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Impact of Roof Shape on Pedestrian-Level Wind Speed by Using CFD Modelling

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Abstract

The comfort, safety, and usability of urban and outdoor environments are all impacted by pedestrian-level wind (PLW). However, in Malaysia, the wind speed is low. This can lead to discomfort for the pedestrian. Previous studies have investigated the effects of roof shape design on improving pedestrian-level mean wind speed (PLMWS). This study explores how different roof shapes impact Pedestrian Level Wind (PLW) speed in urban settings by using Computational Fluid Dynamics (CFD) modelling which is using Ansys Fluent software. By employing a thorough validation process, this study aims to ensure the simulation's reliability, enhancing our findings' accuracy. The research contributes to understanding the intricate relationship between urban architecture and PLW dynamics, emphasizing the influence of diverse roof configurations on wind patterns in urban environments. The study shows that the mean wind speed around multiple buildings with wedged roof designs is the highest ratio at PLMWS around the Eco Tropics commercial area. One of the more significant findings from this study is that wedged roof design shows the optimum performance followed by a vaulted roof, gable roof, and flat roof towards PLMWS around multiple buildings with similar heights. Furthermore, the findings showed that the design of the roof shape had an effect on the mean wind speed at pedestrian-level

1. Introduction

The comfort, safety, and usability of urban and outdoor environments are all impacted by pedestrian-level wind (PLW). According to Van Druenen (2019), in Netherland, an increase in the PLW speed might cause unpleasant and even unsafe conditions for pedestrians. Buildings and clusters of buildings, especially tall structures, significantly impact PLW speed in urban areas. As the wind approaches a building, it is deflected over and around it, causing a large amount of air to descend on the front (windward) side. It seems that the shape of the roof affected the wind speed at pedestrian level (Liu, 2020). As a result, high-velocity wind corner streams are formed as the standing vortex at ground level sweeps around the building's corners due to flow separation (Van Druenen, 2019). However, the opposite happens in Malaysia because the wind speed in Malaysia is lower. According to Hanipah (2016) in Malaysia, Alor Setar, Kuantan, and Subang recorded a mean wind speed of 1.70m/s, 1.69m/s, and 1.6m/s for three years, respectively. The yearly mean wind speed trend at all locations shows only a slight difference. At 13.94% of the time, the mode of wind speed at Kuantan was no wind at all (0m/s) (Hanipah, 2016). A range of 10% to 13% of the remaining locations showed calmness and no wind. Climate and human comfort in Peninsular Malaysia are affected by the low wind speeds prevalent in the region.

In the absence of strong winds, the environment feels hot and humid, especially during the daytime. As a natural cooling mechanism, wind facilitates sweat evaporation and promotes cooling. Without it, the body's ability to dissipate heat becomes compromised, which can lead to heat stress.

Computational fluid dynamics (CFD) is a branch of fluid mechanics that analyses and solves problems involving fluid flows using numerical analysis and data structures. Engineers and analysts use computational fluid dynamics (CFD) software to create simulations of the behaviour of liquids and gases. The simulation takes into account a variety of elements, including the speed of the wind, the direction of the wind, the climatic conditions, the geometry of the buildings, and the terrain surrounding them. Researchers are able to precisely replicate the airflow patterns around structures with a variety of roof types by using CFD modelling. This enables a more in-depth investigation of how the particular roof form affects the flow of wind at the pedestrian level. The results of CFD simulations can provide useful insights into the distributions of wind speed, flow separation, and turbulence severity, all of which are important in determining how comfortable the wind is.

The aim of the project is to investigate and analyse how different roof shapes affect PLW speed in urban environments. In the CFD simulations performed by this project, vital factors such as wind speed, wind direction, and building geometry. This project aims to gain a comprehensive understanding of how different roof shapes impact PLW speed at the pedestrian level by precisely replicating airflow patterns around structures with varying roof shape.

