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The Aerodynamics Study of Skyscrapers in Kuala Lumpur: The Effect on Occupants and Pedestrians Comfort

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ABSTRACT

Skyscrapers have been constructed all over the world because of the social demand for more iconic building, including excellent aerodynamic performance and architectural aesthetic reasons. However, the increasing high-rise buildings in densely built-up cities created low velocity air flow caused by the phenomena of flow separation at pedestrian level and also exerts drag force on the building walls that may affect the occupants' and pedestrians' comfort. Therefore, the objective of this study is to investigate the drag force and pedestrian level wind condition of 15 skyscrapers in Kuala Lumpur of various designs and shapes by using Solidworks Flow Simulation. The effect of the height of surrounding buildings were also investigated. From the results, the bamboo shape of the Telekom tower shows the lowest drag coefficient by 0.1056 compared to others and the ratio of surrounding building height to skyscraper of 0.83 shows the smallest drag.

Introduction

Nowadays, skyscrapers have been a symbol of excellence and wealth of a country. Burj Khalifa in Dubai have been identified as the world tallest building and attracted the tourists to witness the wonderful of the architectures themselves. Tall building is also important as a communication centre, such as the Kuala Lumpur tower in Malaysia that have been known as the communication centre for the nation.

When the rate of growth in a town increase, it affects the rate of population in that area. Land has become limited and makes people uncomfortable. Therefore, skyscrapers are built to save space and facilitate the public. Nowadays, skyscrapers had a space that made for offices and services in a building such as the Shanghai Tower in China is subdivided into five main functional areas which are luxury hotel, office, entertainment, cultural venues, and conference facilities. In Malaysia, there are various of skyscrapers that are similar to this characteristic such as Kuala Lumpur Conventional Center (KLCC) tower, Telekom tower, and Maybank tower which manage to gain tourists' attention from all over the world.

The wind flow plays an important role at pedestrian level, in the aspects of thermal comfort [1-3], ventilation of city [4, 5], public safety [6], and pollutants spreading [5, 7-9]. Regions of flow separation at the pedestrian level experience poor ventilation and reduce the capability of dispersing pollutants. This in turn causes discomfort for the pedestrians. On the other hand, the high drag force exerted by the wind onto the building surfaces, creates vibrations and unwanted noise. This also affects the comfort of the building occupants. The engineering problems such as pollutant dispersion in the built environments, wind load on buildings, and pedestrian wind discomfort have been increasingly solved by using the CFD The CFD results depend on various parameters and numerical conditions to produce the best practical rules [10]. The drag force and coefficient also can be determined by using the CFD.

On the other hand, many researchers have reported that great modification of the corners shape can create a better aerodynamic performance and pedestrian comfort [11,12]. Furthermore, low drag coefficient needs to be emphasised in a building construction. This is because, it will affect the pedestrian and occupants comfort. Hence, the purpose of this investigation is to study the drag force exerted on the skyscrapers in Kuala Lumpur. On top of that. the effect of the height of the buildings surrounding the skyscraper was also being studied.

Methodology

i. Model Design

In this project, the actual dimension and scale is difficult to obtain because of the architectural privacy. Thus, the estimation of dimension used was based on map scaling from Google Maps using pixelscoordinate calculation. Fig. 1 shows the technique to get the dimension by using pixels calculation.

