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2024

Wood 4 Sustainability

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Főszerkesztő: Dr. Csiha Csilla

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Tartalom

Cultural Preservation Meets Modern Design: Investigating the Impact of Traditional Woodcarvings on Natural Ventilation in Johor, Malaysia

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ABSTRACT
This study explores the integration of traditional woodcarving panels in contemporary architecture to enhance natural ventilation and thermal comfort. Focusing on Johor, Malaysia, the research utilises Computational Fluid Dynamics (CFD) simulations to evaluate the impact of woodcarving designs on airflow and indoor environment quality. The analysis centres on woodcarving ventilation panels, which serve the dual purpose of improving air circulation and maintaining aesthetic appeal. The results highlight the potential of combining traditional craftsmanship with modern architectural approaches to create sustainable and culturally relevant building solutions; this research offers valuable insights into how traditional elements can be adapted to contemporary designs to promote functionality and cultural heritage in building practices.

Keywords: Natural Ventilation, Thermal Comfort, Cultural Heritage, Woodcarving Panel, Computational Fluid Dynamics, Industry, innovation and infrastructure

1. Introduction

Heating, ventilation, and air conditioning (HVAC) systems account for a significant portion of energy consumption in buildings, representing approximately 68% of energy use in both the residential and commercial sectors (Orme, 2001). This substantial energy demand has shifted towards more energy-efficient design strategies, such as natural ventilation, to reduce dependence on mechanical systems. Natural ventilation relies on wind and buoyancy-driven airflow to replace indoor air with fresh outdoor air, offering a passive alternative that minimises energy use and addresses health issues linked to poorly maintained HVAC systems. Designing effective natural ventilation systems requires a comprehensive understanding of airflow dynamics, which are influenced by the pressure differences across openings and the resistance posed by their geometry and size (Evola & Popov, 2006). While full-scale experiments provide valuable data on airflow behaviour and pressure patterns in naturally ventilated buildings, computational techniques such as Computational Fluid Dynamics (CFD) have become increasingly popular due to computational power and turbulence modelling advancements.

In traditional Malay houses, carvings are strategically placed on wall openings such as doors and windows to serve both decorative and functional purposes. The carvings function as ventilation panels, allowing airflow while maintaining privacy and security. (Kamarudin & Said, 2010). This study investigates the potential of traditional woodcarving panels to enhance natural ventilation and thermal comfort by integrating their cultural and functional significance into modern architectural designs. Historically, woodcarving panels have been celebrated for their intricate craftsmanship and cultural importance, serving decorative and practical architectural roles. In addition to their aesthetic value, these panels present a practical solution for improving indoor air quality, regulating temperatures, and contributing to energy efficiency in sustainable building designs. By combining artistic tradition with engineering principles, woodcarvings can be adapted to optimise natural ventilation, leading to energy savings and improved comfort in contemporary spaces. To assess the effectiveness of traditional woodcarvings in promoting ventilation, this research incorporates wind analysis and CFD simulations, focusing on Johor, Malaysia. A site visit to Rumah Limas in Johor Bahru was conducted on July 28-29, 2022, during which airflow and temperature data were collected. After that, the airflow through the woodcarving panels will be analysed using CFD, providing detailed insights into how these traditional elements influence airflow and thermal comfort in typical room layouts.

2. Energy consumption in buildings using HVAC

Malaysia's tropical climate, marked by high temperatures and humidity, makes using HVAC systems essential for maintaining indoor comfort in commercial and residential buildings. Air conditioning is especially prevalent in commercial environments, which are critical in managing warm, humid conditions (Teh & Husain, 2024). Beyond providing comfort, HVAC systems are crucial for preserving indoor air quality in sensitive spaces such as libraries and educational institutions (Yau, 2012)(Yau et al., 2008). Recent advancements, such as the integration of Variable Speed Drives (VSD), have demonstrated significant energy savings in larger facilities, including hospitals and commercial buildings. These improvements have resulted in reductions of up to 4963 kWh annually in energy consumption (Dezfouli et al., 2014). Innovative solutions such as the Dual Air Handling Unit have also been developed to boost energy efficiency while maintaining thermal comfort by effectively controlling humidity levels (Azizuddin, 2015). However, the rising demand for energy poses a challenge to sustainability, highlighting the importance of optimising HVAC designs to accommodate future climate conditions (Yau, 2012).

Continuous maintenance and specialised technical expertise are vital to ensure the effective operation of HVAC systems, helping to meet both comfort and energy efficiency requirements (Teh & Husain, 2024). While HVAC systems are indispensable for achieving indoor comfort in Malaysia's climate, significant challenges remain related to high energy consumption and maintenance needs. Addressing these issues is crucial to promote long-term sustainability and efficiency in the country's building sector.

