# Triangular Micro-perforated Panel (MPP) for Low-Frequency Sound Absorbers and Configurable Natural Ventilations

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## Abstract

A compact acoustic unit cell with configurable, tunable, and broadband performance is desirable for versatile applications. This study presents a low-frequency sound absorber based on a triangular labyrinthine architecture integrated with micro-perforated panels (MPPs), which can also serve as a building block for configurable natural ventilation. The triangular geometry enhances packing density and anisotropic design flexibility, while the labyrinthine cavities enable low-frequency operation. The system achieves effective absorption between approximately 500 and 1375 Hz with a thickness of 63.6 mm, and wider bandwidths can be obtained at lower absorption levels. Thinner configurations maintain similar low-frequency performance but with reduced bandwidth. An 84.9 mm-thick triangular MPP achieves a half-absorption bandwidth of 1792 Hz. Theoretical modeling and finite-element method (FEM) simulations are employed to predict sound absorption and transmission loss, while strategies for bandwidth enhancement and sub-wavelength design are discussed. Experimental measurements are also conducted to evaluate airflow characteristics

Keyword: *Sound absorbers, Triangular Micro-perforated panels, natural ventilation, sound transmission loss, airflow*

## Introduction

Noise exposure is a major public health issue affecting both physical and mental health, including sleep disturbance, increased cardiovascular/metabolic risks, and reduced comfort. In addition, noise-induced mental health problems have now emerged as an important research topic, given that noise exerts a substantial and continuous impact on a large portion of the population. Under these circumstances, noise control is inevitable and has become an urgent need in modern society

In this study, we develop tunable, compact, and broadband sound absorbers to enable configurable ventilation for efficient fresh-air circulation. Such ventilation is critical to address thermal comfort as well as noise attenuation, which thus impacts energy utilization in buildings and leads to decarbonization. Meanwhile, conventional ventilation provides only one feature, rather than being present in a single system. In building practice, conventional sound insulation often conflicts with ventilation needs closed windows improve acoustic performance but reduce indoor-air quality and thermal comfort, whereas natural ventilation opens noise-transmission paths into the interior

## Research Method

Analytical calculations and a numerical model based on the Finite Element Method (FEM) are employed to compute sound absorption coefficients, transmission loss, and analyze the associated behavior. Experimental validations are provided to confirm the resulting behaviour following ISO10534-2/ASTM E90

Moreover, airflow characteristics through designated ventilation configurations are investigated experimentally and also discussed to assess the pressure drop and output air velocity.

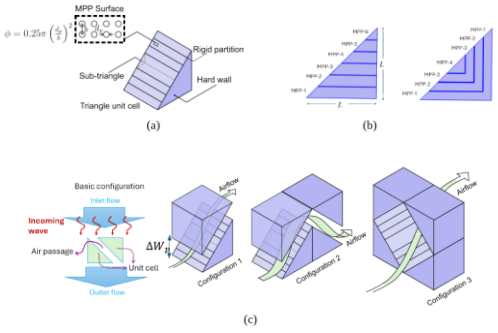



*Figure 1. (a) Unit-cell sound-absorbing structure for the proposed ventilated acoustic metamaterial (VAM);(b) Triangular unit cell configuration: straight cavities and Labyrinthine cavities; (c) schematic illustration of the proposed natural-ventilation configuration derived from the triangular unit-cell geometry.*

Theoretical Model for MPP [Dah-You Maa,1998]:

$$Z_{MPP} = r + j\omega m$$

$$r = \frac{32\eta t_p}{\phi\rho_0 c d_p^2}\left(\left[1+\frac{k_c^2}{32}\right]^{-1/2} + \frac{\sqrt{2}}{32}k_c^2\frac{d_p}{t_p}\right), \quad \omega m = \frac{\omega t_p}{\phi c}\left(1+\left[9+\frac{k_c^2}{2}\right]^{-1/2} + 0.85\frac{d_p}{t_p}\right)$$