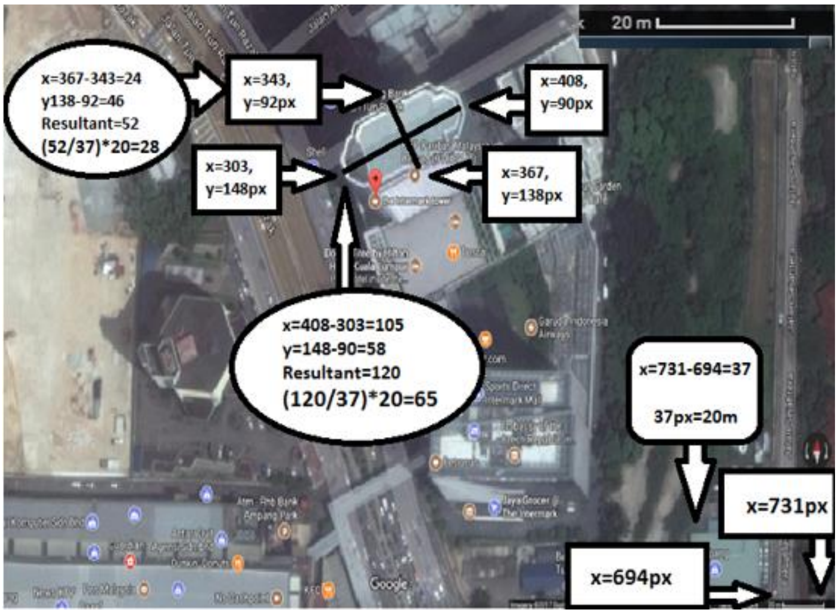

Fig. 1: Scaling for Vista tower

The studies on determining wind directions needed to be done to get results that are almost similar to the actual situation. The wind angle of attack on buildings must be determined according to the actual scenario and this was done approximately by map measurement method. Based on Malaysian Meteorology Department, the east monsoon winds occurs from November to March which is seen as a common phenomenon in weather forecasting from the northeast area as shown in Fig. 2. Fig. 3 shows the CAD modelling for each of skyscrapers used in this studied.

Fig. 2: Angle of wind direction for Ambank tower

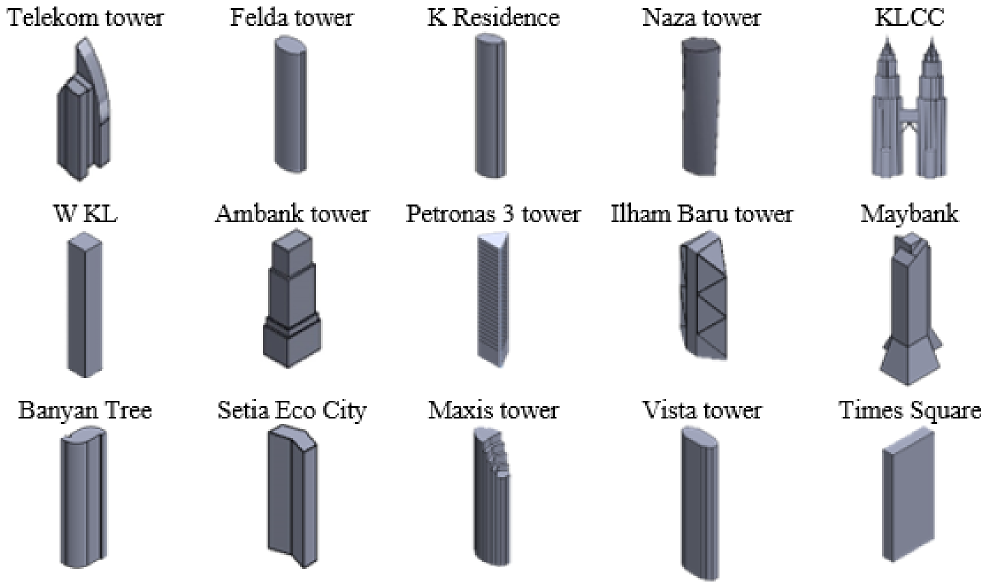

Fig. 3: CAD modelling used in this study

ii. Validation Study

To validate the results in this investigation, two validation methods were used which are simulation study and experimental study. This is to ensure the accuracy of the results obtained.

a. Simulation Study.

The simulation were conducted based on the experimental data of wind by Iqbal & Chan [13] which provided the arrangement and dimensions on buildings as shown in Fig.4. The computational domain of this investigation is shown in Fig. 5.

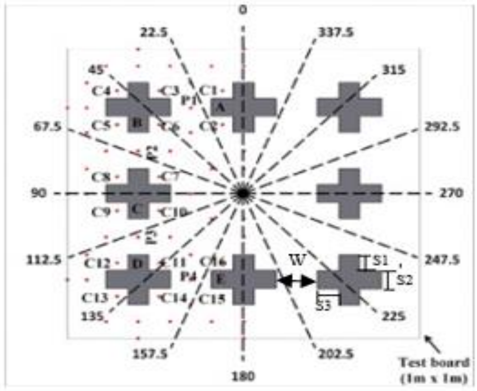

Fig. 4: Building layout for Configuration 1 [13]

