Effects of Building Height and Spacing on Pedestrian-Level Wind Environment

C.W. Tsang[1)], K.C.S. Kwok[1), 2)] and P.A. Hitchcock[1)]

[1)] *CLP Power Wind/Wave Tunnel Facility, The Hong Kong University of Science and Technology, Hong Kong S.A.R., P.R. China*

[2)] *School of Engineering, University of Western Sydney, Sydney, New South Wales, Australia*

Introduction

In many densely populated cities, such as Hong Kong, urban renewal is an important kind of sustainable development for the communities in terms of good use of lands and infrastructure. Under the renewal projects, high-rise buildings are often surrounded by closely packed low-to-middle-rise buildings. It is well known that high-rise buildings affect the surrounding pedestrian-level wind environment. A comprehensive review conducted by Blocken and Carmeliet [1] focused on the unpleasant and dangerous windy conditions caused by buildings that may affect human activities.

In recent years, awareness and concern has increased about the creations of low wind speed areas around buildings which may lead to poor out-door air ventilation. Moreover, many modern building developments are not restricted to a single building but may comprise a group of buildings. There are very few systematic studies focused on the low wind speed areas around a group of buildings [1, 2, 3, 4].

In this research, a series of parametric wind tunnel studies was carried out to investigate building height and spacing effects on the pedestrian-level wind environment around a pair of rectangular buildings. The height of the buildings was changed from 50 m to 150 m; the spacing between buildings was changes from 0 to 31.25 m.

Experimental arrangement

The experiments were carried out in the high speed test section (a boundary layer wind tunnel 29.2 m long, with a 3 m wide by 2 m high cross-section) of the CLP Power Wind/Wave Tunnel Facility (WWTF) at The Hong Kong University of Science and Technology. The mean wind speed profile of the approaching turbulent wind flow followed a power law exponent of 0.2, using a series of fences and roughness blocks, to simulate wind flow above typical suburban terrains. Figure 7 shows the profile of the mean wind speed, U, and turbulence intensity, σ_u/U. The magnitudes of U are normalized by the mean wind speed, U_r, of the approach flow at z = 150 m at prototype scale (750 mm model scale).

The building models were fabricated at a length scale of 1/200 and the experimental arrangement is shown in Figure 8. The building group includes two rectangular cross-section buildings with height h, width b and depth d. The spacing between the buildings is denoted by s. The buildings' width and depth are fixed at 50 m and 25 m, in prototype scale, respectively. In these parametric studies, the buildings' height, h, was changed from 1b to 3b at increments of 0.5b. The spacing, s, was changed from 0 to 0.625b at increments of 0.125b. Only one parameter was adjusted at a time.

The distribution of mean wind speeds at pedestrian level U was measured using 175 Irwin Sensors [5], that were installed at a height equivalent to 2 m above ground at prototype scale (10 mm in model scale). The reference wind speed U_r was measured at a height equivalent to z = 150 m at prototype scale. All measurements were made at a reference mean wind speed U_r of approximately 10 m/s.

