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Wind Power Evaluations near the Facade of High Rise Buildings considering the Interference Effects

*Jinxin Cao[1)], Shuyang Cao[2)] and Yaojun Ge[3)]

[1), 2), 3)] *State Key Laboratory of Disaster Reduction in Civil Engineering, Tongji University, Shanghai 200092, China*
[1)] *jinxin@tongji.edu.cn*

ABSTRACT

Wind velocity fields near the facade of square shaped high-rise buildings were measured in the boundary layer wind tunnel, considering the combination of both two and three buildings. Distances among the buildings and wind directions were varied. Wind velocities at 16 locations with four different facade heights were recorded for each test case. Based the experimental results, critical locations, critical wind directions and critical distance between buildings were discussed in order to maximize wind power generations. For two-building cases, smaller distance between the buildings causes larger wind speeds and two critical facade areas were recommended. For three-building cases, a critical distance between the buildings was found and only one critical facade area can be acquired. These findings can be used for design optimization of high rise buildings when considering facade-integrated wind power systems.

1. INTRODUCTION

Nowadays, wind power is one of the fastest growing industries among the renewable energy technologies, including wind turbine installations on mountains and stretching into the sea. Besides, wind turbines mounted on or integrated into buildings in urban areas are becoming great potential and even popular, which are called Building Augmented Wind Turbines (BAWT). Amongst other building types, the large exposed body of the high-rise building is subject to significant and unique interaction with the wind kinetic energy. Recent successful applications of BAWT in high-rise buildings include Shanghai Center Tower, Pearl River Tower, Bahrain World Trade Center of Dubai and so on. As a classical issue in wind engineering community, wind effects on high-rise buildings or considering their interference effects, have been tremendously investigated in order to reduce wind loads and improve wind-resistant performances of high-rise building, which considered wind as a negative factor. However, few researches have been conducted to investigate the feasibility of harness wind energy around the buildings, which considered as a positive factor (Lu 2013).

[1)] Assistant Professor

Several pioneer work included: investigation on the feasibility study of wind power utilization in high-rise buildings in Hong Kong by Lu (2009), proposing a method and a planning software tool for maximizing the performance of facade integrated wind rotors by Bayoumi (2013), performance assessment of a tall building-integrated wind turbines by Li (2016). In the present study, wind tunnel experiments to maximize wind power generation near building facades was carried out, considering the interference effect of buildings. The experimental findings are expected to be used for design optimization for facade integrated wind energy systems.

2. EXPERIMENTAL SETUP

Wind velocity measurements were carried out in TJ-1 and TJ-2 Boundary Layer Wind Tunnels in Tongji University.

2.1 Experimental models

The prototype of the experimental model is a high-rise building, 40 m in depth, 40 m in width and 100 m in height, as shown in Fig. 1a. A geometry scale of 1:200 was adopted in this study. Two groups of experiments were conducted, including Two-building Case (Case I) in Fig. 1a and Three-building Case in Fig. 1b. For Case I, two same building models were installed in a row (See Fig. 1a and 2a) and the distance between the two building models were varied from 48m to 80m in full scale, in order to investigate the effect of the distance *D* in Fig. 1a on wind speeds and wind energy. For Case II, the third building model was added in front of the previous two buildings with a distance of 48 m in full scale (See Fig. 1b and 2b) and the distance between the third model and previous two models was changed from 12m to 24m, for investigating the of the distance D_2 in Fig. 1b.

