THE EFFECT OF PERFORATED GEOMETRICAL MASHRABIYA AND MALAY CARVING WINDOWS TO THE NATURAL VENTILATION PERFORMANCE

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ABSTRACT

Natural ventilation has the potential to significantly reduce the energy consumption and carbon dioxide emissions associated with mechanically ventilated buildings. Cross ventilation has been proposed as one of the most effective natural ventilation methods for thermal comfort by several studies. It is, however, one of the most misunderstood aspects of passive design's approach to regulating interior temperature. The application of Mashrabiya and the traditional Malay wood carving in modern buildings has proven the misusage of their functions, especially for ventilation, due to the misunderstanding of their original function in their traditional form. This study focuses on natural cross-ventilation improvements in internal air velocity, measured in meters per second in the living room space in Malaysia, using two types of perforated windows, namely, the Mashrabiya window and a perforated Malay carving window element. The study aims to investigate Mashrabiya and Malay carving perforated window elements to determine the design of perforated windows that enhances indoor natural ventilation performance. The aim is achieved by identifying the design of Mashrabiya and Malay carving as window elements and by evaluating the air velocity performance of Mashrabiya and Malay carving as window elements for indoor comfort to determine the best design criteria for perforated window design to achieve the best indoor natural ventilation performance. In this study, the proposed design solution is by introducing the Mashrabiya (W1) and perforated Malay carving window (W2) as two predominant indigenous solutions for traditional houses that can be further developed and utilized in modern houses. The research involves three stages. The first stage includes the inventory exercise on five different reference case studies of perforated windows. This is to ascertain the most fundamental and common pattern, as well as the dimensions of each W1 and W2. The second step involves computer simulations utilizing Computational Fluid Dynamics (CFD) software known as Ansys fluent R2 2021. This program is used to simulate and evaluate natural air velocity and its performance in an interior context and to determine the viability of a recommended design solution. Finally, an empirical method is used to predict the internal air velocity. The result shows that W1 and W2 represent effective passive design strategies for energy saving. The air velocity using W1 is three times higher than the normal speed, which is 4.5/1.5 m/s while using W2 makes the air velocity two times higher than the actual airspeed, which is 3/1.5 m/s. The simulation test and results are discussed based on the Malaysian region with a 1.5 m/s wind speed. Understanding the different effects of the size of the voids and the placement of the patterns are significant to improving the indoor natural ventilation performance in a living room space.

Keywords: Mashrabiya, Malay Carving, Window, Natural Ventilation, Computational Fluid Dynamics (CFD)

1.0 INTRODUCTION

Natural ventilation (NV) is a low-cost method of cooling houses, but its capability and efficacy must be understood. In tropical houses, for example, natural ventilation is the dominating strategy in comparison to other passive techniques, providing a viable option for zero-energy buildings in hot-humid conditions (Sakiyama et al., 2020). The past inspires the modern façade treatment, one of the important elements of designing the façade is the window design.

One of the main references for the perforated window treatment is the Mashrabiya and perforated Malay element window design. For centuries, the Mashrabiya as a standard architectural element and social component, the element was utilized to control the passive cooling system. Malay woodcarving is one of the main elements of façade treatment in the hot and humid environment of Malaysia which is the cross-ventilation main controller in the Malay house. While a person is sitting inside a room decorated with Mashrabiya or Malay carving perforated window, the person enjoys the aesthetic of the textures of the diverse patterns of shadow and light (Alaa, 2016). Mashrabiya and Malay carving windows are outstanding elements that are universally distinguished by their environmental and cultural values. It is quite essential to design buildings with more functional, sustainable, and aesthetical values. However, the efficacy of this approach has not been rigorously tested.

Historically, several architectural solutions were discovered by the ancestors. These ideas were not developed and are thus no longer suitable for modern developments. As a result, there is an urgent need to look back into the ancient window elements and integrate them with modern usage. Reviving traditional architecture faces huge obstacles, requiring the establishment of ideas for future architecture and the development of strategies aimed at preserving regional identities (Abdelkader, 2017). The use of Mashrabiya and Malay carving elements as regenerative heritage window elements is ignored in several modern houses. This includes bigger shaded windows that limit solar heat intake while increasing cross-ventilation throughout the house and reducing air conditioning dependency (Salamah, 2019).

The decorated perforated window element is the main element of natural ventilation and the most crucial multifunctional element that should be implemented in modern housing design, especially in the living room. Perforated panels are a helpful technique for addressing contemporary home ventilation concerns (Othman, & Abdul Majid, 2017).

2.0 LITEATURE REVIEW

2.1 Indoor Natural Ventilation (NV)

The widespread belief about ventilation is that fresh air coming from outside reduces pollutants generated inside the building. This is also the notion upon which ventilation rate recommendations are based. Natural ventilation and air movement may be classified as structural controls since they are not dependent on any sort of energy source or mechanical equipment (Lipinski et. al, 2020). It has three unique functions that are to provide fresh air and convective cooling and to apply physiological cooling.

According to Ward (2008), the Provision of permanent ventilators for openings that are permanently open is required. These kinds of ventilators can be placed into a wall as grilles or 'air bricks,' or they might be combined with windows such as Mashrabiya or Malay carving element window design. While the size of openable windows may be specified in proportion to the room's floor area or volume. Convection cooling is a natural ventilation concept that refers to the interchange of interior air with fresh outside air that may offer cooling if the outside air is cooler than the indoor air. According to Phuong et.al, (2019), the stacks effect refers to the passive passage of air through a structure caused by changes in vertical pressure caused by thermal buoyancy when the air within a structure is warmer than the outside air, less dense air rises as shown in Figure 1.

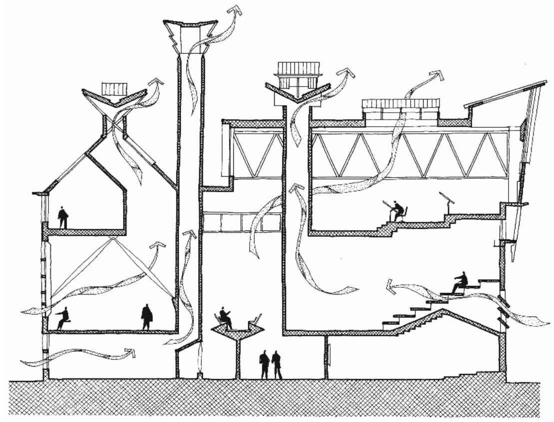


Fig. 1: Stack effect
(Source: Banham, 2022)

2.2 Air Movement

Air movement is essential for physical comfort because it improves heat transmission between air and the human body and speeds up the cooling process. According to MS 1525:2019, air movement in an inhabited area provides a sense of freshness by decreasing skin temperature, and the more diverse the air currents in velocity and direction, the greater the impact. According to the Beaufort wind, the scale of wind differs based on height and speed as shown in Figure 2.

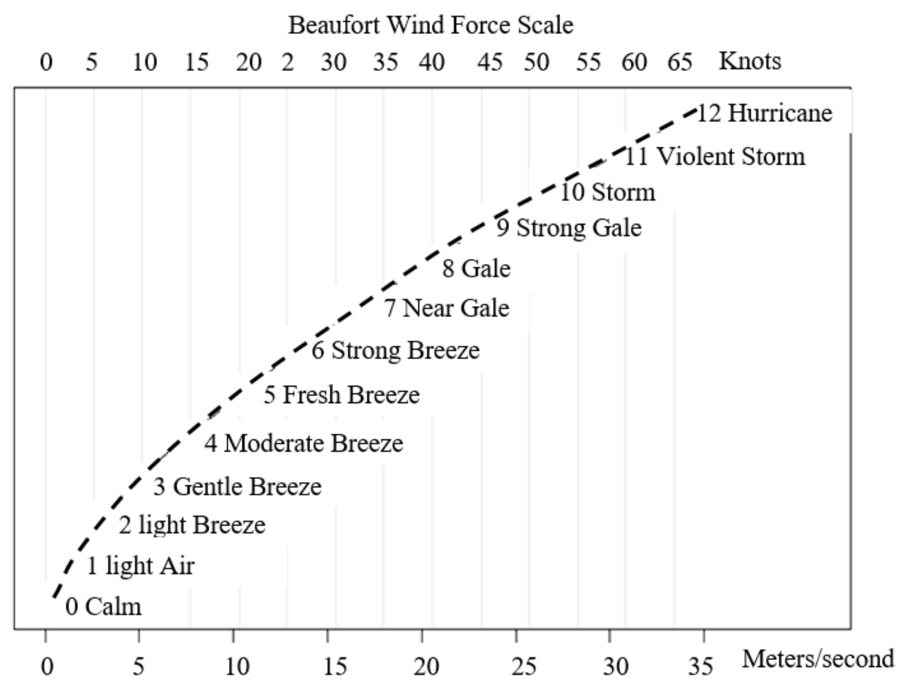


Fig. 2: Wind scale
(Source: Wheeler, D., & Wilkinson, C., 2004)

Thermal comfort is affected by air movement; the presence of air movement promotes evaporative and convective cooling from the skin, which may further improve the occupant's thermal comfort. The effect of airspeed on passengers' sensations is shown in Table 1 (Department of Standards Malaysia, 2019).

Table 1 Effect of wind on occupants

Air speed (m/s)	Mechanical effects	Occupant sensation
= < 0.25	Smoke (from cigarette) indicates movement	Unnoticed, except at low air temperatures
0.25 – 0.5	Flame from a candle flickers	Feels fresh at comfortable temperatures, but draughty at cool temperatures
0.5 – 1.0	Loose papers may be to moved. Equivalent walking speed	Generally pleasant when comfortable or warm, but causing constant awareness of air movement
1.0 -1.5	Too fast for deskwork with loose papers	Acceptable in warm conditions but can be from slightly to annoyingly draughty
> 1.5	Equivalent to a fast walking speed	Acceptable only in very hot and humid conditions when no other relief is available. Requires corrective measures if comfort and productivity are to be maintained

2.3 Thermally Comfortable Indoor Requirements

Malaysia is a humid tropical country located between the Tropics of Cancer and Capricorn. The latitude ranges from 1 to 7 degrees north and the longitude ranges from 100 to 119 degrees east. High temperatures and a consistent diurnal rhythm throughout the year are among the climatic factors. Daily maximum temperatures range between 34°C and 23°C. Temperatures average 26.4°C each year (Al Tamimi & Syed Fadzil, 2011). A healthy indoor living environment and a good quality of life need a comfortable indoor climate. Human thermal comfort has been linked to several variables, including air temperature, air movement, the number of clothes worn, and activity level, as well as the human body itself (Randall, 2006). Regardless of the surrounding temperature, the human body temperature must be kept constant at 37°C.

