

## CROSS VENTILATION ANALYSIS ON THE EFFECT OF SETBACK DISTANCE OF A TERRACED HOUSE USING PIV

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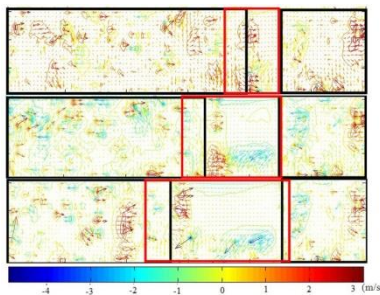
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### Article history

Received  
16 February 2015  
Received in revised form  
29 April 2015  
Accepted  
31 May 2015

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### Graphical abstract



### Abstract

Urban development has become very alarming with the rise of population especially in regions with weak wind such as countries in the tropics like Malaysia. The highly dense structures make it difficult to provide effective ventilation from heat, pollutions, dusts and even bacteria. With time, it will caused the urban area to become 'sick'. Due to this, building arrangement plays an important part in predicting airflow structure and the effectiveness of ventilation from the developed airflow. Through this study, the effects of the setback distance arrangement,  $d$ , on the cross ventilation of two cascading terraced houses were analyzed. Based on the flow structure, the possibility of the negative effects from the upstream house carried in to the downstream house was also observed. The study was conducted experimentally using Particle Image Velocimetry (PIV) with the aid of INSIGHT 4G for post-processing analysis. It was found that the most ideal setback distance was  $d = 0.5H$  even though a higher  $H/W$  threshold ratio of the street canyon allowed the transition of wake interference flow to isolated roughness flow. Apart from that, the provided setback distance,  $d$ , can give sufficient ventilation on the downstream building.

Keywords: Cross ventilation, terraced house, setback distance, PIV, flow structure

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## 1.0 INTRODUCTION

Urban settlements are complex places and are constantly changing as a result of factors such as economic growth and social amenities [1]. This makes it difficult to plan and manage urban growth efficiently and sustainably with the rapid increase in number of people moving to the cities. Evidently, Malaysia's population has grown from 10.2 million to 15 million within the year 2000-2010 [2]. Consequently, this leads to the increase in infrastructure for accommodating, transporting and providing employment for the growing population. As of 2010, Malaysia has the

fourth-largest amount of built-up land in East Asia and Pacific region where, its urban area has grown from 3,900 to 4,600 square kilometers between the years 2000-2010 [2]. From which, the rapid changes in urban settlement have taken a great toll on the urban indoors environment as it is unable to provide effective ventilation for a comfortable living.

In Malaysia, approximately 50 to 60% of electricity is consumed by air conditioning and mechanical ventilation per year especially in residential buildings [3]. In urban area such as Kuala Lumpur, residential housings take up the highest percentage of built-up land [4]. In regard to which the terraced housing is the

most preferred dwelling type like in Johor Bahru where, 69.9% of the population preferred such land-dwellings [5]. Even so, through many statistical, field and simulation studies [3, 6-8] the occupants of such houses show high discomfort level which leads to the excessive use of air conditioning. In line with the Tenth Malaysian Plan [9] the use of electricity can be further reduced through the reintroduction of natural ventilation.

Due to the depletion of natural resources natural ventilation has been reintroduced for replenishing indoor air and help further reduce the use of electricity. Natural ventilation is the utilization of buoyant forces and pressure differences to dilute an air space without the use of mechanical ventilation. Through many studies this can be improved through the use of natural ventilation which can be categorized as single-sided ventilation and cross ventilation. In reducing energy consumption and increasing energy efficiency, this effort has been taken by a number of researchers through the study of isolated buildings with various conditions and influencing factors as such by Yi Jiang *et al.* [10] and Ramponi *et al.* [11].

Yi Jiang *et al.* [10] numerically and experimentally studied on the flow pattern and velocities surrounding a single-sided and crossed ventilation isolated cubic building. This study provided confidence in the application of CFD analysis on the prediction of natural ventilation. Ramponi *et al.* [11] then studied on the cross-ventilation flow for different isolated building configurations. Further looking into studies on isolated buildings Kasim *et al.* [12] expanded the study of cross ventilation by looking at the cross ventilation performance with different building layouts. In this study the researcher investigated the chances of wind-induced ventilated buildings to be affected by the negative effects of neighboring buildings which can be justified from flow structures defined by Oke [13] i.e. skimming, wake interference and isolated roughness flow. Similarly, the current study was also conducted to investigate the possibility of negative effects from the upstream house to be carried in to the downstream house. Even so, there have been

insufficient studies that are directed towards the investigation of terraced houses.

