A parameterization method for evaluating wind pressure difference between buildings' windward and leeward

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1. Introduction

As the main drive for building natural ventilation, the wind pressure difference between windward and leeward wall surfaces is determined by buildings layout, building type and wind direction. Taking regular aligned building groups as the research object, this paper surveyed the design parameters of aligned residential building groups in Guangzhou in China, obtained the wind pressure difference coefficients (WPDC) of buildings in the groups through CFD simulation, and analyzed the changes of WPDCs with design parameters under the conditions of 0° wind direction angel.

2. Simulation Methods

The central city surrounded by dense building groups was focused in the present study, and the boundary layer height was set as 450m and the ground roughness was set as 0.3 according to the national standard of GB 50009-2012. According to the guideline of Architectural Institute of Japan (AIJ), the top boundary was 10H, the inlet and side boundary was 5H and the outflow boundary was 10H away from the buildings, where H was the building's height. The outdoor wind speed in Guangzhou is mainly within the range of 1-4m/s, so the reference wind speed in this paper was set as 3 m/s with a reference height of 10m.

FLUENT was used and the hexahedral structure grid was adopted in the present study (Fig. 1). According to the guidelines of AIJ and European Cooperation in the field of Scientific and Technical Research (COST), the minimum size of grids was set as 1m. The grids were finely divided in the areas close to buildings' surfaces and gradually sparsely divided when away from the buildings.

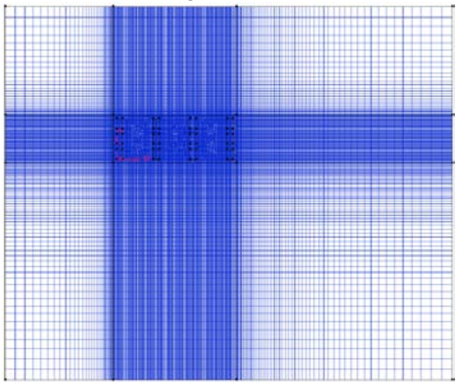

Fig. 1 Computational Domain and Grid

The realizable k-ε turbulence model was used. The SIMPLE algorithm was used for pressure-velocity coupling, pressure interpolation was second order and second-order discretization schemes were used for both the convection terms and the viscous terms of the governing equations. The max residual tolerance was set as 10^{-4} for convergence of calculation.

3. Simulation Conditions

Based on the survey of real cases, the buildings were divided into three categories according to their heights, i.e., high-rise, mid-rise and low-rise buildings, in height of 90m, 45m and 15m, respectively. The width was 25m and the depth was 15m for all buildings. Fig. 2 shows the design parameters of the regular aligned building groups in Guangzhou. For high-rise building groups, the number of rows typically ranges from 2 to 4, and the number of columns is within the range of 1-3. For mid-rise and low-rise building groups, the number of rows typically ranges from 2 to 6, and the number of columns is in the range of 2-3.

According to the winter sunshine requirements, the minimum row spacing was determined as 12m, 27m and 36m for low-rise, mid-rise and high-rise building groups, respectively. The maximum row spacing and the number of row and column were determined according to the distribution of real cases as Fig. 2 shows. Table 1 presents the design parameters of regular aligned building groups in Guangzhou.

