

Study of the Interrelationship between Urban Micro Public Space Morphology and Microclimate

Shanshan HAN¹, Dexuan Song²

¹*College of Architecture and Urban Planning Tongji University;
Key Laboratory of Ecology and Energy Saving Study of Dense Habitat, hanshanshan0816@msn.com*

²*College of Architecture and Urban Planning Tongji University;
Key Laboratory of Ecology and Energy Saving Study of Dense Habitat, dxsong@tongji.edu.cn*

Abstract: In high-density cities, large scale public spaces are becoming more and more precious and scarce. As a complement, micro-public space is an important indicator to measure the quality of urban lives because of its flexible location and convenient accessibility. The geometry prototype enclosed by architectural groups and texture elements as important urban morphology factors are extracted and simplified in this paper to analyze the interrelationship between micro public space morphology and the microclimate. Through the simulation of actual research projects in Shanghai, the accuracy of the simplified model is verified. The spatial and temporal distribution of microclimate is directly related to outdoor thermal comfort. It means that the correlation analysis can not only achieve multi-objective optimization to reduce urban design uncertainty, but also can provide design strategies for healthy urban environment.

Keywords: urban micro public space, urban morphology, microclimate, reactive factors

1. Introduction

With the depletion of urban land resources, activity space is gradually decreasing. The concept of micro public space has increasingly received people's attention. The idea of the miniature public spaces is a broader and richer concept developed on the basis of the notion like pocket parks, mini parks, small squares etc. which were put forward in the 1960s. Unlike other urban public spaces, micro public space is specifically produced in the centre of the city or around the community and is a place for residential daily activities. Beyond this, it also has followed features: 1. small in scale; 2. strong in accessibility; 3. high in usage rate and humanized; 4. Simple in function and human scale. Due to its small size and flexible site selection, it is mostly embedded in residential, working and commercial area. It can not only alleviate the impact of the large-scale park green space lacking caused by the acceleration of urbanization, but also promote rational utilization of street blank spaces and even corner wasteland in urban central areas.

2. The Definition of Urban Micro Public Space



“Micro” or “small” is a relative concept of dimension relationship. The microscopic space in field of environmental psychology discipline refers to an invisible space around the human body while in the perspective of geography it is defined as a concrete space closer to daily life practice. 25m is considered as the most appropriate size in the social environment in Site Planning and it has been pointed out that spatial scales over 100m scarcely emerged in cities (Obuyoshi, 2017). In accordance with above analysis, this paper defines

the concept of “micro-space” in terms of scale, functional attributes and interaction relationship. Consequently, the micro-space refers to the public space in small measurement that mainly served for urban resident daily life in the perspective of human settlements.

Micro public space is defined as a type of space in relation to the large and medium-sized public space in the city, including small parks, small squares, community parks, stadiums and so on. "Small area" is an important feature of micro public space. According to the Hong Kong Planning Standards and Guidelines, the open spaces are categorized into three grades: Regional Open Space (at least 5 ha in size), District Open Space (at least 1 ha in size) and Local Open Space (at least 500 m²). Furthermore, the American Park Association considers the size of the pocket park to be 0.13-2ha and the service radius to be 400m. The Tokyo Park City Park green space construction target determinates the area of the neighbourhood park to be 0.25ha. China's "Park Design Code" (CJJ48-92) stipulates that the area of the residential community should be more than 5,000 square meters.

This study investigates the relationship between urban morphological characteristics and microclimate. The urban forms under various scales of public space are very different. It is determined that the scale of the micro-public space is controlled at 300-15000m², and classified into three categories basing on the size of the area: 300~3000 m² for S-Space, 3000-6000 m² for M-Space, 6000~10000 m² for L-Space (Table 1).

