

AirMorph: A Venturi-Based Passive Ventilation Module for Thermal Comfort in Dense Tropical Housing

Anisah Rahmawati ^{1*}, Siti Badriyah ², Primastiti Wening Mumpuni ³

Institut Seni Indonesia Surakarta, Jl. Ring Road, Mojosongo, Surakarta, 57127, Indonesia

¹ anisahrahma@std.isi-ska.ac.id ^{*}, ² sitibadriyah30@yahoo.com, ³ primastiti@isi-ska.ac.id

* Corresponding Author



Received 25 February 2025; accepted 8 May 2025; published 13 June 2026

ABSTRACT

Indonesia's rapid urbanization and population growth have driven a sharp increase in demand for air conditioning systems, contributing to rising electricity consumption, fossil fuel dependence, and carbon emissions, while simultaneously limiting thermal comfort access for low-income households in tropical urban settings. Existing passive cooling alternatives either rely on water supply and electricity, lack aesthetic adaptability for modern interiors, or remain unrealized beyond theoretical models — leaving a gap for a modular, electricity-free passive ventilation solution suitable for dense tropical housing. This study introduces AirMorph, a passive ventilation module designed on the Venturi and Bernoulli principles to accelerate indoor airflow without mechanical or electrical input. The research employed a three-stage methodology: 3D modelling using SketchUp, Computational Fluid Dynamics (CFD) numerical simulation using ANSYS Fluent, and controlled field testing with digital thermometer measurement. CFD results confirmed accelerated airflow and reduced pressure in the module's narrow cross-section, consistent with the Venturi effect. Field testing showed a consistent average indoor temperature reduction of 1.6 °C per hour, from 31.9 °C to 30.3 °C. Although this reduction is smaller than comparable passive products, AirMorph's key advantages lie in its modular plug-and-play design, compact dimensions, electricity-free operation, and compatibility with modern interior aesthetics — making it a practical and scalable passive cooling solution for densely populated tropical environments.

KEYWORDS

AirMorph;
Natural ventilation;
Venturi effect;
Passive cooling;
Thermal comfort.

This is an open-access article under the [CC-BY-SA](https://creativecommons.org/licenses/by-sa/4.0/) license



1. Introduction

Indonesia's population, which reached 282 million in early 2024, has been accompanied by a sharp increase in demand for air conditioning. The number of households owning air conditioners (ACs) has risen from 10.5% in 2022 to 20.5% in 2024, and Indonesia currently ranks among the leading countries globally in AC unit consumption, with between 3.7 and 4 million units sold annually. This trajectory reflects a broader regional trend: as urbanization and disposable income rise in tropical Asia, mechanical cooling has shifted from a luxury to a perceived necessity (Falchetta et al., 2024; Nur Azizah et al., 2025). However, this dependence carries significant costs. More than 80% of Indonesia's electricity is still generated from fossil fuels, meaning AC usage contributes substantially to national carbon emissions. The refrigerants used in conventional air conditioners also carry ozone-depletion potential, further compounding their environmental impact. From an equity standpoint, both the purchase price and operating electricity costs of air conditioners place them beyond reach for low-income urban households — creating what can be characterized as a comfort access gap in densely populated areas with limited infrastructure for distributed energy.

Indonesia's tropical climate compounds this challenge. Unlike temperate-climate contexts, where passive cooling often targets a narrow comfort band, research on thermal comfort for Indonesian

occupants consistently finds that the adaptive comfort range is higher than international standards — typically between 23 and 29°C — meaning that even modest reductions in indoor temperature can meaningfully improve perceived comfort without reaching the low setpoints of mechanical cooling (Nur Azizah et al., 2025). Moreover, residents of low-income urban housing, who constitute a disproportionately large share of those without AC access, are particularly exposed to chronic heat stress conditions that affect health, productivity, and quality of life (Ramsay et al., 2021).