3. Natural ventilation

In Malaysia's tropical climate, natural ventilation is essential for improving indoor air quality and building thermal comfort. Numerous studies have examined the effectiveness of natural ventilation strategies, providing valuable insights into airflow dynamics, design factors, and regulatory considerations.
Research on traditional Malay houses, for example, has shown that natural ventilation is strongly influenced by architectural features like openings and spatial layouts that help facilitate airflow (Rahmat et al., 2023). Using techniques like the smoke wire method, these studies have demonstrated how airflow can be optimised through careful design, emphasising the role of traditional architectural elements in adequate ventilation. In modern terraced houses, the strategic placement of inlet and outlet openings has been shown to significantly impact cross-ventilation performance, with multi-layered designs enhancing the movement of air (Ali et al., 2023). Experimental data suggest that well-planned positioning of openings can significantly improve indoor air quality, reducing the need for mechanical cooling systems. Additionally, numerical simulations have highlighted the importance of façade openings and window-to-wall ratios (WWR) in optimising natural ventilation for low-energy buildings. Larger facade openings significantly enhanced thermal comfort, as evidenced by improved modified predicted mean vote (PMV) index scores (Al Rikabi et al., 2022). Field studies on air-welled terraced houses revealed that the current regulatory requirement for the Uniform Building By-Law 1984 Malaysia of 10% openings for ventilation may be inadequate for achieving optimal thermal conditions (Leng et al., 2021). These findings suggest revisiting building regulations to support natural ventilation in residential designs better. While natural ventilation provides several advantages, challenges remain in aligning design strategies with building codes and adapting them to diverse climatic conditions. Ongoing research is crucial for refining these approaches and improving their effectiveness across various building types in Malaysia.

4. Traditional woodcarvings in architecture: cultural significance and functional roles

Traditional woodcarvings in Malaysian architecture are a profound reflection of cultural identity, showcasing the Malay community's detailed craftsmanship and aesthetic values. Prominently featured in traditional Malay houses, these carvings go beyond mere decoration, embodying symbolic meanings and historical significance. Traditional woodcarving in Malaysia is guided by six core aesthetic principles: fineness, symbolism, meaningfulness, unity, usefulness, and contradiction. These principles enhance the visual appeal and deepen the cultural resonance of the architectural elements, especially in structures like the Rumah Limas Bumbung Perak (Abdul et al., 2024). The motifs used in these woodcarvings are diverse, ranging from flora and fauna to geometric patterns and calligraphy. In Johor, the Labu Maya motif is particularly prominent, representing the region's cultural identity (Yusof et al., 2023)(Abdul et al., 2024).

The selection of motifs is often influenced by Islamic principles, which shape the design of the woodcarving panels (Yusof et al., 2022). The evolution of these carvings reflects a transition from Hindu-Buddhist influences to motifs rooted in Islamic traditions, signifying a shift in the cultural and religious landscape of the Malay community (Abu Bakar et al., 2022). Woodcarvings are integral to the socio-cultural fabric of Malay architecture, encapsulating the community's beliefs and traditions. Their heritage value is significant, contributing not only to local identity but also to the promotion of cultural tourism (Ahmad & Ab. Aziz, 2022). However, the increasing threat of modernisation and neglect puts this heritage at risk. Many traditional houses with intricate woodcarvings face the danger of demolition, highlighting the importance of continued documentation and study to preserve these art forms (Ahmad & Ab. Aziz, 2022) (Yusof et al., 2022). The role of traditional woodcarvings extends beyond aesthetics; they also serve as cultural narratives, embedding historical and religious meanings into architectural design. In Johor, for instance, woodcarvings often incorporate motifs symbolising the Pillars of Islam, reinforcing the region's cultural and religious identity (Yusof et al., 2022). Efforts to document and analyse these motifs are crucial for maintaining the authenticity of regional identities, as they help protect the distinctive features of Malaysia's architectural heritage (Yusof et al., 2023). While traditional woodcarvings are celebrated for their exquisite beauty and cultural importance, the risk of losing this heritage due to the pressures of modernisation is a growing concern. There is an urgent need for sustained preservation efforts and educational initiatives to highlight the significance of these art forms in Malaysian architecture. By doing so, the unique legacy of traditional woodcarving can be safeguarded for future generations, ensuring its continued relevance and appreciation in contemporary architectural practices.

5. Integration of Malay woodcarving ventilation panels to modern buildings in Malaysia

Malay woodcarving is crucial in blending traditional aesthetics with modern Malaysian architecture. This art form enhances the architectural character of buildings and reflects cultural values and identity. However, integrating Malay woodcarving into contemporary structures presents challenges, including a disconnect from its original philosophical foundations and a need for meaningful discourse on ornamentation in modern architecture. The following sections explore Malay woodcarving's influence, challenges, and potential in modern design. Through various case studies, the integration of

Malay woodcarving into modern architecture has been examined, shedding light on its cultural significance and the challenges it faces. A prominent example is the residential house in Terengganu, as shown in Figure 1, where traditional Malay woodcarving has been successfully incorporated into its modern design. This case demonstrates how woodcarving can enhance contemporary buildings' aesthetic and cultural value, bridging the gap between heritage and modernity. Malay woodcarving is deeply rooted in traditional craftsmanship and cultural narratives, enriching the identity of modern structures.

The principles of Malay vernacular architecture align with sustainable design practices, promoting environmentally conscious construction (Kassim et al., 2017). However, many contemporary applications of woodcarving fail to capture its true essence, leading to a diluted representation of its cultural significance (Nila et al., 2012). Furthermore, the lack of a robust conversation surrounding ornamentation has contributed to the marginalisation of woodcarving in mainstream architecture (Haji Mohamad Rasdi, 2006).

To address these challenges, architects must engage with traditional motifs and techniques, ensuring that Malay woodcarving remains relevant in modern contexts (Yusof & Mohd-Nor, 2021). Ongoing research into local designs and motifs is crucial to preserving the authenticity of this art form and maintaining its cultural relevance (Shaffer et al., 2011). Despite the challenges, integrating Malay woodcarving into modern architecture offers significant cultural expression and sustainability opportunities. By adopting a balanced approach that honours traditional values while embracing contemporary design principles, modern buildings can reflect Malaysia's rich heritage while addressing future demands. This approach can foster Malaysia's more prosperous, culturally connected architectural landscape.

