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A Case Study on Optimization of Urban Design Base on Wind Environment Simulation

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Abstract: Wind environment simulation of a commercial district in Baise city of Guangxi Province, China, is carried out in the design phase. The results are analyzed and based on the evaluation standard for greening building of China. The simulation method is discussed in detail, and some suggestions for wind environment optimization are put forward, which might be helpful for similar research.

Key words: Wind environment, environment optimization, urban design.

1. Introduction

Architectural complex and high and large buildings will significantly change the near surface wind field structure of city. The condition of near-ground wind has a complex relation with the outline and dimension of building, relative location between buildings, and surrounding topographic features [1]. In the case of strong incoming flow, there will be strong wind in some areas near buildings; if strong wind happens at the entrance, passage, terrace of buildings or other places where there is always a large flow of people, then people probably will feel ill and even get hurt due to this, and bad wind environment problems are caused. In ordinary climatic conditions, wind speed directly affects the microclimate in city and the comfortableness of environment; in the case of strong wind, disaster tends to occur, so that glass curtain wall, casement and canopy of buildings are damaged, and the safety inside and outside the building is threatened [2]. If there is a large vortex zone or calm zone in wind field around a building, the urban heat island effect will deteriorate because automobile exhaust, and exhaust gas and waste heat produced by air conditioner external unit around the building are not dispersed. Therefore, evaluation on outdoor wind environment ought to be performed at the stage of building design, to analyze the influence of relative position of buildings on outdoor wind environment.

The Assessment Standard for Green Building (GB/T50378-2014) [3] provides the specific requirements for wind environment optimization, which can be taken as guideline for wind environment optimization, as below:

"Article 4.2.6: The wind environment in the field makes for the comfortableness of walking outside and outdoor activities, windbreak of buildings in winter, and natural ventilation in transition seasons and summer. The total score for evaluating wind environment is 6 points. Wind environment is to be evaluated and graded according to the following rules, and the points can be accumulated:

(1) For typical wind speed and direction in winter, the following rules should be followed to give point, which can be accumulated:

- The wind speed in pedestrian precincts around building is less than 5 m/s, and the outdoor wind speed amplification coefficient is less than 2.2 points;
- Except for the first row of buildings facing the wind, the surface leeway between the windward side and the leeside of buildings is not larger than 5 Pa, 1 point;

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(2) For typical wind speed and direction in transition seasons and summer, the following rules should be followed to give point, which can be accumulated:

• There is no vortex or calm zone in pedestrian precincts inside the field, 2 points;

• The surface leeway between inside and outside of more than 50% openable windows is larger than 0.5 Pa, 1 point."

For purpose of this paper, a large commercial complex project in Baise in Guangxi was taken as an example to discuss the ideas of wind environment optimization developed under the guidance of the Assessment Standard for Green Building (GB/T50378-2014) [3], with a view to providing reference to similar projects.

2. Technical Roadmap

This paper is mainly written to simulate and analyze the wind environment conditions around a commercial complex project in Baise, and put forward suggestions on design amendment in combination with the Assessment Standard for Green Building (GB/T50378-2014) [3].

2.1 Analysis Method

Presently, the main methods of evaluating building outdoor wind environment include wind tunnel test, network method and numerical computation method. Wind tunnel test is mainly applied in building outdoor wind environment and wind engineering, and carried out in atmospheric boundary layer wind tunnel with reduced scale model of actual buildings by producing similar wind field around actual buildings by necessary means, and measuring wind speed and wind pressure and other data with test apparatuses installed on the surface and around the model [4].

The existing researches have covered distribution of wind pressure and wind speed around buildings in places with different topographic features and around high-rise buildings of different shapes, and mutual interference and effect between different height ratios and changes of relative location. However, wind tunnel test also has its disadvantages. It is time- and energy-consuming to make a model; the test cycle is long, and it is difficult to simultaneously research different construction design schemes. A reduced scale model cannot always reflect all characteristics of full-sized structures, and there are some problems in monitoring point arrange and simultaneous pressure measurement, etc., still not solved.

Network method is a method of analyzing natural ventilation from a macro perspective, and is mainly used for air quantity prediction at early design phase of naturally ventilated buildings. It is to calculate wind pressure and natural ventilation rate under heat pressure with mass equation, energy conservation equation, etc. No consideration, however, is given to the influence of air flow behavior inside rooms on natural ventilation effect in network method; it is unable to make detailed analysis of air flow inside the rooms with this method.

