Optimized Approaches to Urban Spatial Form Design for Better Ventilation- A Study in Changzhou, China

Ding Jinming, Southeast University, China

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Abstract
Rapid urbanization process has brought about a global challenge in the ecological environment, such as air pollution and "Urban Heat Island Effect". On one side, climate is one of the most important elements that maintains human survival and production, and also the key factor of spatial morphology. On the other side, different spatial forms also affect local microclimate. Early in 1968, the WMO organized the first international urban climate conference to specially study the influences of urban planning and design that make on the climate. It is indispensable to seek for optimized approaches to urban spatial form design for better environment. Wind environment, a part of urban climate, plays a critical role in improving urban spatial environment. Strategies for better wind environment and constructions of urban ventilation corridor can effectively relieve air pollution and accumulated heat. Countries like Germany and Japan early studied macroscopic ventilation corridor planning, and combined it with urban master plan. Some urban spatial forms, such as density, height, volume rate, etc. have been further studied to seek for specific optimization. While most studies tend to get a qualitative control but have poor implementation. Quantitative studies are essential to be done. In this study, we will first make a simple introduction about the overall background wind environment in Changzhou. Then we will construct three-level ventilation corridors. Multi-dimension spatial morphology factors will be respectively extracted to simulate through CFD. Finally, several specific optimization approaches will be proposed for future urban design.

Keywords: urban ventilation, spatial morphology, CFD simulation, optimization

1 Introduction

1.1 Background

China has begun a rapid urbanization process since the reform and opening. On one side, the fast-paced urbanization has brought about a huge improvement in infrastructure and economic growth. On the other side, it has also led to the explosion of urban population and the expansion of construction land. Furthermore, high-density and high-scale construction has intensified resource consumption and created unprecedented environmental pollution, which has become a global challenge and directly affected people's basic survival.

The problems associated with the urbanization process (but not limited to) mainly include air pollution, "Urban Heat Island Effect", disease transmission etc. Firstly, according to the PM2.5 data released by foreign authorities, in China, every 1% of urbanization will increase the concentration of smog pollution by 0.029%. The health hazards caused by urban air pollution will directly lead to huge urban economic losses. Secondly, due to a large number of artificial heat, high regenerators such as buildings and roads, and reduced greening environment, the city has caused "high temperature", which has many adverse effects on the urban space environment. Thirdly, the high concentration of population in the city and the close communication network have also created more favorable conditions for the spread of infectious and epidemic diseases.

Wind environment, a part of urban climate, plays a critical role in improving urban spatial environment. Strategies for better wind environment and constructions of urban ventilation corridor can effectively relieve air pollution and accumulated heat, and also help reduce the transmission efficiency of airborne diseases and the risk of infectious diseases. Early in 1968, the WMO organized the first international urban climate conference to specially study the influences of urban planning and design that make on the climate. On one side, climate is one of the most important elements that maintains human survival and production, and also the key factor of spatial morphology. On the other side, different spatial forms also affect local microclimate. It is indispensable to seek for optimized approaches to urban spatial form design for better environment.

1.2 Literature review

The theoretical research on urban wind environment involves many disciplines such as meteorology, environmental science, urban climatology, urban and rural planning etc. This paper mainly summarizes the research on wind environment in urban planning and related fields, including the construction of urban ventilation corridor, wind environment impact factors and improvement strategies, and related research on spatial morphology.

The Germany first constructed urban ventilation corridors in response to urban climate deterioration in the Ruhr area. The urban environmental climate map is used to carry out related research on the application of climate spatial planning (Ren et al.,2014). Related researches in China is still in its infancy. As early as in Hong Kong (Chinese University of Hong Kong,2013), in response to the deterioration of space environment in high-density areas, the wind speed ratio is used to assess the impact of buildings on the surrounding environment, and added guidelines on air circulation intentions in the urban design guidelines. Zhu, et al. (2008) have proposed the operation mode of ventilation corridor. Germano M （2007） used parametric analysis method to evaluate the natural ventilation capacity of Basel, and drew the urban ventilation potential level map. Based on RS and GIS technology, Zhan et al. (2015) comprehensively analyzed the characteristics of regional wind environment, found out the urban air inlet, and excavated the existing ventilation corridor. Although some practical techniques, such as wind tunnel experiments and computer numerical simulations, have been applied to the research, most studies paid more attention to theoretical researches, which are out of touch with the practice.

