The Journal of Public Space
ISSN 2206-9658
2020 | Vol. 5 n. 2
https://www.journalpublicspace.org

City Space Architecture

THE JOURNAL OF PUBLIC SPACE

What can urban design learn from changing winds?
A case study of public space in Nanjing (1990s-2010s)

Qiuxia Xu, Zhen Xu
College of Landscape Architecture, Nanjing Forestry University, China
xuqiuxia@njfu.edu.cn | *xuzhen@njfu.edu.cn*

Abstract
Climate is one of the prominent and persistent factors affecting the human habitat. During the recent urbanization, human society has left remarkable environment footprints including the macro- and micro- climates related to human settlement. It's essential for urban planning decision-maker to contextualize people's wellbeing in the public space and micro-climate changes. The adverse changes of micro-climate are usually related more to local developments than to global changes, with the causality relatively feasible to detect.
Characteristic of openness, the open spaces play an important role as outdoor relaxation and wind corridor, which is precious yet vulnerable assets for the citizens' wellbeing. Agglomerated and unintentional developments inevitably change the wind patterns which potentially affect public life. A longitudinal study of such circumstance will provide knowledge and lessons for sustainable and salutary urban design.
Based on CFD simulation, this paper compared the static winter and summer airflows patterns of the Drum Tower area in downtown Nanjing during the period of 1990s-2010s. The results indicated that the wind pattern complexity increased gradually, the outdoor comfortability degraded dramatically in some areas, the environment inequity might be deteriorated too. The researcher suggests putting micro-climate issues firmly on the agenda of public wellbeing policy, involving various stakeholders in the assessment and urban design code with technical and social supports.

Keywords: public space, urban design, CFD simulation

To cite this article:
Xu, Q., Xu, Z. (2020). What can urban design learn from changing winds? A case study of public space in Nanjing (1990s-2010s), *The Journal of Public Space*, 5(2), 7-22, DOI 10.32891/jps.v5i2.1278

This article has been double blind peer reviewed and accepted for publication in *The Journal of Public Space*.
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1. Introduction

Open space is an area where people can enter freely and spontaneously, including parks and public green spaces, idle places, waterfront areas, etc. (Lynch, Banerjee and Southworth, 1990). The design concept of open space is often conducive to the occupation and use of the public, providing residents with recreational places, encouraging outdoor activities and creating a vibrant city. Open spaces also have an important impact on the health of residents. A study in Japan analysed the survival rate of 3,144 elderly people and concluded that urban green space has a positive impact on the elderly (Takano, 2002).

When external conditions, weather and open spaces are attractive, people spontaneously participate in activities including walking, breathing fresh air, stopping to watch interesting things, sun exposure, and so forth (Gehl and Koch, 2011). Recent studies have shown that the wind environment is an important factor in the use of open space (Lin et al., 2012; Zacharias, Stathopoulos and Wu, 2001; Thorsson, Lindqvist and Lindqvist, 2004; Nikolopoulou and Lykoudis, 2007; Eliasson et al., 2007). The wind environment at the pedestrian level is most closely related to human behaviour. Under different outdoor wind speeds at the same temperatures, the human body has different thermal comfort. Neglecting human comfort can lead to a reduction in people's outdoor activities, thereby reducing the city's vitality. The wind environment is also related to heat island effects and air qualities. Oke's observations from a large number of urban heat island effects have found that urban ventilation can promote air circulation, greatly reducing air pollution and even eliminating urban heat islands (Oke, 1973). Liu et al. conducted a study of particulate matters (PM10 and PM2.5) in Beijing for 9 years (2004-2012) and found that the concentration of particulate matter was negatively correlated with wind speed (Liu et al., 2014). Although we cannot change the regional climate, the optimization of build environment can improve the wind comforts of urban outdoor public spaces, thus effectively extending the comfortable time of outdoor climate.

Incorporating climates into the urban design can be traced back to more than 2,000 years ago. In "Ten Books on Architecture", Vitruvius (70BC-15BC) discussed the impact of different climates on the layout of towns and buildings (Vitruvius, 2003). But climate knowledge was rarely applied during urban planning (Eliasson, 2000; Mills, G. 2006), and for the first time in the 1960s and 1970s Germany applied urban climate research to practice (Matzarakis, 2005). Urban planning guidelines, tools like climate maps (Oke, 1984; Bitan, 1988; Golany, 1996), and literature (Balázs, 1989; Evans and Schiller, 1996) have gradually successfully incorporated climate into urban planning. In the current urban planning and design of China, the wind environment of urban outdoor space has not yet received enough attention. Few quantitative winds have been considered in the urban plan or the pre-stage analysis of the urban design.

For urban designers, understanding people's perceptions and assessments of the surrounding environment to urge urban structural reforms is a necessary condition for maintaining the qualities of urban life, such as the reduction of European heatwaves in 2003. The qualities of the public spaces in the city depend on various aspects, and wind comfort has been identified as one of the important factors (Eliasson et al., 2007; Zacharias, Stathopoulos and Wu, 2001). Climate-unaware urban planning exacerbates the already fragile urban microclimate environment, causing public spaces to be

underutilized or idle due to providing an uncomfortable thermal comfort environment and seriously affecting the quality of life of urban populations.
City Centres with dense buildings, overlapping functions, and population agglomeration, face even more prominent problems regarding the wind environment of the city. Since the 1990s, the functions and infrastructures of the old city of Nanjing have been rapidly regenerated, the population has continued to grow, and the urban form has undergone tremendous changes. The high-rise buildings and architectural groups around the open spaces in the urban centre area are increasing, the street canyon effects are enhanced, the space type and spatial form are complex, and the wind environment of the open space faces relatively more complicated factors. Therefore, the wind environment of open space in this high-density urban has become an urgent problem to be solved.
The purpose of this paper is to explore the impact of urban changes on the wind environment in open spaces from a historical perspective. Based on the open space of the Drum Tower area (Nanjing, China) and the surrounding buildings during the period of 1990s-2010s the wind environments on the open space were simulated and it was expected to provide a basis for future urban renewal.

