Optimization of wind environment of cognitive space based on Space Syntax and Numerical Simulation — Case study of Jiangnan residential area

[1]Huagui Guo and *Qingming Zhan

Abstract

Few scholars focus on the simulation and optimization of wind environment of residential cognitive space. To meet the ventilation demand of outdoor activities better, optimization method of wind environment of cognitive space based on Space Syntax and Numerical Simulation was proposed. Firstly, cognitive space area was located through syntactic variables analysis, and outdoor wind environment was simulated through numerical simulation technology. Thus the wind environment of cognitive space of planning scheme was simulated. And the simulated result showed that there existed 23% wind environment area of cognitive space needed to be improved. Secondly, measures of optimizing building distribution and others were attempted to optimize the wind environment. Meanwhile, the specific optimization scheme was proposed. Finally, the wind environment of cognitive space of optimization scheme was simulated. And the simulated result shows that the wind environment area of cognitive space needed to be optimized decreased from 23% to 5%. Thus the optimization measures and scheme optimized the wind environment of cognitive space.

Huagui Guo • Qingming Zhan (Corresponding author)
School of Urban Design, Wuhan University, Wuhan 430072, China
Email: 844172866@qq.com

Qingming Zhan
Email: qmzhan@whu.edu.cn

1. Introduction

The quantitative simulation and optimization of residential wind environment based upon Numerical Simulation lead to various studies. In the level of parameter setting and accuracy of wind environment simulation, Yoshie et al. (2005) and Tominaga et al. (2008) improved the parameter setting of wind environment simulation based on wind tunnel experiment and field measurement and thus offered the mature guideline of parameter setting. Based on the mature guideline of parameter setting, Ma (2007) and Zhao (2008) summarized that the result of wind environment simulation was basically consistent with the actual residential wind environment, through comparing the coherence between the numerical simulation result and the field measurement result. In the level of wind environment simulation and analysis, Zhao et al. (2002), Wang et al. (2006) and Ma et al. (2007) simulated and analyzed the wind environment of building cluster based on numerical simulation technology. Thus the conclusion could be proposed that numerical simulation technology could be used as a powerful tool for the wind environment simulation and analysis of building cluster. And such technology had a great guiding significance on the wind environment optimization for building cluster. Tang et al. (2001) and Blocken et al. (2004) pointed out that the relationship of wind speed at pedestrian height and comfort degree indicated that when the wind speed of one area was higher than 5 m/s or lower than 1 m/s, the wind environment of such area was uncomfortable. In contrast, when the wind speed of one area ranged from 1 m/s to 5 m/s, the wind environment of such area was comfortable. In the level of wind environment simulation, analysis and optimization, Edward (2009) and Edward et al. (2011) proposed the design guideline for the optimization of wind environment of building cluster. For example, the natural wind would flow into the building cluster by appropriately partitioning the skirt building to add the ventilation vent. For another example, the flow of natural wind in the building cluster would be enhanced by gradually increasing the building height along the prevailing wind direction in summer. Tang et al. (2001) analyzed the outdoor wind environment in the case study of Guangzhou residential area based on numerical simulation technology. Thus the conclusions could be proposed that the outdoor wind environment at pedestrian height would be evidently optimized through the measure of overhead building bottom. Meanwhile, the fire road could be considered as ventilation vent and could optimize the outdoor wind environment of calm zone behind the high-rise building. Du et al. (2008) simulated and analyzed the outdoor wind environment in the case study of

Tianjin residential area based on numerical simulation technology. Thus the optimization measures for outdoor wind environment could be proposed such as adding green and vegetation, building layout paralleling with the prevailing wind direction and so on. Blocken et al. (2004), Hu et al. (2007) and Jiang et al. (2008) pointed out that the building layouts of staggered type, inclined type, height combination type and length combination type could evidently improve the ventilation in summer. And the lower building should located behind high building in the south. The simulation and optimization of residential wind environment based upon numerical simulation technology lead to various studies. And scholars focused on simulating and optimizing the whole outdoor wind environment of residential area. However, the outdoor space having better accessibility, having more frequent social activities and further closing to the demand for resident outdoor activities was the cognitive space. Therefore, before the wind environment analysis and optimization, locating the cognitive space area first would be better to meet the ventilation demand for resident outdoor activities.