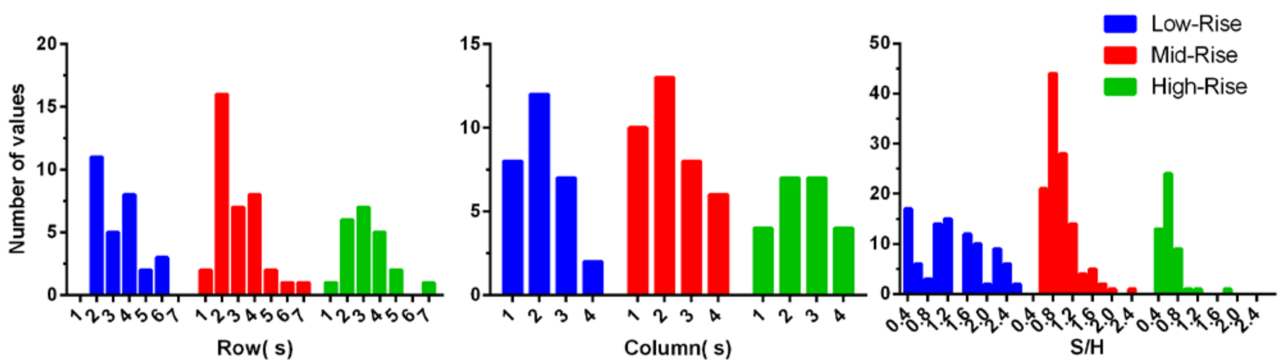

Fig. 2 Histogram of regular aligned building groups in Guangzhou

Table 1 Design parameters of regular aligned building groups in Guangzhou

Building Height (m)	Row spacing (m)	Row Number	Column Number
90	36/56/77	1/2/3 4	1 3
45	27/44/61	1/2/3 6	1 3
15	12/24/36	1/2/3 6	1 3

Note: the layout is named as the row and column number. For instance, 3R1C means three rows and one column layout, and 4R3C means four rows and three columns layout.

4. Results and Discussion

4.1 High-rise Building Groups

The surface-averaged wind pressure coefficients of windward and leeward walls were 0.77 and -0.19, and the WPDC was 0.96 for the detached high-rise building. The WPDC of the building in the aligned group depended on the row number of the building and the row spacing between buildings. The simulation results are shown in Fig. 3 for the cases of row spacing of 36m.

For all the cases, the WPDC of the first row building, which was similar to that of the detached building, was largest (0.83-1.04), and the WPDC of the second row building was smallest (-0.21~-0.07). The WPDCs of the buildings after the third row tended to be as steady as 0~0.06. The WPDCs of buildings changed very slightly with column. For the WPDC of the building located at the last row, the value was largest for 3R1C layout (0.25), and then 4R3C layout (0.03~0.06), and the value of 2R1C layout was smallest (-0.09).

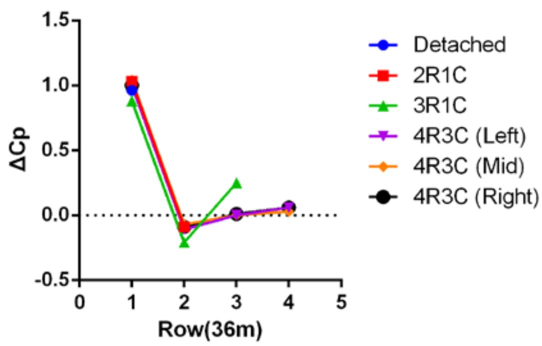

Fig. 3 WPDCs of High-rise Building Groups with 36m row spacing

Similar results were obtained for the groups with 56m and 77m row spacing. The results of all simulation cases were pooled together and the changes of WPDCs with row spacing for the high-rise building group were analyzed as Fig. 4 shows, where S/H means the ratio of row spacing to building height.

It can be seen that of all layouts, the WPDC of the second row building increased linearly and positively with S/H. For 3R1C layout, the WPDC of the third row building decreased first and then increased with S/H in a form of second-order polynomial relationship. For 4R3C layout, the WPDC of building after the third row increased first and then decreased with S/H. Although this change of WPDC is small (from 0.03 to 0.07), the corresponding change of pressure difference might be great and not negligible due to the large wind velocity pressure of high-rise building.