2. Methodology

2.1 Case studies and background

Nanjing is one of the fastest-growing and most densely populated cities in China in the past 20 years. The population of Nanjing has increased by more than 1 million and the city has expanded by 5 to 10 times (Wang et al., 2012). Summer and winter are the representative seasons of Nanjing, and the high humidity exacerbates the summer high heat index and the winter low heat index. Outdoor public spaces in summer and winter have a greater restrictive effect on people's activities, affecting the use of open space.
The annual wind speeds do not change much, and winds will blow in all directions in Nanjing, showing in Figure1. The northeast wind, east wind and southeast wind have a higher frequency, which must be paid attention to in urban planning.

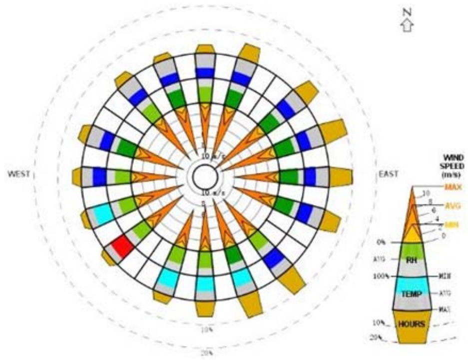


Figure 1. Wind speed and direction in Nanjing.
(Source: Authors)

The Drum Tower area with the important public spaces is an urban centre area with dense buildings, traffic congestion and population agglomeration in Nanjing, China. Since the 1990s, according to the urban planning, this area has begun a large-scale transformation and development in a concentrated manner. The spatial form was large and diversified, and the building height was constantly developing. The most prominent change in the study area was the height of the buildings. In the 1990s, the buildings were dominated by multiple floors, and they were transformed into high-rise buildings in the 2010s. During the same period, 450-metres-high Zifeng Tower was built in this area.
Open spaces, especially civic squares and plazas, had been rare until the 1990s. From then on, the local government gradually invested on construct civic squares to provide outdoor public space for the citizens. The form of ventilation corridors in cities such as

roads and open spaces have remained basically the same, roads have been expanded, and buildings have only been relinquished in some areas. The main open spaces in the area were university, plazas, parks, secondary school, roads and intersections. All the buildings and roads data in this area came from the government.

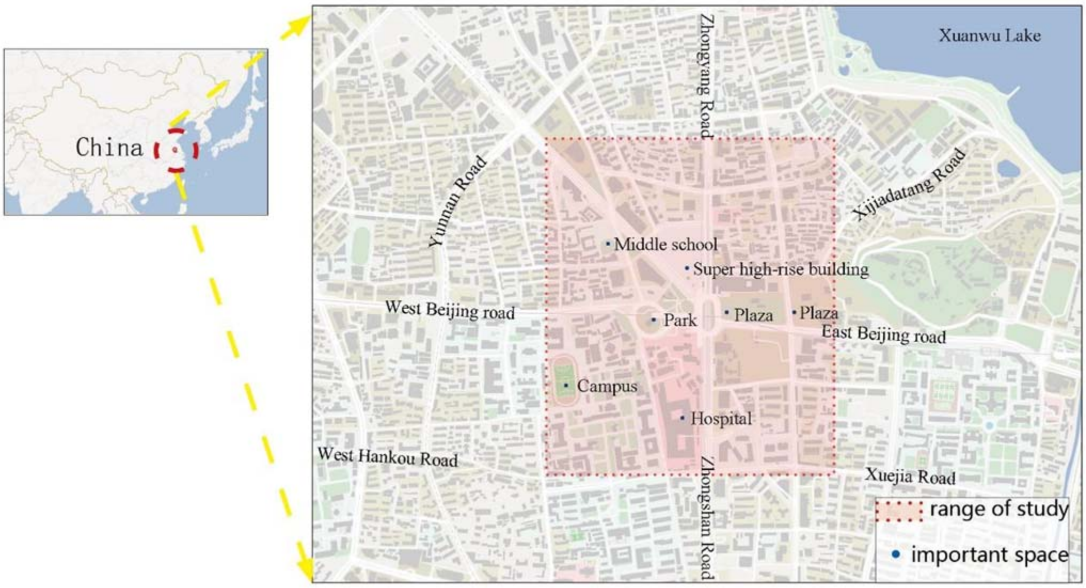


Figure 2. Location of the Drum Tower and Important space
(Source: Authors)

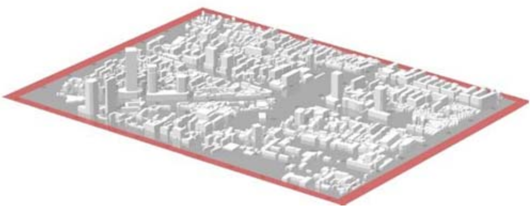


Figure 3. The 3D model of the Drum Tower area, 1990s
(Source: Authors)

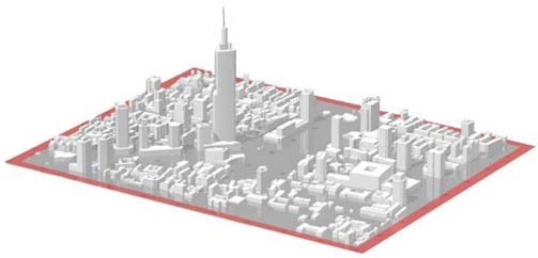


Figure 4. The 3D model of the Drum Tower area, 2010s
(Source: Authors)

