How Urban Morphology Can Be Optimized? Research on Interactive Mechanism Between Urban Morphology and Urban Micro Climate

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Abstract

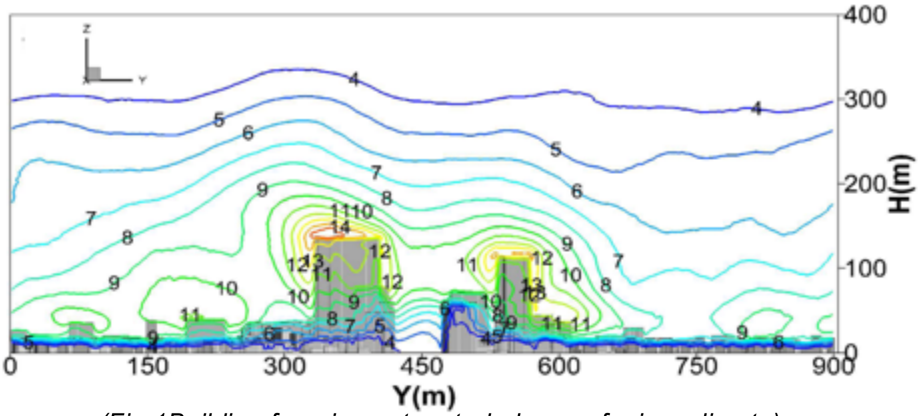
City is a space for people to live, the physical feeling of citizens is direct impacted by urban micro climate, which includes thermal environment, wind environment and acoustic environment. However, traditional urban development pattern, which is led by high-efficiency spatial use result high FAR (Floor Area Ratio), high density and high height urban morphology. Under this spatial development pattern and morphology, which is conducted by this pattern, urban physical environment is impacted negatively. In this study field, the most common research object can be considered is the UHI (Urban Heat Island) effect. Many previous researches have provided many consequences in this area, includes mechanism of UHI and possible resolutions. However, urban spatial is complex system, and UHI only can be believed as a part of urban micro climate. Meanwhile, due to data and analysis techniques limitation, many previous researches are considered lack of quantitative method in some extent. Thus, this research mention to study how to objectively and quantitatively measure the urban micro climate based on urban physical environment big data, and attempt to find out the interaction mechanism between urban 3D morphology and urban micro climate. In addition, attempts to provide possible way which can adopts the research results to guide urban design practice, optimize urban 3D morphology and construct a better urban physical environment.

Key words: Urban Micro Climate, Urban 3D Morphology, Morphology Optimization, Urban Physical Environment, Micro Climate Big Data, Urban Design

1. Introduction

The rapid progress of global climate change and urbanization has caused the city to face a series of city climate problems such as frequent climate extremes, hot summer temperatures, and increased air pollution (Carmin et al., 2012). Therefore, Explore the impact of urban spatial pattern changes on the physical environment of cities, the relationship mechanism between urban 3D morphology and urban physical environment, and use urban micro climate data and law behind these data to guide planning and construction can be considered is a hot topic for current planners, builders, and climatologists. Cities across the world are recognizing increasingly that they will face a growing variety of challenges related to global climate change, and a number of leaders in these cities are starting to adopt some measurement to optimize the urban micro climate (Pelling et al., 2011). However, any researches which keep away from urban 3D morphology to analysis and provide related measurement for optimize urban morphology or urban physical can be believed lack of rationality.

Because many previous researches such as Stathopoulos and Baskaran (1996) and Peter and Richard (1999) have conducted research on urban 3D morphology and urban micro climate, their research consequences prove that the building three-dimensional form is related with urban micro climate directly. The height, form and scale of building will impact on near-surface turbulence, and this effect will influence on urban thermal and wind environment, thus urban micro climate will be changed due to different urban 3D morphology. (Figure 1)



