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EFFECTS OF GAP HEIGHT ON RURAL HOUSES USING COMPUTATIONAL FLUID DYNAMICS (CFD)

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A B S T R A C T

Recently, the number of damaged houses due to strong wind has increased in Malaysia. Previous data showed that the northern region of Peninsular Malaysia is susceptible to strong wind events due extensive open terrain condition. The damage mostly affected the roof of the non-engineered rural houses. There are many factors that may influence the damage of the roof which includes the overhang roof and the gap height. A typical Malaysian rural house with a low-rise gable roofs building is modelled with three variations of gap height. Computational Fluid Dynamic (CFD) was used with the RNG k-ε type of turbulence model to determine the pressure coefficient around the model and the wind flow pattern with the present of a gap. Based on the result from ANSYS, the contour of pressure coefficient along the overhang has been analysed. The study shows that the presence of overhang roof is more prone to cause damage compared to the presence of gap height.

1. Introduction

Every year, Malaysia will face two monsoon seasons, which are the Southwest Monsoon from late May to September, and the Northeast Monsoon from October to March. The Northeast Monsoon brings in more rainfall compared to the Southwest Monsoon. The Northeast Monsoon originates in China and the north Pacific while the Southwest monsoon originates from the deserts of Australia. During the Northeast Monsoon, wind comes from easterly or north-easterly with 10 to 20 knots prevail (Malaysia Meteorological Department, 2016). This will give a huge effect to the northern part of Malaysia especially in rural area since it possesses extensively large open terrain land. This is because the main economy activity in those areas is agriculture, which is paddy plantation. During the wind flow, there is no obstacle to break up the wind hence it will help the wind to escalate. The accelerated wind will achieve high velocity and hit the rural area near the open terrain. Therefore, the houses in rural area are more susceptible to be hit by the strong wind.

In Malaysia, the most threatening wind-related disasters that affect buildings and structures is windstorm. Based on previous research done by Wan Chik et al. (2014), it was found that in 74 strong wind occurrences in Malaysia from 2007 to 2012, 19 of them occurred in Kedah state with 1161 damages reported, which is the highest number of occurrences within 6 years. Most of the rural houses affected are considered as non-engineered houses. During strong wind occurrences, these types of houses are most vulnerable to damage. The damage mostly occurred at the roof of the core house, roof of the kitchen house and sometimes wall of the core house. The roof of a house generally receives the largest wind load thus most vulnerable to wind damage. The slope of the roof, overhang roof and gap height between the core house and the kitchen house is some of the factors that might cause severe damage to the roof. The aim of this study is to determine effect of gap height on rural house with the presence of kitchen house and overhang roof.

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2. Computational Methods

Three models of houses with various gap heights (due to the presence of kitchen house) and a model without kitchen house were studied in this paper. The gaps between the houses that were selected for this study are 0.25 m, 0.50 m, and 0.75 m. The gap height is defined as the gap between the eave of the core house and the ridge of kitchen house. Figure 1 shows the location of the gap height.

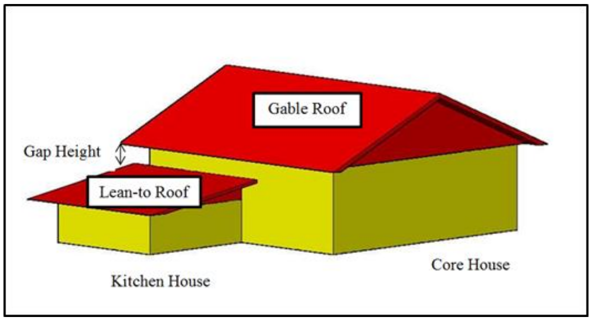


Figure 1: Location of Gap Height

The computational fluid dynamic (CFD) analysis was performed using ANSYS FLUENT 14 where the computational domain and boundary condition that was assigned to all models are as shown in Figure 2. The top boundary was extended 8H vertically from the ground of the model and 5H from the side walls, where H is the height of the house model which is H = 4 m. On the other hand, the inlet and outlet boundary was extended 6H and 16H from the wall, respectively.

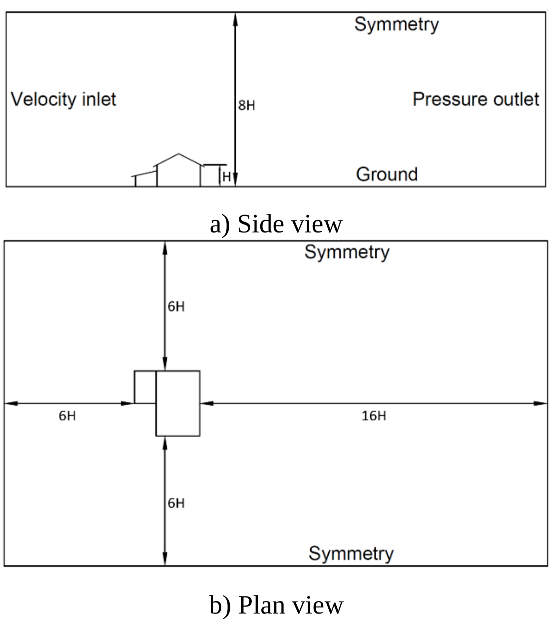


Figure 2: Computational domain and boundary condition for CFD analysis a) Side view, b) Plan view

Symmetrical boundary conditions were applied to left, right and top wall. In CFD simulations, the roughness length was expressed as equivalent to sand-grain roughness with roughness height, k_S and roughness constant, C_S of 0.035 mm and 0.6, respectively.

