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NOISE-REDUCING DEHUMIDIFIER WITH ACOUSTIC METAMATERIAL

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ABSTRACT

This study introduces a novel application of Labyrinthine Acoustic Metamaterials (AMMs) in compact Peltier-based dehumidifiers for effective noise control without airflow degradation. The fan was identified as the primary noise source, with dominant peaks at 805 Hz and 1210 Hz. To attenuate this, we designed a multi-layered AMM structure using COMSOL Multiphysics, incorporating Fano-like interference between straight and coiled paths. Simulations predicted transmission loss peaks at 742.5 Hz and 1205 Hz, and experiments confirmed an average 9.1 dB noise reduction with minimal impact on dehumidification performance (2.87% decrease). This study demonstrates the real-world feasibility of using AMMs to suppress specific frequency noise.

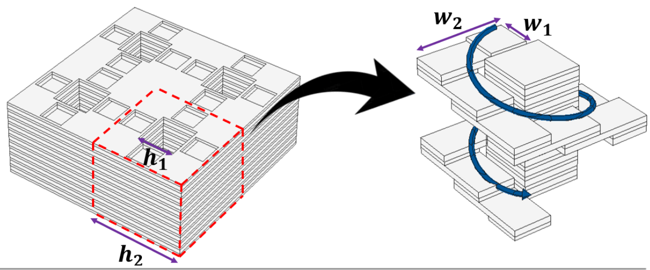
KEYWORD

Acoustic metamaterial, Peltier dehumidifier, Labyrinthine structure, Fano-like interference, Noise reduction, Ventilation

INTRODUCTION

In Korea's humid summer climate, dehumidifiers are widely used to maintain indoor comfort. However, users often report disruptive noise, especially from the internal fan. Existing noise reduction methods such as sponges or perforated panels tend to block airflow, degrade in humid environments, or require large internal space.

To address this issue, we applied labyrinthine acoustic metamaterials (AMMs), which are engineered materials that create frequency-selective attenuation using geometric resonance and interference. Specifically, we focused on Fano-like interference generated by coupling straight (continuous) and coiled (discrete) sound paths. This mechanism enables destructive interference at specific frequencies while allowing air to pass through.



Parameter	h_1	h_2	t_1	t_2	w_1	w_2
Scale [mm]	23	60	1.5	2.5	15	39.75

Figure 1: Schematic of the designed acoustic metamaterial and airflow path.

MATERIAL AND METHODOLOGY

Fan Noise Analysis

We measured the noise from the dehumidifier's internal fan using a LION NL-52A sound level meter. The analysis showed prominent peaks at 805 Hz and 1210 Hz, so we set the target attenuation range to 800–1250 Hz.

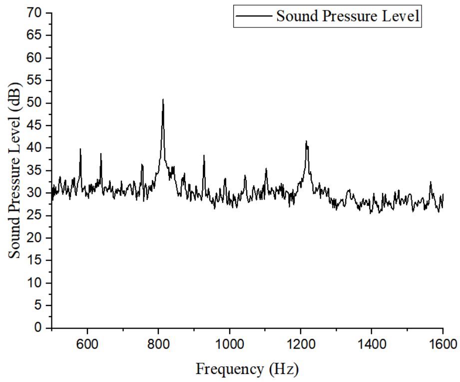


Figure 2: Sound pressure level of the fan.

Metamaterial Design (COMSOL Simulation)

Using COMSOL Multiphysics 6.1, we designed an acoustic metamaterial (AMM) consisting of one straight and four coiled labyrinth paths per unit cell. The full structure had 23 stacked layers with alternating thicknesses of 1.5 mm and 2.5 mm. This arrangement generated geometric resonance and Fano-like interference. Simulations showed transmission loss peaks at 742.5 Hz and 1205 Hz, maintaining around 15 dB attenuation across the target range.

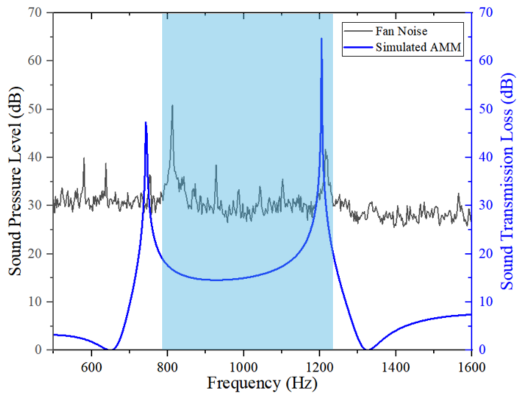


Figure 3: Sound pressure level of the fan and AMM.

Prototype Fabrication

We modeled the dehumidifier and AMM in SolidWorks and fabricated them with PLA+ and ABS using a 3D printer. The cooling system included a Peltier module, a 12V axial fan (PMD1212PTB3-A), and an aluminum heat sink.