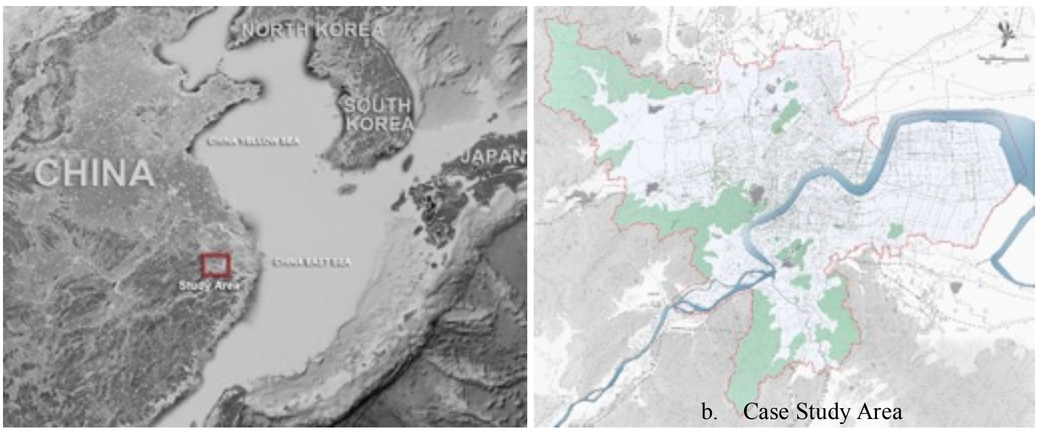
(Fig.1Building form impact on turbulence of micro climate)

Source: Author Made

Based on above expound, what is the interactive relationship between urban 3D morphology and urban micro climate? What is the inner influence mechanism between urban 3D morphology and urban micro climate? How to construct an urban 3D morphology optimization model based on urban micro climate? How to make a better balance between urban physical environment and urban spatial morphology, and to conduct an urban design scheme? These questions are needed answer through in-depth analysis of urban 3D morphology and urban physical environment, and find the law of interactive mechanism between urban 3D morphology and micro climate.

2. Case Study Measurement

According to the previous researches and current computer and urban big data analysis techniques, this research mention to base on urban physical environment big



(Fig.2 The Research Case Study Area)

Source: Author Made

data to measure both urban thermal and wind environment in a large-scale urban site.

2.1. Case study introduction

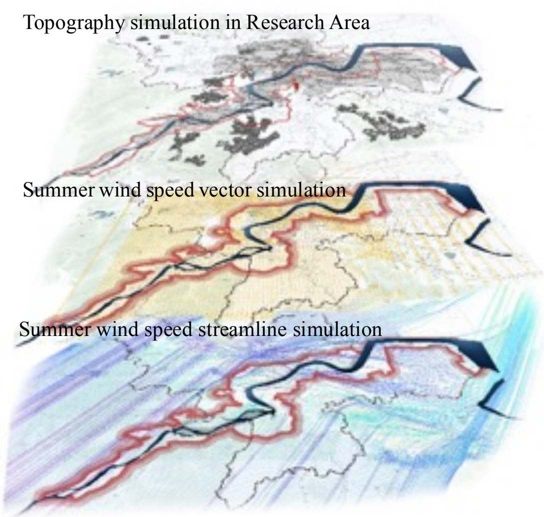
Because the urban micro climate is impacted by the different spatial factors, such as mountain, river, buildings and other urban 3D morphology factors. Thus, this research selected Hangzhou which is a large-scale city with river, mountain, lake and comprehensive urban environment in the east China as the research object in here. The reason for select Hangzhou as the case is there exist all major influence indicators in urban micro climate. Thus, the research consequences can be considered is reliable, effective, and reproducible. The major results of this case can be used to other urban micro climate study, and the core founds can provide positive guide for urban planners or designer to optimize urban 3D morphology globally.

2.2. Method for thermal environment measurement

During the research process, the thermal environment of research area is measured through two steps. Firstly, satellite remote sensing data of 1984, 1991, 2003 and 2015 was acquired through LANDSAT of United States Geological Survey (USGS). Then, Computer simulation technology was adopted to establish urban space model, and software such as ENVI-met, ECOTECT and RayMan were used to simulate and analyze the research area thermal environment. By analyzing the simulation results and comparing the differences of thermal environment under different urban spatial morphological indexes and spatial morphological types, the coupling correlation between urban spatial morphology and urban thermal environment is concluded. Afterwards, site investigation method is adopted to collect Surface temperature, air temperature, relative humidity and other meteorological data, and through combine the land function of the research area and various spatial morphological indicators such as sky visibility to analysis the interactive mechanism between urban 3D morphology and urban micro climate.