Passive cooling approaches, particularly through natural ventilation, offer a promising alternative. Research demonstrates that passive natural ventilation can reduce cooling energy consumption by 30–40% compared to mechanical systems, depending on climate and building configuration (Schulze & Eicker, 2013). Its application in densely populated tropical urban areas, however, faces structural constraints: limited window openings, narrow inter-building clearances, and turbulent airflow patterns characteristic of high-density settlements reduce the effectiveness of conventional ventilation strategies (Omrani et al., 2017). This points toward a need for adaptive, modular design interventions that can enhance passive airflow without relying on electricity, water supply, or large-scale architectural modification. Several prior approaches have addressed this need with varying success. The Beehive, developed by CoolAnt Studio in India, applies evaporative cooling through terracotta sprayed with water, achieving temperature reductions of up to 6°C in factory settings. However, its dependence on water supply and an electric pump limits its application in buildings seeking fully passive, energy-free operation. The Eco-Cooler, introduced in Bangladesh in 2016, uses recycled plastic bottles arranged on a perforated board to redirect airflow using the continuity principle, reducing temperatures by up to 5°C without electricity. Its primary limitations are aesthetic incompatibility with modern interiors and inflexibility for installation in varied building typologies. An academic research also demonstrated that applying the Venturi effect through narrowing air ducts could accelerate natural airflow and improve thermal comfort in residential buildings, but their work remained at the simulation stage without producing an installable product prototype (Zhang et al., 2021).

This study introduces AirMorph, a passive ventilation module designed to address these limitations simultaneously. AirMorph operates on the Venturi and Bernoulli principles — accelerating airflow by passing it through a narrowed cross-section — without requiring electricity or water. Its modular, plug-and-play design allows installation directly onto existing window frames and walls, maintaining compatibility with modern interior aesthetics while remaining accessible for low-income housing contexts. The objective of this research is to develop and test the AirMorph passive ventilation system as an innovative, adaptive, and sustainable solution for improving thermal comfort in Indonesia's dense tropical residential settings.

2. Method

This study employs a quantitative experimental approach through three sequential stages: product design and 3D modelling, numerical simulation using Computational Fluid Dynamics (CFD), and controlled field testing. This multi-stage methodology follows an established workflow for evaluating passive ventilation products, in which digital parametric modelling and CFD simulation precede physical testing to validate aerodynamic performance prior to deployment (Aparicio-Fernández et al., 2021).

The product design stage began with the development of a three-dimensional model of AirMorph using SketchUp software. The module was designed with dimensions of 80 × 45 cm using lightweight, economical, durable, and easy-to-install PVC board material. This size was determined to ensure optimal airflow while maintaining installation flexibility on standard window frames and walls. The module follows a plug-and-play modular system, allowing users to scale the number of units without specialist installation. The 3D model served as the geometric foundation for both the numerical simulation stage and the physical prototype fabrication.

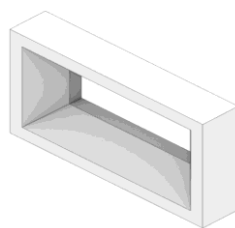


Fig. 1. Three-Dimensional Model of AirMorph Passive Ventilation Module (Author's development, 2025)

The model was developed using SketchUp software with dimensions of 80×45 cm. The module body uses lightweight PVC board material configured as a narrowing-neck channel to induce the Venturi effect when air passes through. The plug-and-play modular design allows units to be stacked or arranged without specialist installation.

The second stage involved Computational Fluid Dynamics (CFD) simulation using ANSYS Fluent software. CFD is widely used for evaluating indoor airflow patterns, velocity distributions, and pressure fields in passive ventilation research, offering quantitative aerodynamic data that field measurement alone cannot capture (Chen et al., 2023). A three-dimensional model of the AirMorph module was constructed within ANSYS Fluent, with boundary conditions defined by incoming airflow velocity at the inlet and pressure conditions at the outlet. The simulation analyzed the flow pattern, air acceleration, and pressure distribution formed inside the module to verify that the Venturi effect occurs when air is forced through the narrowed cross-section — causing flow acceleration and pressure reduction consistent with Bernoulli's principle. CFD simulation thus provided a quantitative picture of the module's aerodynamic performance before field testing.

Field testing was conducted using a digital thermometer to record indoor air temperature under two conditions: before and after installing the AirMorph module. Measurements were taken continuously for one hour at indoor locations, with temperature data collected periodically to ensure result consistency. This before-and-after experimental design follows standard practice for evaluating the thermal performance of passive ventilation interventions in real building environments (Rosulindo & Prasetyo, 2025). The data obtained were analyzed to evaluate the average temperature reduction and its relationship to improved air circulation quality, with the objective of confirming that AirMorph not only reduces indoor temperature but also improves passive air circulation without reliance on mechanical devices.

