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*BUILDING SERV ENG RES TECHNOL* 2014 35: 268 originally published online 19 June 2013
DOI: 10.1177/0143624413486997

Article

BUILDING SERVICES ENGINEERING RESEARCH & TECHNOLOGY

Building Serv. Eng. Res. Technol.
2014, Vol. 35(3) 268–279

DOI: 10.1177/0143624413486997
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# An analysis of wind energy potential for micro wind turbine in Hong Kong

**DHW Li[1], KL Cheung[1], WWH Chan[2], CCK Cheng[1] and TCH Wong[1]**

## Abstract

Renewable energy can play an important role in meeting the ultimate goal of replacing parts of fossil fuels to generate sustainable, inexhaustible, clean and safe energy. One of the promising applications of renewable energy technology is the installation of wind turbine that has been identified as having potential for wide-scale application in Hong Kong. Locally, wind turbines are seldom installed in building developments. The barriers include limited installation space available, the heavily obstructed external environments and noise and vibration problems. The apposite places for the installation would be on the roof/rooftop of low-rise buildings located in low-density zones. Relevant wind data and output power generated on-site, which may be quite site-dependent, are essential for modelling and evaluating the wind energy conversion system. Long-term measured wind data are crucial to the study of wind energy potential. This work studies the wind data and micro-wind turbine used in dense urban terrain and low-density area. Technical data including wind speed and output power were analyzed and reported. To achieve 1% of total building energy consumption generated from wind power, 17 micro-wind turbines are required to be installed in this institutional building located in low-density zone.

***Practical application:*** Wind turbine is one of the typical applications of renewable energy technology. However, micro-turbines are not popularly installed in building developments. This work analyses the measured wind data and the energy performance of micro-wind turbines installed in an institutional building. The findings provide the on-site measured data for design and assessment of micro-wind turbines installed in building blocks.

## Keywords

Wind turbine, wind speed, renewable energy

[1]Building Energy Research Group, Department of Civil and Architectural Engineering, City University of Hong Kong, Kowloon, Hong Kong SAR, China
[2]School of Hotel and Tourism Management, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong SAR, China

**Corresponding author:**
DHW Li, Building Energy Research Group, Department of Civil and Architectural Engineering, City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong SAR, China.
Email: bcdanny@cityu.edu.hk

## Introduction

Hong Kong promulgated its first sustainable strategy including the renewable energy (RE) issue in 2005.[1] Different taskforces have been formed to promote energy efficiency, energy conservation and the use of RE and to collect responses from the public.[2] As most energy is consumed by building stock, encouraging the use of RE and building energy efficiency and conservation would be the appropriate energy policy for buildings. To promote RE in the community, various government bodies have implemented different measures. Incentives include the grid connection of RE systems to the main electricity power. The Electrical and Mechanical Services Department provides guidance on the technical aspects of connecting RE systems to the electricity grid.[3] The Buildings Department gives performance indicators[4,5] to measure RE use and building energy conversation. It is argued that setting certain percentages of total building energy consumption to be generated from renewable sources is an effective energy policy to promote the use of renewable and green energy and to encourage building energy efficiency and conservation designs.

Wind energy has been identified as one of the wide-scale applications in Hong Kong,[6] but wind turbines are seldom installed in building developments. Micro-wind turbines usually installed in areas where wind conditions are not favourable as large-scale wind farm due to their sites at dense urban terrain.[7–10] Locally, there is no large-scale wind farm, and wind turbine projects were mainly rated between 140 and 800 kW.[11] Relevant wind data and output power produced are important information for evaluating the performances of wind turbine. General wind measurements have been taken by the Hong Kong Observatory (HKO), as part of their routine work. Wind energy data are often predicted using the Weibull density function.[12–15] Measured wind data are required to assess mathematical models[16] and are helpful in deriving the recommendations for optimum designs.[17,18] However, local measured data and the relevant literatures, indicating design conditions and procedures, seem to be insufficient for building professionals to design appropriate facilities. The barriers to the use of wind energy are the high-initial costs, the large installation space required and the low-output power. Economic aspects can be evaluated by life-cycle cost analysis in terms of the net present value and monetary payback period for wind system with or without grid-connection.[19,20] A life-cycle assessment and life-cycle cost tool for commercial building development in Hong Kong have been provided.[21] Studies of environmental issues include the reduction in greenhouse gases emission due to renewable and green energy sources.[22] Previously, we presented 30-year and 2-year wind data recorded, respectively, in dense urban terrain and low-density zone.[23] Technical data including wind speed obtained from the HKO between 1979 and 2008 and an institution from 2008 to 2009 and computed output power were reported. This work extends the study to include the analysis of wind data currently recorded in 2010 and 2011. The characteristics of the findings and design implications are discussed.