The ventilation environment of the city's macro, meso and micro scales corresponds to different influencing factors. Zeng et al. (2016) analyzed different influencing factors from the overall urban form, urban structure, urban functional area and several dimensions of different climate zones, and proposed corresponding planning strategies. Based on the improvement of urban microclimate, Ding et al. (2012) proposed relevant indicators for urban texture optimization and urban street space optimization. The influence factors of the wind environment are complex. Scholars have generally constructed a research framework from macro to micro. However, most improvement strategies are stuck in the qualitative analysis, and the operational implementation of urban planning is insufficient.

When it comes to the researches on spatial morphology, more studies concerned about the optimization of urban macroscopic form or microscopic architectural form, while had less discussion on the city districts and blocks. Furthermore, most studies tend to be more qualitive rather than quantitative, and have poor implementation in practice. The universal approaches have not been summarized specifically, and a theoretical framework has not been built completely.

In this study, we will first make a simple introduction about the overall background wind environment in Changzhou in Section 2, in order to achieve several important parameters for later simulation. Then in Section 3, we will construct three-level ventilation corridors to get the optimal ventilation plan. In Section 4, several multi-dimension spatial morphology factors, concerning urban districts, core areas of heat island and blocks, will be respectively extracted to simulate through CFD. Finally, Section 5 will propose several specific optimization approaches for future urban design.

2 Current Situation

2.1 Thermal environment analysis

2.1.1 Average temperature

Some related climate data of Changzhou have been grabbed from the weather website. First is about the average temperature. Changzhou has four distinct seasons, and the average temperature in summer is relatively stable (Figure 1), while the overall temperature in Changzhou has a small increase year by year (Figure 2).

Figure 1: Monthly maximum/minimum temperature during 2014-2018.

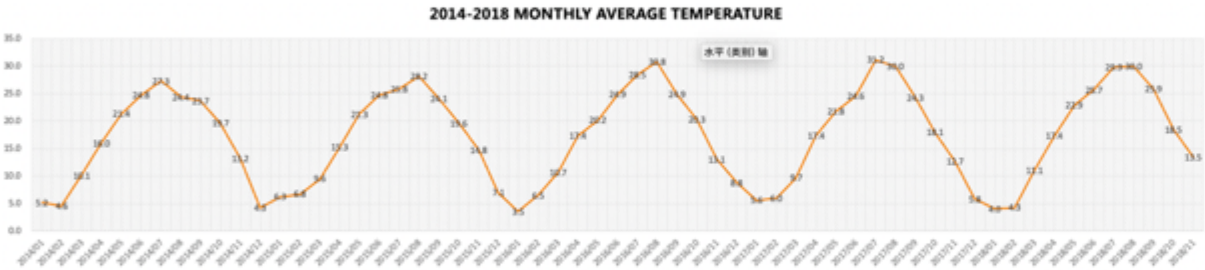

Figure 2: Monthly average temperature during 2014-2018.

2.1.2 Heat island effect

We also grabbed MODIS satellite data to get the thermal environment distribution map of Changzhou over the years (Figure 3). Through these pictures we can see that the heat island effect in the central city is obvious.

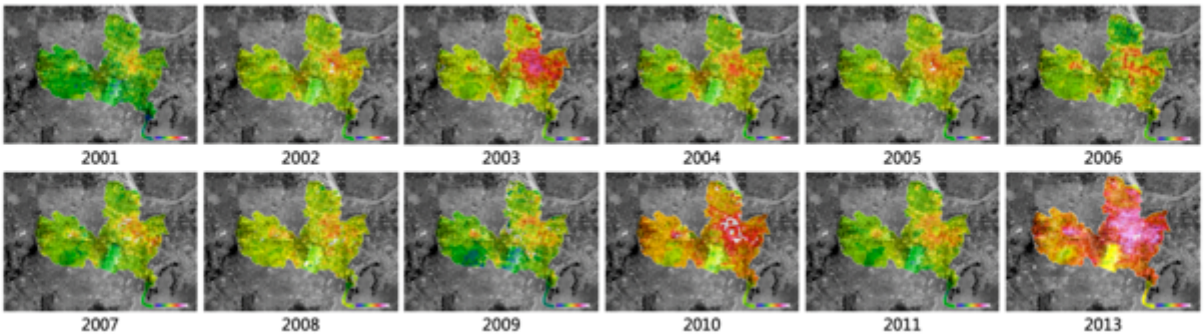

Figure 3: Thermal environment distribution maps of Changzhou.