In recent years, with the rapid development of computer technology, numerical computation has become a mainstream evaluation method. Numerical simulation research of ventilation process is mainly conducted with nodal analysis, mathematical model method, and CFD (computational fluid dynamics) method [5]. Thanks to its advantages of high speed, simpleness, convenience, accuracy, effectiveness, and low cost, CFD method has been used more and more widely for analyzing engineering problems, and gradually becomes an effective means for handling engineering problems, which is widely recognized. CFD simulation refers to solving the flow field model of a certain area or room from a micro perspective with basic mass equation, energy and momentum conservation equations, etc., to analyze the air flow. Regarding natural ventilation simulation, CFD method is mainly adopted for wind field layout optimization for natural ventilation and indoor flow field analysis, and simulating flow field in tall and big space [6]. Detailed visual information provided via CFD can help designer to adjust the strategy of ventilation for specific room or area, to achieve more effective natural ventilation [7].

To achieve the purpose of this project, CFD method was adopted to conduct simulation analysis on the microenvironment of a commercial complex project in Baise, to evaluate the distribution of outdoor flow field. FLUENT series software can be adopted to simulate complex flow ranging from the incompressible to the highly compressible [8]. Since multiple calculation methods and multigrid accelerating convergence technology were adopted, FLUENT can achieve the best convergence rate and solving accuracy. Thanks to its flexible unstructured grid, solution-based adaptive mesh model and mature physical model [9], FLUENT is widely used in transition and turbulence, heat transfer and phase change, chemical reaction and combustion, multiphase flow, rotating machinery, dynamic/deforming mesh, noise, material processing, fuel cell, etc.

In this paper, an outdoor wind environment simulation model of Dingsheng Central City project in Baise was built based on the surroundings of buildings and other related materials. The model covers Baise Dingsheng Central City and the buildings likely to affect the wind environment there around. The height of buildings around the project was set according to the general drawing. The dimension of the external field of the model was mainly determined in such a way that architectural complex boundary air flow is not affected. Through simulation trial based on related engineering experience, the calculation size of the external field was determined to be 1800 m × 1400 m × 450 m (L (length) × W (width) × H (height)). The model and mesh are shown in Figs. 1 and 2, respectively.

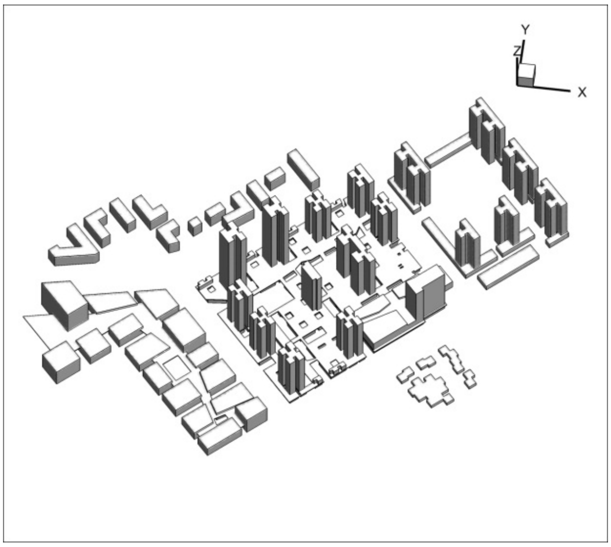

Fig. 1 Model diagram of a commercial complex in Baise.

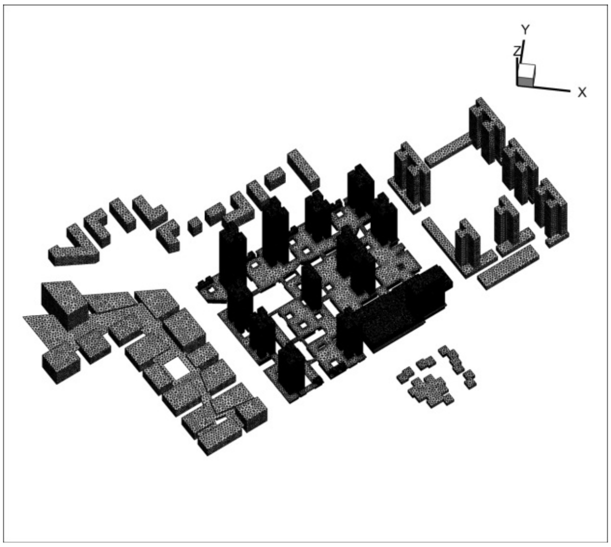

Fig. 2 Mesh diagram of a commercial complex in Baise.