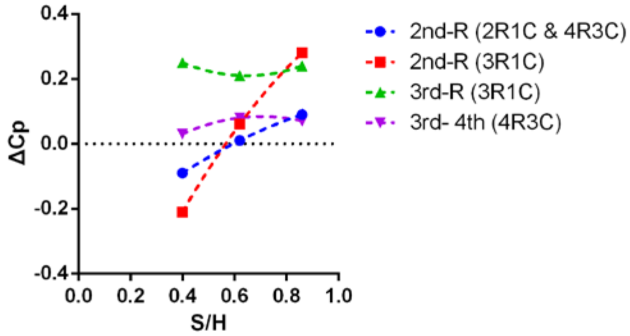

Fig. 4 Changes of WPDCs with S/H for High-rise Building Groups

4.2 Mid-rise Building Groups

The surface-averaged wind pressure coefficients of windward and leeward walls were 0.49 and -0.43, and the WPDC was 0.91 for the detached mid-rise building. The results for the cases with row spacing of 27m are shown in Fig. 5.

The maximum WPDC occurred in the first row (0.85-1.02), which was close to that of the detached building, and the minimum WPDC occurred in some second row (-0.13-0.13). For 6R3C layout, the WPDC of building increased gradually from the second row to the third row and reached a stable number (-0.01 to 0.10) after the third row. The WPDC of building maintained the same for various columns except for that of the last row, which was much higher for the left and right columns. For the WPDC of the building located at the last row, the value was largest for the left and right columns of 6R3C layout and 3R1C layout (0.27-0.29), and then the middle column of 6R3C layout (0.04), and the value of 2R1C layout was lowest (-0.10).

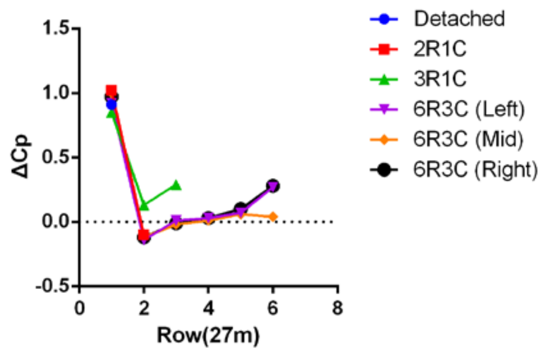

Fig. 5 WPDCs of Mid-rise Building Groups with 27m row spacing

Similar results were obtained for the groups with 44m and 61m row spacing. The results of all simulation cases were pooled together and the changes of WPDCs with row spacing for the mid-rise building group were analyzed as Fig. 6 shows

For 2R1C and 6R3C layouts, the WPDC of the second row building increased linearly and positively with S/H. For 3R1C layout, the WPDC of the second row building decreased first and then increased with S/H, while the WPDC of the third row building increased linearly with S/H. For 6R3C layout, the average WPDC of the third to fifth row buildings increased linearly with S/H, while that of the last (sixth) row building decreased first and then increased with S/H for the left and right columns.

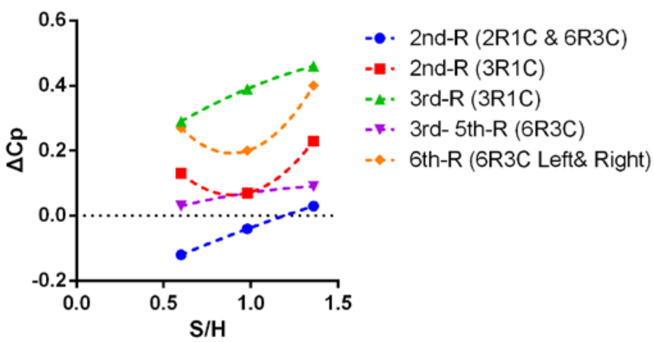

Fig. 6 Changes of WPDCs with S/H for Mid-rise Building Groups

4.3 High-rise Building Groups

The surface-averaged wind pressure coefficients of windward and leeward walls were 0.56 and -0.22, and the WPDC was 0.78 for the detached low-rise building. The results for the cases with row spacing of 12m are shown in Fig. 7.

