Wind Engineering Joint Usage/Research Center
FY2017 Research Result Report

Research Field: Wind disaster and wind resistant design

Research Period: FY2017～ FY2018

Research Number: 173002

Research Theme: Study on the characteristic of pedestrian-level wind speed around square buildings: Effect of height, width, size and approaching flow

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Budget [FY2014]: 300000JPY

*If the research was not continuous, this will be the Final Result Report, so the contents of the report has to be detailed.
*There is no limitation of the number of pages of this report.
*Figures can be included to the report and they can also be colored.
*Submitted reports will be uploaded to the JURC Homepage.

1. Research Aim

In past studies, （Xu et al. 2017）, some parameters such as corner modifications, angle of helical models, number of sides of building plan, projected width, etc, had been investigated. All results of the experiment models were comparative discussions under the conditions of “same height and same volume”. However, some phenomenon in past study cannot be explained by the existing results. In this study, a series of wind-tunnel tests were carried out to investigate the characteristic of pedestrian level wind around square buildings with various dimensions: height effects, width effects, size effects.

2. Research Method

For this research, using the thermistor sensors and hot-wire sensor to test wind speed around the super tall buildings and the inflow wind speed, calculate the mean speed-up ratio. Use each point’s wind speed ratio to draw the contours; and then compare different models’ contours to find difference of the high wind speed ratio area.

3. Research Result

3.1 Model Configuration

As the **Table. 1** shown, the building models were made at a scale ratio of 1/500 and represented three building configurations. Case I comprised 13 models which represented square type buildings with the same width and varying height, as **Table 1(a)** shown. The building width (B) and Depth (D) was set at 50m, and the height was changed from 50m to 600m, to investigate the height (H) effect with the varying aspect ratio. Case II comprised 7 models which represented square type buildings with the same height and varying width, as **Table 1(b)** shown. The building height (H) was set at 400m, and the width (B) was changed from 26.6m to 133.3m. Case III was focus on investigate the width (B) effect with the varying aspect ratio. Case III comprised 5 models which represented square type buildings with varying size, as the **Table 1(c)** shown. The aspect ratio and side ratio of all models in Case III were fixed as 8 (H/B) and 1 (B/D), respectively. The building height was changed from 200m to 600m at increments of 100m at prototype scale, to investigate size effects with the same aspect ratio.

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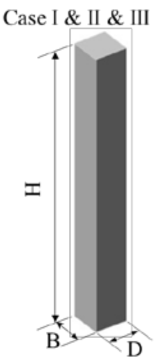
<tr><td rowspan="15">

Model configuration</td><td colspan="4">Table 1(a).Case I:Effec of height</td><td colspan="4">Table 1(b).Case II: Effect of width</td></tr>
<tr><td>No.</td><td>H(m)</td><td>B(m)</td><td>D(m)</td><td>No.</td><td>H(m)</td><td>B(m)</td><td>D(m)</td></tr>
<tr><td>1</td><td>50</td><td>50</td><td>50</td><td>1</td><td>400</td><td>26.7</td><td>26.7</td></tr>
<tr><td>2</td><td>100</td><td>50</td><td>50</td><td>2</td><td>400</td><td>36.4</td><td>36.4</td></tr>
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<tr><td>4</td><td>200</td><td>50</td><td>50</td><td>4</td><td>400</td><td>66.7</td><td>66.7</td></tr>
<tr><td>5</td><td>250</td><td>50</td><td>50</td><td>5</td><td>400</td><td>80</td><td>80</td></tr>
<tr><td>6</td><td>300</td><td>50</td><td>50</td><td>6</td><td>400</td><td>100</td><td>100</td></tr>
<tr><td>7</td><td>350</td><td>50</td><td>50</td><td colspan="4">Table 1(c).Case III: Effect of size</td></tr>
<tr><td>8</td><td>400</td><td>50</td><td>50</td><td>No.</td><td>H(m)</td><td>B(m)</td><td>D(m)</td></tr>
<tr><td>9</td><td>450</td><td>50</td><td>50</td><td>1</td><td>200</td><td>25</td><td>25</td></tr>
<tr><td>10</td><td>500</td><td>50</td><td>50</td><td>2</td><td>300</td><td>37.5</td><td>37.5</td></tr>
<tr><td>11</td><td>600</td><td>50</td><td>50</td><td>3</td><td>400</td><td>50</td><td>50</td></tr>
<tr><td colspan="4" rowspan="2"></td><td>4</td><td>500</td><td>62.5</td><td>62.5</td></tr>
<tr><td>5</td><td>600</td><td>75</td><td>75</td></tr>
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Table 1. Model configurations

The definition of wind direction for models is shown in Fig. 1. The wind direction interval in the tests was 22.5° for square type models

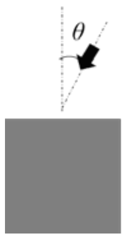


Fig.1 Definition of wind direction

3.2 Parameters for Describing Pedestrian-level Wind Characteristics

3.2.1 Speed-up ratio R

The speed-up ratio R is defined as:

$$R = \frac{U_i}{U_{i0}} \tag{1}$$

where U_i is the mean pedestrian-level wind speed at point i around a building model, and U_{i0} is the mean wind speed at the same point without the building.

3.2.2 Absolute normalized speed up area $A^*_{0,R}$ and relative normalized speed up area $A^*_{B,R\text{-}int}$

The absolute normalized speed-up area $A^*_{0,R}$ is defined as follows, based on the plan area of reference square model, case I-8, which the height of the building is 400m, the width and depth is 50m. A_R is the total area inside a contour line corresponding to speed-up ratio R as shown in **Fig. 2**. It can be reflected the absolute area of high wind speed zone around target buildings.

$$A^*_{0,R} = \frac{A_R}{B_0^{\ 2}} \tag{2}$$

The relative normalized speed-up area $A^*_{B,R}$ is defined as follows, based on the plan area B^2 of the target square model. It can be reflected the relationship between the area of models section and the area of high wind speed zones around buildings, and eliminate the effect of building width.

$$A^*_{B,R} = \frac{A_R}{B^2} \tag{3}$$

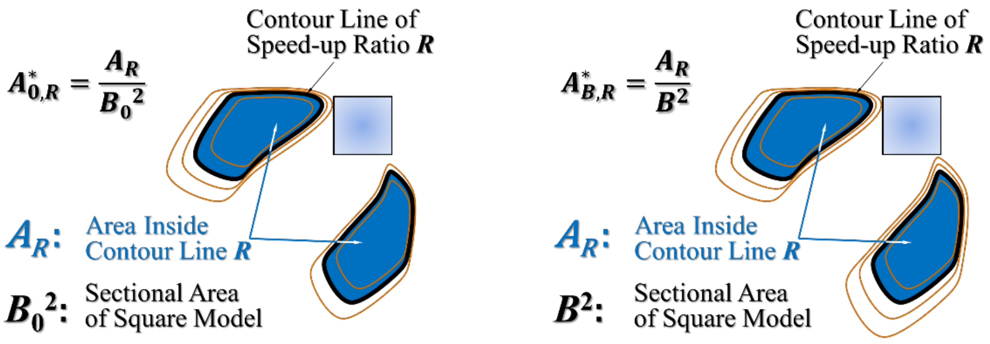


Fig.2 Absolute normalized speed up area $A^*_{0,R}$ and relative normalized speed up area $A^*_{B,R}$

3.2.3 Absolute integrated speed up area $A^*_{0,R\text{-}int}$ and relative integrated speed up area $A^*_{B,R\text{-}int}$