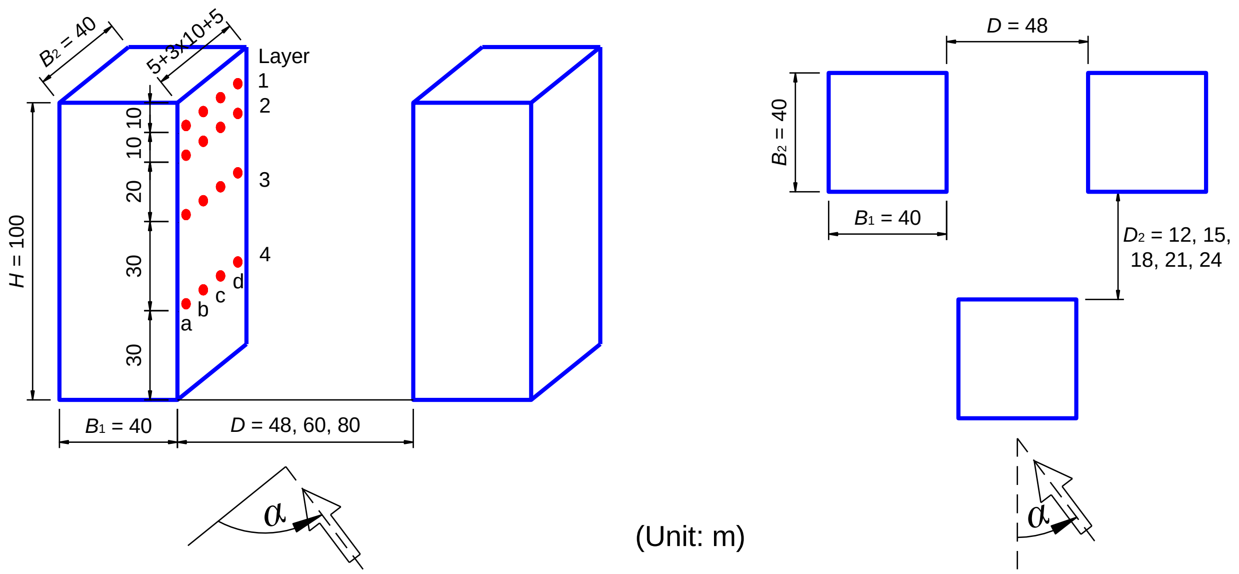
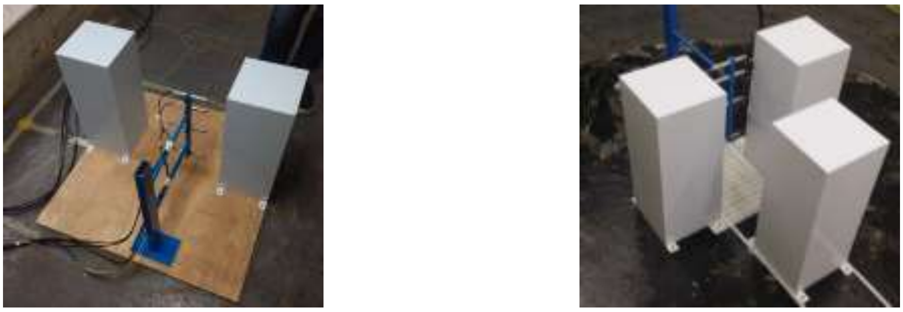


Fig. 1 Layout of test models for (a) Two-building Case (Case I) and (b) Three-building Case (Case II)



(a) (b)

Fig. 2 Experimental setup for (a) Case I (Back view) and (b) Case II (Front view)

2.2 Velocity measurements

Since the main focus of this study is the utilization of facade area for wind power generation, wind speeds at totally 16 points, distributed in four layers with the height of 30 m, 60 m, 80 m and 90 m in full scale, near the facade of the target building model (see Fig. 1a) were measured for each test case. Uniform upstream flow was adopted for this preliminary investigation. TFI Cobra probe with a four-hole 2.6 mm - diameter head and a 30 mm long by 2 mm – diameter shaft was used for wind velocities at each point. The probe is effective in various wind velocity ranges between 2 m/s to 100 m/s within a cone of influence of ±45°. The measurements were carried out with a sampling frequency of 500 Hz and a sampling period of 60 s for each sample.

