



Comparative Air Flow Analysis Between Johor and Szombathely: Evaluating Woodcarving Ventilation Panels



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ABSTRACT

This study explores the potential of using woodcarving ventilation panels to enhance natural ventilation (NV) in buildings, particularly in extreme climate conditions in two different locations: Johor, Malaysia, and Szombathely, Hungary. The main aim is to assess how these panels contribute to airflow dynamics and temperature regulation within buildings. The research employs Computational Fluid Dynamics (CFD) simulations to model airflow and temperature distribution in identical building models subjected to high wind speeds and temperatures, simulating worst-case scenarios. The findings reveal that while Johor experiences moderate wind speeds resulting in steady but less dynamic airflow, Szombathely benefits from stronger winds, producing more effective ventilation and cooling. These results suggest that woodcarving panels can improve airflow and thermal comfort but are more effective in areas with higher wind speeds. The study concludes that while NV is beneficial, integrating HVAC systems is essential for maintaining optimal comfort in extreme conditions.

TANULMÁNY INFÓ

Kulcsszavak:

Fafaragásos táblák
Természetes szellőzés
CFD szimulációk
Légáram dinamikája
Hőkomfort

KIVONAT

Johor és Szombathely szélviszonyainak összehasonlító elemzése: fafaragásos szellőzőablak táblák értékelése. Jelen tanulmány a fafaragásos szellőzőablak táblák természetes szellőzés fokozásában betöltött szerepét vizsgálja szélsőséges klimatikus körülmények mellett két különböző helyszínen: Johor, Malajzia és Szombathely, Magyarország. Azt vizsgáljuk, hogy mennyire járulhatnak hozzá az ilyen táblák a légáramok dinamikájához és a hőmérséklet szabályozásához az épületen belül. A kutatás során a Numerikus Folyadék Dinamika módszerét használtuk a légáram és hőmérsékleteloszlás modellezésére a legrosszabb esetben megfelelő magas környező hőmérsékleti és szélsébségi viszonyok azonos kialakítású épületekre való alkalmazásával. Megállapítottuk, hogy míg Johor esetében a jellemző mérsékelt szélsébség stabil, de kevésbé dinamikus légáramokat eredményez, Szombathely előnyt élvez a hatékonyabb szellőzést és hűtő hatást eredményező erősebb széljárásból. Az elemzés eredményei arra utalnak, hogy a fafaragásos táblák javíthatják a belső légáramokat és a hőkomfortot, de hatékonyságuk a magasabb szélsébségű helyszíneken érvényesül. A tanulmány fő következtetése, hogy míg a szellőzőablak táblák nyújtotta természetes szellőzés értékelendő, szükséges lehet fűtő-szellőző és légkondicionáló (HVAC) rendszerrel való integrálása az optimális komfortérzet fenntartására extrém körülmények között is.

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1 INTRODUCTION

Natural ventilation (NV) has long been a fundamental strategy in vernacular architecture, particularly in tropical and temperate climates, to enhance indoor thermal comfort and reduce reliance on mechanical cooling systems (Abdul Rahim and Szabó, 2023). Across cultures, traditional ventilation methods, such as woodcarving ventilation panels, have been employed to facilitate airflow while preserving aesthetic and cultural identity (Abdul Rahim – Kovács, 2024; Muhammad – Rosdi, 2023; Yusof et al., 2020). Traditional designs often incorporate NV strategies, such as cross ventilation and wind catchers, which enhance thermal comfort and air quality (Michael et al., 2014; Pan et al., 2024). In Malaysia, the intricate woodcarving panels of traditional Malay houses intensify passive cooling. These panels allow air to flow freely while maintaining privacy and aesthetic value, playing a crucial role in optimising indoor thermal conditions (Tong et al., 2024). While woodcarving elements are prominent in Malaysian architecture, similar decorative wooden structures exist in Hungarian heritage architecture, such as the Székely gate, which is primarily constructed from wood, showcasing traditional craftsmanship that emphasises organic architecture principles (Jeffrey, 1995). However, these Hungarian structures primarily serve symbolic and ornamental purposes rather than ventilation. The design of these gates reflects traditional craftsmanship, serving as ornamental features that enhance the aesthetic appeal of rural architecture (Preda et al., 2018). Inspired by the functional use of woodcarving panels in Malay architecture, this research explores their potential integration into Hungarian housing to improve NV in temperate climates.