Table 1. Micro Public Spaces and Area Distribution in Shanghai

S			
Area	Xuhui Mall—2500 m ²	ABC Square—2400 m ²	Union Square—3000 m ²
M-			
Area	Xinyi Park—5000 m ²	Zhonghe Square—3800 m ²	Lanxin Square—3000 m ²
L			
Area	Boyang Park—6500 m ²	Huimin Park—6000 m ²	Songhe Park—9500 m ²

The classification methods of micro public spaces overlap with each other to some extent. For example, according to the function, it can be divided into public activity space mainly for public communication; the recreation space for the public to carry out leisure and recreation activities; the community open space mainly composed of urban communities. In terms of the positional relationship between the site and the main road, it can also be classified into following three types: 1. the open space with the total length of the adjacent side of the main road is greater than the depth; 2. open space with the total length of the adjacent side of the main road is less than the depth; 3. closed space where the main road is not adjacent.

3. Literature Review and Research Methodology

The study first identified urban form factors and key environmental parameters through literature review. And then the geometric prototype and texture elements of the miniature public space enclosed by the building group was simplified. The simulation was to performed analyse the simplified model of the urban form factor to study relationship between city shape and microclimate. Finally, the simplified simulation was validated by the actual project simulation.

In the field of environmental climate science, the research of urban microclimate involves three levels: Urban Boundary Layer, Urban Canopy Layer and Urban Street Canyon (USC). Urban Street Canyon studies urban space enclosure pattern such as streets and squares. The literature research on this point is mainly divided into the following aspects: architectural orientation, urban texture characteristics, street aspect ratio, building density, and building enclosure. The urban form factors selected in this paper include building density, building envelope, street aspect ratio, urban texture characteristics, Sky View Factor(SVF), etc. By controlling a single variable during the study the reliability of the simulation can be improved. It is shown that urban block and street space have an impact on the micro-environment in Urban Street Canyon, involving local temperatures, sunshine, wind and air quality in the space. In this article, the main performance indicators for the microclimate environment are the average radiant temperature (T_{mrt}), Universal Thermal Climate Index (UTCI) and wind speed. With the continuous revision and development of the thermal comfort model, the UTCI model has been increasingly used by researchers. Compared with the traditional empirical model, UTCI pays more attention to the human body's heat balance and can directly calculate the equivalent temperature. Compared with the complex experienced model, UTCI pays more attention to the objectivity of the model, which is the most comprehensive and widely used in human fitness indicators.

In 2013, Maro Sino et al. (2013) found that the requirements of residents in different climate zones for micro-public spaces varied greatly. In London, the most considerable factor in designing a successful park is tree and green surface, while in Athens it refers to the ample shade. The highest temperature in Shanghai is 36.8 °C and the lowest temperature is -4.5 °C. The annual average temperature is approximately 16.7 °C. July is the hottest month in one year and June 29 to July 5 is the hottest week. A typical week in summer start from August 24 and end in August 30. Contrarily, January 6th to January 12th is the coldest week and the coldest month is January. February 17th to February 23th is the typical winter week. The purpose of the microclimate design is to encourage users to participate in the local region frequently. Nevertheless, too many activities should be also avoided in maximum degree.

4. Microclimate Analysis According to Space Morphology Factors

4.1 Building density

The building density is the ratio of the sum of the floor area to the base area. The greater the building density, the narrower the air tunnel, and the greater the building's outdoor wind environment is affected by the building density. The public space forms in the building group, and the base scale has a great influence on the simulation results. In order to guarantee the precision, the layout of the "1" type building is estimated as the standard type in terms of setting building simplified model. During simulated period, the base scale remains constant and the

number of buildings randomly reduces. When the number of buildings is the least (5 buildings), the density is 4.30%. As the number of buildings increases by a factor of 5, the building density is 8.59% (10 buildings), 12.89% (15 buildings), and 17.19% (20 buildings) respectively (Table 2). The public space will also be randomly divided into smaller from 8000 to 600 m² by enlarging the building density.

