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# Campus Wind Environment Evaluation
## (Case Study: North China University of Technology)

**[1*]Biao Wang, [2]Shuai. Sun, [3]Ying Li, [4]Yuxin. Hou, [5]Yaning Xie, [6]Qiutong Jin, [7]Yuyao Ren**

[1]*Ph.D., Instructor, Dept. of Architecture, North China University of Technology, Rd.5 Jinyuanzhuang, Beijing 100144, China.*

[2]*Ph.D., Assistant Professor, Dept. of Landscape, North China University of Technology, Rd.5 Jinyuanzhuang, Beijing 100144, China.*

[3,4,5,6,7]*B.Sc. Dept. of Architecture, North China University of Technology, Rd.5 Jinyuanzhuang, Beijing 100144, China.*

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**ABSTRACT:** Wind environment in the populated built area especially in campus is important. This study tested 57 crossroad spots over of the whole campus in North China University of Technology (NCUT). The data of wind speed and direction were measured at fixed time and fixed place. The average, maximum values as well as the speed variation scale were calculated. Wind comfort criteria were adopted to examine the spots of still wind zone, wake flow zone and risky zone. The overall measured data in wind scale map was analyzed to find out the changes of wind speed and direction in different seasons and in different locations of the school. Research and analysis show that The results show that the overall wind environment of the campus is good, the average wind speed is between 0.04-4.8, the average wind speed in spring (1.38m/s) is slightly larger than that in autumn (0.87m/s). However, the overall frequency of campus wind comfort location measurement is not high (52% and 30% in spring and autumn respectively). Finally, with analysis results, some suggestions were given to improve the wind environment of NCUT campus. Additional CFD simulations are undertaken in order to help identifying the wind risky points.

**Keywords:** *Wind environment, Campus environment, CFD simulation, Wind comfort.*

## INTRODUCTION

University campus is an important place for college students to study and live in. The quality of the wind environment not only affects the normal development of teaching-practice activities, but also affects the learning and living environment as well as physical and mental health of college students and teachers. Du et al. (2018) have conducted a close study of HKPoly University campus wind environment with CFD simulation. Regarding the comfort analysis of the wind environment, the "China Ecological Housing Technology Assessment Manual" stipulates that when the wind speed is less than 1 m/s in the wind shadow area, the pedestrians basically do not feel the wind comfort. Therefore, the basic outdoor wind speed generally needs to meet more than 1 m/s to achieve better comfort, especially for hot and humid climate cities. Based on the research of green campus in his thesis, Wei (2017) summarized the numerical evaluation criteria of wind speed in wind environment at pedestrian height in summer. In the cold weather in winter, the wind speed based on winter wind protection should be kept relatively low in the urban block area to prevent heat loss to meet the demand of thermal comfort. It is recommended that the wind speed in pedestrian level around the building (1.5m high from the ground) should be less than 5 m/s. At the same time, in order to facilitate the spread of air pollutants on the campus, the wind speed above 1.0m/s should be maintained to ensure air quality. Regarding health and health, Hou Lu shows that for environmental sanitation, when the wind speed is lower than 0.4 m/s, it is not conducive to the

*Corresponding Author Email: uangning@hotmail.com

discharge of pollutants in the air.

As early as the 1970s, Davenport, proposed an outdoor wind comfort criterion that defines the comfort sensation caused by different wind speed ranges for different types of activities. Based on the type of activity mentioned here, the Dutch Wind Disaster Standard (NEN8100) defines the wind comfort and safety at the pedestrian scale with a maximum wind speed of 5 m/s as the critical wind speed (NEN, 2006). Murakami et al. (1980) found that wind speeds of 5-10 m/s have a certain impact on people through the investigation of more than 2,000 people. The wind speed of 10-15 m/s has a serious impact, while more than 15 m/s may cause very much serious impact. China's "Green Building Evaluation Standards" GB/T 50378–2019 (2019) Article 8.2.8 stipulates that for the winter condition, the wind speed at a height of 1.5 m is suggested to be less than 5 m/s for pedestrian area around the building, and less than 2 m/s for outdoor activity areas and children playgrounds. Japanese scholar Shushang Murayama (1992) has conducted abundant experimental research and found that the human body feels relatively comfortable at a height of 1.5m in wind of 1-4m/s. If it is below 1m/s, it may cause discomfort due to weak wind (especially in summer). In summary, we can use 1-5 m/s as a better wind comfort zone, 5 m/s as the basic wind speed limit affecting people's normal activities, and 15 m/s is the threshold of wind environment hazard.

