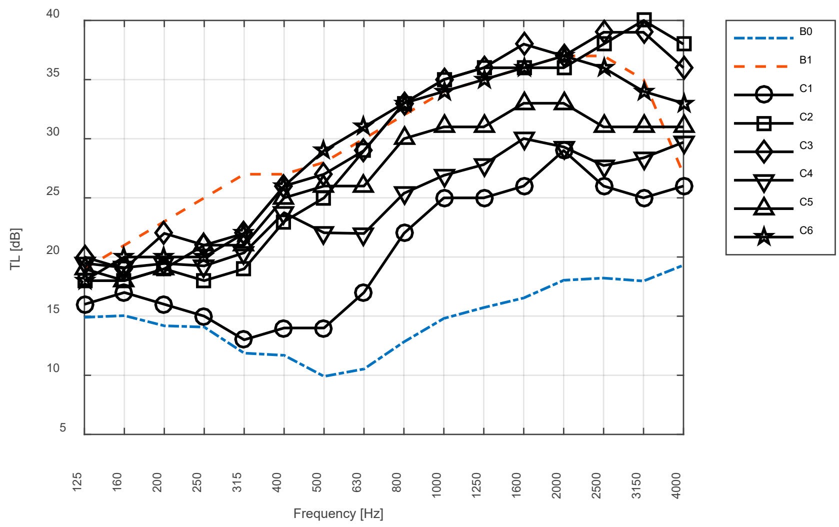

Figure 5. Sound transmission loss of 8 partitions.

In order to prevent the fiber release, the fiberglass should be covered by a cover in reality, accordingly the sound absorption performance of the fiberglass might be affected. On the base of the configuration of Case 6, the paper employed the perforated metal sheet to cover the fiberglass as shown in Figure 6A. The perforated metal sheet composed of stainless steel SUS304 is of thickness 0.5 mm as displayed in Figure 6B; the diameter of the hole is 1 mm; the distance between two holes is 2 mm; the perforated rate is 22.6%. The TLs of the two cases are plotted in Figure 7. It can be seen that the TL is slightly decreased due to the presence of the metal sheet.

(A) **(B)**

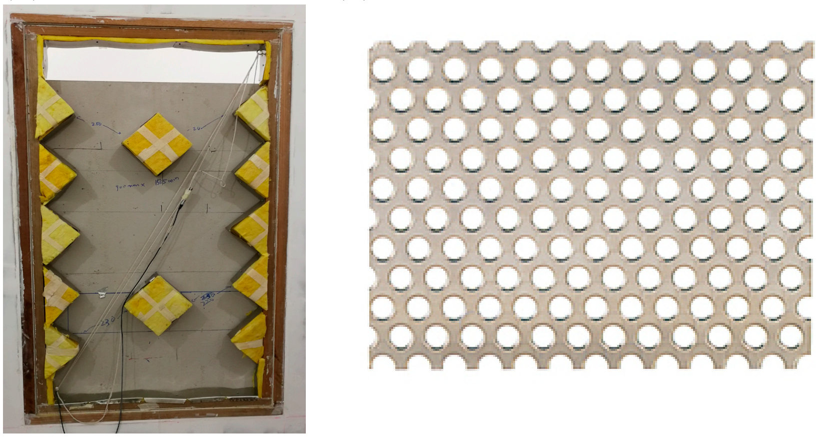

Figure 6. (**A**) Case 6-1: with perforated metal sheet, STC 30. (**B**) Perforated metal sheet.

