inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 3.8

STUDY OF PASSIVE/ACTIVE CONTROL ON OPENINGS FOR NATURAL VENTILATION IN BUILDINGS

J. Maillard, C. Guigou-Carter

CSTB, 24, rue Joseph Fourier, 38400, Saint-Martin-D'hères, France

Tel.: +33 4 76 76 25 21 / Fax: +33 4 76 44 20 46 / Email: j.maillard@cstb.fr

Keywords:
ACTIVE NOISE CONTROL, SOUND INSULATION, VENTILATION SYSTEM, DUCT

ABSTRACT
In this paper, the potential of using passive/active control to increase the sound insulation performance of natural ventilation openings is discussed. An opening is represented by a rectangular duct located in a rigid wall. Sound transmission through the opening can be improved in the mid-high frequency range using a passive control approach, i.e. by covering the opening walls with porous material. At low frequencies where sound transmission is dominated by the plane wave, a single-channel active control system is more appropriate. A 3-dimensional theoretical model based on the combination of a wave and a modal approach was developed to evaluate the sound transmission through the opening. A prototype of such a passive/active system was then mounted in a concrete wall representative of a building exterior wall to verify the analytical predictions and validate the approach.

1 - INTRODUCTION
Natural ventilation systems can improve thermal comfort in buildings at a small cost in comparison to mechanical ventilation or air conditioning systems. However, the relatively large section openings prevent the use of such systems in urban areas where the level of sound insulation from exterior noise should be high. This paper presents an opening for natural ventilation systems with improved sound insulation. Passive and active noise control techniques are combined in order to attenuate acoustic waves transmitted through the opening. The passive control approach improves sound insulation in the mid-high frequency region with the use of porous material. In the low frequency region, passive control becomes inefficient. Active noise control (ANC) [1] is implemented to enhance the low frequency sound insulation. In the past, ANC has been applied successfully in one-dimensional systems such as ventilation ducts and industrial chimney [2-3]. In these systems however, the controller is often designed to attenuate single tones related to the fundamental frequency of the duct fans. Also, the systems are implemented in relatively long ducts thus allowing appropriate positioning of the error microphone and secondary source improving control efficiency. In the present study, the incoming noise (exterior noise) will be broadband and the length of the opening duct will be much shorter (approximately the thickness of a building outside wall).

The first part of the paper briefly introduces the numerical model used to estimate the performances of the passive/active opening. In a second part, the experimental prototype is presented along with the test apparatus used to validate experimentally the proposed technique. The third section discusses the main results of this study.

2 - THEORY
This section gives a brief description of the theoretical model used to predict the sound insulation performance of a passive/active rectangular opening. The model is based on previous work by Park and Eom [4] who derived a theoretical model of the transmission loss of a rectangular aperture with rigid interior walls located in a thick hard screen. The model is generalized here to the case of an aperture with interior walls covered by a porous layer in order to predict the effect of passive control. The porous layer is considered using a surface complex acoustic impedance. The present model also includes the radiation of a monopole source located inside the aperture in order to predict the active control performance. Active

control is implemented with a single loudspeaker flush mounted in a wall and a microphone positioned near the transmission side of the aperture. Knowing the contribution from the incident field and the secondary point source at the location of the error microphone, the amplitude of the secondary source that minimizes the pressure at the error microphone is obtained using optimal control theory [1]. The performances of the controller can thus be predicted. It should be noted that optimal control theory is applied in the frequency domain and, therefore, neglects the coherence and causality constraints that are inherent to the time domain feedforward controller used in practice. The analytical model was used to select the dimensions of the aperture, as well as the position of the active control elements.

3 - EXPERIMENTAL SETUP

This section describes the experimental prototype of the aperture. The experiments were conducted to evaluate the sound insulation performances of the passive/active aperture and to validate the theoretical model.

The aperture made of particleboard is mounted in a concrete wall of thickness 20 cm doubled with a thermal/acoustical lining consisting in a 1.25 cm thick gypsum board and a 9.75 cm thick polystyrene layer. Including the 2 cm air gap between the wall and the lining, the aperture length is 33 cm. The section of the aperture is set to 15 ×20 cm^2 including a 3 cm thick layer of porous material (glass wool). A drawing of the aperture is shown in Figure 1(a) along with a block diagram of the controller. The active control system includes a speaker mounted in the top interior wall of the aperture behind the porous material. The error microphone is positioned on the main axis of the aperture close to the end opening. The controller used for the experiments is a single channel feedforward controller based on the Filtered-X LMS algorithm [1]. This time domain controller requires a reference signal coherent with the disturbance source. This signal is provided here by an additional microphone positioned near the opening of the aperture on the incident side.