A research conducted on terraced housing similar to the current study would be by Kubota *et al.* [14] and Mohamad *et al.* [15, 16]. Kubota *et al.* [14] conducted a case study using the wind tunnel on the wind environment in a neighborhood residential area in Johor Bahru Metropolitan City which provided information on the effects of building arrangement on the airflow of the wind. Whereas, Mohamad *et al.* [15, 16] performed simulation cases of typical terraced houses in Malaysia and showed the effects of urban planning and building design factors on the ventilation performance. In relation to Kubota *et al.* [14] and Mohamad *et al.* [15, 16] this current research is conducted to study the effect of the setback distance on the cascading terraced houses in relation to its breathability.

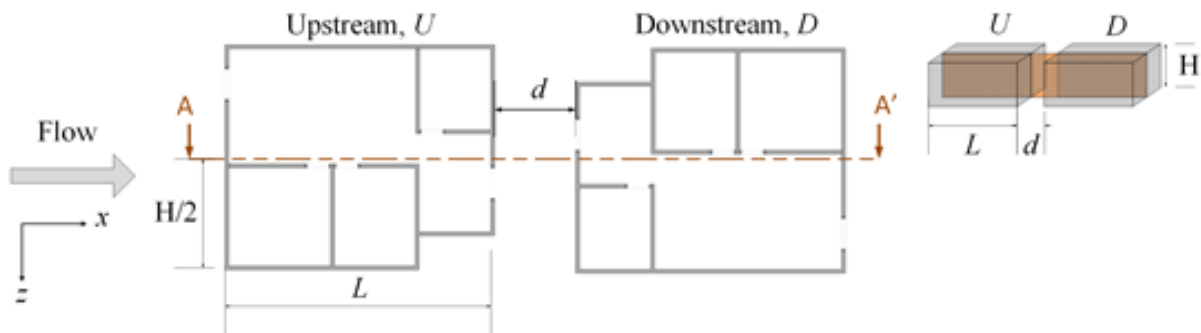
## 2.0 EXPERIMENTAL SETUP

### 2.1 Building Models

As previously studied by Mohamad *et al.* [15] and Tuan *et al.* [17] the building model that was represented in this study is a basic intermediate single-storey terraced house as in Figure 1. The model was scaled down to a ratio of 1:50 to the actual dimensions. The length of each terraced house model is  $L = 26$  cm and a height of  $H = 6$  cm. The cases that were conducted experimentally using the PIV are as listed in Table 1 where,  $H$  is the respective height of the building. The cross section at A-A' on vertical plane of the building is the point of interest of this analysis.

**Table 1** Experimental cases conducted

Experimental Case	Setback distance
Case 0.5H	3 cm
Case H	6 cm
Case 1.5H	9 cm



**Figure 1** Plan view layout of upstream and downstream buildings

## 2.2 PIV Setup

The PIV experiment was conducted in an open circuit architectural wind tunnel at the Faculty of Architecture, Planning and Surveying, Universiti Teknologi MARA (UiTM), Shah Alam. The wind tunnel has a test section of 1000 mm x 1000 mm x 6000 mm. The fetch was arranged with roughness elements of dimensions 20 mm x 30 mm x 30 mm and the wind tunnel inlet was equipped with three spires for developing thick layer turbulence. The wind tunnel has 9 fan-blades powered by an AC motor of 37 kW / 50 HP with a maximum speed of 20 m/s. For this experiment, with the model was placed within the test section, the inlet velocity was set to 5 m/s [15, 17]. The schematic diagram of PIV experimental setup can be seen in Figure 2.

The 2D PIV system was performed by illuminating seeding particles with a light sheet produced by an Nd:YAG laser. The reflected images of the placement of particles were instantly captured using a digital charge-couple device (CCD) camera. The seeding particle used was an olive oil and generated using Laskin nozzles (atomizer). Referring back to the point of interests across cross-section A-A' (Figure 1) this experiment was conducted on the vertical plane of the building model. The laser was projected at the center of the building model (across A-A') and the camera was positioned perpendicular to the building model. This PIV system by TSI was used with the aid of INSIGHT 4GTM software for data storage and analysis.