2.2 Research methods

In recent years, a specific software of computational fluid dynamics (CFD) has come out, which is low-cost and controllable compared to wind tunnel simulation. Studies have shown that the reliability of CFD for fluid simulation has been widely used in the urban-scale (Murakami et al., 1999). The commercial CFD software XFlow2017 was chosen for this study as it had been used extensively in the automotive industry, aviation, construction, civil engineering, and other industries. XFlow2017 uses the large eddy simulation (LES) model, which has been proven to be more accurate compared to the Reynolds-Averaged Navier–Stokes (RANS) at lower wind speeds (Blocken et al., 2016). Combined CFD software with historical maps of the 1990s and 2010s, the

historical wind environments were deduced, based on the maps of the two periods the buildings modelled in three dimensions by AutoCAD.
To make modelling simpler and manageable, during the modelling process, the outlines of the buildings were simplified. The height of the building was stretched based on the number of layers as building height was indicated this way on the historical maps. Such simplification provides sufficiently accurate buildings for simulation of wind environment particularity on such a large scale. The shrubs and arbours were omitted during the modelling process, and the sloping roofs were also reduced to flat roofs because of the incomplete records of roof forms, shrubs, and arbours in the 1990s. On the other hand, Xu and Han (2018) found that the flat roof or sloping roof and the shrubs and arbours have little effect on the wind environment at large scales.

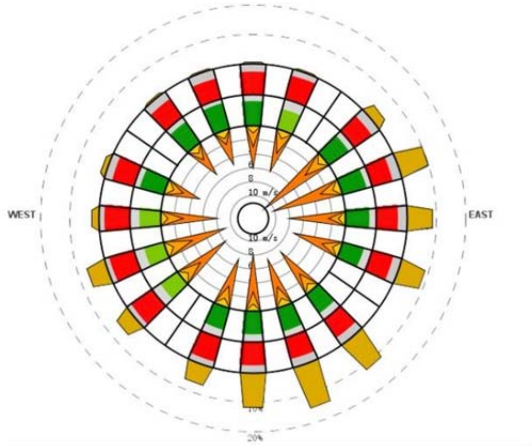


Figure 5. Wind speed, direction, frequency statistics in summer
(Source: Authors)

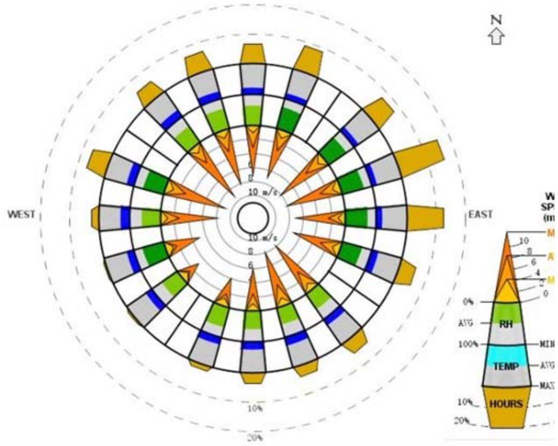


Figure 6. Wind speed, direction, frequency statistics in winter
(Source: Authors)

This paper simulated the wind environment in summer and winter. The meteorological data was the Chinese Standard Weather Data standard provided by the US Department of Energy (gathered and organized jointly by Tsinghua University and the China Meteorological Administration) and the sampling point is 582380. Then wind speed and direction data were analysed in 2016 by the Climate Consultant 6.0 developed by Robin Liggett and Murray Milne at the University of California, Los Angeles Energy Design Tool Research Group. The wind is a process of random fluctuations over time, but average wind speed is an effective and simple parameter for evaluating wind conditions (Melbourne, 1978), so this paper simulated with the average wind speed. In Figure 5 and Figure 6, the wind direction with the highest frequency of summer (June to August) in Nanjing was south-southeast (SSE), and the average wind speed of the dominant wind was about 3m/s. In winter (December to February), the wind direction whose frequency of occurrence was highest was east-northeast (ENE) and the average wind speed of the dominant wind was about 3 m/s. In this paper, the average wind speed of the dominant wind direction was used as the simulation data for the Drum Tower area. Both periods used the same wind speed and direction instead of the average speed for different periods, so we assumed that the wind speed changes were entirely determined by build environment changes.

2.3 Defining Comfort Criteria

Choosing appropriate wind comfort evaluation criteria is the key to the reliable evaluation of pedestrian level wind environment. Regarding the evaluation of the wind environment, there are significant differences in the criteria for the threshold value of wind speed comfort in various countries or studies. In 2006, the Ministry of Construction of China issued the "Green Building Evaluation Standard", which required that the wind speed was less than 5m/s around the pedestrian area in the outdoor, which did not affect the comfort of outdoor activities and building ventilation (Wang and Qin, 2006). In addition to wind speed, the frequency of wind speed is also very important. The American Society of Municipal Engineers proposed wind comfort indicators for various outdoor activities, which specified the average wind speed and gust wind speed threshold and maximum allowable overrun probability for different activities, as shown in Table 1 (American Society of Civil Engineers, 2003). Such standards need to be observed for a period of time, while also ignoring the decline in comfort caused by weak winds in urban centres. Low wind speeds lead to a decline in air quality, pollutants could not be eliminated, and the possibility of epidemics increased (Ng, 2009). The authors of the book Urban Planning and Atmospheric Environment (2004) recommended 1m/s as the standard for urban air pollution diffusion. Furthermore, to enhance the ventilation for pedestrians, in 2015, the Hong Kong Government has developed detailed technical guidelines and plans for high-density, low-speed cities, entitled "Feasibility study for establishment of air ventilation assessment (AVA) system". It was considered that the wind environment with a wind speed exceeding 1.5 m/s pedestrian level was acceptable, but the wind comfort was not specified (Ng, 2009). From the perspective of thermal comfort, Cheng and Ng combed the research on the thermal comfort of the area close to Hong Kong's climate and proposed that 1m/s to 2m/s in the shade is required in summer (Cheng and Ng, 2006). The thermal comfort in cold winter was different from the demand for wind in the hot summer. The wind will worsen the feeling of cold in the outdoors. Yang et al. (2015) believed that the wind speed of 1~2m/s in winter is tolerable. Based on the above various standards and considering the balance of climatic conditions in Nanjing, thermal comfort, mechanical comfort and air quality in Nanjing, we concluded that the acceptable wind speed in summer was 1m/s≤v<5m/s and the acceptable wind speed in winter was 1m/s≤v<2m/s.