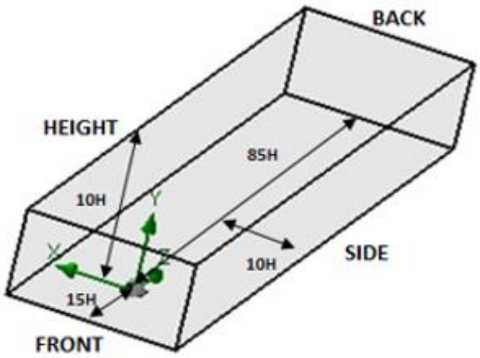

Fig. 5: Optimum computational domain

The side distance for S1, S2, and S3 from Fig. 4 are 0.048, 0.052, and 0.057 m, respectively, while the height of the model is 0.4 m. The building separation variable, shown as W in Fig. 4 used in Case 1 is 0.054 m. Velocity goals are pointed approximately 0.007 m above ground at corner centers C1 to C16 as shown in Fig. 4 that are specified as the main data of attention. The point goals act as the data recording to the further evaluate of normalised velocities (V/V_o) with reference velocity to 10 m/s. Analysis on each parameter was tested independently to define the optimum settings until the results are close to the original study. The optimum control parameters are listed in Table 1.

Table 1: List of applied settings [13].

Parameter	Setting
Computational domain size	Front : 15H Back : 85H Sides : 10H Height : 10H
Input velocity	$V_z = 10\left(\frac{y}{1.8}\right)^{0.15}$
Input turbulence intensity	10%
Ground & wall condition	Smooth adiabatic real wall
Mesh refinement	Initial global mesh : Level 8 Initial ground mesh : Level 8 Refinement : Level 4

In representing the exposure terrain assumptions, the power law exponent of 0.15 was used in mean velocity profile. The tallest height, H was used to determine the computational domain size as signified in Fig. 3. These settings were validated by comparing the wind velocity results with those of Iqbal & Chan [13]. Solidworks turbulence model used in this study was based on the modified k-ε turbulence model with damping functions proposed by Lam & Bremhorst [14]. The turbulence intensity used was 0.1% with length set at 0.0001m. The global meshing of the overall setup followed the automatic settings with the highest resolution of 8 and refinement level set at 8, the highest.

b. Wind Tunnel Experiment

Wind tunnel experiment was conducted in the subsonic wind tunnel laboratory at University Pertahanan Nasional Malaysia (UPNM). The turbulence intensity of the wind tunnel that was previously measured is 0.1%, which is the similar to the simulation settings in Solidworks Flow Simulation. In order to validate the result with Solidworks Flow simulation, the simplest design which is K residence was fabricated by using 3D printer. Next, a steel rod was attached to the model before being connected to the force balance device, as shown in Fig. 6. Steel rods with the diameter 5.5 mm and 200 mm length were inserted half of the model which was located at the centre of gravity. The clay was used to make sure the rod and model are tight for each other.

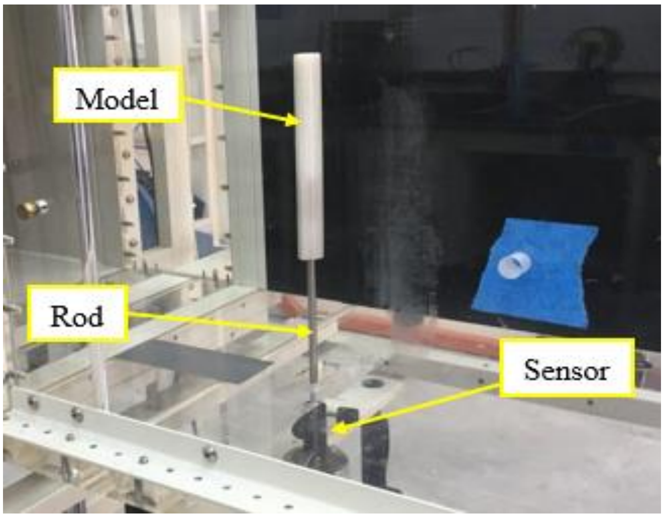

Fig. 6: Installation of K Residence model in test section wind tunnel

The the angle of attack of the model was the set to 53°. After that, the velocity was set at u = 7 m/s. The experimental conditions were fixed according to the simulation settings, for the purpose of validation. The selections of values were made based on the dimensional analysis and actual orientation angle of the building facing the incoming wind.

iii. Effect of skyscraper parameters

Based on the validated settings, the wind flow behaviour for the three types of building parameters were investigated to study the effect on occupants and pedestrians comfort. All of the dimensions were scaled down with ratio of 1:500m. Three skyscrapers with the lowest drag coefficient were then selected to be further tested in Solidworks flow simulation with different orientations and heights of building surrounding [15] as shown in Fig. 7 and Fig. 8.