Space Syntax investigates relationship between spatial organization and human society. And syntactic variables of integration and others could contribute to the quantitative analysis of residential spatial organization (Hillier, 1997; Bafna, 2003). Thus a number of scholars made contributions to researching spatial organization based on Space Syntax. Hillier et al. (1993) pointed out that the higher integration was, the more frequent human social activities inside the city and the higher space utilization frequency would be. Li et al. (2004) pointed out that integration was a direct variable for analyzing spatial organization and the higher integration one area was, the higher accessibility the area would be in the case study of Wuhan City. Zhang et al. (2004) pointed out that the higher integration one area was, the higher pedestrian flow and traffic flow the area would be.

Space syntax theory is beneficial to locate the cognitive space area with high accessibility and frequent use, while numerical simulation technology is beneficial to simulate and optimize the outdoor wind environment for planning scheme. Therefore, combining space syntax theory and numerical simulation technology can be used to optimize the wind environment of residential cognitive space and then meet the ventilation demand of outdoor activity better. Firstly, in the case study of Jiangnan residential area planning, the wind environment of cognitive space of planning scheme was simulated based on space syntax theory and numerical simulation technology. Secondly, measures of overhead building bottom, optimizing building distribution and adding ventilation vent were attempted to optimize the wind environment of cognitive space of planning scheme. Meanwhile, the specific optimization scheme was proposed. Finally, the wind environment of cognitive space of optimization scheme was quantitatively simulated, so that the wind environment of residential cognitive space could be optimized and then meet the ventilation demand for outdoor activity better.

2. Methodology

2.1 Technical Roadmap

The optimization method of wind environment of cognitive space contained three parts, the wind environment simulation of cognitive space of planning scheme, the wind environment optimization of cognitive space of planning scheme and the wind environment simulation and verification of cognitive space of optimization scheme. And the specific technical flowchart could be shown in Fig.1.

Firstly, based on the figure of residential layout, syntactic variable was analyzed to identify the cognitive space area and then the area of cognitive space was obtained. Meanwhile, the residential three-dimensional model was constructed to simulate the whole outdoor wind environment and then the figure of whole outdoor wind environment was produced. Thus the wind environment of cognitive space of planning scheme was simulated and analyzed, through the overlay of the cognitive space area and the figure of outdoor wind environment simulation.

Secondly, the problems and reasons of wind environment of cognitive space were analyzed. And then the measures of overhead building bottom, adding green and vegetation, optimizing building distribution, adding ventilation vent and choosing the pattern of building stagger layout were attempted to optimize the wind environment of cognitive space of planning scheme. Meanwhile, the specific optimization scheme was proposed.

Finally, the wind environment of cognitive space of optimization scheme was quantitatively simulated and analyzed to verify the optimization of wind environment of cognitive space.

