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Effect of lift-up design on pedestrian level wind comfort around isolated building under different wind directions

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Abstract

The pedestrian level wind environment is seriously worsen by moderated air flow in the built-up cities like Hong Kong. The lift-up design is therefore adopted in the building constructions to improve the weak wind condition. In order to evaluate the influence of lift-up design on the pedestrian level wind comfort, the wind flow around isolated buildings with and without Lift-up design are simulated respectively via CFD approach. The turbulence model and numerical method are firstly validated by comparing the simulated wind flow data with a wind tunnel test. Then the validated model is used to simulate the wind flows around the isolated buildings. Results show that the lift-up design can improve the wind comfort at pedestrian level and its effects are highly rely on the approaching wind direction. Specifically, the wind comfort is better under the oblique wind direction than the other wind directions.

Keywords: Lift-up design; Pedestrian level wind comfort; Computational fluid dynamics (CFD) simulation; Mean wind velocity ratio (*MVR*)

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1. Introduction

The moderated air flow at pedestrian level caused by the increasing high-rise buildings in densely built-up cities results in unfavorable wind velocity and thermal comfort conditions, which in turn may eventually affect human health. The issue is more serious in the subtropical urban cities, such as the hot and humid summer in Hong Kong [1, 2]. For the purpose of improving the wind flow in a densely built-up city, Hong Kong SAR government established the air ventilation assessment (AVA) scheme [1]. However, the achievement of an acceptable wind comfort around the buildings is difficult in most urban areas.

In order to improve the weak wind condition at pedestrian level in densely built-up urban are-as, the lift-up design, in which the building block is "lifted" off the ground supported by the modern structural pillar, has been introduced into building design and urban planning [3]. The lift-up design can be regarded as one of the prominent design because it is feasible to implement and it has gained increasing attention in south-eastern Asian cities, like Hong Kong. A majority public amenity venues and transportation interchanges in Hong Kong are located in the lift-up areas underneath the high-rise buildings. However, the potential benefits of the lift-up design in improving the weak wind condition at pedestrian level have not been totally explored or understood. Previous studies have already shown that the lift-up area can create a local cooling spot for the pedestrian activities in hot and humid Hong Kong, which can in turn encourage more outdoor activities [3-6].

This study sets out to provide an insightful understanding about the effects of lift-up design on pedestrian level wind comfort around the isolated building. The lift-up design at the Hong Kong Polytechnic University (HKPolyU) campus are chosen in this study three typical wind directions are selected, including normal, oblique and parallel approaching wind directions. The turbulence model and numerical method are firstly validated by comparing the simulated wind flow data with the wind tunnel test

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results. The validated model is then utilized to simulate the wind flow around the isolated buildings with and without lift-up design. The mean wind velocity ratio (*MVR*) and mean wind velocity change ratio (Δ*MVR*) are employed to identify the wind comfort and to quantitatively evaluate the improvements due to the lift-up design.

Nomenclature

U_p mean wind velocity at the pedestrian level, m/s
Ur reference mean wind velocity at 200m in the in situ condition, m/s

2. Methods

2.1 Identification of pedestrian level wind parameters

In order to make the findings universal, normalized mean wind velocity known as the mean wind velocity ratio (*MVR*) is adopted in this study. The *MVR* is defined as follows:

$$MVR = U_p / U_r \qquad （1）$$

In order to quantitatively assess the effects of lift-up design on the wind environment around the building, the mean wind velocity change ratio (Δ*MVR*) is proposed here, which is calculated as the following equation:

$$\Delta MVR = (MVR_{LU} - MVR_{NLU}) / MVR_{NLU} \qquad （2）$$

here, the subscript *LU* means building with lift-up design, and the subscript *NLU* means building without lift-up design. MVR_{LU} is the value of *MVR* at pedestrian level with the lift-up design, while MVR_{NLU} is the value of *MVR* at same spot without lift-up design.

2.2 Identification of pedestrian level wind comfort

The annual average mean wind velocity at 200m reference height is 5m/s at the location of the HKPolyU campus and the probability of exceedance is close to 50% [7]. In order to reach the threshold value of 1.5m/s, which is the minimum noticeable wind velocity for human [8] and also meets the requirement for a person to achieve neutral thermal sensation in hot and humid summer of Hong Kong [9], an *MVR* value equal or over 0.3 is required in this study to maintain a comfortable wind environment for pedestrian activities. Therefore, when the value of *MVR* is lower than 0.3 can be deemed as uncomfortable in this study.