2.2 Parameter Setting

2.2.1 Incoming Flow Boundary Conditions

The wind speed in building incoming flow direction equally distributed, and the incoming flow wind speed at levels of different heights progressively increases in a gradient way along the building height direction. According to atmospheric boundary layer theory, the wind velocity gradient varies from landform to landform, as shown in Fig. 3.

Thus, wind speed differs at different heights. The computational formula about height and wind speed is as below:

$$V_h = V_0(h/h_0)n$$

where:

V_h—wind speed at the height of h, m/s;

V_0—wind speed at the reference height of h_0 (generally 10 m), m/s;

n—index. For urban area, n = 0.2~0.5; for open area or coastal area, n is about 0.14. Since Baise Dingsheng

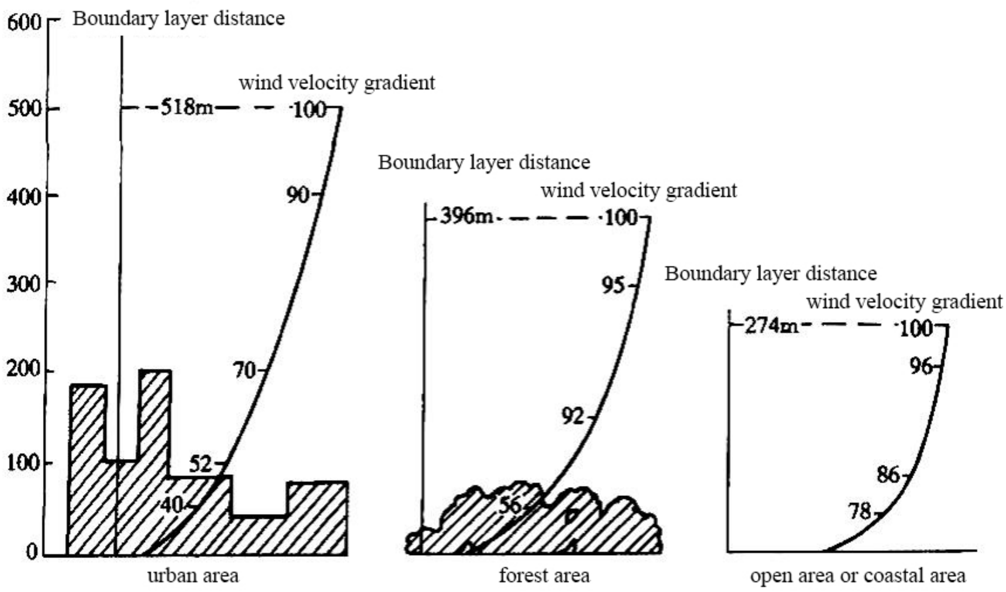

Fig. 3 Atmospheric boundary layer curve chart of different landforms.

