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Comparison of wind tunnel and on site measurements for urban wind energy estimation of potential yield

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A R T I C L E I N F O

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A B S T R A C T

There is a need to compare wind tunnel results with field measurement wind data in order to examine the validity of wind tunnel data in providing realistic estimates of urban wind energy potential and assess the probable errors involved. The paper refers to and discusses two Montreal building cases with different upstream roughness homogeneity. In the first case, field wind speed measurements are used to calculate the wind energy potential for a building with upstream rather homogeneous suburban type of terrain. In the second case, the building upstream terrain is very rough and highly nonhomogeneous. The calculated wind energy potential based on the field measurements was compared with the estimated value based on respective boundary layer wind tunnel data. In the first case, where the upstream terrain is homogeneous, the difference between the estimation of wind energy potential and the calculation using the field measurements is less than 5%. However, in the second case with the nonhomogeneous upstream terrain conditions, the difference between the estimation of the wind energy potential and the calculation using the field measurements is increased by up to 20%.

1. Introduction

Urban energy generation such as that produced by reduced-scale wind turbines installed on or around buildings can be defined as micro-generation. Recently, there is a growing interest in the use of wind energy in buildings for distributed generation. Since the generated power is a function of the cube of the wind speed, a small increase in the wind speed leads to a large difference in wind energy generation.

The prediction of the wind speed in the built environment is difficult, due to the roughness and the frictional effects, which reduce the wind speed close to the ground. In addition, several adjacent buildings influence the wind regime around a specific building in the urban environment. The most dependable method for the wind assessment in the urban environment is to directly measure the wind speed, ideally at the position and the height of the proposed wind turbine. However, measuring the wind speed at a site is both time consuming and expensive, i.e. normally not appropriate for the early stages of wind energy development. Fortunately, several methods are available for the initial assessment of wind resource in urban areas, with varying degrees of resolution and accuracy. These are, in order of increasing accuracy, wind atlases, numerical methods including CFD, wind tunnel modeling and direct wind resource measurement (European Commission, 2007).

A wide range of wind atlases is available at the continental and national level. In Canada, the Canadian wind energy atlas - http://www.windatlas.ca - covers a wide area but its low resolution means that it can only give a general picture of the wind resource. Another issue is that the wind atlases cannot take into account the local variations and their effect on the wind distribution.

On a more refined scale, wind speeds can be determined by using wind tunnel models, which must be combined with data at known locations. This role is usually fulfilled by local meteorological station measurements, other weather-related recorded data or airport data. The wind tunnel tests are used to give a more accurate estimate of wind without actually undertaking a wind measurement campaign.

The performance of a wind turbine in the built environment is only successful when there is adequate wind supply for it. Therefore, buildings exposed to either undisturbed or, even better, accelerated wind flows would be expected to augment their wind energy potential, as also mentioned by Arriago (2009) referring to buildings higher than their directly adjacent buildings. Many different types of wind turbines exist for the urban environment and they can be divided into two main groups depending on the orientation of their axis of rotation: Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT). A typical example of HAWTs associated with the Bahrain World Trade Center is shown in Fig. 1. It has been reported that these turbines provide about 11–15% of the building's power consumption (https://commons.wikimedia.org/wiki/File:Bahrain_World_Trade_Center.jpg?

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Fig. 1. Urban Wind Turbines: Bahrain World Trade Center Towers. (https://commons.wikimedia.org/wiki/File:Bahrain_World_Trade_Center.jpg?uselang=nl).

uselang=nl).

This paper is organized as follows: Section 2 refers to wind modeling and describes the wind tunnel facility and the instrumentation used in the measurements of this study, Section 3 describes the methodology used in the estimation of the wind energy and in Sections 4 and 5 this methodology has been tested using rather homogeneous and nonhomogeneous case studies prior to concluding in Section 6.