## Site and wind turbine information

The institutional building is located in a low-density area facing several building blocks and hillsides. Figure 1 shows the site layout plan. The institution is a three-storied block. As shown in Figure 2, various RE facilities including three micro-wind turbines were mounted on the roof for electricity generation. Each turbine is of six-blade having a diameter of 900 mm. The turbines were individually placed on three 6-m poles, which were fixed into the floor level in order to reduce shading effect due to surroundings. The output energy is transmitted to a 12-V lead-acid battery for storage and supplies the power to lamps located inside a laboratory. A small weather station was mounted at the parapet with a height of 160 m above mean sea-level for collecting the wind data at an interval of 5 min.

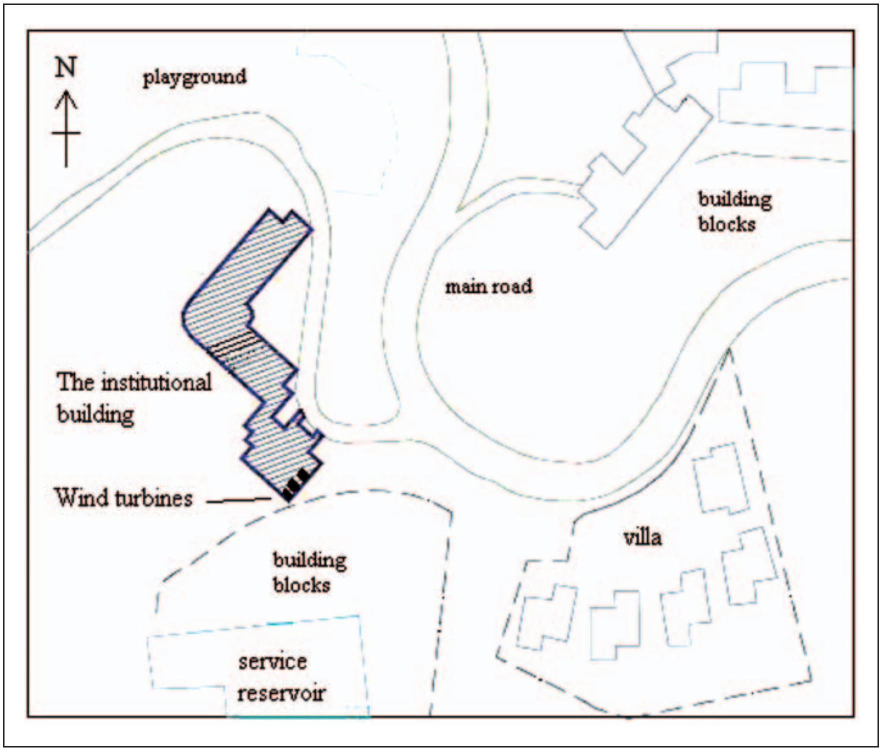


**Figure 1.** Site map for the institutional building.

**Figure 2.** The three micro-wind turbines.

## Data measurement and analysis

To understand the local wind resource, a long-term measured wind database is a pre-requisite. In Hong Kong, the wind data have been recording and publishing annually by the HKO for a long period. The wind data employed for the study were recorded in King's Park weather station located at the city centre representing a dense urban terrain. Wind data were captured at a position of 89.6 m above mean sea-level by Mk 4 cup-generator anemometers installed on top of a mast near the western end of the station. The direction and speed are values for the 60 min ending on each hour. In principle, as many years as possible should be considered for a proper study. Generally, it is believed that weather data based on not less than 30 years can be employed for most wind-related energy system design and analysis.[24] Shorter periods may inherit variations from the long-term average. Longer periods, therefore, can yield quantitative, representative and persuasive results. The 33-year wind data recorded from 1979 to 2011 were obtained from the HKO for the study, and Figure 3 shows the annual average wind speed. The wind speed increased from 2.1 m/s in 1979 to 3.4 m/s in 1982 and quite stable between 1982 and 1998 ranging from 3 to 3.5 m/s. Afterwards, it dropped gradually from 3.1 m/s in 1998 to 2.4 m/s in 2011. The frequency of occurrence for the hourly wind speed was analyzed for every 0.5 m/s, and the results are displayed in Figure 4. The figure shows slightly skewed to the left with two marked peaks of 13.9 and 10.9% at 0.5 and 3 m/s, respectively. Cumulative frequency distribution for the hourly wind speed was calculated and is depicted in Figure 5. About 50% of time, the wind speed exceeds 3 m/s. The findings indicate that the prevailing wind speed at dense urban terrain is quite low.