To make overall comparisons between the normalized speed-up areas of models, the absolute integrated speed up area $A^*_{0,R\text{-}int}$ and relative integrated speed up area $A^*_{B,R\text{-}int}$ for all wind directions are introduced. This is defined as the averaged normalized speed-up area considering all wind directions as shown in **Eq. (4)** and **Eq. (5)**.

$$A^*_{0,R\text{-}int} = \frac{\sum_{\theta_j}^{N} A^*_{0,R,\theta_j}}{N} \tag{4}$$

$$A^*_{B,R\text{-}int} = \frac{\sum_{\theta_j}^{N} A^*_{B,R,\theta_j}}{N} \tag{5}$$

where the numerator is the sum of the absolute normalized speed-up areas $A^*_{0,\,R}$ and relative normalized speed-up areas $A^*_{B,\,R}$ corresponding to speed-up ratio R and wind direction θ_j, and the denominator N is the number of wind directions tested. These parameters can be a representative index showing the speed-up nature of pedestrian-level wind for individual building models under the ideal conditions of uniform wind directionality at the construction site.

3.3.4 Effect of Height with same width

Effect of height, aspect ratio and turbulence intensity in boundary layer flow

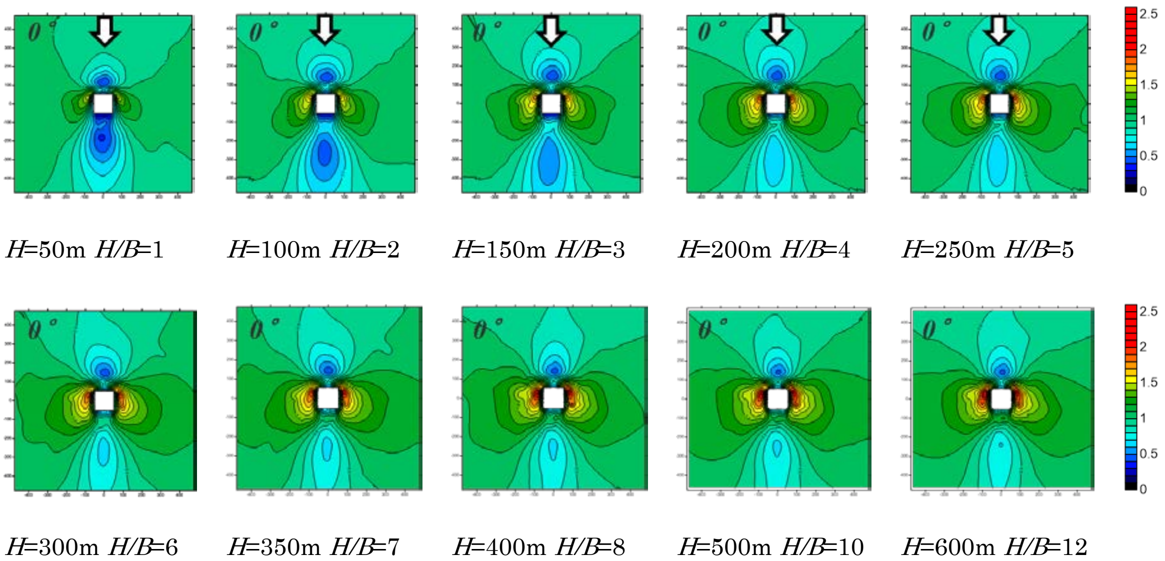


Fig. 3. Speed up ratio distribution around building with different height and same width for wind direction Θ=0°in boundary layer flow （B=50m, H=50m to 600m）

Figure 3 shows the speed up ratio distribution around square building with different heights and same width for wind direction Θ=0° in boundary layer flow. For Θ=0°, it can be noted that the maximum speed up ratio and the area of high wind speed zones increase as the height and aspect ratios increasing. When the building height increases from 50m to 300m (*H/B*=1~6), the corresponding maximum speed up ratio and the area of high wind speed zones show the significant increase. When the building height exceeds 350m (*H/B*=7), the increasing tendency of the high wind speed zone around the building can still be observed, but becomes smaller. Similar phenomenon has been observed for wind direction Θ=45°**.**

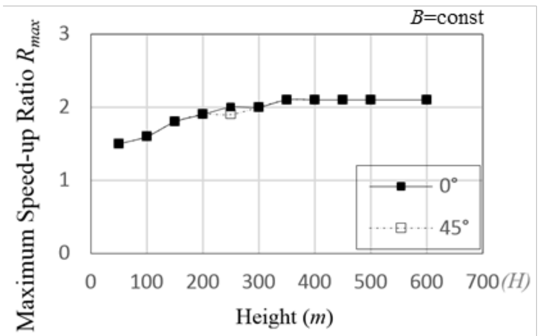


Fig.4 Variation of maximum speed up ratio of square buildings with different height *H* and same width *B* for wind direction Θ=0° and Θ=45° in boundary layer flow

The variations of maximum speed up ratio R_{max} of square buildings with different heights H and same width B for wind direction Θ=0° and Θ=45° in boundary layer flow are shown in **Fig. 4**. The minimum of R_{max} is 1.7 corresponding with the Case I-1 (H=50m, *H/B*=1), which increases until around 2.1 with the height of the building first, then almost keeps constant from 350m to 600m (*H/B*=7~12). The maximum speed-up ratio R_{max} seems to have the limitation, and increasing the height of the building will not effect on the maximum speed up ratio when the height of the buildings exceeds 350m.

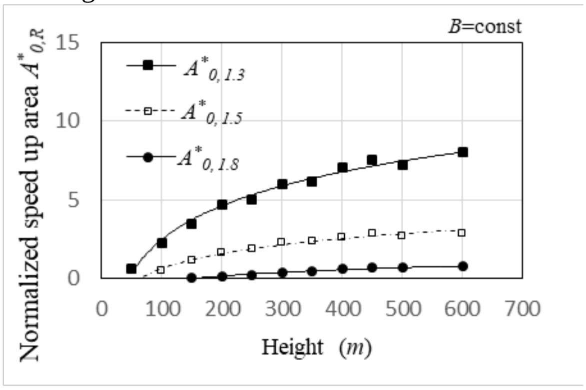


Fig.5(a) Variation of absolute normalized speed up area $A^*_{0,1.3}$, $A^*_{0,1.5}$, $A^*_{0,1.8}$ with the height of building for Θ=0°in boundary layer flow

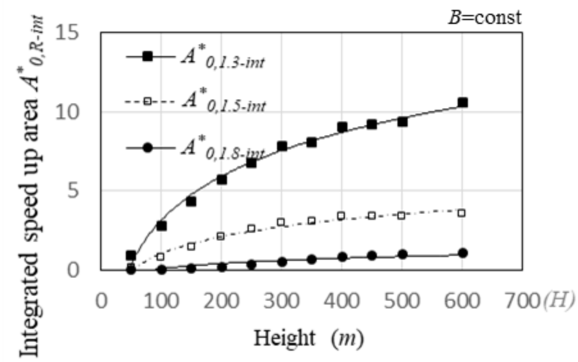
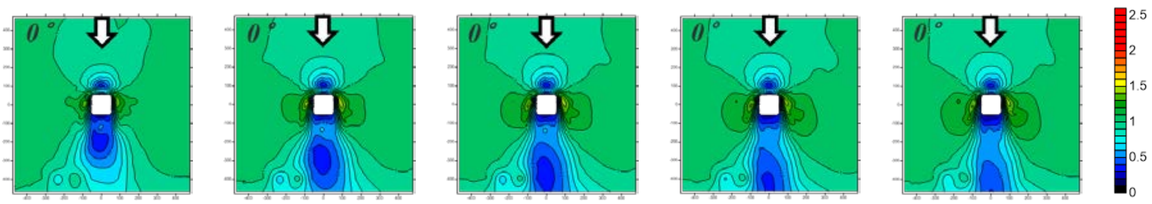


