

Numerical investigation on the effect of overhang roof around rural house

*Taksiah A. Majid¹⁾, Shaharudin Shah Zaini²⁾, Mohd Azmi Ismail³⁾, Siti Noratikah Che Deraman⁴⁾ and Jing Lin Poon⁵⁾

^{1), 2), 4), 5)} *Disaster Research Nexus, School of Civil Engineering, Universiti Sains Malaysia, Engineering Campus, Penang, Malaysia*

³⁾ *Advance Packaging and SMT Group, School of Mechanical Engineering, Universiti Sains Malaysia, Engineering Campus, Penang, Malaysia*

¹⁾ taksiah@usm.my

ABSTRACT

Most of the rural houses in the Northern region of Peninsular Malaysia are classified as non-engineered building. These rural houses are characterized by having overhang roof and kitchen house. There have been many cases of such houses being damaged during thunderstorm events. This study investigates the change in the distribution of pressure coefficient pattern around an isolated rural house model by varying the overhang length. The roof pitch of core house was maintained at 27° in all cases. Computational fluid dynamics (CFD) simulations based on Reynolds-averaged Navier-Stokes equations (RANS) was used together with turbulence model, RNG $k-\epsilon$. The results showed that pressure coefficient under the overhang roof between the core and kitchen house increased with the increase in the overhang length. Moreover, as the overhang length increase, the recirculation size of the vortex became larger.

1. INTRODUCTION

In Malaysian rural area, most of the houses are considered as non-engineered buildings as they were built without proper design considerations. 'Non-engineered' buildings are defined as unsystematically designed and poorly built structure (Winarno et al., 2010). Generally, these buildings are either landed or elevated structure and considered as low rise buildings (Irtaza et al., 2015). Rural houses can be divided into two main spaces that form quite rigid layout relationship namely core house and kitchen house (Yuan, 1991; Hassan and Ramli, 2010; Roosli, 2015). Basically, new extensions are added on to the basic core house at various stages and times as and when the need arise (Yuan, 1991). Malaysia is a tropical climate country and seasonally exposed to strong wind during thunderstorm. In Malaysia, windstorm occurrence keep increasing

¹⁾Associate Professor

^{2),3)}Senior Lecturer

^{4),5)}Graduate Student

from year to year since 2010 until 2013 (Majid et al., 2016) and it is affecting rural houses. The strong wind, generated during thunderstorm can seriously damage the roofing system of rural and non-engineered houses as shown in Fig. 1. These pictures were captured during windstorm events in Balik Pulau, Penang and Kepala Batas, Penang. Some of the features of rural houses in this region are the presence of the kitchen house and overhang roof as shown in Fig. 1 (b). Overhang roof is used to protect the wall façade during heavy rain. This overhang can initiate damage to the roof due to the fact that it behaves similar to a cantilever member and there is no adequate support to hold the member from uplift pressure.



Fig. 1 Damaged to rural houses during windstorm in (a) Balik Pulau, Penang and (b) Kepala Batas, Penang

The study on the wind pressure distribution surrounding a structure can be carried out either experimentally using wind tunnel test or numerically using computer simulations. It cannot be denied that the wind tunnel test is more effective and accurate, but can be time consuming and costly. On the other hand, Computational Fluid Dynamics (CFD) analysis (CFD) been successfully used by researchers to evaluate the interaction between wind and structures numerically (Huang et al., 2007; Irtaza et al., 2015).

2. METHODS

A schematic view of the building model used in the study is shown in Fig. 2. An isolated gable-roof of core house with the presence of kitchen house for which the eave height (H_e), width and length was 4 m, 8 m and 12 m, respectively. The 27° roof pitch model was tested with four different overhang dimensions namely, 0.5 m, 0.75 m, 1.0 m and 1.25 m. The mean streamwise velocity approaching flow was set at 26.4 m/s. The shape of the model was relatively similar to the typical rural house in the Northern region of Peninsular Malaysia.