2.3 Turbulence model validation

The turbulence model used in this study is the Steady Reynolds Averaged Navier-Stokes (SRANS) re-normalization group (RNG) k-ε turbulence model, considering that can provide sufficient accuracy at economic numerical cost [10] and this turbulence mod-el has been widely used and reliable in wind engineering [11-13]. The wind tunnel tests conducted by Xia et al. [6] is used as the validation case, the detailed description of the tests can be found in the work by Xia et al. [6] and Du et al. [3].

For the computational domain, the upstream, downstream, lateral, and height length are 5H, 15H, 5H and 5H, respectively, which meets the requirements of the CFD practice guidelines [14, 15]. The whole computational domain is constructed with the hexahedra grids. Figure.1 shows the horizontal lines at pedestrian level plan ($Z/H=0.01$) at which the experiment data and the simulation results are compared. The pressure and momentum equations are coupled using the SIMPLEC algorithm, and the second-order upwind scheme is utilized in the discretization scheme. The residuals in the simulation are all set as 10^{-6}. The validation results between the wind tunnel data and the simulated results with and without lift-up design are shown in Figure.2. It can be obtained from these figures that the CFD simulations can provide sufficient accuracy for predicting the wind flow around the buildings with and without lift-up design.

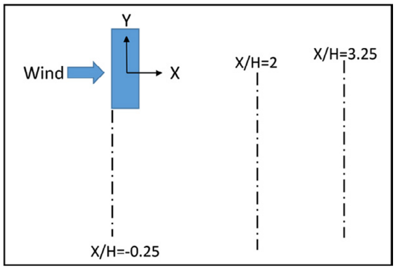

Fig.1. Comparison lines at pedestrian level plan.

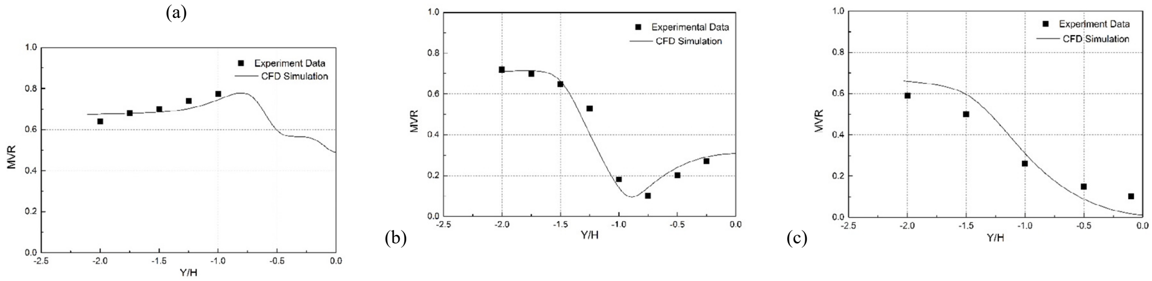

Fig.2. Comparison of values of the *MVR* between wind tunnel data and numerical results with lift-up design: (a)*X/*H=-0.25 ; (b)*X/*H=2 ; (c)*X/*H=3.25.

2.4 Building configuration description

The lift-up design in HKPolyU campus is selected in this study and the model scale is 1:200. The dimension of the isolated buildings with and without lift-up design are schematically shown in prototype in Figure.3 (a)-(b). Apart from the normal approaching wind directions (θ=0°), the current study also considers the oblique approaching wind directions (θ=0°) and the parallel approaching wind directions (θ=0°), which can be seen in Figure.3 (c). It should be mentioned that the validated turbulence model and numerical methods in Section 1.3 are used to simulate the wind flow around the isolated building with and without lift-up design.

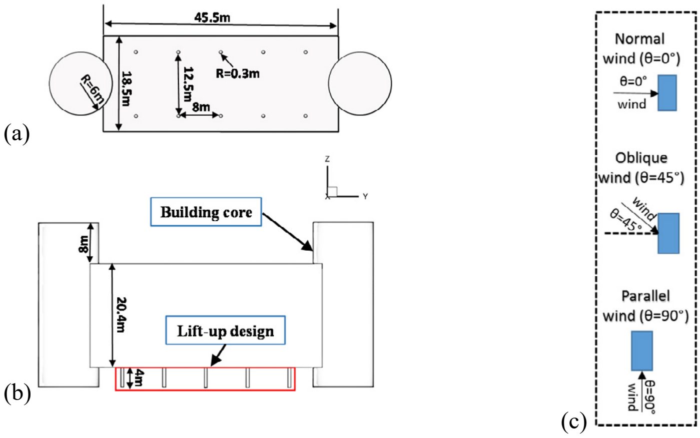

Fig.3. The basic building dimension (a)-(b) and wind directions (c).

