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Urban wind energy: Some views on potential and challenges

Ted Stathopoulos [a], Hatem Alrawashdeh [a,*], Ayman Al-Quraan [b], Bert Blocken [c,d], Aierken Dilimulati [e], Marius Paraschivoiu [e], Pragasen Pilay [f]

[a] Department of Building, Civil and Environmental Engineering, Concordia University, Montreal, Quebec, Canada
[b] Presently, Department of Electrical Power Engineering, Yarmouk University, Irbid, Jordan
[c] Department of the Built Environment, Eindhoven University of Technology, Eindhoven, the Netherlands
[d] Department of Civil Engineering, KU Leuven, Leuven, Belgium
[e] Department of Mechanical, Industrial & Aerospace Engineering, Concordia University, Montreal, Quebec, Canada
[f] Department of Electrical and Computer Engineering, Concordia University, Montreal, Quebec, Canada

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ABSTRACT

Urban wind energy consists of the utilization of wind energy technology in applications to the urban and suburban built environment. The paper provides some views on the progress made recently in the areas of wind resource assessment in the urban habitat; the utilization of suitable wind turbines for enhancing the exploitation of these resources; and the significant role of knowledge of building and urban aerodynamics for an optimal arrangement of interfacing augmented wind with its extraction mechanisms. The paper is not intended to be exhaustive, rather its purpose is to provide some views on the above-mentioned topics from the viewpoint of wind engineering and industrial aerodynamics in the context of buildings and cities.

1. Introduction

Wind has been used as an energy source since ages. The power of wind was used to sail ships, to mill grain and to pump water. Wind power is currently considered as one of the most viable alternatives to fossil fuels because it is renewable, widely distributed and clean with no greenhouse gas emissions produced during operation. In most cases, the energy of the wind is harnessed through large wind-power plants to supply economical clean power. However, in urban and suburban areas, the land is limited and this is considered a major restriction for the installation of large plants. An alternative option is to resort to building-integrated wind energy systems. Much less attention has been given to wind energy installations near buildings (Campbell and Stankovic, 2001; Beller, 2009; Sharpe and Proven, 2010). The concept of on-site micro wind energy generation is interesting because the energy is then produced close to the location where it is required. Campbell and Stankovic (2001) distinguish between three categories of possibilities for integration of wind energy generation systems into urban environments: (1) siting stand-alone wind turbines in urban locations; (2) retrofitting wind turbines onto existing buildings; and (3) full integration of wind turbines together with architectural form. Category 2 and 3 are often referred to as "building-integrated wind turbines".

Most of the early actual installations of wind turbines in urban contexts have been established in category 1 (Sharpe and Proven, 2010). They were generally conventional Horizontal Axis Wind Turbines (HAWT), intended to be mounted on the top of masts in fairly open areas. The performance of these systems has been reported to be very site-specific (Peacock et al., 2008) and in many cases the proximity to buildings has decreased the performance (e.g. Mithraratne, 2009). Campbell and Stankovic (2001), Mertens (2006), Lu and Ip (2009) and Balduzzi et al. (2012a), among others, investigated the potential to take advantage of augmented airflow around buildings, addressing both category 2 and category 3 applications. Category 2 includes traditional or newly developed wind turbines that can be fitted onto either existing buildings or new buildings, without the need for specially modifying the building form. Examples are the roof-mounted ducted wind turbine by Grant et al. (2008), the modern adaptation to the Sistan wind energy mill by Müller et al. (2009), the Crossflex design by Sharpe and Proven (2010), which is a new development of a Darrieus turbine form, and the 3-in-1 wind–solar and rain water harvester with power-augmentation-guide-vane (PAGV) for a Vertical Axis Wind Turbine (VAWT) by Chong et al. (2011). Finally, category 3 consists of modified building forms for full integration of wind turbines. Well-known examples of buildings designed for integration of large-scale

* Corresponding author.
E-mail address: h_alraw@encs.concordia.ca (H. Alrawashdeh).