Before the formal experiments, calibration of the probes and wind speed measurements at four different heights (150 mm, 300 mm, 400mm, 450mm in model scale, corresponding to 30 m, 60 m, 80 m and 90 m in full scale, respectively) without building models were carried out. The results are presented in Table 1 and can be used to compare to those with building models.

Table. 1 Wind speed at different height in wind tunnel without building models

Height (mm)	150	300	400	450
Case I (m/s)	8.87	9.24	9.95	10.00
Case II (m/s)	9.37	9.86	10.00	10.00

3. TWO-BUILDING CASE (CASE I)

3.1 Critical location

The critical locations near the facade of the building where the largest wind speed was recorded were mainly investigated since it is an important optimization parameter for BAWT designers. Take mean wind speed distribution results with D/B_1 = 1.2 under wind direction of 30 degrees as an example, two critical positions can be found at two corners of the target facade, including 1d at the top and 4a near the bottom (See Fig. 3) and the values are 11.5 m/s and 11.9 m/s, respectively. Compared to reference wind speed (10 m/s), values at the two locations increased by 15% and 19%, which indicate a 1.5 and 1.7 times increase in wind energy (proportional to U^3).

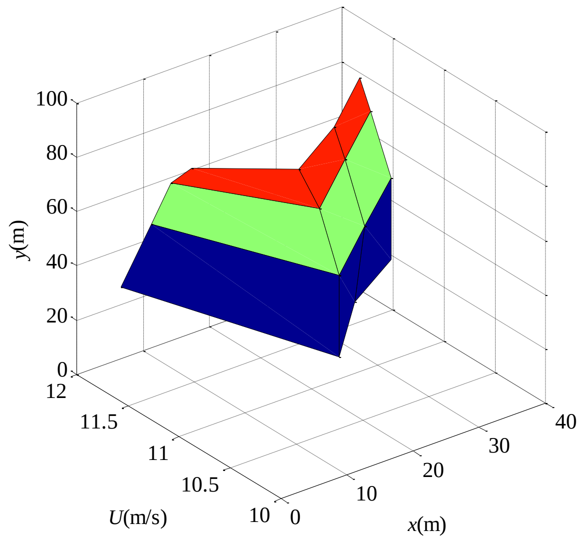


Fig. 3 Mean wind speed distribution for Case I with D/B_1 = 1.2 under wind direction of 30 degrees

3.2 Effect of wind direction

Although upstream wind characteristics cannot be determined, the designers may improve their designs in order to maximize wind power generation based on the investigation of effect of wind direction on wind speed (energy) values. Results of mean wind speed at two critical locations mentioned above with D/B_1 = 1.2 were chosen as shown in Fig. 4. For both locations, mean wind speeds from -45 to 0 degrees are relatively small, while they become larger from 15 to 45 degrees. Peak mean wind speeds for both locations were recorded at 30 degrees which can be regarded as the critical wind direction from these measurements.

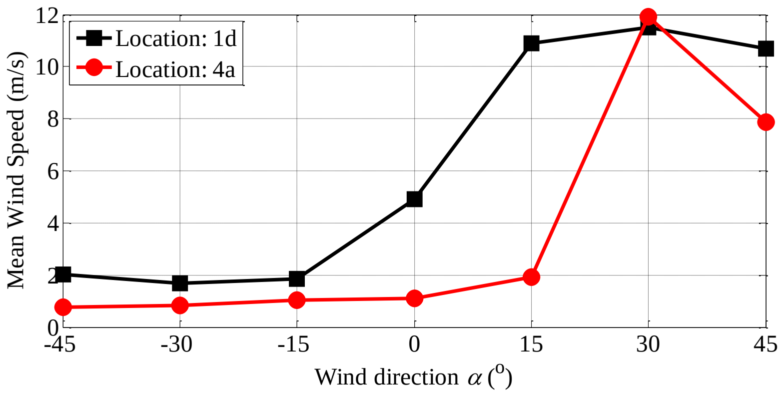


Fig. 4 Variation of mean wind speed at Location 1d and 4a in Case I due to wind direction (D/B_1 = 1.2)