Previous studies highlighted the role of woodcarving ventilation panels in optimising NV in tropical climates. Traditional Malay houses utilise NV to achieve thermal comfort, with optimal indoor temperatures ranging from 25°C to 27°C (Alkausar – Riyani, 2023; Nik Hassin – Misni, 2023). In contrast, Hungarian vernacular architecture has been studied mainly for its thermal insulation properties rather than NV. The use of heavy materials, such as brick or stone, helps to absorb heat during the day and release it at night, maintaining a stable indoor temperature (Sood, 2023). Comparative studies of NV across different climatic regions have been conducted, concluding that regional climate conditions significantly influence the efficiency of passive ventilation strategies. In arid and semi-arid regions, cross-ventilation with opposing windows significantly improves NV rates, achieving substantial energy savings. Windcatchers further enhance ventilation and reduce cooling demand (Ayoobi et al., 2024). They are effective in improving air quality and reducing energy consumption for air conditioning in tropical climates, even with slight temperature differences between indoor and outdoor spaces (Bernal et al., 2024). Additionally, with climate change causing higher summer temperatures in Hungary, the need for improved passive ventilation solutions has become increasingly important (Fürtön et al., 2022). However, no direct comparison has been made between NV performance in Malaysia and Hungary using the woodcarving ventilation system.

This study presents a comparative simulation of NV performance through traditional woodcarving ventilation panels in two distinct climatic zones, tropical Johor Bahru, Malaysia, and temperate Szombathely, Hungary. By integrating cultural woodcarving designs into ventilation strategies and analysing airflow performance through transient CFD simulations, this research bridges architectural heritage with environmental performance. The novelty lies in applying traditional woodcarving ventilation in both local and foreign contexts and evaluating its effects under real summer weather conditions. This cross-cultural and cross-climatic analysis offers new insights into how culturally significant designs can be adapted for contemporary passive ventilation strategies across diverse regions.

2 MATERIALS AND METHODS

This study employed CFD simulations to analyse the effectiveness of woodcarving ventilation panels in enhancing NV in two distinct climates: Johor, Malaysia (hot-humid climate) and Szombathely, Hungary (temperate climate). The methodology consists of computational modelling and simulation analysis. To evaluate thermal comfort in the studied buildings, we used the ASHRAE 55 standard (2020) as the primary guideline for determining acceptable comfort conditions. According to this standard, thermal comfort is influenced by factors such as temperature, humidity, and air velocity (Agrawal and Tiwari, 2010; Olesen and Brager, 2004). To assess the adequacy of passive airflow, we measured indoor temperatures, relative humidity, and air velocity across the room.

2.1 Computational Modelling

The floor plan in *Figure 1* features an 11m x 6m floor plan with a 3.5m ceiling height designed to optimise NV. Two human figures are positioned to simulate thermal comfort—one between the living and kitchen areas and another in the bedroom. The floor plan includes multiple rooms, seven windows, and ten woodcarving ventilation panels, such as those above the main entrance and bathroom shown in *Figure 2*. These panels integrate traditional motifs, enhancing airflow and preserving cultural significance. The open interior doors mimic typical usage, further promoting air circulation. This setup enables the analysis of how woodcarving elements affect airflow and thermal comfort in modern architecture.

