http://www.jtdweb.org/ ISSN1346-7824

An Improvement of Lighting Effect for Soundproof windows

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A new type of window has been presented in previous study. When attention to the lighting's effect, this window has a defect needs to be improved. The parallelepiped form of soundproofing unit is used to improve the lighting effect. Based on the experiment and the comparison with the acoustic characteristics of rectangular shaped, the characteristics of parallelepiped soundproofing unit will take to considering. As the results, the soundproofing techniques of rectangular soundproofing unit can be applicable for parallelepiped soundproofing unit in practical use.
Keywords: sound propagation, soundproof, higher-order mode, wave equation, windows

1. INTRODUCTION

A concept or manufacturing window which is capable of ventilating, regulating sunlight and reducing traffic noise for the developing tropical countries have been presented in previous study[1]. This window combines two basic unit components of ventilation and lighting as shown in **Fig. 1(a)**. The latter can be constructed using one or two glass layers which are mounted at an incline between two rectangular ventilation components with input and output openings at both ends. However, when attention to the lighting's effect, this window has a defect needs to be improved. Since the Sun's rays are oblique almost all the time, a perpendicular shape of the rectangular ventilation components will prevent a large amount of light ray from reaching the glass layer of the lighting unit as shown in **Fig. 1(a)**. Our task is to maximize the area of the surface at which the Sun's rays can be received. In order to meet that demand, the shape of rectangular ventilation components should be oblique at the angle that can fit well to the direction of the Sun's ray. This concept suggests a new design of the SVU in the form of an oblique parallelepiped as shown in **Fig. 1(b)**.

Due to the fact that the soundproofing unit must have a large volume to attenuate the low frequency noise, many resonance of the higher-order mode waves will be generated inside the unit [2]-[5]. Consequently, in order to have a great soundproofing effect, it is necessary to take into consideration the dimension and placement of input and output openings in such a way that would minimize the effects of the higher-order mode. Needless to say, a more important selection is the shape of the unit.

This paper deals with a parallelepiped shape and those basic acoustic characteristics. Based on the experiment and the comparison with the acoustic characteristics of rectangular shaped, the characteristics of parallelepiped soundproofing unit will take to considering.

2. ACOUSTIC CHARACTERISTIC OF SOUNDPROOFING UNIT

In order to achieve a high soundproofing effect, we need to find out the resonance mechanism and the resonance frequency according to the shape of the soundproofing unit. Hereinafter, we will summarize some analysis methods used for the study of the rectangular soundproofing unit.

At first, let we consider the resonance frequencies of higher-order mode wave in rectangular soundproofing unit which has a dimension of $a \times b \times d$. Based on the wave equation, the average sound pressure on the output becomes [1]

$$\bar{P}_0 = j\frac{4k\rho c}{S_{ab}}\left[\frac{1}{\sin(kd)}\left(-U_i + \cos(kd)U_0\right)\right.$$

$$\dot{\sum}\left\{\frac{1}{\mu_{m,n}\sinh\left(\mu_{m,n}d\right)}\ \theta_{m,n} + \frac{\cosh\left(\mu_{m,n}d\right)}{\mu_{m,n}\sinh\left(\mu_{m,n}d\right)}\lambda_{m,n}\right\}$$

$$\left.\Delta_{m,n}\right] \quad (2)$$

where the first term on the bracket represents the sound pressure of the plane wave and the second one represents the sound pressure components of the higher-order mode wave, respectively. Other symbols in Eq.(1) are defined in [1]. The average sound pressure become great when its denominators become zero, namely at the following resonance frequencies of

$$\sin(kd) = 0 \quad \therefore \quad f = \eta\frac{c}{2d} \quad (\eta = 1, 2, 3....) \quad (2)$$

$$\mu_{m,n}\sinh\left(\mu_{m,n}d\right) = 0$$

$$\therefore \quad f_{m,n} = \frac{c}{2\pi}\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 - \left(\frac{\eta\pi}{d}\right)^2}$$

$$(\eta = 0, 1, 2, 3....) \quad (3)$$

Generation mechanism of these frequencies can be understood according to the calculation example shown in **Fig. 2** with $\sin(kd)$ and $\mu_{m,n}\sinh(\mu_{m,n}d)$. Note that, $\sin(kd)$ is shown on a magnification of 10 for convenience and the dimensions of the cavity used in calculation are a=0.48m, b=0.075m and d=0.29m, respectively.