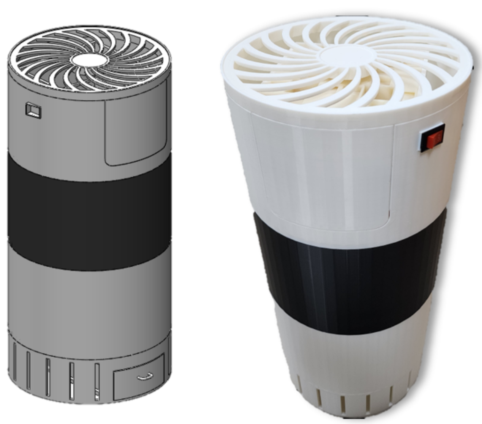


Figure 4: Dehumidifier prototype.

Experimentation

To evaluate the effectiveness of the metamaterial, we tested the dehumidifier both with and without the AMM installed. Noise levels were measured under identical operating conditions to assess the reduction effect. Instead of airflow, we focused on comparing the dehumidification performance of both setups.

RESULT AND DISCUSSION

The acoustic metamaterial (AMM) designed in this study effectively reduced the noise generated by the dehumidifier's fan. Based on sound level measurements, the AMM achieved an average noise reduction of 8.7 dB, which was clearly perceptible. The measured peaks at 805 Hz and 1210 Hz matched the target range, and the observed attenuation aligned well with simulation results.

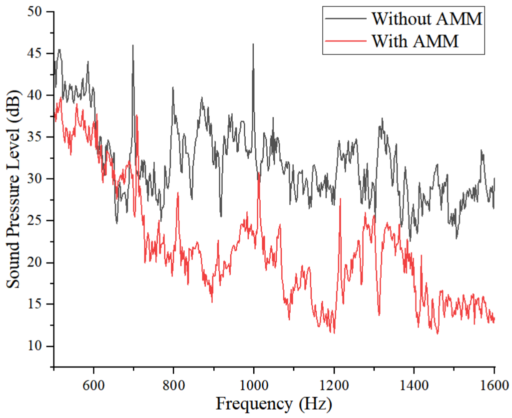


Figure 5: Sound pressure level comparison with and without AMM.

In addition to noise reduction, the AMM did not interfere with the dehumidification process. A 30-minute test confirmed that the amount of water collected was nearly the same with or without the AMM, indicating that its open structure had minimal impact on dehumidification efficiency.

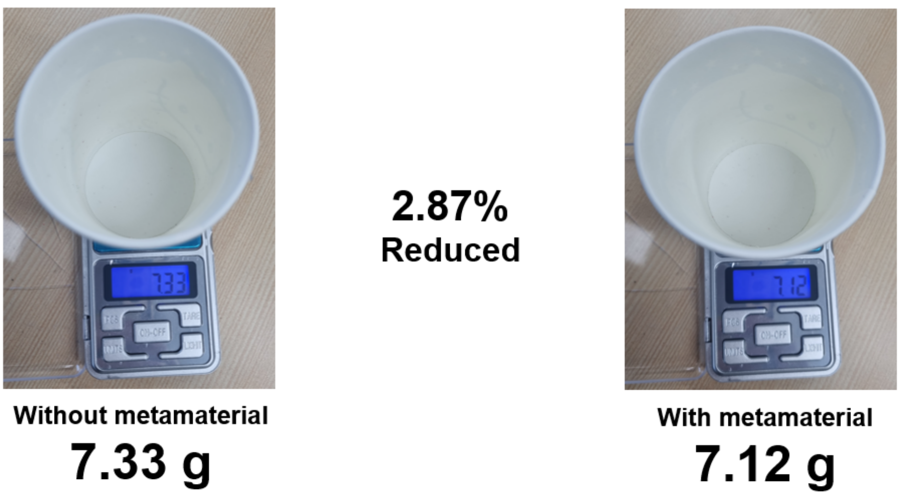


Figure 6: Dehumidification performance test by measuring the amount of water collected after 30 minutes

CONCLUSION

This study demonstrated the effectiveness of a labyrinthine acoustic metamaterial (AMM) for reducing fan noise in a compact Peltier-based dehumidifier. By targeting dominant noise frequencies between 800 and 1250 Hz, the AMM achieved an average sound pressure level reduction of 8.7 dB, which was also noticeable in real-use conditions. Simulation results aligned with the experimental data, confirming consistent transmission loss at the target frequencies.

Importantly, the AMM caused minimal impact on dehumidification performance. The amount of water collected during a 30-minute operation showed only a slight difference between setups with and without the AMM, indicating that its open structure preserved functional airflow.

These results suggest that AMMs can be a practical and compact solution for noise control in small appliances, offering effective sound attenuation without compromising core performance.

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