Fig. 5(b) variation of absolute integrated speed up area $A^*_{0,1.3\text{-}int}$, $A^*_{0,1.5\text{-}int}$, $A^*_{0,1.8\text{-}int}$ with the height of building in boundary layer flow

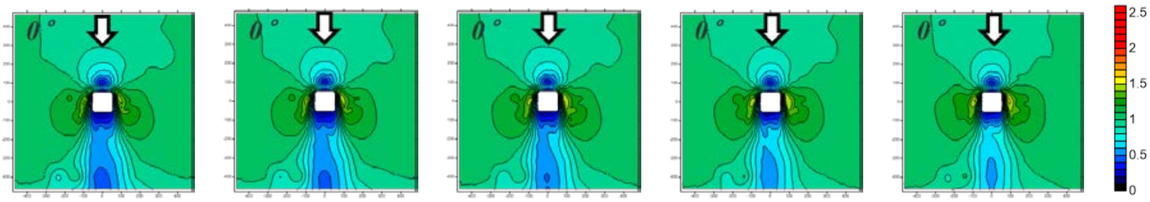
For each Case I models, the sectional areas are exactly same, and there are no difference between absolute normalized speed up ratio $A^*_{0,R}$ and relative normalized speed up area $A^*_{B,R}$. Here, the absolute normalized speed up area $A^*_{0,R}$ is chosen as represented to investigate the variation of high wind speed zone around Case I models. The variation of absolute normalized speed up area $A^*_{0,1.3}$, $A^*_{0,1.5}$, $A^*_{0,1.8}$ with the height of building for Θ=0° and variation of absolute integrated speed up area $A^*_{B,1.3\text{-}int}$, $A^*_{B,1.5\text{-}int}$, $A^*_{B,1.8\text{-}int}$ with the height of building are shown in **Fig. 5**, respectively. From the schemes, it can be noted that the relationship between absolute normalized speed up area $A^*_{0,R}$ and the height of building is logarithmic distribution for wind direction Θ=0° and 45°, and presents the convergent tendency. When the height of the building is lower, the increasing height of building will cause the significant increase of absolute normalized speed up area $A^*_{0,R}$. However, when the height of the building becomes higher, the increasing tendency becomes smaller and smaller. This suggests that as the height of the building increases, the variation of height shows less and less effect on absolute normalized speed up area $A^*_{R,Br}$.The absolute integrated speed up area $A^*_{0,R\text{-}int}$ presents the similar tendency which is shown in **Fig. 5(b)**.

Effect of height, aspect ratio in uniform turbulence flow

The speed up ratio distributions of square buildings with different heights *H* and same width *B* for wind direction Θ=0° in uniform turbulence flow are shown in **Fig. 6**. Compared with **Fig. 3** (in the boundary layer flow), the characteristic of pedestrian level wind shows the significant difference for same models in the different approaching flow. The maximum speed up ratio and area of high wind speed zones for square model in uniform turbulence flow are much smaller than them in boundary layer flow. It can be noted that the area of high wind speed zone shows a little increase tendency with the increase of building height.



H=50m *H/B*=1 *H*=100m *H/B*=2 *H*=150m *H/B*=3 *H*=200m *H/B*=4 *H*=250m *H/B*=5



H=300m *H/B*=6 *H*=350m *H/B*=7 *H*=400m *H/B*=8 *H*=500m *H/B*=10 *H*=600m *H/B*=12

Fig. 6. Speed up ratio distribution around building with different height and same width for wind direction ϴ=0°in uniform turbulence flow（*B*=50m, *H*=50m to 600m）

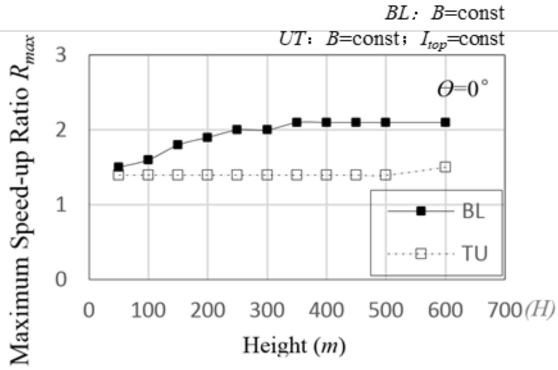


Fig.7(a) Variation of Maximum speed up ratio of square buildings with different height and same width for wind direction *ϴ*=0° and *ϴ*=45° in boundary layer flow and uniform turbulence flow

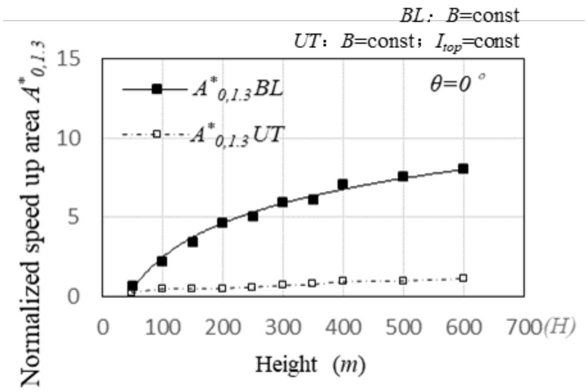


Fig.7(b) Variation of absolute normalized speed up area $A^*_{0,\ 1.3}$ with the height of building for *ϴ*=0°in boundary layer flow and uniform turbulence flow

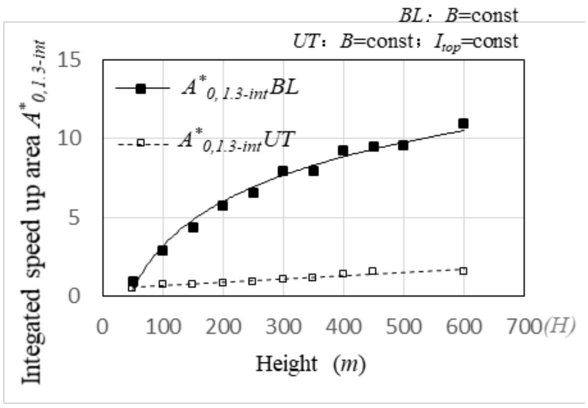
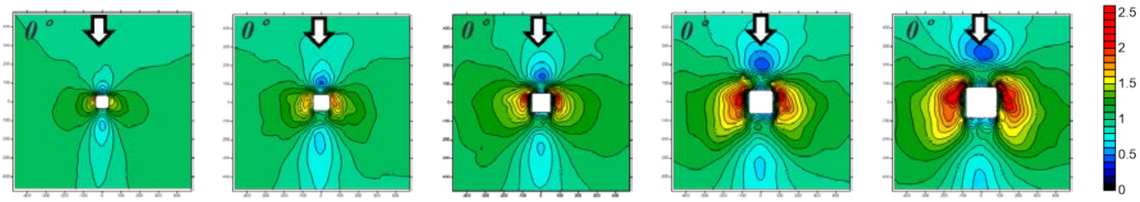