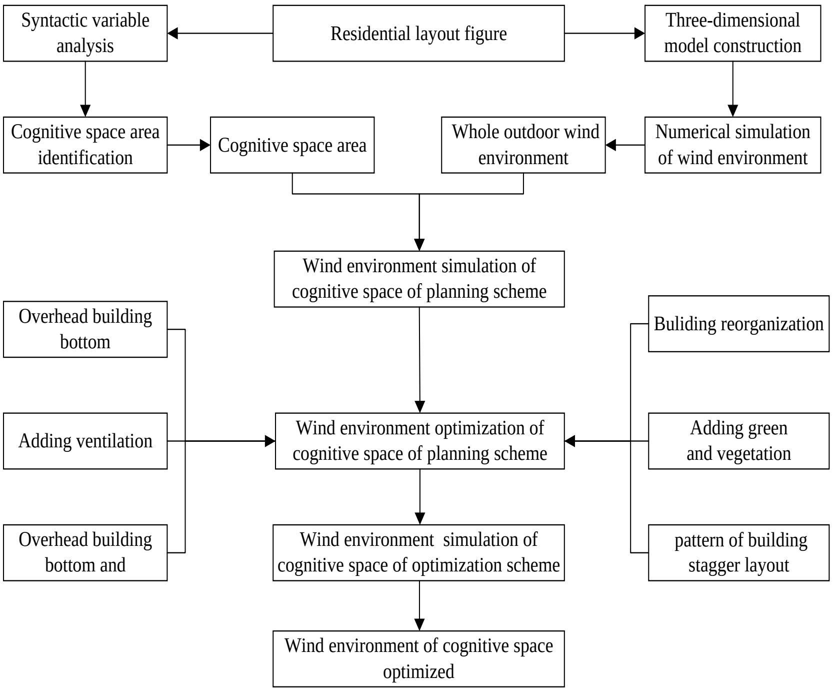

Fig. 1 Technical flowchart

2.2 Study Area

Jiangnan residential area is located at Jinshan new district of Fuzhou City in China. And the study area covering 11.59 hectare planned 64 high-rise buildings and the skirt building in the north and east of residential area to meet the demand for commercial development (see Fig.2). The ventilation of study area was evidently affected by the monsoon and the sea-land breeze. Thus the wind environment in summer reflected that the prevailing wind direction contained the southeast, the north by east and the south by west. And the most frequent wind direction was southeast, covering 4.69m/s wind speed. Therefore, the summer wind environment covering 4.69m/s wind speed in the southeast direction would be analyzed and optimized in this study.

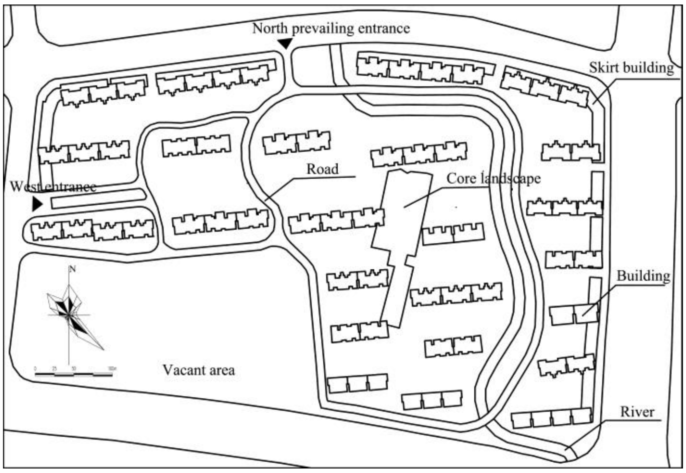

Fig. 2 Jiangnan residential Plan

2.3 Data Preparation

Data for this study contained the map and other planning data provided by the Planning and Design Institute of Fuzhou City. And the data needed to be prepared contained three parts, the analysis data of cognitive space, the numerical simulation data of wind environment and the analysis data of wind environment of cognitive space. Thus the data preparation has been made as follows:

- The figure of residential layout would be produced by collating the original map data in the CAD Software. And the syntactic variable of integration would be analyzed by transforming CAD document into DXF file and then importing such document into Depthmap10.0 Software. Then the integration analysis result in MIF format could be produced. Thus the figure of cognitive space analysis would be produced by importing the integration analysis result into Arcgis10.0 for the interpolation visualization of integration value.
- The residential three-dimensional model in STL format was constructed based on the figure of residential layout. Then the model would be imported into Phoenics2009 Software and the parameter setting of wind field would be done. Thus the figure of numerical simulation of wind environment would be produced by operating the wind field to simulate the wind environment.
- The area of cognitive space would be obtained by dividing the result of cognitive space analysis into several grades. Thus the figure of wind

environment of cognitive space would be produced through overlaying the cognitive space area and the figure of wind environment simulation.

