

Large eddy simulation of natural ventilation for idealized terrace houses due to the effect of setback distance

L Tuan^{1,3}, A Abd Razak^{1,4}, S A Zaki², A F Mohammad¹, and M K Hassan¹

¹Faculty of Mechanical Engineering, Universiti Teknologi MARA (UiTM) Shah Alam, Malaysia

²Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Kuala Lumpur, Malaysia

Abstract. Similar to most tropical countries, Malaysia have low wind speed and airflow characteristics to provide an effective natural ventilation system for comfortable living especially in terrace houses. Even so, by designing them with suitable threshold height/width, H/W , ratio may help reduce heat sink, or even the accumulation of contaminants within the setback distance. Through this study, the downstream building of these terrace houses will be investigated due to the effects from an upstream building. With the use of Large-Eddy Simulation (LES) method, the formation of the vortex within the threshold H/W ratio will be clearly simulated and allow the observation of flow regimes developed by each model. With increasing threshold H/W ratios the models will exhibit some wake interference flow and skimming flow which will determine the negative or positive effect of ventilation from the upstream building towards the downstream building. The airflow characteristics of the downstream house will also be analysed and the most effective layout in providing a better air circulation may be determined. Improving the natural ventilation of such houses could significantly reduce these negative effects such as the accumulation of dust, smoke or bacteria. In turn, with the alarming rate of depletion in natural resources and its effects to the environment, this study can significantly reduce energy usage for ventilation and space cooling.

1. Introduction

Natural ventilation has been long used for space cooling and the removal of contaminants in buildings for comfortable living. By permitting natural ventilation, the indoor air will be cooler, cleaner and fresher without the use of any mechanical forces. Since, there have been a high rate of depletion in natural resources in the recent years, the use of mechanical ventilations need to be greatly reduced. This has led to the reintroduction of natural ventilation for heat removal and ventilation. Hence, ways to promote natural ventilation inside a building need to be further studied especially in the tropical climates.

Malaysia is a tropical country that experiences hot and humid climate throughout the year. The climate within this region is generally known to have high ambient temperatures at an average minimum of 23°C and an average maximum of 33°C with small diurnal and annual ranges [1]. Also, in this region, the wind speed varies between the range of 1 m/s to 3 m/s (light breeze) in major towns [2]. The high temperature and low wind speed experienced by this region contributes to the lower comfort level indoors, as the weather is unable to provide good ventilation for buildings. In many cases, this has caused the overheating of outdoor environment in urban areas.

In many countries like Malaysia mechanical cooling and ventilation techniques are highly used for comfortable living. In Malaysia, the percentage of the yearly energy consumption for domestic use is 29% [3]. From that 29% energy consumption, 7.105 GJ/year is yielded for the cooling and ventilation of

³ Author to whom any correspondence should be addressed.

⁴ Author to whom any details of research funding should be addressed.



buildings. Based on the Building and Climate Change 2007 report it is targeted for Malaysia to reduce the use of electricity by 5.6% and fuel demand by 26.7% annually [4]. This is one of the many challenges in building design of homes in the tropics to achieve comfortable living. During the past few decades, there have been many experiments and research carried out on naturally ventilated buildings in order find solutions for achieving energy saving, green energy, energy efficiency and sustainable energy goals due to the depletion of natural resources. In the area of cross ventilation, one of the recent researches conducted particularly on the improvement of natural ventilation of the terrace housing community in Malaysia is the work by Mohamad et al [5].

Mohamad et al. [5] stated that there are many challenging factors that influence the analysis of natural ventilation such as wind velocity, wind direction, temperature difference, opening design, building shape and adjacent building and much effort are being put in to hurdle over these challenges. One of the many studies in simulating the effects of natural ventilation using the LES method is by Yi Jiang et al. [6]. In justification to its capabilities, the LES method is very outstanding in accounting unsteady flow and generating detailed information on the flow structure, including turbulence statistics, has been proven in many studies to date [7].