2.4 Wind Conditions In Malaysia

Air movement cooling is most necessary when no other means of heat dissipation are available when the air is as warm as the skin and the surrounding surfaces are equally heated. Air passing across the skin surface promotes heat dissipation by enhancing convective heat loss and evaporation. Malaysia is subjected to greater winds in the early and late seasons. Malaysia's yearly means wind speed is 1.5 m/s. However, cities on the Malaysian east coast, such as Mersing, Kota Baharu, and Kuala Terengganu, are subject to stronger winds. The wind in Malaysia is blowing inward and outward between South-West (SW) and North-East (NE), therefore the model for the test is set to be facing the major source of the wind flow which is the North.

Thermal comfort requires air circulation inside buildings to be regulated between 0.1m/s and 1.5 m/s (Nugroho, et al, 2007). The air velocity in the Malaysian climate with a maximum of 1.5 m/s based on the wind rose for Kuala Lumpur, Malaysia in Figure 3. To minimize irritation effects (papers, light items blown about) under hot circumstances, Szokolay, S. (2012) recommended that 1.0 m/s would be the most pleasant air velocity and 1.5 m/s is within an acceptable range. There is no cooling impact when the air velocity is less than 0.25 m/s.

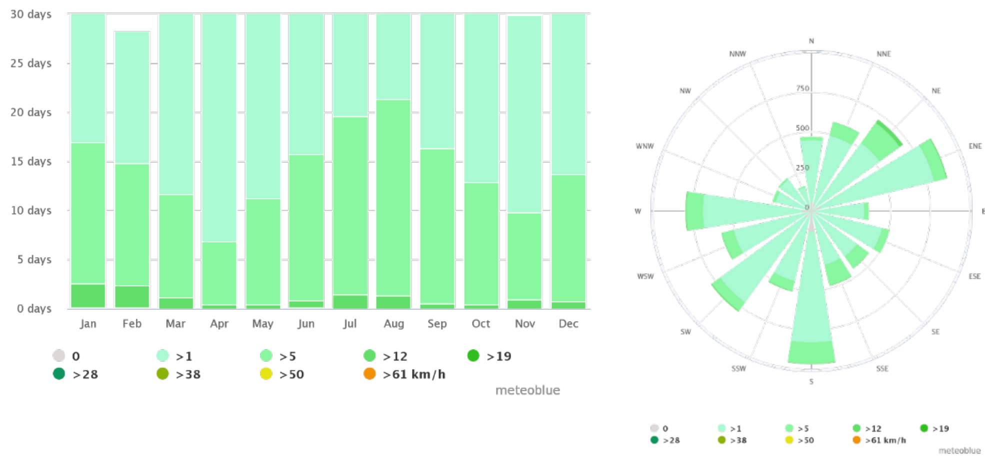


Fig. 3 : Wind rose Malaysia
(Source: Meteoblue, 2021)

2.5 Window Types

Window types vary in terms of shape, size, design, materials, and function while it might be fixed to the wall for viewing purposes only or might be openable and adjustable for ventilation purposes. When selecting a window sash, window functioning is an important factor to consider. A variety of window operations should be considered to meet ventilation, operability, screening, and daylighting needs, with a variety of designs and functionalities suited for certain scenarios. As shown in, (a, b, c, d, e, f, and g) represent the types of inlets that affect ventilation performance inside an enclosed space (Moore, F., 1993).

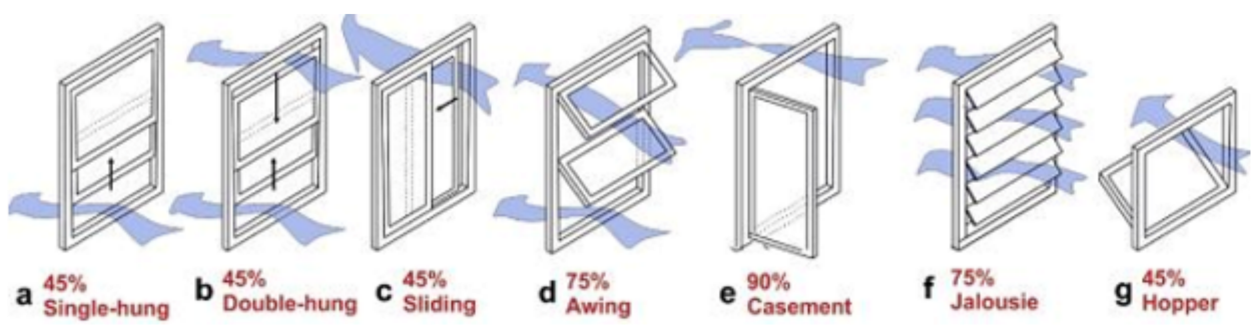


Fig. 4: Types of inlet openings
(Source: Moore, F.,1993)

There are some basic elements of ancient Arab architecture that are considered successful architectural solutions created by the ancestors, in which the air temperature in the long summer months is taken into consideration. The invented perforated elements overcome the harsh climate with simple solutions. More studies on the historical natural ventilation elements are required to regenerate and develop these elements to be applied in modern architecture today. One of the most important traditional architectural innovations is the traditional perforated Mashrabiya window as well as the Malay carving window which are used to distribute air and direct it into the interior of the building, and they vary based on climatic regions in terms of function and pattern of the incoming air.

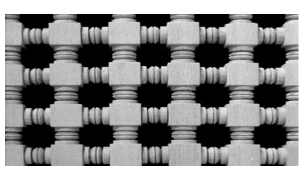
2.6 Theories Of Natural Ventilation

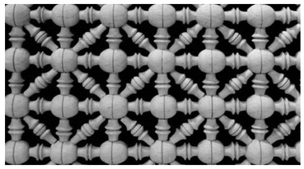
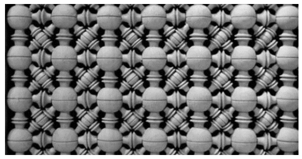
Daniel Bernoulli's principle is the theoretical method that led to the concept stated by him in the 1700s. In 1738, Daniel Bernoulli published his study on fluid mechanics (Mikhailov, G. K. 2005). He was a mathematician who devised a formula that mathematically describes how increasing the flow rate of fluid leads to a reduction in the static pressure produced by that fluid. The Law of Conservation of Energy is used in this calculation. According to Daniel Bernoulli's principle, the fluid must transform its potential energy into kinetic energy to increase its speed. The static pressure declines as velocity rises. The Venturi effect also contributes to the validation of the simulation findings, since it relates to the rise in fluid velocity caused by a reduction in the flow section in restricted flows. Giovanni Battista Venturi (1746-1822), an Italian scientist, researched the area of fluid mechanics and published his findings in 1797. These findings pertain to fluid flow within a constricted tube, where he found that fluid motion occurs at a greater velocity in the region with a short section area yet at a lower static pressure value. The region with a larger section area had a lower fluid velocity but a higher static pressure, indicating that the perforated Mashrabiya and Malay carving window enhance the indoor air velocity.

2.7 Perforated Mashrabiya And Malay Carving Window

Mashrabiya window is a decorative element made of wood and carved into geometric embellishment (El Semary et al., 2017). The variety of designs of Mashrabiya reflects distinctive characteristics, creating a unique harmony in the house's interior (Alaa, 2016). Mashrabiya size is related to the proportions of the human body. A typical single traditional Roshan unit is 3 meters in height, and 2.3 meters in width (Ashour, 2018). Mashrabiya window can be classified into simple, moderate, and complex forms as shown in Table 2.

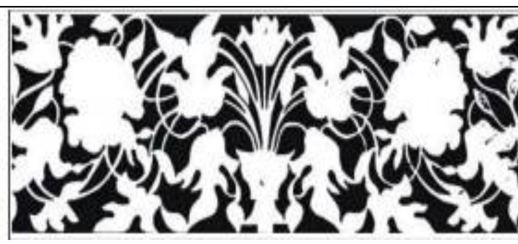
Table 2 Classification of Mashrabiya types.

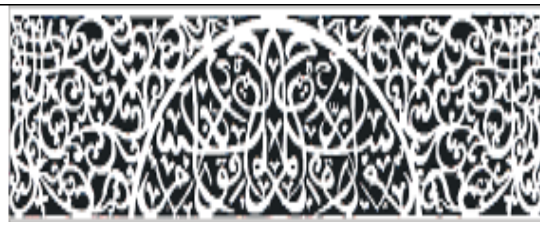
Complexity rate	Picture	Description
Simple		The large size of connected cubes with equally large voids horizontally and vertically into a repeated frame.

Moderate		A composition of balls connected with long diagonal, horizontal, and vertical balusters with a small size of voids.
Complex		A composition of balls connected with short diagonal, horizontal, and vertical balusters with a smaller size of voids.

The perforated Malay carving window is a Malay traditional wooden window that has a variety of carvings that demonstrate superior workmanship According to Kamarudin and Ismail (2011), Malay carving panels are classified into three basic patterns which are single, frame, and complete with distinct carving forms and sizes. These carved features include ventilation panels for walls, doors, and windows, and railing panels for windows. As shown in Table 3, the Malay carving is mainly a floral pattern with different levels of intricacy and the most complicated pattern is the one that contains a combination of floral pattern and calligraphy. According to Kamarudin and Said (2011), perforated Malay carving windows can be classified based on complexity to be in a simple, moderate, and complex form.