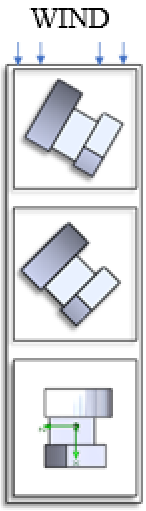

Fig. 7: Different Orientation of skyscrapers (Top view)

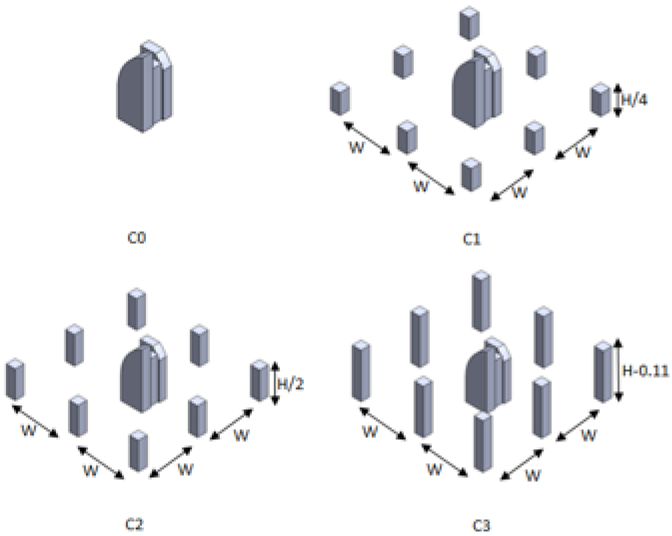

Fig. 8: Building configuration showing different surrounding building heights [14]

Results and Discussion

i. Validation Study

Simulation and wind tunnel experiment were conducted to validate the study.

a. Simulation Validation

Fig. 9 shows the validation results comparison with reference to the corner positions as shown in Fig. 4. The normalised wind velocities produced in the integrated simulation shows a similar trend with the results of Iqbal & Chan [13], which are almost the same at corners C3, C9, and C10. However, there are errors that are obvious which can be detected at corners C14 and C4.

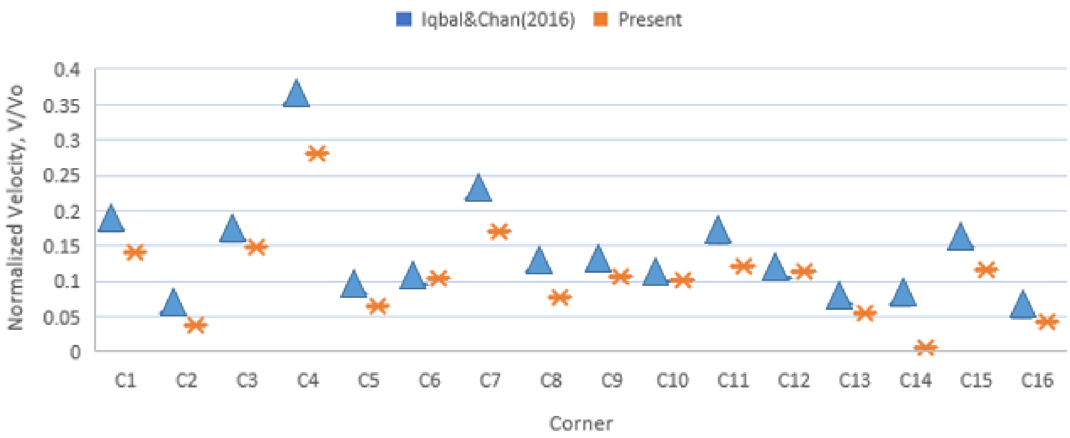

Fig. 9: Normalised wind velocity at corners for the optimum setting

This is due to several lacks of element in the Solidworks flow simulation such as inefficient resource optimization and the complexity of the case studied. Besides that, the higher meshing setting is also a restriction for the reason of lower CPU processing power. This problem might be attempted at the specific spots by manually applying localised mesh. However. the overall validation results can be deemed as reliable since the majority of the corners are in good agreement with Iqbal & Chan [13].