In general, there are three main types of wind environment assessment criteria at the pedestrian height, namely the relative comfort assessment criteria, the wind speed probability statistical evaluation criteria and the wind speed ratio evaluation criteria:

Relative comfort evaluation criteria;

There is a large uncertainty due to wind speed and wind direction. The relative comfort standard is used to quantify the discomfort caused by wind environment, with the maximum acceptable frequency index of the human body. The Dutch wind disaster standard adopts relative Comfort standard (NEN8100).

Wind speed probability evaluation standard;

Because the most intuitive feeling of the wind is the wind speed, the indicator mainly expresses the direct feeling of the person, generally including five levels of comfort, discomfort, very uncomfortable, intolerable and dangerous, respectively corresponding to the wind speed. The general thresholds are 5 m/s, 10 m/s, 15 m/s and 20 m/s. The wind speed here is defined by the average wind speed in 10 minutes or in 1 hour.

Wind speed ratio evaluation standard;

The wind speed ratio is defined as the ratio of the average wind speed of the selected measuring point to the initial average wind speed of the unaffected free wind. This index is used to test and evaluate the influence of terrain and buildings on the wind environment and thus judge and identify bad wind environment. If the average wind speed ratio at a certain point is large, it means that the influence rate of buildings and terrain on the wind environment is high, which indicates that there is big variation in the wind environment.

In order to discover the problems of existing university campus wind environment, and to propose a better optimized wind environment plan for future campus planning, we take the North China University of Technology (NCUT) as the research object, and measure the wind speed level at different locations on the campus. The experimental data observes the wind speed around the campus, maps the wind environment, judges the area with poor wind environment and the area with relatively good wind environment, and analyzes the causes of these phenomena. Finally, the analysis data proposes to improve the campus wind environment and comfort level.

## MATERIALS AND METHODS

The subject method includes measurement experiments and numerical simulation experiments. Field measurement experiments are conducted to obtain specific wind environment data, but are limited to the number and distribution of points. Numerical simulation experiments are used to assist in the

Fig. 1: Wind gauge used for the measurement.

analysis of wind environment data in more regions and different measurement heights. However, because the initial conditions and the inaccuracy of the model physical environment may cause some errors between the simulation results and the actual measurements, the numerical simulation results are used in data analysis and interpretation based on actual measurements. The measurement experiment was conducted through the school's open laboratory project, involving 20-30 students. The experiment selects the main road intersections in the campus of NCUT to measure the wind speed and direction of the pedestrian height (2m). The campus is around 500 m x 500 m and has a L-form public road separating it into two parts. After two years, two seasons of spring (from March to June) and autumn (from September to November), a total of 20 days of samples are collected. Each measurement is approximately 1 week apart and the measurement time is essentially 16:30-17:30. The experimental measurements are the average wind speed, maximum wind speed and high frequency wind direction of each measure point. The wind gauge with wind vane can directly read the instantaneous wind speed with an accuracy of 0.1m/s (Fig. 1). The measurer observes the instantaneous wind speed digital change, and records the average value of the data appearing in around every five seconds. For each measurement point a total of 20 sets of average values, and the approximate range of the wind direction were recorded. Each measurement point takes about 2 minutes. There are 57 measuring points on the campus plane, and the measurement is performed in eight groups at the same time (Fig. 2). The measurement interval between every two points is not more than 30 minutes, which ensures that the measurement time at each point is basically the same.

## RESULTS AND DISCUSSION

According to the integration of the measurement data of the four semesters in the past two years, we can map the average wind speed and high-frequency wind direction distribution in the spring and autumn of the NCUT campus, the maximum wind speed distribution map and the wind speed variation distribution map (Fig. 3, 4).