Figure 1. Integration of traditional woodcarving in a modern building. Photograph courtesy of Warisan Seni Ukir Kayu, Terengganu (2023)

Table 1. summarises the findings from the site visit analysis conducted in Johor, Malaysia, on the 28th and 29th of July 2022. The table highlights the diurnal pattern of air movement, which shows consistently increased air movement in the afternoon. At the same time, the morning hours are characterised by "Too Still" conditions, particularly at indoor points. This observation reflects a typical daily temperature and airflow variation in Johor, with still conditions in the morning being a recurring feature, which can affect thermal comfort. The parameters recorded during the site visit shown in Table 2.

6. Methodology

6.1. Temperature and Airflow Analysis

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. Specific temperature, humidity, wind speed, and comfort conditions during 28^{th}-29^{th} July 2022

Parameter	Details for 28^{th} – 29^{th} July 2022
Temperature Range	Morning Low: 23°C Afternoon High: 32°C
Predominant Wind Directions	South (S)
Maximum Observed Wind Speed	Up to 7 m/s primarily from South directions

6.2. Geometry Setup and Woodcarving Design Analysis

The floor plan depicted in Figure 2. illustrates the modelled structure used for analysing the integration of traditional woodcarving elements into modern architectural designs. The basic room layout measures 1000 cm × 600 cm, with a ceiling height of 350 cm. The design incorporates multiple rooms with strategically positioned doors and windows to optimise natural ventilation and daylighting. Traditional woodcarving elements are integrated into the openings to enhance airflow while preserving the cultural significance of the motifs. The structure features seven windows along the walls to facilitate cross-ventilation, and the doors enable air circulation between rooms. Additionally, ten woodcarving ventilation panels are installed above the windows, including one in the bathroom and one above the main entrance door on the exterior wall, as shown in Figure 3. The figure also highlights a simplified model designed for Computational Fluid Dynamics (CFD) analysis, focusing on airflow patterns and thermal comfort within the building. To further enhance the realism of the simulation, two human figures were included in the scenario to evaluate thermal comfort under the given conditions shown in Figure 4. One is between the living area and kitchen, and the other human figure stands in the bedroom. This addition allows for a more accurate assessment of how airflow and temperature distributions impact occupants within the space. The layout plays a crucial role in examining the influence of woodcarving elements on ventilation efficiency, particularly under summer conditions.

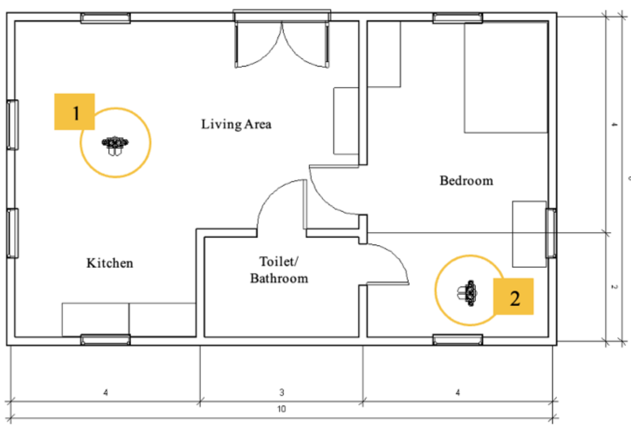

Figure 2. Floor Plan

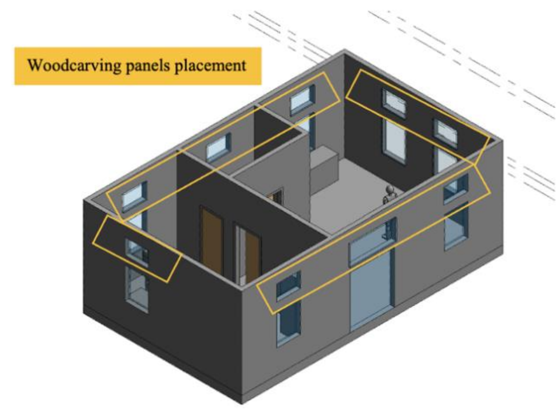

Figure 3. Woodcarving panels placement

To simulate realistic airflow: Figure 5. shows two interior doors that are left open, mimicking actual usage scenarios where doors remain open for improved air circulation. The woodcarving designs documented in Rumah Limas MBJB, depicted in Figure 5, were implemented as ventilation panels within these models for Johor simulation. This 3D modelling approach facilitates the visualisation of how traditional designs can be integrated into contemporary architectural layouts and assesses their potential impact on building performance. The carving found in Rumah Limas Hutan Bandar includes the ukiran kerawang tebuk tembus (rata or tidak bersilat) and the ketumbit flower motif. The ukiran kerawang tebunk tembus carving exhibits intricate patterns and designs, while the ketumbit flower motif depicts the graceful beauty of the torch ginger flower, commonly found in Southeast Asia.

The woodcarvings in Rumah Limas Hutan Bandar were carefully categorised based on their specific location and type. Each carving was meticulously assessed to determine the ratio of solid (opaque) material to void (cut-out) space, expressed as a percentage or ratio. Regarding the woodcarvings in Rumah Limas Hutan Bandar, the Free Area Ratio (FAR) ranged from 1:1.56 for C1, 1:3.7 for C2, to 1:1.68 for C3. The chosen panels were C1 to be implemented in the model. The size was adjusted based on the opening in the newly constructed geometry using Autodesk Revit.