2.3. Method for wind environment measurement

Similar with the thermal environment measurement, the method of measurement the wind environment is includes three steps. The first step is Use field research method to calculate the space form indexes such as the scale of land use, number of building stories, density and floor area ratio in research area as the basis of wind environment case study. Afterwards, computer numerical simulation method was also used to establish the space model of the central area, and conduct numerical simulation for the wind environment at the mean wind speed of prevailing wind direction in research area with CFD software scSTREAM to generate the simulation results and comprehensively analyze



(Fig.3 wind environment measurement)

Source: Author Made

the space distribution characteristics of the wind speed at the pedestrian height and evaluate the merits of the wind environment. Then, conduct multivariate linear regression analysis on the wind speed parameters and space form parameters of blocks with data analysis software SPSS, and discuss the correlation between each space form index and the wind speed level at the pedestrian height, further evaluate the characteristics and causes by comparing the differences of wind environment in different types of space units, summarize the influential factors of urban space form on the wind environment and discuss optimization strategies for urban 3D morphology.

3. Measurement Results

Through above method to measure both urban thermal and wind environment in research area, the distribution and data analysis results can be fund. Meanwhile, through the superposition analysis of the elements in the urban 3D morphology, the interactive mechanism between the 3D morphology and the urban microclimate is further analyzed, and on this basis, the optimization strategies and methods of urban spatial form are proposed. According to the optimization strategies, two round urban design schemes have made to optimize the urban 3D morphology for batter urban physical environment.

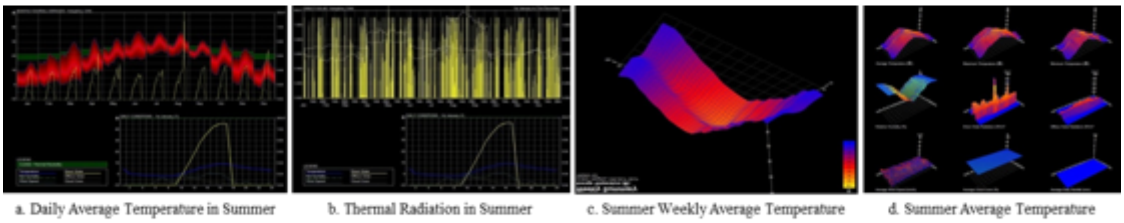
3.2. Thermal Environment

Based the thermal environment data which is acquired through LANDSAT of USGS, using GIS as the data processing platform, the temperature inversion of the satellite remote sensing data of research area in 2015, and the thermal environment in the urban area was simulated. Based on the measurement results, the high temperature period is concentrated between June to August. (Table 1) In summer, the temperature change is smoothly, (Figure 4) the urban thermal environment distribution different is impacted by urban 3D morphology mainly.

Table 1: The Average Data of Thermal Environment in Research Area

The Average Data of Thermal Environment in Research Area												
Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
Extreme heat	23.9	28.5	32.8	34.8	36.5	39.7	40.5	41.6	38.7	35	31.2	26.5
Average heat	8.3	10.3	14.8	21.1	26.3	29.1	33.6	32.8	28.2	23.2	17.3	11.3
Average degree	4.6	6.4	10.3	16.2	21.4	24.7	28.9	28.2	24	18.8	12.9	7
Average cold	1.8	3.5	7	12.4	17.5	21.4	25.2	24.9	20.9	15.4	9.3	3.7
Extreme cold	-8.6	-9.6	-3.5	0.2	7.3	12.8	17.3	18.2	12	1	-3.6	-8.4
Precipitation(mm)	80.6	88.2	140.7	123.1	128.6	219.4	172.9	162.1	123.5	78.5	71.5	48.9
Relative humidity	75	75	75	74	74	80	76	78	79	76	74	73
Insolation duration	102	97.2	116.4	140.6	164.7	136.6	212.7	193	143.9	144.6	129	128.7

(Source: Author Made)



(Fig.4 Research Area Temperature Fluctuation in Summer)