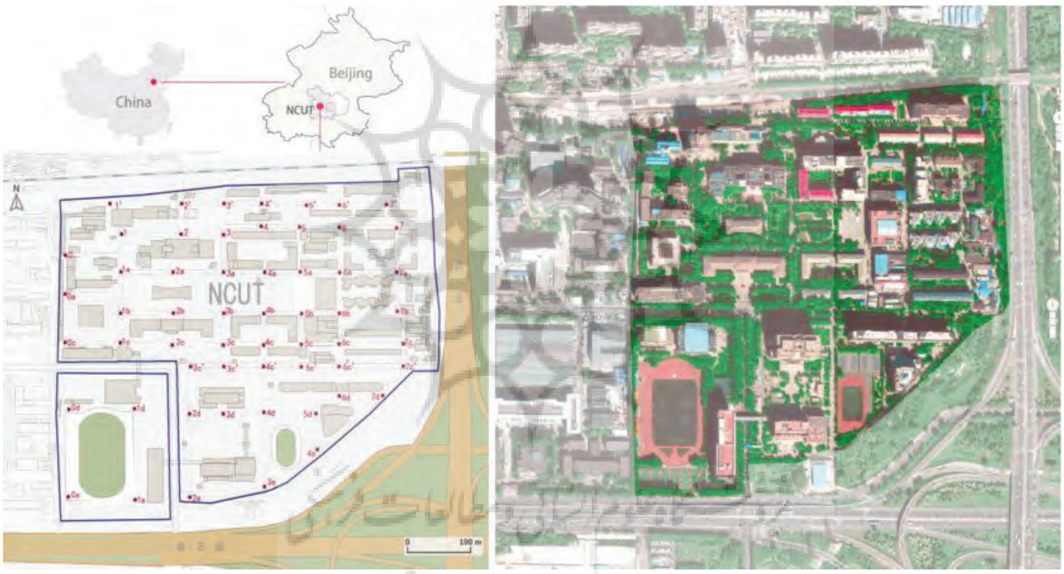


Fig. 2: NCUT campus location, satellite map and measurement points on the plan.

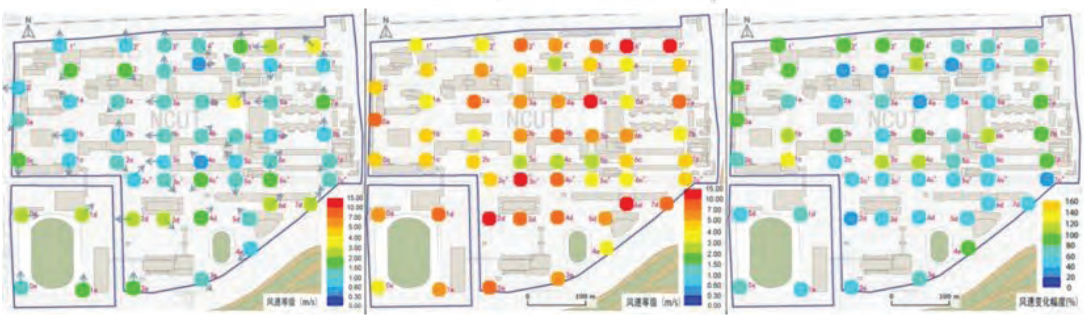

Fig. 3: Spring campus: measurement of the average wind speed distribution (left), maximum wind speed distribution (middle) and wind speed variation distribution (right).

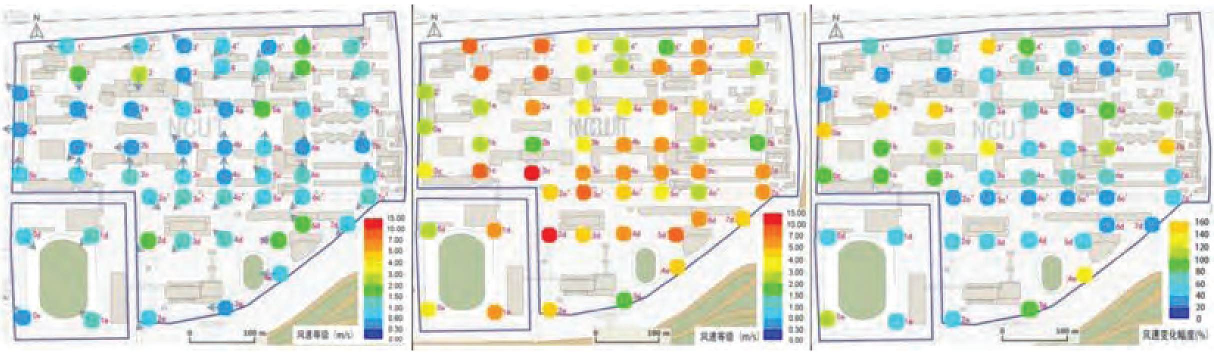

Fig. 4: Autumn campus: measurement of the average wind speed distribution (left), maximum wind speed distribution (middle) and wind speed variation distribution (right).