3.3 Effect of distance between two buildings D

The effect of distance between two buildings (D/B_1) has been numerously investigated from the viewpoint of local wind pressures over the facades or overall wind forces on buildings. The present work varied the values of the distance between two buildings (D) for the effect on wind power generations. Although wind speeds at all locations and all wind directions has been measured, results of two critical locations under the critical wind direction of 30 degrees are presented in Fig. 5. With the increase of the value of D/B_1, mean wind speeds slightly decrease, regardless of the locations. For location 4a, the value decreases from 11.9 m/s to 11.1 m/s, and the wind power increase varies from 69% to 37%.

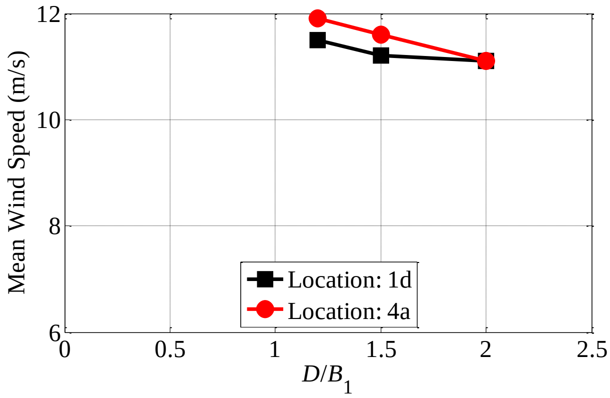


Fig. 5 Variation of mean wind speed for Location 1d and 4a in Case I due to variation in D/B_1 (wind direction: 30 degrees)

4. THREE-BUILDING CASE (CASE II)

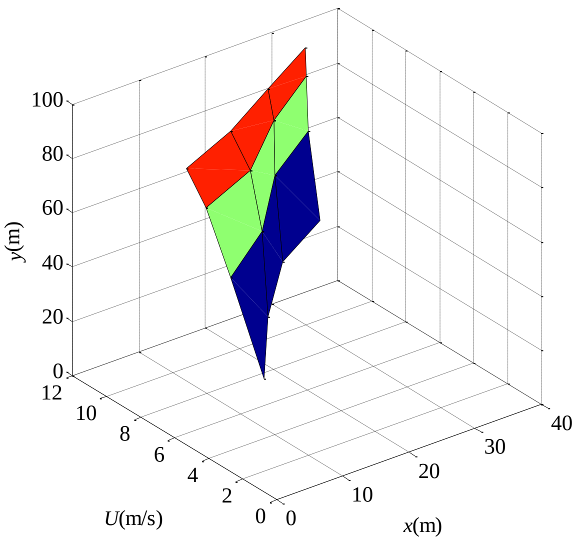


Fig. 6 Mean wind speed distribution for Case II with D_2/B_2 = 0.75 under wind direction of 45 degrees

4.1 Critical location

Unlike Case I, only one critical location, 1d, was found at the top corner of the facade. As shown in Fig. 6, mean wind speed results with D_2/B_2 = 0.75 under wind direction of 45 degrees decrease monotonously, from layer 1 to 4 and from layer d to a. The smallest value occurs at the location 4a, where the largest value was recorded for Case I. The value at location 1d is 12.0 m/s, which results in a 20% increase in mean wind speed and a 73% increase in wind power generation.

4.2 Effect of wind direction

Similar to Case I, mean wind speeds at location 1d vary significantly for different wind directions for Case II. With D_2/B_2 equals to 0.75, mean wind speeds at location 1d are small from -45 to 0 degrees and increase significantly from 15 to 45 degrees, as shown in Fig. 7. Besides, the values keep slightly increasing for wind directions from 15 to 45 degrees, which indicates the wind direction of 45 degrees is the critical one for Case II.