2. Literature Review

2.1 Types of Roof Shape

There are four types of roofs commonly used in architectural design: gable roofs, flat roofs, vaulted roofs, and wedged roofs. Gable roofs are characterized by two sloping sides meeting at a ridge and are commonly seen in residential properties. There are several types of flat roofs, most of which have a horizontal or slightly sloped surface. Flat roofs are often found in modern and commercial buildings. The vaulted roofs are characterized by curved shapes that resemble the arches or domes of a building. These roofs add aesthetic appeal and spaciousness to the building, while wedged roofs are characterized by a single sloping plane, higher on one side and lower on the other.

Vaulted roofs, distinguished by their curving design resembling a barrel or a dome, have the amazing capacity to dramatically enhance wind speeds that are audible to people on the ground. According to Abohela (2013), vaulted roofs can increase wind speed by 56.1%. The constriction of the airflow within the vaulted structure causes an acceleration of air velocity, which is what is known as the Venturi effect. The increased wind speed made possible by vaulted roofs can have many benefits. First, these roofs' improved air movement in warm weather offers much-needed heat relief. The increased wind speed encourages natural cooling, making the area more comfortable for pedestrians and lessening the effects of hot temperatures. The increased wind speed brought on by vaulted roofs helps improve air quality. These roofs help to disperse pollutants and stagnant air by accelerating airflow, which reduces the build-up of contaminants and encourages improved ventilation in the neighbourhood.

The fascinating capacity to affect wind speeds at the pedestrian level is a feature of wedge-shaped roofs, distinguished by their tapering design that narrows towards the top. According to Abohela (2013), these roofs increase the wind speed by up to 9.3%. The Venturi effect is thought to be responsible for this occurrence, which occurs when the airflow becomes more constrained within the wedge-shaped roof. Wedge-shaped roofs may allow higher wind speeds, which can be advantageous in various ways. The comfort they offer during hot weather conditions is one crucial advantage. These roofs' enhanced air circulation can produce a nice wind for pedestrians, promoting natural cooling and easing pain from high temperatures. Wedge-shaped roofs can also help to improve air quality since they increase wind speed. These roofs serve to disperse pollutants and stagnant air by accelerating airflow, which reduces the accumulation of contaminants and improves ventilation in the area.

According to Badas (2017), their findings revealed that the roof pitch plays a significant role in influencing ventilation, as higher pitches result in increased turbulence and enhanced airflow. This effect was particularly evident in narrow canyons. Additionally, the study demonstrated that the friction coefficient is consistent with turbulent air exchange across different roof pitches, suggesting that the correlation between these two parameters is independent of the roof pitch. Gable roofs with steeper pitches may enhance natural ventilation in urban canyons, leading to improved air quality and reduced heat stress (Hågbo, 2022). For gable roof, the wind speed has improved by 15.8% compared to the initial wind speed.

The flat roof is characterized by its horizontal or nearly horizontal orientation. Even though flat roofs are an option for roofing, they are less common around the world than gable roofs. As opposed to gable roofs, flat roofs are less effective at shedding rainwater and snow compared to gable roofs. They are frequently constructed of concrete, asphalt, or metal. Even with this limitation, flat roofs can still improve natural ventilation in urban canyons. In contrast to flat roofs, gable roofs tend to enhance ventilation better than flat roofs due to their steeper pitch. In urban canyon environments, flat roofs may not maximize natural ventilation as efficiently as gable roofs with a higher pitch when it comes to natural ventilation (Badas, 2017). Flat roof can increase 31.3% of wind speed performance.

(a) **(b)**

(c) **(d)**

Fig. 1 *Types of Roof Shape (a) Flat Roof (b) Gabled Roof (c) Vaulted Roof (d) Wedged Roof.*

2.2 Wind Comfort and Height for Pedestrian Level

To comprehend and evaluate the wind conditions directly affecting pedestrians, it is crucial to know the wind speed at 1.5 metres above the ground or the pedestrian-level wind speed. This particular height was selected for assessing pedestrian wind comfort because it corresponds with the typical height at which most people stand and walk. Researchers can get important insights into people's environmental conditions when navigating urban areas by concentrating on the wind speed at 1.5 metres. This height is crucial for determining how wind affects pedestrian comfort, safety, and the use of outdoor places (Hågbo, 2022).