From the average wind speed distribution map, the average point in spring is higher than that in autumn, and the average in spring and autumn is 0.3-3 m/s. According to the literature, the wind speed less than 0.4 m/s will affect the diffusion of air pollutants. It is found that the average wind speeds of all the points in the campus are above 0.55m/s in spring, but there are three points (0a, 2b and 7b) in autumn with an average wind speed of 0.3- 0.4 m/s, which implies a risk of certain pollutants gathering. Considering that the wind comfort is poor under the condition of 0.6m/s, there may be still a certain sense of wind discomfort in the autumn in these points. According to the 1-5m/s as the generally comfortable wind speed standard, we found that all the points on the campus meet the requirements, and the overall wind environment is good.

According to the statistical radar chart of the highest wind frequency and the spring and autumn of different measuring points, it is found that the main wind direction in the spring is northeast wind and southwest wind, and the main wind direction in autumn is northwest wind and southwest wind. To be more complex and changeable, the overall wind corridor in campus at the pedestrian height is suggested to locate in the southwest to the north.

According to the maximum wind speed distribution map, there are some points (spring: 5a, 6', 7', 3c', 2d and 6d; autumn: 2c and 2d) that reach a very uncomfortable wind speed zone of 10 m/s, which should be taken protective measures. These points are mainly distributed around the high-rise buildings and have a certain open space. According to the magnitude of wind speed change, the wind speed change of most points is between 40-80%. At the same time, most of the points in spring have changes larger than that of autumn, but the points with changes greater than 120% in autumn are more than that in spring. Overall, the points with larger changes are mainly located in the surrounding area of the campus.

In addition, in order to better discover the law and analyze the wind environment of the campus, we have the average wind speed and change interval, the average maximum wind speed and the change interval, the average variation range and the change range of the instantaneous wind speed in the spring and autumn and the two seasons, and the wind comfort zones.

Table 1: Analysis of measured wind environment in each season.

| | Av. wind speed (m/s) | Av. wind speed interval (m/s) | Av. max. wind speed (m/s) | Max. wind speed interval (m/s) | Av. wind speed change (%) | Pct. of comfort-able wind measures (%) | Pct. of wind shadow measures (%) | Pct. of static wind measures (%) | Risky wind points | Av. Ratio of risky wind of each point (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| Spring | 1.38 | 0.1-5.7 | 2.58 | 0.4-9.5 | 59.9 | 51.6 | 40.8 | 9 | 2 | 0.8 |
| Autumn | 0.87 | 0.02-4.2 | 1.5 | 0.3-6.6 | 67.4 | 29.9 | 57.4 | 19.6 | 0 | 0 |
| Av. | 1.13 | 0.04-4.8 | 2.04 | 0.3-7.9 | 67.6 | 40.4 | 53.9 | 16 | | |

The area, wind shadow area, static wind area and wind disaster point were analyzed and statistically analyzed, mainly through the frequency ratio of the instantaneous wind speed of each measuring point appearing in a certain interval, as shown in Table 1.

It can be seen from the table that the average wind speed and the average maximum wind speed in spring are larger than those in autumn, and the overall variation range of average and maximum wind speed are also larger; however, the wind speed changes at specific points are larger in autumn, indicating that the average wind speed change is larger than that of spring. The overall average is less than 1 m/s and the wind comfort is not very good in autumn. Generally, the frequency of wind comfort zone measurement is not high (only 40%), and the percentage of comfortable points in spring is higher than that in autumn, though it’s only half of the instantaneous wind speed is between 1-5 m/s. On the other hand, the wind shadow area and the static wind area in autumn are generally larger than those in spring. Especially in the static wind zone, the instantaneous wind speed in the autumn measuring point accounts for nearly 20%, which has greater discomfort and risk of pollutant accumulation. However, for wind danger with instantaneous wind speeds greater than 15 m/s, only one point each day (5a and 6') were found in two days of spring, with potential wind danger rates 0.6% and 1% respectively, which surpass the dangerous wind environment standards (0.05%) and thus special attention for these two points is required.