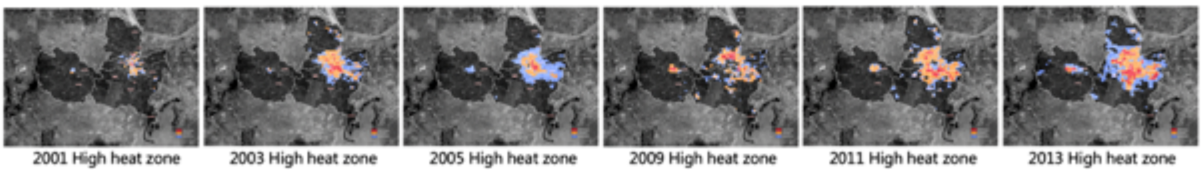

Figure 4: Areas with high heat.

Based on the thermal environment data, the areas with highest heat and higher heat were extracted to further analyze the core planning areas with the most severe heat island effect. (Figure 4) Then we superimpose these distribution maps to obtain the most severe areas in Changzhou. And these areas are the most important objects to analyze and design in later planning. At the same time, we found some villages and towns around the city have also become hot, which are distributed in scattered around the city, and needed to be controlled in the planning to avoid environmental degradation. Last but not least, it is also worth analyzing that in the urban heat island center, there are also some relatively good areas, which should be further studied to get some successful experience for later design.

2.2 Wind environment analysis

2.2.1 Dominant wind direction

Changzhou is located in the climatic zone transitioning from the north subtropical zone to the warm temperate zone. Related wind environment data have been sort out to get the dominant wind direction and average wind speed. In the summer, the dominant wind is east-southeast (ESE), and in the winter is north-northeast (NNE). (Figure 5)

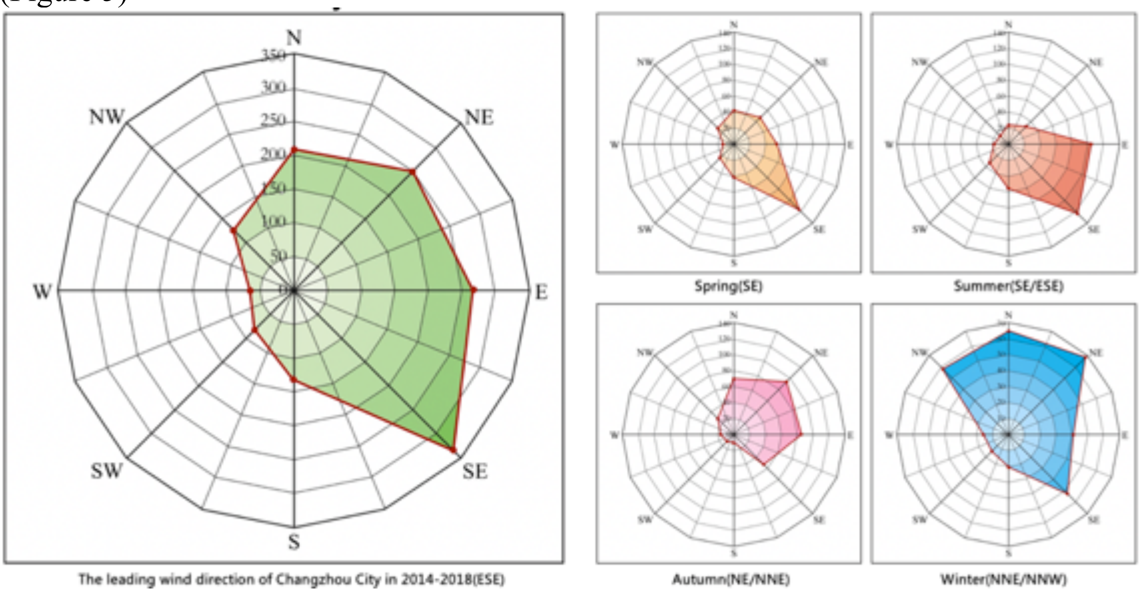

Figure 5: Dominant wind direction.

