Experimental and analytical approach to study on the sound-proofing and ventilating effects of rectangular cavity

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The present paper aims to theoretically and experimentally investigate the soundproofing characteristic of rectangular cavity with input and output opening at various positions. By the reason that the rectangular cavity must have a large volume to attenuate low-frequency noise, many resonance of higher-order mode wave will be generated inside the unit. Therefore, to minimize these waves in order to have a great soundproofing effect, the determination of the shape and dimension, moreover, the placement of these input and output is very importance. Acoustic characteristic of the rectangular cavity with input and output opening at various positions has been presented by solving the wave equation considering the higher-order mode wave effects. To prove the theory, experiments were carried out and excellent agreement is obtained.

Keywords: sound propagation, soundproof, higher-order mode, wave equation, windows

1. INTRODUCTION

In tropical developing countries where the environment is featured by the hot humid climate, ample wind is needed to get rid of the high relative humidity [1]. However, as the result of inadequate developments and explosion of transportation demand, the noise growth emitted from huge amount of vehicles makes the people here supplement their windows with glass panes and close them almost all day to prevent noise propagation. This is leading the ability of natural ventilation of the building impossible. Consequently, the occupants have to depend on the air conditioning equipment to cope with the heat caused by having windows closed all day. Moreover, these behaviors turn back increasing the noise by equipment operation and emit CO2 to the surroundings. In addition to glass facades of the buildings, all creates the phenomenon called green house and contribute to the climate change.

Attending that demand, a concept for manufacturing windows which are capable of ventilating, regulating sunlight and reducing traffic noise for the developing tropical countries, especially low-cost to produce have been presented [2]-[3]. These windows combine two basic components which are ventilation unit and lighting unit. The former also serves as an import function in reducing noise. Due to the fact that the ventilation unit must have a large volume to attenuate low-frequency noise, many resonance of higher-order mode wave will be generated inside the unit. Consequently, it is necessary to take into consideration the selection of size and placement of input and output openings in such a way that would minimize the effects of higher-order mode in order to have a great soundproofing effect.

In previous papers, the characteristic of sound propagation in the rectangular ventilation having an input and output located in various positions has been presented by solving the wave equation, considering the higher-order mode effects.

The present paper aims to experimentally investigate the soundproofing characteristics of rectangular cavity with input and output opening at various positions. The main parameters varied in the tests were based on the results obtained by the previous study

2. COMPUTATION OF THE VENTILATIONUNIT WITH VARIOUS POSITION OF INPUT AND OUTPUT

Combinations of input and output positions are shown in **Fig. 1** in which (a) and (b) are the cases where they are in opposite faces while (c) and (d) are in faces which crossed right angles. Difference between (a) and (b) is whether they are located in big or small cavity area, however it is quite similar in the theoretical analysis.

Hereafter, we will call (a) and (b) as Model-1.Similarly, difference between (c) and (d) is whether they are located in big or small side area which crossed right angles. We will call (c) and (d) as Model-2. Note that, the sound propagation in (a) is the same as (c) and that in (b) is the same as (d).

Considering the rectangular soundproofing ventilation unit which has a dimension of $a \times b \times d$. Dimension of an input and output are $S_i = (a_{i2} - a_{i1})(b_{02} - b_{01})$ and $S_0 = (a_{02} - a_{01})(d_{02} - d_{01})$, they located on the face which has a section area of $S_{ab} = a \times b$ and $S_{ad} = a \times d$, respectively.

For Model-1, the average sound pressure level on the output becomes

$$\bar{P}_0 = j\frac{4k\rho c}{S_{ab}}\left[\frac{1}{\sin(kd)}\left(-U_i + \cos(kd)U_0\right) + \dot{\sum}\left\{\frac{1}{\mu_{m,n}\sinh\left(\mu_{m,n}d\right)}\theta_{m,n} + \frac{\cosh\left(\mu_{m,n}d\right)}{\mu_{m,n}\sinh\left(\mu_{m,n}d\right)}\lambda_{m,n}\right\}\Delta_{m,n}\right] \quad (1)$$