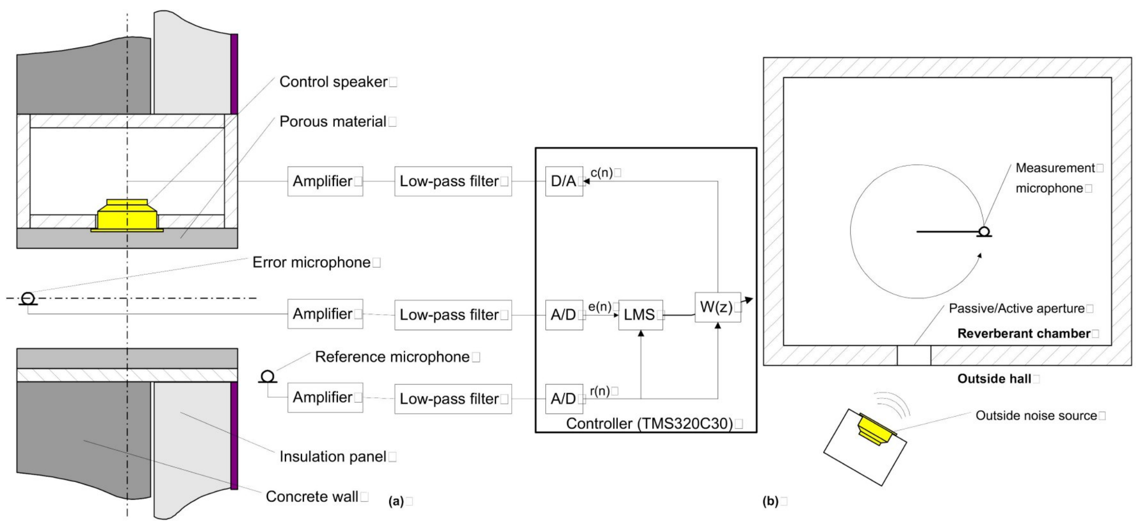

Figure 1: Block diagram of the single channel feedforward controller and configuration of the active aperture for experimental validation.

Figure 1(b) presents a schematic of the measurement setup used to evaluate the aperture performance. The aperture is installed in the wall of a reverberant chamber located inside a larger hall. A noise source (loudspeaker) is positioned approximately 1.5 m away from the aperture at a 30° angle with its main axis and about 50° below its mid-section horizontal plane. The source is excited by a band limited white noise weighted to approach a road traffic noise spectrum. The free field sound pressure level at 1 m along the loudspeaker axis is 84 dB(A). The acoustic intensity generated by the noise source at 1.5 m was estimated in anechoic conditions assuming the radiated sound at the measurement point can be represented by a plane wave. The transmitted acoustic power inside the reverberant chamber is estimated from the mean sound pressure level, measured inside the chamber with a rotating microphone, and the equivalent area of open windows (absorbing power) of the chamber. The insulation performance of the system considered is presented in terms of the element-normalized level difference, $D_{n,e}$, as defined in [5].

4 - RESULTS

Figure 2 presents a comparison between predicted and measured transmission loss of the opening with rigid interior walls and with the porous layer (passive control) in the case of a diffuse incident field. For the rigid wall opening, the difference between the predicted and measured acoustic performance is less than 2 dB in the low to mid frequency range; in the high frequency range, the slight discrepancy is related to the fact that the admittance of the interior walls is no longer zero (walls are not perfectly rigid). When the opening interior walls are covered by a porous layer, the predicted transmission loss is very close the measured one. As expected, the presence of the porous layer greatly improves the transmission loss above 500 Hz. Therefore, the model developed for this study is able to closely predict the behavior of transmission loss as well as its level. Note that the analytical model was mainly used to select the dimensions of the duct, as well as the position of the active control elements.

