

CULTURAL PRESERVATION MEETS MODERN DESIGN: INVESTIGATING THE IMPACT OF TRADITIONAL WOODCARVINGS ON NATURAL VENTILATION IN HUNGARY

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ABSTRACT

This study investigates the integration of traditional woodcarving panels to enhance natural ventilation (NV) and thermal comfort in modern architecture. Focusing on Szombathely, Hungary, the research employs wind analysis, microclimate assessment, and Computational Fluid Dynamics (CFD) simulations to assess the effect of woodcarving designs on airflow and indoor comfort. The panels derived from Hungarian cultural motifs were analysed using Free Area Ratio (FAR) values of 46.57% and 44.85%. Simulation results revealed air velocity improvements of up to 2.2 m/s inside living spaces, indicating significant passive cooling benefits. The findings highlighted the potential of integrating cultural craftsmanship with contemporary architectural design to promote sustainable, energy-efficient buildings honouring local heritage.

Keywords: Natural Ventilation, Thermal Comfort, Cultural Heritage, Woodcarving panel, Computational Fluid Dynamics (CFD)

1.0 INTRODUCTION

Integrating traditional elements like woodcarving into modern architecture has gained attention for aesthetic and functional benefits (Zhang, 2024; Xu, 2024). Woodcarving, especially in the form of ventilation panels, has been used across cultures, including Hungarian architecture, to enhance natural ventilation (NV) and improve indoor air quality (IAQ) (Callegari, 2024). With the growing impact of climate change, particularly in temperate regions like Szombathely, Hungary, effective NV strategies are increasingly critical to maintaining indoor comfort, especially during hot summers (Olewi, Sulaiman, & Mohamed, 2023). Szombathely experiences a temperate climate characterised by warm to hot summers and cold winters. As an inland city in western Hungary, it lies far from large bodies of water such as the Adriatic or Black Sea, limiting maritime influence and contributing to more extreme temperature fluctuations. Urban areas like Szombathely are also affected by the Urban Heat Island (UHI) effect, where temperatures are higher than in surrounding rural areas due to surface materials and anthropogenic heat sources (Zsolt, 2009). This phenomenon intensifies summer heat stress, making passive cooling solutions particularly important. Uncomfortable summer conditions typically last from late June to early September, with daytime temperatures frequently exceeding 30°C. Due to the city's inland topography and absence of coastal ventilation, localised strategies such as passive NV are crucial for heat mitigation. Historical data from Hungary's 2007 heatwaves indicated significant health impacts, reinforcing the urgency of thermal comfort interventions in urban environments (Paldy & Bobvos, 2010).

Buildings consume a substantial amount of energy, with Heating, Ventilation, and Air Conditioning (HVAC) systems accounting for approximately 50% of total use (Cho, Woo, Park, & Shin, 2013). While active systems

such as heat pumps and intelligent energy management have improved efficiency (Nguyen & Nassif, 2016), reducing dependency on mechanical cooling remains a key goal of sustainable architecture. Natural ventilation (NV) offers a passive, energy-saving alternative that improves air quality and reduces environmental impact. However, in climates experiencing extreme summer heat, passive solutions alone may be insufficient for maintaining thermal comfort.

This study examines how woodcarving ventilation panels can improve NV and thermal comfort in Szombathely's climate. The hypothesis is that while woodcarving panels enhance airflow, their ability to regulate temperature during extreme heat may be limited, requiring additional cooling methods. Computational fluid dynamics (CFD) simulations assess airflow and temperature within a building, considering Szombathely's wind speeds of up to 14 m/s and summer temperatures reaching 34°C. The study also analyses the panels' Free Area Ratio (FAR) for its impact on NV efficiency.

This research also draws parallels to the Malaysian context, where the decline of traditional Malay architecture elements such as woodcarvings and passive ventilation systems has similarly raised concerns about cultural erosion and environmental inefficiency in modern construction, particularly in states like Kelantan (Abdul Razak & Sabil, 2024; Harun, Mohd Ariffin, & Abdullah, 2017). The research aims to contribute to understanding how traditional elements like woodcarving can be adapted to modern architecture for better energy efficiency and comfort, particularly in climates experiencing extreme summer heat. The findings suggest the benefits of combining passive and active cooling methods for improved thermal comfort.