## 3.0 RESULTS AND DISCUSSION

The study of cross ventilation needs detailed information on the indoor and outdoor airflow to determine the ventilation performance. The characteristics of the indoor and outdoor airflow can

be observed from velocity profiles as in Figure 3 and Figure 4. Figure 3 shows the streamwise velocity across the downstream house whereas Figure 4 shows the streamwise velocity across the upstream house. To observe the effect of the setback distance towards cascading terraced houses, the downstream house is mainly observed. Figure 3 clearly shows that a setback of  $d = 0.5H$  is able to induce the highest wind velocity near the point of exit of the downstream house,  $x/L = 260\text{cm}$ . Even so, the backflow within this area causes stagnation within the downstream terraced house where  $d = H$  exhibits the highest stagnation and even though the arrangement  $d = 1.5H$  draws the highest average velocity across the downstream house it exhibits the highest fluctuation near the exit,  $x/L = 260\text{cm}$ .

In effect of the high velocity drawn into the downstream house for  $d = 1.5H$  terraced arrangement, the probability of contaminants and pollutants to be transported indoors are relatively higher. Even so, traces of wake interference can be identified within a setback distance of  $d = 1.5H$  which allows the dispersion of those contaminants and pollutants to disperse before entering the downstream house as observed in Figure 5(c). Whereas, for arrangement  $d = 0.5H$ , Figure 5(a) shows the development of skimming flow within the setback distance. This type of flow regime limits the exchange between the ground-level air and the cleaner air above [8]. The formation of skimming increases the chances of contaminants and pollutants to be transported into the downstream house but the relatively lower average wind velocity entering the downstream house also lowers the chances. From Figure 5 it can be clearly seen that by increasing the setback distance  $d$  will allow the transition of skimming flow to wake interference flow and allow the dispersion of contaminants from the canyon.