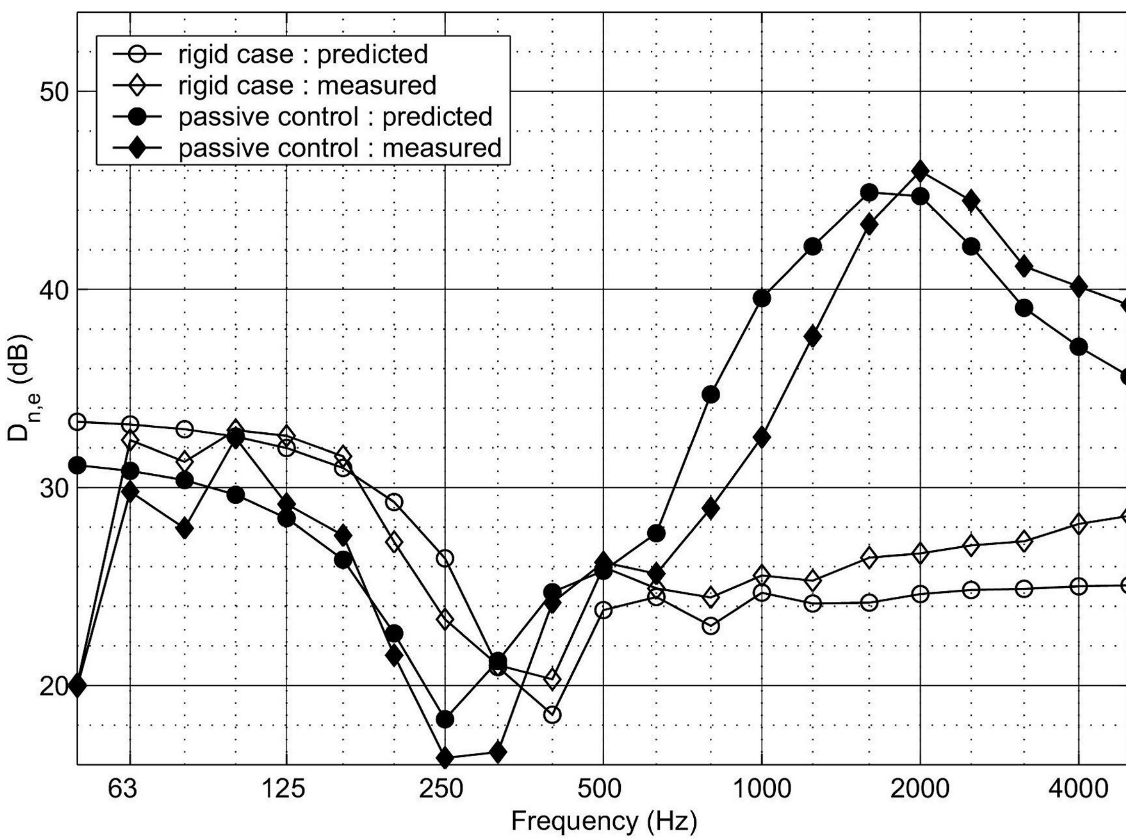

Figure 2: Comparison of predicted and measured transmission loss.

The measured transmission loss before and after active control is applied is shown in Figure 3. The reference microphone is positioned along the loudspeaker axis at about 50 cm from the duct aperture. The error microphone is located inside the duct on the central axis at about 2 cm from the exit of the duct. The normalized transmission loss for the rigid duct (no control) is between 24 and 30 dB over the whole frequency band. Applying passive control (porous layer lining the duct interior walls), the transmission loss remains mostly unchanged at low frequencies, while above 500 Hz, it is greatly improved (as it was observed previously, see Figure 2). Invoking the active control increases the normalized transmission loss in the frequency range below 500 Hz. This clearly shows the complementarity of passive (above 500 Hz) and active control (below 500 Hz) and therefore the advantage of combining them. Overall, active/passive control improves the sound insulation by more than 10 dB(A) (compared to the rigid duct). Passive control is associated with a 7 dB(A) improvement, active control with about 5 dB(A).