3. Results and discussion

The general features of the *MVR* distributions around the isolated building with and without lift-up design under normal wind direction are shown in Figure. 4. Three wind velocity zones are indicated both around the building with and without lift-up design: an upstream low wind velocity (ULWV) zone, a lateral high wind velocity (LHWV) zone, and a downstream far-filed low wind velocity (DFLWV) zone. However, two different wind velocity zones are indicated around the building, which are shaded in Figure. 4. One is the downstream near-field low wind velocity (DNLWV) zone which is indicated near the leeward side of the isolated building without lift-up design is replaced by the near-field high wind velocity (DNHWV) zone when the lift-up design is used. This can be explained by the fact that the wind flow passes through the lift-up area directly, which can be found in Figure. 5. Another is a local wind amplification zone in the lift-up area, resulting in the lift-up wind velocity (LUWV) zone. This phenomenon can be accounted for the Venturi Effect.

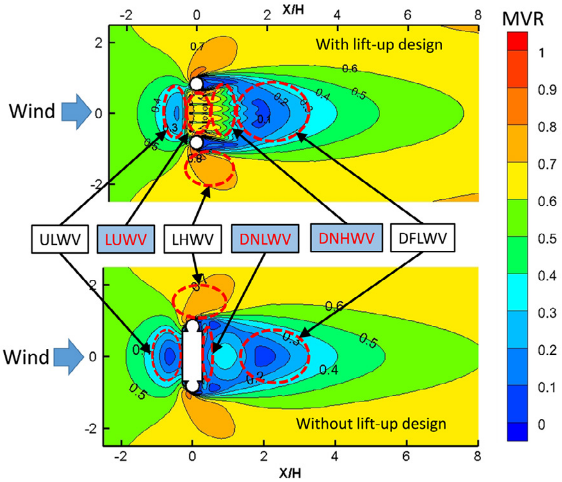

Fig. 4. General features of the *MVR* distributions at pedestrian level around the isolated building under normal wind direction: with lift-up design (upper); without lift-up design (lower).

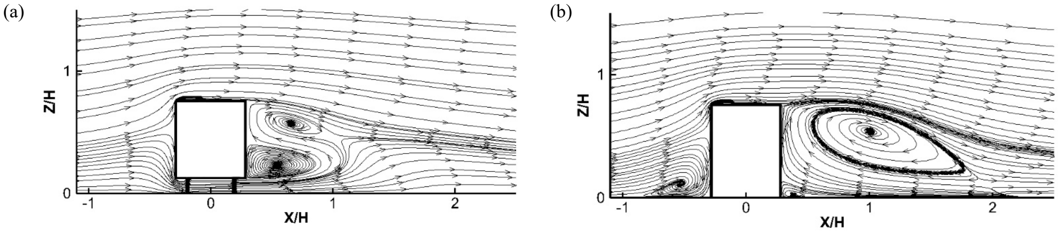

Fig. 5 Wind flow pattern with streamlines on the x-z plane at y/H=0 under the normal wind directions: with lift-up design (left); without lift-up design (right).

Figure. 6 presents the general feature of the *MVR* distributions around the isolated building with lift-up design at pedestrian level under oblique and parallel wind directions; the normal wind direction is shown in Figure. 4. It can be seen from Figure. 6 that the *MVR* flow pattern shifts to the downstream of building and the most affected area changed from the centerline of the building to the downstream side under the oblique wind direction.

For the high wind velocity zones, it can be obtained that the LHWV zone has the comfortable wind environment for the pedestrian activities ($MVR \geqslant 0.3$) under three wind directions while the LUWV zone and DNHWV zone are only favorable for pedestrian activities under normal and oblique wind directions. The reason for the low wind environments of LUWV zone and DNHWV zone under the parallel wind direction is due to the blockage effect of the building cores. For the low wind velocity zones, the ULWV zone and DFLWV zone have the uncomfortable wind environment for pedestrian activities ($MVR<0.3$) under three wind directions. Besides, it is obvious that the size of ULWV zone and DFLWV zone are much smaller under oblique wind direction than that under the normal wind direction. Although the wind uncomfortable zones under the oblique and the parallel wind direction have the similar area size, the advantages of lift-up design are not fully exploited under the parallel wind direction. Therefore, the pedestrian level wind comfort is generally better under the oblique wind direction for the isolated building with lift-up design.

To quantitatively assess the effects of the lift-up design on pedestrian level wind environment, the ΔMVR distributions around the isolated building under three wind directions are presented in Figure. 7. It is clear that the significant wind amplification effect at pedestrian level around the isolated building caused by the lift-up design occurs only in the building surroundings, and the amplification effect decreases as the distance become farther from the building. In addition to this, it is interesting to find that the results of Δ*MVR* become negative in some places of the leeward side. This is can be explained for the fact that with lift-up design a part of wind flow behind the building is induced to the upper stratum, see Figure. 5. Therefore, the strength of the horizontal flow with lift-up design is weaker than the strength of the reattachment flow without lift-up design in the leeward side of the building. Furthermore, the wind velocities in the ULWV zone and DNLWV zone are greatly increased under normal and oblique wind direction by the lift-up design. However, the wind velocities change slightly under the parallel wind direction.