2. Wind modeling and experimental facilities

For winds near the ground surface, frictional effects play a significant role. Ground obstructions retard the movement of air close to the ground surface, causing a reduction in wind speed. At some height above ground, the movement of air is no longer affected by ground obstruction. This height is called gradient height Z_G which is a function of ground roughness. The unobstructed wind speed is called gradient wind speed, V_{Z_G} and it is considered to be constant above gradient height. The power law, which is used by some engineers to represent the variation of wind speed with height, is an empirical equation, which for the case of mean speeds takes the form of:

$$\frac{V_Z}{V_{Z_G}} = \left(\frac{Z}{Z_G}\right)^{\alpha} \tag{1}$$

where:

Z_G Gradient height
α Power-law exponent

Table 1
Suggested Values of Z_G and α for Various Terrain Conditions (Davenport, 1960, modified).

Terrain description	Gradient height $Z_G(m)$	Power-law exponent α
Rough sea	250	0.12
Open grassland	300	0.15
Forest and suburban areas	370	0.22
City centers	460	0.33

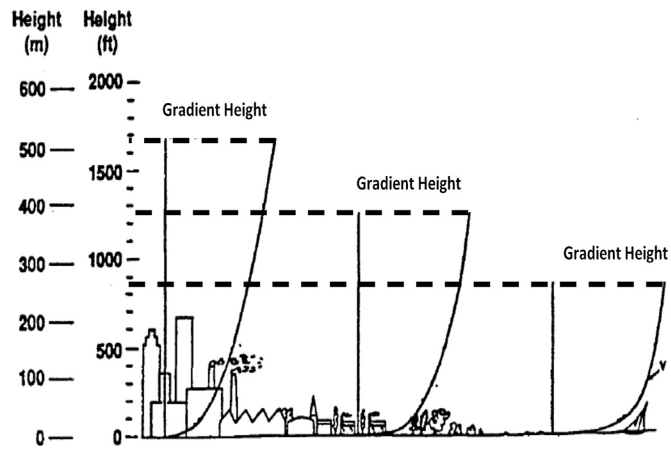

Fig. 2. Variation of Wind Speed with Height (Stathopoulos, 2007).

Both variables are functions of the ground roughness. Typical values of Z_G and α are given in Table 1. Fig. 2 shows typical variations of wind speeds above different ground roughness (Stathopoulos, 2007).

Wind tunnels have been a key element in scientific research in a number of fields. Since the 19th century, experimenting with race cars, airplanes, weather patterns, and various other areas has been made much easier because of this development. Moreover, wind tunnels have a variety of important uses in the world today including the design of buildings (Vasan and Stathopoulos, 2014). A photo of the atmospheric boundary layer wind tunnel of Concordia University is shown in Fig. 3. This wind tunnel is 12.2 m in length and 1.8 m in width with a suspended roof that allows the height to be adjusted between 1.4 m and 1.8 m. The wind tunnel can be operated at velocities from 3 m/s to 14 m/s. A turntable, 1.6 m diameter, at the test section allows the model to be rotated

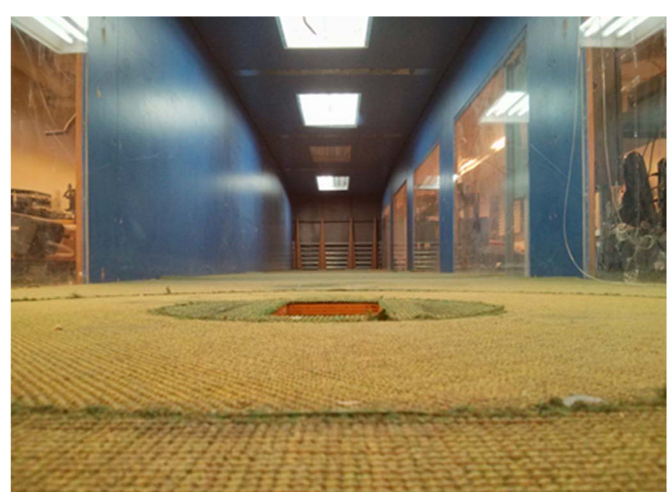

Fig. 3. View of Test Section and Upstream Fetch of Atmospheric Boundary Layer Wind Tunnel at Concordia University.