b. Experimental Validation

Table 2 shows the tabulation of drag coefficient for K residence tower. It can be seen that only 1.6% of percentage differences between the drag coefficient values for the subsonic wind tunnel experiment and Solidworks flow simulation. The differences may be due to the surface of model is not too smooth during finishing process. Therefore, the data for simulation and experimental is valid and useful.

Table 2: Tabulation data of Drag Coefficient, C_D

Drag Coefficient (Experimental)	Drag Coefficient (Simulation)	Percentage Differences (%)
0.1274	0.1253	1.6

ii. Effect of skyscraper parameters

Drag coefficient and pressure surface represents the comfort of occupants inside skyscrapers while the normalised velocity contour represents the comfort for pedestrians. The higher drag coefficient and pressure surface, the higher discomfort of occupants due to the vibrations on the windows. In terms of flow separation, the region of low velocity represents indirectly the level of discomfort of the pedestrian since in low velocity regions, the air at the ground level is well ventilated.

a. Skyscraper's shapes.

The lowest drag produced is the bamboo shape which is the Telekom tower while the highest drag is the KLCC tower as shown in Fig. 10. Besides that, the highest value of normalised velocity area is the triangular shape while the lowest value is the ellipse shape as shown in Fig. 11. The shapes influenced the drag formation and the area of low velocity. The corner modification of the shapes also contributes to the better comfort of pedestrian and occupants in terms of low drag, low surface pressure as shown in Fig. 12 and low velocity area. Therefore, the shapes that have good aerodynamic characteristics are very important for designing skyscrapers.