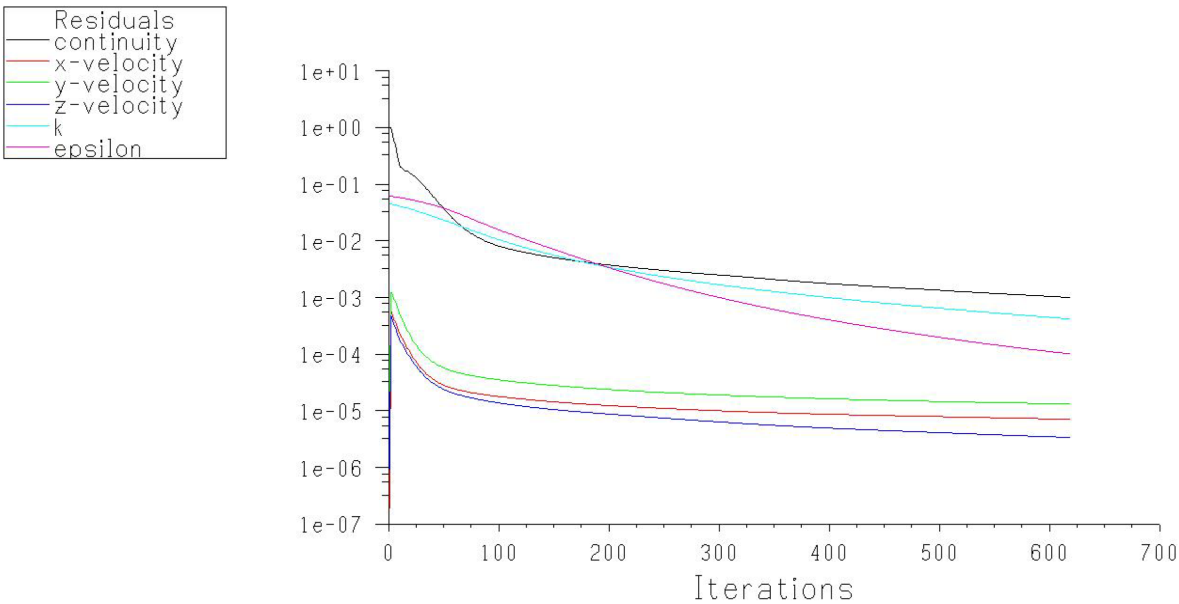

Fig. 4 Convergence curve of CFD computation.

Central City project is located at downtown area of Wuhan, the value of n is set to be 0.25 for simulation computation.

2.2.2 Outflow Boundary Conditions

Air flow on building outflow surface is considered according to fully developed turbulent flow, and the boundary conditions are set according to free exit.

2.2.3 Convergence Judgment

For the termination criteria of CFD numerical simulation algebraic equation, a residual error below 1.0E-4 of continuity equation and energy equation is taken. The convergence curve and the values of observation points are shown in Fig. 4.

2.3 Simulated Condition

Baise is in subtropical monsoon climate zone. According to the Special Meteorological Data Set for Analysis of Thermal Environment of Building in China

[10] and related meteorological data provided by China Meteorological Data Service System, the outdoor meteorological parameter statistics is as below:

The table above shows that the prevailing wind directions in summer, winter and even in the whole year all are SE (southeast), and only wind speed slightly differs in different season. Therefore, for wind environment simulation, two kinds of conditions are enough, namely summer condition and winter condition. As to primary wind direction in a year, if summer wind meets the requirements, then the condition in the whole year also meets the requirements undoubtedly. Simulated conditions are shown in Table 2.

In Condition 1, it is mainly to, under the condition of average wind speed in the prevailing wind direction in summer, analyze leeway front and behind building and wind environment around building, and determine the natural ventilation conditions, and whether vortex or calm zone will form around to affect the surrounding air quality. In Condition 2, it is mainly to, under the condition of average wind speed in the prevailing wind direction in winter, analyze flow filed and wind speed around build, and determine whether zone of excessively high wind speed will form or not.

3. Simulated Result Analysis

3.1 Simulated Result and Optimized Analysis of Condition 1

Condition 1 refers to summer condition, when the wind direction is SE (south by east 45°), and the wind speed is 1.8 m/s.

3.1.1 Cloud Altas of Wind Speed 1.5 m up Away from the Ground and Optimization Ideas

Fig. 5 shows cloud altas of wind speed 1.5m up away from the ground around a commercial complex in Baise under the condition of average wind speed in the prevailing wind direction in summer of SE. As shown in the figure, the wind environment in major street is good, the run of streets and region division are rational. In some areas, the wind environment is bad, which are boxed in red. Since both the prevailing wind direction in summer and the primary wind direction in a year are southeast wind (SE), it is supposed to reduce the density on the windward side in southeast, the width of effective windward side, and backwind shadow in area shape building. The blocks at the top right corner of Number 1 area in the figure can be properly adjusted, and lined up. Wide open space should be reserved on the south, which can be used as group activity space at the top left corner. Opening can be set in the southeast direction to reduce the density of windward side. The opening directions on the right side of the two blocks at the bottom can be properly changed to rightwards. For Numbers 2, 4 and 5 areas, proper air opening can be properly reserved on the southeast side. For Number 3 area, the opening direction can be properly changed, and proper air opening can be reserved on the linking part in the middle.

3.1.2 Cloud Altas of Wind Speed 5.7 m up Away from the Ground and Optimization Ideas

Fig. 6 shows cloud altas of wind speed 5.7 m up

Table 1 Outdoor meteorological parameter for design use.

Season	Wind direction	Wind speed (m/s)
Prevailing wind direction in summer	SE	1.8
Prevailing wind direction in winter	SE	2.1
Primary wind direction in a year	SE	1.9

Table 2 Simulated condition.