This ensures the comparison results will use similar models with the same panel size. The sizes of woodcarving panels used in the Johor situation are shown in Figure 6. The Table 3 provides an overview of the placement and specifications of woodcarving panels used in the modelled structure. These panels, labelled with distinct codes, are strategically positioned to enhance ventilation and airflow while contributing to the cultural aesthetic of the design. The panels labelled WC1 are placed above the windows and the toilet wall. Eight panels are installed, each measuring 61 cm x 91 cm, ensuring uniformity in size and design across the specified locations. These panels facilitate natural ventilation while preserving privacy in the respective spaces.

The panel labelled WC2 is positioned above the main entrance. This location features a single, larger panel measuring 80 cm x 180 cm, making it a prominent decorative and functional element. Its size and placement emphasise its role in allowing air circulation at the building's main access point while maintaining a visually striking feature that reflects traditional design motifs.

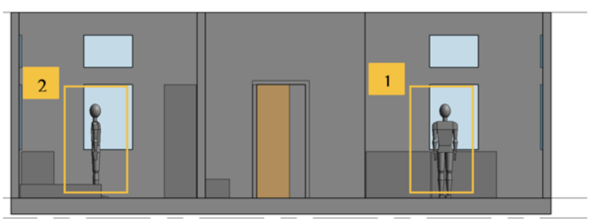

Figure 4. Human figure placement

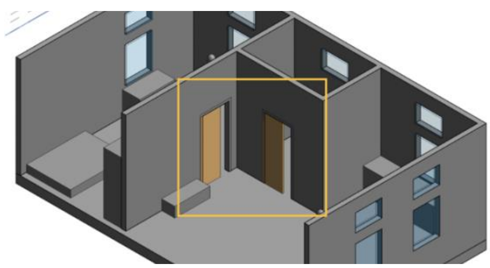

Figure 5. Interior door condition

Figure 6. Woodcarving panels located in Rumah Limas Hutan Bandar MBJB (photo: author)

Table 3. Woodcarving type for Johor situation

Location	Code	Panel	Description
Above the windows & toilet wall	WC1		QTY: 8 Nos Size: 61 cm x 91 cm
Above the main entrance	WC2		QTY: 1Nos Size: 80 cm x 180 cm

6.3. Parameters set up

The external air volume and the materials set-up for the CFD simulations shown in Figure 7 and Figure 8 was carefully defined to reflect realistic environmental conditions. Its dimensions were 1289 mm in height, 3413 mm in width, and 6701 mm in depth, 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.

The height of the air volume was determined to be three times the height of the building geometry, while the width and depth were set at five and six times the respective dimensions of the geometry. This setup, combined with positioning the external air volume at -22.5 degrees, simulated the natural wind flow conditions, which are rarely perpendicular to building facades. The wind direction for Johor is shown in Figure 9. Materials were assigned to the geometry after defining the external air volume, as specified in Figure 9. After creating the external air volume and setting its dimensions, the boundary conditions summarised in Table 4 were applied.

