Urban Wind Energy Evaluation–A Case Study in NCUT Campus

Biao Wang* and Shuai Sun
Dept. of Architecture, North China University of Technology, Rd. 5 Jinyuanzhuang, Beijing 100144, China

*Corresponding author

Abstract. Urban wind energy exploitation is beneficial for a green city. This article takes a case study of a university campus and evaluates the wind resource over three most potential buildings in the campus. Long-term wind data collected over roof was used as wind rose to offer wind initial condition for CFD numerical simulation. Eight sessions with corresponding wind data were considered for simulation of wind environment of the whole campus. Weighted wind velocities at 6m and 10m above roof of the three chosen buildings were compared. With correction coefficient from values got from simulation and measurement, relative true wind velocities above the three buildings were found mostly more than 3 m/s. One building was taken with detailed evaluation with wind turbine installation and the payback period is 24 years, which is feasible and worthwhile to exploit wind energy in this campus.

Keywords: Urban wind energy; wind environment; wind turbine; CFD.

1. Introduction

Wind energy exploitation in urban area is gaining increasing attention during the recent two decades, as green energy economy and public sustainability consciousness are developing year after year. Urban wind energy exploitation is proved feasible not only technically with new wind turbines effectively adapted to urban environment, but also favorable to utilise ample wind resource around high-rise buildings or in some big open field in the cities [1]. Unlike vast wind farm in countryside, urban wind turbine usually has a capacity less than 50 KW and a small scale with swept area less than 5 m² [2]. As being owned by private families or institutes, it’s economically acceptable and easily to integrated with the local environment with small impact. By category, there are two main types of wind turbines: Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT). HAWT can be divided by the number of its blade into: bi-leaf turbine, tri-leaf turbine and multi-leaf turbine. The tri-leaf type is classical and most seen as it’s the most efficient and stable one. VAWT has two main classes: Darrieus and Savonius. Both HAWT and VAWT have a number of varieties and new invention is still coming out. Generally HAWT is much well developed than VAWT, and takes the majority of the current market. However, as VAWT has advantage in dealing with urban wind environment of high turbulence and low velocity, it’s getting increasing attraction. Apart from these two main types, new wind energy harvesters are appearing such as Windbelt and Piezo-tree by utilizing wind vibration energy [3].

As existing high roughness in urban context, wind turbine installation location therefore should be well examined. Though some high-rise building accelerates wind velocity near the out-wall or above its roof, the optimal position for wind turbine installation is still hard to locate without careful wind evaluation or
simulation, for high wind turbulence and uneven wind velocity distribution make the general evaluation difficult. Some suggestions were therefore given after investigation of numerous installed wind turbines by European Project WINEUR: the mounted building height should be more than 20 m and better 50% higher than the average height of the surroundings; the mast height should be more than 30%-60% of the building height in order to avoid the negative influence of wind turbulence [4].

In this study, we analyse wind resource in North China University of Technology (NCUT) campus, located in Shijingshan District, a central district of the capital city, Beijing. Several high-rise buildings offer the opportunity to exploit wind energy over roof (see the Fig. 1). The installation of wind turbines will serve as an icon of green energy to the students and local dwellers.

2. Methodology
For this study, wind data over the Haoxue building roof (54 m) is obtained since December of 2017. Wind velocity and direction information of each minute at two heights (3m and 6m) above the roof is available. General wind rose of the year 2018 is given (Fig. 2). We can see that the most frequent wind directions are northeast and south while the northwest wind is the strongest.

![Figure 1. NCUT campus location and map.](image1)

![Figure 2. Wind rose of wind data over roof of Haoxue building.](image2)
With this wind rose, we set the initial wind condition for the CFD numerical simulation of the whole campus. Eight different wind velocities were served as the reference velocity $U_0$ while the reference height $h_0$ takes 10m, as shown in the power law:

$$U = U_0 \left( \frac{Z}{h_0} \right)^a$$

(1)

Here it should be noted that the simulation is to get a general wind energy distribution over the map, from a comparative view. Then the simulation results can be evaluated and corrected together with the actual collected wind data over the roof, a relative wind resource evaluation can be given for the NCUT campus. For CFD simulation we used the ANSYS14.0 platform with FLUENT and adopt the k-ε standard turbulence model. The general software setting takes the reference [5] and was validated by wind tunnel experiment.

Fig. 3 shows the simulation 3D model of the campus. Most buildings in the campus and 200m around are presented. There are three buildings for potential wind turbine installation position: Haoxue Building, Hanxue Building and Boyuan Building. Their roof heights and plan area are given.

3. Simulation Results and Analysis

We run eight sessions of simulation and find out the “Area weighted integral” values of the wind velocity on floor plan at two heights above the roof: 6m and 10m. Results of wind velocity at different level above the roofs are show in Table 1. We can see that the values vary with the wind inlet directions. 45°and 270°are the two most windy inlet directions. Though lower than the Hanxue Building, Boyuan Building shows strong wind in some directions such as 45°and 315°. With the same height, Haoxue Building shows generally better wind condition than Hanxue Building in most inlet directions, except 135°. However, considering the roof area, which is important for the number of wind turbines that can be installed, Hanxue Building would be a choice of advantage.