3. Results and Discussion

Field testing of the AirMorph module demonstrates a consistent average indoor temperature reduction of 1.6°C per hour, from an initial reading of 31.9°C to 30.3°C after one hour of operation. This result was recorded under controlled conditions using a digital thermometer, with measurements taken periodically before and after module installation (Figure 2). The consistency of this reduction across repeated measurements indicates stable and reliable performance under the tested conditions.



Fig. 2. AirMorph Field Test Temperature Readings Before (Left) and After (Right) Module Installation (Author's documentation, 2025)

When compared to prior passive cooling innovations, AirMorph achieves a lower absolute temperature reduction: The Beehive reduces temperature by up to 6°C, while the Eco-Cooler achieves up to 5°C (Hadi et al., 2023). However, both products carry structural limitations that restrict their applicability in the Indonesian context. The Beehive relies on a continuous water supply and an electric pump, meaning it cannot function as a fully electricity-free passive system. The Eco-Cooler, while electricity-free, is manufactured from recycled plastic bottles and is designed for installation on simple rural walls — its size, fixed form, and lack of aesthetic adaptability limit deployment in modern urban interiors. AirMorph's 1.6°C reduction, while modest by comparison, is achieved without water, without electricity, and through a modular form that is dimensionally compact and visually compatible with contemporary interior finishes.

The significance of a 1.6°C reduction should also be understood in the context of Indonesian residential settings, where the adaptive thermal comfort range for occupants is generally higher than international standards, and even incremental temperature reduction meaningfully improves perceived comfort (Nur Azizah et al., 2025). Furthermore, experimental studies on residential air conditioning in Indonesian conditions confirm that adjusting indoor temperature by even a single degree produces measurable reductions in compressor load and energy consumption (Sunardi et al., 2020), suggesting that AirMorph's passive reduction carries genuine energy-saving potential in hybrid settings where occupants may reduce or delay AC use.

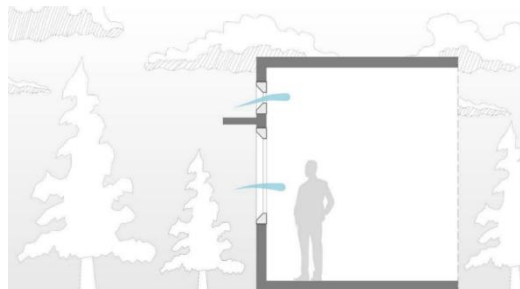


Fig. 3. Observed airflow pattern through the AirMorph module during field testing (Author's documentation, 2025)

These field results are further reinforced by Computational Fluid Dynamics (CFD) simulation using ANSYS Fluent, which provides a quantitative picture of the module's internal aerodynamic behavior (Figure 4). The simulation shows a clear increase in airflow velocity at the narrowed neck section of the module, consistent with the Venturi effect: as air is forced through the constricted cross-section, velocity increases and static pressure decreases, driving natural air circulation within the enclosed space. This is consistent with findings that CFD-based study of the Venturi effect in residential buildings in China confirmed that narrowing air duct geometry produces statistically significant improvements in indoor airflow velocity (Zhang et al., 2021). The pressure drop observed in the AirMorph simulation creates a self-sustaining circulation dynamic that does not require any mechanical input — the module draws air in passively and expels it at higher velocity, improving air quality without increasing energy demand (Shukla et al., 2019).

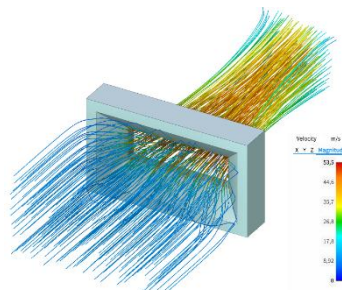


Fig. 4. ANSYS Fluent CFD simulation results showing airflow velocity distribution through AirMorph (Author's documentation, 2025)

The velocity contour map shows accelerated airflow at the module's narrowed neck section (peak velocity approximately 53.5 m/s at the constriction) consistent with the Venturi effect principle. Reduced pressure at the constriction generates passive circulation without mechanical input.

