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16th Australasian Wind Engineering Society Workshop: Effects of Building Lift-up Design on Pedestrian Level Wind Environment

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Abstract

There are few studies that are focused on the pedestrian-level wind environment for different building designs, especially those with a lift-up design. This research work studies three selected building configurations that resulted in the lowest wind speed zones from a systematic study by Tsang et al. (2012). A 3.5 meter-tall open ground floor was added to each of the three configurations, and scale models of the three designs were studied in a wind tunnel to assess their influences on airflow and ventilation around the buildings. Undesirable areas of low wind speed leading to poor air ventilation and at the other extreme, discomfort due to strong wind conditions are both identified in the results.

Introduction

Constructing a new building will always affect the microclimate at the building and its surrounding area. This can lead to low airflow or poor outdoor ventilation around the building blocks, which can negatively influence indoor air quality, pollutant dispersion in the surroundings, and airborne transmission of infectious diseases. In recent years, emissions from vehicle exhaust have become one of the major urban air pollutions due to the dynamic growth of vehicle population and the corresponding increase in environmental pollution despite significant improvements in fuel and engine technology (Vardoulakis et al. 2003). Therefore, air pollution problem due to a lack of ventilation associated with stagnant or slow air movement area affects the health of urban inhabitants and pedestrians walking on the street. Conversely, high wind speeds can also be encountered in densely built up areas that can introduce discomfort or danger. The air flow patterns at pedestrian level around buildings, particularly high-rise buildings, are generally complicated. Although the wind environment has been investigated from 1960, Blocken and Carmeliet (2004) found that most of the studies were conducted within the wind engineering community, mostly for investigating the pedestrian comfort criteria (Davenport 1972, Hunt et al. 1976, Isyumov and Davenport 1975, Lawson 1973, Lawson 1975, Lawson and Penwarden 1975, Lawson 1990, Melbourne 1978, Penwarden 1973, Penwarden and Wise 1975). There are insufficient studies focusing on the pedestrian-level wind environment that governs pollutant dispersion and air quality (e.g. Tsang et al., 2012) for different building designs, especially those with special design features and/or building configurations.

Buildings with a lift-up design create air flow paths to enhance ventilation and pollution dispersion at pedestrian level Three tall building configurations; singular building (SB), a row of buildings (RB) and a row of building with podium (PB) were selected based on a systematic building designs studied by Tsang et al (2012) that resulted in low wind speed zones. A 3.5m lift-up in prototype scale was added to each of the three configurations producing three lift-up designs for comparison with three without. Scale models of the designs were studied in the wind tunnel to ascertain the influence of lift-up design on airflow and ventilation around the buildings.

Research Methodologies

The experiments were conducted in the high speed test section of the CLP Power Wind/Wave Tunnel Facility (WWTF) at The Hong Kong University of Science and Technology (HKUST). It is 3m in width, 2m in height and 29m in length. A series of spires and roughness elements were placed at the entrance of the test section to create a fully developed turbulent boundary layer flow, which was used as the approaching flow. The approaching turbulent wind flow was characterized by a power law exponent of 0.2 to simulate a suburban terrain. The wind profiles for these experiments are shown in Profiles of mean wind speed and turbulence intensity. The measured U (mean wind speeds) and TI (turbulence intensities) are generally within 5% of the suburban target U and TI. The reference mean wind speed Ur was approximately 10m/s at 150m in prototype scale above ground, which was measured by a hotwire anemometer.