Where

$$\theta_{m,n} = \frac{U_i}{S_i}\int_{a_{01}}^{a_{02}}\int_{b_{01}}^{b_{02}}\cos\left(m\pi x/a\right)\cos\left(n\pi y/b\right)\,dx\,dy$$

$$\lambda_{m,n} = \frac{U_0}{S_0}\int_{a_{d1}}^{a_{d2}}\int_{b_{d1}}^{b_{d2}}\cos\left(m\pi x/a\right)\cos\left(n\pi y/b\right)dx\,dy$$

$$\Delta_{m,n} = \frac{1}{S_0}\int_{a_{d1}}^{a_{d2}}\int_{b_{d1}}^{b_{d2}}\cos\left(m\pi x/a\right)\cos\left(n\pi y/b\right)\,dx\,dy$$

$$\mu_{m,n} = \sqrt{\left(m\pi/a\right)^2 + \left(n\pi/b\right)^2 - k^2}$$

U_i and U_0 are volume velocity of input and output, symbolic $\dot{\sum}$ means $\sum_{m=0}^{\infty}\sum_{n=0}^{\infty}$ without m=n=0. For Model-2, the average sound pressure level on the output becomes

$$\bar{P}_0 = j4kZ_0\left[\frac{1}{k\sin(kd)}\left(-\frac{S_i}{S_{ab}}U_i + \frac{S_0}{S_{ad}}\cos(kd)U_0\right) + \dot{\sum^*}\left(\frac{I_{m,n}}{S_{ab}S_i}\frac{\cos(n\pi)}{\mu_{m,n}\sinh(\mu_{m,n}d)}U_i + \frac{O_{m,n}}{S_{ad}S_0}\frac{1}{\beta_{m,n}\tan(\beta_{m,n}b)}U_0\right)O_{m,n}\right] \quad (2)$$

where

$$I_{m,n} = \int_{a_{i1}}^{a_{i2}}\int_{b_{i1}}^{b_{i2}}\cos\left(m\pi x/a\right)\cos\left(n\pi x/b\right)\,dx\,dz$$

$$O_{m,n} = \int_{a_{01}}^{a_{02}}\int_{z_{01}}^{z_{02}}\cosh\left(\mu_{m,n}(z-d)\right)\cos\left(m\pi x/a\right)dx\,dz$$

$$\beta_{m,n} = \sqrt{k^2 + \left(n\pi/d\right)^2 - \left(m\pi/a\right)^2}$$

The average sound pressure on the output of Model-1 and Model-2 are the same component as shown in Eq. (1) and Eq. (2). The first term and the second term in right blanket represent a standing wave and higher-order mode waves, respectively. In order to obtain a effective soundproofing, low level of $\bar{P}_0$ is preferable, in other words, low value of sound level defined by $\theta_{m,n}$, $\lambda_{m,n}$, $\Delta_{m,n}$ and $O_{m,n}$ are required. All these factors include a definite integral of $\cos(m\pi x/a)$ which has an interval relating to the input or output dimension. It is consider that when locating the center of input or output at x=a/2 and take an integration with an interval [h - a/2,h +a/2], by the symmetry distribution with respect to a/2,much of the value of $\theta_{m,n}$, $\lambda_{m,n}$, $\Delta_{m,n}$ and $O_{m,n}$ will become zero. Especially, when we select the integration interval from 0 to a, not only all of odd mode wave level but also many even mode wave level will become zero. The measurement of insertion loss with various form of input and output was carried out with the ventilation unit having a dimension of 48cm x 7.5cm x 29cm. Measured results are shown in **Fig.3.** Note that, all of input and output have a same cross section area of 86.4cm2.

3.CONCLUSION

Based on the results obtained by the theoretical calculation, experimentally investigate the soundproofing characteristics of rectangular cavity with input and output opening at various positions was carried out. Because the higher order mode waves generate very high level of sound pressure, especially at the resonance frequencies, therefore the selection of size and placement of input and output opening in such way that would minimize their effects is very importance. Obtained result shows that when selected one side of input/output equal to those of the cavity, not only all of odd mode wave but also many even mode wave can be eliminate (**Figures 2-4**).

5. REFERENCES

[1]Hansen, Terri, "Copenhagen brings indigenous climate change issues to world stage | Indian Country Today | UN Declaration". Indian Country Today. Retrieved 2009-12-19.

[2]Y. Nishimura, S. Nishimura, T. Nishimura, T.Yano Sound propagation in soundproofing casement windows. Journal of Applied Acoustics 2009; 70(2009); pp. 1160-1167.

[3]Y. Nishimura, Q.Nguyen Huy, S. Nishimura, T. Nishimura, T. Yano The acoustic design of soundproofing doors and windows. The Open Acoustics Journal, 2010, 3 (2010); pp.30-3

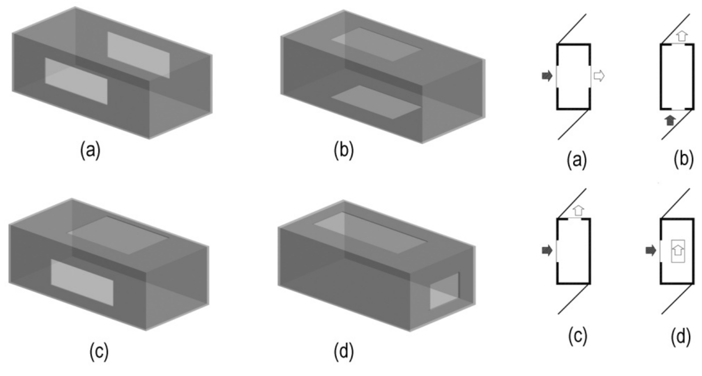

Figure 1- Combination of the input and output on unit.