Table 3 Classifications of Malay carving types

Complexity rate	**Picture**	**Description**
Simple		Combination of relief and perforation forms.
Moderate		An example of perforated wall panels is an asymmetry shape centered on an axis and carved with floral designs at the Dato Biji Sura residence.

Complex		An example of a wall panel carved with a calligraphy motif in the traditional style.

3.0 METHODOLOGY

The research method is based on two approaches which are: the first step is conducting an inventory exercise on the most common five samples studies to identify and record the existing Mashrabiya and perforated Malay carving window elements, while the second step is simulating and evaluating Mashrabiya and perforated Malay carving window element and their performance on the natural ventilation of the living room space using Computational Fluid Dynamics (CFD) Ansys fluent R2 software. The simulation test is conducted on the most common pattern of each Mashrabiya window (W1) and perforated Malay carving window (W2), as shown in Figure 5 where the Mashrabiya window (W1) is mainly a geometrical pattern while perforated Malay carving window (W2) is mainly floral.

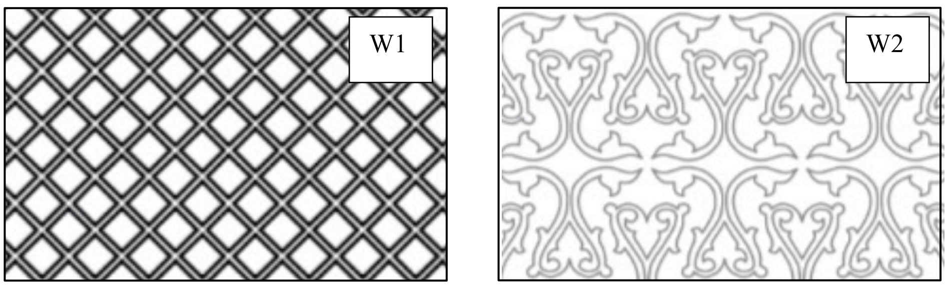


Fig. 5: Mashrabiya window (W1), Malay carving window (W2) in 3D AutoCAD

3.1 Computational Fluid Dynamics (CFD) Computer Simulation

Computational Fluid Dynamics CFD simulation in Ansys fluent 2021 R2 software simulates and predicts the behavior of all fluids, including gas. The geometric Mashrabiya design and floral perforated Malay window carving will serve as variables. CFD gives whole-flow field data, offers complete control over boundary conditions, and enables simple and fast parametric analyses .The natural airflow is tested using CFD simulation software to compute the natural airflow rate and velocity. The simulation is conducted to determine and compare the change in the airflow by the installation of perforated windows, which is Mashrabiya or Malay carving. CFD Ansys 2021 R2 is most widely used as an alternative for the testing to predict the flow behavior through Navier-Stocks equations and various turbulence models along with visual effects for the results obtained. Figure 6 shows various steps to execute a CFD simulation. After preparing the selected pattern of the Mashrabiya window and Malay carving window, domain discretization, i.e., meshing and physics definition is done for the system. The solver computes the results which can be visualized using post-processing (Jaat, N. et, al. 2019).

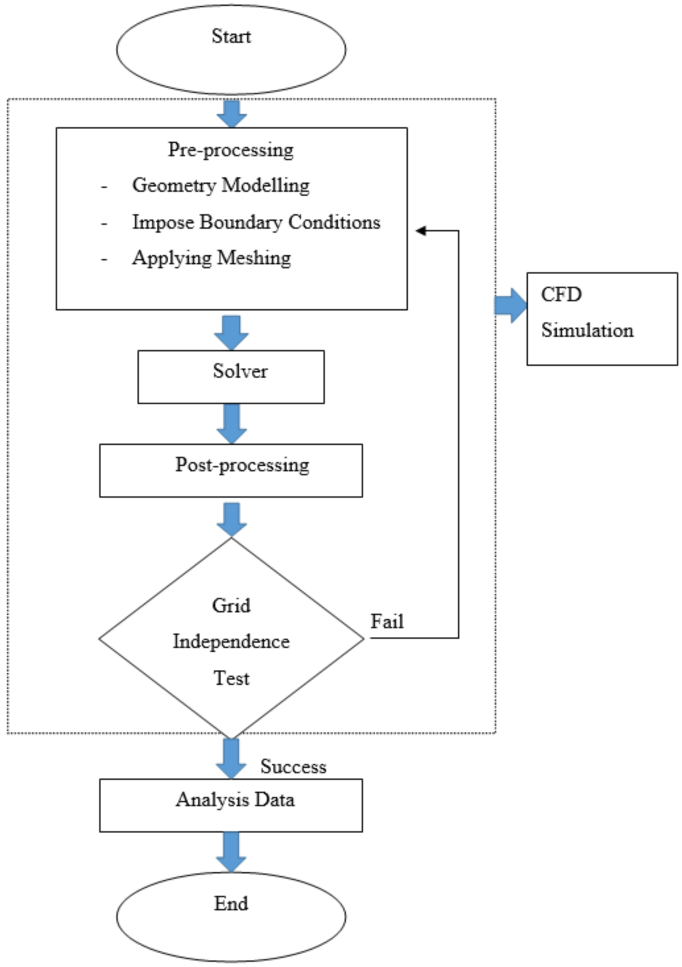


Fig. 6 The Ansys Fluent process
(Source: Jaat, N. et, al. 2019)

3.2 Setting Up The Model Conditions And Process

The tested field for CFD simulation is two rooms with 3000 mm x 3000 mm x 3000 mm dimension as a controlled domain of the study as shown in Figure 7. The Mashrabiya is 2.4 m to 2.7 m in height which is tall enough to stand for an average person with a full-sized bed width of 2.3 m in width (Germanà, 2018). Each room has a window as well as a door with a standard size of 2200 mm x 900 mm as an outlet that is fully open.

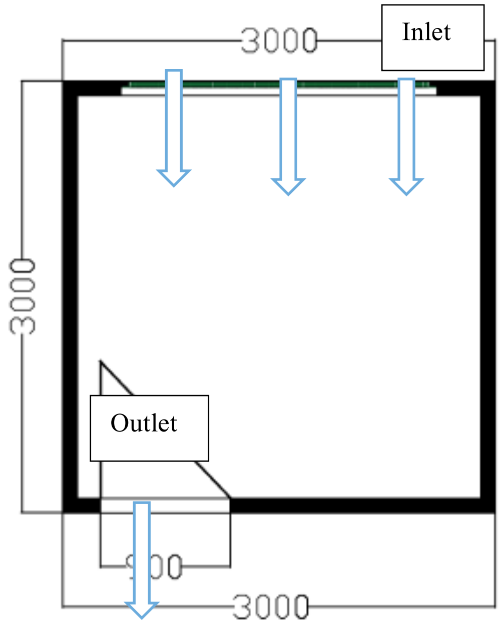


Fig. 7: Floor plan of the tested living room

Mashrabiya window (W1) and perforated Malay carving window (W2) are relatively similar in terms of solidity and voids which makes each of W1 and W2 contain three levels of perforated pattern sizes which are fine (estimated 20 mm void) in the lower part, bigger (estimated 50 mm) in the middle part as well as the biggest in terms of void (estimated 75 mm) in the upper part of the window. The three levels are divided based on the literature to represent a typical shape of Mashrabiya and Malay carving window with controlled dimensions of the window within 2200 mm width and 2700 mm height.

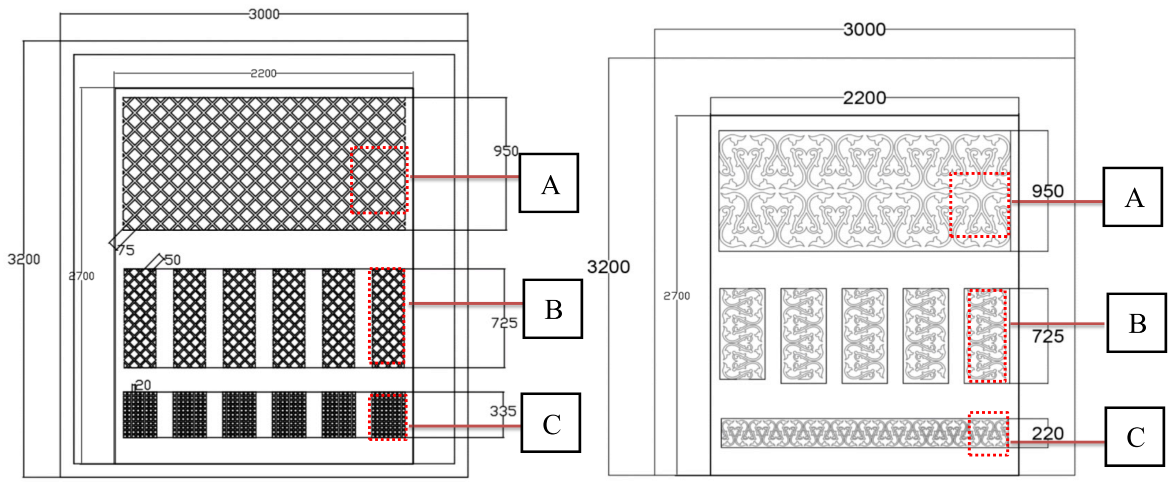


Fig. 8: Proposed common Sample of Mashrabiya (W1)
and a common Sample of Malay Carving (W2)

In Figure 8, (A) illustrates an estimated smallest void of Mashrabiya geometrical pattern and Malay carving floral pattern, (B) represents a bigger void, and (C) shows the biggest pattern voids as a window panel chosen for the CFD simulation. AutoCAD extrusion and 3D modeling are made after modeling a room of 3000 mm X 3000 mm X 3000 mm dimension for a typical living room.

3.3 CFD Ansys Fluent

The first step after the 3D modeling in CAD format is to export each model to sat format to make it visible by the CFD workbench window. As shown in Figure 9, there are several tools in the CFD simulation, fluid flow (fluent) tool is the best tool to give the required results on natural ventilation performance in the indoor space. The form of the air in this tool is fluid while the walls of the room are set solid.