2.0 LITERATURE REVIEW

2.1 Natural Ventilation and Thermal Comfort Standards

Natural ventilation (NV) uses natural airflow to enhance indoor air quality (IAQ) and thermal comfort while reducing energy consumption. It adapts to local climates, using techniques such as cross-ventilation and windcatchers to regulate temperatures (Ahmed, Kumar, & Mottet, 2021). While NV performs well in temperate climates, it may not be sufficient during heatwaves or extreme summer temperatures, requiring hybrid strategies combining passive and mechanical methods.

The ASHRAE Standard 55 adaptive model is often referenced to define thermal comfort benchmarks in NV-based designs. This model accounts for temperature, humidity, airspeed, and metabolic rate in non-mechanically cooled environments. Table 1 presents key adaptive comfort parameters relevant to NV-based design.

Table 1: Adaptive Comfort Model from ASHRAE Standard 55

Parameter	Value	Unit
Summer Clothing Indoors	0.5	Clo
Activity Level Daytime	1.1	Met
Predicted Percent of People Satisfied	90.0	%
Comfort Highest Summer Temperature	26.7	°C
Maximum Humidity	84.6	%
Minimum Dry Bulb Temperature for Sun Shading	23.8	°C
Minimum Global Horizontal Radiation for Sun Shading	315.5	Wh/sq.m
Maximum Wet Bulb Temperature (Direct Evaporative Cooling)	20.0	°C
Minimum Indoor Air Velocity for Comfort	0.2	m/s
Maximum Comfortable Air Velocity	1.5	m/s
Maximum Mechanical Ventilation Velocity	0.8	m/s
Maximum Perceived Temperature Reduction (Fan-Forced Ventilation)	3.0	°C

Table 2 presents climate-specific comfort parameters for Szombathely, Hungary. These highlight local wind, temperature, and humidity patterns crucial for evaluating passive NV systems' performance during summer.

Table 2: Summer-specific temperature, humidity, wind speed, and comfort conditions in Szombathely, Hungary.

Parameter	Details for summer (June – September)
Temperature Range	Morning Low: 18°C Afternoon High: 34°C
Adaptive comfort zone	Temperature: 20°C - 27°C Humidity: 30% - 70%
Predominant Wind Directions	North-Northwest (NNW), North (N), Northwest (NW)
Common Wind Speeds	Frequently between 2 - 6 m/s (7 - 22 km/h)
Maximum Observed Wind Speed	Up to 14 m/s (50 km/h), primarily from northern directions
Calm Periods	Few, with speeds below 2 m/s (7 km/h)
Humidity Range	Generally, falls between 30% to 70%
Percentage of Time in Comfort Zone	Approximately 8.1% of the summer season fits within the Adaptive Comfort Zone

2.2 Székely Gate woodcarving and its relation to Hungarian culture

Székely woodcarving, seen in the traditional Székely gate (Figure 1), is a key element of Hungarian cultural heritage. These carvings, featuring floral and geometric motifs, serve aesthetic and symbolic purposes, often representing life and continuity. The intricate design of Székely woodcarving could be adapted for modern use, such as in architectural ventilation panels, to improve airflow and cooling in contemporary buildings (Bárth, 2023)



Fig. 1: Hungarian Székely Gate.

(Source: <https://www.hungarikum.hu/en/content/sz%C3%A9kely-gate>).

2.3 Integration of ventilation panel into modern buildings

Incorporating NV into modern design, including through woodcarving panels, has gained attention in sustainable architecture. Vernacular buildings have long employed bioclimatic design to optimise airflow, with examples like Mediterranean timber projections offering passive cooling (Thravalou, Michael, Neophytou, & Philokyprou, 2023). Similarly, a study in Malaysia comparing Mashrabiya and Malay carved window panels found that these traditional perforated designs significantly enhance internal air velocity up to three times the base wind speed, demonstrating the airflow potential of carved openings in passive ventilation systems (Baydoun & Sopian, 2022a).