Table 2. Model of building density change (Site : 125m*125m)

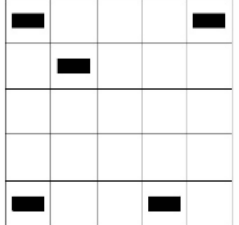
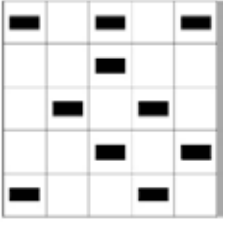
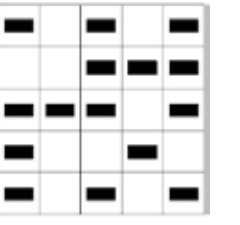
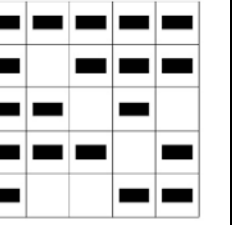
			
4.30%	8.59%	12.89%	17.19%

Table 3. Wind Map and Average Wind Speed According to Building Density (Site : 125m*125m)

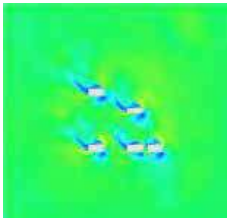
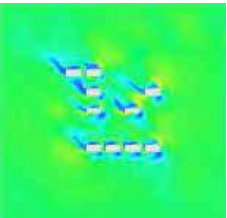
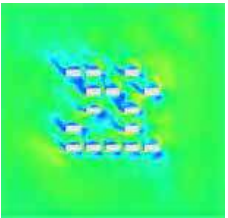
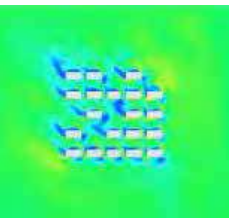

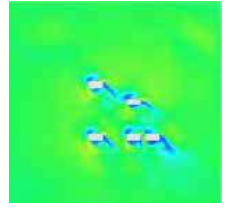
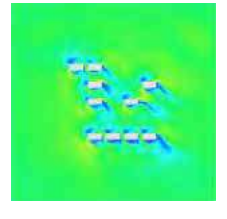
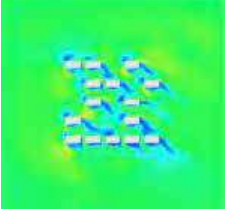
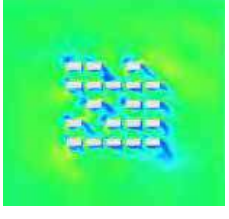

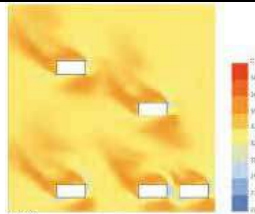
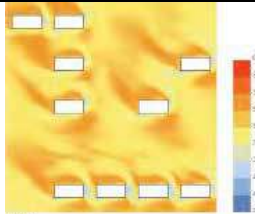
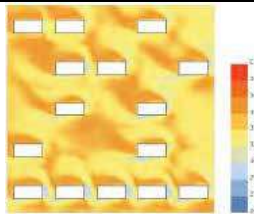
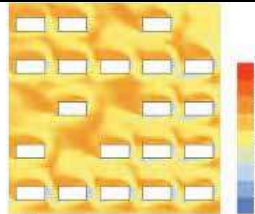
Summer					
Speed	1.933m/s	1.761m/s	1.636m/s	1.530m/s	
Winter					
Speed	2.038m/s	1.798m/s	1.629m/s	1.569m/s	

Table 4. UTCI Simulation According to Building Density (Site : 125m*125m)