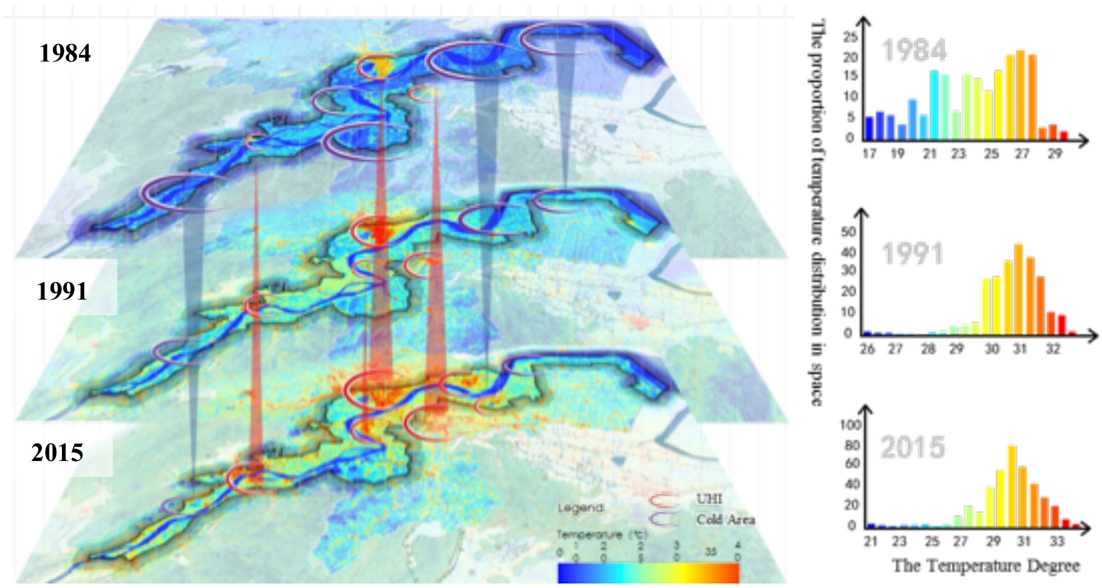
Source: Author Made

In addition, the study also based on the urban thermal environment data of 1984, 1991, 2015 to conduct land surface temperature retrieval through GIS data analysis platform. Based on this, the changing law of urban thermal environment and heat island effect in research area during the past 30 years can be dynamic analysed. As the most direct reflection of interaction between urban 3D morphology and urban thermal environment, the appears of UHI (Urban Heat Island) usually related with the change of urban Spatial. Through observation the measurement results, (Figure5-a) the UHI range in research area illustrates an extensive expansion during the past 30 years. Meanwhile, behind the extensive expansion of UHI, the average temperature in study area also increase 2 to 3 degrees than before. (Figure 5-b)

Through observation the phenomenon of thermal environment distribution transformation and UHI range expansion, the generation mechanism behind the phenomenon is interaction between urban 3D morphology and urban microclimate. During land expansion of urban space, the land surface condition has changed, it direct led the heat capacity of urban surface is changed. Meanwhile, enhancement of building height and density also exacerbated UHI effect. As the Figure 8-a illustrates the all UHI ranges in 2015 is the new developed urban area, the land surface is hardening in these sites. However, in 1984, these sites are all with natural surface.

3.3. Wind environment

Urban wind environment is high related with thermal environment, both wind and thermal environment together constitute the urban microclimate. Based on the computer simulation techniques and practice measurement of wind in research area,