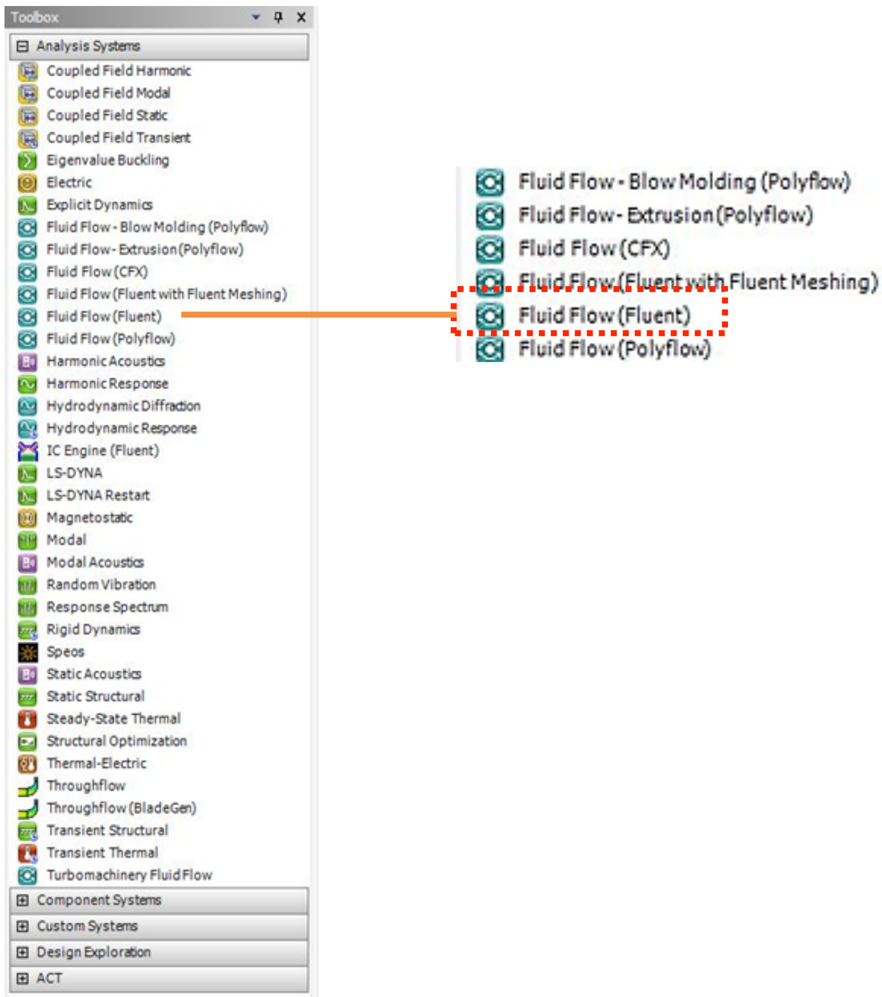


Fig.9: CFD Ansys Fluent R2 2021 toolbar

After choosing the fluent fluid flow, another special toolbar will pop up to start the simulation including the geometry, mesh, setup, and solution, as well as the result as shown in Figure 10. Each step requires some procedure and sequence to move to the next step and reach the result after getting a green tick beside each step.

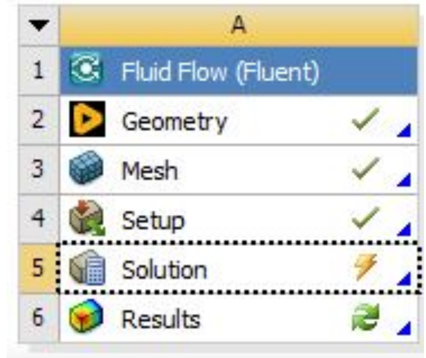


Fig. 10: CFD Ansys fluent process

3.4 Geometry

During the geometry modeling and flow domain stage, the model is dragged into the Ansys fluent window in its Sat format, the geometry of the model can be edited and refined at this stage in addition to the unit set to the millimeter. To simplify the model geometry, the model is edited by using (the Boolean) tool giving the order unite for all models' parts for a smoother process as shown in Figure 11.

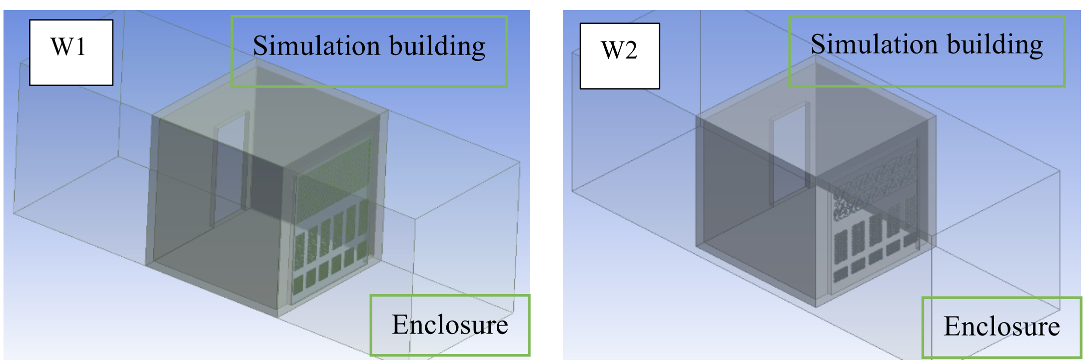


Fig. 11: Ansys fluent design modeler for Mashrabiya (W1) and perforated Malay carving (W2)

Next, boundaries are set using an external domain box with 3000 mm extrusion from the front side, as well as 3000 mm extrusion at the back. The boundary is recognized after determining and specifying the name of each face such as the inlet side as a windward and the outlet as a leeward which are the two sides of the main domain (boundary) as shown in Figure 12, while the other four surfaces in green are set as a fluid boundary without any value.

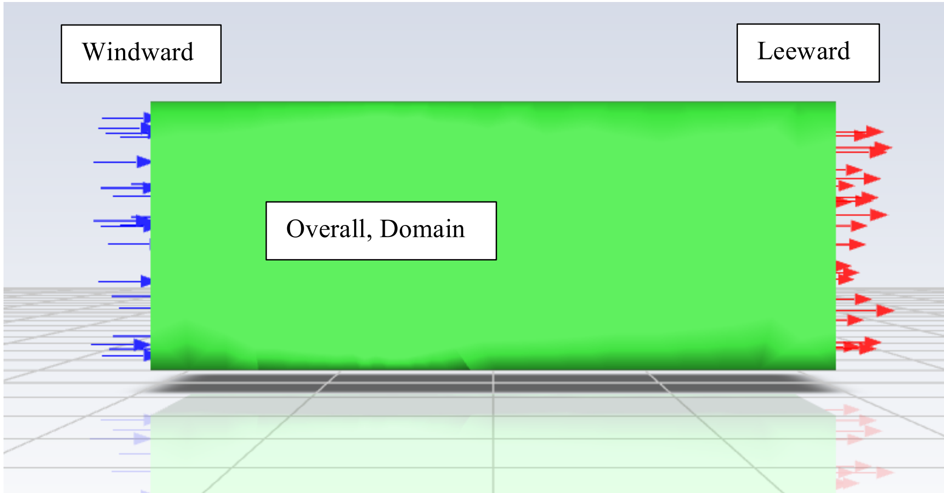


Fig. 12: Boundary domain enclosure setup at CFD

3.5 Meshing

For the stage of meshing production, the size of the body faces is adjusted based on the details of perforated faces, segments and vertex are then changed. The meshing algorithm is set based on the level of fineness that the mesh needs to achieve as shown in Figure 13.

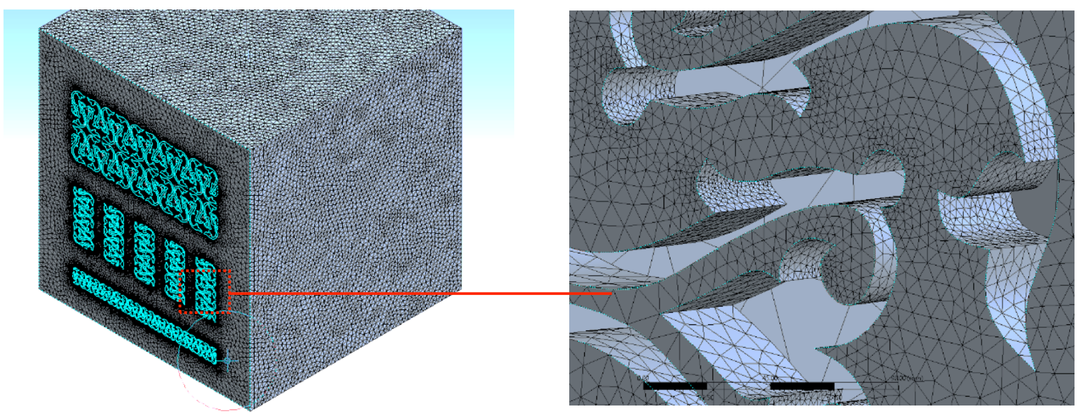


Fig 13: The level of intricacy during meshing generation in W2

The quality and sizing of the mesh are adjusted based on the level of the detail for Mashrabiya and perforated Malay caring, the mesh vertexes and nodes heavily influence whether the simulation can be run or if the results are accurate enough, and it might take several tries to be achieved as shown in Figure 14. During this stage, it is discovered that Mesh generation for Mashrabiya is lower in value compared to the meshing of the Malay carving window due to the higher details and faces that require more vertex.