2. Simulation Setting

2.1. Building Models

The building model of this study adopted a basic intermediate single-storey terrace house which is similar in layout and dimension to a previously conducted study by Mohamad et al. [5]. In comparison to his study, this current study is modelled with an opposing downstream building set at a separation distance, d , of $0.5H$, H and $1.5H$. The cases evaluated are as summarized in Table 1. The target building for this study is the downstream structure ($H2$) and will be analysed at each point $P1$, $P2$, $P3$, $P4$, and $P5$ of each consecutive room. Point $P1$ is the Living room, point $P2$, $P3$ and $P4$ are the bedrooms, and point $P5$ is the utility room (see, Figure 1). Abiding the Uniform Building by-laws [8] the openings of the rooms are the doors which are made greater than 10% of the floor area with a minimum dimension of 2m in height and 0.75m in width [8]. Apart from that, the building height is modelled with a standard height of 3m [8].

2.2. Computational Domain and Boundary Conditions

The computational domain that was modelled is as in Figure 2. The limiting boundary conditions are set up similar to Mohamad et al [5]. The inlet, outlet and lateral boundaries of the domain of the building are treated as periodic condition, and the top boundary of the domain is treated as free-slip condition. The bottom boundary and surface of the building model are treated as non-slip conditions that will guide the computations throughout the simulation. For all the models that will be carried out, the initial velocity of the wind will be directed at a zero incidence angle perpendicular to the front façade of the building (in the horizontal x-direction), at 5m/s. The respective axis orientation and domain sizes are as labelled. A summary of the steps carried out in OpenFOAM for this particular simulation is as in Figure 3.