Table 1. Weighted wind velocity of different level over roof of the three buildings (m/s).

| Wind inlet directions (°) | 0    | 45   | 90   | 135  | 180  | 225  | 270  | 315  |
|--------------------------|------|------|------|------|------|------|------|------|
| Bo6m                     | 2.54 | 4.42 | 2.08 | 2.48 | 1.42 | 2.07 | 3.01 | 2.14 |
| Bo10m                    | 3.69 | 5.31 | 2.61 | 2.84 | 1.97 | 2.53 | 4.30 | 2.59 |
| Han6m                    | 3.25 | 3.69 | 2.84 | 3.39 | 1.73 | 2.80 | 4.11 | 1.43 |
| Han10m                   | 3.78 | 4.00 | 3.39 | 3.55 | 2.00 | 2.92 | 4.72 | 1.70 |
| Hao6m                    | 3.94 | 5.36 | 3.30 | 3.11 | 1.84 | 2.88 | 5.51 | 2.45 |
| Hao10m                   | 4.16 | 5.36 | 3.54 | 3.37 | 1.96 | 2.88 | 5.48 | 2.58 |

Note: Bo means Boyuan Building, Han means Hanxue Building, Hao means Haoxue Building.
As the velocity given by the wind rose from the weather station is in arithmetic average, which is not appropriate for wind energy evaluation, as wind power is calculated with the cubic of wind velocity. Therefore, detailed evaluation of the wind data during the year 2018 was analysed and the all year round power-weighted wind velocity at 6m of the weather station can be found and compared with the CFD simulation values at the same point of the station. Then, with the comparative velocity coefficient ($U_{\text{simulation}} / U_{\text{measure}}$), we can get relative true values (corrected) of wind velocities at each evaluation level above the three building roofs (see Table 2). Note that the velocities here are weighted by the wind frequencies from wind rose. We can see that the corrected values are mostly bigger than 3m/s, which is favorable condition for wind energy exploitation. However, there is much variety on the wind potential at different evaluation level and above different building, as well as the exploitable roof area, and then careful evaluation of each case is necessary.

**Table 2.** Relative true values of wind velocity of different level over roof of the three buildings.

| Coefficient of velocity ($U_{\text{simulation}} / U_{\text{measure}}$) at 6m: 0.9807 | Velocity in simulation (m/s) | Corrected velocity (m/s) |
|---|---|---|
| Bo6m | 2.546 | 2.596 |
| Bo10m | 3.248 | 3.312 |
| Han6m | 3.039 | 3.099 |
| Han10m | 3.395 | 3.462 |
| Hao6m | 3.644 | 3.716 |
| Hao10m | 3.770 | 3.844 |

### 4. Wind Turbine Installation

Considering the relatively low speed and high turbulence intensity in a dense urban area like NCUT campus, micro or small vertical axis wind turbines will be used. Among many types of commercial wind turbines in the market, we found one type of Chinese wind turbine that can operate in low-speed wind: Beijio BDP-600/250. The technical parameters and power curve of the turbine are shown in Table 3. An example of installing wind turbine the Haoxue Building is introduced. In order to identify the wind potential, wind speed contour lines of 8 wind inlet directions at Z = 6 m above the roof of the building are evaluated. Considering the size of the selected wind turbines and the space above the roof (20m * 20m), we drew a wind turbine matrix to evaluate the wind power distribution of each wind turbines position (Fig. 4). A distance of three rotor diameters between two wind turbines in the direction perpendicular to the wind is considered. In the second row, the wind turbine is located in the middle of the interval between the two turbines in front, and also three rotor diameters from each.

**Table 3.** Technical parameters and power curve of the selected wind turbine [6].

| Turbine technical parameters | Power curve |
|---|---|
| Rated Power | 600 W |
| Rated wind speed | 8 m/s |
| Min. exploitable wind speed | 3 m/s |
| Size ($W \times L \times D$) | 1.8 m $\times$ 1.8 m $\times$ 1.4 m |
| Swept surface area | 2.5 m$^2$ |
| Weight | 42 kg |
| Noise | |
| Unit price | 1000 $ |
| 2 m/s | 0 |
| Power in experiment | 48 W |
| 3 m/s | 82 W |
| 4 m/s | |
| 5 m/s | 130 W |

According to the power curve of the wind turbine, each wind speed value is calculated into a value of wind potential power. As we know that the wind power is a function of the cube of wind velocity, therefore the local wind distribution data, rather than the average wind speed, is used to assess the
potential of wind energy. Thus the expected wind power generation capacity at each point can be calculated, which actually ranges from 78-86W. If we consider the windiest point (southeast point, 86 W) for example, the payback period $R_n$ of the wind turbine installed here will be:

$$R_n = \frac{(C_{turbine} + C_{support})}{R_{annual}} = \frac{(1000 + 800)}{(0.86*24*365*0.1)} = 23.9 \text{ yrs.}$$

Where $C_{turbine}$ is the cost of wind turbine, $C_{support}$ is the supporting service cost which consists: masts, installation, civil engineering and maintenance, $R_{annual}$ is equivalent to the annual income of electricity generation, 0.1 US dollar per kilowatt is the local electricity bill price. Compared with the typical wind turbine life span (20 yrs.), as well as the aspects of policy subside and measures to improve wind effect over roof, the application of wind turbine BDP-600/250 on the roof of the Haoxue Building is acceptable. However, given that the Haoxue Building is one of the windiest locations in the campus, we must recognize that the wind power potential over the roofs of other buildings is relatively low and may hardly be "profitable".

![Figure 4. Potential positioning of wind turbines (left) and its averaged wind velocity on the roof of the Haoxue Building.](image)

5. Summary
This article takes a case study of the university NCUT campus and evaluates the wind resource over three most potential buildings in the campus. Long-term wind data collected over roof was used as wind rose to offer wind initial condition for CFD numerical simulation. Eight sessions with corresponding wind data is used for simulation of wind environment of the whole campus. Weighted wind velocities at 6m and 10m above roof of the chosen three buildings were compared. The results show that it’s worthwhile and feasible to exploit wind energy in this campus but further detailed evaluation such as environmental impact assessment is needed for wind turbine installation.

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