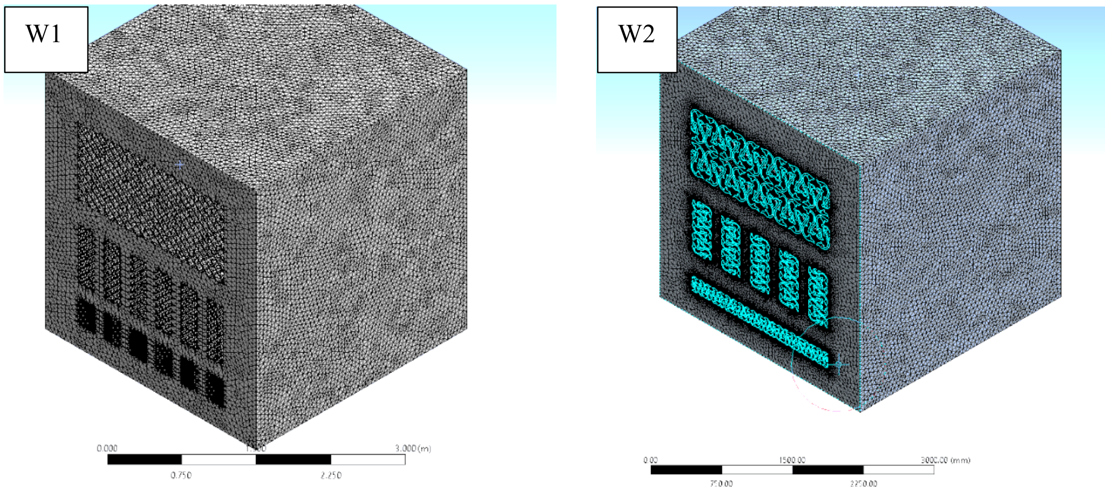


Fig. 14: Ansys fluent design modeler for Mashrabiya (W1) and perforated Malay carving (W2) during mesh generation

3.6 Setting Up

For the setting up conditions as a preparation for a solution, the gravity is set to -9.81 ms², the inlet is set to 1.5 m/s according to the wind velocity average in Malaysia, and an outlet that is leeward is set as a pressure outlet with 0 value. According to the annual average temperature in Malaysia (Al Tamimi & Syed Fadzil, 2011), the temperature is set to be 27°C. As shown in Figure 15, the inlet is facing the Mashrabiya and perforated Malay carving window which is coming from the direct north at degree 0 and with velocity inlet 1.5 m/s, while the outlet is set facing the door opening to such the air and create air movement. The outlet is set with pressure at 0 value to drive the air to it and create natural air movement.

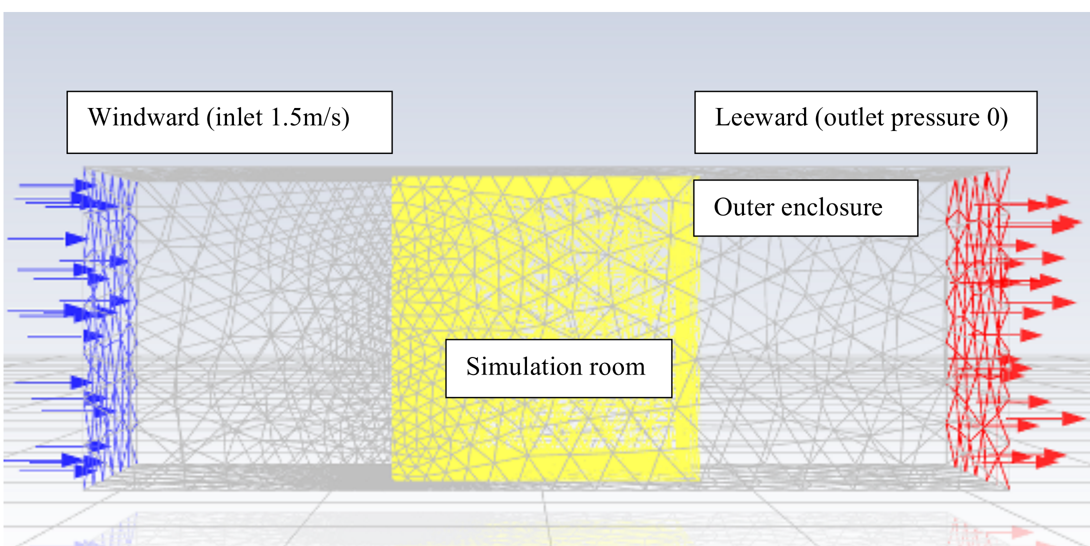


Fig. 15: Inlet and outlet setting

3.7 Solution And Convergence

When the solution is initialized, the starting velocity is set to 1.5 m/s with the temperature at 300 Kelvin (K) which is equal to 27°C. Residual monitoring is done, and convergence criteria are set up. As the simulation proceeds, initiating and calculation are conducted in the next step by specifying the required iterations parameter as well as the reporting intervals, while the number of iterations parameter is set to 100 with reporting interval 1 for both Mashrabiya and perforated Malay carving simulation. Additionally, the residual plot indicates a solution's stability. The presence of sudden spikes indicates that the solution ran into difficulties. Such simulations cannot be relied upon for their outcomes as shown in Figure 16.

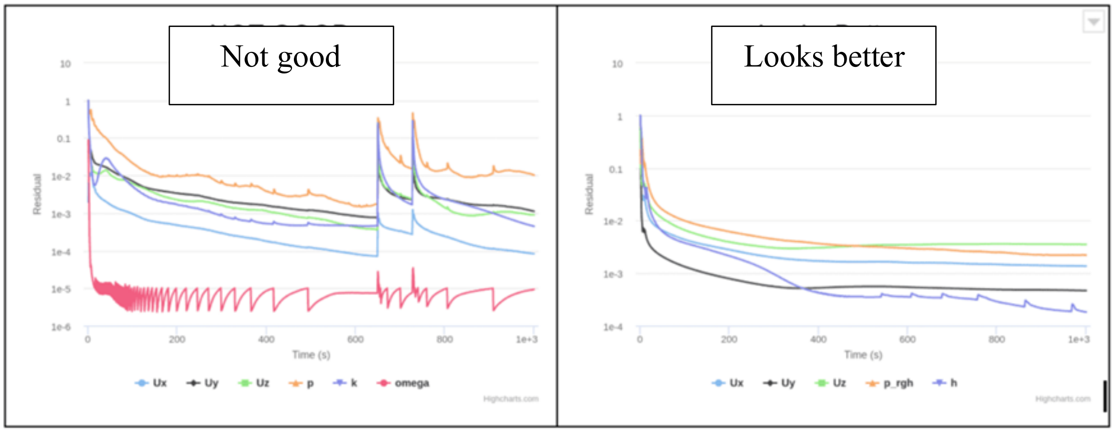


Fig. 16: Comparison of valid and invalid convergence history at CFD
(Source: Oezcan. M, 2020)

Continuity - 0.001, X Velocity - 0.001, Y Velocity - 0.001, Z Velocity - 0.001 are the convergence criterion for different parameters. The iterations continue till the convergence is reached to the closest possible value at 1e-03. Thus, the convergence history is shown in Figure 16, and the validation of the simulation is shown in Figure 17.

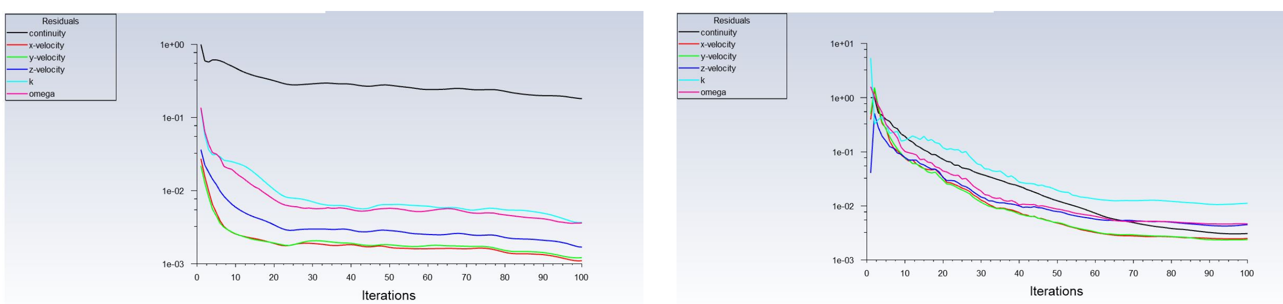


Fig. 17: Convergence history for W1 and W2

4.0 RESULT

The last phase in CFD Autodesk simulation is to solve the simulation. By hitting the "run calculation" button after entering all inputs and data, the simulation calculation will begin. In this research, it is unnecessary to include parameters and instead concentrate on airflow movement. The results are determined based on color-coding, the outcomes display the natural air velocity passing through the Mashrabiya and Malay carving window in both visual and numerical data taken from Ansys fluent simulation program. The result is collected using several methods such as contour, streamline, wind direction vector, set planes, and tapping points. Three horizontal planes are set at three different distances, and three lines crossing the simulation building at three levels similarly in each window type, with a slight difference in tapping point C and the placement of the tapping points at the X axis due to the difference in the solid and void location between W1 and W2 as per shown in Figure 18, Table 14 and Table 15 accordingly.