Measurement apparatus [2] as shown in **Fig. 3** was used to measure the resonance frequency of ventilation unit. Two microphones were located at both sides of the cavity to measure the sound pressure P_A and P_B, respectively. Relationship between them is given by

$$\begin{pmatrix} P_A \\ U_A \end{pmatrix} = \begin{pmatrix} \cos\left(kL_0\right) & jZ_0\sin\left(kL_0\right) \\ j\frac{1}{Z_0}\sin\left(kL_0\right) & \cos\left(kL_0\right) \end{pmatrix}$$

$$\begin{pmatrix} A_w & B_w \\ C_w & D_w \end{pmatrix}\begin{pmatrix} P_B \\ U_B \end{pmatrix} \quad (4)$$

where the first term in right side represents the four-pole parameters of the input pipe which has in length L_0 and the second one represents those of a cavity. Symbol U_A, U_B and Z_0 represent a volume velocity and acoustic impedance of inlet pipe, respectively. By installing the microphone 2 on the output, U_B will become zero thus Eq. (4) can be obtained as

$$20\log_{10}\left|C_w\right| = 20\log_{10}\left|P_A / P_B\right|$$

$$-20\log_{10}\left|Z_0\sin\left(kL_0\right)\right| \quad (5)$$

It can be seen that C_w can be found by subtracting the acoustic characteristic of inlet pipe from the measured results of sound pressure P_A and P_B. Note that, the relationship between C_w and our predicted Eq. (1) can be found as

$$C_w = \frac{U_0}{P_0}\bigg|_{U_L=0} \tag{6}$$

Experimental was performed with 2 parallelepiped form of ventilation units which have the same rectangular form dimension (a=48cm, b=7,5cm, d=29cm). The external angle θ are 45^0 and 60^0, respectively. **Figure 5** shows the C_w characteristic when θ=45^0. Symbols x represents the resonance frequencies of the standing wave, at the frequency when sin(kd)=0 in **Fig.2**. Similarly, symbol ○and●are those of higher order mode, when m=2, n=0 and m=4, n=0, respectively. Regarding to the resonance frequencies, both of the standing wave and higher order mode of parallelepiped shape are slightly lower than that of the rectangular one in the low frequency range. However, different between them become large when θ=60^0 as shown in **Fig. 6**. We can see that the value C_w of parallelepiped shape is almost lower than that of rectangular in whole measurement frequency range. **Figure 7** shows the variation of C_w depending θ, it can be concluded that no significant change when θ changes. **Figure 8** shows the special case of parallelepiped unit when θ=45^0 at the input side and θ=60^0 at output one.

4. CONCLUSIONS

Acoustic characteristic of the parallelepiped soundproofing unit was estimated by the comparison with those of rectangular ones. From the results obtained by measurement based on insertion-loss method, we may conclude that although there are some discrepancies on the resonance frequency and C_w level, the acoustic characteristic of parallelepiped soundproofing unit can be considered as similar with those of rectangular ones. Therefore, the soundproofing techniques of rectangular soundproofing unit can be applicable for parallelepiped soundproofing unit in practical use.

In order to maximize the soundproofing capability, it is necessary to minimize the effect of the plane wave sound pressure component. Moreover, it is necessary to use sound absorbent material effective with current noise pollution inside the soundproofing unit. This technology will be present in an upcoming report.

5. REFERENCES

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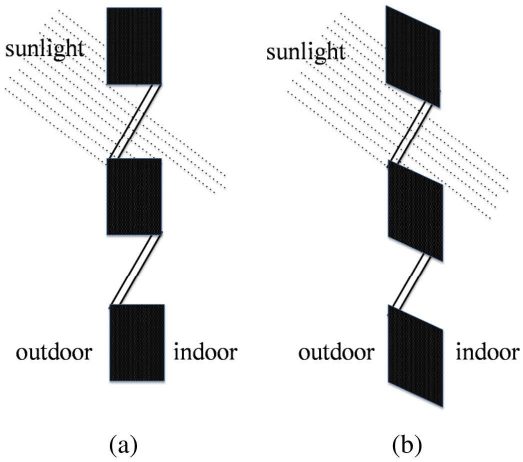