The Weibull distribution provides a close approximation to the probability laws of many natural phenomena. One of the applications has been used to represent wind speed distributions for wind load studies. Recently, most attention has been focused on this method for wind energy applications not only due to its greater flexibility and simplicity but also because it can give a good fit to experimental data. Mathematically, the Weibull two-parameter density function for wind speed is given as:

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \qquad (1)$$

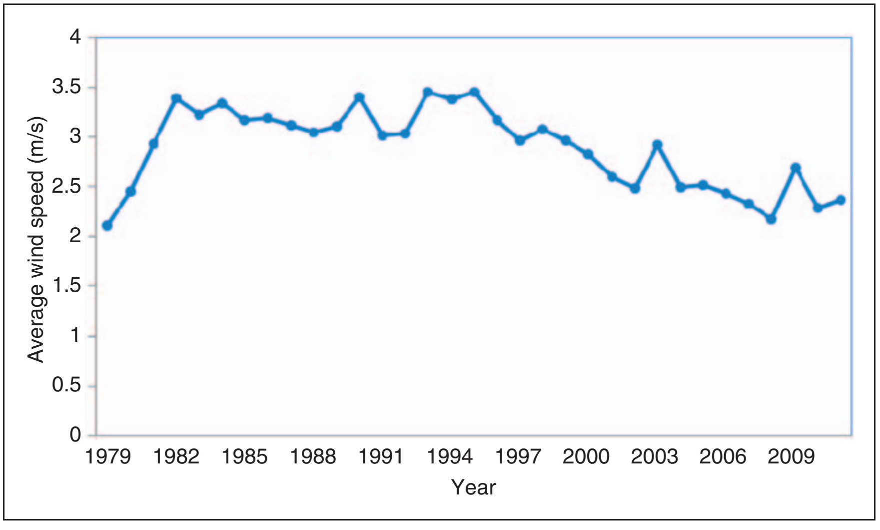


**Figure 3.** Annual average wind speed from 1979 to 2011 recorded in King's Park Station.

where f(v) is the probability density function of the wind achieving speed v, k is a shape parameter and c is a scale parameter.

The Weibull parameters c and k can be approximately determined as

$$k = \left(\frac{\sigma}{\overline{v}}\right)^{-1.086} \quad (1 \leq k \leq 10) \tag{2}$$

$$c = \frac{\overline{v}}{\Gamma(1 + 1/k)} \tag{3}$$

where $\overline{v}$ is the average wind speed $= \frac{1}{n}\sum_{i=1}^{n} v_i$, $\sigma^2$ is the variance of wind velocity $= \frac{1}{n-1}\sum_{i=1}^{n} (v_i - \overline{v})^2$ and $\Gamma$ is the gamma function.