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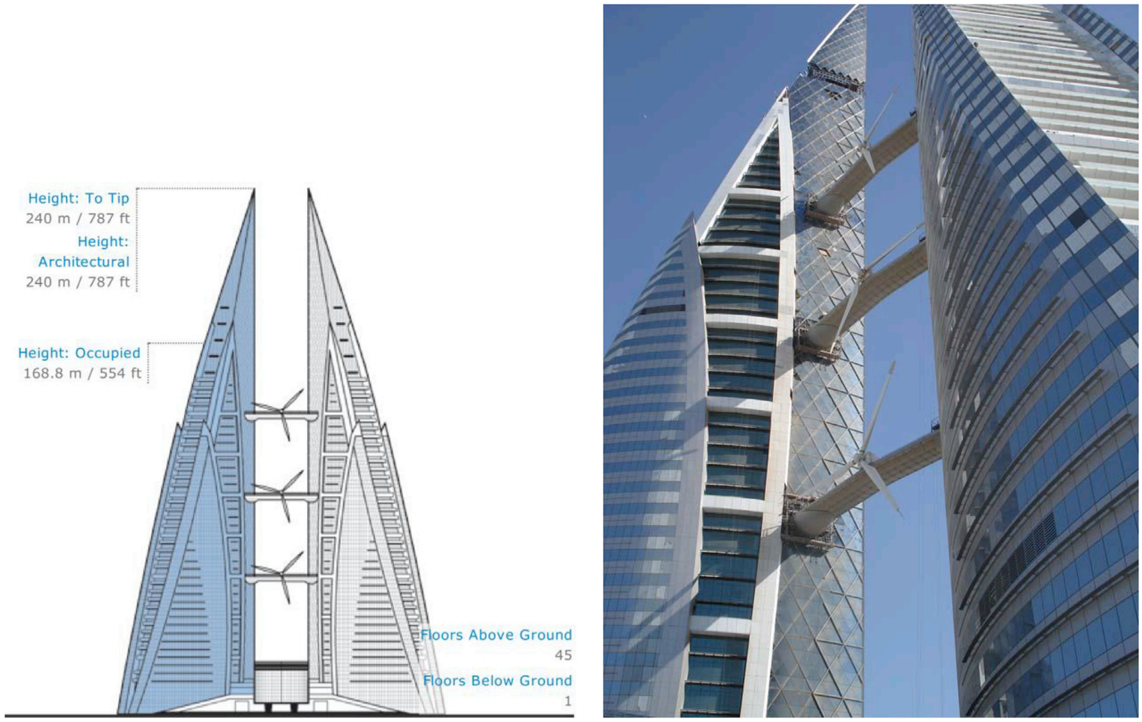

Fig. 1. Wind turbines integrated in between the Bahrain World Trade Center Towers. (http://www.skyscrapercenter.com/building/bahrain-world-trade-center-1/998).

wind turbines are the Bahrain World Trade Center (2011), the Strata Tower in London (2011) and the Pearl River Tower in Guangzhou, China (2011). Fig. 1 shows the Bahrain World Trade Center Towers, where three wind turbines facing the prevailing wind direction are suspended on bridges between the two towers of the center.

As it is well known, the mean wind speed in urban environments is lower than the wind speed in rural areas. However, the wind speed in urban environments at particular locations close to tall buildings is dramatically high. Urban wind energy generation such as that produced by small-scale wind turbines installed on or around buildings can be defined as micro-generation. A key advantage of such installations is that the produced energy can be consumed directly at the site of installation and the owner of the building obtains free extra energy source. There is a growing interest in the use of wind power in buildings for distributed generation. Since the theoretically generated power is a function of the cube of the wind speed, a small increase in the wind speed can lead to a large difference in wind power generation. Therefore, it is of interest to properly assess the wind resource in an area and attempt to enhance it by various aerodynamics techniques. This is contrary to the traditional wind engineering approach where the focus is in reducing wind speeds and pressures to minimize wind-induced building loads and contribute to the economy of a safe building design (e.g. Isyumov and Davenport, 1975; Murakami, 1997; Stathopoulos, 1997; Baker, 2007; Solari, 2007; Franke et al., 2007; Tominaga et al., 2008; Blocken, 2014, 2015; and Meroney and Derickson, 2014).

The wind resource assessment in the urban habitat has been a topic of interest in the research world for many years. This paper seeks to provide some views on the progress made recently on different related fields. Initially, a brief introduction for the methods used for initial assessment of wind speeds in an urban location are provided with a focus on indirect methods such as atmospheric boundary layer wind tunnel testing and Computational Fluid Dynamics (CFD). Then, recent progress on some working mechanisms of wind turbines and the aerodynamics of the urban environment and their characteristics is discussed.

2. Estimation of wind speeds in an urban location

Several methods are used for the initial assessment of wind resources for a specific site based on data measured by meteorological stations. The most prominent and widely used are probabilistic mathematical functions such as Weibull and Rayleigh; wind atlas data; and indirect methods such as atmospheric boundary layer wind tunnel testing and numerical simulation with Computational Fluid Dynamics (CFD) (Ishugah et al., 2014). It was demonstrated that Weibull and Rayleigh probability functions are effective in case of open areas like offshore with high mean speeds (Jamil et al., 1995 and Adaramola et al., 2014). Also, there were attempts to fit models for wind speed distributions for energy applications. For instance, Mathew et al. (2002) offered an analytical approach to study the wind energy density, the energy available in the wind spectra, and the energy received by a turbine by using the Rayleigh wind speed distribution. Moreover, Mathew et al. (2002) addressed a method to identify the most frequent wind speed that carries the maximum amount of energy associated with it.

The prediction of the wind speed in the built environment is difficult, due to the varying roughness and the drag exerted by surface-mounted obstacles on the flow (and vice versa), which reduce the wind speed close to the ground. In addition, the presence of adjacent buildings influences the wind regime around a specific building in the urban environment. Therefore, it is conceivable that lacking accurate approaches for assessment of wind speed in urban areas is a major impediment to the successful development of micro-scale energy generation.

The most dependable method for the wind assessment in the urban environment is to directly measure the wind speed on-site (full-scale), 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, let alone that it cannot work at the building design stage. Various approaches, including atmospheric boundary layer wind tunnels and Computational Fluid Dynamics (CFD), have been widely used to predict the wind speed in urban environment. Of these two approaches,