2.2.2 Average wind speed

According to the data, we can calculate the average annual wind speed is level 3-4, which is mainly 5.5 meters per second. (Figure 6)

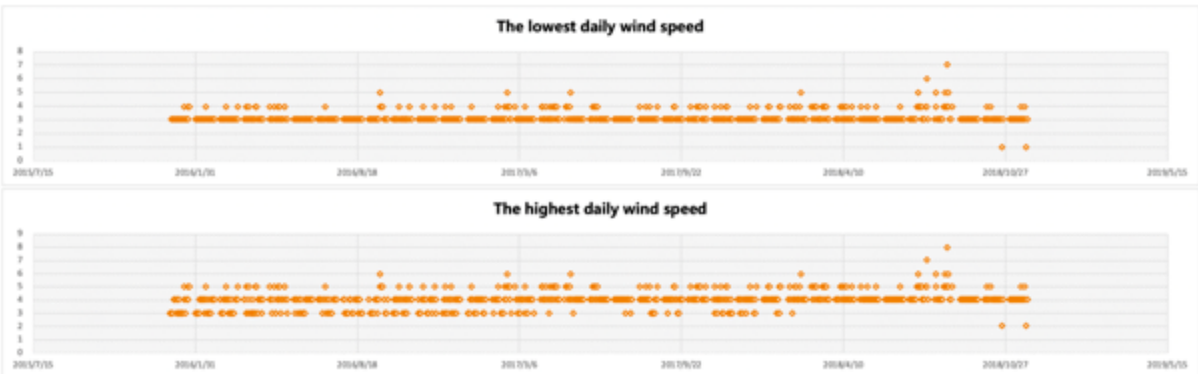

Figure 6: The lowest/highest daily wind speed.

2.2.3 Relationship between air pollution and wind

We further studied the relationship among air pollution, wind speed and wind direction. According to the data, the overall air quality in Changzhou is good. The air quality is good in summer, the second is in autumn, and the worst in winter. (Figure 7)

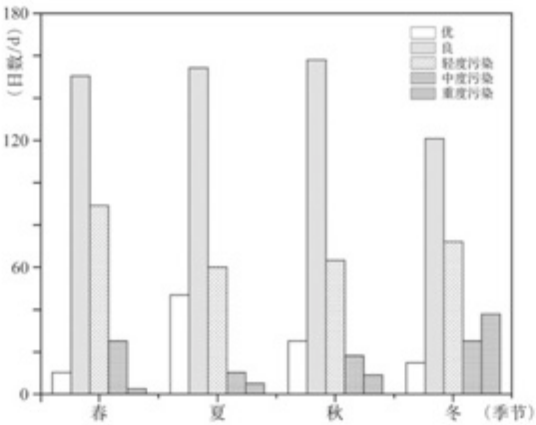

Figure 7: Distribution of daily air quality grades in Changzhou.

Through cross-analysis, it can be seen that the wind speed has obvious effects on the diffusion of pollutants: the higher the wind speed, the faster the pollution disperses. (Figure 8) In addition, the dominant wind to the southeast brings clean air at sea, which is conducive to dispersing pollution. While when the air reaches heavy pollution, the northwest wind component increases, indicating that the pollutant transport in the upstream area has a greater impact on the air quality of Changzhou. (Figure 9)

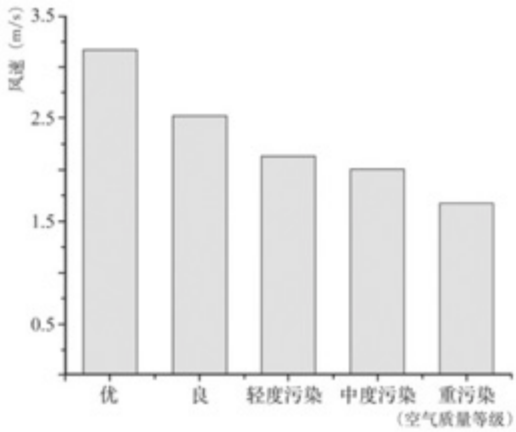

Figure 8: Average wind speed of various air quality levels.