Recent innovations, such as semi-transparent photovoltaic façades, integrate NV with energy efficiency (Ni, Shi, Lei, Wang, & Xu, 2022). However, NV's success depends on local, historical, and economic factors, requiring

careful design adjustments to ensure effectiveness across diverse environments (Yin & Qi, 2022). In the context of Hungary, adapting Székely carving techniques into functional panels may offer a unique opportunity to blend cultural heritage with climate-responsive design.

3.0 METHODOLOGY

3.1 Site-specific microclimate analysis

Microclimate analysis is crucial for optimising architectural design to improve occupant comfort and energy efficiency. Architects can refine NV strategies and reduce reliance on mechanical cooling by assessing factors like temperature, humidity, wind patterns, and solar radiation (Graham, Berardi, Turnbull, & McKaye, 2020). This study uses Climate Consultant 6.0 to analyse Szombathely's summer climate, ensuring that traditional woodcarving panels are effectively adapted to modern contexts. The adaptive comfort model from ASHRAE Standard 55 defines thermal conditions for naturally ventilated spaces, relevant in the absence of mechanical cooling.

As shown earlier in Table 2 (section 2.1), Szombathely's summer climate (June-September) features temperatures ranging from 18°C in the morning to 34°C in the afternoon, with an adaptive comfort zone between 20°C and 27°C. The dominant wind directions are NNW, N, and NW, with speeds between 2-6 m/s (7-22 km/h), occasionally reaching 14 m/s (50 km/h). Relative humidity generally falls between 30-70%, with ideal NV conditions occurring only 8.1% of the time. Szombathely was chosen due to its distinct summer climate and available EPW data, offering insights into passive cooling strategies in Hungary's warm summer conditions and the potential of woodcarving panels to enhance airflow and comfort.

3.2 Geometry setup

A basic room model 10m x 6m x 3.5m was developed in Autodesk Revit to explore the integration of traditional woodcarving elements in modern architecture (Figure 2). Woodcarving panels were positioned above windows and the main door to assess their impact on NV, shown in Figure 3. Two human figures were included in the bedroom and kitchen (Figure 4), with interior doors left open (Figure 5) to simulate realistic thermal comfort conditions under peak summer temperatures and maximum wind speeds. The model was simplified for seamless CFD integration, ensuring accurate airflow analysis and ease of interpretation.

The base model was developed as a simplified representation of a compact residential unit, rather than being modelled after an existing building. Its rectangular form and dimensions reflect common housing typologies in low-rise urban settings. The orientation of the building aligns with the prevailing wind directions in Szombathely, primarily from the NNW, ensuring optimal conditions for cross-ventilation studies. While the design is hypothetical, it was informed by climatic data and vernacular spatial layouts. Figure 2 shows the floor plan and window-door arrangements selected to simulate real-world passive cooling scenarios.

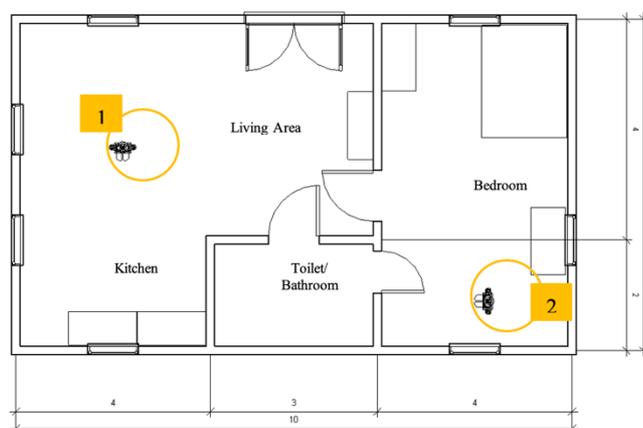


Fig. 2: Floor plan.