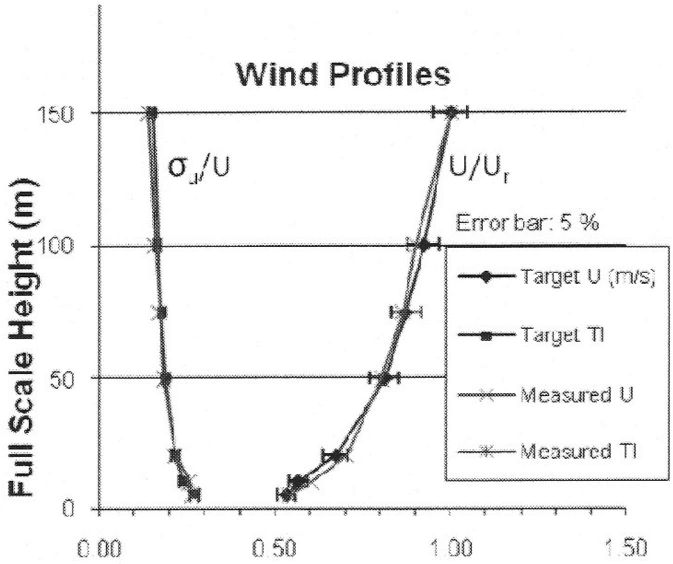


Figure 7 Profiles of mean wind speed and turbulence intensity

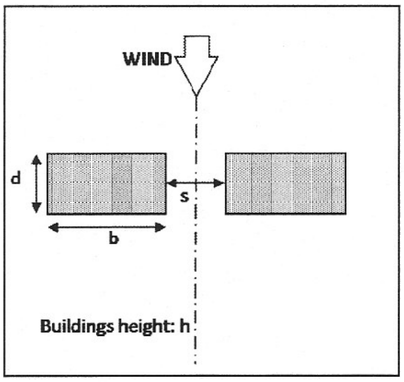


Figure 8 Plan view of the building models

Experimental results and discussion

General features

Figure 9 shows the normalized pedestrian-level mean wind speed distribution, U/U_r, on the left half of the building group. The values of mean wind speed at pedestrian level are normalized by the reference mean wind speed U_r of the approach flow at $z = 150$ m in prototype scale. The normalized mean wind speeds range from 0.0 to 1.0. An initial test was conducted with no building installed, for which the normalized mean wind speed is around 0.5. A value of U/U_r between 0.3 and 0.8 is considered to be reasonable for normal outdoor wind comfort and air ventilation purposes. Areas with a U/U_r value outside this range, $U/U_r \geq 0.8$ and ≤ 0.3, are regarded as high wind speed zones and low wind speed zones respectively.

It can be seen from Figure 3 that there are two high wind speed zones and three low wind speed zones. The two high speed zones occurred at the side and between the buildings. The three low speed zones are located at the near-field upstream, near-field downstream and far-field downstream areas. As the research focused on natural outdoor air ventilations, the effects of building height and spacing on these three low speed zones are of particular interest and they are discussed further in the following sections.

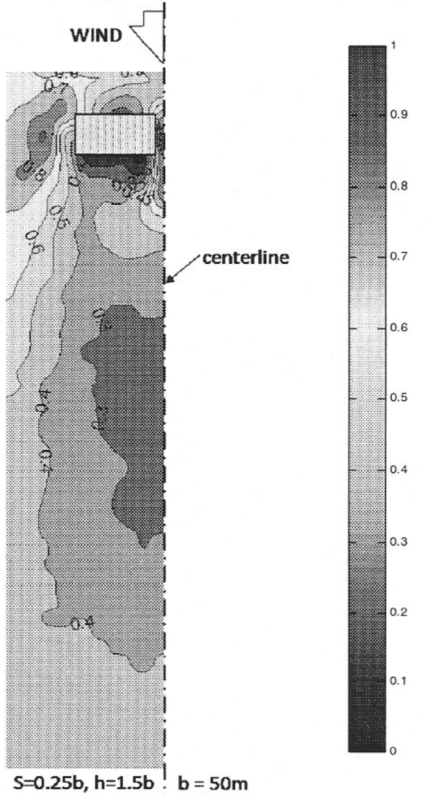
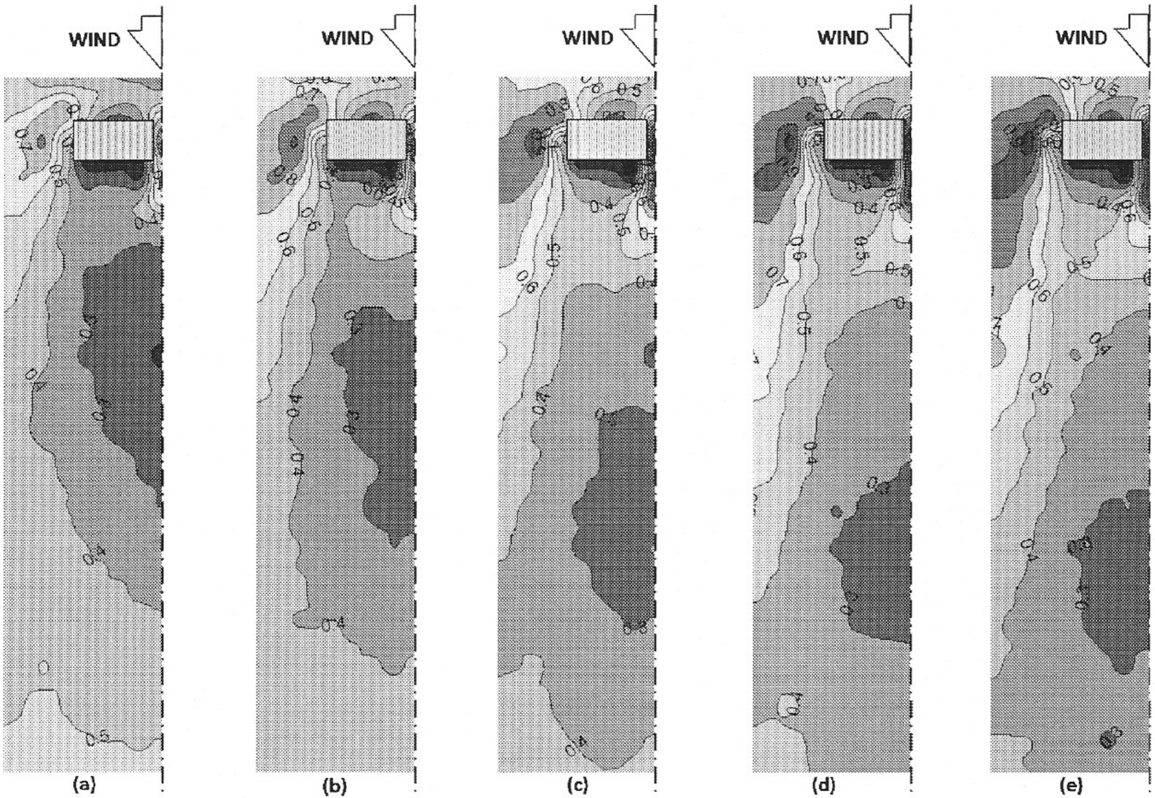