Condition	Season	Wind direction	Wind speed (m/s)
Condition 1	Prevailing wind direction in summer	SE	1.8
Condition 2	Prevailing wind direction in winter	SE	2.1

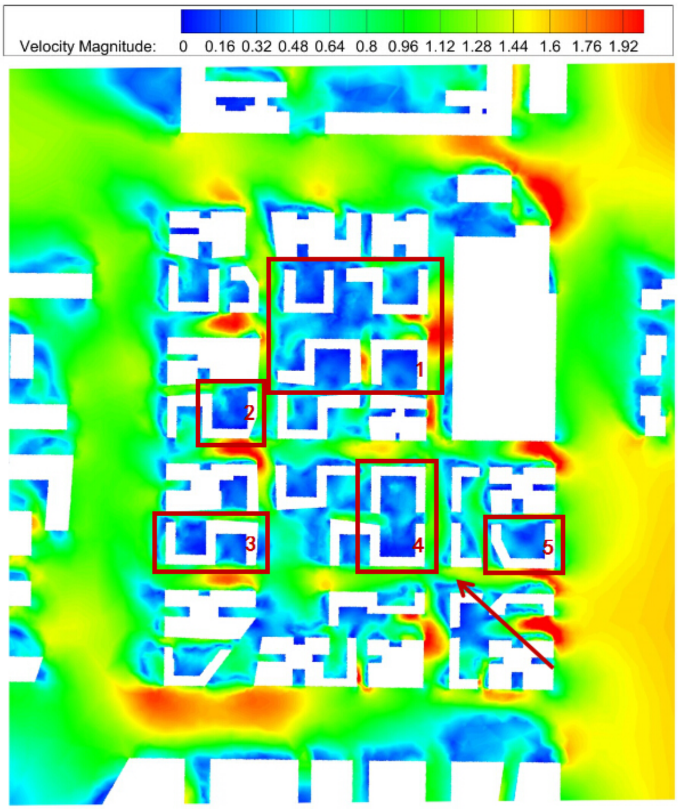

Fig. 5 Cloud altas of wind speed in prevailing wind direction in summer 1.5 m up away from the ground.

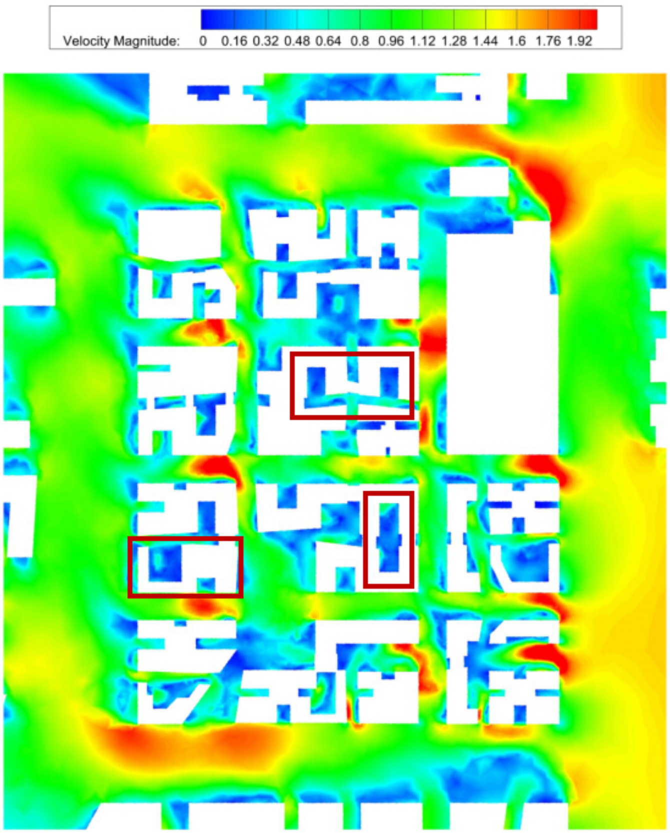

Fig. 6 Cloud altas of wind speed in prevailing wind direction in summer 5.7 m up away from the ground.

away from the ground around a commercial complex in Baise under the condition of average wind speed in the prevailing wind direction in summer of SE. As shown in the figure, the wind environment on the second floor as a whole, with few weak wind zone. The three areas where the wind environment is relatively bad are significantly affected by the first floor. Thus, the wind environment on the second floor can be improved by adjusting blocks on the first floor.

3.1.3 Cloud Altas of Wind Speed 12m up Away from the Ground and Optimization Ideas

Fig. 7 shows cloud altas of wind speed 12 m up away from the ground around a commercial complex in Baise in the prevailing wind direction in summer of SE. The high-rise area is hardly covered, the overall wind environment is good, and it is unnecessary to consider shape optimization. Fig. 8 shows longitudinal section cloud altas of wind speed around a commercial complex in Baise in the prevailing wind direction in summer of SE. Obviously, the longitudinal section shows that the optimization of wind environment should focus on skirt building, the plate-type high-rise buildings based on skirt building are largely spaced, and in certain angle with the incoming flow wind direction, and the wind shadow and vortex zone are small.