The computational mesh used for the simulation was created in a structured domain. For efficient computation of turbulence, the mesh arrangement is made finer at the house compared to the domain. High meshing smoothness and fine quality meshing will give more accurate result for simulation but it takes a longer time to compute, hence the region that away from building was meshed with a coarser structured mesh. Factor of 1.075 was used to increase the cell size away from the building since following the suggestion by Abohela et al. (2013) and Montazeri & Blocken (2013) where a ratio between two consecutive cells must not exceed 1.2 when the cells are stretched. Figure 3 shows the example of the overall mesh of the model.

Wind velocity was set to be 26.4 m/s. This speed is in accordance to the Beauford Scale which stated that the equivalent speed for storm at 10 m above ground is 26.4 m/s. The approaching wind is set to follow a wind profile with power law relationship as shown in equation 1.

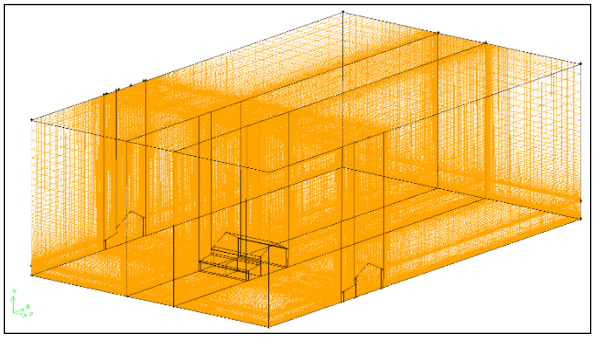
$$u = u_r \left(\frac{z}{z_r}\right)^{\alpha} \tag{1}$$

where,

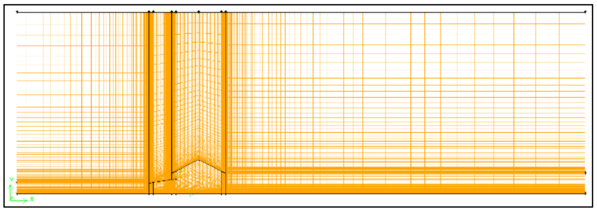
u	= wind speed
u_r	= wind speed at height z_r
z	= height
z_r	= reference height
α	= wind shear exponent

The mean streamwise velocity of the approaching flow obeyed a power law with an exponent of 0.25, which corresponds to a suburban terrain. Turbulence model of RNG k-ε was used in this study. This method was used following the recommendation by Tominaga et al. (2015) and Quan et al. (2006) where the RNG k-ε was reported to perform better than other models and save the calculation time, respectively.

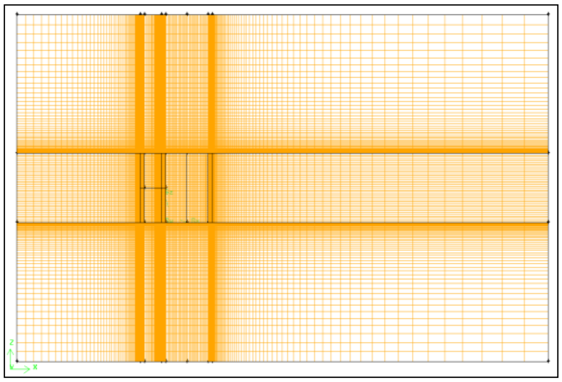
For the pressure, momentum and turbulence equations, second-order differencing was used with a "SIMPLE" pressure-velocity coupling approach. This setting was recommended by Abohela et al. (2013), Tominaga et al. (2015), Irtaza et al. (2015) and Montazeri & Blocken (2013). A total of 4000 steps of iteration were used in this study. The computational results were considered as converged when all the scaled residuals leveled off and reached a value ranging from 1×10^{-4} until 1×10^{-7}.



a) 3D view



b) Side view



c) Plan view

Figure 3: Mesh arrangement for whole computational domain a) 3D view, b) Side view, c) Plan view

3. Results and discussions

In the present study, the effects of variation of gap height on the pressure coefficient, C_P along the overhang roof were analyzed. For this purpose, the nett C_P values were monitored at three locations as shown in Figure 4. All measurements were observed at a cut section through the center of the kitchen house.