Figure 9 Distribution of normalized pedestrian level mean wind speed: General features

Height effects

The effects of building height on U/U_r around the buildings are shown in Figure 10. The buildings width, b, depth, d, and spacing, s, were fixed at 50 m, 25 m (0.5b) and 12.5 m (0.25b) respectively. The building height, h, was varied from 50 m (1.0b) to 150 m (3.0b). As the building height increases, the low speed zone at the near-field upstream area does not change significantly. At the near-field downstream area, the extent of the low speed zone decreases as height increases and becomes stable as $h \geq 2.0b$. The far-field downstream low speed zone is located further downstream and shrinks as building height increases, and becomes stable as $h \geq 2.5b$. These results show that as building height increases, the low speed zones in close proximity to the buildings are slightly improved, and the far-field low speed zone is shifted further downstream. The magnitude and extent of the low wind speed zones gradually became insensitive to increases in building height as $h \geq 125$ m (2.5b).



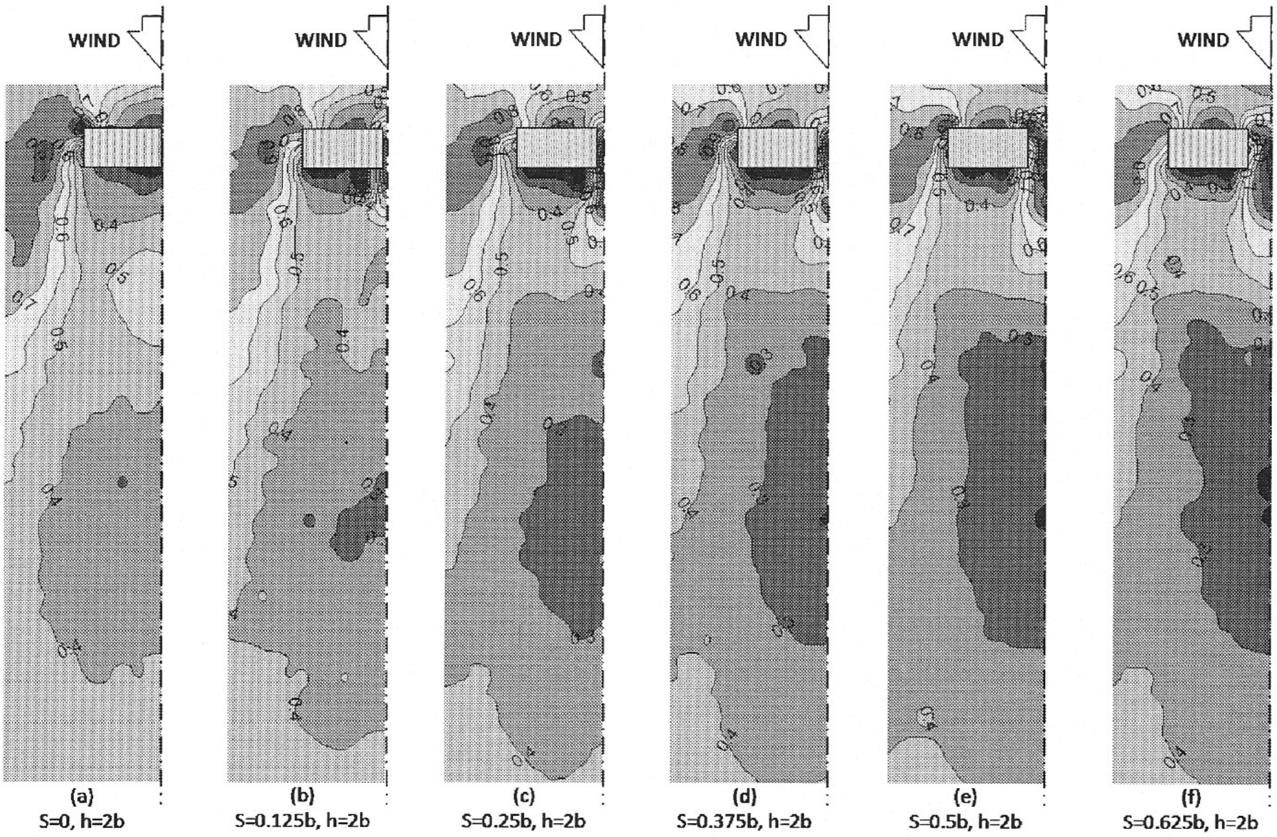
(a) S=0.25b, h= b
(b) S=0.25b, h=1.5b
(c) S=0.25b, h=2b
(d) S=0.25b, h=2.5b
(e) S=0.25b, h=3b