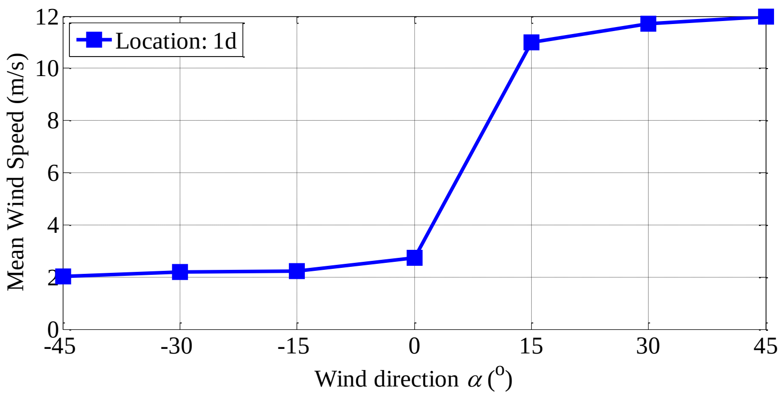


Fig. 7 Variation of mean wind speed at Location 1d in Case II due to wind direction (D_2/B_2 = 0.75)

4.3 Effect of distance among three buildings D_2/B_2

In Case II, the distance between the two buildings D in Case I was fixed at $1.2B_1$, based on the findings in Section 3, and the distance between the third building and previous two buildings D_2 was varied from $0.6B_2$ to $1.2B_2$, as shown in Fig. 1b. Since 45 degrees is the critical wind direction, results at location 1d with 45 degrees wind direction for different distance parameter D_2/B_2 are summarized in Fig. 8. Although the distance parameter D_2/B_2 do not affect the values significantly, a peak can be found when D_2/B_2 equals to 0.75. Wind speed values with smaller or larger distance were smaller than the value with D_2/B_2 equals to 0.75, from which a critical distance can be therefore recommended from the viewpoint of wind power generation.

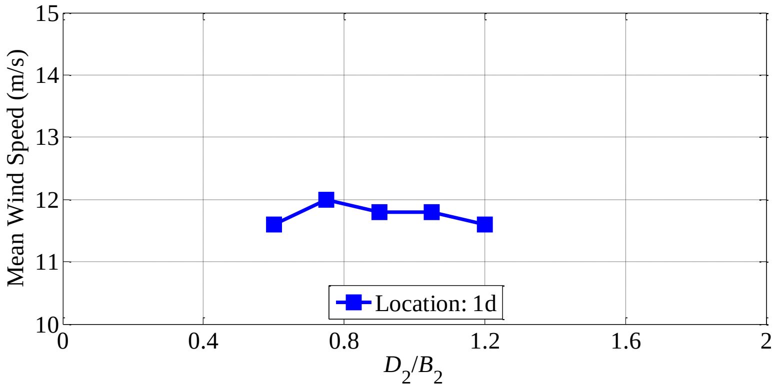


Fig. 8 Variation of mean wind speed for Location 1d in Case II due to variation in D_2/B_2 (wind direction: 45 degrees)

3. CONCLUDING REMARKS

Wind speed measurements near the facade of a high-rise building were conducted through wind tunnel experiments, considering both two-building and three-building cases. Based on wind speed results, critical locations, critical wind directions and critical distance between buildings were discussed for the purpose of maximizing wind power generations. Although the wind tunnel experimental results on wind speed fields are limited due to the number of measurement points, the present work can be utilized for both reference for design optimization of high rise buildings when considering facade-integrated wind power systems and case validation of Computational Fluids Dynamics (CFD) results for similar purposes. It is recommended to carry out more systematic investigations considering more design parameters and more measurement locations, which help to generalize the experimental findings for practical designs.

ACKNOWLEGEMENT

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