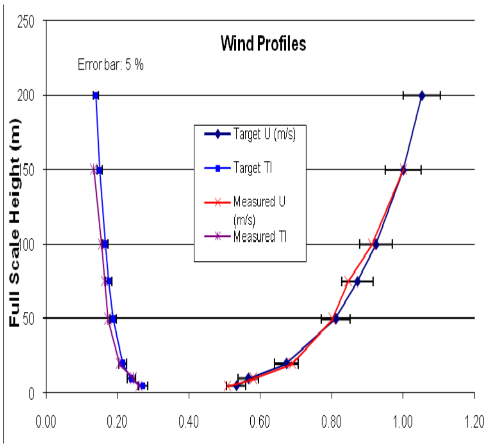


Figure 1 - Profiles of mean wind speed and turbulence intensity

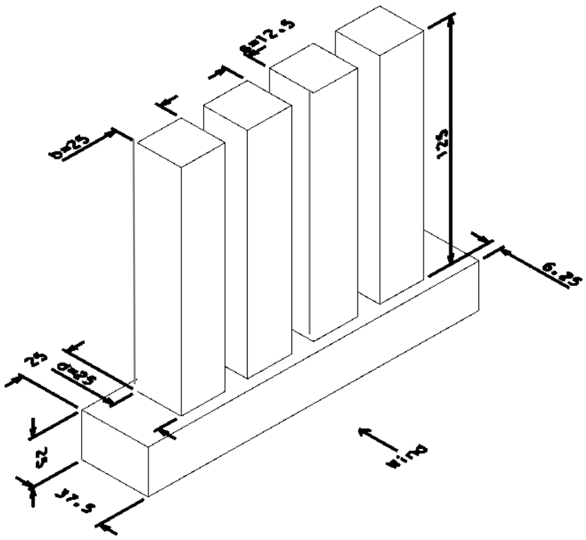


Figure 2 - Isometric of podium building

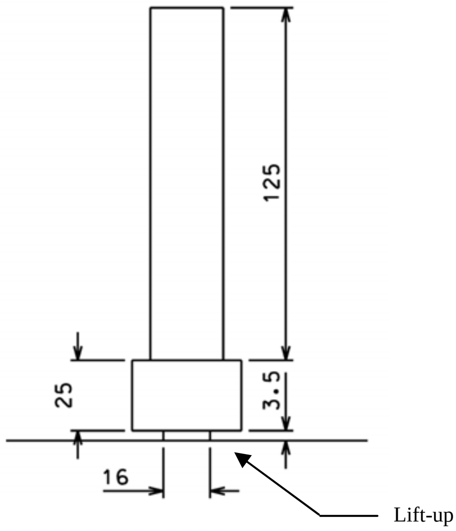


Figure 3- End elevation of podium building with lift-up design

Table 1 - Buildings' geometries

Building Type[1]	Building Height (h) (m)	Building Width(b) (m)	Building Depth(d) (m)	Spacing(s) (m)	Podium included	Lift-up height (h) (m)	Central Core Size (m)	Total height (m)
SB	50	75	25	N/A	N/A	N/A	N/A	50
Lifted_SB	50	75	25	N/A	N/A	3.5	8x8	53.5
RB	125	25	25	12.5	N/A	N/A	N	125
Lifted_RB	125	25	25	12.5	N/A	3.5	16x16	128.5
PB	125	25	25	12.5	187.5(b) ×37.5 (d)	N/A	N/A	150
Lifted_PB	125	25	25	12.5	187.5(b) ×37.5 (d)	3.5	16x16	153.5

1 - SB: singular building; RB: a row of buildings; PB: a row of building with podium