Table 1. Comfort Criteria, Based on 5% or 20% probability of Exceedance
Source: American Society of Civil Engineers (2003)

Comfort Level Guideline	Activity	Comfort Ranges for $\underline{U}$ and U_{GEM} 5% probability	Description of Wind Effects	Approximate Corresponding Range for $\underline{U}$ and U_{GEM} at 20% probability
C1＋	Exceeds Comfort Criteria	＞10m/s	Umbrellas used with difficulty Hair blown straight Difficult to walk straight Wind noise on ears unpleasant	6.8m/s

C1	Walking Purposefully or Business Walking	0-10m/s	Force of wind felt on body Trees in leaf begin to move Limit of agreeable wind on land	0-6.8m/s
C2	Strolling or Window Shopping	0-8m/s	Moderate, raises dust, loose paper Hair disarranged Small branches move	0-5.4m/s
C3	Standing or sitting-short exposure	0-6m/s	Hair is disturbed, clothing flaps Light leaves and twigs in motion Wind extends lightweight flag	0-3.9m/s
C4	Standing or sitting-long exposure	0-4m/s	Light wind felt on face Leaves rustle	0-2.6m/s

3. Research results and analysis

3.1 Analysis of summer wind environment changes

When it was the summer simulated at an average speed of 3 m/s with prevailing wind direction (ESS), the average speed was 0.71 m/s at the pedestrian level wind (h=1.5 m) in the study area at the 1990s, and the maximum wind speed was 11.27 m/s. The maximum wind only appeared in the narrow space between buildings. In the 2010s, the average wind speed at 1.5m height in the area increased slightly to 0.84m/s, and the maximum wind speed at the pedestrian level reached 18.04m/s, which also appeared in the narrow space between buildings. In the 1990s, the wind speed in this area of 74.82% was <1m/s. After 20 years of urban development, the low wind area (v<1m/s) decreased by 8.54%, and the region wind speed in 1~2m/s of the area increased by 7.37%. The specific speed distribution was shown in Figure 7, Figure 8. The wind speed distribution trends were consistent in the two periods that the larger the wind speed, the smaller the coverage area.

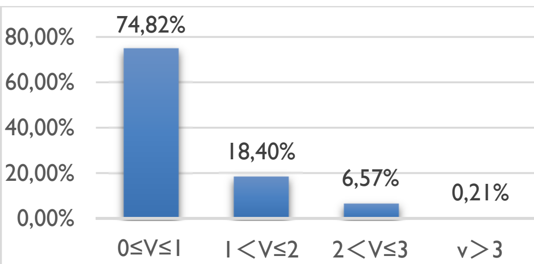


Figure 7. The distribution of wind speed at 1.5m height in the summer, 1990s (Source: Authors)

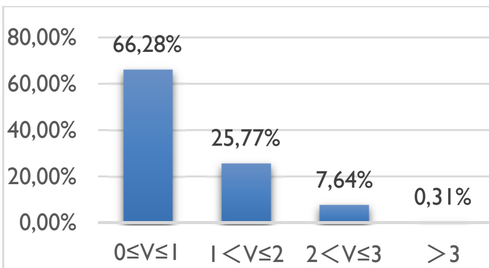
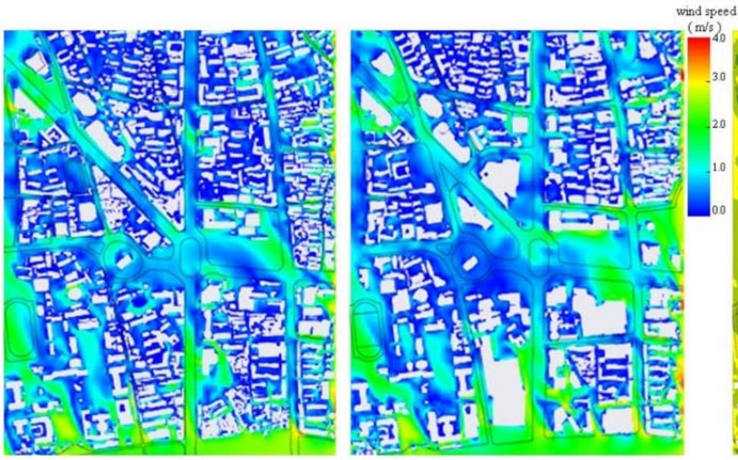


Figure 8. The distribution of wind speed at 1.5m height in the summer, 2010s (Source: Authors)

In the two periods, wind speeds > 4 m/s appeared only in a very small range, and even difficult to find in the visual representation. Therefore, in the illustrated process, with a maximum threshold of 4 m/s, the wind speeds of outdoor spaces at 1.5m height in the two periods were as follows Figure 9. The spatial distributions of wind environment on outdoor spaces at pedestrians-level in the two periods were generally similar. Most of the open spaces inside blocks were in low wind speeds, such as the outdoor spaces in the residential area, campus, main roads, intersections, parks, and plazas. The areas with relatively high wind speed were the spaces along the road and the large open spaces. To find the specific wind speed changes in the open space, we overlaid the pedestrian level wind speed of the 1990s and 2010s in ArcGIS, and removed all the architectural areas in the two periods, as Figure 10. We found that the wind speed increase area was larger, and most of the residential areas and roads wind speeds increased, while the large-scale wind speed reduction appeared in campus, middle school, parks, and squares. In the continuous open space in the middle, there are more speed decelerating areas and a large area of low wind speed. Changes in some areas may be overlooked due to the changes in the building or non-building properties over two periods.