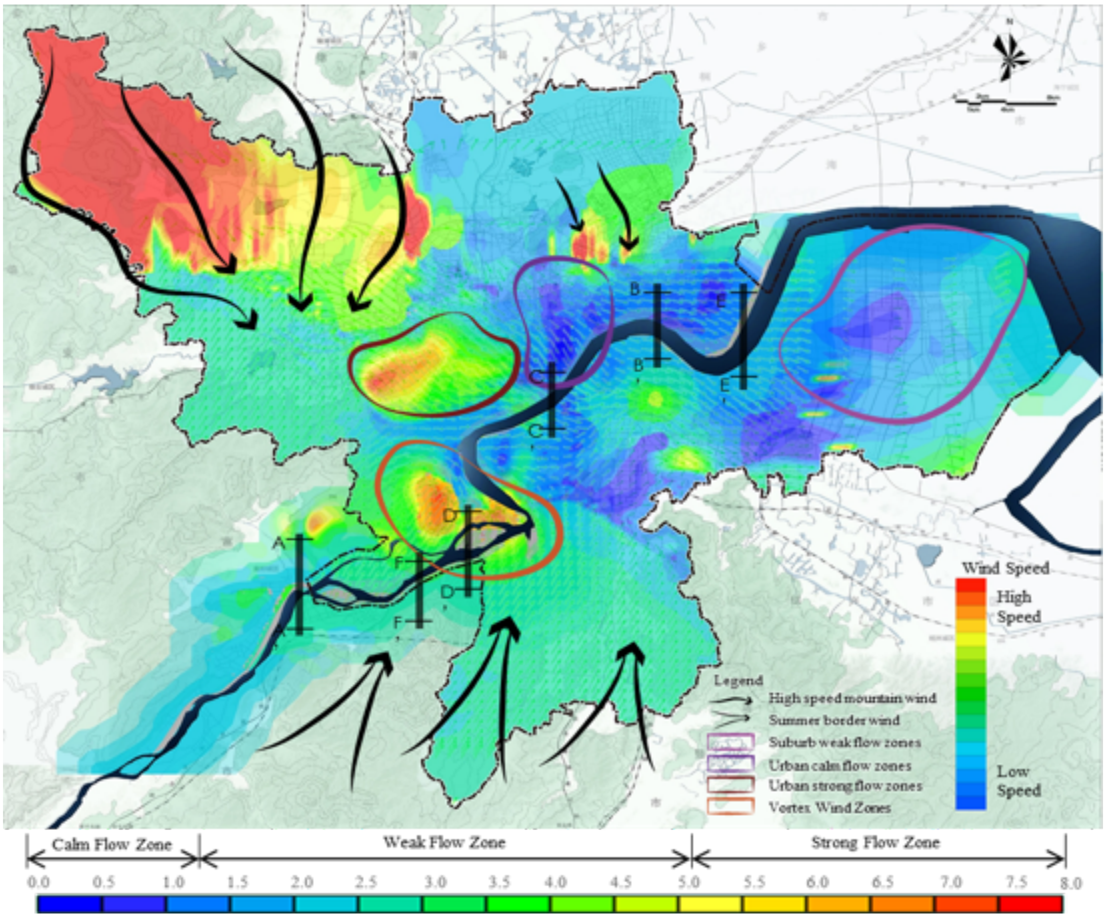
a. Thermal Environment Simulation Distribution b. Temperature Change

(Fig.5 Thermal Environment and Temperature Change in Study Area)

Source: Author Made

this research adopts Phoenics fluid calculation software simulation technology to measure wind environment. Before conducts urban wind environment simulation based on urban 3D morphology, statistical analysis of wind direction, wind speed and wind frequency is conducted in study area in June, July and August firstly. The results indicated that in research area, the dominant wind direction in summer is southwest wind, with a maximum wind speed of 7.2 m/s, an average wind speed of 2.6 m/s, and a minimum wind speed of 0.9 m/s.

According to the above wind environment basic analysis, the computer simulation techniques was selected to conduct the further in-depth measurement of urban wind environment in the area. Through CFD software scSTREAM to generate the simulation results and comprehensively analyze the space distribution characteristics, the wind speed in the study area is concentrated in the range of 2~5m/s, and wind environment illustrates the segmental variation characteristics. (Figure 6)



(Fig.6 Wind environment simulation results in study area)