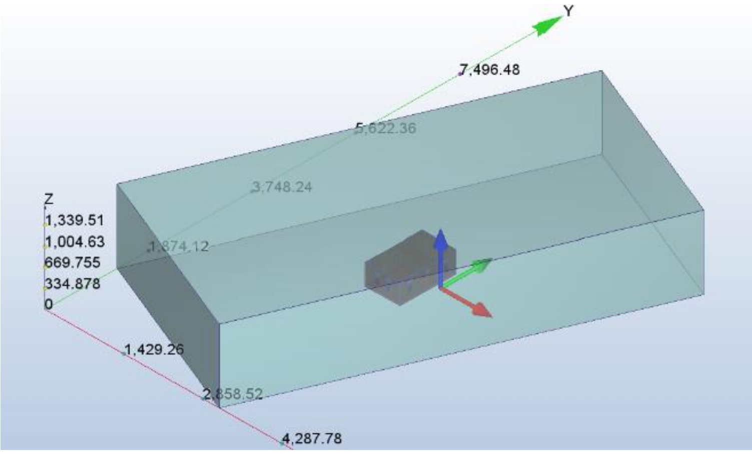

Figure 7. Geometry imported to CFD Autodesk

Figure 8. Materials set-up

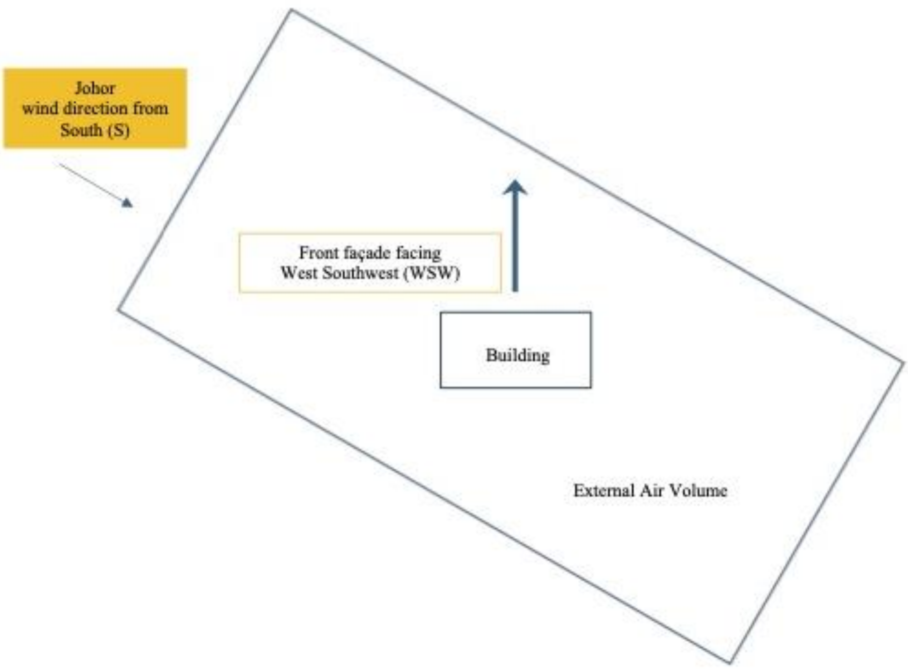

Figure 9. Wind and building front facade direction for Johor

Table 4. Boundary condition for Johor Building

Boundary condition	Value (Johor)	Surface/Volume
Temperature	32°C	north-facing external air volume
Velocity	7 m/s	north-facing external air volume to simulate wind flow
Pressure	0 Pa	South-facing external air volume, acting as the outlet.
Film coefficient	20 W/m²K	entire outer surface of the building
Human	60 W/m²K	two human figures positioned within the building to assess thermal comfort

Material Edits for the Johor Building:

1. Walls:

- Material: Wall 2
- Thermal conductivity: 1.2 W/mK
- Density: 1920 kg/m^3
- Specific heat coefficient: 880 J/kgK

The wall material represents typical brick-plastered walls commonly used in modern Malaysian buildings with a standard thickness of 150 mm (6 inches). This material was saved as Wall 2, allowing it to be applied to other parts of the simulation for accurate thermal performance modelling under different boundary conditions. These material updates ensure that the building components, such as walls, windows, and doors, are accurately represented with their respective thermal properties. This approach enables a more realistic simulation of thermal performance and airflow within the building, considering the climate conditions of Johor. The framework provided allows for evaluating how architectural features and materials influence ventilation and thermal comfort in the modelled environments. A significant challenge encountered during the study was the complex geometry of the woodcarving panels, which rendered them unsuitable for direct import into Autodesk CFD for simulation purposes. Free Area Ratio (FAR) was employed to quantify the airflow resistance of the panels to overcome this. This metric facilitated the representation of the woodcarvings as resistive boundaries in the CFD simulation. By defining the resistance based on the calculated ratio of solid material to open spaces, the airflow through the woodcarving panels was effectively restricted in line with their design characteristics. This approach enabled the accurate modelling of airflow dynamics without the need for detailed simulation of each void in the carvings, thereby streamlining the computational process. The resistive boundary condition was applied in Autodesk CFD, allowing the woodcarving panels' influence on natural ventilation and airflow efficiency within the room to be analysed.

The documentation of the overall and solid areas of the woodcarving panels, derived from SketchUp models, was a crucial step in determining the FAR. This methodology ensured that the panels' cultural and functional significance was preserved while maintaining the practicality of the simulation process.

The formula for calculating the FAR is as follows:

$$FAR = \frac{Total\ Area}{Solid\ Area}\ x\ 100\ .$$

To simplify the simulation process, the complex geometry of the woodcarvings was replaced with a resistance boundary condition based on FAR. The FAR analysis highlights the proportion of void areas in the panels, reflecting their potential for ventilation and structural integrity. Among the four evaluated panels, the first panel, with dimensions of 180 cm x 80 cm, had an FAR of 43.14%. This indicates a moderate balance between solid and void areas, suitable for maintaining ventilation while ensuring structural stability. The second panel, measuring 61 cm x 91 cm, shows a FAR of 37.73%, reflecting a design that leans more towards solidity than ventilation, making it ideal for areas requiring higher coverage. The CFD simulation was conducted as a steady-state analysis to evaluate airflow patterns and natural ventilation efficiency within the modelled room, focusing on how traditional woodcarvings influence ventilation. The simulation began by configuring boundary conditions, with airflow entering through the woodcarving panels, replicating Johor climate conditions. An unstructured grid mesh was employed, with finer elements around the woodcarving panels to ensure accurate airflow capture.

7. Result

7.1. Flow and Temperature Distribution

This section analyses Johor's airflow and temperature distribution patterns, as depicted in the CFD simulations in Figure 10. and Figure 11. These simulations provide insights into how local climatic conditions impact airflow dynamics and thermal comfort within buildings. The analysis focuses on how varying wind speeds and ambient temperatures influence airflow distribution and the resulting temperature gradients inside the buildings. In Johor, a tropical region, the simulation is based on an initial wind speed of 7 m/s and an ambient temperature of 32°C, which reflects the region's typical hot and humid climate. The results show a very mild temperature gradient within the building, with most of the indoor air volume remaining at approximately 32°C. Temperature increases above 32°C occur only in the immediate vicinity of human metabolic heat sources, reaching up to 34°C. This subtle temperature variation indicates that the climate is not excessively hot but still warm enough to affect indoor comfort.

Although solar radiation would normally heat external surfaces, such as walls and windows, transferring heat into the interior, it is important to note that these effects were not modeled in this simulation. Internal heat sources, such as occupants, further contribute to localized temperature increases. The airflow in Johor is steady, with wind velocities ranging from 0 to 10 m/s, suggesting that the natural ventilation effect is relatively mild. In Johor, the steady wind speeds lead to a calm airflow around the building, with minimal turbulence and consistent wind velocities. While this airflow is adequate for maintaining thermal comfort in milder conditions, the relatively gentle airflow might not be sufficient during periods of intense heat, especially in a tropical climate like Johor's. The CFD simulations demonstrate the impact of local climatic factors on indoor airflow and temperature regulation. Moderate wind speeds result in a stable temperature distribution inside the building, with minimal temperature and airflow fluctuations. However, this natural ventilation may not be sufficient for cooling during extreme heat.