1990s 2010s

Figure 9. Wind speed at 1.5m height in the summer (Source: Authors)

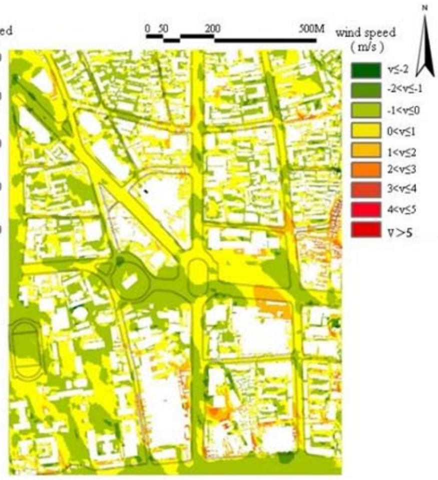
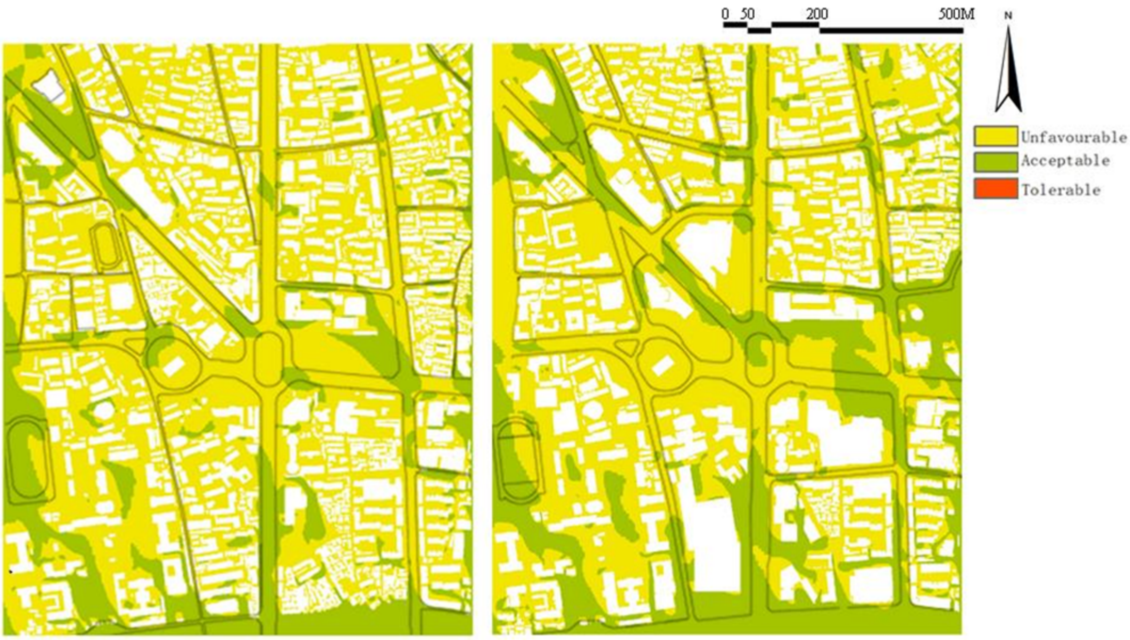


Figure 10. Changes of wind speed at 1.5m height in the summer between the 1990s and 2010s; v>0m/s is the wind speed of the 2010s higher than 1990s, and v<0m/s is the opposite. (Source: Authors)

Combined with the comfort evaluation criteria of pedestrian level wind environment in summer, the 1990s and 2010s outdoor spaces were classified into three categories: unfavourable areas, acceptable areas, tolerable areas, as shown in Figure11. With the average wind speed of the dominant wind direction in summer, 25.17% of the outdoor spaces pedestrian height in the 1990s are acceptable, and the acceptable areas of the 2010s outdoor spaces increased, accounting for 33.72%. The added acceptable area was mainly in the middle of the continuous open space and spaces along with the roads. Unfavourable areas, which may cause problems such as sultry heat and degraded air quality due to low wind speeds, accounted for a large area in both periods. However, with two decades of urban form change, the unfavourable areas have decreased.

Table 2. Assessment results of the wind comfort at 1.5m height for summer
Source: Authors

Comfort zone	1990s		2010s	
	Are(m^2)	Proportion (%)	Are(m^2)	Proportion (%)
Unfavorable areas	612669	74.83	547020	66.28
Acceptable areas	206150	25.17	278314	33.72
Tolerable areas	5	0	5	0



1990s 2010s

Figure 11. Assessment results of wind comfort at 1.5m height for summer
(Source: Authors)

3.2 Analysis of winter wind environment changes

When it was simulated at an average speed of 3 m/s with prevailing wind direction in the winter, the average speed in the study area was 0.70 m/s at 1.5m height in the 1990s, and the maximum wind speed was 3.17 m/s. The average wind speed increased to 0.88 m/s and the maximum wind speed was 17.12 m/s in the 2010s. The 1990s wind speeds were mainly concentrated in 0~2m/s, accounting for 97.38 %. After 20 years of urban development, the outdoor spaces with wind speed <1m/s were reduced by 6.98%, and the range of wind speed 1-2m/s remained unchanged. The specific wind speeds were shown in Figure12 and Fig13.