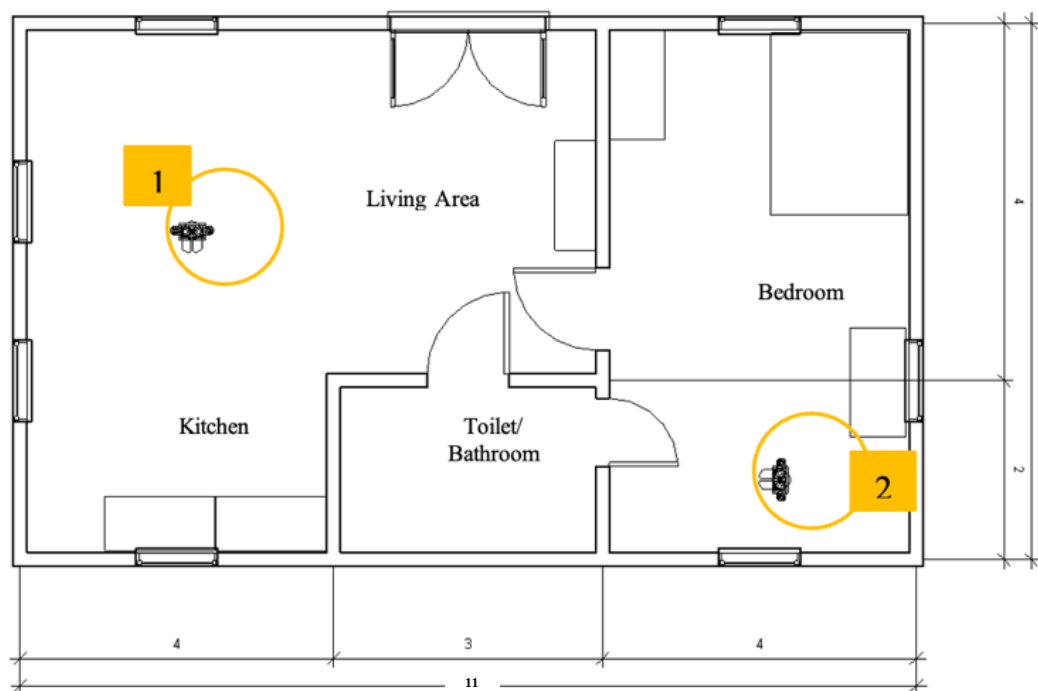


Figure 1. Floor plan

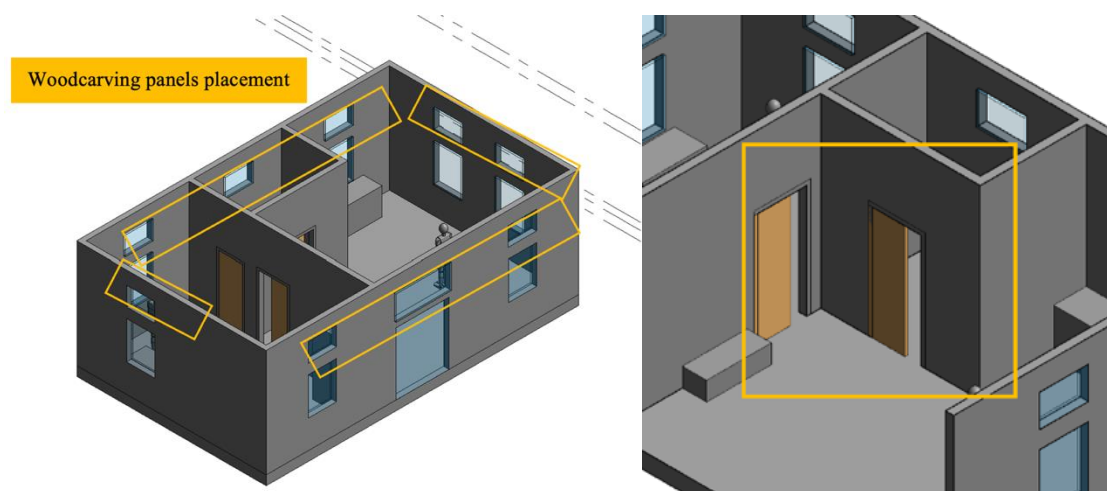


Figure 2. Woodcarving placements and interior doors' position

The woodcarving designs from Rumah Limas Hutan Bandar MBBB and Székely Gate motifs were implemented as ventilation panels in the CFD models for the Johor and Szombathely simulations. These 3D models demonstrate how traditional woodcarvings, such as the *ukiran kerawang tebuk tembus* and *Ketumbit* flower motifs from Rumah Limas and the *kaputükör* design from Székely gates, can be integrated into modern architecture. The carvings, categorised by their void-to-total area ratios, were scaled to fit the building openings in Autodesk Revit to ensure consistency in panel sizes for the simulations.

Table 1. Woodcarving ventilation panels placement.

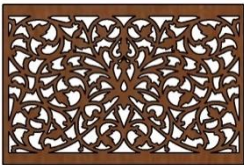
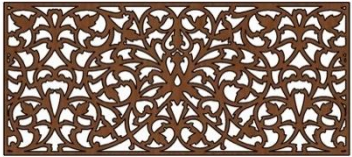
Location	Code	Panel	Description
Above the windows & toilet wall	WC1		• QTY: 8 Nos • 609.6 mm x 914.4 mm
Above the main entrance	WC2		• QTY: 1Nos • 800 mm x 1800 mm
Above the windows & toilet wall	WC3		• QTY: 8 Nos • Size: 609.6 mm x 914.4 mm
Above the main entrance	WC4		• QTY: 1 Nos • Size: 800 mm x 1800 mm

Table 1 shows the woodcarving panels (WC1, WC2) placed above windows and the bathroom wall, with one larger panel above the main entrance in the Johor situation. In

Szombathely, similar arrangements were made, with panels (WC3 and WC4) located above windows, the bathroom wall, and the main entrance. These panels, varying in size from 609.6 mm x 914.4 mm to 800 mm x 1800 mm, were chosen for their ability to enhance ventilation while preserving cultural motifs. This integration facilitates NV while contributing to the aesthetic and cultural significance of the designs.