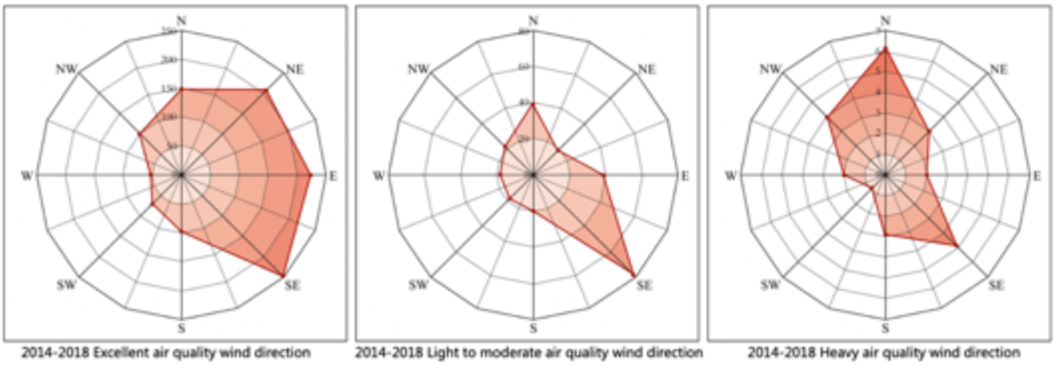

Figure 9: Wind direction with different air quality.

2.3 Wind environment simulation

Based on the basic spatial data and specific parameters that have been summarized above, we conducted the wind environment simulation through CFD. (Figure 10) According to the simulation results, the most prominent areas with poor ventilation are extracted, and the static and stable wind areas are delineated. Finally, the areas with the most severe wind and heat environment are superimposed, and the most comprehensive and prominent areas are selected as the space foundation and focus of the construction of the ventilation corridor. (Figure 11)

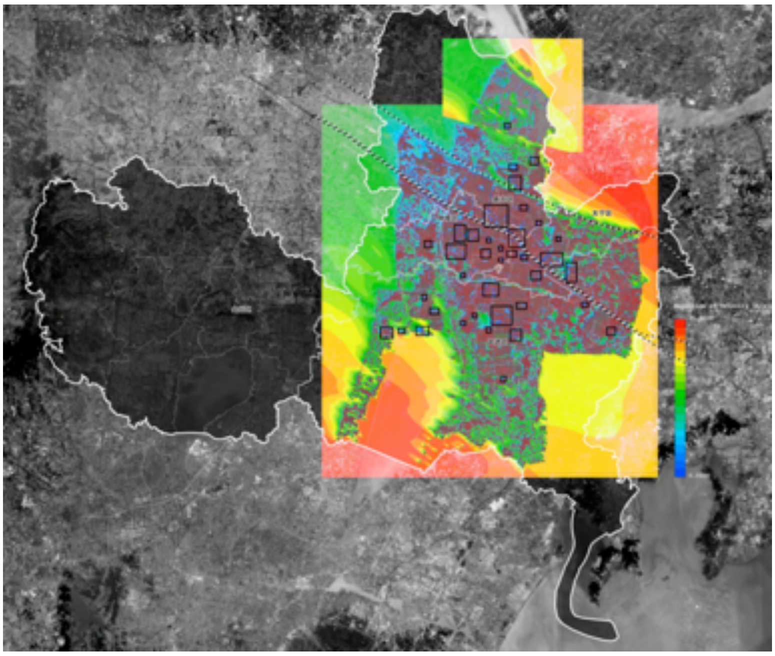

Figure 10: Wind environment simulation through CFD.

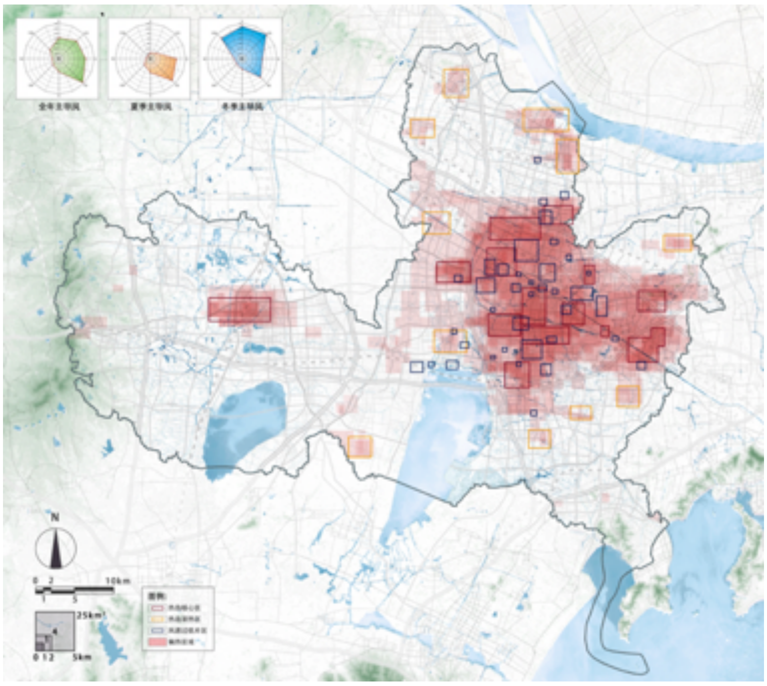

Figure 11: Wind and heat environment overlay.