In the 1990s, the relatively high wind speeds in the study area appeared in the continuous open space. Its long axis had a small angle with the prevailing wind in winter, forming a continuous ventilation corridor. And its wind speed was relatively uniform, between 1~2m/s. The outdoor spaces of the densely built residential area were in a large area with very low wind speeds. In addition to some architectural wind shadow areas, the outdoor spaces of middle school and the university had a wind speed of about 1 m/s in most areas.

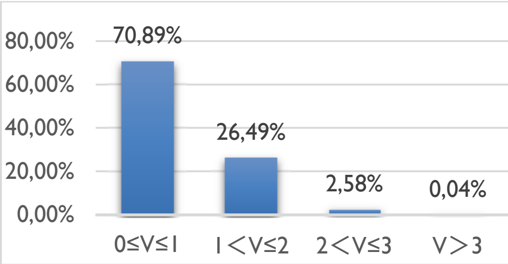


Figure 12. The distribution of wind speed at 1.5m height in the winter, 1990s
(Source: Authors)

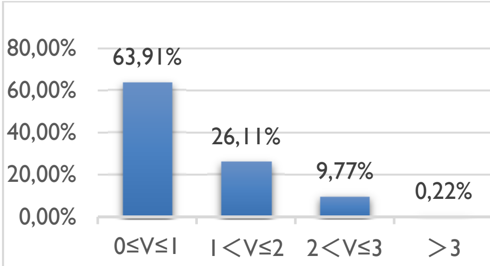
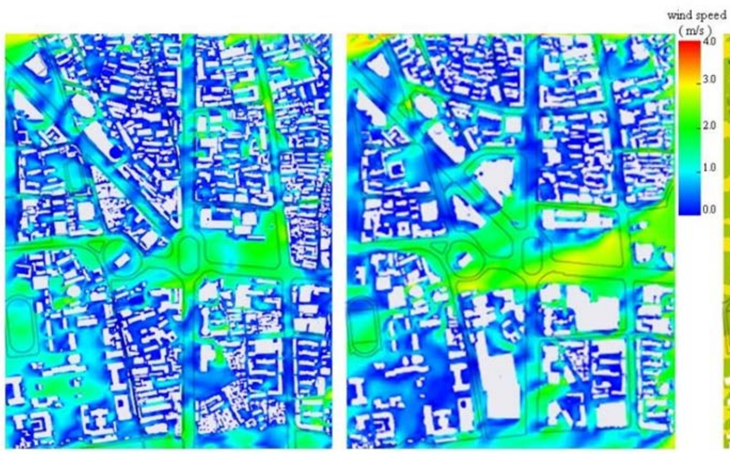


Figure 13. The distribution of wind speed at 1.5m height in the winter, 2010s
(Source: Authors)

In the 2010s, the wind speed in continuous open space was uneven, and some wind speed increased the area with a high wind speed of 2.8m/s, and some wind speeds decreased to cause low wind speeds. Large spaces of residential areas were still at low wind speeds. The wind speeds in the outdoor spaces of the middle school and the university slowed down, and some even experienced a slowdown of 1-2 m/s. The outdoor spaces of the campus were at a low wind speed of about 0.5 m/s. There were no high wind speeds in the new plazas around the high-rise buildings. The wind speeds in the north of the north-south road slowed down and in the south increased.



1990s 2010s
Figure14. Distribution of wind speeds at 1.5m height in the winter
(Source: Authors)

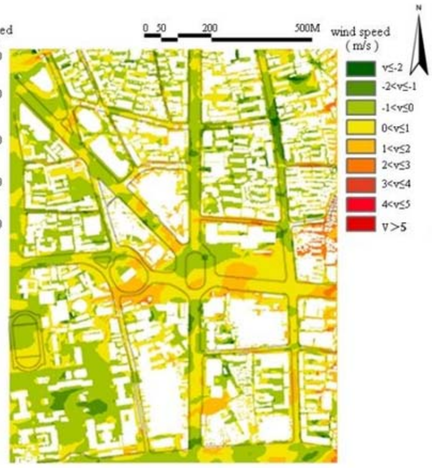


Figure 15. Distribution of wind speed changes at 1.5m height in the winter between the 1990s to 2010s; v>0m/s is the wind speed of the 2010s higher than 1990s, and v<0m/s is the opposite.
(Source: Authors)

Combined with the comfort criteria of the winter wind environment, wind environments of the outdoor spaces were evaluated at 1.5m height in the 1990s and 2010s. We divided the wind environment into three categories the same as summer, as shown in Figure16. 26.11% of the outdoor spaces were relatively comfortable and acceptable at 1.5m height in the 1990s. Its area was close to the 2010s, accounting for

26.49%. In the 1990s, the comfort zone mainly existed in the continuous open space, the campus, and the corners around high-rise buildings. The acceptable areas of the campus and the continuous open space were reduced, the added acceptable areas were the corner spaces around the high-rise buildings. In the two periods, the unfavourable areas of air quality degradation accounted for a large area due to low wind speeds, which was the same as the summer. In the 1990s, the tolerable areas, which affected human activities due to the excessive wind speed, accounted for 2.62%, increased to 9.98% in 2010s. The added tolerable areas were mainly in continuous open space.

