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Advances in wind energy resource exploitation in urban environment: A review

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ABSTRACT

Wind energy continues to stand out as a more established and mature technology to offset a large proportion of power. Efforts aimed at improving wind energy use to meet the energy demand in turbulent urban wind environment have been the main technical focus. In previous studies on wind resource and behavior in urban environment, different designs of horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs) have been reviewed. This paper vividly captures the fact that wind resource has a great potential to be fully explored and developed in the urban environment. Varying ways of application and application techniques being applied for electrical generation, ventilation and pollution dispersion, onshore cooling and dehumidification of coastal urban cities, and economics and environmental benefits of applying wind energy in urban environments are summarized. Although many new ideas and solutions that factor technical, economical and environmental sustainability in urban areas are coming up every day, challenges in design are gradually being solved to take advantage of urban low and turbulent wind speed characteristics, installation space challenges, vibration and noise reduction, among others. Some of the unique solutions that have been and are being developed in the applications of wind energy technology in urban environments are also reported in this paper.

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1. Introduction

Increase in urbanization and industrialization around the world in recent years has led to a consequent rise in energy demand [1,2]. The expectation that more people will move to urban areas during the next few decades, especially in developing countries [3], has increased the need for more safe, secure, affordable and environmental friendly energy sources to satisfy the growing population [4–6]. In recent years it has been reported that approximately 75% of generated power is consumed in cities [7]. Generation of power within the city could be of great importance to help reduce both the generation load and transmission infrastructure. In addition, it may also minimize transmission losses due to reduced distance from users [8]. With the global energy demand in 2040 being expected to be about 30% higher than that of 2010 [9], it is predicted that more challenges such as increased environmental problems, depletion of fossil fuels and unstable oil prices will intensify. For these reasons, urgent need for the incorporation of alternative energy as well as energy efficiency measures has to be incorporated in urban planning and construction [10]. In recent years, it has been widely projected that wind energy will be among the best alternative energy sources needed for urban environment as it is clean, affordable, safe, and available in the long-term.

A lot of efforts have been made in the last few decades in exploring wind energy and improving wind energy application technologies to optimize performance and increase generation in turbulent urban wind profile [11]. Until now, two main approaches that have been integrated in large scale wind energy in urban settings are either locating wind energy farm in the periphery of the urban areas or integration of wind energy systems into the building design. Although the former has been widely employed in the recent years to overcome the challenges of turbulence, noise, size, space and visual impact created in the city among others, wind turbines outside the city comes with additional cost to provide electricity network to transmit power to a distant electrical load [12]. On the other hand, the latter eliminates the need to expand the high voltage electricity network to provide electricity for these loads although it faces challenges such as low or poor wind turbine output, shadow flicker, strong visual impact and to some extent vibrations and noise issues in buildings [13]. In addition it also requires detailed planning and design to be able to take maximum advantage of the wind in the urban environment.

As wind energy continues to stand out as a more established and mature technology to offset large proportion of power, it is important to note that more still needs to be done to exploit its full potential especially in urban environment. Many researchers are now studying urban wind characteristics [14], with many focusing on building mounted turbines [15,16]. Based on the World Wind Energy Report in 2011 [17], advances in wind turbines aerodynamics, their structural dynamics and micrometeorology have contributed to a 5% annual increase in the energy production of the turbines within the last 2–3 decades [18,19]. In addition to the improvement in energy output of the turbines, the weights of the turbines as well as the noise they emit have also been halved over the last few years [19–21]. Moreover, the designs have been improved to adapt to urban high rise applications [16]. As wind energy applications techniques continues to be applied in urban environment, researchers are also carrying out studies on pedestrian level wind in urban streets, thermal environments in urban areas, onshore flow in coastal urban areas, street ventilation and pollutant dispersion [22–24].

As wind energy resources, exploration and use in urban areas come under increasing scrutiny as part of renewable energy solutions, the need to consider the suitability of wind resources and its exploitation technology in the urban environment becomes a timely option. Kaldellis and Zafirakis [25,26] did a systematic study presenting the main trends, prospects and research and development directions in wind turbine technology. They investigated the main technological developments throughout the entire period of wind energy growth and outlined the most important research efforts associated with the establishment of wind energy. They further forecasted the most challenging future of research and development with a reflection on growth trend. Islam et al. [6,19] reviewed some progress and recent trends of modern wind energy technologies. Their research projection estimated that the Vertical Axis Wind Turbine (VAWT) can dominate the wind-energy technology due to their relatively less space requirements as well as potential to produce more energy compared to the Horizontal Axis Wind Turbine (HAWT). Dennis et al. [27] did an overview of world wind energy scenarios, the current status of wind turbine development, development trends of offshore wind farms, and the environmental and climatic impact of wind farms. Hameed et al. [18] did a comparative study of wind energy, problems, solutions and suggestion as a result of the implementation of wind turbine. They reported that wind energy development would reduce both environmental pollution and water consumption. However, noise pollution, visual interference and negative impacts on wildlife were still matters of concern.

To date, substantial publications on wind energy have mainly focused on regional wind energy assessment [28], wind speed distribution functions [29,30], economic aspects of wind energy [31] and regional wind energy policies [32]. Despite the fact that several works have been done on wind turbines aerodynamics and design [33], urban micrometeorology [34,35] and urban pollution dispersion [36,37], no or very little work has been done on wind energy resource and its applications in urban environment. This article, therefore, provides knowledge on wind energy layout in urban environment for natural ventilation, its potential in pollution dispersion as well as energy generation and its potential implications economics and environmental of urban environments. In addition, this paper also captures the fact that wind resource has a great potential to be fully explored and developed for onshore cooling and dehumidification of coastal urban cities. It is expected that this review will be useful for researchers as well as professionals, urban planners and architects, in the wind energy field.