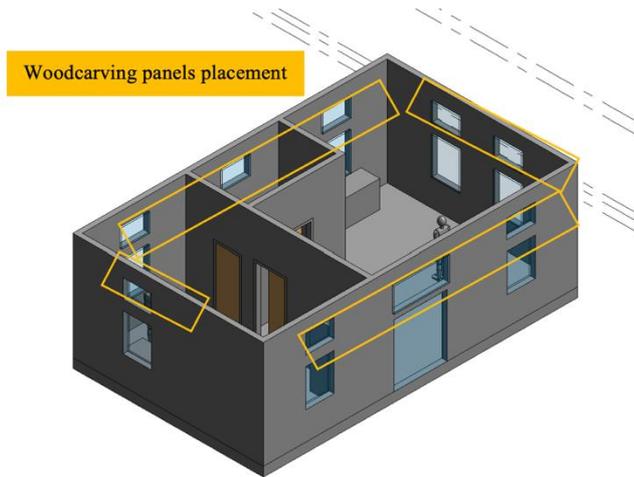


Fig. 3: Woodcarving panels placement.

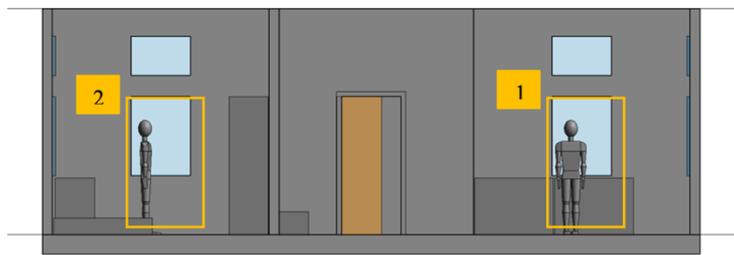


Fig. 4: Human figure placement.



Fig. 5: Interior doors condition.

3.3 Woodcarving design analysis

The kaputükör or gate mirror is a traditional decorative element from the Székely gates of Hungary, known for its intricate and symbolic patterns. These gate mirrors are essential to Hungarian cultural heritage, often representing values and beliefs deeply rooted in the region's folklore (Preda et al., 2018). Figure 6 shows a traditional kaputükör design, which inspires the reinterpretation used in this study.



Fig. 6: Kaputükör minták (Source: Kovács, 2005)

To support airflow analysis, the design was simplified into a black-and-white representation (Figure 7), where white indicates solid (positive) space and black represents void (negative space). This approach improves the clarity of FAR calculations and the accuracy of airflow simulation in CFD models.