Fig.7(c) Variation of absolute integrated speed up area $A^*_{0,\ 1.3\text{-}int}$ with the height of building in boundary layer flow and uniform turbulence flow

Figure 7 shows the variation of maximum speed up ratio R_{max} , absolute normalized speed up area $A^*_{0,\ R}$ and absolute integrated speed up area $A^*_{0,\ R\text{-}int}$ with the height of the building in boundary layer flow and uniform turbulence flow, respectively. From the graphs, it can be noted that the maximum speed up ratio almost keeps constant, while the absolute normalized speed up area $A^*_{0,\ R}$ and absolute integrated speed up area $A^*_{0,\ R\text{-}int}$ show a little increasing tendency with the increasing height of the building and the aspect ratios. Besides, the difference of maximum speed up ratio and speed up area in two different approaching becomes larger and larger with the height and aspect ratio of building increasing. This may suggest the significant effect of wind profile on pedestrian-level winds. For the building in boundary layer flow, the down wash shows significant effect on pedestrian level winds which creates the higher maximum wind speed and the larger high wind speed zones than that in uniform turbulence flow. For the buildings in uniform turbulence flow, the down wash effect is not significant with the height of building increasing, which causes the maximum speed up ratios of the buildings almost keep 1.5. While the area of the windward side gradually becomes larger as the increase of the buildings, and the blockage effect of buildings on the flow increases, which induces the area of high wind speed zones increasing.

3.3.5 Effect of Width with same height

Effect of the aspect ratio in boundary layer flow



B=26m *H*/*B*=15 | *B*=37.6m *H*/*B*=11 | *B*=50m *H*/*B*=8 | *B*=66.6m *H*/*B*=6 | *B*=80m *H*/*B*=5

Fig. 8. Speed up ratio distribution around building with different width for wind direction *Θ*=0°in boundary layer flow （*H*=400m, *B*=26m to 80m）

Figure 8 presents the speed up ratio distribution around the square buildings with different widths for wind direction *Θ*=0° in boundary layer flow. Here, it can be observed from **Fig. 8** that for the square building with same height, the variation of the width shows the significant effect on pedestrian level wind. With the increasing width, the maximum speed up ratio and high wind speed zones around building increase significantly.

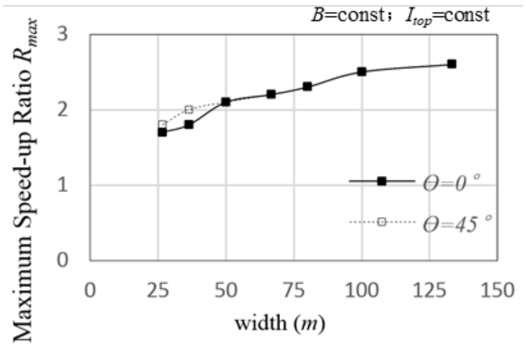
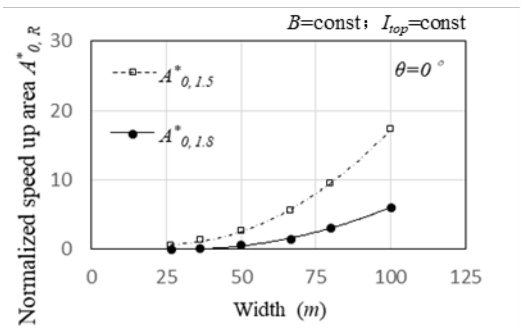


Fig.9 Variation of Maximum speed up ratio of square buildings with different width *B* for wind direction *Θ*=0° and *Θ*=45°

The maximum speed up ratio R_{max} of square buildings with various widths for $\theta = 0°$ and $\theta = 45°$ is presented in **Fig. 9**, which illustrates the relationship between the width of building and the maximum speed up ratio. Here, the increase of maximum speed up ratio due to the increase of the width of the building is clearly shown for these test models. Model 3-1(B=26.6m H/B=15) shows maximum speed up ratio R_{max} = 1.7 and 1.8 and model 3-6 (B=133m, H/B=4) shows 2.6 and 2.6 for $\theta = 0°$ and $\theta = 45°$, respectively. This suggests that the wider building more easily creates the unsafe wind conditions at pedestrian level height.



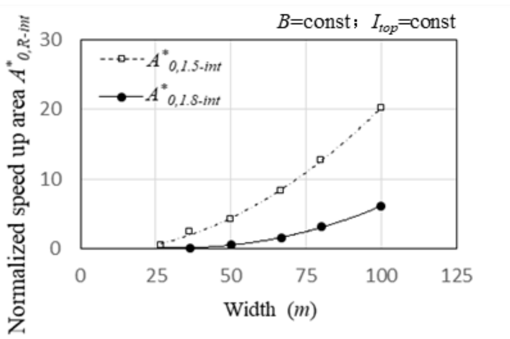


Fig.10(a) Variation of absolute normalized speed up area $A^*_{0,1.5}$，$A^*_{0,1.8}$ with the width

Fig.10(b) Variation of absolute normalized speed up area $A^*_{0,\ 1.5\text{-}int}$，$A^*_{0,\ 1.8\text{-}int}$ with the

of building for Θ=0°in boundary layer flow **width of building in boundary layer flow**

The variations of absolute normalized speed up area $A^*_{0,\ 1.5}$, $A^*_{0,\ 1.8}$ with the width of buildings for wind direction Θ=0° and the variations of absolute normalized speed up area $A^*_{0,\ 1.5\text{-}int}$, $A^*_{0,\ 1.8\text{-}int}$ with the width of the buildings are shown in **Fig. 10**, respectively. Here, the result of absolute normalized speed up area $A^*_{0,\ 1.3}$ isn't presented here because the area of absolute normalized speed up area $A^*_{0,\ 1.3}$ was out of the measurement area. From **Fig. 10 (a)**, it can be observed that the relationship between the absolute normalized speed up area $A^*_{0,\ 1.5}$, $A^*_{0,\ 1.8}$ and width of the buildings is quadratic distribution for wind direction Θ=0°. The absolute normalized speed up area $A^*_{0,\ 1.5}$, $A^*_{0,\ 1.8}$ increases significantly as the width increases. Compared to Case II-1 (B=26.6m H/B=15), the width of the Case II-6 (B=100m, H/B=4) increases by 3.75 times, resulting in a nearly 40 times increase in absolute normalized speed up area $A^*_{0,\ 1.5}$. The integrated speed up area $A^*_{0,\ R\text{-}int}$ is shown in **Fig. 10 (b)** which presents the similar variation with the width. This is because the larger the width of the buildings, the stronger the blockage effect acting on the airflow, which leads to the increase of wind speed and area of high wind speed zone at pedestrian height. This suggests that the absolute normalized speed up area $A^*_{0,\ R}$ is very sensitive to the building width. For the buildings with same height, the wider the building width, the larger the high wind speed zone will be created.