Figure 1 Proposed method to improve a lighting effect

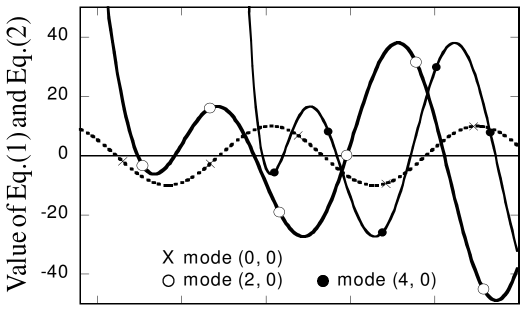

Figure 2 Curve of $\sin(kd)$ and $\mu_{m,n}\sinh(\mu_{m,n}d)$

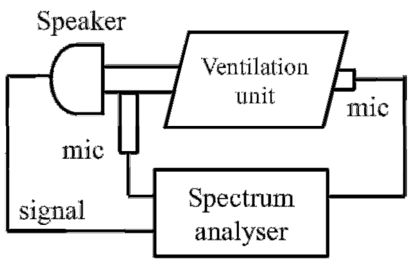

Figure 3 Experimental apparatus

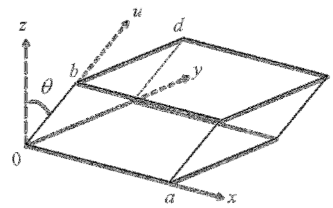

Figure 4 Parallelepiped shape

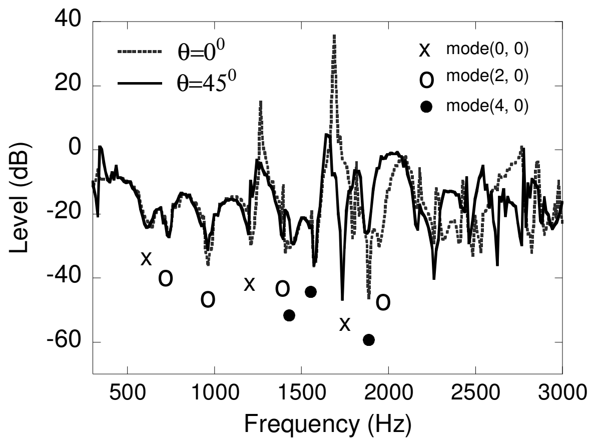

Figure 5 C_w characteristic when θ=45^0

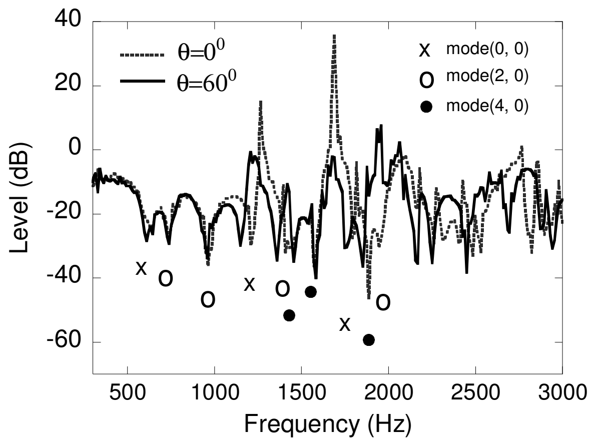

Figure 6 C_w characteristic when θ=60^0

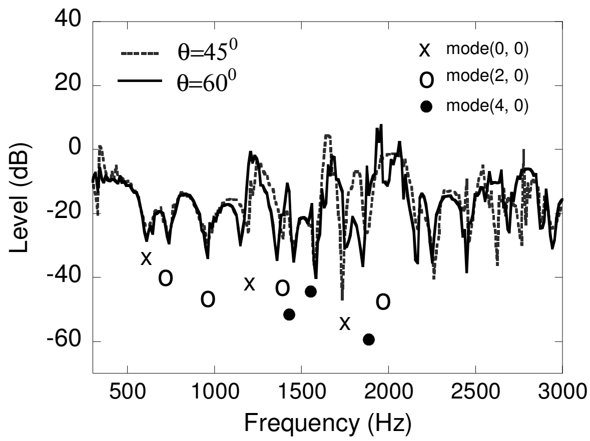

Figure 7 Comparison between θ=45^0 and θ=60^0

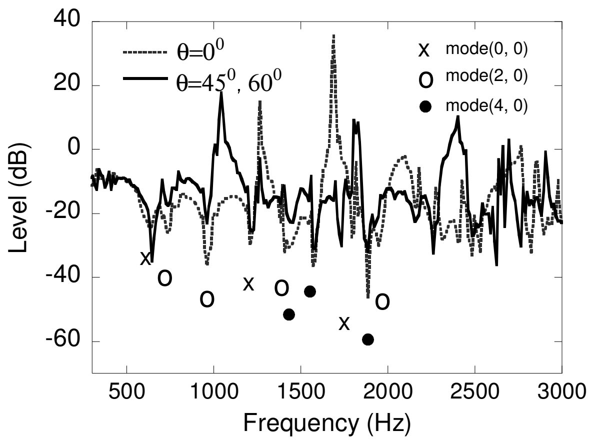

Figure 8 Special case when θ=45^0 at input and θ=60^0 at output side