The ideal wind speed for pedestrian level tends to be between 1.5 and 3.8 metres per second (m/s). This range has been chosen based on elements that affect pedestrian comfort and safety. Wind gusts beyond 3.8 m/s can make it uncomfortable or even dangerous for walkers. In comparison, gusts below 1.5 m/s could not be sufficient to provide cooling effects (Blocken, 2016). The precise ideal wind speed within this range can change depending on several variables, such as the current weather, the time of day, and the pedestrians' activity. For example, a wind speed of 2 m/s may provide more noticeable relief and perceived comfort than a wind speed of 3 m/s in hot and humid regions. Depending on the activity, a different optimal wind speed for pedestrian comfort may be required. Higher wind speeds may be more bearable for pedestrians moving around or exerting themselves physically since the extra airflow helps remove body heat and gives the impression of cooling. However, motionless or still pedestrians may be more vulnerable to discomfort at higher wind speeds, mainly if it produces powerful gusts or turbulence (Blocken, 2016).

2.3 Roof Design Parameter

2.3.1 Roof Shape

Besides influencing wind pressure distribution, roof shape plays an important role in pedestrian-level wind speed as well. Research has demonstrated a growing interest in studying the effect of roof shape on pedestrian-level wind speed in recent years (Goh & Teo, 2016). It is crucial to understand how roof design affects the wind flow around buildings in order to ensure pedestrian comfort, safety, and usability. Wind patterns and speeds at ground level can be affected greatly by the roof shape. A study found that the shape of the roof affected the wind speed at pedestrian level and the characteristics of vortex found on the windward part of the roof (Liu, 2020).

2.3.2 Roof Slope

It has been reported that for the best ventilation conditions, a gable roof building with a roof pitch of 45 degrees would be the most suitable option (Perén, 2015). According to previous studies, increasing the slope of a roof can increase wind speed. This phenomenon occurs due to the alteration of airflow patterns caused by changing roof geometry. As the slope of the roof increases, the wind encounters a greater obstruction, resulting in an increased speed (Hosseini, 2017).

2.3.3 Roof Height

In previous studies, thermal comfort and buoyancy were analysed using different roof heights or rise/run ratios of roof shapes. Hosseini (2017) demonstrated that there is a presence of vortex and buoyancy force on the leeward side of a building when the rise/run ratio is increased. It has been noted that buoyancy improves thermal comfort around buildings. Overall, for this study's informants, more research is needed on rise/run ratios for pedestrian level wind speed. Researchers are fewer in number.

2.4 Benefit of Good Design of Roof Shape

2.4.1 Increase Wind Speed

Gable roofs have distinctive architectural characteristics that affect wind movement around buildings. They are characterised by their two sloping sides that meet at a ridge. Gable roofs' design encourages the formation of turbulence and eddies, which can lead to an increase in wind speed and better air circulation (Badas, 2017). When the roof's shape is carefully considered, it can disrupt the airflow around it and form turbulent zones and eddies. The disruption of stagnant air pockets caused by these dynamic air movements significantly improves the building's internal and external air circulation (Liu, 2020). As a result, airborne contaminants such as odours and pollutants are more easily dispersed, creating a cleaner and healthier environment.

2.4.2 Improve Thermal Comfort Environment

According to Hosseini et al. (2017), it was determined that the air temperature and air quality in urban canyons can be significantly influenced by the shape of a roof. According to numerous studies, a roof's shape significantly affects the air's temperature and quality in urban canyons. The particulars of the roof shape can significantly alter the microclimate of these urban settings, affecting the thermal conditions and the quality of the air that residents and pedestrians experience. The way that solar radiation, airflow patterns, and the built environment interact is directly impacted by the shape of a roof. Different roof shapes can affect the air temperature and air quality in urban canyons due to variations in solar heat gain, air circulation, and pollutant dispersion (Badas, 2017).