Table 3. Assessment results of the wind comfort at 1.5m height for winter
Source: Authors

Comfort zone	1990s		2010s	
	Are(m^2)	Proportion (%)	Are(m^2)	Proportion (%)
Unfavorable area	580281	70.89	527438	63.91
Acceptable area	216813	26.49	215505	26.11
Tolerable area	21477	2.62	82391	9.98

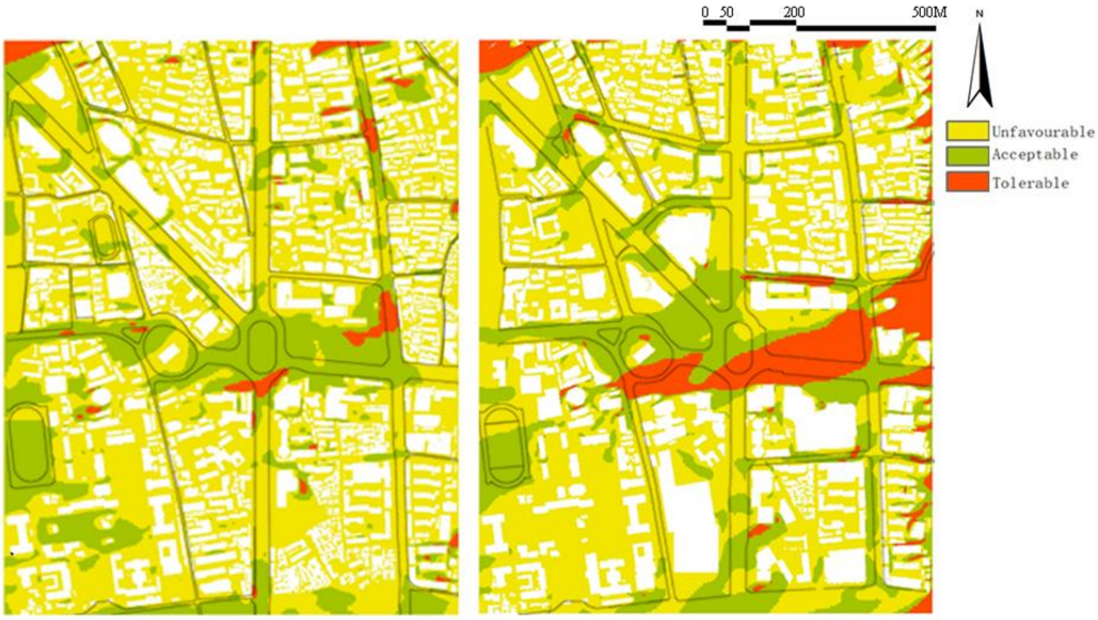


Figure 16. Assessment results of the wind comfort at 1.5m height for winter
(Source: Authors)

4. Discussion

4.1 Overall wind environment changes

In the two periods, the average wind speed was between 0m/s and 2m/s at 1.5m height in most of the study area. Therefore, the pedestrian-level wind environment in the Drum Tower area is low-wind in summer and winter, which is similar to the wind environment in most high-density building cities, Such as Hong Kong and Tokyo (Ng, E. 2009). In the two decades, the overall average speed increased in summer and winter at 1.5m height, the unfavorable wind speed area decreased. In summer, outdoor spaces with relatively comfortable wind speeds increased. Most of the existing research was about the wind weakening phenomenon in the city (Hou et al., 2013; Li et al., 2011). Peng et al. (2018) found that the overall wind weakening in Hong Kong in the past 50 years, but the local weather station showed a slight increase in wind speed from 2010 to 2017 due to the corner effect. For some cities, the reason for the weakening of the wind environment was partly due to the urbanization of the whole city, and some caused by the urbanizations around the wind speed measurement points. In this case, the study area was in central Nanjing with dense buildings in the 1990s and 2010s. In the 2010s, the density of buildings decreased and the building height increased, which is one of the typical models of urban renewal in the central area of big cities. The increase in average wind speed in the study area may be related to the decrease in building density or the corner effect of the high-level buildings. In the 1990s, the residential buildings with small volume and gathering to form a large area of low wind speed areas. In the 2010s, some of these buildings were transformed into giant buildings and the distances between the buildings were increased, so the situation of low wind speed was alleviated. In urban construction, buildings with high density should be avoided as much as possible, or the distance between buildings should be increased. Because the outdoor spaces of this kind of buildings are poorly ventilated at the pedestrian level.

4.2 Wind environment changes in open spaces

In urban planning, the wind environment of urban open spaces should be taken into account when they were used frequently by residents and had a greater impact on their health (Takano, 2002). In the study area, the proportion of acceptable open spaces did not change much, but the spatial organization changed. In the summer, the added open spaces acceptable for comfort were continuous open spaces in the central area (including parks and squares), spaces along the roads, and the reduced acceptable areas were relatively small. In winter, the added acceptable areas were mainly the east-west minor roads, the reduced acceptable open spaces were the campus and continuous open space. In the 2010s, the height of the buildings on both sides of the long axis of the ventilation gallery increased, and its east side changed from the low buildings to open spaces. This caused the wind to directly fill the open spaces, resulting in a faster wind speed into the open spaces. With the influence of the north side high-rise buildings, the wind speeds increased due to the corner effect in some areas. The summer wind environment was more comfortable, but it suffered in the winter. The windward surface of the prevailing wind in summer of open spaces should be open to keep the air flowing, and its windward surface of the prevailing wind in winter should be properly windproof so that it can be more comfortable in both seasons.

The architectural layout of the university had remained largely unchanged, but the changes in the surrounding environment had caused a decline in wind comfort. It gradually became uncomfortable for residents in and around the campus to use open spaces, especially for students at the university. In the design of the buildings, attention should be paid to minimizing the negative impact of the building on the wind environment of the open spaces around it, and some measures can be taken to alleviate the negative impact on the wind in the open spaces. The geometric characteristics of the building can change the airflow pattern at the pedestrian level (Gao et al, 2012). The pedestrian-level wind environment should be simulated during the specific architectures that are designed (Du and Mak, 2018). The architectural design of the overhead floor was a way to reduce the weakening of the wind environment to the surrounding open space (Du and Mak, 2018).