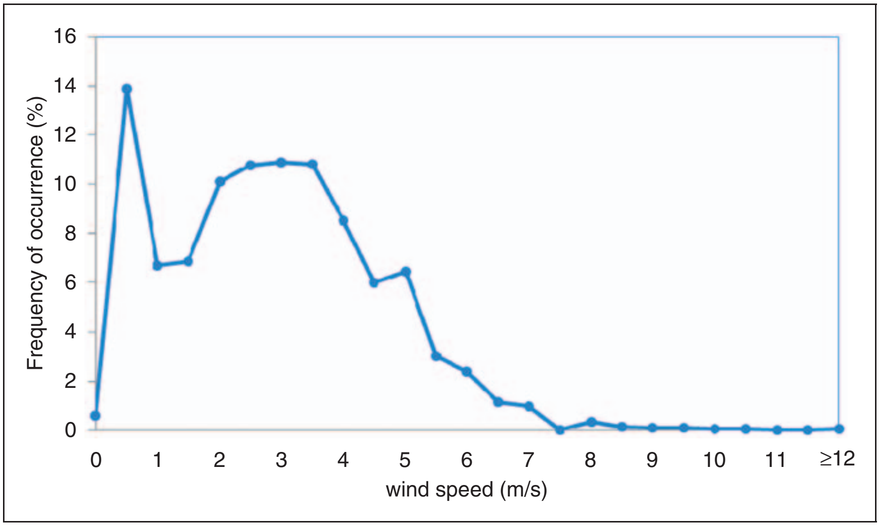


**Figure 4.** Frequency of occurrence for the long-term wind speed (1979–2011) recorded in King's Park Station.

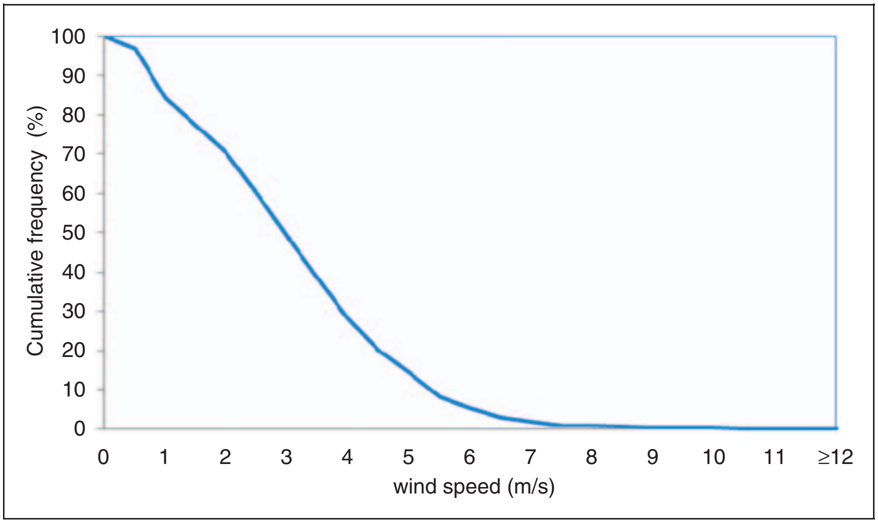


**Figure 5.** Cumulative frequency distribution for long-term wind speed (1979–2011) recorded in King's Park Station.

**Table 1.** Long-term (1979–2011) shape parameters, k and scale parameters, c and average wind speed, at King's Park Station.

| | c | k | mean wind speed $\bar{v}$ (m/s) |
|---|---|---|---|
| Jan | 3.06 | 1.71 | 2.73 |
| Feb | 3.39 | 1.67 | 3.03 |
| Mar | 3.55 | 1.79 | 3.16 |
| Apr | 3.37 | 1.71 | 3.00 |
| May | 3.13 | 1.70 | 2.80 |
| Jun | 3.16 | 1.69 | 2.82 |
| Jul | 3.04 | 1.57 | 2.73 |
| Aug | 2.83 | 1.42 | 2.57 |
| Sep | 3.33 | 1.57 | 2.99 |
| Oct | 3.53 | 1.93 | 3.13 |
| Nov | 3.19 | 1.78 | 2.84 |
| Dec | 2.91 | 1.72 | 2.59 |
| Annual | 3.21 | 1.69 | 2.87 |

Accordingly, the c, k and $\bar{v}$ were computed, and Table 1 summarizes the results between 1979 and 2011 recorded at King's Park Station. It can be seen that the $\bar{v}$ varies from 2.59 m/s in December to 3.16 m/s in March. The range of k is between 1.42 in August and 1.93 in October, but the c value changes from 2.91 in December to 3.55 in March. In general, the c values are in good agreement with $\bar{v}$. Figure 6 plots the mean annual Weibull probability density distribution (f(v)) for the King's Park Station using the 33-year data. The peak f(v) of 0.24 appears at wind speed of around 2.3 m/s. It supports that the wind speed in King's Park Station is rather low.

Wind power $P_W$ (W) is proportional to the cube of v, and it can be given as

$$P_w = 0.5\rho A v^3 \tag{4}$$

where $\rho$ is air density of 1.225 kg/m$^3$ and A is the rotor swept area, m$^2$.