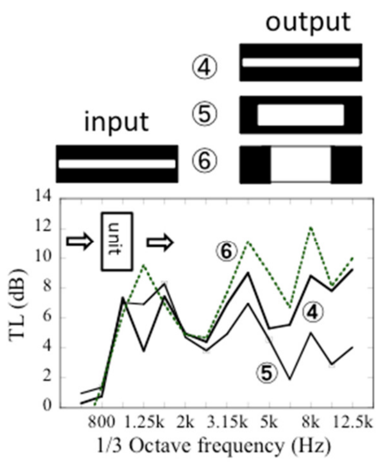

Figure 2 - Measured result of transmission loss with various shape of input and output

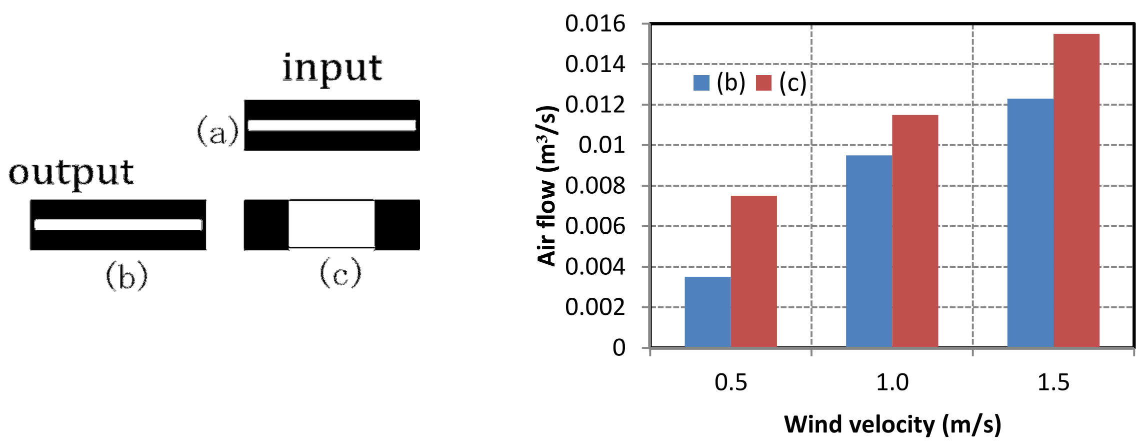

Figure 3 - Measured result of air flow with various shape of input and output

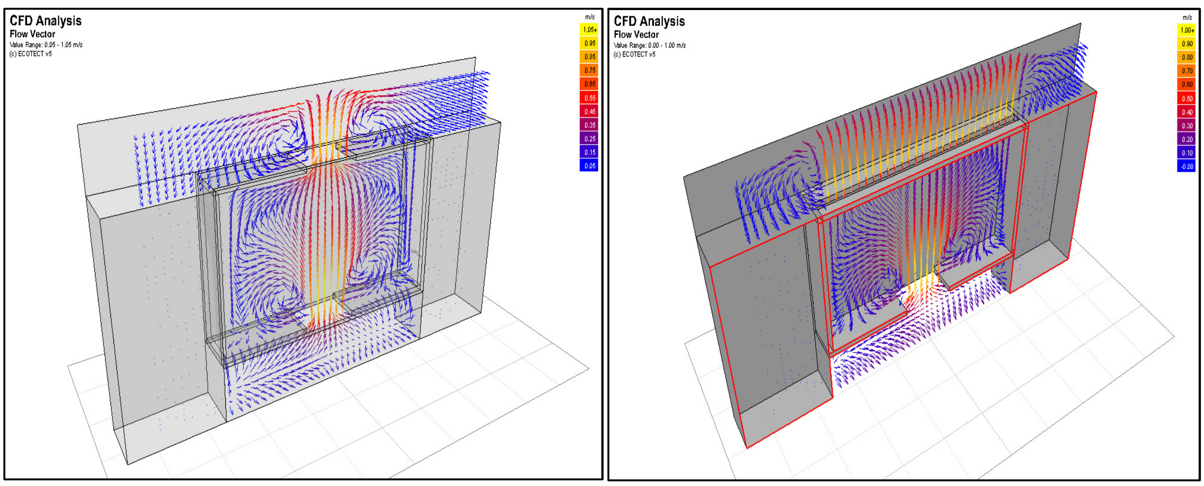

Figure 4 - Measured result of ventilation effect shape of input