Source: Author Made

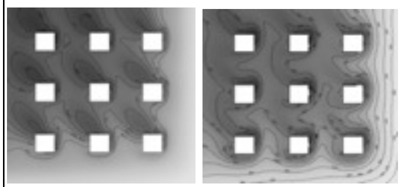
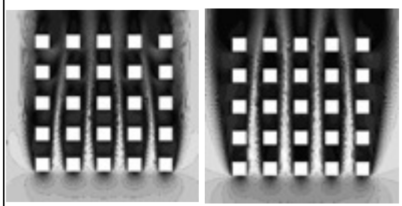
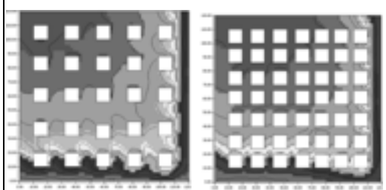
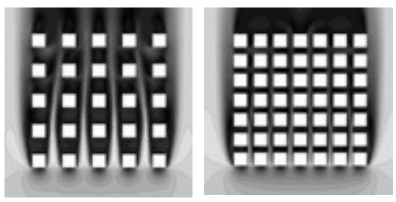
In this extent, the macroscopic wind environment situation in study area is already observed. Similarly, wind environment is impacted by urban factors in some extent, the figure 10 illustrates wind environment is different between urban area, suburb area and country side, thus, compare with thermal environment, the influences of urban 3D morphology on wind environment is more remarkable. (Berghauser and Haupt, 2010)

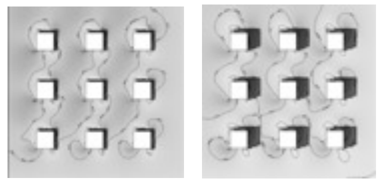
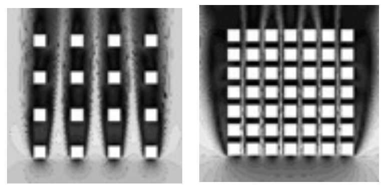
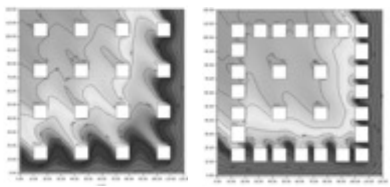
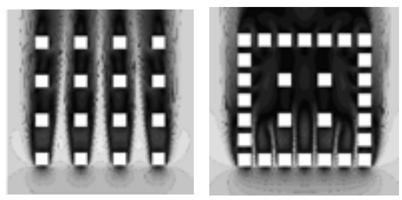
Based on above, both wind and thermal environment is impacted by urban 3D morphology, the comprehensive interaction between urban 3D morphology and urban physical environment will produce different micro climate. Therefore, based on the interactive mechanism between urban 3D morphology and micro climate, optimal microclimate oriented urban 3D morphology optimization way may be fund.

3.4. Interactive mechanism between urban 3D morphology and micro climate

Through above discussion, there exist some commonly influence indexes of both wind and thermal environment on urban 3D morphology. (Table 2)

Table 2: Common Measures of Both Wind and Thermal Environment

Index	Description	Graphical Representation
Height Index	Under the ideal simulation conditions with a wind speed of 1m/s at the height of 10m and not considering anthropologic heat factors, the surface temperature, mean radiation temperature and air temperature in daytime showed certain negative linear correlation in regular layout blocks within a height ranging from 20m to 60m, while certain positive linear correlation in daytime. For wind environment, the overall wind speed at pedestrian height is directly related to the average height in urban blocks, and there is a positive correlation between the two.	Different thermal environment between 20 and 60m building height  20m 60m Different wind environment between 20 and 60m building height  20m 60m
Density Index	Under the ideal simulation conditions with a wind speed of 1m/s at the height of 10m and not considering anthropologic heat factors, the surface temperature, mean radiation temperature and air temperature in daytime showed certain negative linear correlation in regular layout blocks within a density ranging from 16% to 49%, while certain positive linear correlation in daytime. Similarly, based on the simulation of wind environment in different urban density module, the overall wind speed at pedestrian height is directly related to the building density in urban blocks, and there is a negative correlation between the two.	Different thermal environment between 25% and 49% density range  23.75℃ 23.35℃ Different wind environment between 25% and 49% density  Density 25% Density 49% range