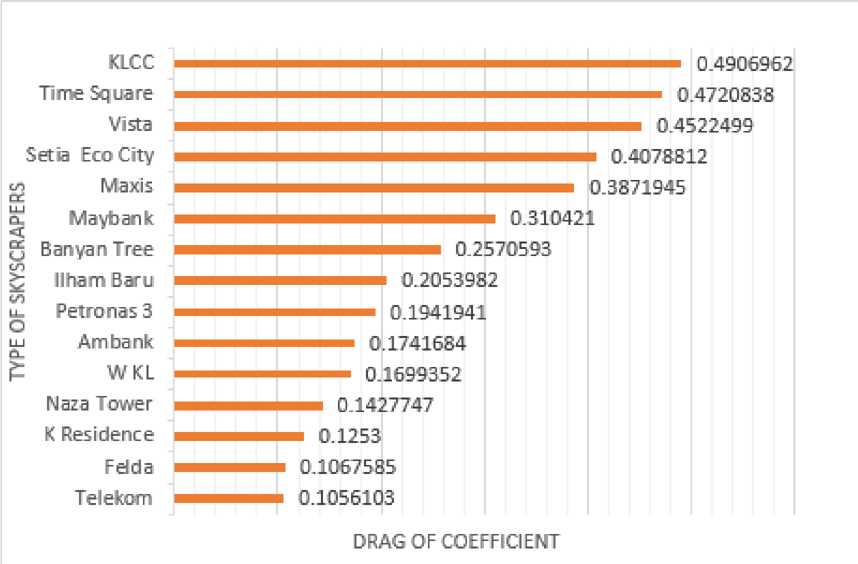

Fig. 10: Drag Coefficient produced from CFD

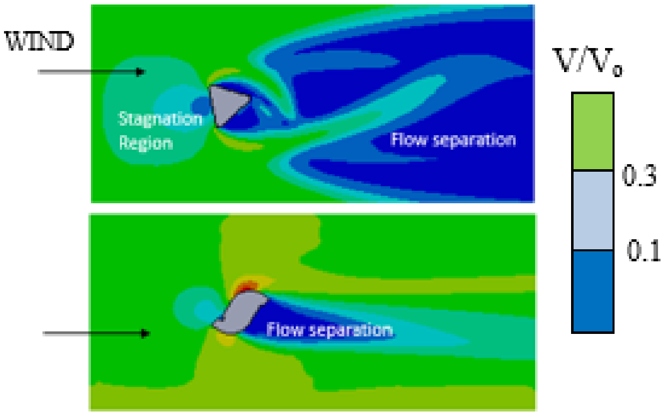

Fig. 11: The normalised velocity contour

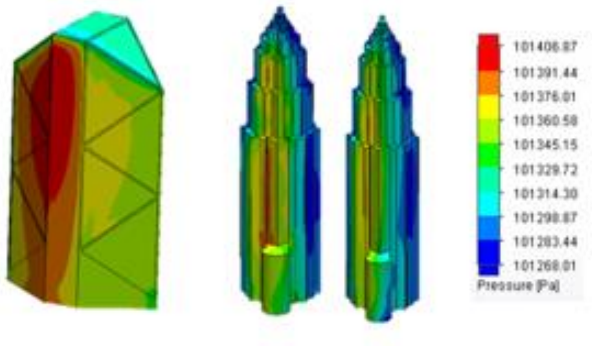

Fig. 12: Surface pressure

b. Skyscraper's orientations.

Fig. 13 shows the normalised velocity contour for various orientations of skyscrapers which represents the flow behavior on different angle of wind attack. The region of relatively low velocity obtained for 90-degree orientation is the smallest compared to the other two orientations. The worst orientation is at 30-degree where wide region of low velocity can be found starting from the mid-section of the building. As for the surface pressure results, large regions of high pressure are clearly visible at the frontal side of the building in the case of 90-degree orientation. This is due to the area being exposed to the incoming wind and may cause discomfort to the occupants residing near the windows facing the wind.

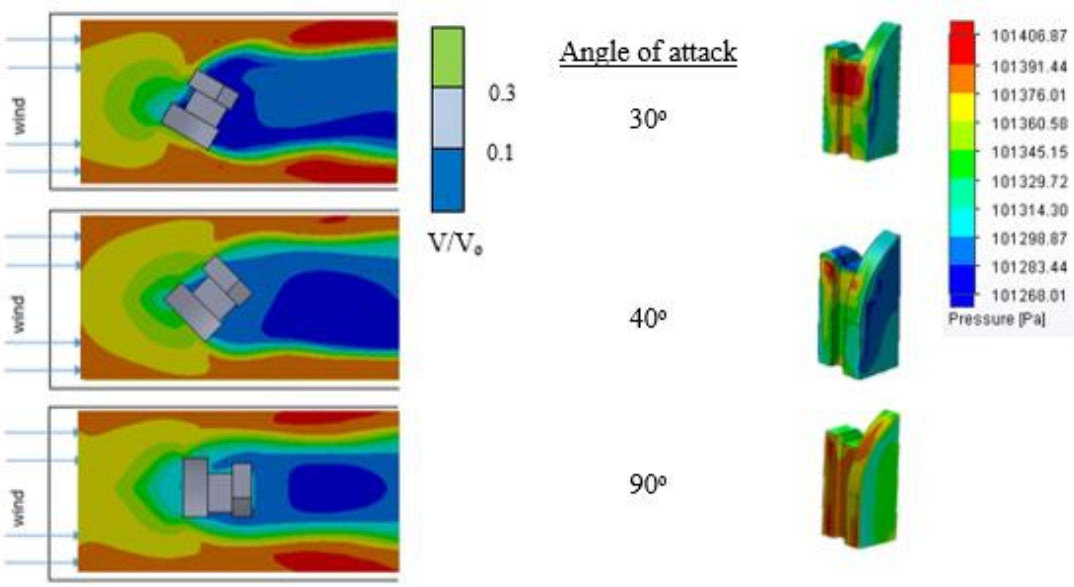

Fig. 13: The normalised velocity contour (left) and surface pressure for each of orientations (right)

Fig. 14 shows the different drag coefficient values obtained for different wind angle of attacks. As shown in the figure, the drag coefficient for the Telekom tower at 90° is the lowest with the value of 0.299 compared to the wind attack at 45° and 30°, which are 0.335 and 0.342, respectively. The results are in good agreement with the outcome from the qualitative analysis shown in Fig. 13 previously.