2.5 Computational Fluid Dynamics (CFD)

An advanced modelling method known as computational fluid dynamics (CFD) is essential for simulating fluid flow and heat transport using mathematical calculations. Engineers, architects, and designers may utilise this effective tool to produce virtual representations of the temperature and airflow conditions within and outside structures. Before the start of construction, experts can review, analyse, and optimise design concepts using CFD. CFD can also be used to evaluate possible alterations and upgrades to existing structures to inform decision-making processes better. The basic idea underlying CFD is to discretise the problem domain into small computational cells and use mathematical equations to solve for fluid flow and heat transfer within these cells.

Complex phenomena, including air flow, temperature distribution, and pressure fluctuations, can be thoroughly analysed using this computational method. The behaviour of airflow and thermal conditions under various circumstances may be understood using CFD models because they faithfully represent the principles of fluid dynamics and heat transfer. Reducing risks and avoiding expensive mistakes are major benefits of using CFD in the design and remodelling processes. They can make educated modifications and optimisations to improve building performance, energy efficiency, and occupant comfort (Van Druenen, 2019).

3. Methodology

This study used CFD modelling which are simulation to assess the effect of different roof shape designs on pedestrian-level wind speed and the most effective roof shape design for improving pedestrian-level wind speed performance. The simulation will be used to imitate the real life situation of the effect of different roof shape designs on pedestrian-level wind speed. The data obtained are discussed and interpreted to get a clearer picture of the objectives of the study.

3.1 Validation of CFD Simulation Model

It is important to use the guideline for the turbulence models when modelling pedestrian-level wind speed by using simulation of CFD. A working group of the Architectural Institute of Japan (AIJ) developed the following guideline based on the results of benchmark tests (Mochida, 2006). A computational fluid dynamics (CFD) simulation is a powerful tool for analysing wind flow, and it provides very accurate data on pedestrian-level wind speed around buildings (Blocken, 2016). The robustness of the CFD simulation is demonstrated through the use of a validation process, which measures the accuracy of the simulations.

3.1.1 Computational Domain

In terms of computational domain size, blockage should be below 3% based on wind tunnel experiments (Tominaga, 2008). The top and lateral boundaries must be at least 5H away from the target building, where H is the building's height. In the wind tunnel, the outflow boundary should be set at least 15H behind the building. The distance between the inlet boundary and the building should correspond to the area covered by a smooth floor upwind.

3.1.2 Computational Grid

Within a distance of between 0.5m and 5.0m around the evaluating points of the 3D model, the grid resolution must be within 1/10 of the building scale, and the grid shapes must be set so that they have a ratio of not more than 1.3 to the adjacent grids, so that it is consistent with the steep velocity gradient that occurs in the region (Tominaga, 2008). Based on this study, it is recommended to set up the evaluating height on the third or upward grid between 1.5 m and 5.0 m (Mochida, 2006). It is the principle of the skewness value that is used to calculate the mesh quality (if the maximum skewness value for all cases does not exceed the threshold value of 0.90 in any case) (Mochida, 2006).

3.1.3 Boundary Condition

A boundary condition is an important component of computational modelling and simulations because it identifies and characterizes the behaviour of dependent variables. Specifically, boundary conditions refer to the constraints or information imposed at the boundary of a computational domain on the flow variables. Various regions can be included in these boundaries, including inlets, symmetry planes, and the ground. Boundary conditions allow the simulation to accurately capture and simulate the interactions between the domain and its surroundings by specifying the values or patterns of the flow variables.

3.1.3.1 Inflow Boundary Condition

A power law is a mathematical model that explains the vertical velocity profile of wind flow near the surface. The model provides an approximate representation of the change in wind speed with height above the ground in various terrains, including urban settings. A power law simulates wind speeds at different heights above ground in urban areas. Complex topography, rough surface, and buildings and structures in urban areas can significantly influence wind flow patterns. To simplify the vertical wind velocity profile, the power law considers these factors.