Intensity Index	Floor Area Ratio is usually used to evaluate the urban development intensity. Through simulation and analysis, for thermal environment in the previous section indicate that the mean air temperature at noon in summer will decrease with the increasing of FAR, and in the early morning will decrease with the increasing of FAR. However, due to the experiment, there is no direct correlation between the overall wind speed at pedestrian height and the FAR in urban blocks. But, reasonable combination of space forms is conducive to the optimization of the wind environment in urban blocks	Different thermal environment between 0.27 and 0.81 FAR  FAR 0.27 FAR 0.81 Different wind environment between 25% and 49% density range  FAR 1.1 FAR 13.1
Enclosed Index	Based on the experiment, the enclosure degree has a significant impact on the internal airflow in the block. The greater the degree of encirclement, the smaller the internal wind speed. Under static wind conditions, the heat is more dissipated through the thermal turbulence, and the degree of encirclement has no significant effect on the thermal environment inside the block. In hot and humid areas, proper wind direction in the summer to reduce the degree of enclosure can effectively alleviate the thermal environment inside the block.	Thermal environment between 40% and 70% enclosed degree  40% 70% Different wind environment between 40% and 70% enclosed  40% 70% degree

(Source: Author Made)

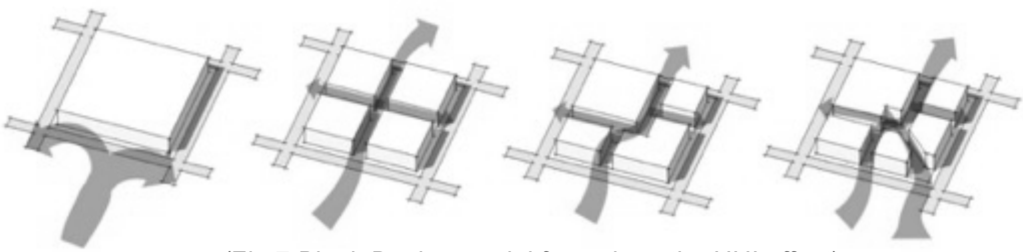
Through above analysis, the interactive mechanism between urban 3D morphology and urban micro climate is complex, the influence indexes are not only included above four indexes. The urban roughness, frontal area index, building slagered height and SVF (Sky View Factor) are also can be considered as index for evaluate the interaction between urban 3D morphology and urban micro climate. However, the urban built environment does not allow to conduct the comprehensive optimize action in each aspect in some extent and construct an absolute best urban micro climate.Therefore, for optimize the large-scale urban 3D morphology, these four indexes which are listed in Table 5 is the main aspect of optimization process.

4. Urban 3D morphology optimization practice

4.2. Thermal environment optimization strategies

Based on the analysis of the mechanism of thermal environment factors set forth in preceding parts, most of the measures for urban design are the guidance and control of urban 3D morphology. Thus, in urban area, street trees, arcades, pulling tent and other continuous shading facilities should be considered to improve body comfort of external space. in the overall design of the block, large volume of podiums should be crushed. Ventilation clearance should be reserved on the frontal area of the block to introduce external airflow into the block to the maximum thus to facilitate heat dissipation within the space. The opening should face the prevailing wind direction in summer (Figure 7).

for more enclosed building layout, the compact form is adverse for ventilation and more anthropologic heat will be generated. Therefore, it is encouraged to keep certain green space within the block for vegetation to release more heat via vegetation transpiration.



(Fig.7 Block Design model for reduce the UHI effect)

Source: Author Made

In addition, excessively low sky visibility or areas with excessively height-width ratio are adverse for air interchange at night. On the main rods, due to the large amount of traffic flow, pedestrian volume and anthropologic heat, building backing distance should be greater to ensure open sky visibility. While for secondary roads, there are less anthropologic heat, sky visibility should be reduced properly to facilitate sun shading and appropriate pedestrian scale.

4.3. Wind environment optimization strategies

Similarly, wind environment optimization strategies are also related with urban 3D environment. However, different with thermal environment, when consider the wind environment optimization, the regional factors may need be involved. Complete protection, restoring natural landscape pattern and establishing networked urban green space system are of great significance to the formation of a good urban climate. It will not only provide more cool and fresh air for the city, but also effectively reduce the urban heat island effect and create a pleasant urban wind environment and thermal environment by protecting and restoring ecological sensitive resources such as rivers, lakes, natural mountains and ecological wetlands, rebuilding the environmental basis of the regional natural background, establishing and preserving urban oases and interlinked green corridor networks, integrating urban artificial greening space with natural ecological space and establishing a complete green ecological network in the city. Thus, the macroscopic strategies for optimization of urban wind environment can be divided into three level, which is planning level, building level and landscape level. (Table 3) Based on the interactive mechanism between urban morphology and micro climate, detailed optimization strategies are detailed provided in these four levels.