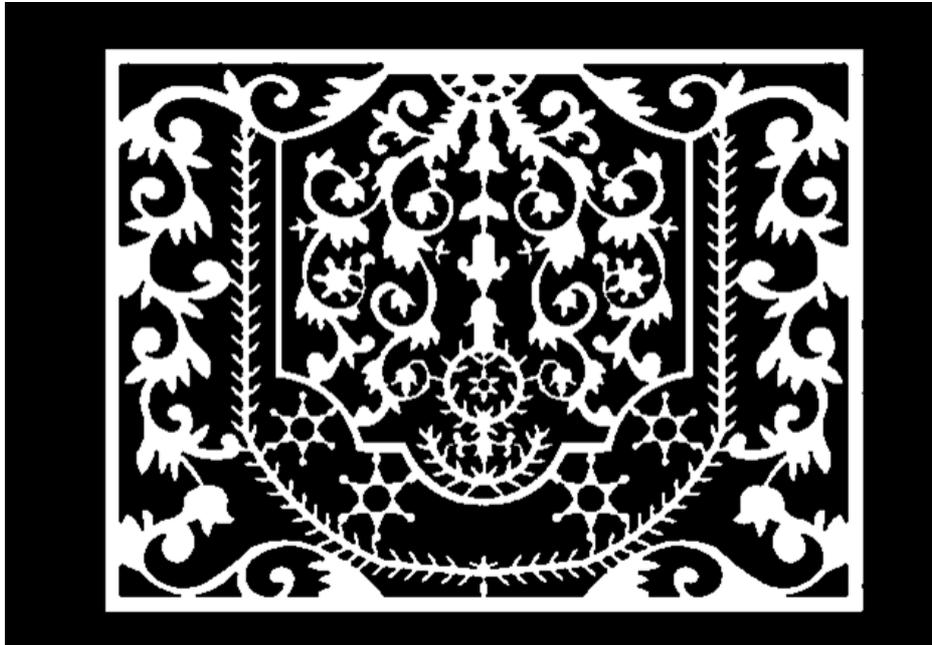


Fig. 7: Reinterpreted woodcarving panel for ventilation use.

The motif is a harmonious blend of floral motifs, celestial elements such as the sun and stars, and nature-inspired designs. The floral motifs symbolise growth and vitality, while the sun and stars evoke timelessness and a connection to the cosmos. These patterns are not merely decorative; they embody cultural and symbolic meanings, reflecting the values and beliefs of the Székely people. The meticulous craftsmanship of the kaputükör significantly enhances the aesthetic and cultural value of Székely gates.

Table 3: Woodcarving panel type for Szombathely.

Location	Code	Panel	Description
Above the windows & toilet wall	WC3		<ul style="list-style-type: none"> • QTY: 8 Nos • Size: 609.6 mm x 914.4 mm
Above the main entrance	WC4		<ul style="list-style-type: none"> • QTY: 1 Nos • Size: 800 mm x 1800 mm

Table 3 shows the installation locations of the woodcarving panels at two critical points within the building: above the windows (WC3), toilet wall (WC3), and main entrance (WC4). The total of 9 units was placed at these locations. These panels maintain consistent design and functionality, supporting cross ventilation within the structure while enhancing its aesthetic appeal.

3.4 Parameter setup for CFD simulation

The external air volume for the CFD simulations shown in Figure 8 was carefully defined to reflect realistic environmental conditions specific to Szombathely, Hungary. Its dimensions were 1289.112 mm (H), 3412.6 mm (W), and 6700.589 mm (D), adhering to the proportional guidelines outlined in the Autodesk tutorial. These proportions ensured that the air volume extended sufficiently beyond the building geometry to accurately model airflow interactions without boundary interference. Combined at -22.5 degrees, this setup simulated the natural wind flow conditions that are rarely perpendicular to the building façade. Materials were assigned as specified in Figure 8.

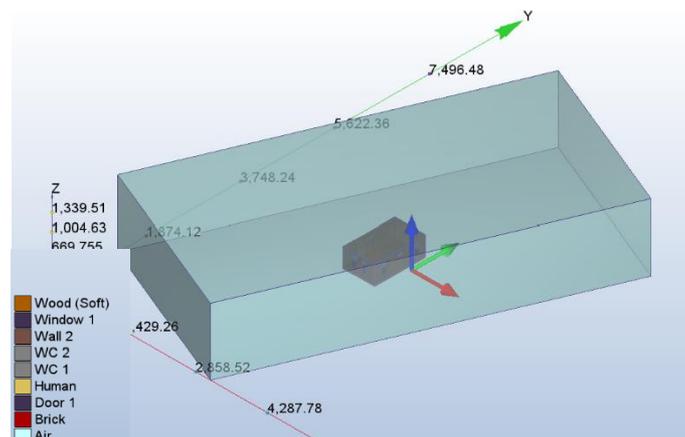


Figure 8: CFD external air volume & materials setup.

With the external air volume and parameters for the ventilation systems established, the simulation then analyses the airflow and thermal conditions based on distinct temperatures and wind speeds. The boundary conditions applied are summarised in Table 4 below:

Table 4: Boundary conditions for Szombathely.

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

Materials settings:

- Walls: hardwood, thermal conductivity: 0.065 W/mK. Saved as Wall 1.
- Windows: Solar window material, thermal conductivity: 0.2 W/mK. Saved as Window 1.
- Entrance door: solar window material, thermal conductivity: 0.23 W/mK. Saved as Door 1.