3. Results

3.1 Wind environment simulation of cognitive space of planning scheme

The wind speed and wind direction simulation figures of outdoor space would be obtained based on the PHOENICS2009 Software. Based on the respective overlay of cognitive space area and the two simulation figures, the wind speed and wind direction simulation figures of cognitive space would be obtained (see Fig.3 and Fig.4). In the two figures, areas of red solid line were the wind environment of residential cognitive space, and areas of purple dotted line were the areas needed to be optimized. Interpreting Fig.3 and Fig.4, the following results could be drawn：

- The average wind speed of cognitive space ranged from 3.20 m/s to 3.70 m/s. And there existed 23% wind environment area of cognitive space (see purple dotted line in the Fig.3 and Fig.4) needed to be improved.
- In the wind environment area of cognitive space needed to be improved, A, B and C were located at the area with excessive high wind speed (velocity > 5 m/s) and near to the prevailing entrance of residential north; D, E, F, G, H and I were located at the area with excessive low wind speed (velocity < 1 m/s); D and E were near to the entrance of residential west; F was located at the area of residential core landscape.

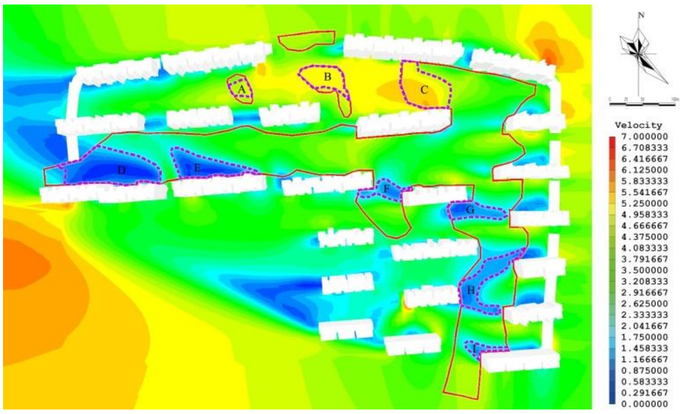

Fig. 3 Wind speed simulation of cognitive space of planning scheme

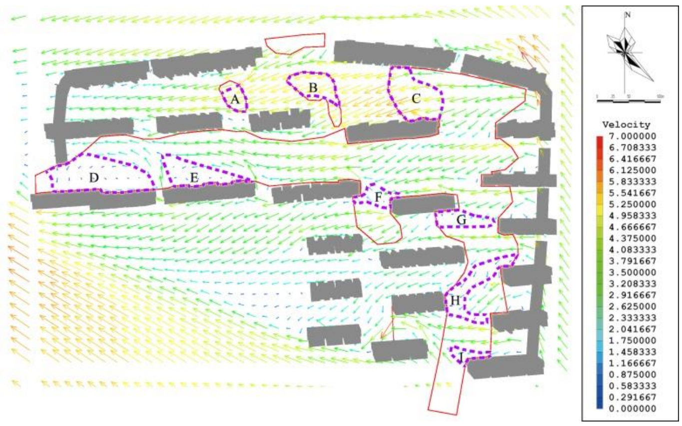

Fig. 4 Wind direction simulation of cognitive space of planning scheme

3.2 Wind environment analysis of cognitive space of optimization scheme

The wind speed and wind direction simulation figures of cognitive space would be interpreted to understand the law of airflow organization. Based on the understanding, the wind environment of cognitive space need to be improved would be optimized through the measures of overhead building bottom, adding green and vegetation, optimizing building distribution and others. Thus the specific optimization scheme of residential layout was proposed through several experiments (see Fig.5). Based on the optimization scheme of residential layout, the wind speed simulation figure of cognitive space of optimization scheme would be obtained through the wind environment simulation and cognitive space analysis (see Fig.6). And in the Fig.6, areas of red solid line were the wind environment of residential cognitive space, and areas of purple dotted line were the areas needed to be optimized. Interpreting Fig.6, the experiment results showed that the average wind speed of cognitive space ranged from 3.60 m/s to 4.30 m/s; there existed 5% wind environment area of cognitive space (see purple dotted line in the Fig.6) needed to be improved.