5 - CONCLUSIONS

This work investigated both analytically and experimentally the potential of using passive/active control to increase the sound insulation performance of natural ventilation openings. Sound transmission through the opening can be improved in the mid-high frequency range using a passive control approach, i.e. by covering the opening walls with porous material. At low frequencies where sound transmission is dominated by plane waves, an active control technique becomes more appropriate. The analytical model was used to select the dimensions of the duct, as well as the position of the active control elements. A prototype of such a passive/active system was mounted in a concrete wall representative of a building

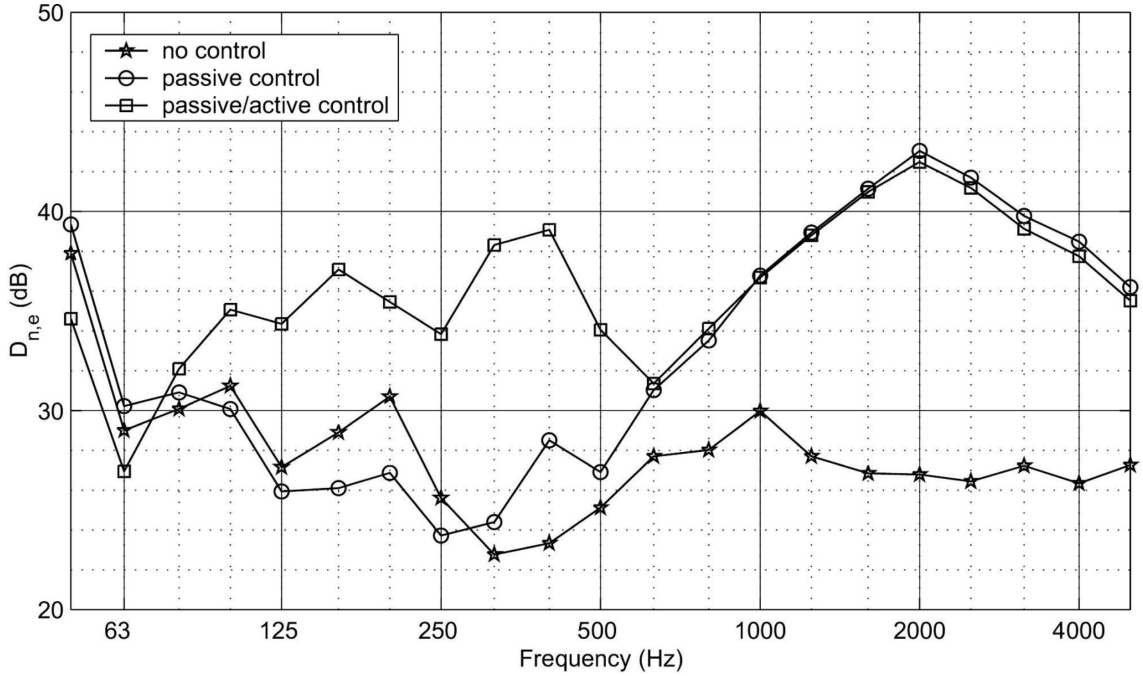

Figure 3: Normalized transmission loss with and without control.

exterior wall to verify the analytical predictions and validate the approach. The results demonstrate the advantage of the active/passive control combination. Sound insulation was increased by 10 dB(A) using active/passive control for traffic noise excitation.

ACKNOWLEDGEMENTS

The authors greatly acknowledge the support of this work by the Agence de l'Environnement et de la Maëtrise de l'Energie. They also would like to thank Professor C.R. Fuller from the Vibration and Acoustics Laboratories, Virginia Tech, USA, for providing the single channel controller and Professor P. Wagstaff from the Université de Technologie de Compiègne, France, for lending the TMS320C30 DSP board used in the experiments.

REFERENCES

1. **P.A. Nelson and S.J. Elliott** , *Active Control of Sound*, Academic Press Limited, 1992
2. **Ch. Carme and al.**, The second generation of active ventilation muffler, In *Noise-Con*, 1997
3. **A. L'Espérance and al.**, Active noise control in large circular duct using an error sensors plane, *Applied Acoustics*, Vol. 57(4), 1999
4. **H.H. Park and H.J. Eom**, Acoustic scattering from a rectangular aperture in a thick hard screen, *Journal of the Acoustical Society of America*, Vol. 101(1), pp. 595-598, 1997
5. **International standard**, *Measurement of sound insulation in buildings and building elements*, ISO 140-10: 1991(E), 1991