			
32.805°C	32.914°C	32.911°C	32.921°C

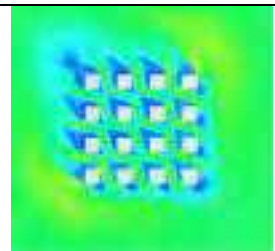
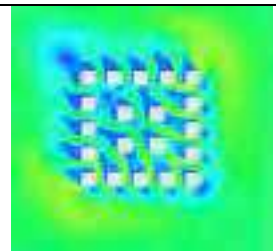
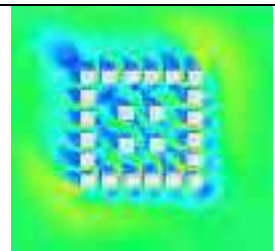
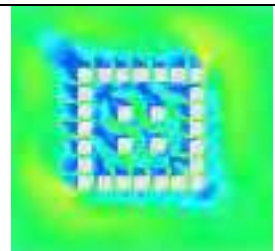
As the building density increases, the overall wind velocity in summer has dropped, and generates easily local high wind speed area (Table 3). Moreover, the ventilation performance of the micro public space in the high-density urban area is highly susceptible to the surrounding buildings as the increase of the static wind zone in the enclosed square. Especially if there is a building blockage in the wind coming direction, it may cause the site to be in a wind shadow area. In summer, this is unfavorable for the wind environment. In winter, this can be used to avoid the cold airflow and improve the thermal comfort.

It can be observed from the UTCI simulation that the change in UTCI is very similar to the wind contour graph and presents a negative correlation with each other (Table 4). That is to say, the UTCI in the static wind zone will be relatively high, and the UTCI in the well-ventilated area will be relatively low. As the density of buildings increases, the shadow area increases, the outdoor thermal comfort decreases as the enlargement of wind shadow area.

4.2 Building Enclosure Degree

In 2012, the Stephen Siuyu Lau et al. (2012) has focused on the guidance of designing small and micro-public open spaces in Hong Kong's high-density urban centers. Stephen Siuyu Lau conducted a comparison research for climatic parameters of different measurement points and relationship with the morphological and greening characteristics and a regression analysis was performed to verify the influence of building geometry and vegetation on outdoor temperature. The results show that wind conditions and building geometry apparently affected outdoor Temperature (Ta). The shading effect of a building may be more important than the shade and evapotranspiration of plants.

Table 5. Wind Map and Speed According to Building Enclosure Degree Variation

0.4	0.5	0.6	0.7
			
0.48m/s	0.47m/s	0.463m/s	0.46m/s

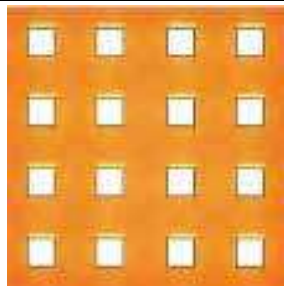
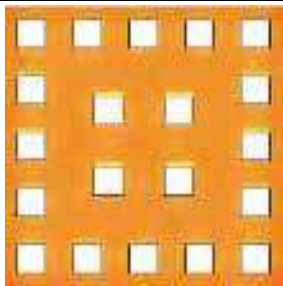
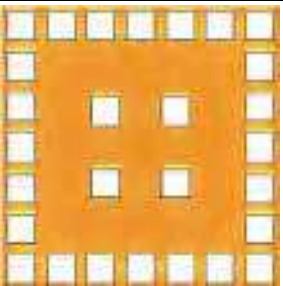

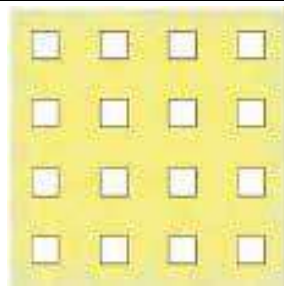
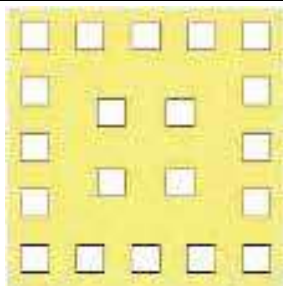
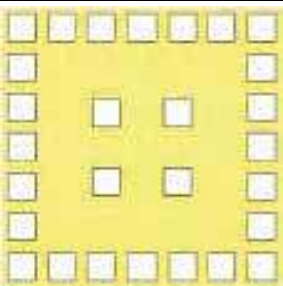