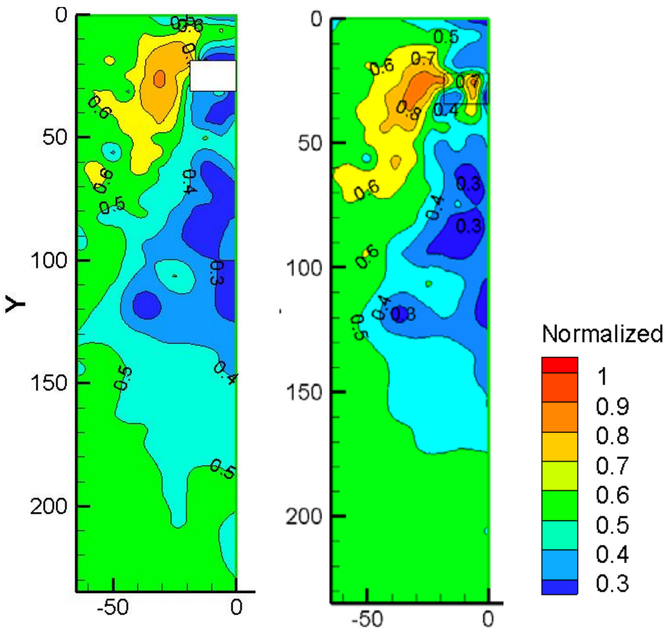
The building models were constructed at a scale of 1 to 200. The prototype sizes of all building configurations are given in Table 1 and an isometric diagram of a podium building is shown in Figure 2 to illustrate the building configuration. In order to provide a better understand of the concept of lift-up design, end elevation of podium building with lift-up design is given in Figure 3. During this study, the test wind direction was normal to the building face and perpendicular to the row of buildings. More than 200 Irwin Probes (Irwin 1981, Tsang et al. 2012) have been used for measuring pedestrian wind speed in this experiment. All the sensors were installed at a height of 2m above ground in full scale (10mm in model scale). The measurement area extends to 1.5d upstream, 2.5d laterally and 15d downstream from the building. By assuming the air flow is symmetrical about the centreline, the measurement points were distributed only on one half of the building.

In this study, mean wind speed (U) was used for wind speed analysis to determine the low wind speed areas where poor air ventilation may exist at the pedestrian level. In the analysing process, mean wind speed U was normalized by the reference mean wind speed Ur of the approach flow at 150m in prototype scale. Baseline studies without building installed were studied as a reference at the beginning and at the end of tests.

Results and discussions

In the wind tunnel study, the wind direction was normal to the building face. For the building configurations without the lift-up design, the wind hits the windward façade of the building and a downwash flow is generated. This downwash results in a backflow in front of the building at pedestrian level. When the two opposing windward and back flows encounter each other, a low wind speed zone is created upstream of buildings. For the buildings with lift-up designs, the low or poor ventilation situation of the upstream near-field has been improved due to a 3.5m lift-up area underneath of these buildings. This is because part of the downwash and the approaching wind can flow through the lift-up area underneath the buildings where there is a reduced blocking of flow. Consequently less backflow wind and approaching wind meets in front of the building at the pedestrian level. Further upstream of the lift-up buildings, a reduction of wind speeds is observed. This is likely due to the increased downwash effects.

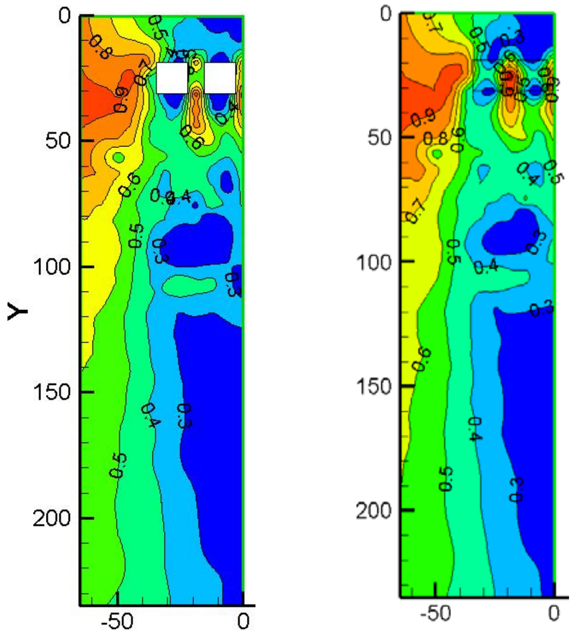
In general, the normalized pedestrian-level mean wind speed distribution (U/Ur) ranges from 0.0 to 1.0. The normalized mean wind speeds is approximately 0.5 when no building is installed. According to Tsang et al. (2012), reasonable threshold values for outdoor wind comfort and air ventilation purpose are from 0.3 to 0.8. Areas where the normalized mean wind speed lower than 0.3 are designated as low wind speed zones, which is equivalent to mean wind speeds roughly 1 to 2m/s for an annual probability of exceedance of 50% in an environment like Hong Kong.