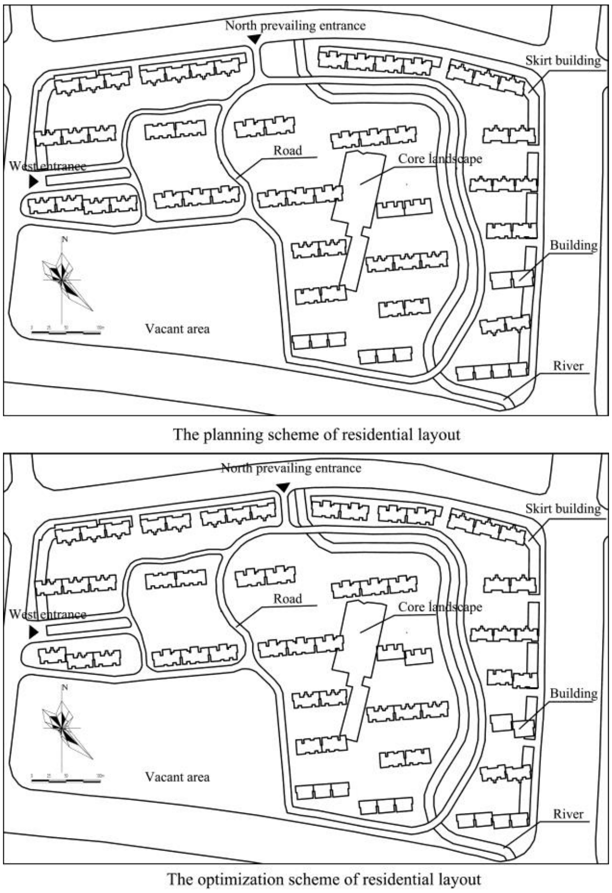

Fig. 5 The planning and optimization schemes of residential layout

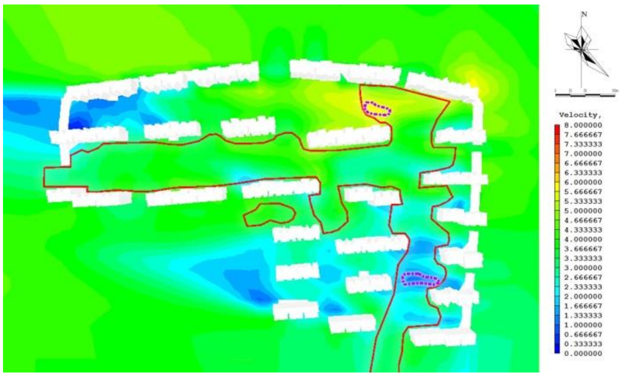

Fig.6 Wind speed simulation of cognitive space of optimization scheme

3.3 Wind environment comparison of schemes

Comparison results of wind environment simulation of planning and optimization schemes were in Table 1 and Table 2.

Table 1. Wind environment comparison of cognitive space

	Average wind speed	Cognitive space area	Uncomfortable area	Uncomfortable Proportion
Planning	3.20-3.70 m/s	47143.10 m^2	10842.91 m^2	23%
Optimization	3.60-4.30 m/s	45699.10 m^2	2284.95 m^2	5%

Table 2. The specific optimization area comparison

Site	Average wind speed		Comfort degree		Uncomfortable proportion	
	Planning	Optimization	Planning	Optimization	Planning	Optimization
A	5.25 m/s	3.88 m/s	Uncomfortable	More comfortable	99.6%	0.2%
B	5.51 m/s	4.32 m/s	Uncomfortable	More comfortable	94.5%	0.0%
C	6.05 m/s	4.89 m/s	More uncomfortable	Comfortable	98.0%	4.8%
D	0.48 m/s	4.21 m/s	More uncomfortable	More comfortable	99.3%	0.1%
E	0.53 m/s	4.23 m/s	More uncomfortable	More comfortable	98.7%	0.0%
F	0.78 m/s	3.33 m/s	Uncomfortable	More comfortable	96.2%	0.1%
G	0.76 m/s	2.33 m/s	Uncomfortable	More comfortable	100.0%	0.0%
H	0.81 m/s	2.02 m/s	Uncomfortable	Comfortable	92.1%	2.8%
I	0.84 m/s	1.99 m/s	Uncomfortable	More comfortable	95.9%	0.0%