The power law equation Kikumoto (2017) is expressed as:
Wind Speed,

$$U_{pL} = U_n \left(\frac{Z}{Zn}\right)^a \tag{3.1}$$

Where;
U_n = 1.66 m/s, wind speed at reference height;
Z = height, m
Z_n = Reference height;
a = 0.16, Terrain Roughness

According to the data analysis from Hanipah M. H. (2016), the yearly mean wind speed at Alor Setar, Kuantan and Subang was 1.70 m/s, 1.69 m/s and 1.60 m/s respectively at reference heights of 10 m, with only minor variations found at each location. In this case, the average wind speed of Alor Setar, Kuantan, and Subang at 10 m height is assumed to be approximately 1.66 m/s.

Table 1 *Terrain Parameters*

Classification	Terrain	Roughness Length (α) (m)
A	Offshore sea, island, coast, lake	0.12
B	Fields, villages, jungles, hills, small and medium-sized cities with sparse houses and suburbs of large cities	0.16
C	Urban area with dense buildings	0.2
D	Forests, orchards, and other areas with dense vegetation	0.25
E	Urban areas with very tall buildings	0.3

3.1.3.2 Lateral and Upper Surfaces of the Computational Domain

According to Tominaga (2015), the calculations around the target building, boundary conditions for the upper and lateral surfaces did not significantly affect the results since the computational domain was sufficiently large. In order to achieve a more stable computation for computational domain, it is recommended to use the slip wall condition (normal velocity components and normal gradients of tangential velocity components are set to zero) (Tominaga, 2008).

3.1.3.3 Downstream Boundary

For the outflow boundary condition, it is typical to set the normal gradients of all variables to zero. The outflow boundary has to be positioned away from the region where there is a negligible impact of the target building on the flow.

3.1.3.4 Ground Surface Boundary

When evaluating the single building model on the ground surface boundary conditions, it is important to ensure that the logarithmic law profiles and turbulent energy at the inflow boundary of the ground surface remain the same until the outflow boundary for the measurement of a simple boundary layer flow without building (Tominaga, 2008). For the boundary condition, it is recommended to use a logarithmic law which includes the roughness parameter.

3.1.4 Convergence of Solution

It is necessary to complete the calculation once the solution has reached a sufficient level of convergence. During each calculation step, it is important to overlap the contours between different calculation results or to monitor variables on specified points to ensure that the solution does not change. The default values for convergence in most commercial codes are not strict in order to emphasize calculation efficiency. For this reason, stricter convergence criteria are needed to ensure that the solution does not change (Tominaga, 2008).

3.2 Actual Case Simulation

3.2.1 CFD Turbulence Model

The standard k-ε turbulence model will be used in this study due to the fact that the study will only focus on the mean wind speed at pedestrian level for a number of reasons. it has been reported that the simulation result of standard k-ε are closer to experimental result as compared to the simulation of Renormalization Group (RNG) k-ε and realizable k-ε (Chew L. W., 2017). It is concluded by Ntinas (2018) that the standard k-ε model is able to predict velocity very well given a conditional distribution of velocity. Therefore, the standard k-ε model is chosen for this study.

3.2.2 Roof Shape Configuration

The height of the roof of the buildings is relatively the same, so it is kept as a constant value for the calculation. The roof shape of case 1 is flat and serves as a reference case (RC). A gabled roof is the roof shape of Case 2, a vaulted roof is the roof shape of Case 3 and a wedged roof is the roof shape of Case 4.

3.2.3 Convergence Criteria

A tolerance of residuals is set for all parameters in this study, and iterations are continued until the residuals are no longer decreasing after a certain number of iterations

3.3 Data Extraction Location for Analysis

A measurement of the turbulence model is taken in both the vertical and horizontal sections of a building in the middle of the building and in the height of the building at pedestrian level which is 1.5 meter above the ground.