Table 3: Macroscopic optimization strategies of wind environment

<table>
<tr><td rowspan="24">Optimization strategy of wind environment</td><td rowspan="11">Planning level</td><td colspan="2">I. Protect and restore urban landscape pattern and build a networked urban green space system</td></tr>
<tr><td rowspan="2">II. Create large urban air corridor</td><td>II-1 Scale and direction of urban ventilation corridor</td></tr>
<tr><td>II-2 Building method of urban ventilation corridor</td></tr>
<tr><td rowspan="4">III. Street orientation and form control</td><td>III-1 Street orientation</td></tr>
<tr><td>III-2 Street system mode</td></tr>
<tr><td>III-3 Street canyon section</td></tr>
<tr><td>III-4 Building interface along the street</td></tr>
<tr><td rowspan="4">IV. Block form control</td><td>IV-1 Reduce building density of the block</td></tr>
<tr><td>IV-2 Height design of ladder-type buildings</td></tr>
<tr><td>IV-3 Reasonable layout of public open space</td></tr>
<tr><td>IV-4 Enhancement and control of block permeability</td></tr>
<tr><td rowspan="9">Building level</td><td rowspan="4">V. Building orientation, scale and form</td><td>V-1 Building orientation</td></tr>
<tr><td>V-2 Form and scale of high-rise buildings</td></tr>
<tr><td>V-3 Optimization of large mass platform type buildings</td></tr>
<tr><td>V-4 Building permeability</td></tr>
<tr><td rowspan="5">VI. Arrangement of buildings</td><td>VI-1 Guide of building in direction of air flow</td></tr>
<tr><td>VI-2 Staggered arrangement of buildings</td></tr>
<tr><td>VI-3 Relationship between high-rise building podiums and major pedestrian areas</td></tr>
<tr><td>VI-4 Optimization of linear combination of high-rise buildings</td></tr>
<tr><td>VI-5 Layout optimization of single high-rise building</td></tr>
<tr><td rowspan="4">Landscape level</td><td rowspan="3">VII. Greening and shading</td><td>VII-1 Green coverage of land</td></tr>
<tr><td>VII-2 Greening and distribution of recreational space and pedestrian areas</td></tr>
<tr><td>VII-3 Roof greening and vertical greening</td></tr>
<tr><td colspan="2">VIII. Windproof measures against strong winds and winter winds</td></tr>
</table>

Source: Author Made

5. Conclusion

Urban 3D morphology is considered as a comprehensive system, meanwhile, urban micro climate is also complex, it impacts by and on the different factors of urban 3D morphology, the any changes of factors belongs to urban 3D morphology are all results the different urban physical environment, and construct the different feeling of people who live in the city. A reasonable and scientific urban 3D morphology can build a comfortable urban micro climate, reduce the UHI and increase the urban ecological security. For this aim, this research through an urban design practice case to analysis the relationship between urban 3D morphology and micro climate through literature review and computer assisted micro climate simulation based on urban physical environment big data. Based on the measurement results, the interactive mechanism between urban 3D morphology and micro climate has been discovered, the analysis consequences indicated that urban micro climate is impacted by different index of urban 3D morphology. In these influence index, the urban height, density, intensity and enclosed index is considered as the major and common measurements impact on both urban thermal and wind environment. Afterwards, this research through these four major aspects to conduct an attempt in micro-climate led urban 3D morphology optimization. Through empirical urban design practice, some strategies are proved can promote and positive impact on urban micro climate, and these strategies are also suitable for other city or site around the world. Summarize above, the consequences of this research proved the interactive mechanism between urban micro climate and comprehensive urban 3D morphology based on digital measurement techniques and physical environment big data. Additionally, the optimization strategies in here are also contribute for further urban design practice. However, there also exist some limitation. Urban space is complex, there exist more potential index may impact on urban micro climate, these indexed should be analysis more detailed in further research.

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