3.1 Application and Design Solution

Beyond its aerodynamic performance, AirMorph's design addresses several practical constraints that have limited the deployment of prior passive ventilation products. The module's plug-and-play system (Figure 5) allows users to adjust the number of units installed depending on the size of the opening and the desired airflow rate, without requiring specialist installation skills or permanent structural modification. This scalability makes the product particularly suited to low-income housing contexts, where residents typically lack access to professional installation services and require cost-effective, reversible interventions (Wijaksono, 2024).

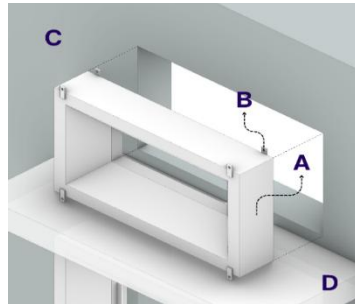


Fig. 5. AirMorph plug-and-pay modular system showing component configuration (Author's documentation, 2025)

During the design development process, several improvements were incorporated to enhance field suitability. A canopy was added above the inlet to prevent rainwater ingress, and window screening material was integrated to filter insects and fine particulate matter. These additions ensure that AirMorph functions not only as a passive ventilation system but also provides basic environmental filtration for indoor spaces without reducing airflow effectiveness. The resulting product represents a design solution that simultaneously addresses thermal comfort, indoor air quality, and installation practicality — a combination that neither the Beehive nor the Eco-Cooler fully achieves (Jeddy et al., 2023).

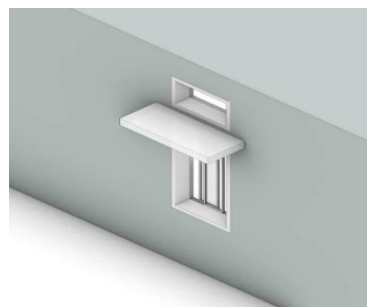


Fig. 6. AirMorph Module Showing Canopy and Window Screen Additions for Field Deployment (Author's documentation, 2025)

The canopy (top) prevents rainwater ingress during wet-season conditions, while the integrated window screen filters insects and fine particulate matter. Both additions were incorporated following initial field testing without reducing measured airflow velocity at the outlet.

4. Conclusion

This study developed and tested AirMorph, a passive ventilation module based on the Venturi and Bernoulli principles, as a practical solution for improving thermal comfort in dense tropical residential interiors without reliance on electricity or water. Field testing demonstrated a consistent average indoor temperature reduction of 1.6°C per hour, confirmed across repeated measurements, while CFD simulation using ANSYS Fluent validated the underlying aerodynamic mechanism — showing

accelerated airflow velocity and reduced static pressure at the module's constricted neck section, consistent with the Venturi effect. Although this temperature reduction is lower than comparable passive products such as The Beehive (up to 6°C) and the Eco-Cooler (up to 5°C), those products carry structural limitations — dependence on water supply, electricity, or fixed large-panel installation — that restrict their applicability in the Indonesian urban context. AirMorph's competitive advantage lies not in the magnitude of its temperature reduction but in its combination of electricity-free operation, modular plug-and-play installation, compact dimensions, compatibility with modern interior aesthetics, and suitability for low-income housing where access to mechanical cooling systems remains constrained (Schulze & Eicker, 2013; Wijaksono, 2024).

These findings suggest that AirMorph represents a viable and scalable passive cooling intervention for dense tropical housing in Indonesia, where even modest indoor temperature reductions carry meaningful implications for thermal comfort and energy consumption given the country's higher adaptive comfort range (Nur Azizah et al., 2025; Sunardi et al., 2020). Future research should address two primary limitations of this study: field testing was conducted under controlled single-room conditions, and the temperature reduction metric does not yet account for relative humidity, air change rate, or occupant thermal sensation vote — all of which are relevant to a fuller evaluation of thermal comfort performance in real residential settings (Iqbal et al., 2022). Testing across varied building typologies, opening sizes, and climate sub-zones within Indonesia's tropical belt would further establish the generalizability of AirMorph's performance. Development of an updated prototype incorporating real-time airflow monitoring would additionally allow the relationship between Venturi geometry parameters and measured thermal comfort outcomes to be systematically optimized.