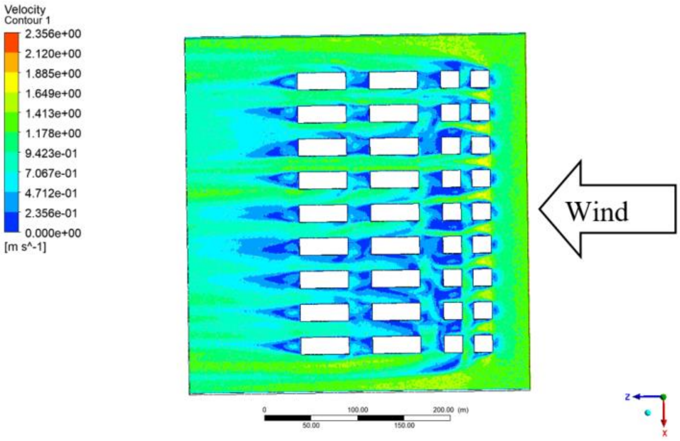


Fig. 2 *The illustration of data extraction location*

3.4 Pedestrian Level Wind Parameter

The mean wind velocity ratio (MVR) is combined with the characteristics of a particular wind climate to determine the level of wind comfort. It can be calculated using the following equation:

$$MVR = \frac{U_p}{U_r} \tag{3.2}$$

where, U_p stands for the mean wind speed at pedestrian level of 1.5 m. Meanwhile, U_r represents the reference mean wind speed at a certain height without considering the effects of urban architecture.

4. Result and Discussion

4.1 Model of Building

In this analysis, the satellite image from Google Earth is used to digitise the building plan of Eco Tropics Commercial Area and then drawn in SOLIDWORKS as shown in Figure 2. The 2D plan then extrude to the height of the building to make a 3D model of the buildings. The benefits of using the SOLIDWORKS software are saving cost and time for development of 3D model.