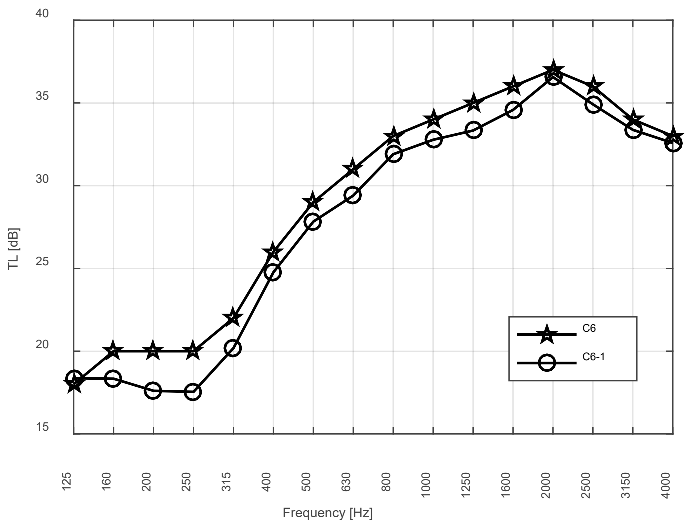

Figure 7. Comparison of TLs of Cases 6 and 6-1.

In addition, Sound Transmission Class (STC) [16] that rates the sound transmission loss into a single value is frequently used to characterize the noise reduction performance of partitions, and thereafter was employed alternatively for comparing the noise reduction performance of the partitions. The STC rating provides a single-parameter indicator for the speech noise reduction of partitation. The rating methodology is based on the measured spectra of transmission losses (TL) in the previous section compared to a standard reference contour provided by the ASTM E413-04 [16]. The STCs of all the cases are listed in Table 1. It can be seen that the STCs of Cases C3 and C6 are STC 32, which is 1 STC point higher than that of Case B1. The STC rating of ventilation partitions with acoustical treatment is at least 22 STC points and up to 21 STC points higher than that of ventilation partition without acoustical treatment in the present study.

The questionnaire survey conducted in [17] demonstrates that the air supply provided by the plenum window is not sufficient for residents. The mechanical ventilation system could be involved in the future to supply sufficient air. In fact, more configurations could be proposed to balance noise reduction, light penetration and air supply efficiency based on various requirements.

DISCUSSIONS

In order to understand the noise reduction mechanism of ventilation partitions and how the sound absorbers affect the sound radiation in the cavity between the two panels, the sound pressure levels (SPLs) at 7 measuring points, as depicted in Figure 3, along the diagonal line on the middle cross-section of the cavity were measured.

Figure 8 plots the difference ΔL between the SPLs and the averaged sound pressure level L_s in the source room with respect to Case B0. It can be seen that ΔL at the 7 points is larger or smaller than 0 dB at octave-band frequencies lower than 800 Hz. Besides, even the Point 1 is in front of the opening facing to the source room, the SPL at this point does not always present the largest. The reason is the following: since there is no acoustic treatment implemented for Case B0, the cavity is of hard surface boundaries, the modal behaviour of the cavity plays important roles on the noise radiation in these octave bands. In the contrast, at higher octave-band frequencies, ΔL of all the points is smaller than 0 while that of the points not facing to the openings is similar, which confirms that the sound energy in the cavity might be evenly distributed in the cavity because of the diffuse field in the cavity [18].

Likewise, ΔL of Case C3 is plotted in Figure 9 as an example, as similar features were found for other cases with the sound absorbers. It can be seen that the variation tendency of ΔL at the 7 points is very different from that of Case B0. Due to the good sound absorption performance of sound absorbers, the SPL at most octave frequency bands decreases as the distance between the measuring points and the opening on the source room side increased. Accordingly, the ventilation partition with the sound absorbers added-in can be taken as a duct silencer. Last but not least, due to the poor sound absorption performance of sound absorbers at low frequencies, the SPLs at low frequencies approximate the averaged sound pressure level L_s, same to Case B0.