The power output generated by wind turbine ($P_o$ in W) expressed in terms of wind speed is often supplied by the turbine manufacturer. Based on the information from the catalogue, the following equations for the wind turbines installed in the institutional building were obtained:

$$P_o = 0 \quad (\text{for } v < 2.7\text{m/s}) \tag{5}$$

$$p_o = 0.3v^2 + 5.8v - 17.6 \quad (\text{for } 2.7\text{ m/s} \le v \le 16\text{m/s}) \tag{6}$$

$$p_o = -23v^2 + 741v - 5816 \quad (\text{for } 16\text{ m/s} < v \le 18\text{m/s}) \tag{7}$$

$$P_o = 70 \quad (\text{for } v > 18\text{m/s}) \tag{8}$$

No power output is generated when v is less 2.7 m/s (i.e., cut-in wind speed). When v is between 2.7 and 16 m/s, $P_o$ increases with increasing v. Afterwards, $P_o$ drops gradually with increasing v up to 18 m/s. When v is more than 18 m/s, $P_o$ becomes quite constant of 70 W. The performance of wind turbine can be demonstrated using the power coefficient $C_p$ defined as[7]:

$$C_p = P_o/P_w \tag{9}$$

Using equations (5–9), the $C_p$ and output power for the micro-wind turbine at various wind speed were determined, and the results are shown in Figure 7. It can be observed that the $C_p$ varies up to 0.4. With v between 4 and 17 m/s, the corresponding $C_p$ is 0.07 or more.

The generated output power is the essential information for evaluating the performance of wind energy system, which strongly depends on the wind speed for a given location. The wind speeds measured from January 2008 to December 2010 (36 months) at the institutional building were gathered and analyzed. Figure 8 exhibits the hourly wind speed in different months. The hourly wind speed varies from 3.49 m/s in December to 5.37 m/s in April, which is more than that in King's Park Station. Frequency of occurrence for the hourly wind speed at an interval of 0.5 m/s is shown in Figure 9. It is slightly skewed to the

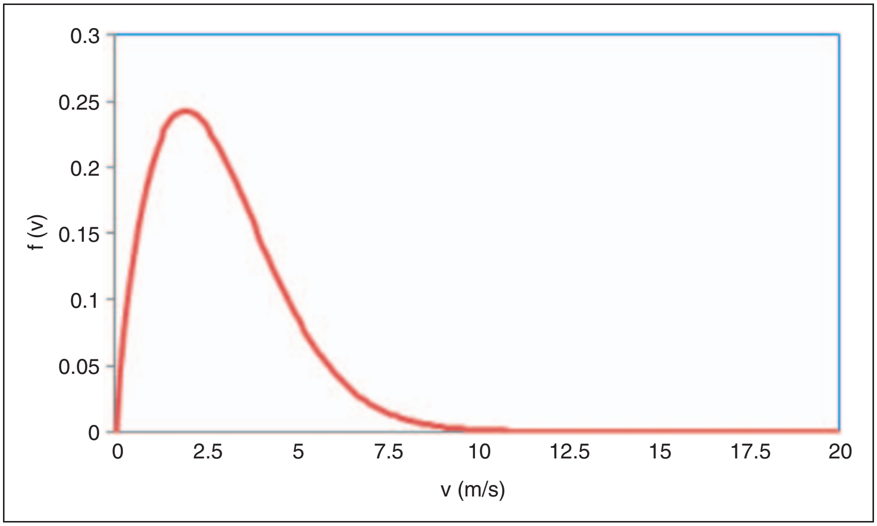


**Figure 6.** Weibull probability density function for the whole year of the King's Park Station based on data recorded between 1979 and 2011.