Table 1. Evaluated cases

Simulation Case	Setback distance
Case 0.5H	1.5m
Case H	3m
Case 1.5H	4.5m

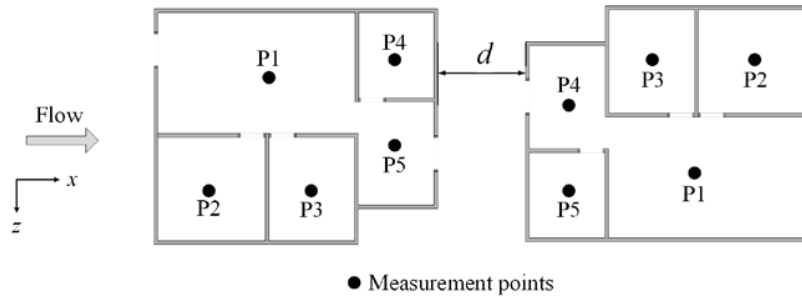


Figure 1. Model layout of the buildings

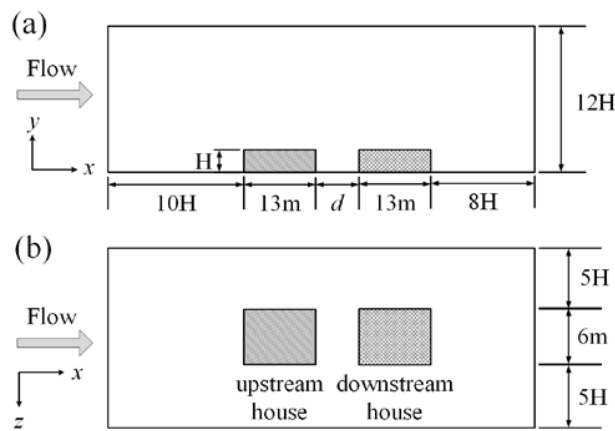


Figure 2. Computational domain size (a) Sectional side view (b) Plan view

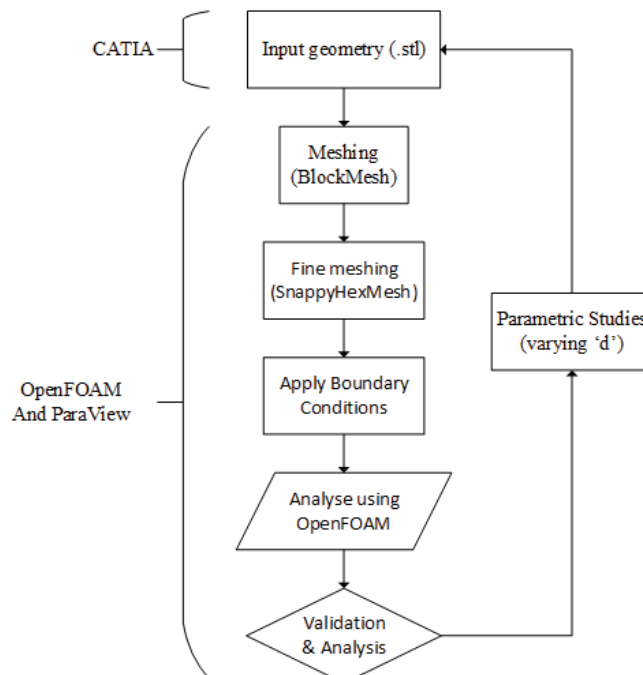


Figure 3. Summary of simulation steps

3. Result and Discussion

The validations of the cases were compared with the experimental data obtained from Yi Jiang et al. [6] as in Figure 4. The mean velocity distribution obtained from this study generally agreed to the experimental results of his study. However, there were some discrepancies found especially at the front façade of the building ($y/H < 1$) and near the roof height ($y/H = 1$). This may be due to the coarseness of the grid as stated by Yi Jiang et al. [6].

Focusing on the target building, the velocity distribution at each consecutive room of the downstream house starting from the point of entry at, $P5H2$ until the exit route, $PIH2$ is as in Figure 5. Generally, the flow across the downstream target building will be affected by the shear stress of the ceiling. This can be seen in the range of $y/H > 0.9$ where the profile seem to “stick” to the ceiling or backflow occurs. This backflow may also occur due to short ceiling height where a higher grid discretization level is needed to better simulate the profile near the ceiling. Despite the discrepancies from the effect of the ceiling some similarities between the cases can also be seen at a height ratio between $0.6 < y/H < 0.9$ (between the door height and the ceiling). Here, the velocity tends to increase at an almost constant value along that range of height ratio. Apart from that it can be seen that the profile generated by Case $1.5H$ over-estimated the other two cases, Case $0.5H$ and Case H . This shows that the velocity across the rooms are better in each of the consecutive rooms for Case $1.5H$ which shows that the target building is better ventilated with a higher setback distance.

Looking closely at point of measurement, $PIH2$, it was found that with a higher setback distance there is a higher chance for the air from the downstream house to be replenished outdoors. As we can see from Figure 5, the flow generated is more drawn to the exit or door ($y/H < 0.6$) for Case $1.5H$. However, for Case H and Case $0.5H$, the flow generated are less drawn to the exit than Case $1.5H$ but rather, it is more drawn to the ceiling. Thus, this clearly shows that by increasing the setback distance can possibly improve the ventilation rate of the downstream house.

Even so, from this induced wind flow there may be some other impacts of the setback distance that results in carrying negative effects from the upstream house such as “dirt and dust”. This may be observed as in Figure 6. This figure shows the streamtracer and velocity profile across the upstream and downstream house. From this figure we can clearly see the wind flow across the cascading buildings and it can be seen that a higher setback distance will induce a stronger wind flow within the upstream house. When this happens there are more chances of the wind to “pick up” any negative effects from the upstream house and carry it to the downstream house especially from isolated rooms i.e. bedroom 3 ($PIH4$). However, with the formation of wake interference flow (highlighted by yellow box in Figure 6) within the threshold H/W further downstream of the wind distribution the accumulated particles may be dispersed from the area.

4. Conclusion

The simulation focuses on the flow fields inside and around a basic single-storey intermediate terrace house in Malaysia. The simulated model was varied with three different setback distance configurations of $0.5H$, H and $1.5H$. For the three cases, the velocity distributions inside the consecutive rooms were determined. It was found in the present study that the higher the setback distance, d , the higher the chances of ventilation to happen. However, with a higher setback distance, there is a higher chance of some negative effects from the upstream house to be carried into the downstream house such as dust and dirt. On the other hand, after further analysis of the results, the formation of wake interference flow within the threshold H/W will help to disperse these negative effects from the area. Depending on the setback distance, the higher the H/W ratio, the slower the rate for the carrying winds to disperse.

5. Acknowledgement

This research is financially supported by grant-in aid for scientific research (600-RMI/FRGS 5/3 (73/2013)) from the Ministry of Education, Malaysia.