a) Singular Building

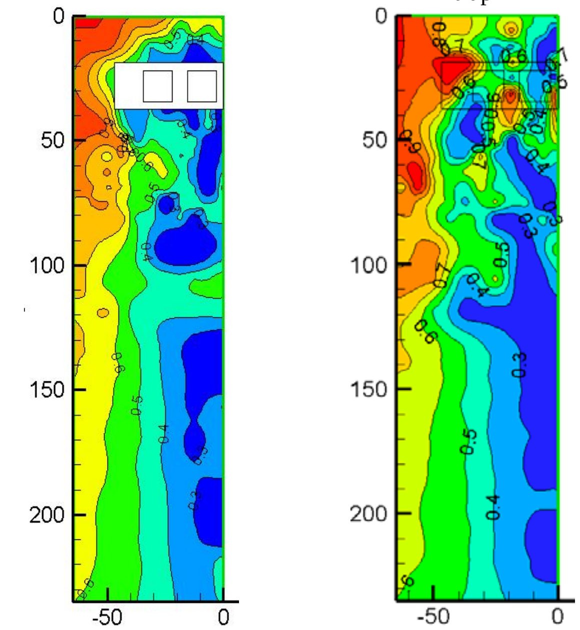
b) Singular Building with Lift-up

Figure 4 - Distribution of the normalized mean wind speed with and without lift-up design for Singular Building



a) A row of buildings

b) A row of buildings with lift-up



c) A row of buildings with podium

d) A row of buildings with podium and lift-up

Figure 5 - Distribution of the normalized mean wind speed with and without lift-up design for a Row of Buildings and a Row of Buildings with Podium

According to Tsang et al. (2012), in terms of wake flow for non-lift-up design, recirculation due to building blockage is occurring in the downwind near-field which generates the rotational flow that results in the formation of vortices. This is indicated by low wind speeds that create poor ventilation. The observed low wind speed zone in the downwind far-field is caused by the reattachment of vertical recirculation behind the building and the strength of the horizontal recirculation. For the lift-up design, it was found that Singular Building with lift-up can not only improve air flow for the surrounding area of the building, but also significantly shorten the length of the wake flow. The lift-up design also improves airflow at pedestrian level for a Row of Buildings. The area of low wind speed zone has been reduced. But these effects cannot be easily identified for a Row of Buildings with Podium with lift-up design. Although the low wind speed area has been reduced around the building and underneath of the podium with the lift-up design, the downstream low wind speed zone is getting even larger than the one without the lift-up design. Additionally, despite there are three to four central cores for these three building configurations, mean wind speed at the pedestrian level underneath part of the building is increased with the lift-up design, which potentially affects the environmental wind comfort.

Conclusions

The general features of the low wind speed areas around Singular Building, Row of Buildings and Row of Buildings with Podium with and without lift-up designs were studied experimentally. The conclusions of this study are listed below.

1) A lift-up design can improve air flow at the pedestrian level for Singular Building and Row of Buildings.
2) A lift-up design does not necessarily improve pedestrian wind environment for Row of Buildings with Podium, only selective areas.
3) For a hot tropical and sub-tropical climate, a lift-up design for a slab building or a cluster of buildings may be considered by architects or urban planners to improve the air movement for pedestrians.
4) For a temperate or cold climate, lift-up design may not be desirable when increased wind speed coupled with low temperature may cause additional discomfort to pedestrians.
5) A lift-up design for podium building increases air flow at selective areas to improve pedestrian wind environment.

Additional studies are recommended to determine the effectiveness of lift-up design, considering the influence of lift-up height, interference/shielding by upstream and/or downstream buildings, and angle of wind incidence.

Acknowledgement

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