3 Construction of ventilation corridors

3.1 The whole city

On one side, the wind environment simulation and the thermal environment overlay both compose the space foundation. On the other side, the base map of water, green space and the road network all compose the potential corridors. And these two both help construct the final ventilation corridors based on water and land double net. Finally, we planned the city's three-level ventilation corridors, (Figure 12) including 4 first-class ventilation corridors, whose width is not less than 150m and the length is not less than 1000m, 12 second-class ventilation corridors, whose width is not less than 50m, and the length is not less than 500m, and several third-class ventilation corridors.

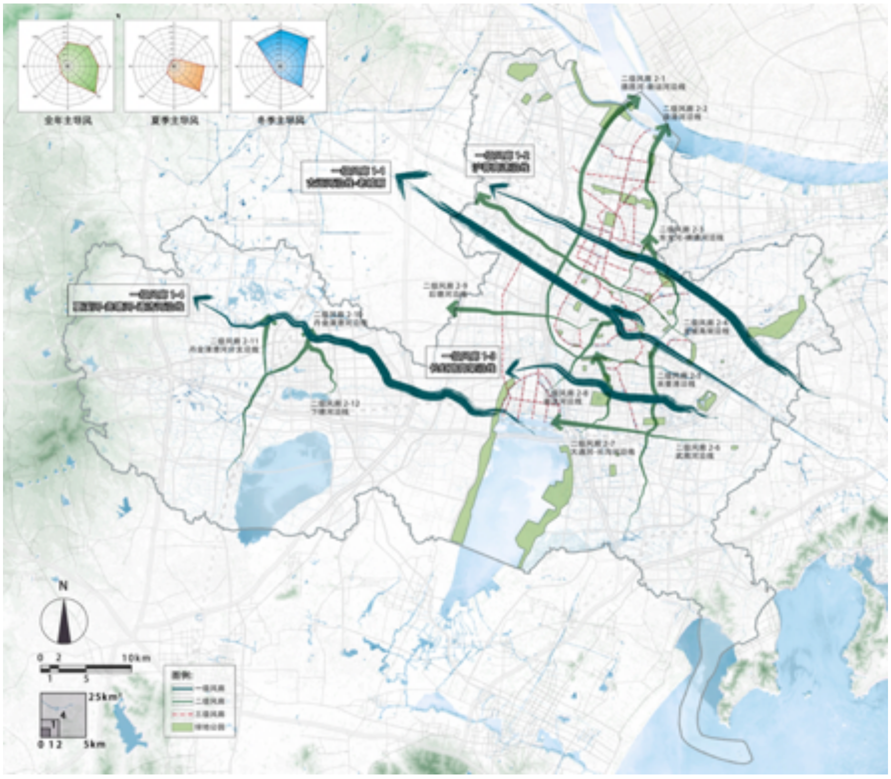

Figure 12: Ventilation corridor planning map.

Then we made some basic control of these ventilation corridors.

3.1.1 Control of the first-class ventilation corridor

The basic principle is to ensure smooth ventilation in four first-class ventilation corridors and strictly control the development and construction inside the corridor. Any tall buildings or trees are forbidden to be built inside the corridor. Furthermore, the height and density of buildings on both sides of the main water bodies or roads inside the corridor should be strictly controlled.

To be specific, the four first-class ventilation corridors should be parallel to the city's dominant wind direction (ESE), or the angle with the dominant wind direction is not more than 45 degrees. The continuous length of the four ventilation corridors shall not be less than 1000 meters, the width of each segment should be no less than 200 meters, and the aspect ratio not less than 20:1. Furthermore, we proposed some quantitative indicators including the construction intensity, distribution of public open space, water and road direction, building density, height, etc. (Table 1)

Table 1: Control of the first-class ventilation corridors.