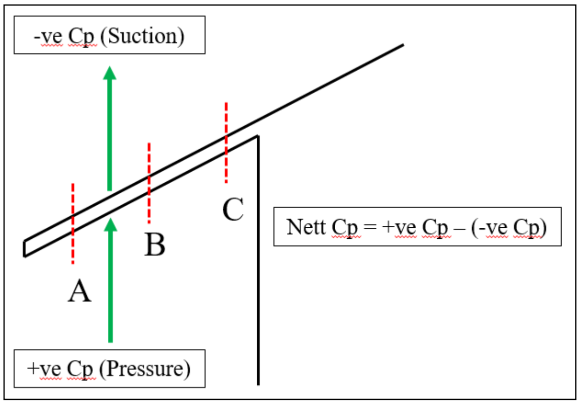
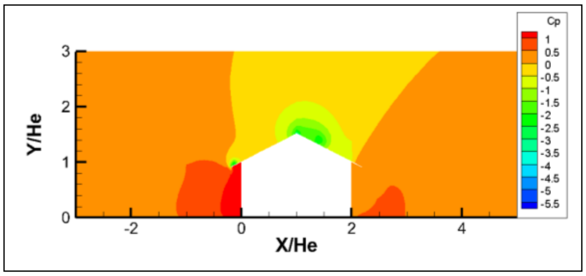


Figure 4: Location of nett C_P along the overhang roof

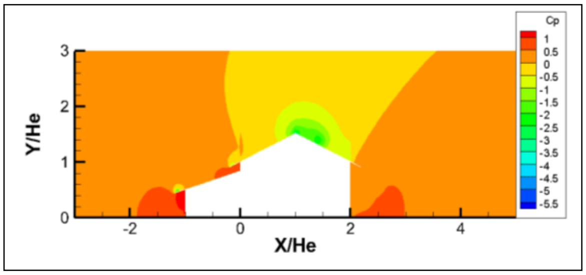
Figure 5 shows the results of the C_P contour along the section of the models. It can be seen that the front part of the houses encounter pressure due to the formation of eddy at the windward wall. On the contrary, the roof ridgeline is showing suction caused by the separation region right after the ridge. These findings are particularly true for all models.

Figure 6 shows the nett C_P (combination of pressure and suction) along the overhang roof. It can be seen that the nett C_P at the far end (location A) is always higher compared to location B and C. The results showed that model with no gap exhibited the highest nett C_P followed by model with gap height 0.75 m, 0.5 m and 0.25 m. This trend is found to be consistent at location B and C. These findings demonstrated that the presence kitchen house that created the gap is not influencing the scale of the nett C_P. This phenomenon is due to the fact that the wind energy has been attenuated as it impinged the wall of the kitchen house and moved along the roof. As a result, lower pressure is accumulated within the gap height area.

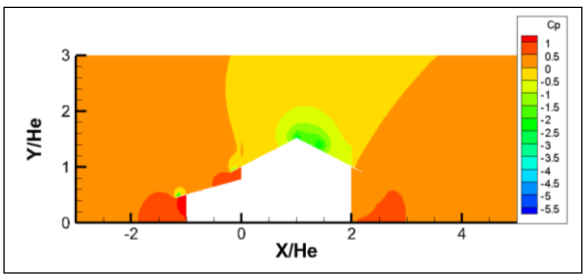
However, post disaster survey conducted by Deraman et al. (2016) showed that rural houses with kitchen house (gap height) and overhang roof were damaged during strong wind event. As such it is believed that the presence of overhang roof is more prone to cause damage compared to the presence of gap height.



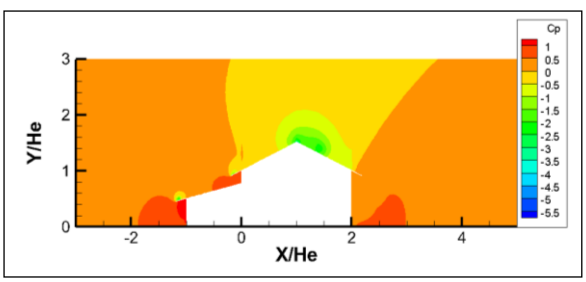
a) No gap



b) 0.25 m gap height



c) 0.50 m gap height



d) 0.75 m gap height

Figure 5: Pressure coefficient, C_P for roof pitch 27° with (a) No gap height, (b) 0.25 m gap height, (c) 0.50 m gap height, (d) 0.75 m gap height

6. Conclusions

In this study, the presence of kitchen house that created the gap height is not contributing to increase in nett C_P where model without kitchen houses consistently exhibited higher C_P compared to other models. However, this finding is only true for roof 27° roof pitch and 0.75 m overhang roof. As such, more CFD work involving models with other roof pitch and overhang length is required in order to determine the full spectrum of the response.

Acknowledgement

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