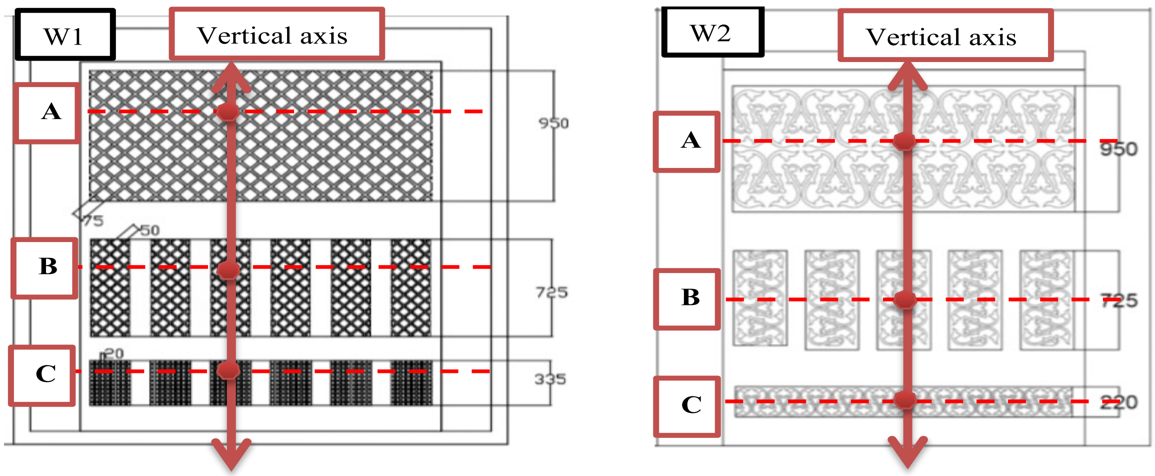


Fig. 18: Tapping points at Mashrabiya window (W1) and perforated Malay carving (W2)

Table 4 Tapping points at Malay carving window (W1)

Tapping Point at Mashrabiya window (W1)	X [mm]	Y [mm]	Z [mm]
A	1500 mm	950 mm	1500 mm
B	1500 mm	725 mm	4500 mm
C	1500 mm	335 mm	7500 mm

Table 5 Tapping Point at Mashrabiya window (W2)

Tapping Point at Malay carving window (W2)	X [mm]	Y [mm]	Z [mm]
A	1450 mm	950 mm	1500 mm
B	1450 mm	725 mm	4500 mm
C	1450 mm	220 mm	7500 mm

5.0 FINDINGS AND DISCUSSION

The researcher chooses one type of perforated Mashrabiya and Malay carving windows in three different void sizes under big, moderate, and small categorization to evaluate their natural ventilation (NV) performance. Indoor environment and thermal comfort under NV mode are usually less predictable than Mechanical Ventilation (MV), and Mashrabiya and Malay carving patterns' impacts on these parameters have not yet been classified. This study aims to investigate the effects of size and design of the perforated window in its both floral and geometrical pattern on the NV performance and thermal comfort of the Living room space. Three different openings in three heights scenarios are defined as simulation tests with nine tapping points as shown in Figure 19, the simulation results reveal that both the perforated windows pattern size and design affected the Indoor Air Distribution (IAD), mean Indoor Air Velocity (IAV), and temperature. The test is conducted at a perforated Malay carving window and a perforated Mashrabiya window at three different heights and two sectional vertical planes. The air velocity is set to 1.5 m/s as the maximum possible wind in the Malaysian region as stated in the Asia-Pacific Wind Industry Daily Newsletter (2022).

Testing is conducted on Mashrabiya and perforated Malay carving. The bands in blue color represent the zones with low prevailing air velocity, the area with medium air velocity is characterized by yellow to orange color, and the dark orange to red color indicates a higher airspeed, where natural ventilation is adequate to provide comfortable indoor environments. Based on the simulation illustrated in streamline plots, the yellowish-orange color refers to the higher velocity of the airflow through the perforated windows while dark blue refers to a minimum airspeed.

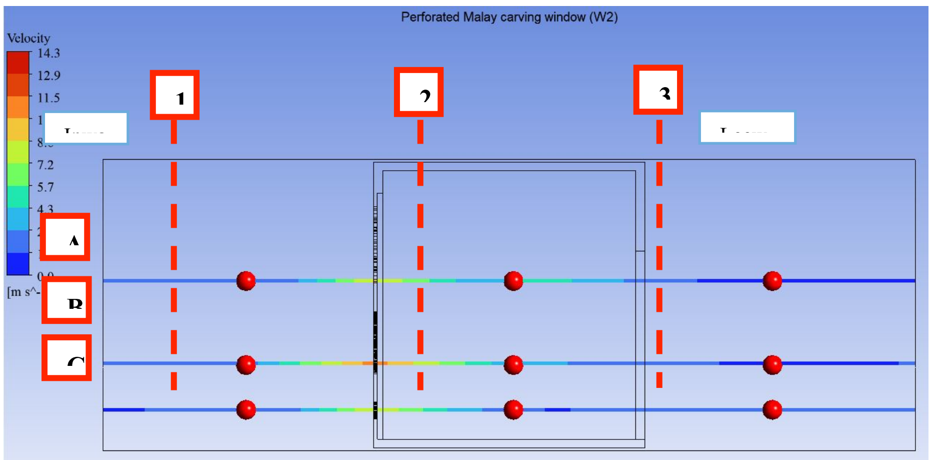


Fig. 19: Tapping points and axis sectional view

Table 6 Analytical comparison between W1 and W2

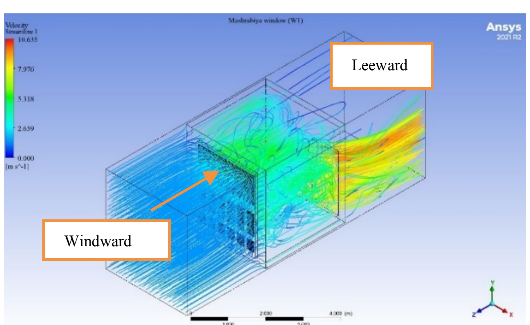
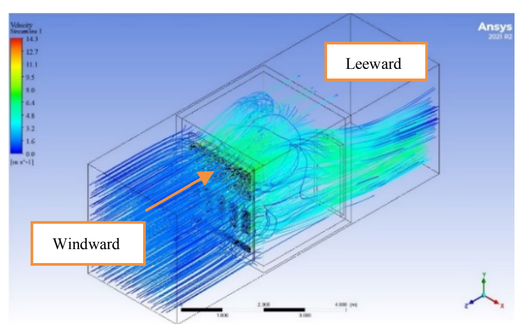
W1 velocity streamline	**W2 velocity streamline**
	
A clear high velocity of natural air passes through the W1 perforated window increasing air velocity to reach its peak at the outlet of the room at 3.2 m/s maximum value.	Less air velocity occurs while the Indoor air velocity is still considered as a comfortable airspeed at 2.6 m/s maximum value.

Table 7 Visualization result and descriptive result

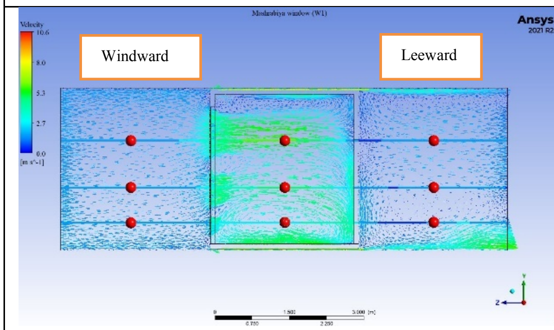
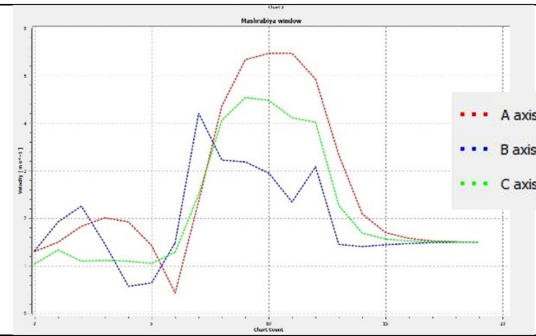
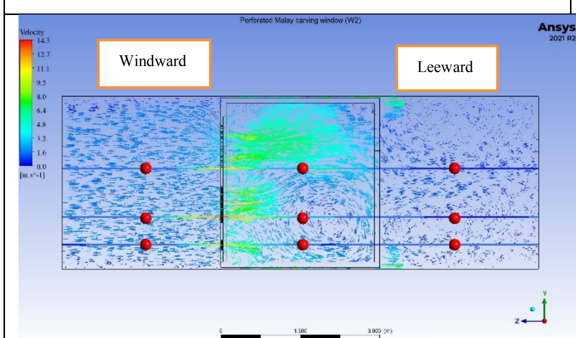
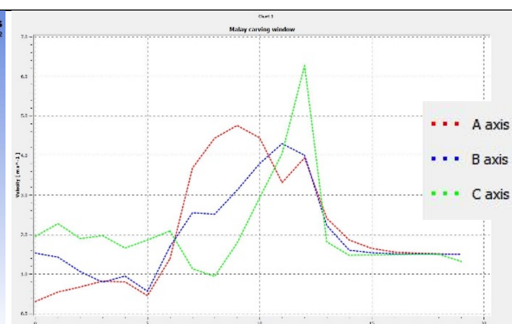
Vector plot at W1	**The line graph at W1**
	
W1 got a high velocity of airflow heading towards the outlet in a downward straight air movement. In 0.8 m/s air velocity.	An axis in the red color line shows the highest air velocity. B axis in blue color line shows low air velocity with fluctuated speed, while C axis in green color line shows medium air velocity value. The stability in value is due to the straight movement of the air pattern in the room.

Table 8 Visualization result and descriptive result

Vector plot at W2	**The line graph at W2**
	
W2 circulated the air particles around the room up and down, which makes an efficient air movement along each corner of the room.	An axis in the red color line shows the highest air velocity. B axis in blue color line shows low air velocity with fluctuated speed, while C axis in green color line shows medium air velocity value. The fluctuation in value is due to the turbulent pattern of airflow in the room.

The vertical velocity contour is measured at the W1 and W2 and compared based on color-coding represented in the legends. The vertical axes are three which are (1, 2, and 3).

Table 9 Streamline plot at axis 1

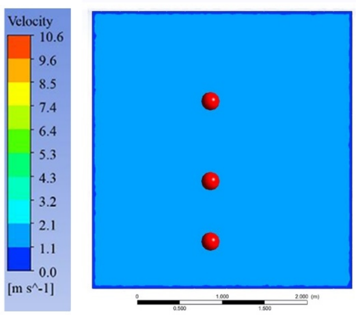
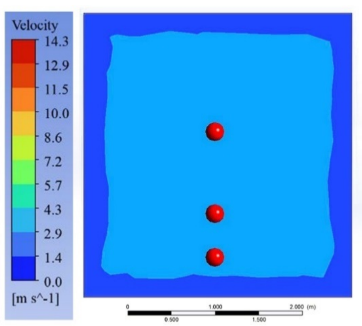
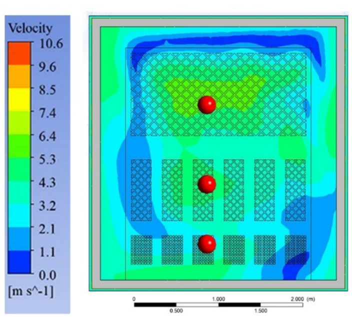
Code	**Streamline Plot At Axis 1** (refer to table 3 & 4)	Description
W1		Light air with 1.5 m/s is shown in this Table since the speed at Axis 1 is still without any interruption.
W2		The air velocity with 1.5 m/s decreases on the window surrounding since it hits the solid surface and bounces back with less speed.