4. Discussions

As stated in the introduction, this study was undertaken to simulate and optimize the wind environment of cognitive space in the planning stage. And the optimization method contained three parts, the wind environment simulation of cognitive space of planning scheme, the wind environment optimization of cognitive space of planning scheme and the wind environment simulation of cognitive space of optimization scheme. Based on the method, the analysis result of wind environment of planning scheme showed that there existed 23% wind environment area of cognitive space needed to be improved. And analyzing the wind environment problems for planning scheme had significant effect on the wind environment optimization. Therefore, the wind environment effect and problems of part areas needed to be improved would be discussed based on the wind speed and wind direction simulation results in this study.

4.1 A, B and C areas with excessive high velocity

A, B and C areas were near to the prevailing entrance of residential north. Thus the abundant pedestrian and traffic flow would be attracted. Then the daily activities of residents such as trip would be largely affected, because of the three areas with excessive high velocity. And the reason for excessive high velocity of these areas could be drawn:

- The prevailing entrance of residential north was too wide to form the large air inlet. Thus the abundant airflow would be attracted to flow into the three areas and then the wind speed of the three areas would be excessively high.
- The townhouse in the north of A and C areas formed the excessive large area of wind-break wall. Thus the southeast wind would rarely flowed into the three areas and then the calm zone with high velocity would be formed in the three areas.

4.2 D and E areas with excessive low velocity

D and E areas were near to the residential west entrance. And west entrance was the starting point of residential landscape axis in east-west direction. Thus the abundant traffic activities would not only be attracted, but also the outdoor recreational activities such as sightseeing would also be attracted. Then the traffic and recreational activities would be largely affected, because of the D and E areas with excessive low velocity. And the reasons for excessive low velocity of D area could be drawn:

- The townhouse in the north of D area formed the excessive large area of wind-break wall. Thus the large wind-shadow area with low velocity in the D area would be formed.
- When the southeast wind flowed into the residential area, the southeast building cluster would firstly militate the southeast wind. Thus the southeast wind would be hindered to flow into the south of D area.

- After the southeast building cluster militated the southeast wind, the direction of air flowing into the south of D area changed from southeast to west and northwest. And the average velocity decreased from 4.69 m/s to 3.5 m/s. Then the militated west and northwest wind would interact with the southeast wind in the south of D area. Thus the the direction of air flowing into the south of D area would be the west and the average velocity decreased to 3.1 m/s.

  And the reasons for excessive low velocity of E area could be drawn:

- The southeast building cluster would firstly militate the southeast wind. Thus the southeast wind would be hindered to flow into the south of E area.
- The townhouse in the south of E area staggered the east adjacent townhouse. When the east airflow of E area flowed into E area, the airflow would be decreased and the wind direction would be changed because of the hindrance of the townhouse in the south of E area. And the triangular area with excessive low velocity would be formed in the E area.

5. Conclusions

The outdoor space having better accessibility, having more frequent social activities and further closing to the demand for resident outdoor activities was the cognitive space. To be better close to the wind environment demand of outdoor activities, the wind environment of cognitive space would be simulated and optimized based on Space Syntax and Numerical Simulation in this study. Thus the conclusions were as follows.

5.1 Wind environment of cognitive space of planning scheme needed to be improved

In the area of cognitive space, there existed 23% uncomfortable wind environment area. And most such areas were located at the residential core area and thus largely affected resident outdoor activities such as recreation, transportation and ornamental. Therefore, the wind environment of cognitive space of planning scheme needed to be improved.

5.2 Wind environment of cognitive space was optimized by optimization scheme

The cognitive space areas of planning and optimization schemes were respectively 47143.10 m^2 and 45699.10 m^2. And in the areas of cognitive space, the uncomfortable area proportion of planning and optimization schemes were respectively 23% and 5%. Thus 18% uncomfortable area was optimized by the optimization scheme in the condition of the two schemes covering similar cognitive space area. Therefore, the wind environment of cognitive space was optimized and improved by the optimization scheme and optimization measures.