Figure 11. illustrates the airflow distribution inside the building, with colour contours ranging from blue to light blue, indicating wind velocities between 0 and 7 m/s. The air entering through the woodcarving ventilation panels is spreading throughout the building in an uniform, steady pattern. Despite the moderate wind speeds, the panels effectively allow air to enter the building and distribute it evenly throughout the interior. This contributes to thermal comfort by preventing the buildup of stale air in the building. As a result, the natural ventilation provided by the woodcarving panels significantly contributes to reducing indoor temperatures and improving overall air quality. The woodcarving ventilation panels in the locations are key in improving airflow and enabling passive cooling.

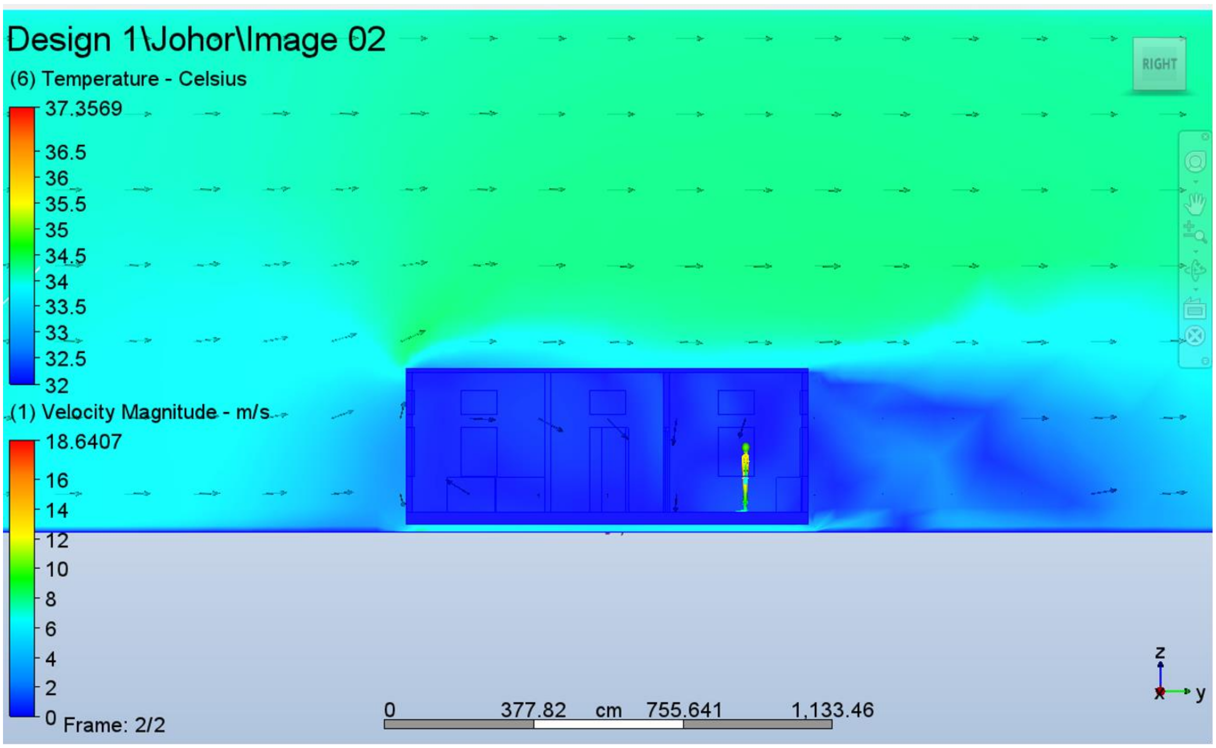

Figure 10. Flow and temperature distribution, vertical plain view

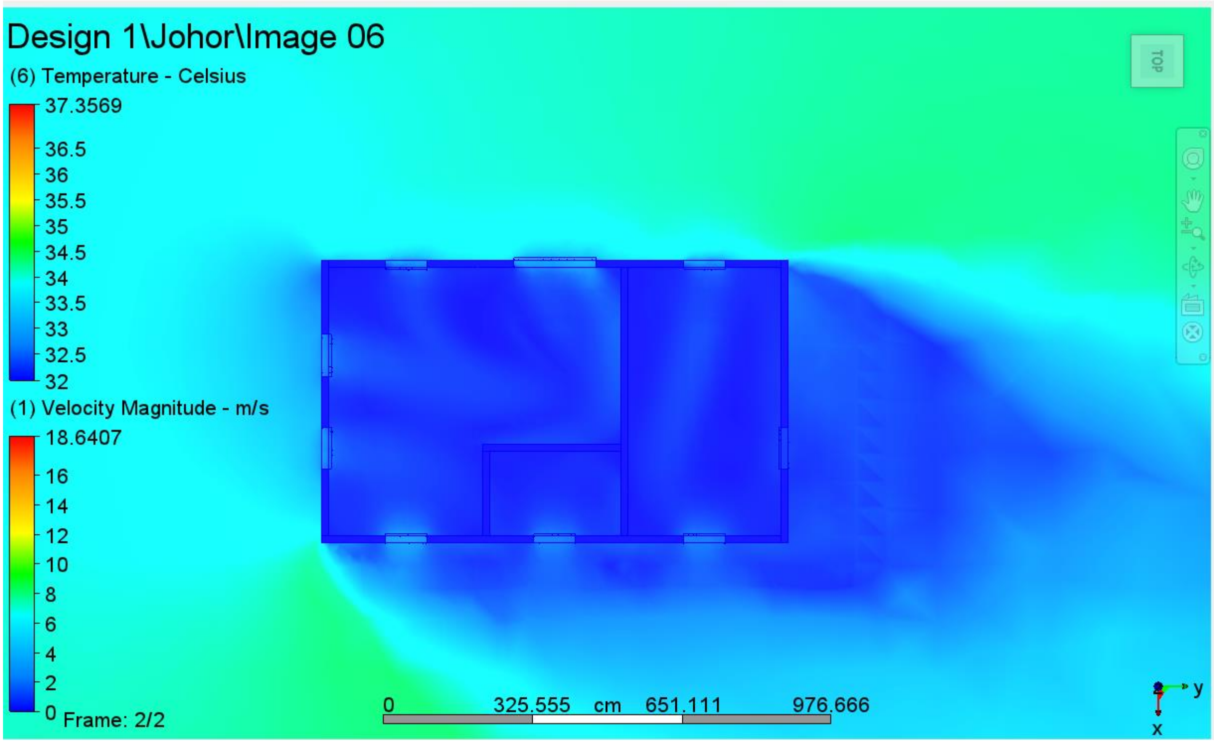

Figure 11. Flow and temperature distribution top plane view

The constant airflow suggests that while the panels provide adequate natural ventilation, the airflow is limited in speed and dynamic movement. It highlights the limitations of passive ventilation in tropical climates.

Table 6. Predicted Mean Vote (PMV) for thermal sensation

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

PMV (Predicted Mean Vote) is an index used to predict the mean thermal sensation of a large group of people based on a seven-point thermal sensation scale.