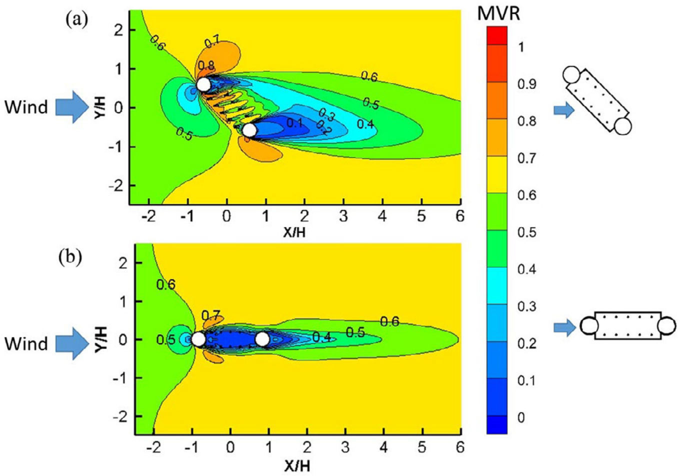

Fig. 6 *MVR* distributions around the isolated building with lift-up design at pedestrian level under different wind directions: (a) Oblique wind (θ=45°); (b) Parallel Wind (θ=90°).

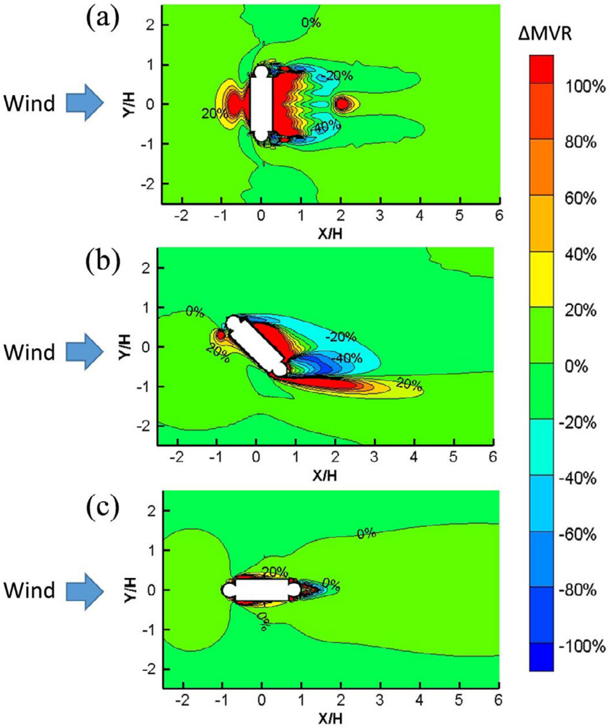

Fig. 7. Effects of lift-up design around isolated building at pedestrian level under three wind directions:(a) Normal wind (θ=0°);(b)Oblique wind (θ=45°);(c) Parallel Wind (θ=90°).

4. Conclusions

This study aims to study the effects of the lift-up design on the isolated building. The lift-up design of the HKPloyU campus is selected as the study model and the wind flows around the isolated buildings with and without lift-up design are investigated under three wind directions: the normal incident wind direction, the oblique wind direction and the parallel wind direction.

The pedestrian level wind comfort around the isolated building with lift-up design under weak wind conditions is evaluated based on the *MVR* distributions around buildings. The results indicate that the lift-up design can help in improving the pedestrian level wind comfort in the building surrounding, especially under the oblique wind direction. The effects of the lift-up design on the pedestrian level are quantitatively assessed by employing ΔMVR. The results show that wind velocities at the ULWV zone, LUWV zone and DNHWV zone are significantly amplified due to the lift-up design while wind velocities at the LHWV zone is insensitive to the lift-up design.

The findings in this study provide an insightful understanding of the effects of the lift-up de-sign on pedestrian level wind comfort around the isolated building under weak wind condition. These findings can also provide the scientific basis for the architects and urban planners to design better precinct that can help in improving wind comfort in the built-up cities. By analysis, it obtains the following conclusions:

- The lift-up design can improve the wind comfort in building surroundings and its influence is highly dependent on the incident wind direction
- The wind comfort is better under the oblique wind direction than the other two wind directions for the isolated building.
- For the recommendation of building design, it should be better when the lift-up area is oblique to the prevailing wind and it should be avoided the lift-up area is parallel to the prevailing wind.

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