This paper proposed the optimization method of wind environment of cognitive space based on Space Syntax and Computer Numerical Simulation. And such method could provide decision support for the simulation and optimization of wind environment of residential cognitive space. Meanwhile, the method could also be implicated in meso-level for the optimization of wind environment of community or neighborhood cognitive space. However, this method also has its weaknesses. Firstly, cognitive space is not fully ventilated. Secondly, the optimization measures proposed in this paper were relatively limited and there would be more optimization measures need to be excavated and verified. Thirdly, simulating and optimizing the wind environment of cognitive space based on planning scheme is lack of support by the measured data of wind environment. Thus accuracy between the simulated results and the measured results were difficult to verify. Such aspects could be improved in the future research.

Acknowledgments

This research is supported by the National Natural Science Foundation of China (No.: 51378399).

References

Yoshie R, Mochida A, Tominaga Y, Kataoka H, Yoshikawa M (2005) Cross comparisons of CFD prediction for wind environment at pedestrian level around buildings. Paper presented at the Sixth Asia-Pacific Conference onWind Engineering, Seoul, Korea, September 2005.

Tominaga Y, Mochida A, Yoshie R et al (2008) AIJ guidelines for practical applications of CFD to pedestrian wind environment around buildings. Journal of wind engineering and industrial aerodynamics 96(10):1749-1761.

Ma J, Chen S (2007) Numerical study of plan arrangement effect on wind environment around tall buildings. Journal of Zhejiang University 41(9): 1477-1481.

Zhao Y (2008) Measurement and simulation of thermal environment of residential district. Chongqing university.

Zhao B, Lin Y, Li X, Jiang Y (2002) Numerical simulation and optimization design of wind environment of building cluster. Urban Planning Forum 2(138): 57-60.

Wang F, Xiao Y (2006) Simulation and evaluation of building cluster's wind environment with PHOENICS software. Journal of Shandong College of Construction Engineering 20(5): 39-42.

Ma J, Chen S, Wang H (2007) Wind Environment Evaluation for Tall Building Complexes with Various Plan Arrangement. Environmental Science and technology 30(6):57-58.

Yang L (2010) The application of CFD technology in the analysis of residential wind environment. Journal of Architecture 4: 5-9.

Tang Y, Meng Q (2001) Study on the simulative outdoor wind environment of high-rise residential area in Guangzhou. Journal of Xi'an University of Architecture and Technology 4: 011.

Blocken B, Carmeliet J (2004) Pedestrian wind environment around buildings: Literature review and practical examples. Journal of Thermal Envelope and Building Science 28(2): 107-159.

Edward N (2009) Policies and technical guidelines for urban planning of high-density cities–air ventilation assessment (AVA) of Hong Kong. Building and Environment 44(7): 1478-1488.

Edward N, Yuan C, Chen L et al (2011) Improving the wind environment in high-density cities by understanding urban morphology and surface roughness: a study in Hong Kong. Landscape and Urban Planning 101(1): 59-74.

Du X, Gao H (2008) Wind environment analysis of Tianjin high-rise residential. Journal of Architecture (4): 42-45.

Hu X, Zhou X, Pu Z (2007) Architecture Layout Based on CFD Simulation of Wind Environment Outdoor. Engineering construction and design 4: 14-18.

Jiang M (2008) Simulation and analysis on wind environment of residential area. Shanxi Architecture 34(4): 38-39.

Hillier B (1997) Cities as movement economies. Intelligent Environments: Spatial Aspects of the Information Revolution, North Holland, Amsterdam, The Netherlands 295-342.

Bafna S (2003) Space syntax: a brief introduction to its logic and analytical techniques. Environment and Behavior 35(1):17-29.

Hillier B, Penn A, Hanson J (1993) Natural movement-or, configuration and attraction in urban pedestrian movement. Environment and Planning B 20(1): 29-66.

Li J, Duan J (2004) Multi-scale representation of urban spatial morphology based on GIS and spatial syntax. Journal of Central China Normal University 03:383-387.

Zhang Y, Wang J (2004) Discussion on space syntax. Architect (3): 33-44.