This scale ranges from cold to hot, with the corresponding values and sensations shown in Table 6. Figure 12. illustrates how the high temperatures in Johor contribute to elevated PMV values, indicating significant thermal discomfort for occupants. PMV, a widely used index for assessing thermal comfort, ranges from -3 (cold) to +3 (hot), with higher values indicating increasing discomfort. In Johor, PMV values range from 2.4 to 3.

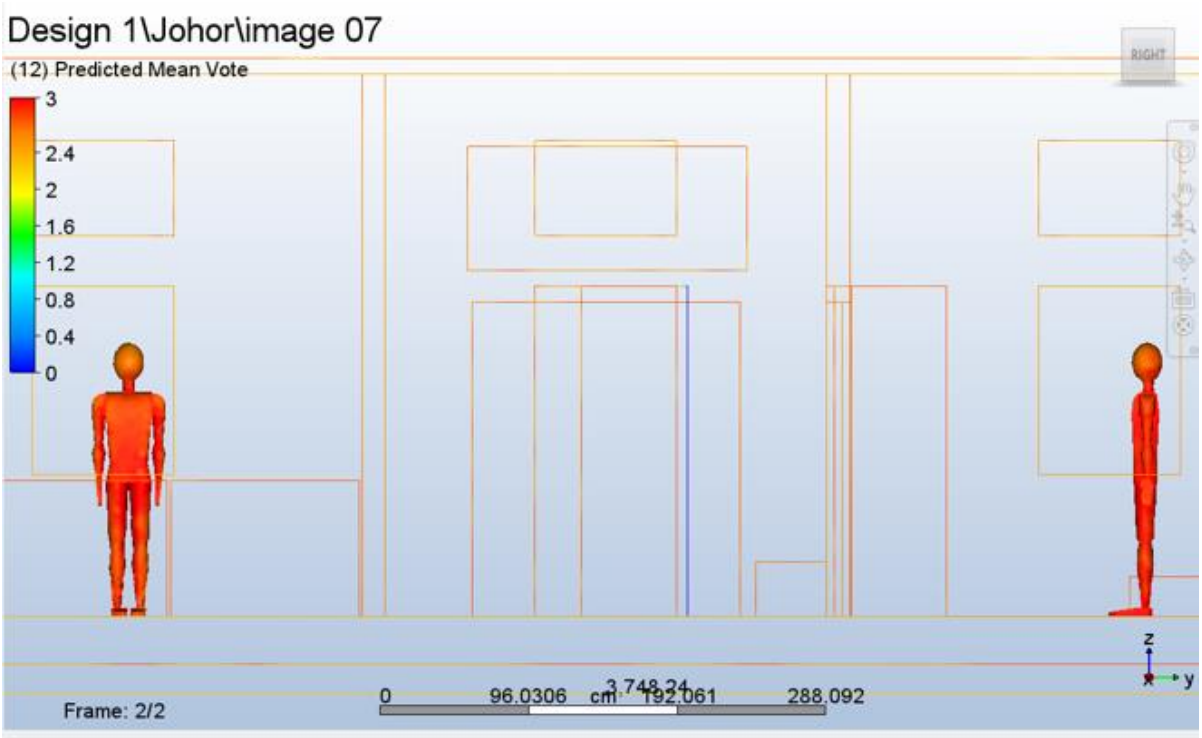

Figure 12. Human figure's positions

In Johor, a tropical climate characterised by high temperatures and humidity, thermal discomfort is exacerbated. Despite a moderate wind speed of 7 m/s, the consistently high temperatures lead to PMV values between 2.4 and 3, shown in Figure 13. and Figure 14., indicating heat stress. While woodcarving ventilation panels help with passive airflow, the temperatures remain high enough to undermine their effectiveness in achieving thermal comfort. Although the woodcarving panels offer some passive cooling by improving natural airflow, the high temperatures remain the dominant factor causing thermal discomfort. In climates with extreme heat, passive ventilation alone is often insufficient to achieve optimum thermal comfort. This is reflected in the high PMV values observed, highlighting the limitations of relying solely on passive cooling solutions. Integrating HVAC systems is essential to address this issue and ensure optimal thermal comfort. HVAC systems provide active cooling and dehumidification, supplementing the natural ventilation provided by the woodcarving panels. This combination improves air circulation, lowers indoor temperatures, and reduces PMV values. In Johor, where heat is persistent, HVAC systems can further enhance cooling during the hottest months, ensuring a comfortable indoor environment.