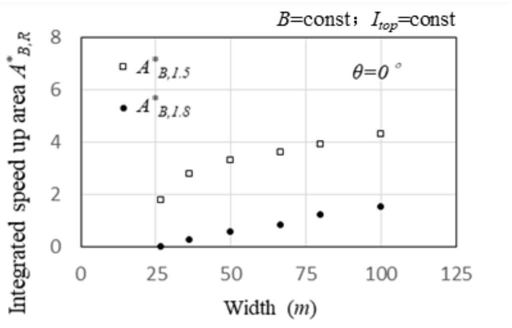


Fig. 11 (a) Variation of relative normalized speed up area $A^*_{B,\ 1.5}$, $A^*_{B,\ 1.8}$ with the width of the buildings for Θ=0° in boundary layer flow

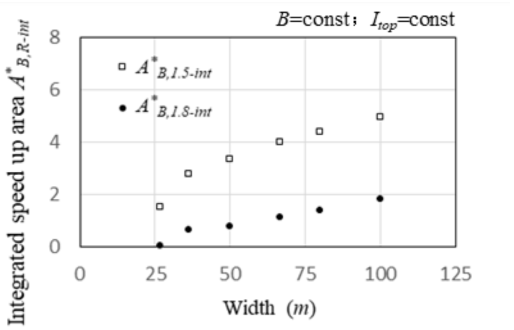
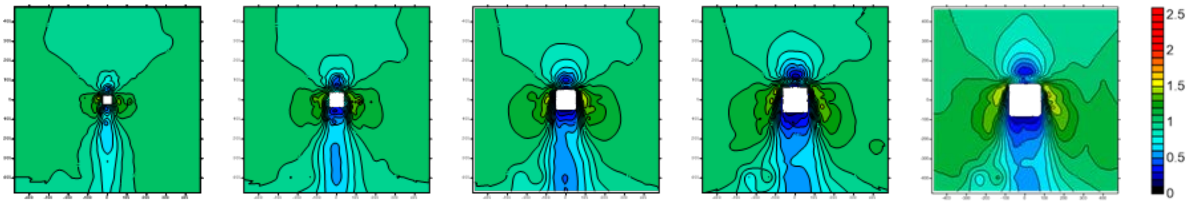


Fig.11(b) Variation of relative integrated speed up area $A^*_{B,\ 1.5\text{-}int}$, $A^*_{B,\ 1.8\text{-}int}$ with the width of building in boundary layer flow

Figure. 11 shows the variation of relative normalized speed up area $A^*_{B,\ 1.5}$, $A^*_{B,\ 1.8}$ with the width of the buildings for Θ=0° and the variation of relative integrated speed up area $A^*_{B,\ 1.5\text{-}int}$, $A^*_{B,\ 1.8\text{-}int}$ with the width of building, respectively. It can be observed that relative normalized speed up area $A^*_{B,\ 1.5}$, $A^*_{B,\ 1.8}$ and relative integrated speed up area $A^*_{B,\ 1.5\text{-}int}$, $A^*_{B,\ 1.8\text{-}int}$ increase with the width, and the tendency of the increase reduces gradually and appears a certain convergence properties. As the aspect ratio of Case II-1(B=26.6m) model is 15, shows the slender propertied, two-dimensional characteristic of the airflow surrounding the buildings is more obvious (See Section 4.1), which gradually reduces and increasingly tends to be three-dimensional flow around buildings with the increase of the width. Besides, more and more high wind speed flow is brought to the pedestrian level due to the blockage of building, leading to the slow increase of the normalized speed up area and presenting the convergent tendency.

Effect of the aspect ratio in uniform turbulence flow



B=26m *H*/*B*=15 *B*=37.6m *H*/*B*=11 *B*=50m *H*/*B*=8 *B*=66.6m *H*/*B*=6 *B*=80m *H*/*B*=5

Fig. 12. Speed up ratio distribution around building with different width for wind direction

Θ=0° in uniform turbulence flow (*H*=400m, *B*=26m to 80m)

Figure 12 shows the speed up ratio distribution around the square buildings with different widths for wind direction Θ=0° in uniform turbulence flow. For the square building with same height, the variation of the width shows the significant effect on pedestrian level wind. With the increasing width, the high wind speed zones around building increase significantly.

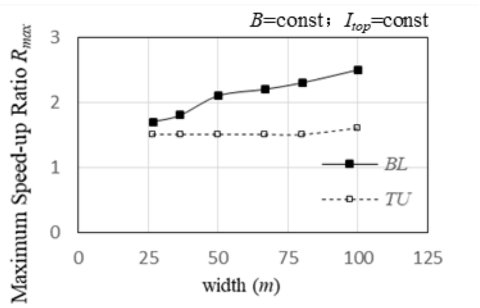


Fig.13 Variation of Maximum speed up ratio of square buildings with different width *B*

Figure 13 illustrates the variation of maximum speed up ratio R_{max}, with the height of the building in boundary layer flow and uniform turbulence flow, respectively. From the figures, it can be noted that the maximum speed up ratio almost keeps constant in uniform turbulence flow. With the increases of the width, the difference of maximum speed up ratio R_{max} for the same models becomes larger and larger. Similar to the Section 4.1, this also suggests the significant effect of approaching flow (down wash) on pedestrian level wind.

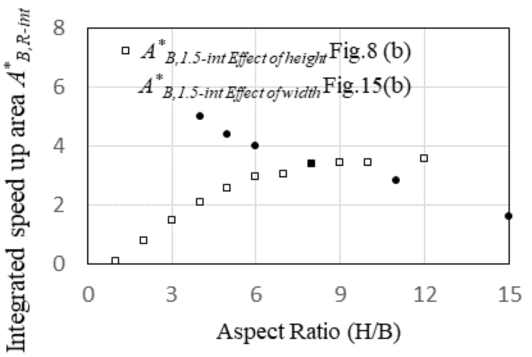


Fig.14(a) The variation of relative integrated speed up area $A^*_{B,R\text{-}int}$ with the aspect ratio of the building for Case I and Case II in boundary layer flow

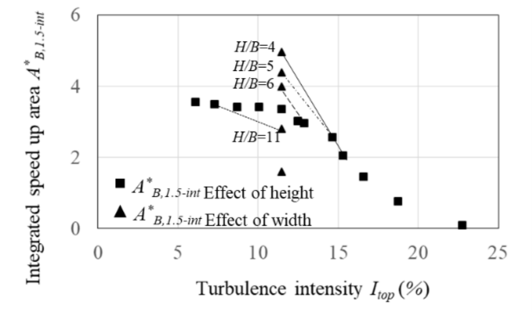


Fig.14(b) The variation of relative integrated speed up area $A^*_{B,R\text{-}int}$ with the turbulence intensity (I_{top}) at the top of the building for Case I and Case II in boundary layer flow

The variations of relative integrated speed up area $\boldsymbol{A^*_{B,R\text{-}int}}$ with the aspect ratio of the building for Case I and Case II in boundary layer flow are shown in **Fig. 14(a)**. Here, the relative integrated speed up area has been used for the comparison to eliminate the effect of building width. From graphs, it can be noted that even for the models with same aspect ratio, the relative integrated speed up area $A^*_{B,R\text{-}int}$ is not same. Compared with the two cases of models, the height and turbulence intensity (I_{top}) at the top of the building are different for models with the same aspect ratios, which causes the difference of the relative integrated speed up area $\boldsymbol{A^*_{B,R\text{-}int}}$. Besides, the larger the difference of height and turbulence intensity (I_{top}) at the top of the building, the larger the difference of the integrated speed up area. **Fig. 14(b)** shows the variation of relative integrated speed up area with the turbulence intensity at the top of the building for Case I models and Case II models in boundary layer flow. It can be observed that the lower the turbulence intensity at the top of models, the larger the relative integrated speed up area will be created around the building with same aspect ratios. This may suggest that the turbulence intensity at the top of the building is one of governing parameter on pedestrian level wind in boundary layer flow. For the building with the same aspect ratios in boundary layer flow, the lower turbulence intensity at the top of the building will cause the larger high wind speed zone around the buildings.