Figure 10 Distribution of the normalized mean wind speed with varying building height and fixed building spacing (b = 50 m)

Spacing effects

Figure 11 shows the effects of building spacing on the pedestrian-level wind environment. The building parameters b, d and h were fixed at 50 m, 25 m (0.5b) and 100 m (2.0b), and the building spacing was varied from 0 to 31.25 m (0.625b). For the case of zero spacing, Figure 11 (a), the two buildings are equivalent to a single slab-like building with corresponding wind environment features. There is a low pressure zone at the leeward side of the building that causes horizontal and vertical recirculation [1]. The horizontal recirculation enhances the near-field wind movements and the vertical recirculation dominates the movements at the far-field area.

In comparison, it was found that there is a slight improvement at the near-field low speed zone as the spacing is increased; additional horizontal recirculation is created by the flow passing through the gap between the buildings. However, the far-field low speed zone is worsened; this is attributed to the weakening of vertical recirculation by the flow passing through the gap. Furthermore, it was observed that when $s \geq 0.5b$, the changes in the pedestrian-level wind environment were less significant.



(a) S=0, h=2b (b) S=0.125b, h=2b (c) S=0.25b, h=2b (d) S=0.375b, h=2b (e) S=0.5b, h=2b (f) S=0.625b, h=2b

Figure 11 **Distribution of the normalized mean wind speed: with varying building spacing and fixed building height (b = 50 m)**

Conclusions

The general features of the low wind speed areas around two rectangular cross-section buildings were investigated experimentally. The effects of building height and spacing on the mean wind speed distribution at pedestrian-level were studied. It was found that there is an improvement for the low speed areas as the building height was increased. For building heights greater than 125 m (2.5b), the pedestrian-level wind environment became relatively insensitive to the change of height. In the study of spacing effects, it was found that the near-field low speed zones were improved as the spacing was increased. However, the increased building spacing had a detrimental effect on the magnitude and extent of the far-field low speed zone.

Acknowledgement

This research project is funded by the Research Grants Council of Hong Kong Special Administrative Region, China (Project HKUST6301/04E).

References

[1] B. Blocken and J.Carmeliet (2004). Pedestrian wind environment around buildings: Literature review and practical examples. Journal of Thermal Envelope and Building Science, Vol. 28, No. 2, 107-159

[2] To, A. P. and Lam, K.M. (1995). Evaluation of pedestrian-level wind environment around a row of tall buildings using a quartile-level wind speed descripter, Journal of Wind Engineering and Industrial Aerodynamics, 54-55: 527-541.

[3] A.K. Ahuja, S.K. Dalui, R.Ahuja and V.K. Gupta (2005). Effect of interference on the wind environment around high-rise buildings. Journal of Wind and Engineering, Vol. 2, No.1, pp. 1-8

[4] E.G. Tulapurkara, B.H.L. Gowda and J.S. Chaukar (2005). Mean velocity field around prismatic bodies in tandem arrangement. Journal of Wind Engineering and Industrial Aerodynamics, 93, 777-796.

[5] Irwin, P.A. (1981). A simple omnidirectional probe for the measurement of pedestrian level winds, Journal of Wind Engineering and Industrial Aerodynamics, 7(3): 219-239