3.1.4 Wind Pressure Statistics on Windward Side and Leeside and Indoor Air Ventilation Potential Judgment

From the aspect of building energy consumption, generally, natural ventilation is rationally utilized to achieve two goals: to improve natural ventilation for cooling and dehumidification, and to shield from wind to reduce heat loss. As far as a certain building or architectural complex is concerned, emphasis may be laid on improving natural ventilation or windbreak, or different goals are to be realized at different stages. In most areas in China, two goals are mainly to be achieved: to enhance natural ventilation in summer, mild season and transition seasons, and to take rational measures for windbreak. According to Figs. 9 and 10, the leeway between windward side and leeside of plate-type high-rise buildings in the upper is larger than 1.5 Pa, there is a large ventilation potential; yet at the skirt building at the bottom, the windward side is mostly covered. The shape of skirt building part should be re-organized.

3.2 Simulated Result and Optimized Analysis of Condition 2

Condition 2 refers to winter condition, when the wind direction is SE (south by east 45°), and the wind speed is 2.1 m/s. According to the Assessment Standard for Green Building (GB/T50378-2014) [3], winter condition is mainly subject to evaluation of wind field and leeway around buildings.

According to the Assessment Standard for Green Building (GB/T50378-2014) [3], under the condition of typical wind speed and wind direction in winter, the wind speed in pedestrian precincts around buildings, outdoor wind speed amplification coefficient and leeway should be considered. Wind speed amplification coefficient refers to the ratio of the maximum wind speed 1.5 m up away from the ground around buildings to the wind speed at the same height in open ground. At the design phase of the project, it can be seen that the maximum wind speed 1.5 m up away from the ground around buildings is 2.1 m/s (Fig. 11), and the wind speed amplification coefficient is 1.05, meeting the design requirements; the average value of leeway is about 3.1 Pa (Fig. 12), meeting the provisions of the Assessment Standard for Green Building (GB/T50378-2014) [3].

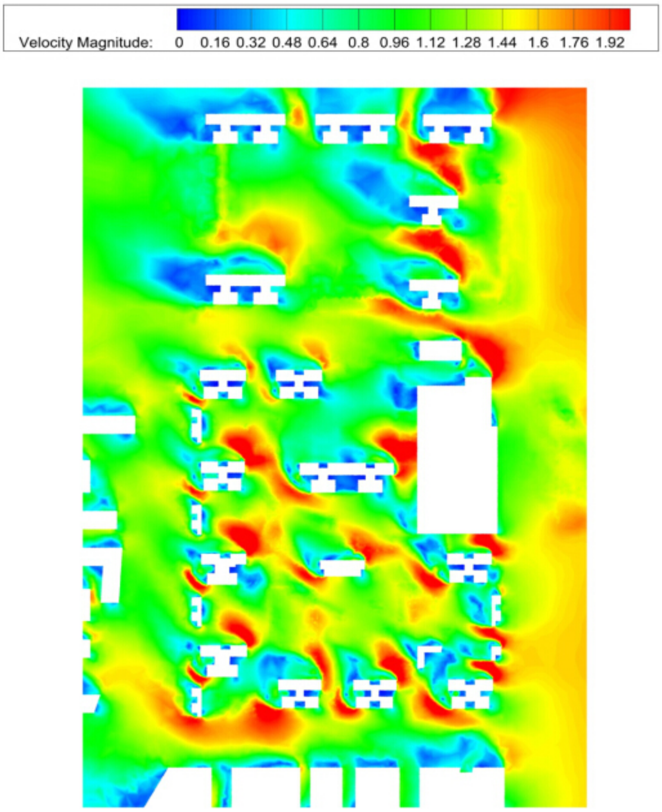

Fig. 7 Cloud altas of wind speed in prevailing wind direction in summer 12 m up away from the ground.