2.2 Simulation Setup

Following Autodesk tutorial guidelines, an external air volume extending beyond the building geometry - three times the building height and five to six times the width and depth - was defined for the CFD simulations to ensure accurate airflow modelling without boundary interference. This volume, with dimensions of 12891 cm in height, 34126 cm in width, and 67000 cm in depth, was positioned at an angle of -22.5° to simulate real-world wind conditions, as shown in *Figure 3*. Materials were also assigned to the building geometry.

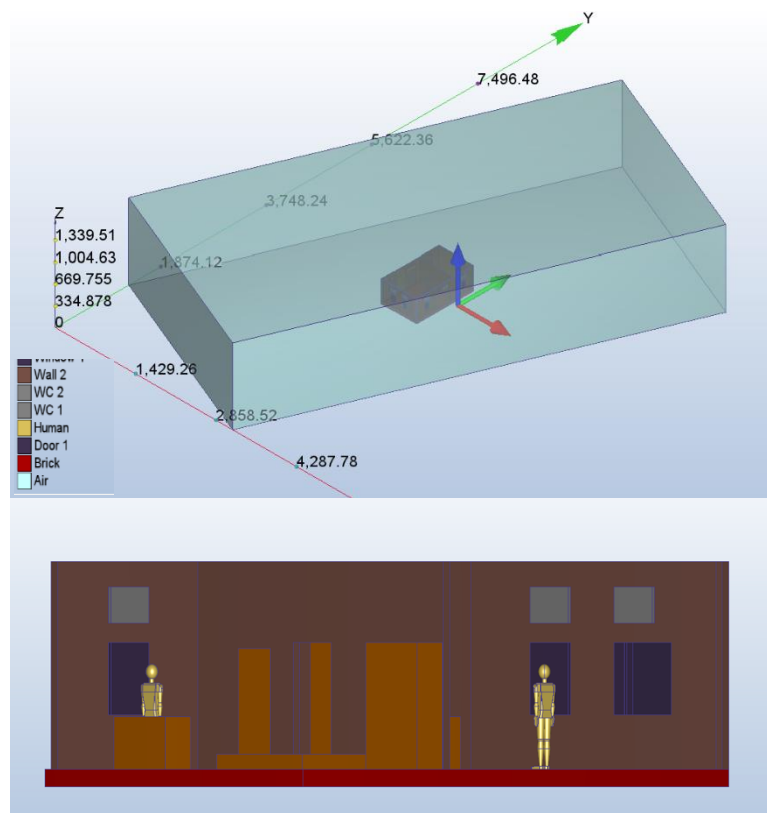


Figure 3. Geometry setup on CFD Autodesk

CFD simulations were conducted under steady-state conditions using the following boundary conditions to replicate real-world climate conditions in Johor, Malaysia, and Szombathely, Hungary. The materials used for the buildings in each location were updated to ensure accurate thermal performance and airflow simulations, considering the specific climate conditions of both regions.

The wind speeds of 7 m/s (for Johor) and 14 m/s (for Szombathely), as shown in *Table 2*, represent the highest recorded values during the selected days, 28–29 July 2022, for both Johor and Szombathely. These values were chosen to simulate peak environmental stress during extreme conditions. For Johor, the data were obtained during a site visit at Rumah Limas Hutan Bandar MJB. For Szombathely, the weather data were extracted from the Energy Plus Weather (EPW) file corresponding to the same dates. While such high wind speeds are not typical of average summer conditions (e.g., Szombathely's summer average is ~ 2.5 m/s), they

were intentionally used to assess the robustness of NV under boundary conditions that may occur during rare but impactful climatic events.

Table 2. Boundary conditions for Johor and Szombathely

Boundary condition	Value (Johor)	Value (Szombathely)	Surface/Volume
Temperature	32°C	34°C	South (Johor) & North-Northwest facing (Szombathely) external air volume
Velocity	7 m/s	14m/s	South (Johor) & North-Northwest facing (Szombathely) external air volume to simulate wind flow
Pressure	0 Pa	0 Pa	North (Johor) & South-Southeast facing (Szombathely) external air volume, acting as the outlet.
Film coefficient	20 W/m ² K	20 W/m ² K	Entire outer surface of the building
Human	60 W/m ² K	60 W/m ² K	Two human figures positioned within the building to assess thermal comfort

The building materials for both regions were modified as detailed in *Table 3*. These materials represent typical components found in Malaysian and Hungarian buildings, ensuring realistic thermal simulations.