### CFD Simulation Analysis

In addition to the above routine field measurements, we also carried out CFD numerical simulation to evaluate the campus wind environment without blind spots.

In this experiment, the ANSYS14.0 platform FLUENT is used for iterative operation, and the k-e standard turbulence model is selected. The most of the parameter settings can be see the reference of Wang et al. (2015). The initial wind condition is $U = U_0(Z / Z_0)^{\alpha}$ (where the reference wind speed $U_0$=3 m/s, the reference height $Z_0$=10m, rough Degree $\alpha = 0.3$), a three-dimensional model of the campus (including surrounding buildings less than 200 m away). Eight wind inlet directions in 360°with an interval of 45°with uniform wind environment condition are considered. Each scenarios result is shown in Fig.5.

In order to compare CFD results and site measurement, we made a superimposition of the different scenarios with their corresponding transparency percentage according to the wind frequency weight in the annual wind rose diagram provided by the campus weather station (Fig.6b). Therefore the overall average wind environment map of the campus can be superimposed and compared with the on-site measured spring and autumn comprehensive average wind environment map (Fig. 7). Wind speed values comparison of each point is shown in Fig. 8.

From the Fig. 7-8, we can find that the CFD simulation result has much similarity with the site measurement: most points has an average wind speed less than 3 m/s, points with high wind speeds (e.g., 1, 2, 5a, 1d and 6d) show much correlation between the two methods. However, there are still some points (e.g. 2b, 4c’, 5c’, 6c’) showing perceptible differences. Here, with the help of numerical simulation, we can find out those wind risky points and especially the statistic wind position in the campus. According to the fine numerical comparison (Fig. 4), we can see that the total average wind speed of the measured points is 1.15 m/s, and the total average wind speed of the numerical simulation points is 1.14 m/s, which shows an average difference of 37%. As we can find from the different wind rose distribution from data of campus wind measurement and from data in weather station installed over roof (Fig. 6), the autumn-spring data can never the same with the annual wind data, let alone on the direction distribution.

### Campus Wind Environment Improvement

Throughout the above measurement results, we found that the main wind environment problems of the North China University of Technology are: some wind points in the spring (5a, 6') have potential wind danger, some points (5a, 6', 7', 2c, 3c', 2d and 6d) are prone to be very uncomfortable wind conditions, and some points in autumn (0a, 2b and 7b) have

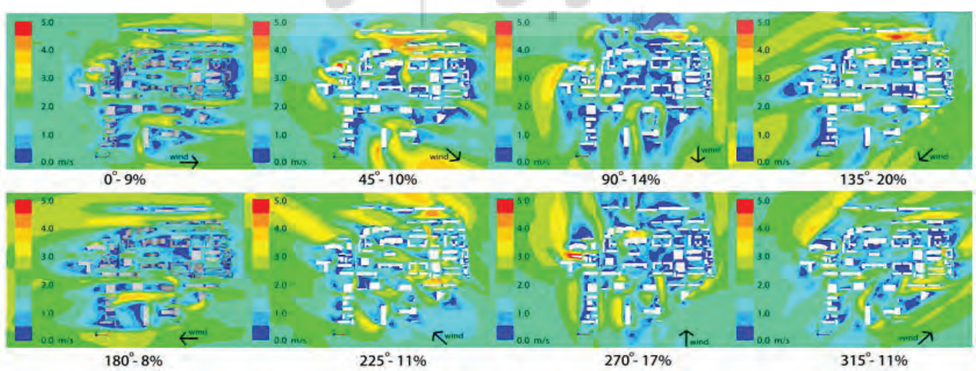


Fig. 5: Wind velocity profile simulation results under different wind inlet direction.