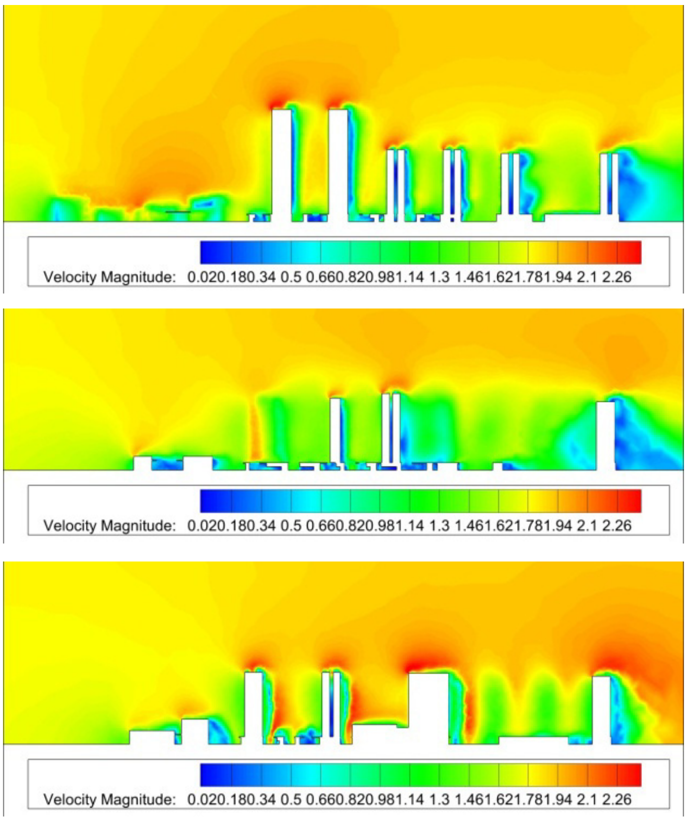

Fig. 8 Longitudinal section cloud altas of wind speed in prevailing wind direction in summer.

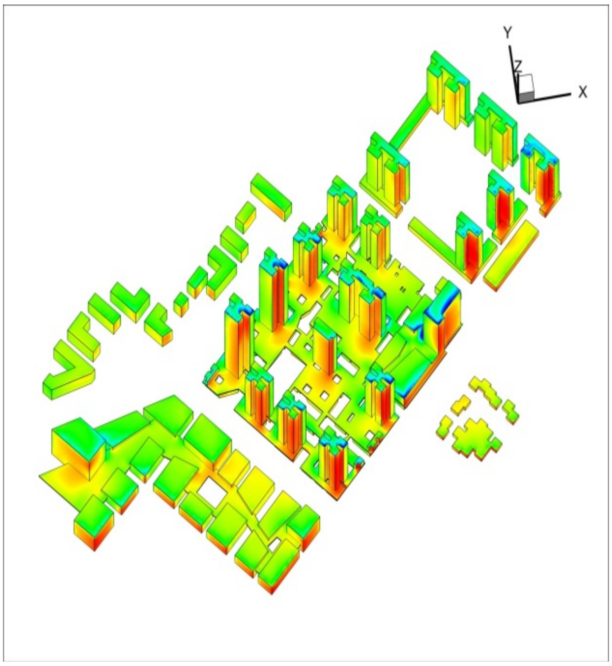

Fig. 9 Wind pressure diagram on windward side in the prevailing wind direction in summer.

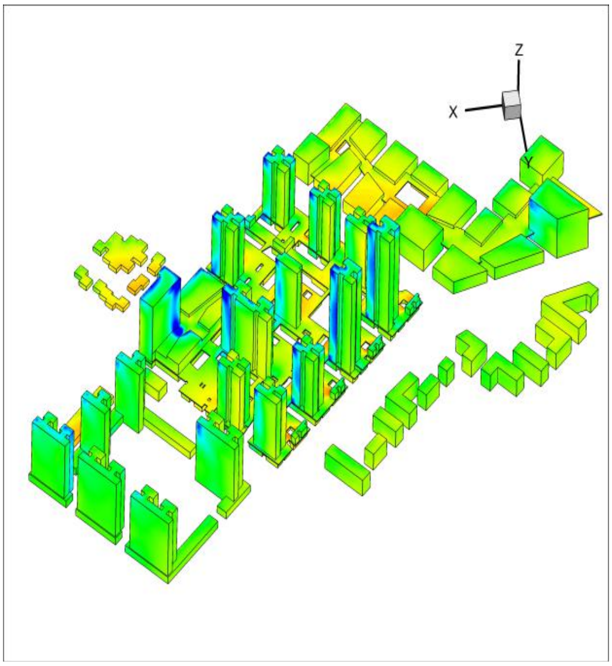

Fig. 10 Wind pressure diagram on leeside in the prevailing wind direction in summer.