Table 3. Materials for both buildings

Material	Johor Building	Szombathely Building
Walls	Material: hardwood, thermal conductivity: 0.16 W/mK	Material: Brickwork thermal insulation, eq. thermal conductivity: 0.065 W/mK
Windows	Default CFD	Material: Window (solar), Thermal conductivity: 0.2 W/mK
Entrance door	Default CFD	Material: Window (solar), Thermal conductivity: 0.23 W/mK

Woodcarving Panel Representation: The woodcarving panels used in the simulation presented a challenge due to their complex geometry, which could not be directly imported into Autodesk CFD. To address this, a Free Area Ratio (FAR) was calculated for each panel to represent airflow resistance. The FAR was used to define the panels as resistive boundaries, enabling an accurate representation of their influence on airflow.

The FAR was calculated using the formula:
$$FAR = \frac{\text{Open Area}}{\text{Total Area}} \times 100$$

This ratio is crucial for assessing a panel's potential to enhance NV. Panels with a higher FAR, such as WC3 and WC4, are more effective in promoting airflow, while WC1 and WC2 provide a balance between structural integrity and ventilation. While FAR is a widely used

static indicator to estimate the potential for NV, its applicability under high wind speeds must be interpreted with caution. At elevated wind velocities, airflow behaviour is influenced not only by the size of the openings but also by pressure distributions, turbulence, and vortex formation. Therefore, FAR in this study serves as an initial comparative metric of panel openness rather than a definitive predictor of ventilation efficiency. The CFD simulations provide a dynamic understanding that complements FAR by capturing real airflow phenomena such as jetting, separation, and recirculation that FAR alone cannot represent (*Table 4*).

Table 4. Free area ratio

Woodcarving Panel	FAR
WC1	0.4314 or 43.14%
WC2	0.3773 or 37.73%
WC3	0.4657 or 46.57%
WC4	0.4485 or 44.85%

3 RESULTS

This section presents a detailed analysis of the CFD simulation results for airflow and temperature distribution in two different climates: Johor, Malaysia (hot-humid climate) and Szombathely, Hungary (temperate climate). The simulations focus on the effectiveness of woodcarving ventilation panels under extreme conditions. Identical building models were used for both regions to ensure a consistent basis for comparison.

3.1 Airflow Distribution and Velocity Magnitude

Figure 4 illustrates the air circulation pattern in the Johor case study. The airflow pattern in the figure shows a combination of smooth directional flow and localised circulation. Air enters the building through openings, creating a generally consistent horizontal flow across most rooms. In certain areas, especially near corners and around partitions, the vectors curve and form swirling patterns, indicating vortex formation and recirculating zones. These vortices suggest reduced airflow efficiency in those regions. The direction and density of the streamlines also show how air is guided by the room layout, with some zones experiencing faster, more concentrated flow, particularly along narrow paths between openings. *Figure 5* illustrates the airflow distribution inside the building, with wind velocities ranging from 0 to 3.5 m/s in (a) and 0 to 2 m/s in (b) Johor. These velocities fall within the range considered beneficial for NV according to ASHRAE 55, which notes that air speeds up to around 0.8 m/s are generally comfortable for occupants under warm conditions, and higher speeds may enhance thermal comfort through convective cooling. However, excessively high speeds may lead to discomfort due to drafts. The variation in velocity indicates the dynamic nature of airflow through different parts of the building, with higher velocities potentially improving heat dissipation and indoor air quality, especially in open-plan spaces or near openings. In the figures, the visibility of red colour was used to indicate areas with the highest wind speeds or velocities, providing a clear visual reference for airflow intensity across the interior space.

