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Wind power evaluation and utilization over a reference high-rise building in urban area

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ABSTRACT

To help design wind turbines around numerous high-rise buildings with promising wind in Hong Kong, this paper presents an integrated method of both macro (weather data and domain topography) and micro aspect (Computational Fluid Dynamics, CFD) analysis. Long-term wind data are compared at dense urban and small island stations. The prevailing wind is found to be from the East, and the average wind speed for the urban location is much lower, say 2.93 m/s at 25 m above ground level. The need to integrate wind turbines into high-rise buildings is necessary. This research demonstrates that the wind power density at 4 m above the building roof is enhanced numerously by 1.3–5.4 times with 5–7 m/s inlet velocity. Wind power utilization around the windward top roof is the most promising under the dominant wind direction. The thickness of wind speed below 8 m/s is only 3.6 m at these areas. Due to high-rise building height and concentration effects, the wind power enhancement for 7 m/s inlet velocity is around 4 times of that for 5 m/s, which is even larger than the cube of these two velocity ratio 7/5, i.e. 2.7 times determined from the general model between wind power and velocity.

1. Introduction

Potential applications of renewable energy have been on many countries' working agenda in recent years. One energy strategy is seeking to maximize our city's own generation of renewable energy and thus to minimize the impacts on health and on local and global environment. Recently, to cut greenhouse gas emissions, under UK government regulations, potentially all new buildings must be zero-carbon by 2019 [1]. For urban buildings, wind power, as one of renewable energy resources, is seen as an opportunity [2–5] as the disturbed flows around buildings can locally increase wind speeds and the energy yields may be increased compared to open sites.

Wind energy in buildings, with turbines being mounted on or integrated into buildings, involves many different challenges compared to stand-alone wind energy systems and wind farms. The existing utilization types of wind turbines located at the high wind speed zones in urban buildings are building mounted (small-scale wind turbines), including Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT), and building integrated turbines. Incorporating wind turbines into the building design are stepping into our lives. Bahrain World Trade Center with its intuitive wind use of façade engineering in Dubai [6] was shortlisted for several awards, such as 2009 NOVA Award and International Environmental Excellence Award (see Fig. 1). Three 225 kW wind turbines are integrated into three sky bridges between the two towers. The turbines, 29 m in diameter, are aligned north, which is the direction from which air from the Persian Gulf blows in. The sail-shaped buildings on either side are designed to enhance wind through the gap to provide accelerated wind passing through the turbines, which was confirmed by wind tunnel tests. This significantly increases their potential to generate electricity, and the wind turbines are expected to provide 11–15% of the towers' total power consumption. Recently, the first rooftop turbines in world were built into fabric of apartment block in London [7] and will generate 8% of the building's electricity needs minimize the tower's environmental footprint. Unlike a conventional turbine standing in a field, the three in the Strata tower will use the Venturi effect to suck air in from many angles and accelerate it through the tubes.

There are existing cases of wind power utilization into or on urban buildings [8]. However, there are very limited research studies on the wind power utilization over existing urban high-rise buildings. To find out the distance, height, roof shape and surrounding effects of buildings on wind power, Lu's group [9,10] preliminarily investigated the wind aerodynamics and wind flows over high-rise buildings for wind power utilization. It is found that the concentration effect of buildings and the heights of buildings could enhance wind power utilization by increasing the wind speed by 1.5–2 times and wind power density by 3–8 times under the

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Fig. 1. Bahrain World Trade Center with its intuitive wind use of façade engineering in Dubai [6].

given simulation conditions. It concludes that wind power utilization in urban high-rise buildings is theoretically feasible and effective enhancement methods could be proposed based on the simulation results. The installation location of wind turbine should avoid the built low wind speed and higher turbulence areas.

Hong Kong is characterized by a long coastline, numerous islands and tremendous existing high-rise buildings for such a relatively small territory, and provides opportunities for wind power applications. Wind power was already proved to be one of the potential renewable energy resources in Hong Kong [11]. At the moment, offshore wind farms in Southeastern Waters are proposed by different local parties. Besides the rural areas, topographically, Hong Kong is also a dense urban city characterized by high-rise buildings. As the energy yields of wind turbines have the cubic relationship with wind speed, the wind speed increase due to the effect of surrounding buildings could make wind turbines in favor of wind. Wind changes, however, over different terrains, and wind speed and direction inputs are very important for the analysis of wind power utilization in buildings.

To evaluate the wind power utilization into or on existing urban high-rise buildings, this paper aims to further develop the integrated method including macro wind data and terrain topography analysis and micro Computational fluid dynamics (CFD) analysis by analyzing and investigating a local reference high-rise building based on our preliminary study [10]. Long-term wind data from two weather stations are analyzed and compared to identify the changes of wind speed and wind direction due to the surrounding urban environments. Computational fluid dynamics (CFD) tool is used to integrate the analyzed weather wind data and topographic characteristics, and then evaluate the wind power utilization around the high-rise building.

2. Wind data analysis

In order to obtain reasonable and practical inlet reference for the wind power evaluation and flow simulation of the reference building, hourly wind data of two weather stations (see Fig. 2) are used to analyze the wind power potentials [12]. The wind data from 1979 to 2000, for the weather station of Waglan Island without surrounding obstacles, represent the wind conditions in Hong Kong; while the weather data from 1978 to 2007, for the Astronomical Hong Kong Observatory (HKO) at Tsim Sha Tsui (TST) can only represent the wind conditions of specific urban location. These long time data up to 30 years can be solid practical wind evidence for the analysis and prediction in this work. The reference building, Lee Shau Kee Building in the university campus, is located very near to the TST HKO as demonstrated in Fig. 2.

2.1. Wind direction

Wind is changing all the time, and eight directions are equally divided into 12.5% in a circle, in which each direction contains 45° with 22.5° to the left and right of the direction point. In detail, the eight directions are North (N), Northeast (NE), East (E), Southeast (SE), South (S), Southwest (SW), West (W) and Northwest (NW). Based on the provided weather data, wind direction distributions are calculated by self-programmed statistic codes. For Waglan Island, the prevailing wind direction is the East, and other dominant directions are North and Northeast, as demonstrated in Fig. 3. For the HKO (TST), the prevailing wind direction is also the East, and over 50% wind flows from the direction (see Fig. 3). Less wind blows from the North and Northeast, and it is because the meteorological station is surrounded by high-rise buildings which could affect the local wind direction and wind speed distributions.

2.2. Wind speeds & their Weibull distribution

The average wind speed is calculated to be 6.8 m/s at 26.3 m above ground level and 82 m above sea level for Waglan Island and 2.93 m/s at 25 m above ground level and 90 m above sea level for TST weather station. The average wind speed on Waglan