The degree of enclosure refers to the ratio of the length of the building facade along the street to the total extent of the base line, reflecting the openness of the street space. It has a greater impact on solar radiation and ventilation, but more effect on ventilation. The smaller the degree of enclosure, the more open the neighbourhood. The height of the experimental building model for enclosing degree is fixed at 20m, and the outer periphery of the buildings is arranged equidistantly with 4*4, 5*5, 6*6, 7*7 body blocks with same central plot. Simulated wind speed and Tmrt with variations of enclosure are shown in Table 5 and Table 6.

By enhancing the degree of building enclosure, the airflow increasingly difficult to penetrate into the interior of the block. On the other hand, the local high level of wind velocity is easily formed. In this experiment, the enclosure extent has negative influence on the wind speed at the pedestrian height of 1.5m above ground level.

By comparing the average Tmrt of the summer solstice day through experiment, with the large level of encirclement the mean Tmrt is the highest at noon during the day and the lowest is achieved in the night. When the degree of encirclement is small, this Tmrt condition indicates contrary performance totally with the large enclosure level. It is indicated that in hot summer and cold winter regions, the variation of the enclosure has negligible effect on the thermal environment inside the block regardless of flow. The relationship between the

dominant wind direction and the degree of enclosure should be properly considered to effectively adjust the microclimate of the plot.

Table 6. Tmrt Change under Different Enclosure Degrees

0.4	0.5	0.7	
			 12:00
24.24°C	24.12°C	23.67°C	Tmrt
			 20:00
20.95°C	21.05°C	21.23°C	Tmrt

4.3 Street Aspect Ratio

Street aspect ratio refers to the ratio of the average building height on both sides of the street to the width of the street (H/W). According to the aspect ratio, the street canyon can be divided into three types: shallow canyon when $H/W < 0.5$; standard canyon when $H/W = 1$; deep canyon when $H/W > 2$. Street aspect ratio has the most significant impact on the specific linear micro public spaces. The most famous Nanjing East walking street in Shanghai is a linear urban public space with a total area of about 3ha. In addition, Shanghai has a number of linear miniature public spaces such as the 550m long Duolun Pedestrian Street (Figure 1) and the 200m long Wujiang Road Pedestrian Street (Figure 2).

Through wind tunnel experiments, Oke (1981) found that when the dominant wind direction is perpendicular to the block canyon and the height and width are relatively small ($H/W < 0.5$), there is no excess airflow exchange between the vortex area on the canyon side and the adjacent buildings. The airflow pattern is similar with that around isolated buildings which is called isolated rough flow. As H/W increases to 0.5~0.65, the airflow between the downward of the layer canyon-side vortex zone and the upward face of the adjacent building forms a secondary circulation which is called the wake interference flow. When the H/W enlarges more than 0.65, the airflow over the building gradually separates from the airflow in the layer canyon, forming a stable circulating flow in the layer canyon, called taxiing airflow. Therefore, the appropriate street aspect ratio can be applied to make the airflow pass through the street and improve the street wind environment.



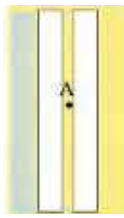

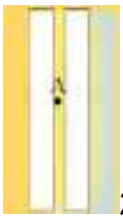
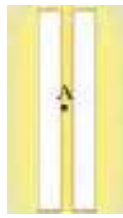
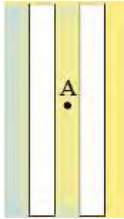

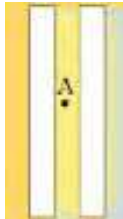
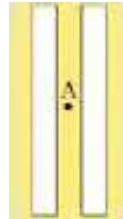
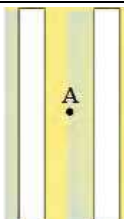
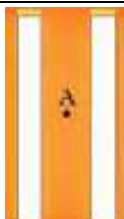
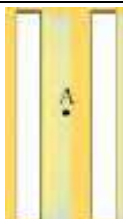
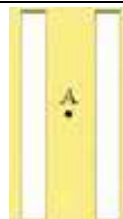
Figure 1. Duolun Walking Street