These updates ensure accurate thermal properties for walls, windows and doors, supporting a realistic simulation of airflow and thermal performance based on Szombathely's climate.

3.4.1 Justification for Using Free Area Ratio (FAR) Instead of Window-to-Wall Ratio (WWR)

The window-to-wall ratio (WWR) is a commonly used metric in building design to assess the proportion of glazed openings relative to wall surface area. However, WWR is limited in its applicability to non-glazed, perforated elements such as traditional woodcarving panels. WWR does not capture the airflow elements, such as conventional woodcarving panels. It does not account for airflow behaviour or permeability, which are essential for accurate simulation of NV performance (Rana, Hasan, Sobuz, & Tam, 2022).

In contrast, the FAR provides a more appropriate metric, specifically quantifying the percentage of open (void) area in a perforated panel relative to its total area. This makes FAR particularly effective for evaluating the airflow performance of carved wood panels used in passive cooling applications. Studies have shown that perforated architectural elements, such as Mashrabiya and traditional Malay carving windows, can significantly enhance indoor air velocity and thermal comfort by facilitating controlled cross-ventilation (Baydoun & Sopian, 2022b).

FAR directly correlates to airflow resistance and pressure drop, critical for realistic CFD simulations. Its adoption in simulation modelling helps guide design strategies in climates where passive ventilation is necessary to reduce reliance on mechanical systems.

$$\text{FAR formula: } FAR = \frac{\text{Void Area}}{\text{Total Area}} \times 100$$

Table 5: FAR for woodcarving panels.

Woodcarving Panel	FAR
WC3	0.4657 or 46.57%
WC4	0.4485 or 44.85%

The FAR analysis shows varying balances of solid and void areas. WC3 (46.57%) is highly effective for maximising airflow while retaining sufficient material for support, and WC4 (44.85%), balancing ventilation and decorative appeal, is optimal for enhancing NV. Using boundary conditions based on Szombathely's climate, the CFD simulation was validated by comparing the results with local data. An unstructured grid mesh ensured accurate airflow capture, particularly around the woodcarving panels.

4.0 RESULTS

4.1 Flow and temperature distribution

This section presents a comparative analysis of airflow and temperature distribution patterns in Szombathely, as depicted in the CFD simulation in Figure 9. The simulation is based on a wind speed of 14 m/s and an ambient temperature of 34 °C. Szombathely ranges from 34 °C to 36.8 °C, with more pronounced temperature gradients observed between the cooler incoming airflow and the warmer air downstream of the building. Inside, the temperature ranges from 34 °C to 35.2°C, while the external temperature fluctuates between 34°C and 36.8°C, contributing to significant temperature fluctuations.

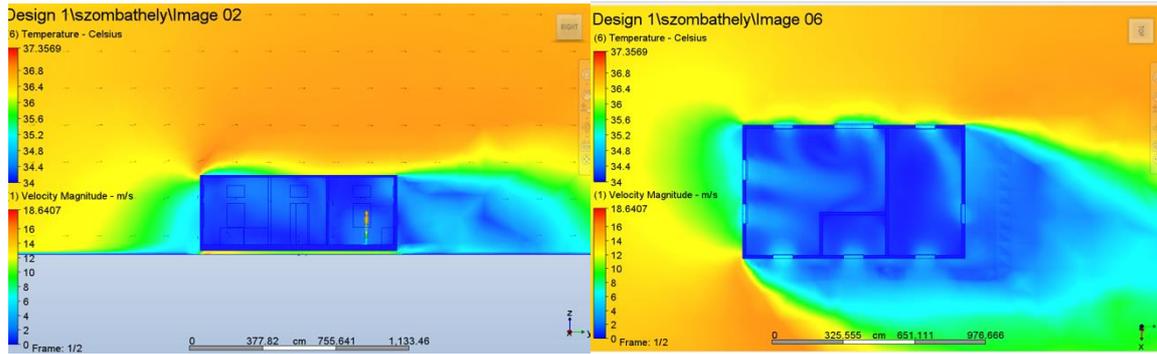


Figure 9: Flow and temperature distribution.