6. References

- [1] Rajalingam J K 2005 *Kolej Universiti Teknikal Kebangsaan Malaysia*
- [2] Kubota T and Ahmad S 2006 *J of Asian Arch and Building Eng* **5** 199-206
- [3] Kubota T, Jeong S, Toe D H C, Ossen D R 2011 *J of Int Dev and Coop* **17** 61-9
- [4] Initiative C 2007 *Buildings and Climate Change*
- [5] Mohamad M F, Hagishima A, Tanimoto J, Ikegaya N and Omar AR 2013 *13th Conf of Int Building Performance Simulation Assoc Chambery France*
- [6] Jiang Y, Alexander D, Jenkins H, Arthur R and Chen Q 2003 *J of Wind Eng and Ind Aerodynamics* **91** 331-53
- [7] Walton A, Cheng A and Yeung W 2002 *Atmospheric Environment* **36** 3601-13
- [8] Uniform Building By-Law (UBBL) 1984 Malaysia

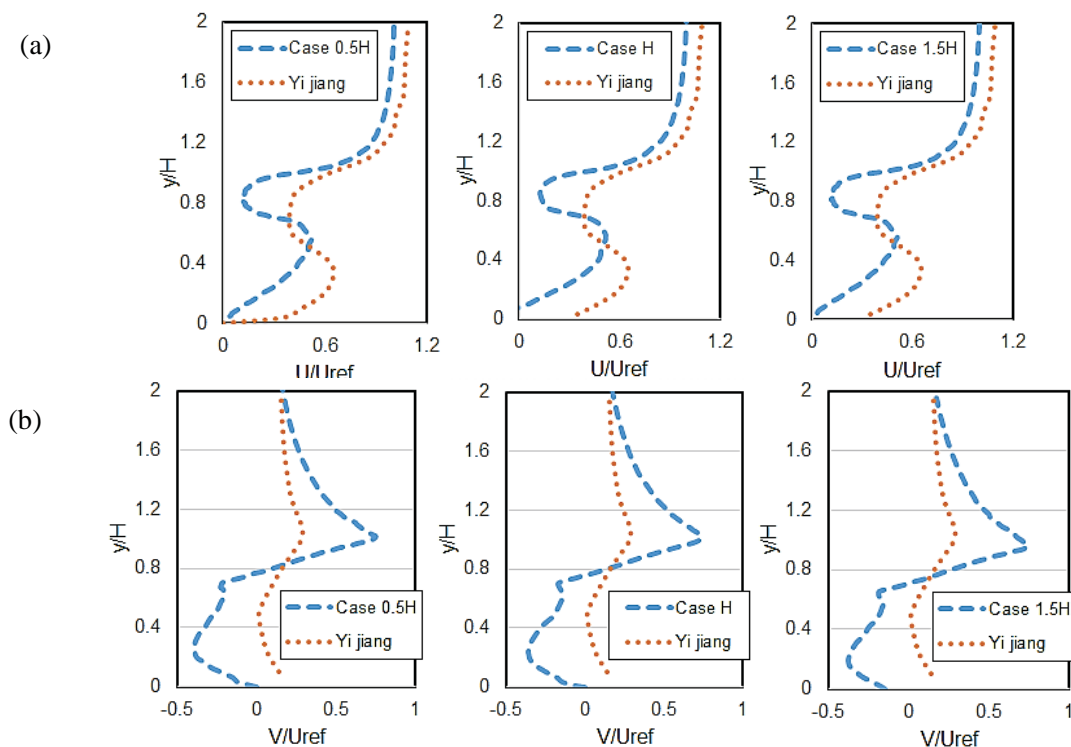


Figure 4. Mean velocity distribution for cross ventilation (a) streamwise (U/U_{ref}) and (b) vertical (V/U_{ref})