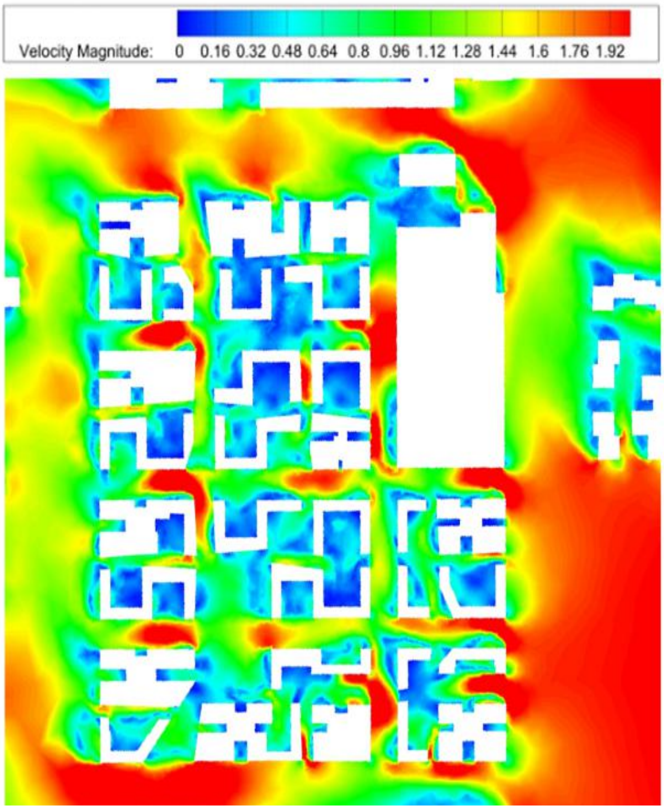

Fig. 11 Cloud altas of wind speed in prevailing wind direction in winter 1.5 m up away from the ground.

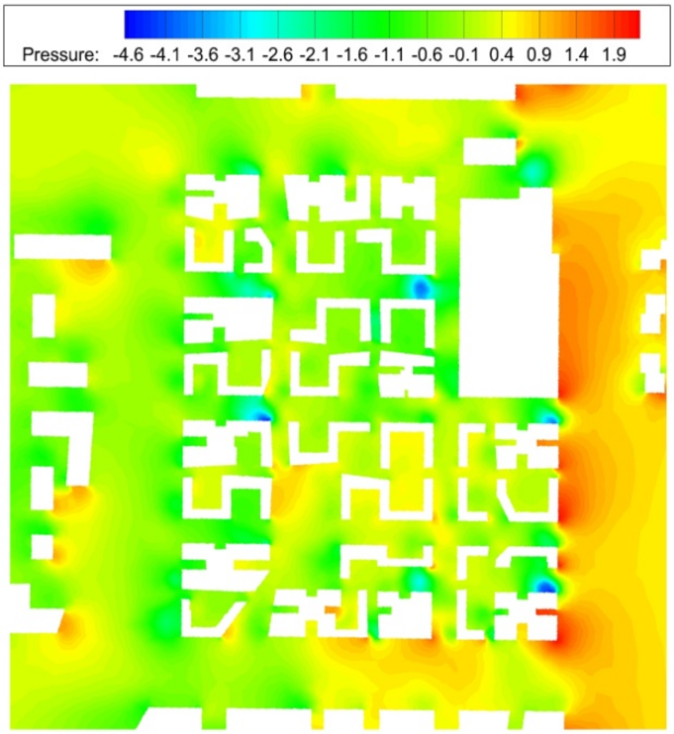

Fig. 12 Cloud altas of wind pressure in prevailing wind direction in winter 1.5 m up away from the ground.

4. Conclusions

Based on the simulation of the two conditions above, summarization and conclusion can be drawn as below:

- First, CFD can be adopted for simulation, optimization and prediction of wind environment around buildings. Besides, FLUENT was taken as an example to introduce the methods of setting boundary conditions of numerical simulation software;
- Second, the method of judging wind environment simulation provided in the Assessment Standard for Green Building (GB/T50378-2014) [3] has been analyzed in detail with example of actual project;
- Last, from the perspective of wind environment optimization at design phase, in most areas in China, basically two goals are to be realized: to enhance natural ventilation in summer, mild season and transition seasons, and to take proper measures for windbreak in winter. In the case in this paper, the possibility of optimizing summer wind at design stage was discussed, namely optimizing building density and building coverage on windward side to reduce wind shadow zone, and improve environment quality.

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