References

- Chen, X., Chen, X., Su, R., & Cao, B. (2023). Optimization Analysis of Natural Ventilation in University Laboratories Based on CFD Simulation. *Buildings*, 13(7), 1770. <https://doi.org/10.3390/buildings13071770>
- Falchetta, G., Cian, E. D., Pavanello, F., & Wing, I. S. (2024). Inequalities in global residential cooling energy use to 2050. *Nature Communications*, 15(1), 7874. <https://doi.org/10.1038/s41467-024-52028-8>
- Hadi, D. S. N., Supriyanta, S., & Wibowo, M. F. R. (2023). Efektivitas Penghawaan Alami dalam Kenyamanan Termal: Intervensi Fasad dan Teknologi Eco-Cooler pada Ruang Aula. *Sinektika: Jurnal Arsitektur*, 20(1), 7–14. <https://doi.org/10.23917/sinektika.v20i1.19207>
- Iqbal, M., Dastur, M., & Fikry, M. (2022). Indoor Thermal Comfort Improvement of the Naturally Ventilated House in Tropical Climate, Indonesia. *Proceedings of Malikussaleh International Conference on Multidisciplinary Studies (MICoMS)*, 3, 00007. <https://doi.org/10.29103/micoms.v3i.48>
- Jeddy, N., Muftida, L., & Pratiwi, T. (2023). Pendinginan pasif pada bangunan di iklim tropis. *Applicable Innovation of Engineering and Science Research (AVoER)*, 15(1), 34–41.
- Nur Azizah, J., Joana Febrita, & Yudi Chadirin. (2025). Indoor Thermal Comfort in Tropical Urban Houses in Indonesia: The Effect of Outdoor Temperature and Windows. *Jurnal Teknik Sipil Dan Lingkungan*, 10(2), 347–356. <https://doi.org/10.29244/jstil.10.2.347-356>
- Omrani, S., Garcia-Hansen, V., Capra, B. R., & Drogemuller, R. (2017). On the effect of provision of balconies on natural ventilation and thermal comfort in high-rise residential buildings. *Building and Environment*, 123, 504–516. <https://doi.org/10.1016/j.buildenv.2017.07.016>
- Ramsay, E. E., Fleming, G. M., Faber, P. A., Barker, S. F., Sweeney, R., Taruc, R. R., Chown, S. L., & Duffy, G. A. (2021). Chronic heat stress in tropical urban informal settlements. *iScience*, 24(11), 103248. <https://doi.org/10.1016/j.isci.2021.103248>
- Rosulindo, P. P., & Prasetyo, B. Y. (2025). Investigasi kualitas udara ruang perkuliahan di Kota Bandung menggunakan ventilasi pasif. *Jurnal Teknologi Terapan (JTT)*, 11(2), 190–200. <https://doi.org/10.31884/jtt.v11i2.775>
- Schulze, T., & Eicker, U. (2013). Controlled natural ventilation for energy efficient buildings. *Energy and Buildings*, 56, 221–232. <https://doi.org/10.1016/j.enbuild.2012.07.044>
- Shukla, A., Sharma, V., Kapoor, N., & Kumar, A. (2019). Assessment Of Venturi Effect For Enhancing Natural Ventilation In Composite Climate Of India. 688–695. <https://doi.org/10.26868/25222708.2019.210665>

Sunardi, C., Hikmat, Y. P., Margana, A. S., Sumeru, K., & Sukri, M. F. B. (2020). Effect of room temperature set points on energy consumption in a residential air conditioning. 070001. <https://doi.org/10.1063/5.0018806>

Wijaksono, S. (2024). Passive designs of low-income housing with natural ventilation in tropical region. IOP Conference Series: Earth and Environmental Science, 1324(1), 012051. <https://doi.org/10.1088/1755-1315/1324/1/012051>

Zhang, L., Tian, L., Shen, Q., Liu, F., Li, H., Dong, Z., Cheng, J., Liu, H., & Wan, J. (2021). Study on the Influence and Optimization of the Venturi Effect on the Natural Ventilation of Buildings in the Xichang Area. Energies, 14(16), 5053. <https://doi.org/10.3390/en14165053>