Table 10 Streamline plot on axis 2

Code	Streamline Plot At Axis 2	Description
W1		The air velocity ranges from 2.1 m/s to 5.3 m/s, and the distribution of the air is equal since the air maintains its straight path with minimum interruption.

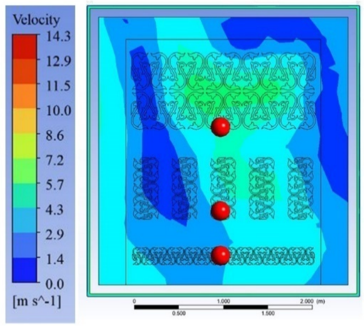
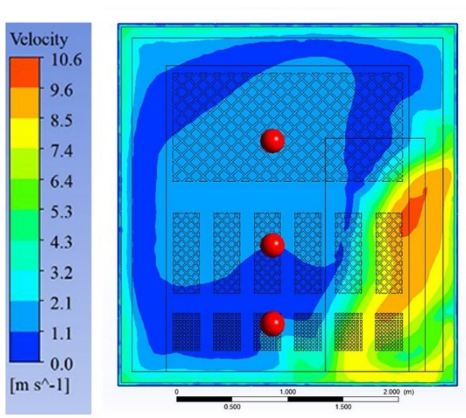
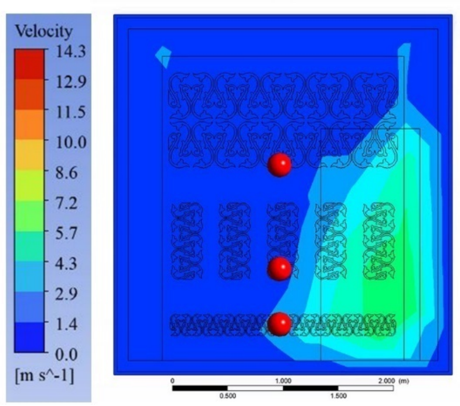
W2		The air velocity ranges from 0.9 to 4.3 m/s. The distribution of the air is random and circulated since the air circulated along with the curvy faces of the Malay carving window perforation.

Table 11 Streamline plot at axis 3

Code	Streamline Plot At Axis 3	Description
W1		A strong wind with about 4.5 m/s value occurs at the door opening in the case of a fully open room with a minimum distribution of the air around with 2.1 m/s value.
W2		Less air velocity occurs while the Indoor air velocity is minimum. The door opening sides receives relatively light breezes at 4.3 m/s.

As shown in Tables 7,8,9, the airspeed values are high since the study is conducted based on a cross-ventilation case with a maximum wind speed of 1.5 m/s. However, the airspeed increases when passing by each of W1 and W2, with a higher speed at W1 compared to W2. The air velocity using W1 is three times higher than the normal speed, which is 4.5/1.5 m/s while using W2 makes the air velocity two times higher than the actual airspeed, which is 3/1.5 m/s. The horizontal velocity contour plots are measured at the W1 and W2 and compared based on color-coding represented in the legends. The horizontal axes are three, which are (A, B, and C) as shown in Tables 10, 11, 12 and 13.

Table 12 The streamline plot at axis A

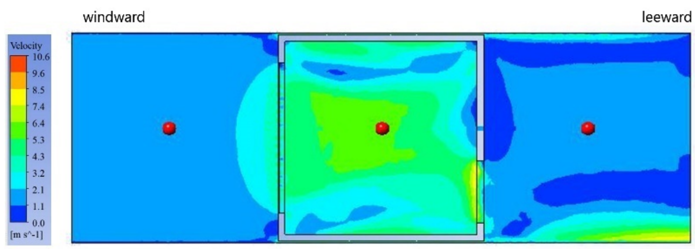
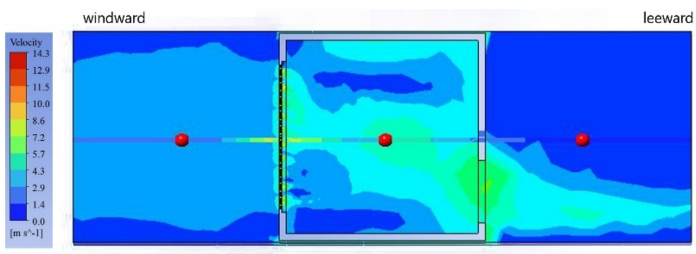
Code	**Streamline Plot At Axis A** (refer to table 3&4)	**Description**
W1		The pattern void opening is maximum, and the indoor air velocity is bout 4.3 m/s
W2		The pattern void opening is maximum, and the indoor air velocity is bout 2.9 m/s. The air velocity is less in W2 compared to air velocity at W1

Table 13 Streamline plot at axis B

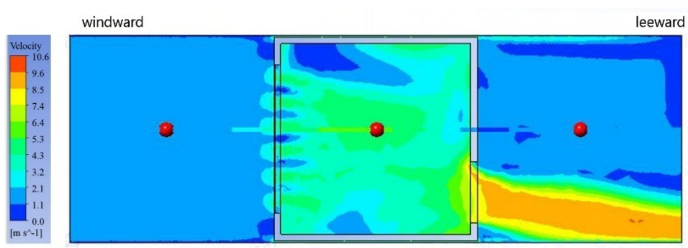
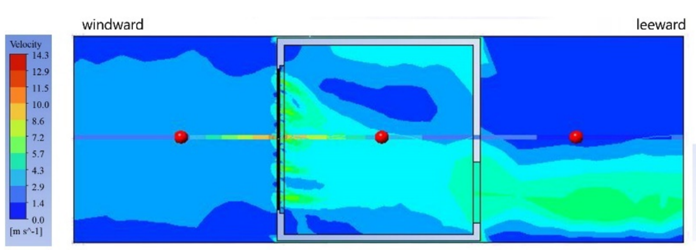
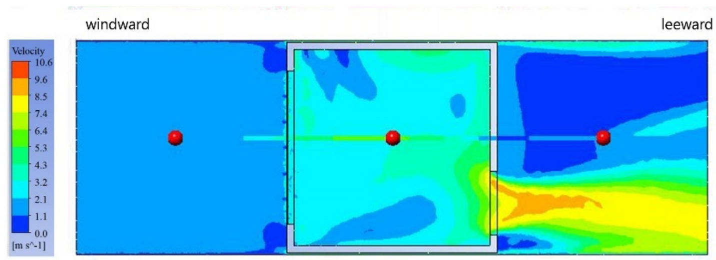
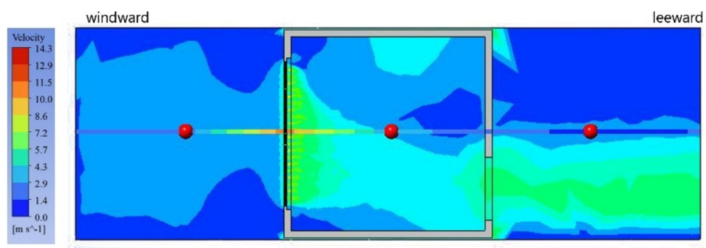
Code	**Streamline Plot At Axis** B (refer to table 3&4)	**Description**
W1		The pattern void opening is maximum, and the indoor air velocity is bout 3.2 m/s
W2		The pattern void opening is maximum, and the indoor air velocity is about 1.8 m/s. The air velocity is less in W2 compared to W1

Table 14 Streamline plot at axis C

Code	**Streamline Plot At Axis** C (refer to table 3&4)	**Description**
W1		The pattern void opening is maximum, and the indoor air velocity is a 3.2 m/s
W2		The pattern void opening is maximum, and the indoor air velocity is about 2.1m/s. The air velocity is less in W2 compared to W1

A comparison between the findings and literature reveals the Mashrabiya and Malay carving windows patterns and size effects on mean IAV, significantly accelerating the air velocity from 1.5m/s to about 4.5 m/s approximately. Based on the simulation, the perforated Malay carving allows less amount of air to pass through with a light breeze at about 3m/s maximum, in comparison to the geometric perforated Mashrabiya window that allows more amount of air with 4.5m/s maximum value to pass through with less blockage. The air velocity using W1 is three times higher than the normal speed, which is 4.5/1.5 m/s while using W2 makes the air velocity two times higher than the actual airspeed, which is 3/1.5 m/s. Tables 14 and 15 show the average measure airspeed at the tested tapping points in different heights of different activities such as sleeping, sitting, and standing, measured using CFD Ansys fluent automatic calculation.

Table 15 Tapping point at (W1) average air velocity [m s^-1]

Tapping Point at (W1)	**1**	**2**	**3**
A	1.5726	5.4747	2.01294
B	1.52154	4.57937	1.11332
C	1.47069	2.94555	1.24344
Average Air velocity [m s^-1]	**0.99741**	**4.333207**	**1.456567**

Table 16 Tapping point at (W2) average air velocity [m s^-1]

Tapping Point at (W2)	**1**	**2**	**3**
A	1.58015	4.76166	0.77678
B	1.51574	2.29648	0.778875
C	1.488	3.14127	2.05002
Average Air velocity [m s^-1]	**1.527963**	**3.399803**	**1.201892**

A healthy indoor living environment and a good quality of life need a comfortable indoor climate. Thermal comfort requires air circulation inside buildings to be regulated between 0.1m/s and 1.5m/s (Nugroho et al., 2007). To optimize the best performance, air movement must be directed toward the body surface due to the 'Venturi effect. At the same time, the upper opening can circulate the air to reach the body skin of the occupants. Table 16 shows the average velocity value measured at the lines passing throw the mentioned tapping points. The numerical data approve the fact that a bigger void achieves higher airspeed. Since airspeed is increased by the usage of W1 and W2, further study on a specific case study is required to keep the indoor air velocity within the range of comfortable indoor air velocity according to the Department of Standards Malaysia, 2014.