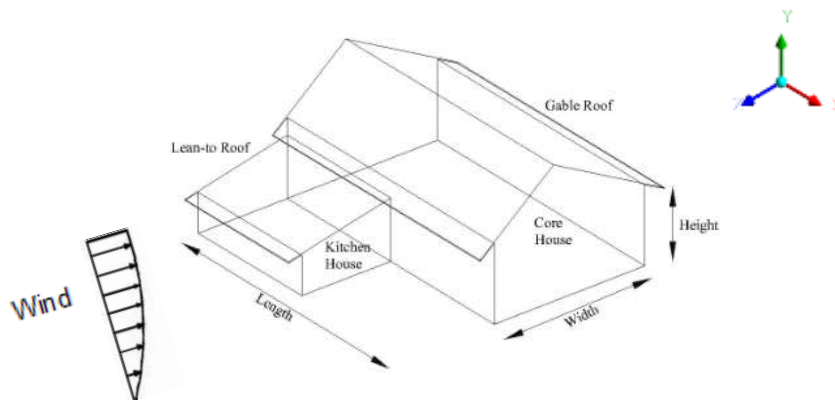


Fig. 2 Schematic view of rural house

2.1 Computational methods

In order to perform the steady-RANS equation, ANSYS Fluent 14.0 was used. This software is based on finite volume method for solving the flow equation with the capacity of dealing both structured and unstructured grids in its solver. RNG $k-\epsilon$ model was applied following the suggestions from Tominaga et al. (2015). Standard wall functions were applied to the wall boundaries (Lauder and Spalding, 1974). The second order implicit scheme was used for time discretization while the second order upwind discretization scheme was used to obtain higher accuracy. The SIMPLE algorithm was used for pressure-velocity coupling.

The computational domain size and boundary conditions was set as shown in Fig. 3. The size of computational domain for lateral and the top boundary was recommended by Mochida et al., (2002), Shirasawa et al., (2003) and Tominaga et al., (2008) while the outflow boundary should be set to be at least $10H_e$ behind the building as suggested by Tominaga et al. (2008).

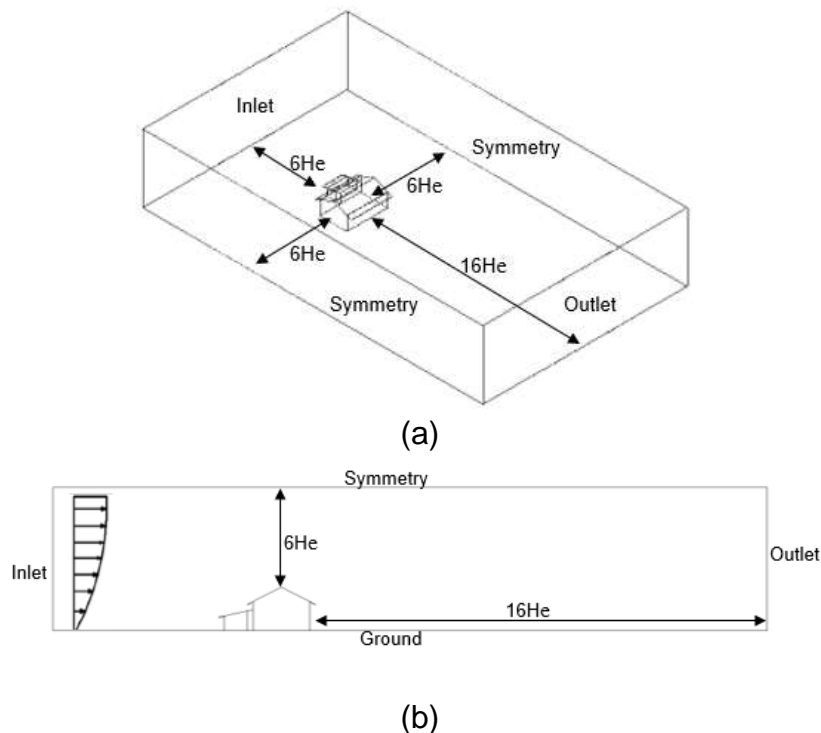


Fig. 3 Dimension of the computational domain in (a) 3D view and (b) side view

The boundary condition followed the setup from Tominaga et al. (2015). The inflow boundary condition was set as vertical wind profile of streamwise velocity and obeyed a power law relationship with an exponent of 0.25, corresponding to a suburban terrain category. The power law equation was incorporated into the algorithm via User Define Function. Likewise, the outflow boundary condition from the domain imposed zero static pressure and need to be placed far from the region where the influence of the target house was negligible. The upper and side of the domain was set as symmetry boundary conditions, implying zero normal velocity and zero gradients for all the variables at these boundaries (Tominaga et al., 2015). The boundary condition corresponding to the actual ground surface was used with roughness height, $k_s = 0.001$ m and roughness constant, $C_s = 1.0$.

