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Rooftop Wind Resource Assessment using a Three-Dimensional Ultrasonic Anemometer

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Abstract

In July 2007 Murdoch University was awarded a grant to conduct research into 'Initiating Best Practice Guidelines for Rooftop Wind Systems.' The current focus of the project involves two primary initiatives: a computer simulated modeling exercise and an onsite rooftop wind monitoring station. This paper focuses on the methodology and justification for developing the monitoring station. An ultrasonic three-dimensional anemometer was chosen as the key piece of equipment in order to be able to collect data at a fast scanning rate (ensuring a suitable level of detail for analysis of turbulence) and to develop a three-dimensional wind profile. The wind regime on a rooftop in the complex terrain of the built environment is highly dynamic, turbulent, and includes a strong vertical component. Site selection for turbines must be informed by a proper feasibility study involving accurate data. The initial phase of the project to predict the resource and deploy the monitoring station has been completed, however long-term data collection, additional modeling, and the development of guidelines is still in process.

Keywords

Rooftop wind, ultrasonic anemometer, wind assessment, feasibility study, building integrate wind turbine.

Introduction

Building integrated wind turbines (BUWTs) have the potential to make a significant contribution to the energy needs of buildings, thereby reducing their carbon intensity, overall emissions and the cost of energy [1]. These are turbines that have been designed for the built environment and can be located on or next to buildings. Typically these types of 'urban wind turbines' are less than 20kW in rated capacity. Currently there are over 32 manufacturers and 57 different urban wind turbine products available in Europe alone, with many more in research and development stages [2, 3].

Initial attempts to integrate wind turbines into the built environment involved simply mounting existing small wind turbines onto buildings. A prime example of this is the Green Building in Temple Bar, Dublin where three small horizontal-axis wind turbines were installed along with solar hot water and photovoltaic collectors [4]. The application resulted in excessive noise, vibration, and eventual cracking of the turbine blades. The wind turbines were determined to be uneconomical and were eventually replaced by photovoltaic panels [5]. While small wind turbine technology has now been more appropriately and intentionally adapted to building-integrated applications, there remains a lack of understanding about wind flows in urban environments and how to accurately predict the wind resource for use in feasibility studies. The Carbon Trust's report on the feasibility of building integrated wind turbines in 2004 listed "assessment of the wind regime in urban areas" as a key recommendation for research and development in this area [1]. Thus there is a need for simple and accurate tools and procedures for urban wind resource analysis in order to ensure a successful urban wind turbine industry. This study lays the initial groundwork for developing an urban wind resource monitoring station as well as comparing and validating computational models with observed wind data in order to help develop best-practice guidelines and urban wind resource analysis tools.

Background

The first rooftop wind systems in Australia were installed by the Capital City Committee of Adelaide (South Australia) in 2006 [6]. To date five systems have been installed and there are plans for up to twenty more [7]. There have been problems with some of these rooftop wind systems, likely due to poor wind resources at the location or improper site selection for the turbine. Other agencies in Australia are currently assessing the potential for rooftop wind projects including Sustainability Victoria, the City of Melville in Western Australia, and numerous property developers seeking to reduce the carbon impact of their buildings [8].

Rooftop wind systems present a unique challenge when conducting feasibility studies due to the dynamic and turbulent nature of wind in the built environment. The WINEUR *Report on Resource Assessment* (2007) stated that lower annual mean wind speeds (AMWS) and turbulent flow are the two key features of the urban wind regime [9]. There is a concern that environmentally conscious homeowners, businesses, local government bodies and other organizations will install rooftop wind systems as a signal of their support for sustainability, but may do so without adequate consideration of safety, structural building integrity or turbine performance. The potential consequence of such projects could be:

- The failure of the project due to issues such as underperforming turbines, noise, and vibration (e.g. The Green Building in Dublin).
- The development of a negative reputation for wind energy and the renewable energy industry.

In July 2007, Murdoch University was awarded a grant by the Sustainable Energy Development Office (SEDO) of the State Government of Western Australian to conduct research into 'Initiating Best Practice Guidelines for Rooftop Wind Systems'. This project involved a two-part feasibility study for the installation of a rooftop wind turbine on a local government building. The first part of the study involved generating local wind resource data for the location using computational modeling software. The second part involved developing and deploying a wind resource monitoring station. The results of the monitoring campaign feed into the feasibility study in terms of predicting the height at which the proposed rooftop wind turbine can avoid increased fatigue due to turbulence and harness the additional power available due to the speed up of air over regions of separated flow.

Wind Resource Modeling

Computer simulation modeling was used to generate the predicted wind resource at the proposed turbine location. The Air Pollution Model (TAPM), developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO), was chosen because it uses time-referenced synoptic data from synoptic weather databases and surface roughness maps. Synoptic weather data for the years 1996 to 2007 from the Climate Data Assimilation System (CDAS) was translated into the TAPM format as the primary input to the program. Other key inputs included grid parameters, land surface characteristics, and date/time selection criteria. In order to model the local wind resource the Wind Atlas Analysis and Application Program (WAsP) was used. WAsP processes an Observed Wind Climate (OWC) to create a Regional Wind Climate (RWC) and finally provides a Predicted Wind Climate (PWC) at a specific location and altitude. For the purpose of this modeling exercise the OWC input for WAsP was the output of the TAPM process at an altitude of 250 meters directly above the proposed turbine location. The data consisted of hourly wind speed and wind direction for ten years (87,600 hours). The OWC was entered along with surface roughness characteristics, topographical features, and objects within 100 metres of the proposed turbine location. The PWC generated from this process predicted a long term average wind speed of 3.72 meters-per-second at the proposed hub height of 18.4 metres. The predominant wind direction is South and South-Southeast (see Figure 1 below.)