Figure 2. Wujiang Walking Street

In this experiment the block and building model was simplified into a long strip and performed in a 100m*200m site. The block width is 10m, 20m, 40m, and the aspect ratio (H/W) is 2, 1, 0.5 respectively with 20m building height. *Table 7* shows the measurement point locating the centre of the block. It can be observed from the simulation that as the aspect ratio of the block increases, the average radiant temperature decreases during the day. Meanwhile, the temperature is also reduced significantly. The phenomenon is basically consistent with other scholars' conclusions. On the other hand, with the aspect ratio of the block becomes larges, the visibility of the sky becomes smaller, which is not conducive to heat dissipation at night. Therefore, the average Tmrt at night is positive to the aspect ratio, but the effect on long-wave radiation at night is relatively weak.

Table 7. Tmrt Change Tendency Under Different H/W

Time	8:00	12:00	16 : 00	20:00
H/W=2	 21.02°C	 22.72°C	 21.81°C	 22.00°C
H/W=1	 20.69°C	 23.26°C	 21.28°C	 21.65°C
H/W=0.5	 20.20°C	 24.07°C	 20.50°C	 21.13°C

4.4 Urban texture element

Urban texture elements can be divided into two types: different textured protrusions and variant textured ground surfaces. Protrusions include isolated building, building group, urban forests and sky garden that has developed in recent years. The variant textured ground surfaces refer to urban greening, squares and water. Urban buildings can be regarded as hard elements, and urban greening can be considered as soft mass elements, which are the main factors that interfere with urban microclimate.

Studies and observations have confirmed that urban forests can play a positive role on urban microclimate. Jauregui (1990) reported that the influential range of a large urban park (525 ha) in Mexico City reaches one park's width away from the park and the green area is 2–3.8°C cooler than outside the park. At the smaller scale, even a park as small as 60m*40m can lead to a T_a reduction of 3.8°C inside the park compared with the surrounding area (Saito, Ishihara and Katayama, 1990).

Shashua-Bar and Hoffman (2000) observed the cooling effect of 11 wooded sites with various geometric configurations in Israel and developed an empirical model for predicting the cooling effect of green areas based on the observations. The areas range from 450 to 10000 m². He concluded that the shading effect by tree canopy and the T_a of non-wooded surroundings were most important for the T_a variance inside the sites. In Chang et al.'s (2007) research about 61 Taipei city parks (ranging from 0.1 ha to more than 20 ha), results showed that urban parks were on average cooler than their surroundings.

The temperature can be diminished by the vegetation function of shadowing, evapotranspiration and photosynthesis. However, more vegetation may not cause a temperature drop because it also blocks wind flux and thus affects the heat exchange process, which may be the main strategy for relieving UHI intensity in tropical climate zones. Further research should be performed on the optimal design of greening and the strategic design of the spatial layout.







4.5 SVF

SVF means the area ratio of the visible area of the sky at a position to the entire sky hemisphere. It is one of the important parameters reflecting the geometric shape of the city mainly ranging from 0 to 1. The height, shape and layout of elements such as buildings, structures and green plants in the city will have an impact on the surrounded SVF value. For example, SVF value is small in a dense urban centre while it is large in a flat and open suburb. Therefore, SVF reflects the degree of closure of the block space, and the SVF value is small, which means that the block space is relatively closed. The SVF value can be calculated in terms of the building density, height, spacing and other indicators, and is also a crucial indicator reflecting the urban fabric morphology.

In recent years, Hong Kong scholars (Grimmond, Potter and Zutter, 2001) have concluded based on field measurement research in Hong Kong that when the SVF of a city's street space is larger than 0.5, the probability of generating UHI is negligible. While the heat island effect can be obviously induced under SVF value smaller than 0.35. This indicates that the urban design or the combination pattern design of the construction could optimize the city space condition under specific constant SVF value.