The maximum WPDC occurred in the first row (0.79-0.84), which was close to that of the detached building, and the minimum WPDC occurred in the second row (-0.06~-0.13). For 6R3C layout, the WPDCs of buildings in the left and right columns kept the same, while those of the middle column were different. For the buildings in the left or right columns, their WPDCs increased gradually from the second row to the fourth row, reached stable after the fourth row, and increased again in the last row. For the buildings in the middle column, their WPDCs increased a little from the second row to the third row and maintained unchanged after the third row. For the WPDC of the building located at the last row, the value was largest for the left and right columns of 6R3C layout and 3R1C layout (0.32-0.35), and then the middle column of 6R3C layout (0.00), and the value of 2R1C layout was lowest (-0.06).

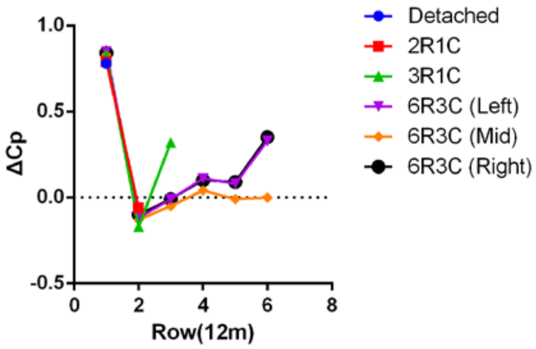

Fig. 7 WPDCs of Low-rise Building Groups with 12m row spacing

Similar results were obtained for the groups with 24m and 36m row spacing. The results of all simulation cases were pooled together and the changes of WPDCs with row spacing for the low-rise building group were analyzed as Fig. 8 shows

For 2R1C and 6R3C layouts, the WPDC of the second row building increased linearly and positively with S/H. For 3R1C layout, the WPDC of both the second and third row buildings increased with S/H. For 6R3C layout, both the WPDC of the fourth to fifth row buildings and the last (sixth) row building in the left and right columns increased first with S/H and then decreased.

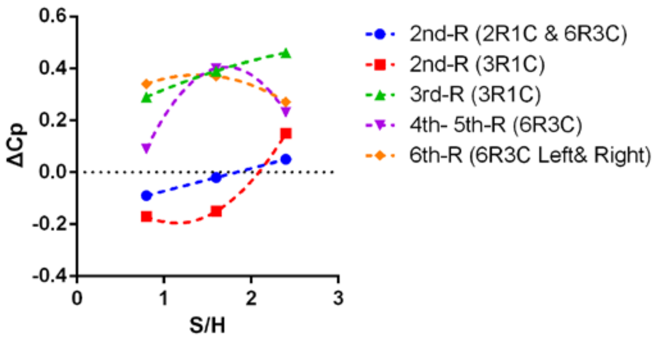

Fig. 8 Changes of WPDCs with S/H for Low-rise Building Groups

4.4 Discussion

In the regular aligned building groups, the buildings of the first row blocked the rear buildings and the WPDC of the rear buildings should be calculated by taking account of this shielding effect. Hussaine (1980) found that the WPDC of the second-row building is positively related to S/H through a wind tunnel study, which is consistent with the results of the present study. The present study also indicates that the WPDC change rate with S/H is bigger when the building is higher.

The study of Tsutsumi (1992) et al showed that, as the number of building rows increases, the wind pressure coefficients for the windward face of backward buildings only changed slightly. They also found that the coefficient was lowest for the second-row buildings, and then gradually increased from the third-row buildings, and reached steady after the fourth row. The present study found the same pattern for the low-rise building group. For the high-rise and mid-rise building groups, the present results show that the wind pressure coefficient reached steady after the third row.

5. Conclusion

The WPDCs of buildings in the regular aligned building groups in Guangzhou were studied by numerical simulation and the main conclusions are as follows.

The WPDC of building is largest in the first row and smallest in the second row. The WPDC of building reaches steady after the third row for the mid-rise and high-rise building groups and reached steady after the fourth row for the low-rise building groups. The WPDCs of buildings in the second row increase linearly and positively with S/H for all cases.

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