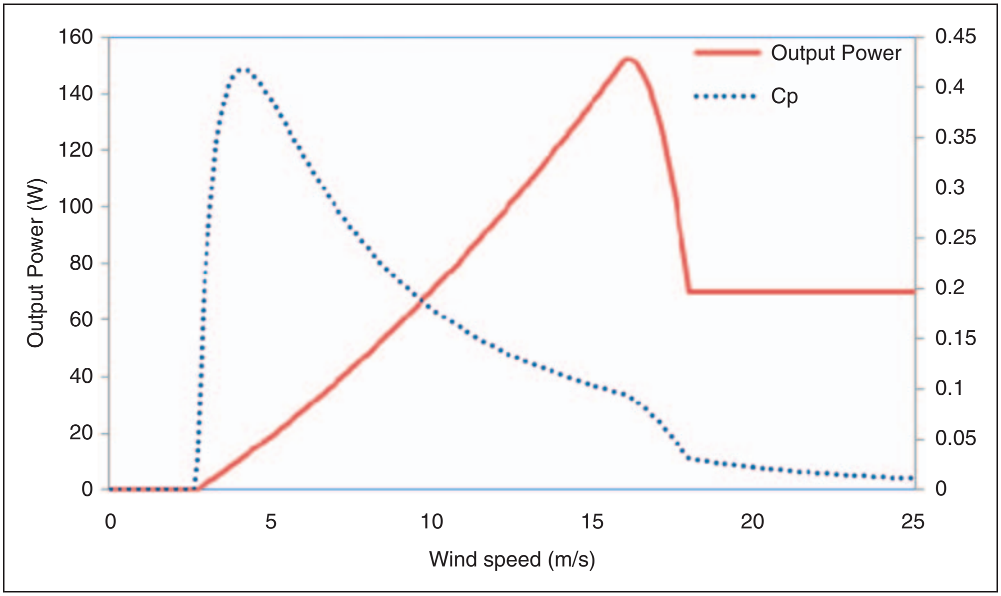


**Figure 7.** Power coefficient and output power versus wind speed.

left with a marked peak of 9.8% at 1 m/s. Cumulative frequency distribution for the hourly wind speed was calculated and is presented in Figure 10. At 50% of time, the wind speed exceeds 3.5 m/s. Generally, the wind speed at the institutional building is larger than that recorded at King's Park Station. The results indicate that building located in low-density area with high-hub level has large prevailing wind speeds.

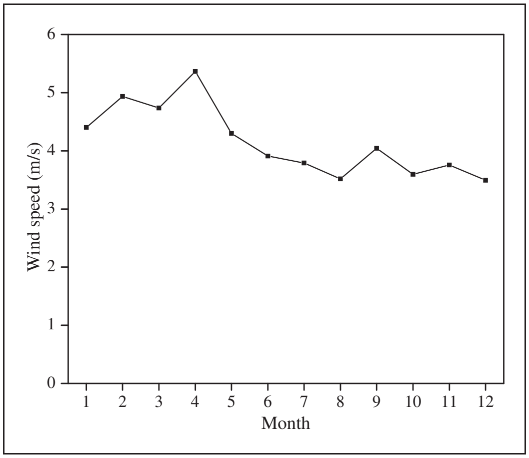


**Figure 8.** Average wind speed for the institutional building in different months.

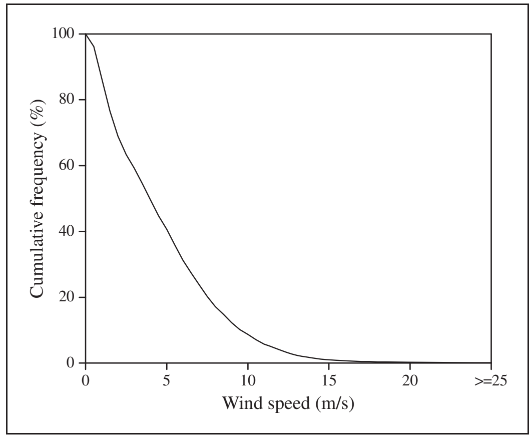


**Figure 10.** Cumulative frequency distribution for the wind speed recorded in the institutional building.

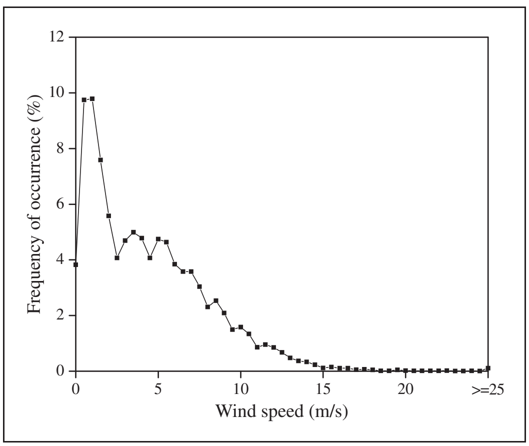


**Figure 9.** Frequency of occurrence for the wind speed recorded in the institutional building.

The percentage of operating hours in a year relies on the wind turbine and the wind speed for a given location. The operating hours are the time when the wind speed is more than the cut-in value (i.e., 2.7 m/s for the present case). Since the wind speed sometimes is lower than 2.7 m/s, the operating percentage would be less than 100%. Figure 11 displays the operating percentage in different months for King's Park Station and the institutional building. The peak value of 58.4% appears in October, while the minimum value is 43.6% in August for King's Park Station. With larger wind speed, the maximum operating percentage of 69.4% occurs in February, and the mean value is 58.6% for the institutional building. The monthly $P_o$ for the two places was estimated, and Figure 12 shows the results. The $P_o$ ranges from 3.6 kWh in December to 6 kWh in March for King's Park Station. With less shading effect and higher hub height, the $P_o$ for the institutional building is higher, ranging between 5 kWh in December and 9.45 kWh in April. The $P_o$ for the whole year was determined to be 82.1 kWh. The mean annual electricity consumption for the institution between 2008 and 2010 was 136,400 kWh (112 kWh/m$^2$). To achieve 1% of the electricity generated by wind energy, 17 micro-wind turbines with the total rated power of around 2.5 kW should be installed. In considering the wind power potential, type of wind turbine and the site features such as terrain and height should be carefully evaluated.