Table 17 Comparison of average velocity at tapping lines A, B, and C

Average Velocity at Tapping line	**Mashrabiya window (W1) [m s^-1]**	**Malay carving window (W2) [m s^-1]**
A (big)	2.57881	3.09146
B (medium)	2.16333	2.61312
C (small)	1.94495	2.54328
Comparison explanation	Average is 2.23 Note: The bigger void, the higher airspeed is.	Average is 2.75 Note: The bigger void, the higher airspeed is.

The results in Figure 20 show the high direct velocity of air in the W1 case in comparison with the gentle airspeed with turbulent movement at W2.

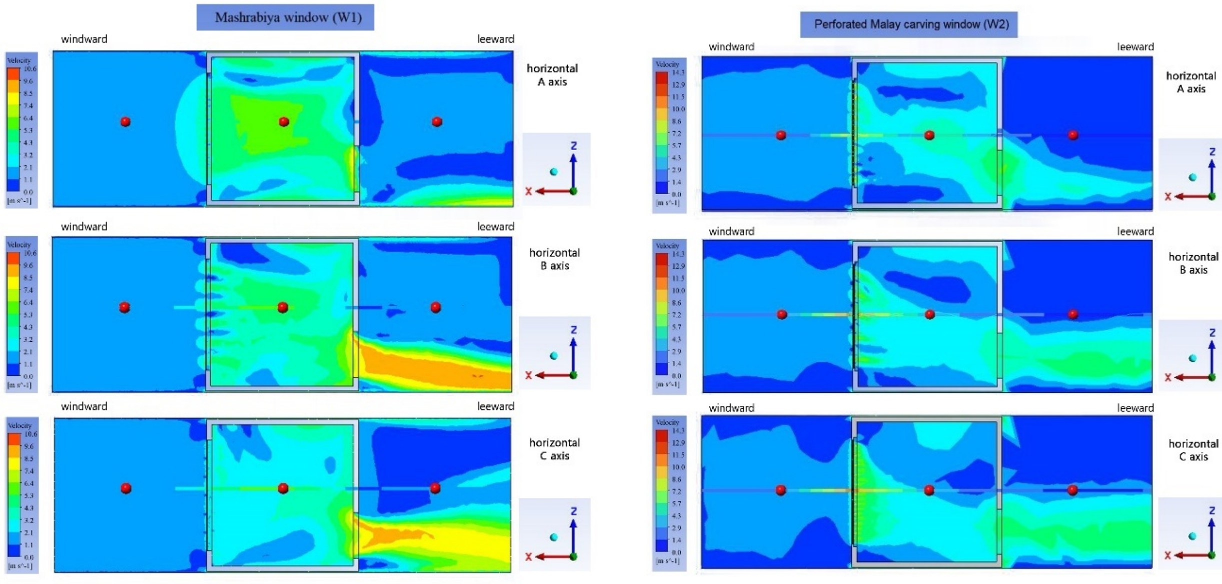


Fig. 20: Horizontal contour plots at W1 and W2

The pressure drops because of the formation of the vortex in both Mashrabiya and Malay carving due to flow separation across them. A larger width of opening provides a longer distance and bigger volume to fill until balancing the velocity flow for creating a larger vortex next to the Malay carving, and hence a higher magnitude of flow separation is achieved as shown in Figure 21. This vortex narrowed down in the Mashrabiya window. As a result of the increased velocity caused by turbulence inside that area, Bernoulli's Principle states that the pressure decreases (Kamela, M. 2007).

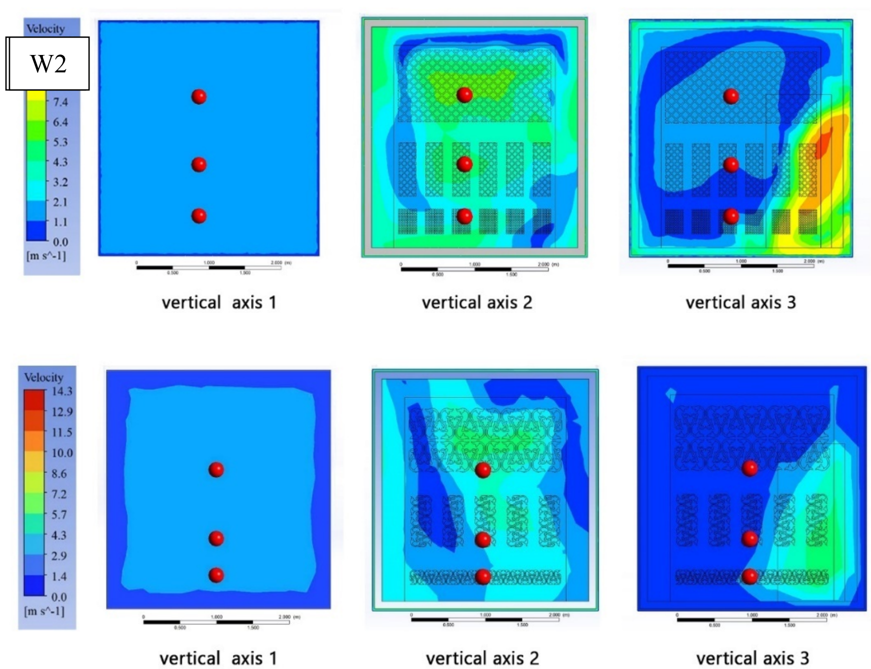


Fig. 21: Vertical contour plot

As shown in Figure 22, the airflow movement has circulated the air in the room in a random turbulent direction in the test used on the perforated Malay carving window, unlike the geometrical perforated Mashrabiya window that is flowing in a straight movement into the room space. Thus, the air distribution performance of the geometrical perforated Mashrabiya differs from the perforated Malay carving (floral pattern) air distribution which spreads along with the room at different sides and directions, which gives a guide for the architects and designers to understand their usage and placement.

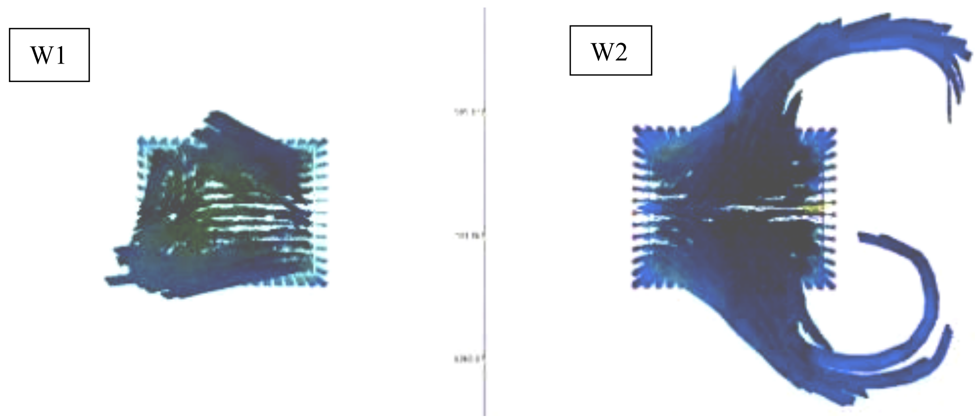


Fig 22: Elevation illustration of airflow density in perforated the Mashrabiya window (W1), and Malay carving window (W2).

Based on the analysis and comparison of the tests and evaluations above, the geometrical perforated Mashrabiya window allows straight airflow distribution to pass through and regulate into one direction, while the perforated Malay carving window distributes the air in different directions around the room. Clear recognition of the criteria of each pattern in terms of performance and spread is achieved by looking at the result produced by CFD Ansys fluent 2021. Different sizes of windows can be designed in the perforated method; however, the best criteria of perforated window design are when Mashrabiya is placed at the lower part to direct the airflow directly to the occupant's body, in his sitting and sleeping position while Malay perforated carving can be placed at upper part with a minimum size of ornamentation to circulate the air all around the room and increase the air velocity at the same time. Hence, utilizing Mashrabiya at a lower level and Malay carving at a higher level should be applied in a living room space to increase the air velocity by using these passive strategies and to preserve the aesthetic heritage of the perforated panels.

6.0 CONCLUSION

According to the constant changes in people's ideas, much more attention is paid to energy-saving issues for a better quality of life (Hilorme et. al, 2019). This study highlights the importance of understanding the indoor natural ventilation performance by the installation of perforated Malay carving windows and Mashrabiya windows, with consideration of their role in adding an aesthetic value to the building. Revising the original function of these two chosen window designs helps to design a new standard of modern perforated window treatment that can be an innovative solution for the design of windows aimed at enhancing the energy efficiency of the construction sector while also adding to the aesthetic value of cities. Results that are determined by CFD Ansys fluent R2 2021 software can help the designer to implement the real function and performance of window design in both geometrical and floral forms of the perforated window in a variety of void sizes and patterns. The findings of this study indicate that the pattern of the perforated window has a significant impact on the stability of the velocity within the living room area in Malaysia. When architects and designers install Mashrabiya and perforated Malay carving windows in their structures, they must consider many aspects, including pattern design, voids size, and placement. This will result in improved natural ventilation performance and a more diverse cultural experience. When used properly, perforated windows may provide the necessary naturally ventilated canopy. It is essential to concentrate on the modern shape of perforated decorative windows to remodel a sustainable kind of facade. Designers could change the concept of the perforated window if they consider the rule of using each geometrical and floral pattern to enhance indoor natural ventilation. Hence, it is possible to find the most efficient direction by considering the effect of the pattern of perforation on airflow in comparison with the thermal comfort conditions of the region it belongs to. Finding the optimal characteristics for an efficient perforated window element would enhance both function and aesthetics of buildings. Thus, applying a planned perforated window with a planned combination of floral and geometrical perforated patterns can represent a simple approach to establish a distinctive image for the city while also supporting the renewable energy plan.

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