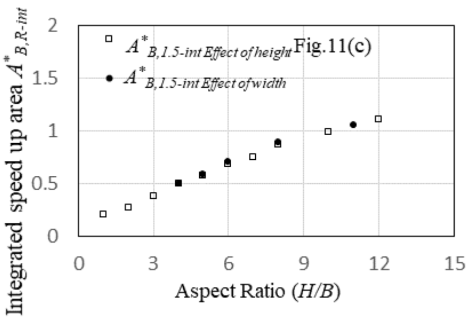


Fig.15(a) The variation of relative integrated speed up area $A^*_{B,R\text{-}int}$ with the aspect ratio of the building for Case I and Case II in boundary layer flow

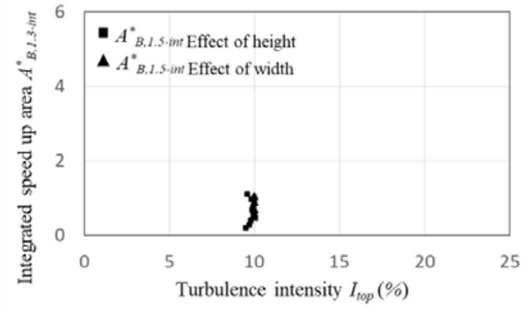
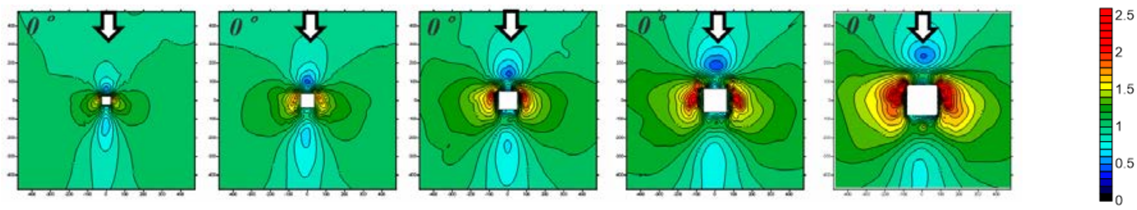


Fig.15(b) The variation of relative integrated speed up area $A^*_{B,R\text{-}int}$ with the turbulence intensity (I_{top}) at the top of the building for Case I and Case II in boundary layer flow

The variations of relative integrated speed up area $A^*_{B,R\text{-}int}$ with the aspect ratio and turbulence intensity (I_{top}) at the top of the building for Case I and Case II in uniform turbulence flow are shown in **Fig. 15(a) and Fig. 15(b)**, respectively. It can be observed that the relative integrated speed up area increases linearly as the aspect ratio increases for both Case I and Case II models. The turbulence intensity (I_{top}) at the top of the building in these two case are the same for models with the same aspect ratios, which causes the relative integrated speed up area $A^*_{B,R\text{-}int}$ around the models keep constant.

3.3.6 Effect of size with same aspect ratio

Effect of the height and turbulence intensity in boundary layer flow



H=200m *B*=25m *H*=300m*B*=37.5m *H*=400m*B*=50m *H*=500m *B*=62.5m *H*=600m *B*=75m

Fig.16 Speed up ratio distribution around the square buildings with the size for wind direction *Θ*=0° in boundary layer flow （*H*/*B*= 8）

Figure 16 shows the speed up ratio distribution around the square buildings with different sizes for wind direction *Θ*=0° in boundary layer flow. From the figures, it can be noted that even the aspect ratios of each buildings are same, with the increasing of the size (height and width), the maximum speed up ratio and high wind speed zones around building increase significantly.

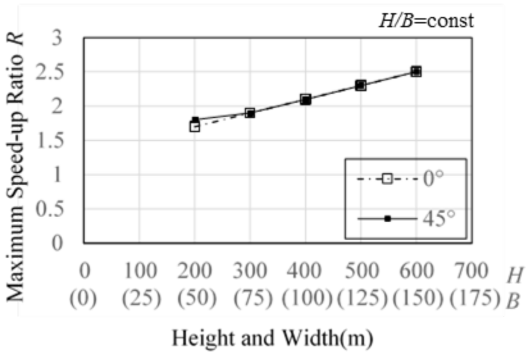
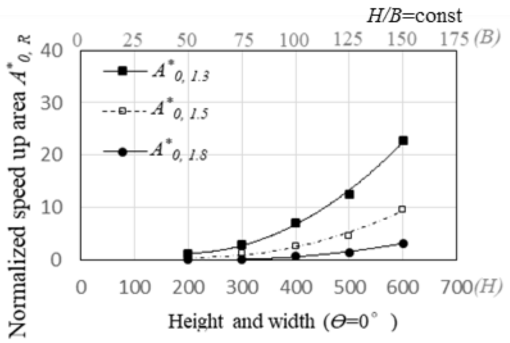


Fig.17 Variation of Maximum speed up ratio of square buildings with the size for wind direction *Θ*=0° and *Θ*=45° in boundary layer flow

The maximum speed up ratios with sizes (height and width) of the building for 0° and 45° in boundary layer flow are shown in **Fig.17**. It can be clearly seen that maximum speed up ratio increases with the size (height and width) of the building increasing.



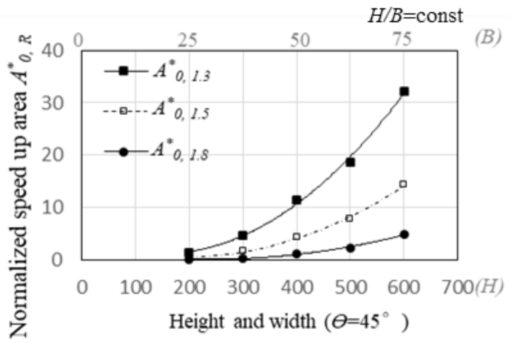


Fig.18(a) Variation of absolute normalized speed up area $A^*_{0,1.3}$, $A^*_{0,1.5}$, $A^*_{0,1.8}$ with size (height and width)of building for *Θ*=0°in boundary layer flow

Fig 18(b) Variation of absolute normalized speed up area $A^*_{0,1.3}$, $A^*_{0,1.5}$, $A^*_{0,1.8}$ with size (height and width) of building for *Θ*=45°in boundary layer flow

The variations of absolute normalized speed up area $A^*_{0,\ 1.3}$, $A^*_{0,\ 1.5}$, $A^*_{0,\ 1.8}$ with the size (height and width) of buildings for wind direction *Θ*=0° and the variations of absolute integrated speed up area $A^*_{0,\ 1.3\text{-}int}$, $A^*_{0,\ 1.5\text{-}int}$, $A^*_{0,\ 1.8\text{-}int}$ with the size (height and width) of the buildings are shown in **Fig. 18**, respectively. This figure suggests that the relationship between the absolute normalized speed up area $A^*_{0,\ R}$ and size (height and width) of the buildings is quadratic distribution for wind direction *Θ*=0°. The absolute integrated speed up area $A^*_{0,\ R\text{-}int}$, $A^*_{0,\ R\text{-}int}$, $A^*_{0,\ R\text{-}int}$ presents the similar tendency which is shown in **Fig.18(b)**. For the buildings with the same aspect ratio, the larger the size (height and width), the higher the wind speed and the larger the normalized speed up area at the pedestrian level height.