The airflow inside the building is shown with colour contours ranging from blue to light blue, indicating wind velocities between 9 and 14 m/s. The simulation shows a dynamic airflow pattern in Szombathely, with stronger winds creating turbulence and noticeable variations in wind direction and intensity throughout the building. These higher wind speeds make the woodcarving panels more effective in promoting cross-ventilation, resulting in more efficient cooling and better temperature regulation. The stronger winds enhance the exchange of indoor and outdoor air, increasing the building's NV capacity and providing more effective cooling during warmer months.

4.1.1 Air volume flow rate comparison

The volumetric airflow rate ($Q = A \times v$) was calculated based on the surface area and mean perpendicular air velocity for WC3 and WC4 to provide a more accurate comparison between the two panel types. The surface areas of the panels are approximately 0.56m² (WC3) and 1.44 m² (WC4), with mean air velocities of 1.8m/s and 2.5m/s, respectively. The resulting volumetric flow rates are:

- WC3: 1.8 m/s x 0.56m² = 1.0m³/s
- WC4: 2.5m/s x 1.44m² = 3.6m³/s

This shows that WC4 facilitates 3.6 times more airflow than WC3. Although WC4's velocity is only 1.4 times higher than WC3's, its significantly larger surface area contributes to a much higher volumetric air flow, confirming that opening size must be considered alongside airspeed when assessing NV effectiveness.

4.2 Predicted mean vote (PMV)

PMV (Table 6) evaluates thermal comfort by considering factors like airflow velocity, temperature, clothing, metabolic rate, humidity, and radiant heat. Autodesk CFD calculates PMV to predict a group's mean thermal sensation on a seven-point scale, from -3 (cold) to +3 (hot), with 0 indicating neutral comfort. Table 6: Predicted mean vote values

Value	Sensation
-3	cold
-2	cool
-1	slightly cool
0	neutral
+1	slightly warm
+2	warm
+3	hot

The PMV value reaches 3, as shown in Figure 10, indicating extreme discomfort due to persistently high temperatures despite the strong natural airflow from the north-northwest. This highlights the limitations of relying solely on passive ventilation during extreme heat. Figure 10 further shows varying PMV values across the human figure, with light blue and green areas (values between 0.4 and 1.6) on the legs, knees, and arms indicating mild discomfort. As the PMV increases, it reaches 2.4 in the abdominal area (yellow), signifying noticeable thermal discomfort. These values represent the varying discomfort levels experienced by different body parts due to Szombathely's environmental conditions. The surrounding air's PMV values, shown in the

hollow human figure (Figure 11), range from 0 to 1.2, with most values between 0 and 1, suggesting that the surrounding air is neutral to slightly warm, causing minimal discomfort.

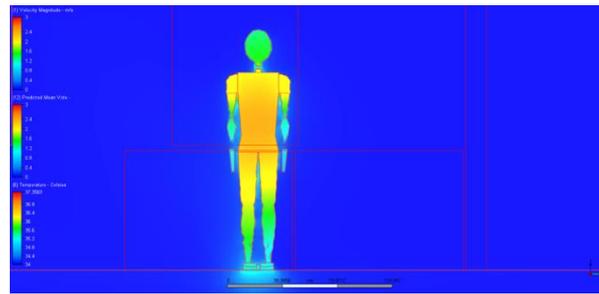


Figure 10: PMV value for human.

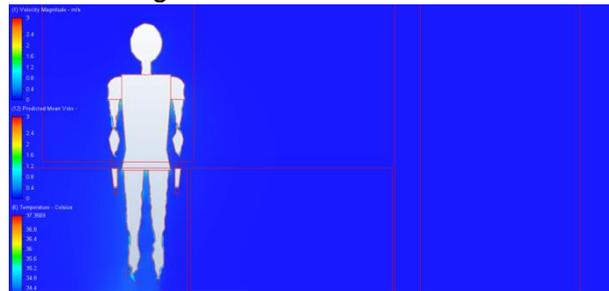


Figure 11: PMV of the surrounding air.