This study included high-rise buildings and even super high-rise buildings of up to 450m. The wind speed around those buildings increased at pedestrian height (h=1.5m) to form a corner effect, but there was little high-speed turbulence affecting winter wind comfort. It had certain benefits to solve urban air pollution and hot air in summer. The vortex was formed on the back of the building to form a complex wind environment when the downdraft in the windward side of the high-rise buildings formed a reflow. It had a negative effect on the elimination of pollutants in the wind shadow area (Oke, 1988). In our study, we found that the presence of high-rise buildings might be beneficial to human comfort by increasing wind speed, but it may be unfavourable to human health due to the concentration of pollutants caused by the vortex on the back of the building. Previous studies were ideal for wind conditions around the building (Li and Stathopoulos, 1997). The shape, orientation, adjacent buildings or obstacles of the building have a large impact on the wind speeds and directions around the building. These should also be considered when designing or researching. The open spaces in the central area of the city are the main concentrated area for outdoor activities of residents, so the quality of its wind environment is crucial. Especially for the elderly and children, they are often vulnerable and sensitive to the wind environment (Takano, 2002). Uncomfortable open spaces have a certain impact on their outdoor activities and outings and even affect their health.

4.4 Wind changes in a ventilation corridor

Connected open spaces and main roads are the main air ducts in the central area of the city, especially important for cities with quiet or weak winds. The "Chapter 11: Urban Design Guidelines" in the Hong Kong planning standard and guideline defines ventilation corridors as large open spaces, such as main roads, connected open spaces, landscaping, non-construction sites, building line setback zones and low-rise buildings; and urban structures that run through high-rise buildings. In this study, the Square, the road intersection, the park, and connected roads formed a continuous ventilation corridor. The long axis of the corridor was at a small angle with the dominant wind direction in winter, and the angle between the dominant wind in summer was about 77.5°. In the winter, the effect of the ventilation corridor was exerted. The direction of the ventilation corridor is within 30° of the prevailing wind, and the ventilation efficiency was better in the air duct (Oke, 1988).

The road angles in the study area had not changed, some buildings on both sides of the road have retreated a certain distance, and the height of the buildings on both sides has increased. We found that most of the ventilation conditions were improved on roads with an angle of less than 30° with the prevailing wind direction, possibly due to the increase in the height of the buildings on both sides to form a street canyon effect. When the ratio H/W (H: average height of the canyon walls, W: the canyon width) is large, the airflow in the street is accelerated in the street, and vortex will occur in the street (Hunter, Watson and Johnson, 1990). When the ratio H/W was greater than 1/5, the airflow above the street is difficult to enter the space (Moonen, Dorer and Carmeliet, 2011). The main road is often polluted by air pollution, and vortex will accumulate pollutants and affect the air quality of the street (Sini, Anquetin and Mestayer, 1996). The ratio H/W of the ventilation corridor and the angle with the street wind have a great influence on the wind environment and should be paid attention to in urban planning.

5. Conclusion

Global warming, heat island effects, and high concentrations of particulate matter are threatening public safety and health. Inadequacies of urban built environments are often verified, leading in many cases to these issues. These issues will become more prominent in the coming decades, and there is an urgent need to actively intervene in these issues in combination with microclimate and urban planning. In urban microclimate, because of the direct relationship between sunshine and urban form, it is the most widely used in urban planning and design. The wind rose diagram is one of the important tools for determining the urban wind environment in the early planning and design. It has certain guiding significance for the location selection of urban industrial and residential areas. For the planning and design of the block scale, the wind speed and direction will also have a large change due to the influence of the surrounding complex buildings, so the wind rose diagram has no guiding significance. However, climatology has certain thresholds for urban planners and designers. It is urgent to enhance multidisciplinary work including urban planning, landscape architecture, and climatology, etc. Applying climate knowledge to urban planning and design at the block scale will significantly improve urban microclimate, thereby extending the stay of urban residents in open spaces and slowing global warming and increasing urban resilience to climate change.

This paper provides a brief history of urban spatial attributes in the central area of Nanjing. It emphasizes the problems of open space in the development of urban blocks that ignore the microclimate, especially the wind. Many cities are experiencing the process of external expansion and internal spatial restructuring. In this process, urban design often involves changing urban space properties, thus affecting the wind environment. Although there are great differences in climate and built environments in different regions, the influence of urban form changes on the wind environment in open spaces still has applied lessons.

The process of urban planning is complex, and the local government policies and the economic interests of developers are usually given priority. Residents are often in a passive position. In the process of spatial property reorganization, buildings around the open space lacking wind environment assessment may lead to changes in wind comfort conditions in open spaces. Although it may be unintentional, the interests of the residents will be impaired. At the individual level, the profitability of urban residents is different, which may lead to internal contradictions among residents and create new environmental injustices. The starting point of modern urban planning is the responsibility of public interest to market failures, considering the needs of society and the interests of individual residents. Open space is the medium for maintaining and realizing the public interest. The assessment of the wind environment in an open space and the improvement of the wind environment comfort of pedestrians are just one of the elements of environmental equity. In urban planning and design, it is necessary to coordinate with other equally important factors to plan and design most optimally. However, due to the lack of plants record in the 1990s, plants were not considered in wind simulation. The wind speed to be presented might higher than the actual speed because plants weaken the wind speed. We also lack actual measurements of wind speed through the placement of the weather station. The accuracy of the simulation will not be verified in this case. Thus, future research can further refine the built environment, including plants, building roofs, etc. By combining measured data with simulated data, our results will be more credible.

Acknowledgement

This work was supported by the Humanity and Social Science Youth Foundation of Ministry of Education [grant number 18YJCZH043].

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