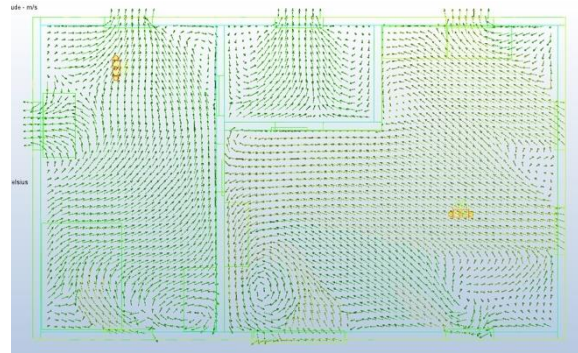


Figure 4. Overall air circulation in Johor

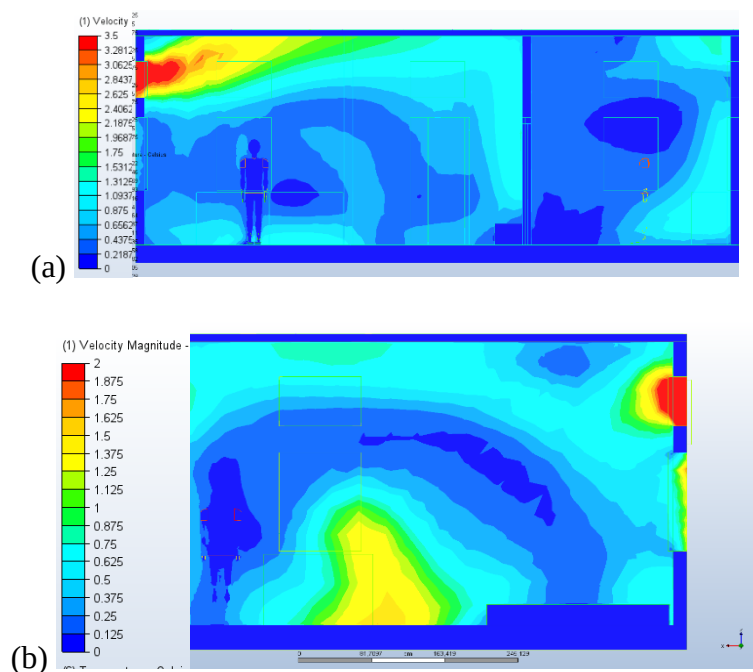


Figure 5. Overall air velocity distribution in Johor

In Szombathely, *Figure 6* illustrates the airflow pattern, which reveals a more directional and intensified flow, especially on the right-hand side of the building. The vector lines in this region are denser and more aligned, indicating strong, uninterrupted airflow, likely due to favourable wind entry and exit paths. In contrast, the left side of the building exhibits more dispersed and slower airflow, with several vortices and recirculation zones forming in corners and near walls. These circular patterns indicate areas where air movement is less effective, possibly leading to stagnant zones or uneven ventilation. *Figure 7* experiences stronger winds, causing airflow velocities of 0 to 5 m/s inside the building, as shown in (a) and 0 to 2.5 m/s in (b). The dynamic airflow is characterised by higher velocities and turbulence. The stronger winds enable greater exchange of indoor and outdoor air, which enhances NV and provides more cooling and better temperature regulation. Higher air velocities, especially when occupants have some control over their environment, can significantly improve thermal comfort by increasing convective heat loss. In this case, the stronger winds facilitate a greater exchange of indoor and outdoor air, thereby enhancing NV effectiveness and inducing better temperature regulation and cooling, which is particularly beneficial in hot and humid climates. Nonetheless,

areas experiencing wind speeds near or above 5 m/s should be carefully evaluated to avoid discomfort from drafts.