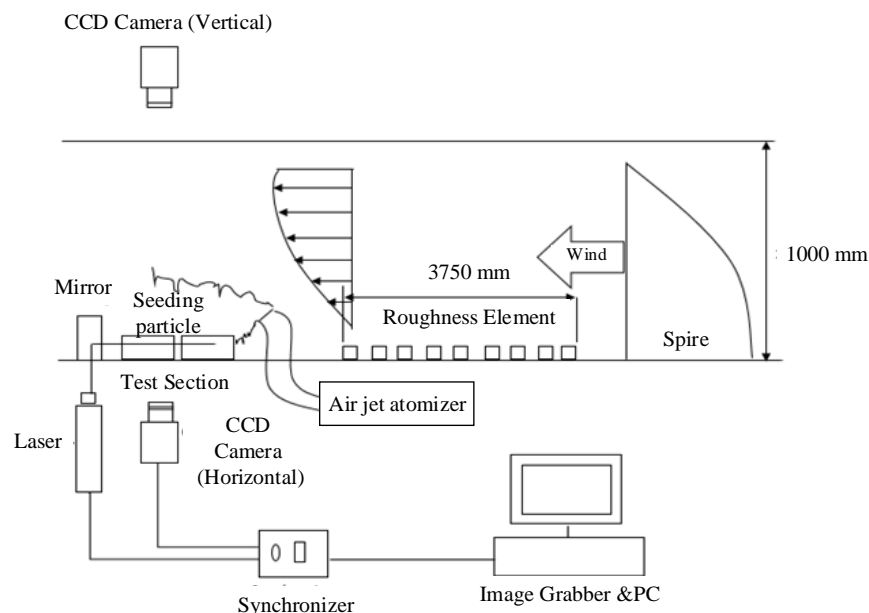


Figure 2 Schematic of PIV experimental setup

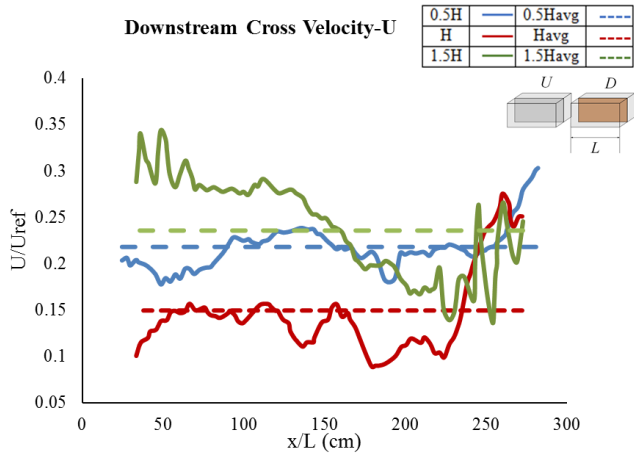


Figure 3 Downstream Cross Velocity-U Profile

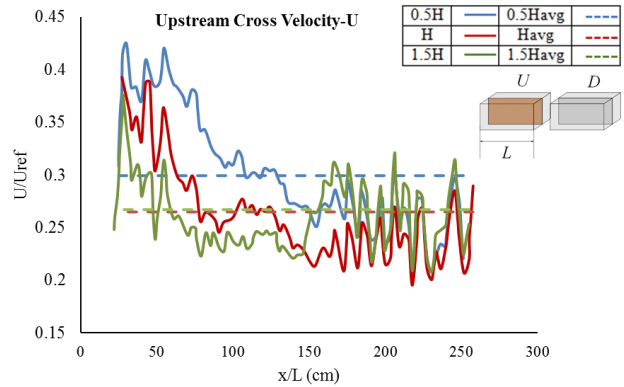


Figure 4 Upstream Cross Velocity-U Profile

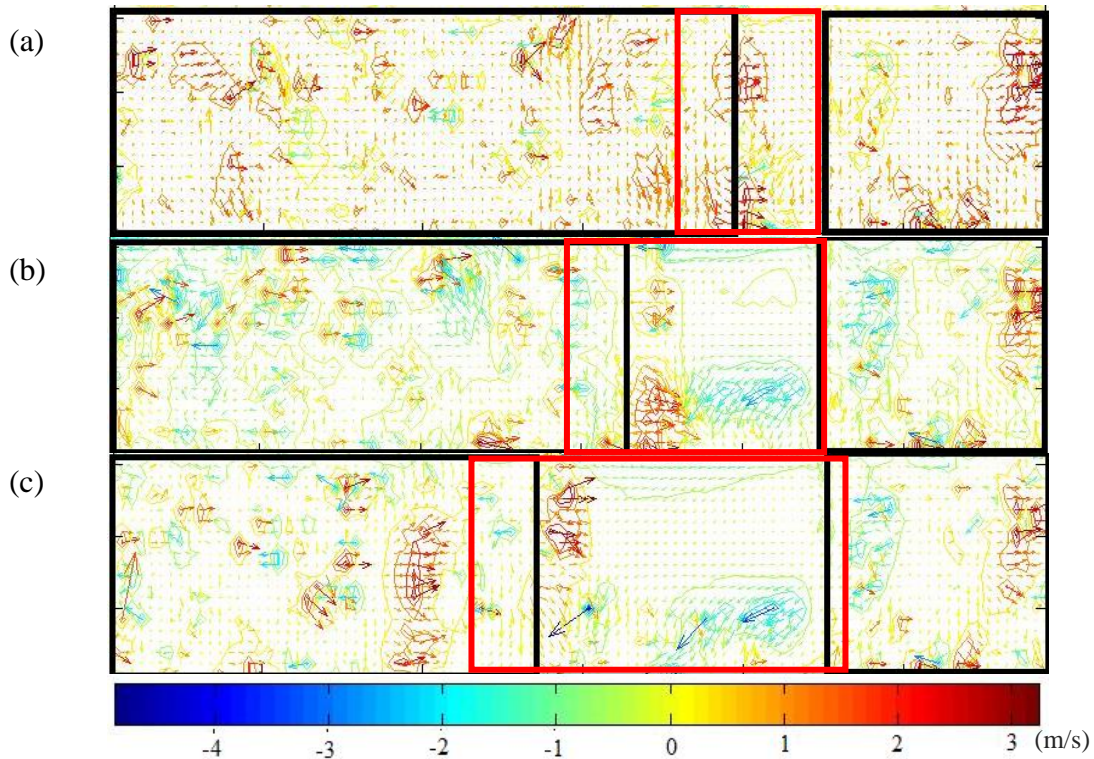


Figure 5 Velocity structure across setback distance in m/s (a) H (b) 2H (c) 3H

### 4.0 CONCLUSION

From this cross ventilation analysis it was found that the ideal setback distance to transport contaminants and pollutant from the downstream house is 0.5H. Even so, by increasing the setback distance, d, reduces the probability of contaminated wind to be transported into the downstream house. With an increase in setback distance the transition of skimming flow to wake interference flow is possible.

### Acknowledgement

The authors would like to sincerely thank Universiti Teknologi MARA (UiTM) as the research institute facilitating this research with the support of grant-in aid (600-RMI/FRGS 5/3 (73/2013)) from the Ministry of Education. We are also grateful to the Institute of Graduate Studies (IPSiS) UiTM for the conference support fund and the Faculty of Architecture, Planning and Surveying, UiTM for facilitating the Wind Tunnel Lab.

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