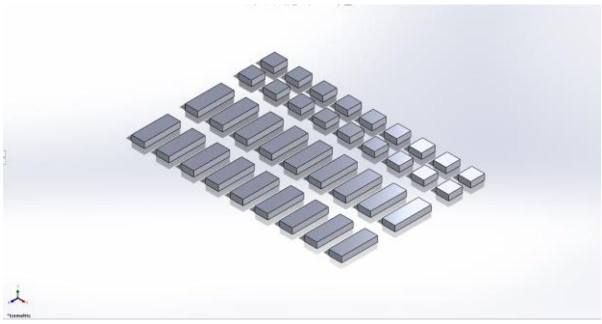


Fig. 3 *3D building of Eco Tropics Commercial Area using SOLIDWORKS.*

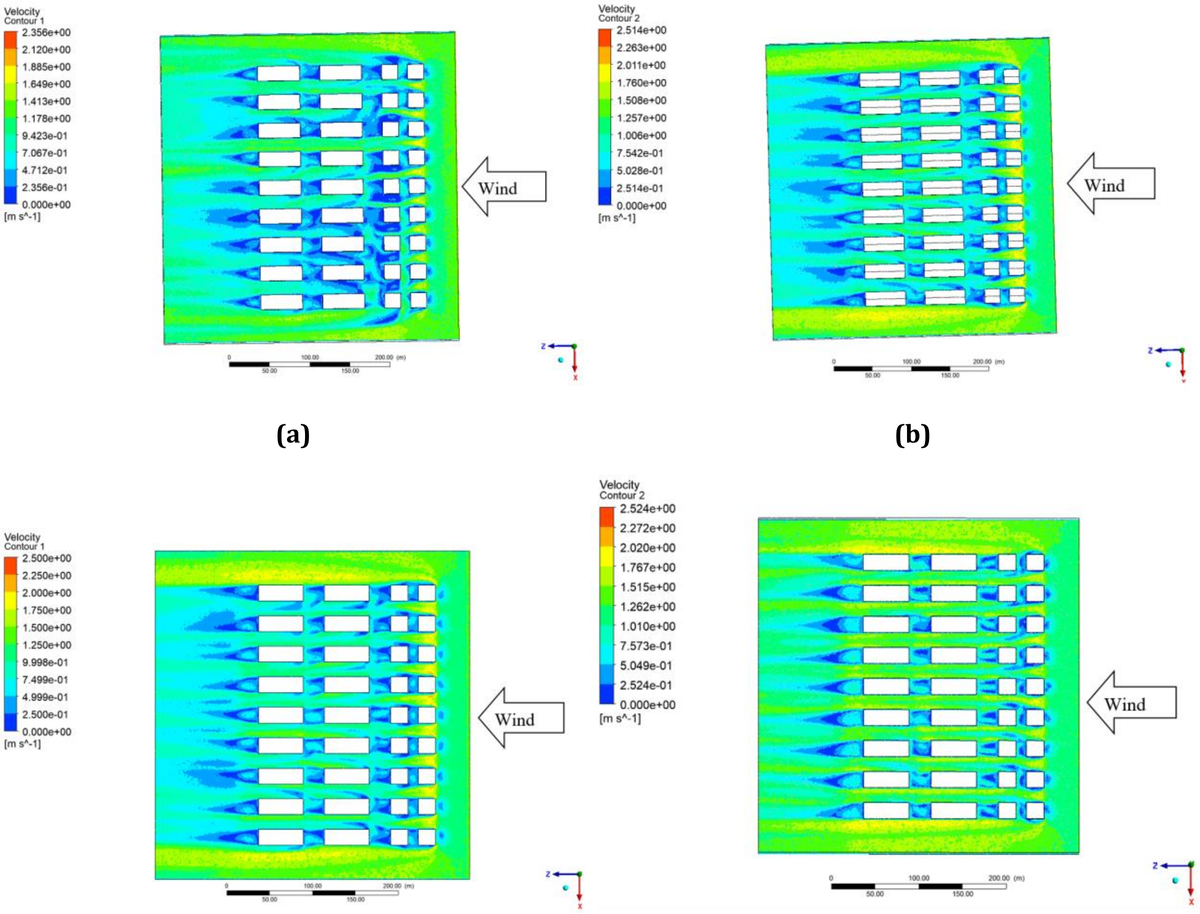
4.2 CFD Simulation Result

4.2.1 Average Velocity on Pedestrian Level Wind

As shown in Table 2, the average wind speed on PLW varies depending on the roof shape. Case 1, the reference case, has the lowest wind speed at 0.835 m/s. Wedged roofs, on the other hand, experience the highest wind speeds, reaching 1.121 m/s. Compared to the reference case, all different roof shapes show improvement in wind speed. Case 2 has the most minor improvement, at only 10.0%, while Case 4 boasts the most enormous improvement, 34.2%. The improvement difference between case 2 and case 3 is not significant in multiple buildings with similar height cases as both cases improve only 10% and 12%, respectively. Essentially, the wedged roof design leads to the highest wind speeds. In contrast, compared to the reference case, other roof shapes all experience an increase in wind speed, with Case 4 demonstrating the most notable improvement.

Table 2 *Average Velocity on PLW.*

Case	Design	Average Velocity on PLW (m/s)	Improvement from RC(%)
1	Flat Roof	0.835	Reference Case
2	Gabled Roof	0.918	10
3	Vaulted Roof	0.935	12
4	Wedged Roof	1.121	34.2



(a) **(b)**

(c) **(d)**

Fig. 4 *Contour of wind speed at PLW for (a) Flat Roof (b) Gabled Roof (c) Vaulted Roof (d) Wedged Roof.*

4.2.2 Mean Velocity Ratio

The equation 3.2 shows the MVR equation where Up is the mean wind speed at pedestrian level of 1.5 m above ground level to the reference mean wind speed, Ur which is 1.66 m/s for all four cases. The data of mean wind speed value for all cases are then divided with the reference mean wind speed 1.66 m/s to obtain the MVR values as shown in Table 2.