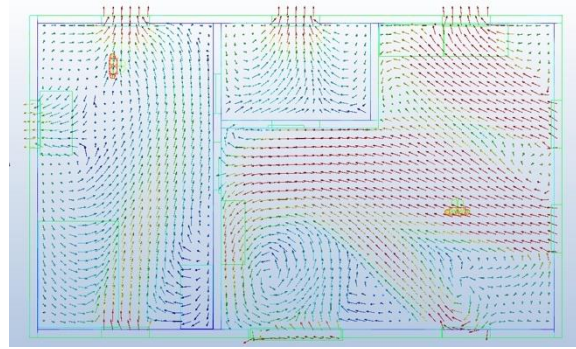


Figure 6. Overall air circulation in Szombathely

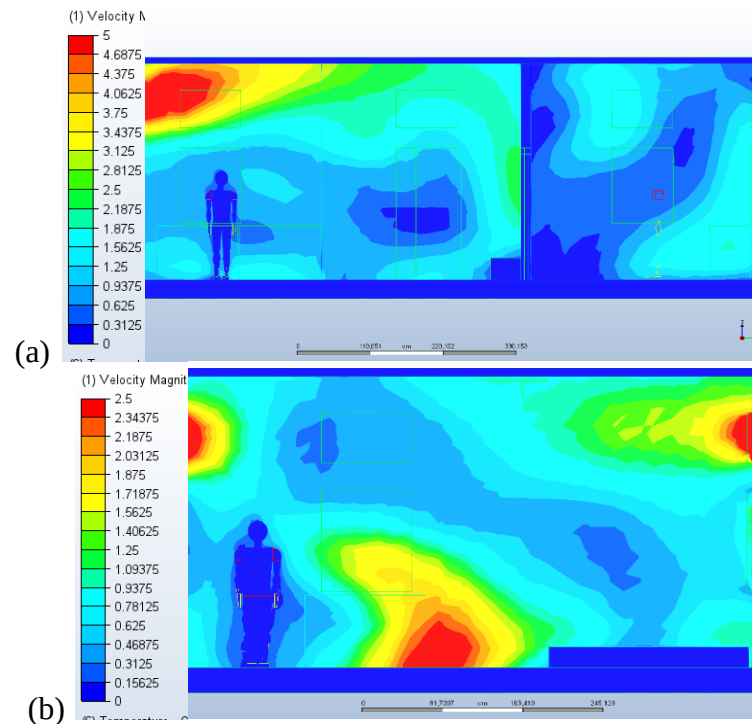


Figure 7. Overall air velocity distribution in Szombathely

The graph in *Figure 9* compares the velocity magnitude (m/s) against the distance from Point A to Point B, shown in *Figure 8*. In Johor, the airflow velocity remains low and steady, below 1 m/s for most of the distance. In Szombathely, the airflow starts higher (around 2.5 m/s) and remains consistently higher, indicating more efficient ventilation and cooling, especially during extreme temperatures.



Figure 8. Point A and Point B plotting

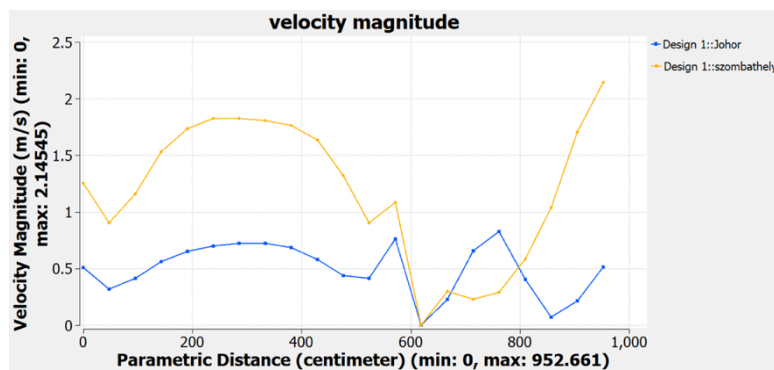


Figure 9. Change of velocity magnitude along the path from point A to B

3.2 Flow Dynamics and Air Circulation

Figure 10 and Figure 11 provide velocity vector representations of the airflow dynamics. In Johor, wind velocities range from 0 to 0.6 m/s around the human figures, suggesting a steady but moderate airflow. In Szombathely, the airflow around the two human figures ranges from 0 to 2 m/s, indicating a more dynamic circulation and better penetration of airflow throughout the building. The increased wind speeds in Szombathely lead to more effective cooling and improved thermal comfort compared to Johor, where moderate wind speeds result in more stable but less dynamic airflow.