Control elements	**Standards**
Proportion of construction land	≤20%
Building density	≤25%
Building height	≤10m
Wind resistance rate	≤0.6
The ratio of the height of the adjacent building at the border of the corridor to the width of the corridor	≤0.5
Opening degree	≤40%

3.1.2 Control of the second-class ventilation corridor

Similarly, we also made some control of the second-class ventilation corridors. The basic principle and the direction of corridors are similar to the first-class as mentioned above. While the continuous length of these 12 ventilation corridors shall not be less than 500 meters, the width of each segment should be no less than 80 meters, and the aspect ratio not less than 20:1. The quantitative indicators also have some differences. (Table 2)

Table 2: Control of the second-class ventilation corridors.

Control elements	Standards
Proportion of construction land	≤25%
Building density	≤30%
Building height	≤25m
Wind resistance rate	≤0.7
The ratio of the height of the adjacent building at the border of the corridor to the width of the corridor	≤1
Opening degree	≤30%

3.2 The core area of the city

To be more specific, we further studied the core area of the city. The third-level ventilation corridors were further constructed based on the water-land dual-network to connect the urban green space park in series. (Figure 13) The three-level wind corridors form a core corridor system together. At this level, except basic control, we proposed several detailed strategies to guide subsequent design, which will be introduced in detail in Section 4.

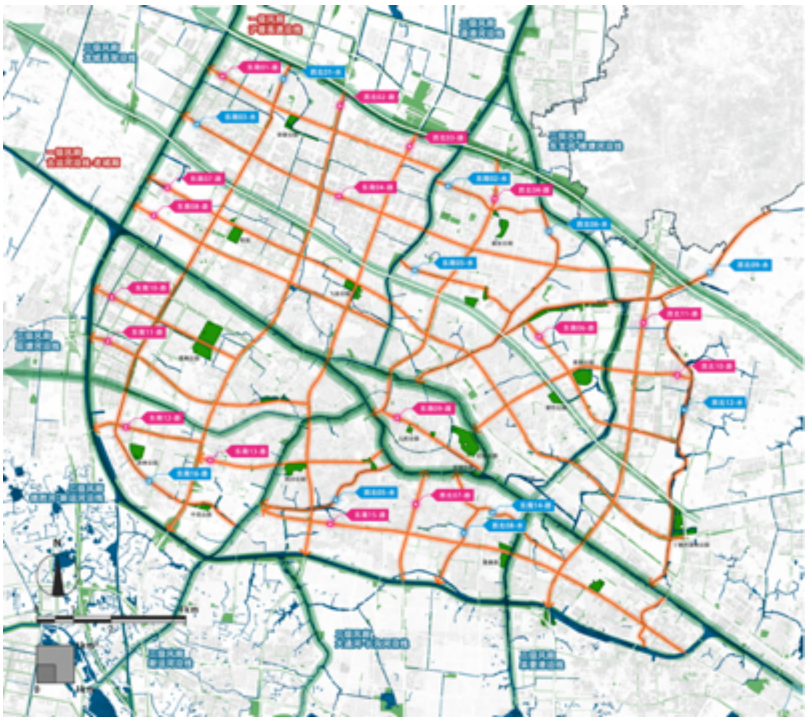

Figure 13: Core area ventilation corridor planning map.

4 Detailed strategies

4.1 In summer

According to different dominant wind directions in four seasons, we conducted simulation respectively to make a comparison. (Figure 14)