This paper investigated SVF in 6 public spaces including S-Space, M-Space shown in *Table 8*. The result suggests that the public space with an area greater than 6000 m² has a large SVF value and basically does not generate urban heat island effect. When the area is between 3000 and 6000 m², a slight UHI may be produced. Note that surrounded building enclosure and height should be pay attention to controlled to avoid significant UHI with the area less than 3000 m².

Table 8. SVF Changes Under Different Areas

500~3000 m ²	3000~6000 m ²	6000~10000 m ²
		
Tongji Union Square	Xinyi Park	Boyang Park
		
ABC Square	Zhonghe Square	Songhe Park

5. Case Analysis of Micro Public Space

As the spatial form in the actual project is much more complicated than the simplified model, this paper verifies the reliability of the simplified model by investigating the five actual projects and wind simulation. The size of selected 5 actual project areas are similar with each other in the range of 2000~4000m², so as to eliminate the influence of the area factor (Table 9). The surrounding cities varies diversely in form, and Huoshan Park has a high degree of openness where one side is adjacent to the road, and one side is only obscured by the buildings on the corners, forming a very small static wind zone. Other areas are under good wind flow condition and can bring thermal environment improvement. Zhonghe Square and Tongji Union Square have a weakness airflow environment as the blockage of surrounded buildings and high level of enclosure degree. The businesses around Tongji Union Square are mainly catering, causing a large amount of waste heat to be discharged into the square. It is difficult for residents to stay in it for a long time because of the poor ventilated performance resulting in a hot thermal environment. (Figure 3, Figure 4) In the narrow gap between the buildings, an obvious blast jet zone was formed, which adversely affected the surrounding pedestrians. Tongji Mall and ABC Square are close to linear narrow spaces, which are closely related to street aspect ratio and direction. When the orientation of ABC Square and the wind direction are close together, cross-ventilation condition is formed leading to a better airflow environment. Moreover, as the narrow space of Xuhui Mall and the wind direction are under an angle, wind calm area is formed at the entrance and the high air velocity zone is generated at the exit. It can be predicted that as the angle further increases, the wind environment will continue to be exacerbated.

Table 9. Wind Map of 5 Actual Cases

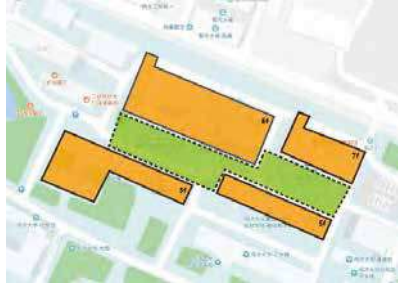
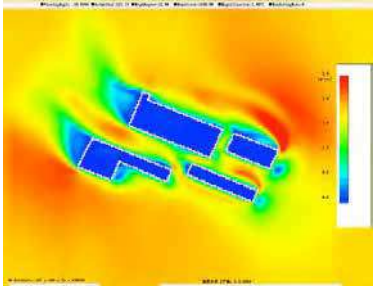