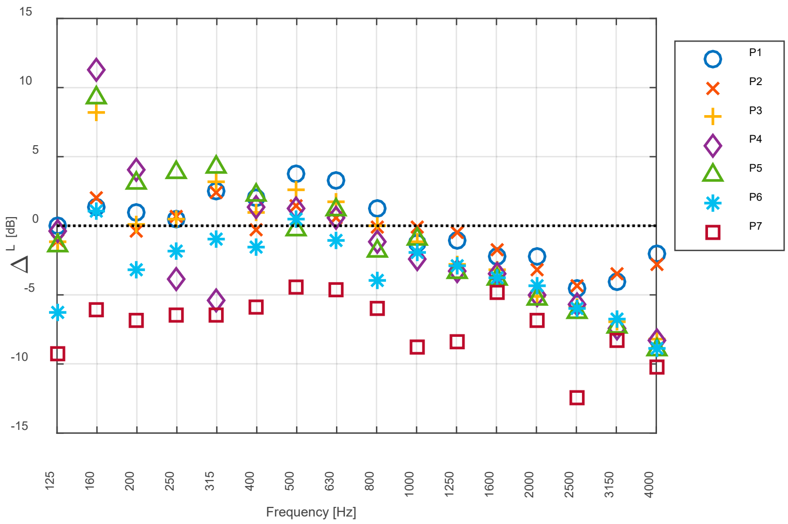

Figure 8. Level difference ΔL of Case B0.

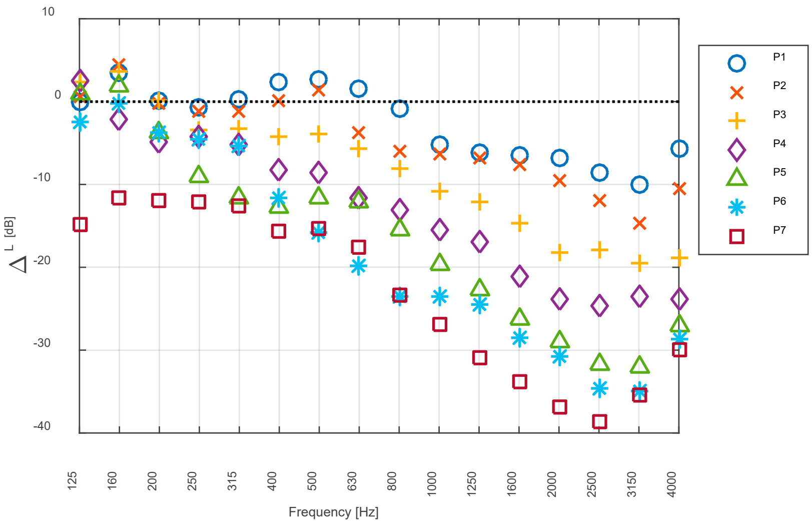

Figure 9. Level difference ΔL of Case C3.

CONCLUSIONS

The paper experimentally studied the TLs of ventilation partitions. The ventilation partitions consist of two partition panels with two staggered openings. The paper used calcium silicate boards as partition panels. The sound absorbers made up of fibreglass were placed in 6 different patterns in the cavity between the two panels, therefore the TLs of 6 different ventilation partitions with sound absorbers were measured in the laboratory environment. Meanwhile, the ventilation partition without any sound absorber and a closed single-layered partition were tested as a reference. The comparison of ventilation partition with and without acoustical treatment demonstrates that the added-in sound absorbers can help to maximally increase the STC rating by 21 STC points. Besides, the noise reduction performance of ventilation partitions with sound absorbers at some frequency bands is even better than that of the single-layered partition. Without sound absorbers, the cavity between the two partition panels is of rigid boundaries, the cavity resonance plays an important role on the noise radiation in the cavity at low frequencies. The implemented sound absorbers, which modify the boundary conditions of the cavity, abate the influence of the cavity resonance and then moderately increase the noise reduction at low frequencies. Because of good sound absorption at middle and high frequencies, the larger surface area of sound absorbers in the cavity results in the better the noise reduction performance. Additionally, it should be noted that the cover on the sound absorbers in reality might affect the sound absorption performance of sound absorbers and accordingly adjust the noise reduction levels of ventilation partitions. In the future, more configurations could be designed and tested, not only taking into account the noise reduction performance, but also the light penetration and air supply efficiency.

AUTHOR CONTRIBUTIONS

The idea was conceived by LD, SKL and SEL. LD conducted the measurement and wrote the manuscript. SKL and SEL revised the manuscript accordingly. All the authors gave final approval to submit the paper.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interests.

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