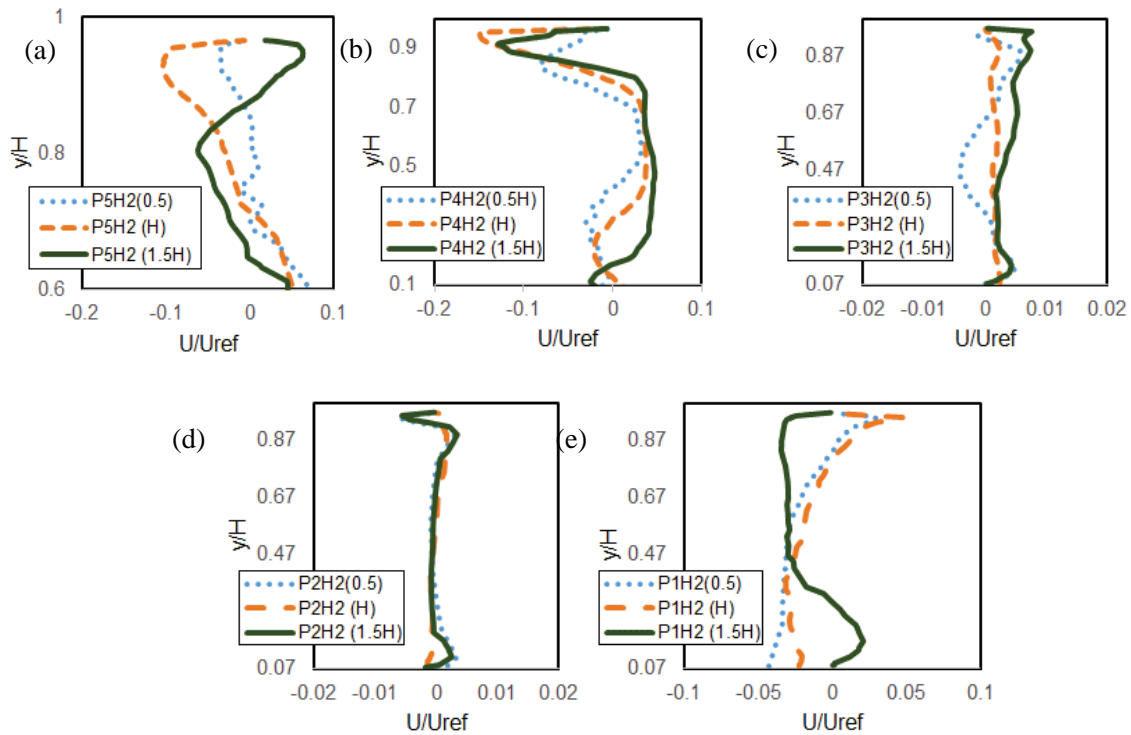


Figure 5. Streamwise mean velocity distribution at each consecutive rooms (a) *P5H2*, point of entry (b) *P4H2* (c) *P3H2* (d) *P2H2* (e) and *P1H2*, exit route

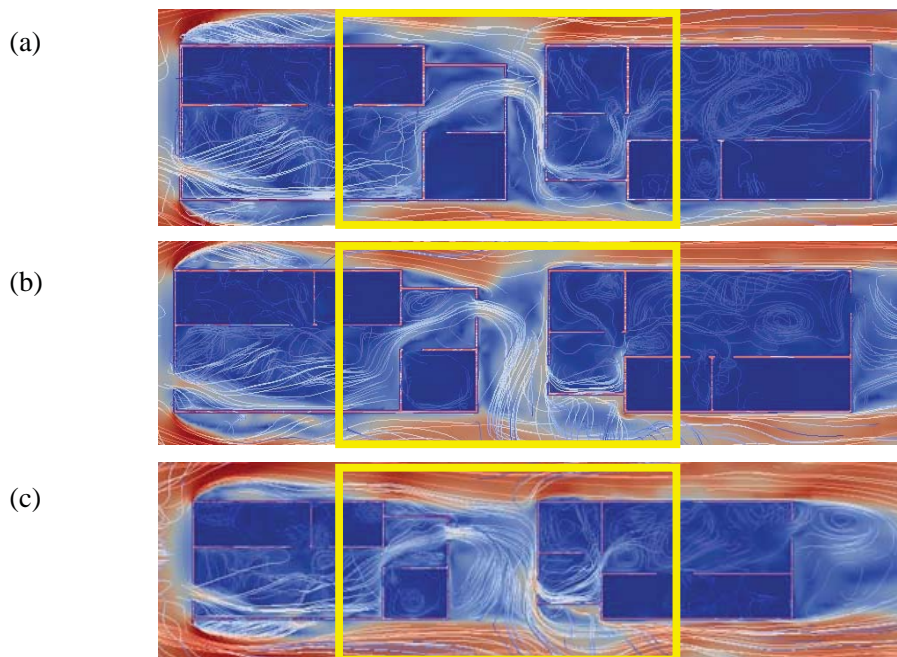


Figure 6. Flow Regime Generated at Threshold H/W (a) Case $0.5H$ (b) Case H (c) Case $1.5H$