3. RESULTS OF CFD ANALYSIS

3.1 Streamlines

Fig. 4 shows the streamline patterns for rural house models with different overhang roof length. In general, it can be seen that the changes of overhang length affect of wind flow underneath of overhang. The recirculation eddies were formed mostly at windward section. This phenomenon is due to the fact that the wind was blocked by the house. The presence of the kitchen house changed the direction of wind flow underneath the overhang.

In the case where the overhang roof was 0.5 m, a small recirculation eddy was formed underneath the overhang between core and kitchen house as shown in Fig. 4(a). Fig. 4(b) shows the effect of wind underneath overhang of 0.75 m length. From this figure, it can be seen that the diameter of recirculation eddy underneath the overhang is getting larger than 0.5 m. The same trend was also observed for models with overhang length of 1.0 m and 1.25 m.

As all the models have the same roof pitch, the effect of wind flow pattern at the leeward side of the house was almost similar. The reverse flow was generated leading to the formation of swirling. The changed in the wind direction induced positive pressure underneath the overhang. It can be clearly seen that the flow reattaches to the windward roof surface without any separation zone and hence created positive pressure on the overhang of the roof.

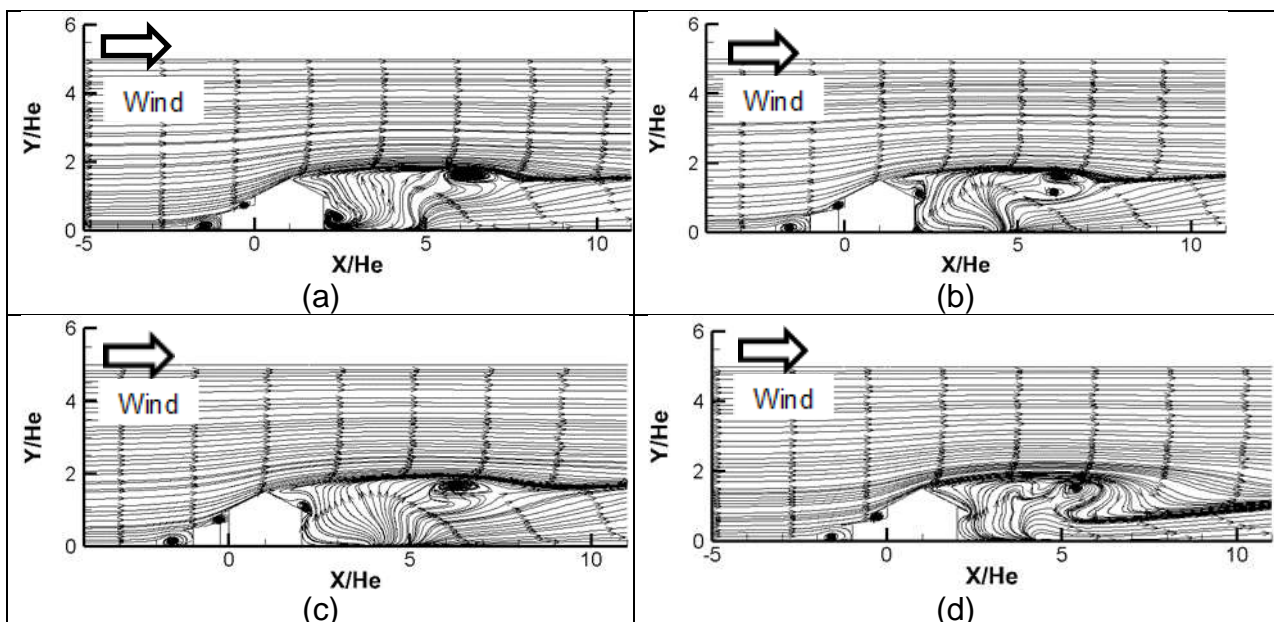


Fig. 4 Streamline flow pattern for (a) 0.5 m; (b) 0.75 m; (c) 1.0 m; and (d) 1.25 m overhang length

Also noted was the presence of mixing layer behind the core house where the turbulence wake region occurred. It was found out that eddies were formed at the ridge edge of the leeward roof as shown in Fig. 4(b) and 4(c). The reattachment point for the recirculation region is approximately 12 m behind the house. Eddies also formed at the corner of the house at the backside of the house as shown in Fig. 4(c) and 4(d). The wake region occurred behind the core house pattern was relatively similar except for the model in Fig. 4(d) where the mixing layer produced a S-shape flow instead of parabolic as shown by other models.