The economical issue, climate change and global environmental hazard posed by emissions from burning fossil fuel have become a strong driving force for the use of renewable and sustainable energy. In Hong Kong, electricity is mainly generated using fossil fuels by two local

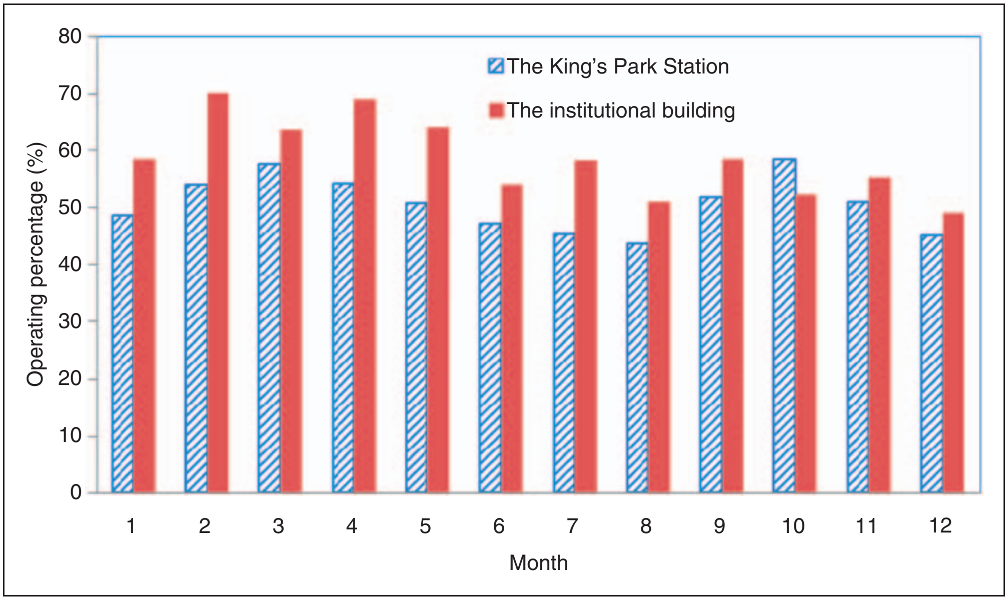


**Figure 11.** Monthly operating percentage of the micro-wind turbine installed at King's Park Station and the roof of the institutional building.

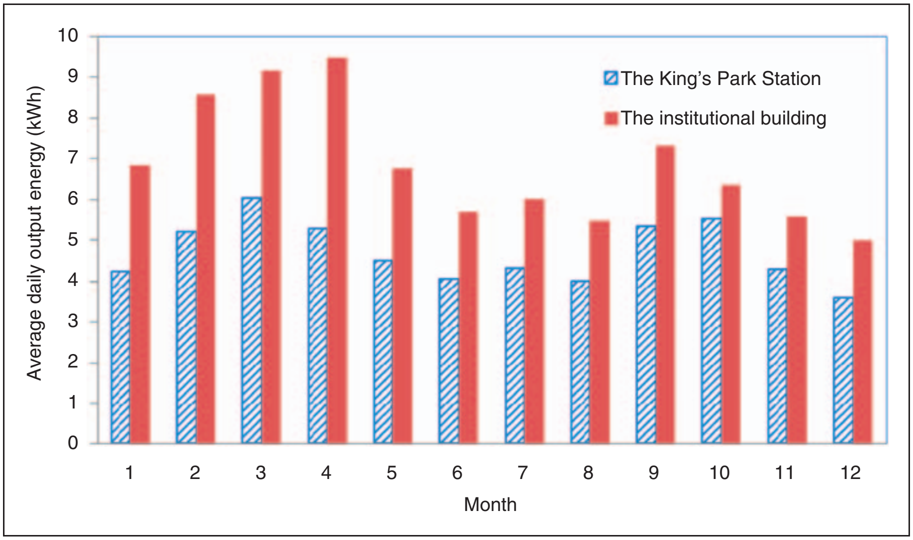


**Figure 12.** Daily energy output in various months for the micro-wind turbine installed at the King's Park Station and the roof of the institutional building.