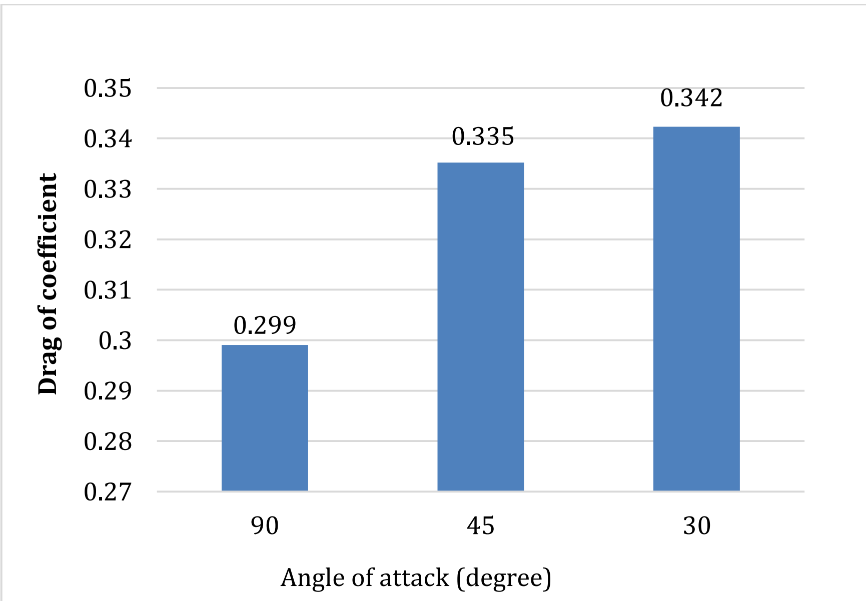

Fig. 14: Drag Coefficient for different angle of attack

The Telekom tower has a unique curved shape that has good aerodynamic characteristics as depicted in Fig. 15. The incoming flow is being streamlined following the curve instead of stagnating on the wall surface. This in turn reduces the stagnation points on the wall surface hence reducing the separation region created at the rear section of the building. On the other hand, if the mentioned aerodynamics surface is not aligned with the incoming flow, the drag coefficient will increase significantly which leads to occupants' discomfort as can be seen for the cases of 45-degree and 30-degree. Therefore, adherence to the basic aerodynamics shape with correct orientation with respect to the incoming wind direction is important in designing skyscrapers.

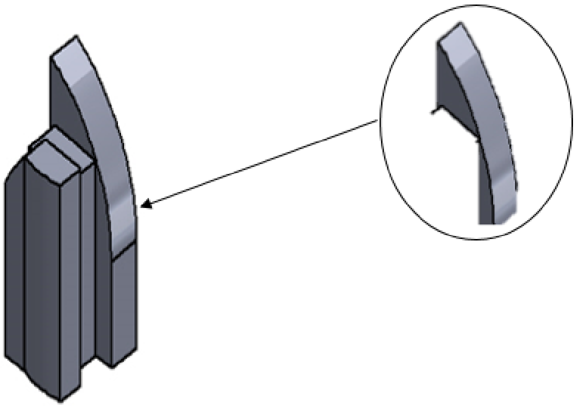

Fig. 15: Shape that allow wind flow smoothly

c. Skyscrapers' buildings surrounding.

Fig. 16 shows the result on the effect of the height of surrounding buildings on the skyscrapers. The height parameter is being represented in terms of the ratio of the height of the surrounding building, to the height of the skyscraper. It can be seen that the lower the height of the surrounding building, the smaller the region of low velocity. However conversely, the surface pressure on the wall facing the flow is relatively high. This can be easily understood as the wall of the skyscraper is facing the incoming flow directly without the flow being obstructed by any surrounding building in comparison to the other two cases. Apart from that, spots of low speed region in between the buildings are also minimal especially compared to the ratio of 0.83, where low speed regions spots can be observed almost at every area between the buildings.