3.2 Spatial distribution of pressure coefficient

Fig. 5 compares the spatial distributions of the static pressure as expressed by the pressure coefficient. The results showed that the area of positive pressure underneath the overhang between the core and kitchen house became larger with the increase in the overhang length. This phenomenon is particularly true for all models. In the case of models with overhang length 0.5 m, 0.75 m and 1.0 m, the region of negative pressure (suction effect) that appeared near the ridge to the leeward side of the roof was smaller than the region of model with 1.25 m overhang length.

Fig. 5(a) shows that overhang length of 0.5 m produced the highest positive pressure coefficient underneath the overhang between the core and kitchen house compared to other models. This is due to the fact that shorter length of overhang generated small formation of eddy, thus the wind impinged the house directly. Fig. 5(a), 5(b) and 5(c) showed relatively similar pattern on the distribution of pressure coefficient but different in terms of the magnitude.

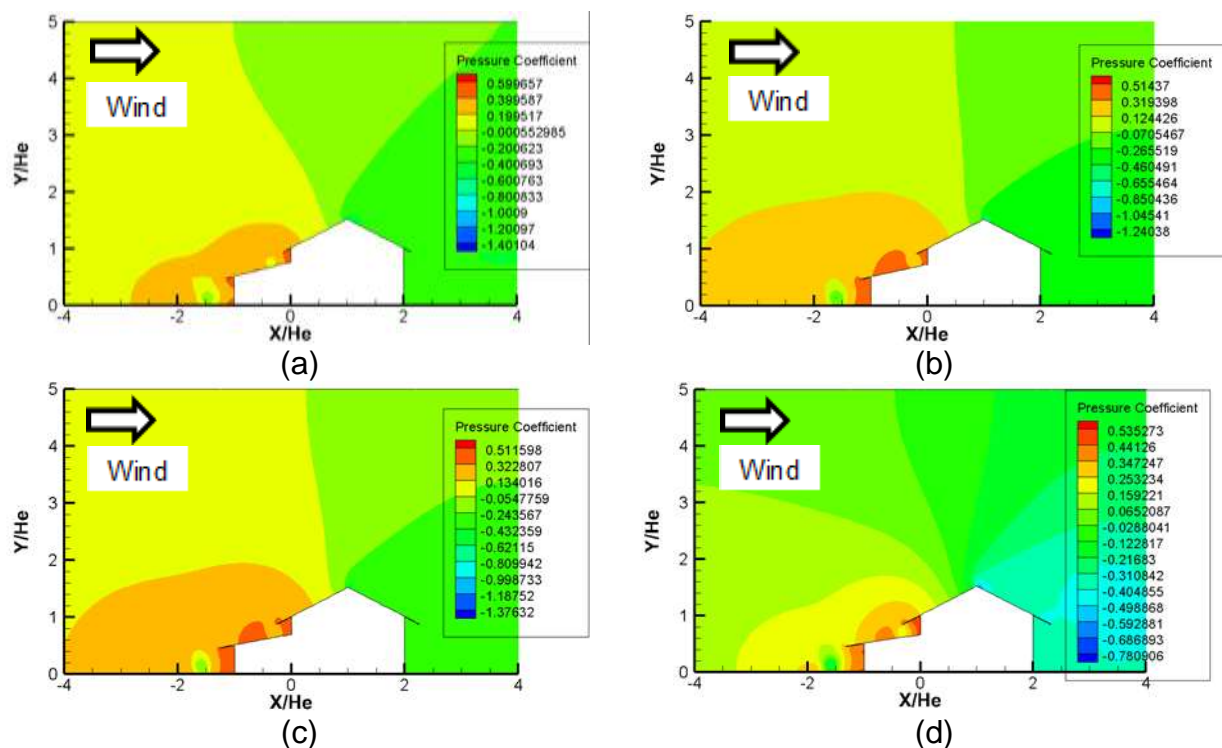


Fig. 5 Contour of the pressure coefficients for different overhang length (a) 0.5 m; (b) 0.75 m; (c) 1.0 m; and (d) 1.25 m

In the case of model with 1.25 m overhang, the pressure coefficient was found to be higher than 1.0 m and 0.75 m but lower than 0.5 m. This anomaly suggests that there is a limit to the overhang length that can effectively reduced the pressure underneath the overhang roof. Also noted was the presence of high suction at the ridge of the house as shown in Fig. 5(d) compared to other models. However, the pattern of

pressure coefficient showed that all suction occurred almost at the halfway of the windward surface of the roof for all models.