power companies. Pollutants produced from electricity generation are considered one of the main causes of the local air pollution. The fossil fuels used for electricity generation include coal, oil and natural gases. The estimation of the emissions reduction is based on the actual electricity generation from various amounts of the fossil fuels. Table 2 summarizes the electricity

**Table 2.** Electricity generation and gases emission produced by the local power company between 2008 and 2011.

| | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|
| Electricity generated | 24,324 GWh | 24,920 GWh | 24,552 GWh | 24,955 GWh |
| $CO_2$ | 17,991 kton | 19,173 kton | 17,995 kton | 20,149 kton |
| $SO_2$ | 24.4 kton | 29.4 kton | 12.3 kton | 9.83 kton |
| $NO_X$ | 24.1 kton | 25.6 kton | 17.3 kton | 21.1 kton |
| Particulates (total) | 0.9 kton | 1.66 kton | 1.17 kton | 1.15 kton |

and gases emission for the 4-year period between 2008 and 2011[25] produced by one of the local power companies, which supplies electricity for the institution. The annual electricity produced by this power company increased from 24,324 GWh in 2008 to 24,955 GWh in 2011. For $CO_2$ emission, the annual value ranged between 17,991 and 20,149 kton. For other pollutants, the emissions were far less than $CO_2$, ranging from 9.83 to 29.4 kton for $SO_2$ and varying between 17.3 and 25.6 kton for $NO_X$. For particulates, the amount of emission was just between 0.9 and 1.66 kton. The greenhouse gases and pollutants emissions were reduced significantly in 2010 and 2011. The environmental benefits could be predicted using the calculated results. If one micro-wind turbine was proposed to be installed in King's Park Station for producing electricity, the annual emissions of $CO_2$, $SO_2$, $NO_X$ and particulates would be reduced by 43, 0.043, 0.05 and 0.0028 kg, respectively. For the institutional building, every micro-wind turbine can reduce the annual emissions of $CO_2$, $SO_2$, $NO_X$ and particulates by 62.6, 0.063, 0.073 and 0.0041 kg, respectively. In Hong Kong, most electricity is expended by building stocks.[26] It would be beneficial to the environment if wind turbine systems can be widely adopted in Hong Kong. The finding supports that buildings located in low-density areas with high-hub height would be the apposite places for installing wind turbines, and the potential of applying micro-wind turbine system would be more appropriate than PV facility.[27]

## Conclusions

A brief analysis of wind energy and micro-wind turbine for Hong Kong was conducted. The 33-year long-term (1979–2011) wind speeds recorded at King's Park Station located in dense urban terrain were analyzed. The annual mean wind speed varied between 2.1 and 3.5 m/s. Statistical results showed that over 50% of time, the wind speed was more than 3 m/s. Studies were also conducted to an institutional building representing a low-density zone with a high-hub level using 3-year data from 2008 to 2010. With less shading effect, the prevailing wind speed was larger than that in King's Park Station. The performance of the micro-wind turbine was studied. With the cut-in wind velocity of 2.7 m/s, the annual output power would be 56.3 and 82.1 kWh when one micro-wind turbine was considered to be installed, respectively, in King's Park Station and the institutional building. If the mean annual electricity consumption for the institutional building between 2008 and 2010 represents the prevailing annual value, 17 of the micro-wind turbines are required to achieve 1% of the electricity generated by wind power. The findings show that buildings located in low-density areas with high-hub height would be appropriate for installing small-scale wind turbine system. The present study can be considered a preliminary work to provide some on-site measured data for design and evaluation of micro-wind turbines installed in building blocks. Checking the results will be carried out in the future when more reliable measured data are available.

## Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

## Acknowledgements

The work described in this study was fully supported by a General Research Fund from the Research Grants Council of the Hong Kong Special Administrative Region, China [Project no. 9041470 (CityU 117209)]. Mr. K. L. Cheung is supported by a City University of Hong Kong studentship. The authors thank Mr. Samuel K. W. Lau, Mr. Terry C. H. Law, Miss Mandy S. M. Wong and Miss Kristine P. Y. Cheung for their help with data collection and analysis.

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