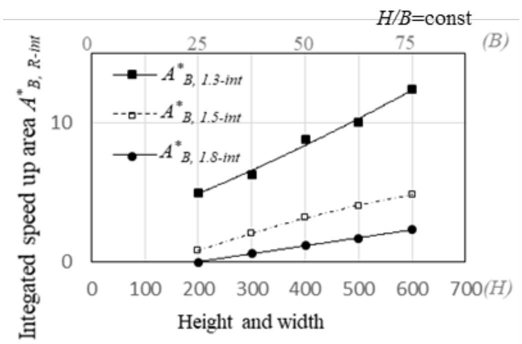
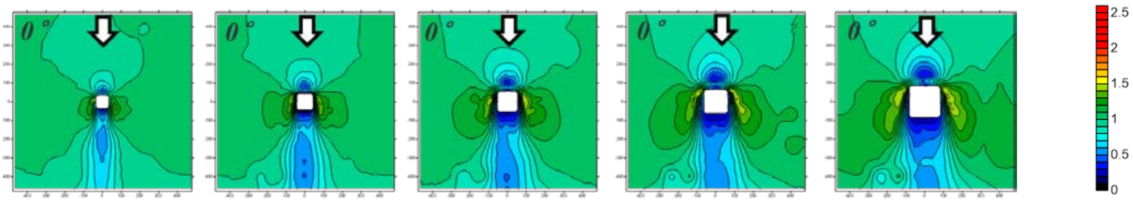


Fig.19 Variation of relative integrated speed up area $A^*_{B,\ 1.3\text{-}int}$, $A^*_{B,\ 1.5\text{-}int}$, $A^*_{B,\ 1.8\text{-}int}$ with size (height and width) of building in boundary layer flow

Figure 19 shows the variation of relative integrated speed up area $A^*_{B,\ 1.3\text{-}int}$ with the size (height and width) of buildings for wind direction *Θ*=0° and 45°. It can be noted that the relative area of high wind speed zones around buildings linearly increases with the size (height and width) of the building increasing. It may suggest that, for the buildings with the same aspect ratio, eliminating the width effects of building, the relationship between the high wind speed zones and height and width of building is a linear positive dependence.

Effect of the turbulence intensity in uniform turbulence flow



H=200m *B*=25m | *H*=300m *B*=37.5m | *H*=400m *B*=50m | *H*=500m*B*=62.5m | *H*=600m *B*=75m

Fig.20 Speed up ratio distribution around the square buildings with size （height and width） for wind direction *Θ*=0° in uniform turbulence flow （*H/B*= 8）

Speed up ratio distribution of square buildings with different size（height and width）in uniform turbulence flow for wind direction *Θ*=0°, is shown in **Fig. 20**. Compared with **Fig.16**, it can be noted that the speed up ratio distribution of the same building in different coming flow shows the significant difference. The maximum speed up ratio and high wind speed zones of the square building in the uniform flow are much smaller than those in the boundary layer flow.

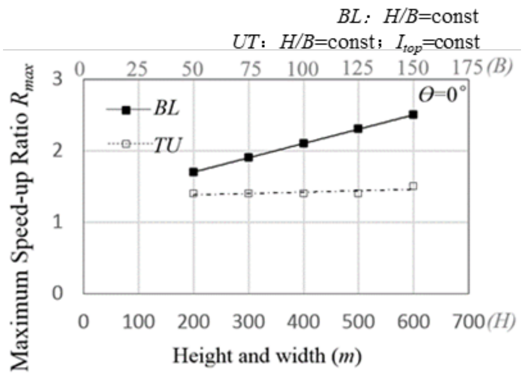


Fig.21 Variation of Maximum speed up ratio of square buildings with the size（height and width） for wind direction *Θ*=0° in boundary layer flow and uniform turbulence flow

The variation of maximum speed up ratio of square building with size （height and width）s in boundary layer flow and uniform turbulence flow for wind direction *Θ*=0° is presented in **Fig. 21**. The maximum speed up ratios of building in uniform flow are almost constant. Besides, as the height and width of the building increasing, the difference of maximum speed up ratio between two different types of coming flow becomes larger. For Model 1-5 （*H*=600m, *B*=75m）, the maximum speed up ratio is 2.6 in boundary layer flow and 1.5 in uniform turbulence flow.

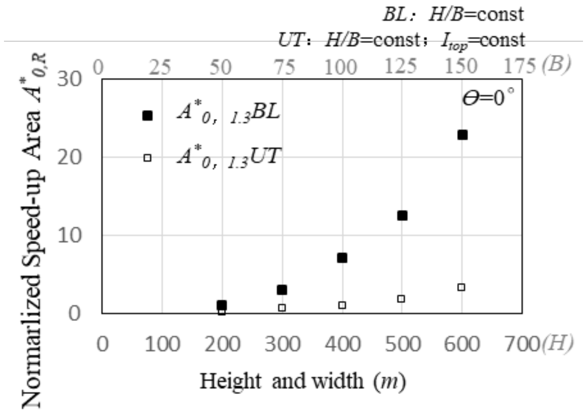


Fig.22(a) Variation of absolute normalized speed up area $A^*_{0,\ 1.3}$ with the size （height and width） of building for wind direction Θ=0° in boundary layer flow and uniform turbulence flow

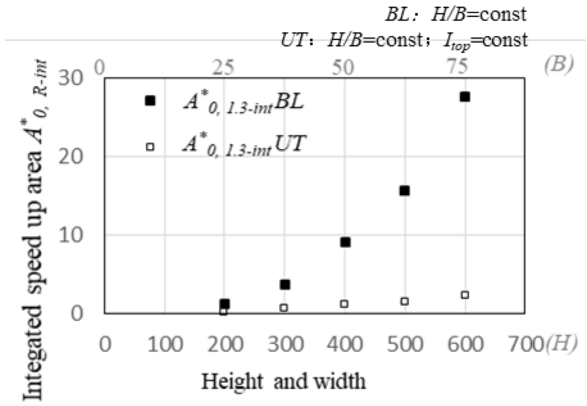


Fig.22(b) variations of absolute integrated speed up area $A^*_{0,\ 1.3\text{-}int}$ with the size （height and width） of building for wind direction Θ=0° in boundary layer flow and uniform turbulence flow

The variations of absolute normalized speed up area $A^*_{0,\ R}$ with the height and width of buildings for wind direction Θ=0° and the variations of absolute integrated speed up area $A^*_{0,\ 1.3\text{-}int}$, in boundary layer flow and uniform turbulence flow are shown in **Fig. 22**, respectively. The absolute normalized speed up area $A^*_{1.3,\ Br}$ and absolute integrated speed up area $A^*_{0,\ 1.3\text{-}int}$ show quartic distribution with the height of the building for wind direction Θ=0° in uniform flow. However, the increasing tendency is much smaller than that in boundary layer flow.