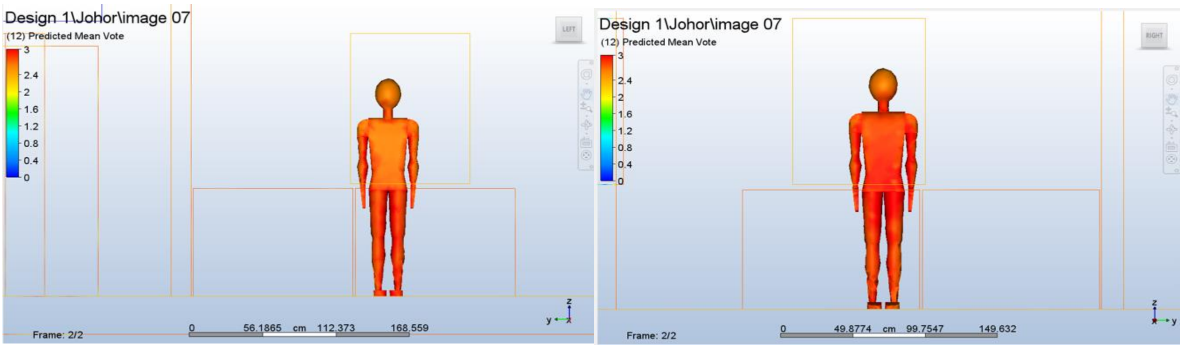

Figure 13. First human figure front and back

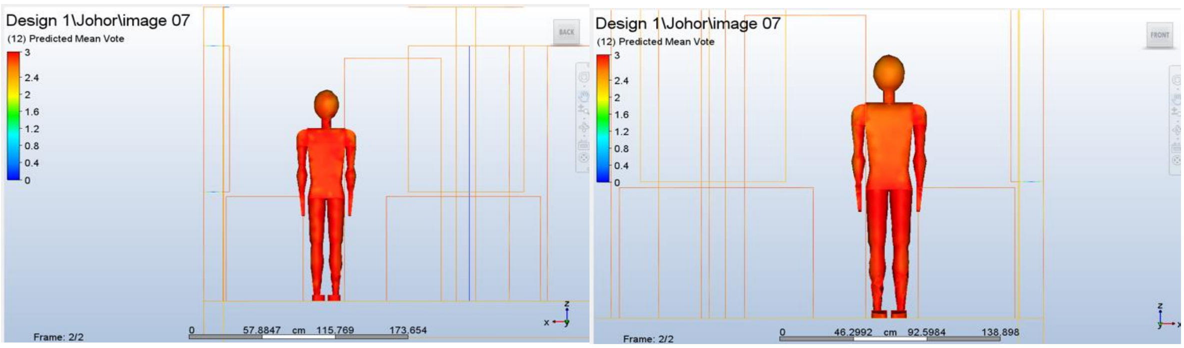

Figure 14. 2nd human figure front and back

4. Conclusion

The results of this study demonstrate the importance of woodcarving ventilation panels in enhancing natural airflow and facilitating passive cooling in indoor spaces. Although wind speeds in the regions studied were moderate, the design of the woodcarving panels proved to be effective in allowing air to enter the building and distribute it evenly throughout the interior. This airflow distribution is critical in preventing the accumulation of stale air, which can contribute to thermal discomfort. The natural ventilation provided by these panels plays a significant role in reducing indoor temperatures, especially in spaces that rely on passive cooling solutions. By improving airflow, the panels help to prevent the stagnation of warm air inside the building, which can causes heat buildup and discomfort. This dynamic airflow helps maintain a more stable and comfortable indoor environment, even without active cooling systems.

In addition to temperature regulation, improved airflow contributes to better indoor air quality by promoting fresh air circulation. This is especially important in maintaining a healthy indoor environment, as stagnant air can lead to higher levels of CO_2 and humidity, which can negatively affect occupant comfort and health. Therefore, the woodcarving panels not only provide aesthetic and cultural value but also enhance the functionality of the building by supporting passive cooling and improving overall indoor air quality. However, while the panels effectively improve airflow and indoor temperatures to some extent, their performance still depends on external factors such as wind direction, speed, and ambient temperature. In climates with extreme heat or where wind conditions are less favourable, relying solely on passive ventilation may not be sufficient to achieve optimal thermal comfort.

To strike a balance between natural ventilation and HVAC efficiency, the panels should remain open during favorable conditions for passive cooling, but for periods of extreme heat or when the natural airflow is insufficient, the system should be supported by HVAC to prevent energy loss, ensuring optimal thermal comfort inside. While woodcarving ventilation panels offer significant passive cooling benefits, it is essential to consider integrating active systems, such as HVAC, for spaces where passive cooling alone is insufficient. Combining passive and active strategies ensures that buildings can maintain optimal thermal comfort and air quality throughout the year, addressing the challenges of varying environmental conditions.

Ultimately, this study underscores the value of combining traditional architectural features with modern technologies, providing a more holistic approach to building design that balances cultural heritage, sustainability, and occupant comfort.

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