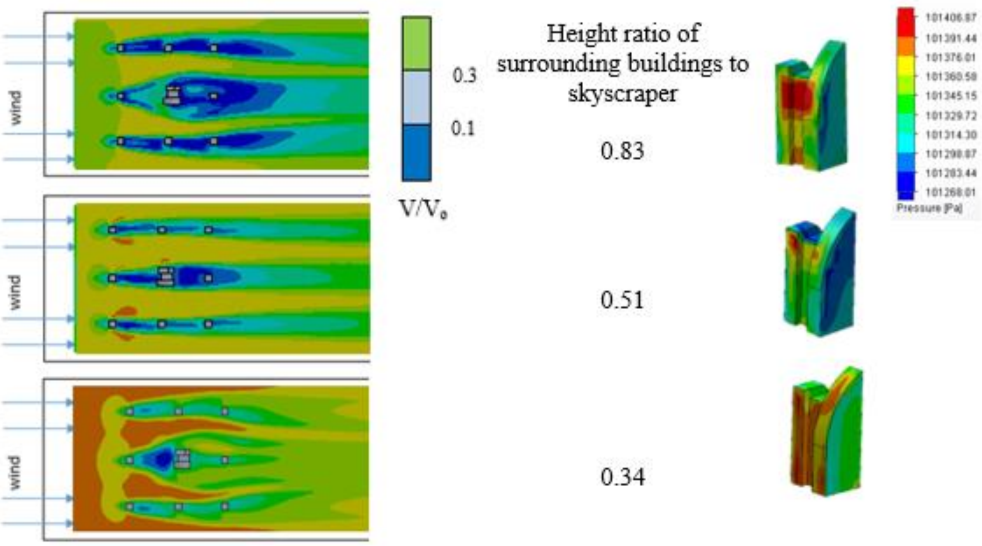

Fig. 16: The normalised velocity contour and surface pressure for different height surrounding buildings

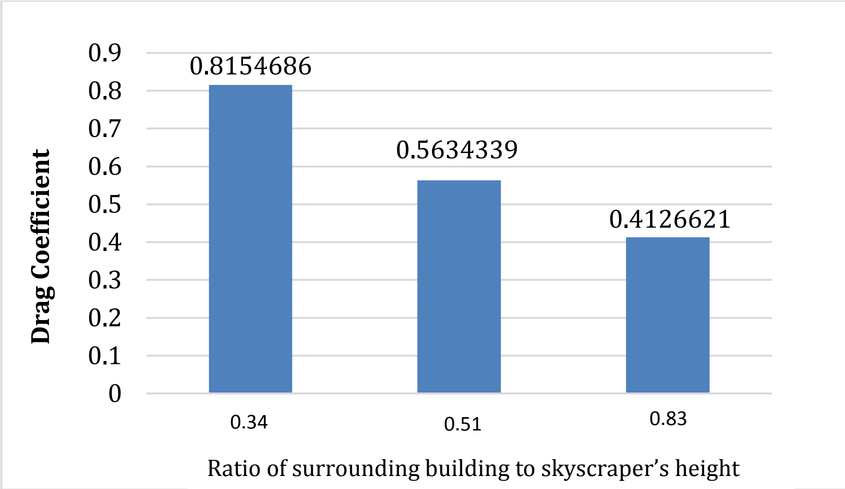

Fig. 17: Drag Coefficient for different height of building's surrounding

Based on Fig. 17, the lowest height of building surrounding of the skyscrapers which is 0.34 ratio, produced the highest drag coefficient 0.82, in comparison to those of the other heights. This happened because the incoming wind is more concentrated on the higher level of the skyscraper's surface hence causing the additional pressure on the wall.

When having tall surrounding buildings, it reduces the overall drag coefficient of the skyscraper as shown in Fig. 15 for the ratio of 0.83. However, the drawback is significant number of low velocity spots are being produced in the vicinity area and this will cause the pedestrian to have less ventilation on ground level. On the other hand, by having lower surrounding buildings, pedestrians will have a relatively better comfort level since low velocity spots are minimal, but the drawback will be high surface pressure on the walls and high drag coefficient which is undesirable for the building's occupants.

Conclusion

All three factors; shapes, orientations and height of surrounding buildings play a vital role in contributing to the comfort of both occupants and pedestrians. The shape with good aerodynamic characteristics is favourable for both occupants and pedestrians comfort. The orientation angle of skyscrapers facing incoming wind is also an important design factor to ensure that less low velocity regions is being created. Finally, by having the skyscraper surrounded by tall buildings will reduce the overall drag coefficient, however the trade-off is the pedestrians' comfort. All these three factors will have to be carefully considered to ensure the comfort of both pedestrians and occupants are well taken care of.

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