Table 3 shows the MVR performance towards roof shape design. The flat roof that act as reference case obtain MVR value of 0.503 which is the lowest compared to roof which for gabled roof is 0.553, vaulted roof is 0.563 and the highest MVR is wedged roof which is 0.675. This showed that the wedged roof has more wind speed available at pedestrian level around the building. The gabled roof, on the other hand, is the lowest compared to the other roofs.

The previous researcher which had a study on the same design of roof shape with this study on the heterogeneous building (Yau, 2022). The MVR from the previous study is quite low compared to this study as the different type of building which is the previous study focusing on heterogeneous building while this study is focusing on multiple building with similar height. A possible explanation for this might be that the difference kind of arrangement of building affecting the wind speed at pedestrian level. The wedged roof design is the best design for both building design. This indicates that wedged roof is the best roof for improving the wind speed at PLW around the building.

Table 3 *MVR against roof shape design compared with previous researcher.*

Case	Design	MVR	MVR previous Researcher (Yau, 2022)	Percentage Different (%)
1	Flat Roof	0.503	0.234	14.9
2	Gabled Roof	0.553	0.231	39.4
3	Vaulted Roof	0.563	0.221	54.9
4	Wedged Roof	0.675	0.247	73.3

4.3 Summary

To summarise, this chapter highlights both objectives, which are identifying the effect of different roof shape designs on pedestrian-level wind speed and determine the most effective roof shape design for improving PLW speed performance. Wedged roof shows the best performance in improving PLW speed around multiple building with similar height area. The reference case which is flat roofs shows the worst performance towards PLW speed around multiple building with similar height area.

5. Conclusion and Recommendation

5.1 Conclusion

This study focusing on different roof shape affecting the PLW speed at multiple building with same height. The first objective is to identify the effect of different roof shape designs on pedestrian-level wind speed. This was achieved by using CFD modelling and the result shows that there are differences in average wind speed at PLW when the shape of roof is changed.

The second objective, which involved determining the most effective roof shape design for improving pedestrian-level wind speed performance was also achieved by using CFD modelling. The results show that the wedged roof design best improves pedestrian-level wind speed performance. Comparing the wedged roof to the reference case which is flat roof, the wind speed increased by 34.2%. Other roof types, such as the vaulted and gabled designs, showed slightly better results than the reference case, with only 10% and 12% better, respectively.

The limitations of this study correspond to the different harnesses or difficulties that may obstruct the research's progress. While attempting to accomplish the research aims, the researcher came across a variety of limitations.

One was when the researcher needed to learn to use two software programs, SOLIDWORKS and Ansys Fluent. For SOLIDWORKS, it takes a small amount of time, but when it comes to Ansys Fluent, the process of getting the most accurate data is the one that challenges the researcher. Besides, the simulation takes much time, even when getting accurate data. Despite these limitations, the findings of this study can still serve as a future reference for developers when designing the roof of a building in the future.

This study primarily determines the most effective roof shape design for pedestrian level wind speed using CFD modelling in Malaysia. Based on the findings, several suggestions for future research within this topic are proposed:

- Incorporate detailed vegetation and urban morphology, including trees, shrubs, and other vegetation, along with accurate building heights and geometries, to create a more realistic representation of Malaysian urban environments.
- Optimise roof features. Investigate the impact of roof pitch, overhangs, and ventilation openings on wind speed and comfort.
- Consider air temperature, humidity, and sun radiation to create a more complete picture of pedestrian comfort.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Ahmad Alif Aiman Ahmad Hashim, Mohd Hafizal Hanipah;* ***data collection:*** *Ahmad Alif Aiman Ahmad Hashim;* ***analysis and interpretation of results:*** *Ahmad Alif Aiman Ahmad Hashim;* ***draft manuscript preparation:*** *Ahmad Alif Aiman Ahmad Hashim. All authors reviewed the results and approved the final version of the manuscript.*

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