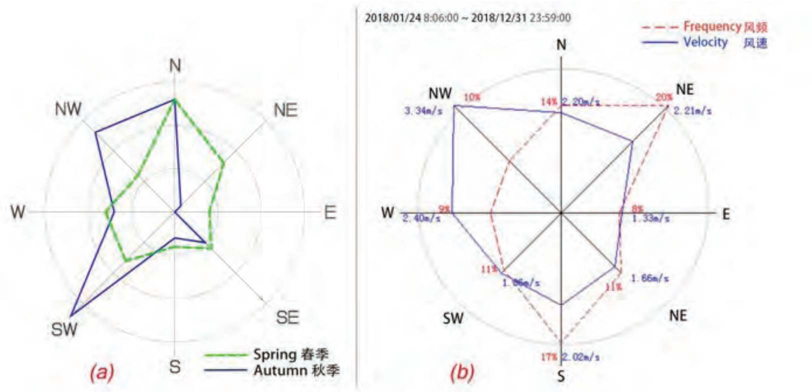


Fig. 6: (a) wind rose distribution from data of campus site measurement (H=2m), (b) wind rose distribution from data of meteorology station on top of roof (H=60m).

very low wind speed and are difficult to diffuse pollutants. Based on this, we intend to adopt includes the following wind environment optimization strategies:

**1) Landscape plant configuration**

On the one hand, green space and vegetation can regulate the air temperature and humidity of the campus through evaporation, shading and cold storage in the soil, dust and sound insulation, and absorb air pollutants. At the same time, it can also form a wind gallery or a wind-blocking forest according to the combination of shapes and forms. Fig. 9a shows an example of hedge with around 2m in height and 0.6m in width. Note that the hedge needs some regular maintenance.

Considering the spring wind disaster point (5a, 6') and the overall wind speed over-point (5a, 6', 7', 2c, 3c', 2d and 6d), refer to the high-frequency wind direction of each point (Fig. 7 Left), we recommend encrypting the heightened shelter forest in the northeast corner of the campus near the Fifth Ring expressway of Beijing to reduce the impact of the strong winds on the points of 6' and 7'.

**2) Landscape wall configuration**

The layout of the wall has an important influence on the wind environment at the pedestrian scale. Fig. 9b shows an example of artistic wall in brick and steel with around 3m in height. It may be integrated with fountain and sculpture, or some benches for people to rest.

About the NCUT campus wind environment, we found the main reason for the strong winds at 5a is that, the south side of the point is a square, and the north side is a high-rise dormitory building, thus forming two north and south and east and west wind corridors. From the perspective of optimizing the wind environment, it is not realistic to renovate the building, and it is neither appropriate to plant trees in the square. Considering the sidewalk between the points 5a and 5, it is possible to design a windshield wall between the walls and plants. The vines form a landscape piece that reduces the environmental abruptness created by a single windshield fence. In addition, the windy position 6d is located on the elevated corridor of the high-rise dormitory on the north side. The car passage can be redesigned into pedestrian and a wind fence is built in the corridor to

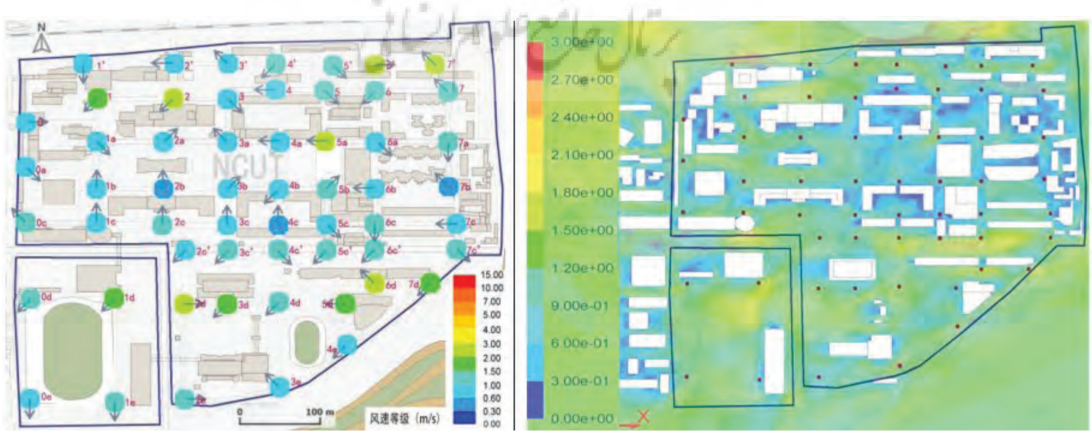


Fig. 7: Measurement of the average campus wind height average wind speed distribution (left), numerical simulation wind average speed with local wind distribution (right)