4. CONCLUSIONS

The research was carried out with the aim to investigate the flow pattern and wind pressure coefficient due to the variation of the overhang length. It can be concluded that:

- 1) The result from streamline shows that the presence of the kitchen house changed the direction of wind flow underneath the overhang roof. The changed in the wind direction generated recirculation eddies and induced positive pressure. The recirculation size of the eddy became larger with the increase in the length of the overhang roof.
- 2) There is no obvious relationship between the overhang length and the magnitude of the pressure coefficient although the increase in the overhang length showed lower pressure underneath the overhang roof in most cases.

ACKNOWLEDGEMENT

The authors express their gratitude for the financial support of the Fundamental Research Grant Scheme (FRGS) from the Ministry of Higher Education Grant (203.PAWAM.6071317), MyBrain15 Scholarship from the Ministry of Education Malaysia.

REFERENCES

- Hassan, A. S. and Ramli, M. (2010), "Natural ventilation of indoor air temperature: A case study of the traditional Malay house in Penang," *Am. J. Eng. and Appl. Sci.*, **3**(3), 521-528.
- Huang, S., Li, Q. S. and Xu, S. (2007), "Numerical evaluation of wind effects on a tall steel building by CFD," *J. Constr. Steel Res.*, **63**, 612-627
- Irtaza, H., Javed, M.A. & Jameel, A. (2015), "Effect on wind pressures by variation of roof pitch of low-rise hip roof building," *Asian J. Civ. Eng. (BHRC)*, **16**(6), 869-889.
- Lauder, B.E. & Spalding, D.B. (1974), "The numerical computation of turbulent flows," *Computer Methods in Applied Mechanics and Engineering*, **3**(2), 269-89.
- Majid, T. A., Zakaria, S. A. S., Wan Chik, F. A., Deraman, S. N. C. and Muhammad, M. K. A. (2016), "Past windstorm occurrence trend, damage, and losses in Penang, Malaysia," *J. E. Sci. Tech.*, **11**(3), 397-406.
- Mochida, A., Tominaga, Y., Murakami, S., Yoshie, R., Ishihara, T. and Ooka, R. (2002), "Comparison of various k- ϵ models and DSM applied to flow around a high-rise building—Report on AIJ cooperative project for CFD prediction of wind environment," *Wind Struct.*, **5**(2-4), 227-244.
- Roosli, R., Abu Bakar, A. H., Abas, N. F., Ismail, M., Abdullah, S. and Yusuf, M. N. (2015), "Criteria and determinants for assessing the sustainability of conservation

- management and process of Malay vernacular house,” *Adv. Environ. Bio.*, **9**(4), 59-61.
- Shirasawa, T., Tominaga, T., Yoshie, R., Mochida, A., Yoshino, H., Kataoka, H. and Nozu, T. (2003), “Development of CFD method for predicting wind environment around a high-rise building part 2: the cross comparison of CFD results using various k- models for the flowfield around a building model with 4:4:1 shape,” *AIJ J. Technol. Des.*, **18**, 169-174.
- Tominaga, Y., Mochida, A., Yoshie, R., Kataoka, H., Nozu, T., Yoshikawa, M. and Shirasawa, T. (2008), “AIJ guidelines for practical applications of CFD to pedestrian wind environment around buildings. *J. Wind Eng. Ind. Aerodyn*, **96**, 1749–1761.
- Tominaga, Y., Akabayashi, S-I, Kitahara, T. and Arinami, Y. (2015), “Air flow around isolated gable-roof buildings with different roof pitches: Wind tunnel experiments and CFD simulations, *Build. Environ.*, **84**, 204-213
- Winarno, S., Griffith, A. and Stephenson, P. (2010), “Reducing earthquake risk to non-engineered buildings: A study of design and construction practices in Indonesia,” *J. Constr. Management*, **10**(1), 75-86.
- Yuan, L. J. (1991), “The Malay house: rediscovering Malaysia’s indigenous shelter system, Malaysia: Institute Masyarakat,” Phoenix Press