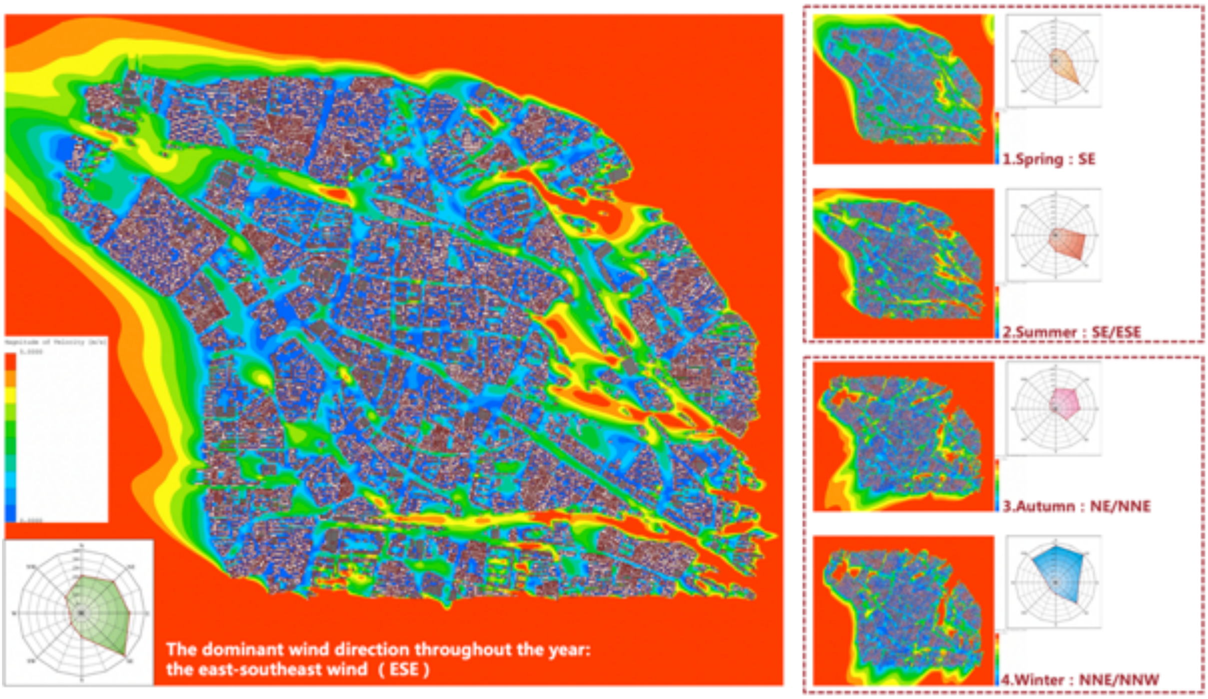

Figure 14: Simulation with different dominant wind directions.

As the wind environment is more significant for the winter and summer seasons of the city, we selected two main research directions to further analyze. In summer, we extracted related river space, street space and construction space that with low wind speed. These areas were superimposed to get the key design locations. In future urban renewal and land development, attention should be paid to the ventilation environment assessment in these areas. And we proposed corresponding suggestions in such areas:

- Connect the surrounding public open spaces squares, etc., and strictly limit the height of the building in the ventilation corridor.
- The buildings should be arranged properly. There must be enough space between the buildings. The front and rear buildings are staggered, and the central axis is as parallel as possible to the prevailing wind, so that the wind can flow between the buildings.
- The height of the buildings shall be reduced towards the ventilation corridor or the public open space, and the building on the edge of the wind gallery or public space may be set aside.
- The height of the buildings should be gradually lowered toward the prevailing wind sourc.
- The building platform should be stepped down towards the road as much as possible to improve the impact of the building on the street ventilation.

- Buildings on both sides of the main river should have sufficient ventilation space to avoid long lengths facing the river.
- Plant appropriate street trees on both sides of the main streets to strengthen urban greening.

4.2 In winter

While in winter, the wind speed should be mainly avoided. On one hand, excessive wind speed in winter makes people feel cold and uncomfortable. On the other hand, winter wind will bring urban pollution according to the analysis in Section 2. Based on the simulation of the dominant wind direction in winter, we proposed some suggestions in related areas:

- Increase the perimeter of buildings or structures, and it is not advisable to leave excessive open space.
- Increase tree greening and reduce the impact of excessive wind speed.
- Buildings around the area with excessive wind speed should be enhanced with wind-shielding measures. The main façade of the building should not be oriented towards the wind source. The influence of wind should be mitigated by architectural design techniques.

5 Conclusion

To sum up, we have done a lot of preliminary work on analyzing the current situation in Changzhou, including the heat island distribution and background wind environment according the data we achieved. Then we have summarized the areas with the most severe wind and heat environment which especially need to be planned. Furthermore, we construct three-level ventilation corridors based on water and land double nets both in the city area and core area, and propose different control strategies respectively. Finally, based on the simulation study of the dominant wind direction respectively in summer and in winter, we extract some key areas which need to be paid more attention in the future urban design, and we propose some corresponding suggestions to improve the wind environment in the old town area.

In ongoing study, we will extract those key areas and conduct further simulation to analyze specific issues. Then multi-dimension spatial morphology factors will be respectively extracted to simulate through CFD. Specific correlation strength and quantitative standards can be summarized to build the research framework for better urban ventilation. Also, we will conduct multi-scenario designs to check if the strategies can really lead to optimization.

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Contact email: 863235311@qq.com