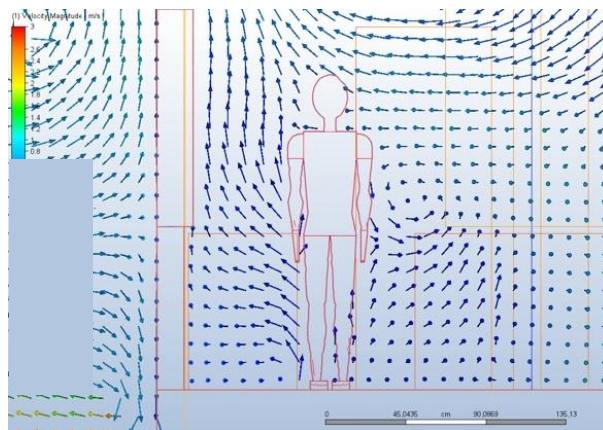


Figure 10. Air circulation near human figures in Johor

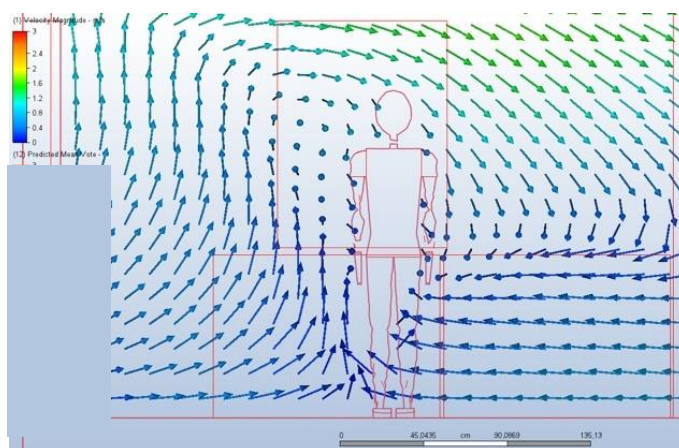


Figure 11. Wind circulation near the human figure in Szombathely

While the woodcarving ventilation panels help improve airflow and passive cooling in both Johor and Szombathely, the extreme temperatures in both locations remain a significant challenge to achieving optimal thermal comfort. Passive ventilation alone may not be sufficient to address these extreme conditions. Integrating HVAC systems can help supplement passive cooling by providing active cooling and dehumidification. In Johor, HVAC systems can enhance cooling during the hottest months, while in Szombathely, they can help maintain comfortable indoor temperatures during high outdoor temperatures, supporting the effectiveness of the NV system.

4 DISCUSSION

The integration of passive NV, particularly through traditional woodcarving elements, plays a significant role in maintaining thermal comfort in buildings (Jay et al., 2023; Nugroho, 2024), especially in climates with moderate temperatures. However, as observed in the Johor and Szombathely case studies, passive airflow alone does not suffice to maintain optimal comfort in conditions where the indoor temperature exceeds 34°C, which falls outside the acceptable range defined by ASHRAE Standard 55 for naturally ventilated spaces. This highlights the limitation of relying solely on passive design strategies in both tropical and temperate climates (Alkausar – Riyani, 2023).

Although high wind speeds are generally beneficial for NV, this study treats the combination of high wind speed and high temperature as a worst-case scenario for thermal comfort due to potential draft discomfort and elevated heat gains in extreme conditions. This can cause sensations such as discomfort from still, humid air or excessive draft, depending on airflow direction and velocity. By connecting airflow performance to user sensations as described in ASHRAE 55, such as air movement acceptability and occupant satisfaction, a fuller picture of the thermal experience emerges (Candido – Dear, 2012). Moreover, the interaction between airflow and characteristics and human comfort is complex. Factors such as airflow velocity, turbulence, and the spatial arrangement of ventilation openings significantly influence user perceptions of comfort (Sholanke et al., 2022). For example, in areas where airflow is inadequate or overly turbulent, occupants may experience discomfort in the form of stickiness, draft discomfort, or lack of cooling, which detracts from the intended benefits of NV. Therefore, a more detailed understanding of how these airflow characteristics are perceived by occupants is necessary for optimising NV systems in future designs.

Beyond thermal comfort, the use of traditional woodcarving for ventilation serves both cultural and functional roles (Haoming – Chen, 2014; Ayowembun – Arifin, 2024). From a

modern user's perspective, the aesthetic value of these features can be preserved while improving thermal performance. This balance between tradition and comfort is crucial for integrating heritage elements into contemporary sustainable architecture.

5 CONCLUSIONS

This study concludes that passive ventilation using traditional woodcarving panels is insufficient to maintain thermal comfort as defined by ASHRAE standard 55, particularly during periods of extreme summer heat in both study regions. A hybrid strategy combining HVAC systems with traditional architectural elements is therefore recommended to achieve comfort standards. Importantly, the refinement of traditional elements should not only focus on preserving cultural identity but also on enhancing performance. Integrating modern design tools and engineering principles can improve airflow delivery and contribute to occupant well-being while retaining the symbolic and historical essence of traditional craftsmanship (Laine et al., 2000; Lyckov, 2024). In conclusion, the effective integration of traditional and modern systems offers a promising path toward designing spaces that respect cultural heritage while meeting the thermal and comfort needs of contemporary users. This approach can help create more sustainable, culturally sensitive and comfortable living environments, both for the present and future generations.

6 FUTURE CONSIDERATIONS

The integration of traditional design elements with modern HVAC systems offers a promising area for further research. Future studies could explore how traditional architecture can be future-proofed by combining eco-friendly HVAC solutions with local materials, ensuring both sustainability and thermal comfort. Consider the broader implications of cultural heritage preservation in modern-day buildings and propose further research into efficient solutions that balance cultural identity with comfort.

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