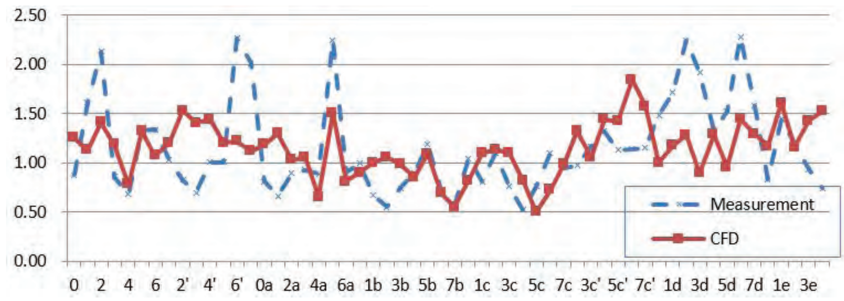


Fig.8: Wind speed comparison between measurement and numerical simulation of each point

ensure the comfortable wind environment of pedestrian.

The two points 0a and 7b are easy to form a static wind zone, possibly due to the proximity of the surrounding walls to the higher walls and the low-rise buildings. Therefore, it may be considered to properly remove low-rise buildings in the courtyard, reduce the height of the surrounding fence or change the physical fence into a railing fence. The improvement of the wind environment at 7b is very important, because the east side of the point is a halal canteen which hosts usually many people. If the polluted air is not reduced in time, it will be a major hidden danger to the health of teachers and students in the long run.

## CONCLUSION

This paper carried out a general survey and analysis of the wind environment of the main traffic nodes of North China University of Technology through the multi-day measurement of 57 points in the spring and autumn. The results show that the overall wind environment of the campus is good, the average wind speed is between 0.04-4.8 m/s, the average wind speed in spring (1.38m/s) is slightly larger than that in autumn (0.87m/s), and the wind direction changes at each measuring point are more complicated. In the spring campus, there are some high wind speeds or dangers. Some parts of the autumn campus are in the static wind zone where there is a risk of pollutant accumulation. This question attempts to adjust the unfavorable position of the wind environment and improve the comfort through the configuration of landscape plants and walls. The overall frequency of campus wind comfort location measurement is not high, 52% and 30% in spring and autumn respectively. It is necessary to elaborate the landscape environment and create a better campus physical environment. The results of CFD simulation are relatively well correlated with the measurement and can be used for better identifying the wind risky points and static wind zones.

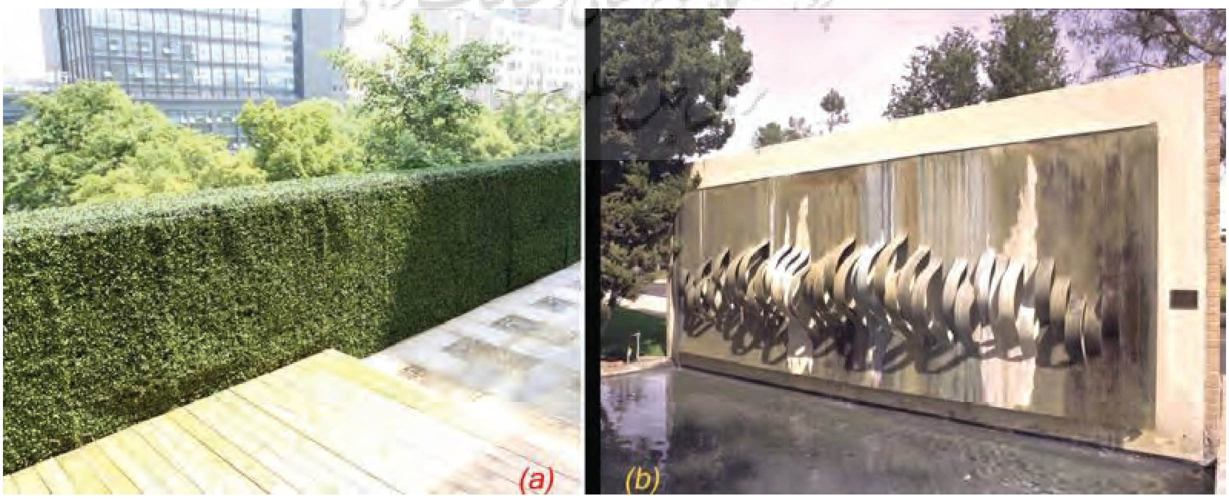


Fig.9: Landscape fence setting reference a: hedge, b: artistic wall

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