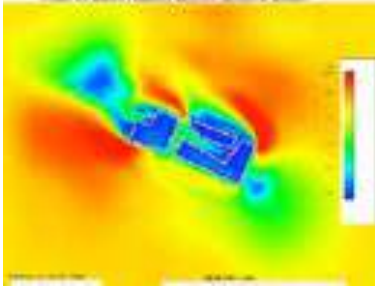

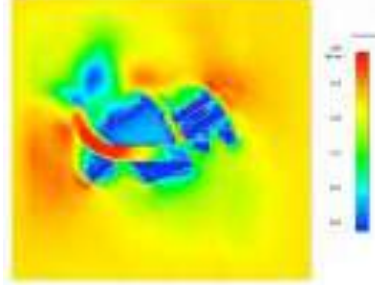

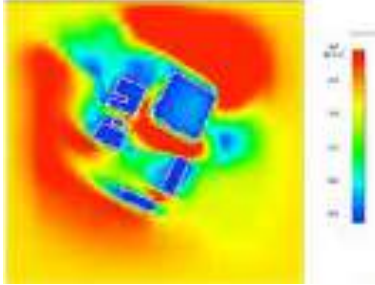

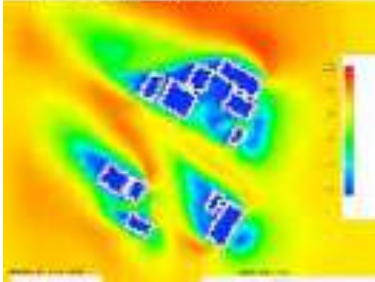
Location	Area	Site Plan	Wind Simulation
ABC Square	2400 m ²		
Tongji Union Square	3000 m ²		
Xuhui Mall	2500 m ²		
Zhonghe Square	3800 m ²		
Huoshan Park	3000 m ²		



Figure 3. Tongji Union Square



Figure 4. Tongji Union Square

It can be observed from the wind simulation comparison between the actual case and the simplified model that although the urban form of the actual project is much more complicated, using simplified model simulation shows a good agreement with the practical cases. In other words, the conclusion of the simplified model can help us to optimize the design of the wind environment in the micro public space. Therefore, simplifying model is an available tool in the process of conducting preliminary design of urban space and qualitative judgment of urban microclimate.

6. Conclusion

The essence of micro-public space is a special functional urban public space created by the designers, scattered or hidden in the urban structure to serve the public directly, could indeed stimulate the social interaction of the crowd. Consequently, urban renewal in high-density central city concentrated on the vitality of public life, especially the updating of small and micro-open spaces is becoming increasingly considerable. Especially with the increase of urban density and mental stress, people need this kind of rest space to get mind relaxation. The present study has provided much useful information for conducting more valid research for future study by refining research methods. It is hopeful that based on the implication from further study in future, a design guideline for policy-makers, urban planners, urban designers and architectures can be formed to create a more energy conscious and comfortable urban environment.

Acknowledgements

The authors acknowledge support from the National Natural Science Foundation of China No.51778424.

References

- [1]Chang C-R, Li M-H, Chang S-D. , 2007, A preliminary study on the local cool-island intensity of Taipei city parks. *Lands Urban Plan*,80(3),86–95.
- [2]Grimmond CSB, Potter SK, Zutter HN, et al., 2001, Rapid methods to estimate sky-view factors applied to urban areas. *International Journal of Climatology*,21(9) ,03–13.

- [3]Jauregui E., 1990, Influence of a large urban park on temperature and convective precipitation in a tropical city. *Energy Build*,15(4) ,57–63.
- [4]Maro Sinou, Amanda Gail Kenton.(2013).Parameters contributing to the design of a successful urban pocket park. PLEA2013-29th Conference, Munich, Germany
- [5]Nobuyoshi A, 2017, *Exterior Design in Architecture* (Beijing, China Architecture & Building Press)
- [6]Oke TR., 1981, Canyon geometry and the nocturnal urban heat island: comparison of scale model and field observations. *Journal of climatology*1: 237–254.
- [7]Saito I, Ishihara O, Katayama T., 1990, Study of the effect of green areas on the thermal environment in an urban area. *Energy Build*, 15(4),93–98.
- [8]Shashua-Bar L, Hoffman ME. , 2000, Vegetation as a climatic component in the design of an urban street: an empirical model for predicting the cooling effect of urban green areas with trees. *Energy Build*,31(2),21– 35.
- [9]Stephen Siuyu Lau., 2012, A preliminary study on environmental performances of pocket parks in high-rise and high-density urban context in Hong Kong. *International Journal of Low-Carbon Technologies*,0,1-11

The tables and figures are drawn by the authors.