The total impedance of the MPP system is given by

$$\frac{1}{Z_t} = \sum_{i=1}^{n}\frac{w_i}{\left(Z_{MPP_i} + Z_{D_i}\right)}$$

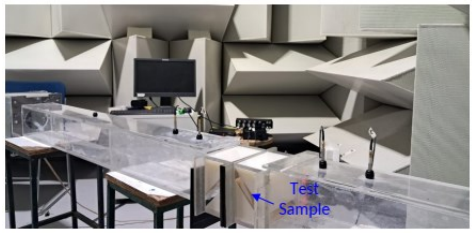
Sound absorption $\alpha$

$$\alpha = 1 - |R|^2 = \frac{4r}{(1+r)^2 + x_m^2}$$

$$x_m = \omega m - \mathrm{AR}\, Z_c \cot kD$$

The absorption bandwidth can be optimized through

$$\Delta f = \frac{f_0}{Q_{rad}}\sqrt{\frac{4r_e}{\alpha_t} - (1+r_e)^2} \qquad \frac{\partial}{\partial r_e}\left[\frac{4r_e}{\alpha_t} - (1+r_e)^2\right] = 0 \Leftrightarrow r_e^* = \frac{2}{\alpha_t} - 1$$



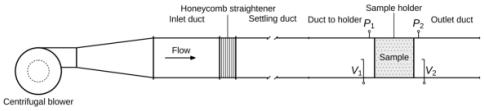
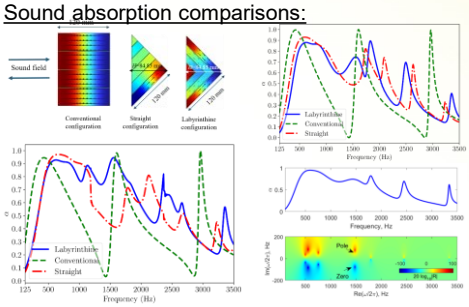




*Figure 2. Measurement setup for acoustics/TL and air flow measurements*

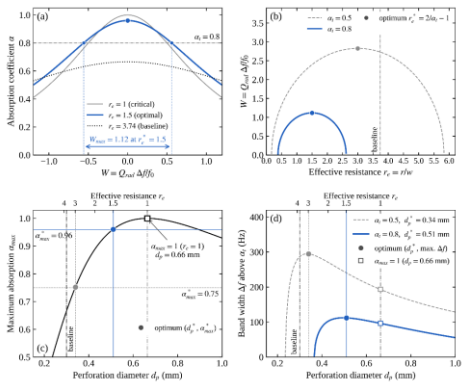
## Discussion & Result

Compared with conventional MPP, the triangular MPP configuration with parallel MPP unit exhibits superior performance for the same MPP surface, particularly the one with labyrinthine cavities, as evidenced by higher sound absorption coefficient (SAC) values and more than a 50% increase in SAC bandwidth for both normal and random incidences. Hence, the triangular–labyrinth acoustic architecture can maintain broadband and omnidirectional performance, but the effective cavity depth should be considered carefully to account for the shorter center-line cavity length due to the architecture. Moreover, optimal broadband and subwavelength structure can be achieved by reducing the dimension up to 63.6 mm thick triangular MPP unit.

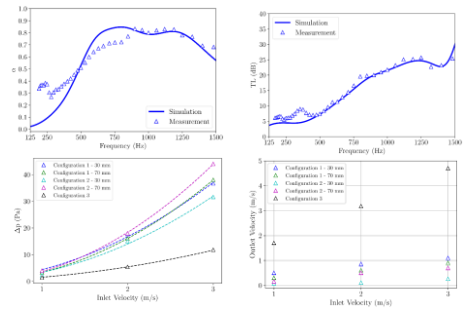
Sound absorption comparisons:




Optimal bandwidth using optimal resistance $r_e^*$:




Experimental validations




## Conclusion

- The issues of broadband performance and sub-wavelength structures are addressed by proposing a triangular–labyrinth acoustic architecture.
- The results demonstrate that the proposed system provides configurable, tunable, broadband low-frequency absorption and attenuation through subwavelength structures. Such characteristics make it promising for building acoustic applications and potentially extendable to urban noise mitigation and mechanical noise control