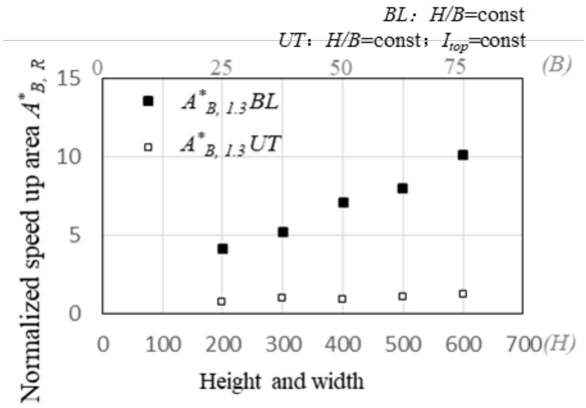


Fig.23(a) Variation of relative normalized speed up area $A^*_{B,\ 1.3}$ with the size （height and width） of building for wind direction Θ=0° in boundary layer flow and uniform turbulence flow

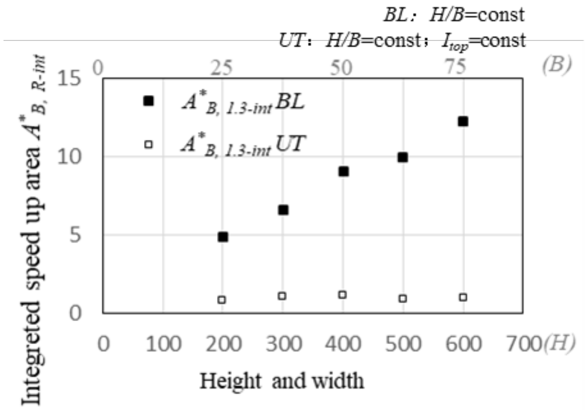


Fig.23(b) Variations of relative integrated speed up area $A^*_{B,\ 1.3\text{-}int}$ with the size （height and width） of building in boundary layer flow and uniform turbulence flow

The variation of relative normalized speed up area $A^*_{B,\ 1.3}$, and relative integrated speed up area $A^*_{B,\ 1.3\text{-}int}$, with the size（height and width） in boundary layer flow and uniform turbulence flow are shown in **Fig.23**. As can be seen from the figure, the relative normalized speed up area $A^*_{B,\ 1.3}$, and relative integrated speed up area $A^*_{B,\ 1.3\text{-}int}$, keeps constant in the uniform turbulent wind flow field for the buildings with the same aspect ratio. This suggests that, for the same condition of coming flow, the area and pattern of the high wind speed area around buildings with the same aspect ratio are same, which conforms to the law of similarity in wind tunnel experiment.

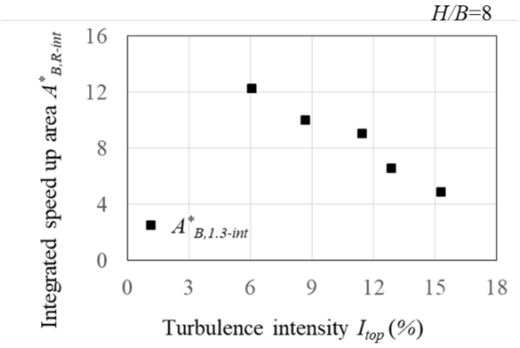


Fig.24(a) The variation of integrated speed up area $A^*_{B,R\text{-}int}$ with the aspect ratio of the building for Case III in boundary layer flow

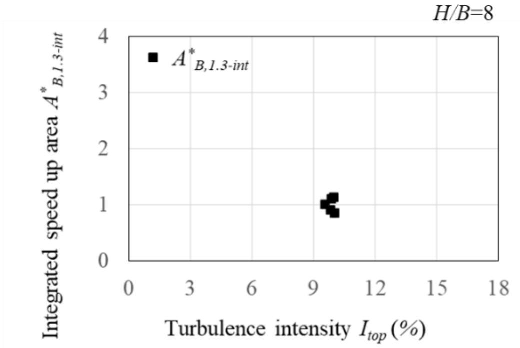


Fig.24(b) The variation of integrated speed up area $A^*_{B,R\text{-}int}$ with the turbulence intensity I_{top} at the top of the building for Case III in boundary layer flow

The variation of integrated speed up area $A^*_{B,R\text{-}int}$ with turbulence intensity at the top of the building for Case III model in boundary layer flow and in uniform turbulence flow are shown in **Fig. 24(a) and Fig. 24(b), respectively**. From **Fig. 24 (a)**, it can be seen that, similarly to **Fig. 15**, for the models with same aspect ratio in boundary layer flow, with the increases of the turbulence intensity at the top of the building, the integrated speed up area presents the linear decrease. For the models in uniform turbulence flow, the integrated speed up area almost keeps constant with the same turbulence intensity at the top of the building. This also suggests that the turbulence intensity at the top of the buildings is one of the govern parameter on pedestrian level wind.

3.3.7 Concluding Remarks

A series of wind-tunnel tests were carried out to investigate the characteristics of pedestrian-level winds around three Types models for studying on the effect of height, width, size, approaching flow. The following conclusions are derived from the present study.

-- For the buildings with the same width (B=50m) in boundary layer flow, the maximum speed-up ratio R_{max} seems to have the limitation, and increasing the height of the building will not effect on the maximum speed up ratio when the height of the buildings exceeds 350m(H/B=7). The absolute normalized speed up area $A^*_{0,R}$ and absolute integrated speed up area $A^*_{0,R\text{-}int}$ presents a geometric logarithm increase with the height, and presenting the convergent tendency. The effect of the variation of height on the pedestrian level wind for buildings with the relatively lower altitude is obvious, while it will become smaller and smaller with the constantly increasing of the height of the buildings. The variations of maximum speed up ratio, the normalized speed up area and the integrated speed up area reflect the effect of height, aspect ratio and turbulence intensity.

--For the buildings with the same width (*B*=50m) in uniform turbulence flow, the pure aspect ratio was been found. The down wash effect is not significant with the height of building increasing, the maximum speed up ratio R_{max} almost keep constant, the absolute normalized speed up area $A^*_{R,Br}$ and absolute integrated speed up area $A^*_{R,Br\text{-}int}$ present a little increasing tendency with the increasing height of the building.

-- For the buildings with same height (*H*=400m), the wider the building width, the larger the high wind speed zone will be created. As the width increasing, the maximum speed up ratio R_{max} increases obviously. The absolute normalized speed up area $A^*_{0,R}$ and absolute integrated speed up area $A^*_{0,R\text{-}int}$ increase quadratically with the width, the relative normalized speed up area $A^*_{B,R\text{-}int}$ and relative integrated speed up area $A^*_{B,R\text{-}int}$ increase with the width, and the tendency of the increase reduces gradually and appear a certain convergence properties.

-- For the square models with the same aspect ratio (*H/B*=8) in boundary layer flow, the maximum speed up ratio R_{max}, the normalized speed up area and integrated speed up area increase with the size of the building increasing. The absolute normalized speed up area $A^*_{0,R}$ and absolute integrated speed up area $A^*_{0,R\text{-}int}$ are changing with the size of the buildings in a quadratic fashion. And it is obvious that the larger the size of the building, the worse the pedestrian level wind environment. With the increasing of the size of the buildings, relative integrated speed up area $A^*_{R,}$

$_{Bco\text{-}int}$, become larger and the tendency of the increase reduces gradually and tends to convergence.

--For the square models with the same aspect ratio (H/B=8) in uniform turbulence flow, the maximum speed up ratio R_{max}, relative normalized speed up area $A^*_{R,Bco}$ and relative integrated speed up area $A^*_{R,Bco\text{-}int}$ almost keep constant which conforms to the law of similarity in wind tunnel experiment.

--The different coming flow for the same buildings will induce significantly different pedestrian level wind. The maximum speed up ratio and the normalized speed up area in the uniform flow are much smaller than those in the boundary layer flow.

- For the building with the same aspect ratios in boundary layer flow, the lower turbulence intensity at the top of the building will cause the larger high wind speed zone around the buildings.

4.Published Paper etc.

[Underline the representative researcher and collaborate researchers]

[Published papers]

[Presentations at academic societies]

[Published books]

[Other]

Intellectual property rights, Homepage etc.

5. Research Organization

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