5.0 DISCUSSIONS

This study aimed to evaluate the effectiveness of woodcarving panels in enhancing NV and thermal comfort in Szombathely, Hungary. The primary hypothesis suggested that woodcarving panels with higher FAR would improve airflow and indoor comfort, which was partially supported.

CFD simulation results showed that panels WC3 (46.57%) and WC4 (44.85%) enhanced airflow, with wind velocities reaching up to 14m/s in internal zones near openings. While both panel types facilitated ventilation, their effects were not directly proportional due to differences in panel area. WC4 was nearly three times larger than WC3, which implies that simply comparing FAR percentages without accounting for airflow volume ($Q = A \times v$) could lead to misleading conclusions.

The volumetric airflow calculation further clarifies the performance difference between the panels. Despite WC4 having only 1.4 times higher velocity than WC3, its larger surface area results in 3.6 times greater air volume flow. This confirms that evaluating NV effectiveness requires considering both panel design and dimension. Larger perforated panels like WC4 enhance aesthetic value and substantially improve indoor airflow performance.

The boundary conditions in the simulation reflected realistic summer scenarios in Szombathely, including a 14 m/s NNW wind, ambient temperature of 34 °C, and appropriate material settings for walls and openings. An unstructured mesh was applied to ensure fine-grained airflow resolution, particularly around the carved panel geometries.

Despite increased airflow, the panels did not significantly reduce internal temperatures during extreme heat, resulting in discomfort (PMV value of 3). This suggests that passive ventilation, although effective in improving airflow, is insufficient for maintaining thermal comfort in extreme conditions (Abdullah et al., 2021). These findings support a hybrid ventilation approach, especially for climates with high solar gain and limited nighttime cooling.

The validity of the CFD results was supported by comparing them with microclimate data, adherence to ASHRAE standards, and the use of industry-standard tools (Autodesk CFD and Climate Consultant 6.0). While

experimental validation was beyond the scope of this study, future work may include wind tunnel testing or on-site monitoring to verify simulation results.

In summary, airflow performance depends not only on FAR, but also on panel area, orientation, and distribution. Effective NV design should balance these factors for cultural integration and environmental performance.

6.0 CONCLUSION

This study explored the integration of woodcarving ventilation panels into a modern building to improve NV and thermal comfort in Szombathely. Using Szombathely, Hungary, as the case study, CFD simulations revealed that woodcarving panels with FAR of 46.57% (WC3) and 44.85% (WC4) significantly improved indoor airflow, with peak internal velocities reaching up to 14 m/s in alignment with outdoor wind speeds.

The ventilation rates exceeded the ASHRAE Standard 55 minimum threshold of 0.2 m/s for occupant comfort in naturally ventilated spaces. However, thermal comfort was not achieved, with PMV values reaching +3, indicating discomfort due to elevated internal temperatures. This outcome highlights the limitation of relying solely on passive ventilation under extreme heat conditions.

Design comparisons between WC3 and WC4 showed that although WC3 had a higher FAR, WC4's larger panel size allowed greater air volume intake. Therefore, NV effectiveness is influenced by both FAR and total panel area. To optimise performance, designers may consider:

- Increasing the number of smaller, high-FAR panels distributed along prevailing wind paths
- Combining perforated panels with shading elements or thermal mass
- Exploring directional carvings to guide the flow

In conclusion, carved wood panels with FAR values above 45% can significantly enhance passive airflow. While they contribute to improved ventilation, their extreme thermal impact remains limited. For achieving full thermal comfort, a hybrid system integrating culturally significant ventilation elements with adaptive cooling strategies (e.g., operable panels, evaporative cooling) is recommended.

The study supports the strategic integration of traditional craftsmanship into sustainable and climate-responsive architecture. Future research may further refine airflow dynamics through experimental validation and explore how pattern geometry or material thermal conductivity variations influence long-term comfort and energy performance.

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