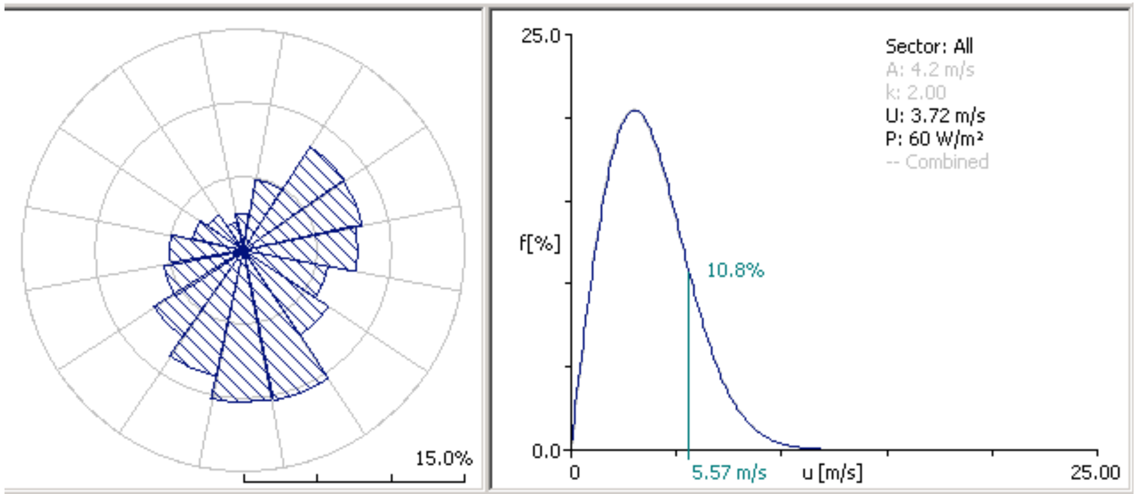

Figure 1: WAsP Predicted Wind Climate for City of Melville Civic Centre.

Rooftop Wind Monitoring

The urban rooftop wind resource is difficult to model, predict, and measure with any degree of certainty. The WINEUR project (Wind Energy Integration in the Urban Environment) is an international collaboration of stakeholders in the European urban wind industry geared toward promoting the emergence of the technology through research and education. WINEUR's *Report on Resource Assessment* (2007) concluded that:

- Wind in the built environment is subject to frequent changes in wind speed and wind direction.
- Prediction of the wind speed in the built environment is difficult due to the high surface roughness of urban terrain.
- Wind flow over buildings depends more on local (micro-scale) parameters than it does on landscape level features or dominant regional wind regimes (meso-scale).
- Wind turbulence is high due to complex obstacles in the built environment.
- Wind atlases, databases, and software programs developed for the large wind industry are not useful in predicting urban wind resources.
- Monitoring should be carried out at or near the location for the proposed turbine as even small deviations in location can result in radically different wind patterns [9].

The purpose of this portion of the project was to develop a monitoring system capable of measuring the rooftop wind resource. One of the issues to be addressed is that conventional wind resource measuring methods are not always suitable for rooftop wind analysis. Conventional methods for on-site wind resource monitoring involve the installation of either a cup anemometer and wind vane or propeller-vane anemometer. This method has been adapted from the large wind industry; however the site conditions involved are dramatically different. Other measurements such as temperature, humidity, and barometric pressure are also commonly taken in order to calculate values such as air density, which is important in determining the power available in the wind [9].

The problem with this type of conventional monitoring equipment for rooftop wind analysis is that it does not respond well to sudden changes in wind speed or direction. Wind flows patterns over rooftops are similar to that presented in Figure 2 below. There is a strong vertical component to the wind as it moves over a building (the arrows in the image show the direction of the wind.) This vertical component can have an affect on the performance of turbines designed to receive wind flow with a primarily horizontal profile. This will have an effect on the output performance of the turbine and may shorten its operational life due to uneven loading on the blades and other effects of turbulence [8]. Some areas in the wind profile over a building will experience a speedup effect, which can potentially be beneficial to the output of a turbine if it is sited correctly. Other areas will experience turbulence and slow-down effects. These areas need to be avoided when locating wind turbines on rooftops.

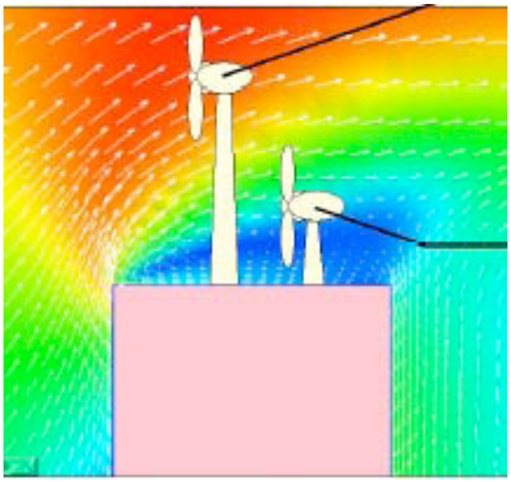

Figure 2: Wind flow over building. (Image courtesy of WINEUR.)

Traditional rotational anemometers (cup or propeller anemometers with wind vanes) are limited in their ability to provide detailed information on the turbulence or vertical component of the wind. These devices operate best in two dimensions measuring wind speed and wind direction on the horizontal plane. Techniques have been employed to integrate a cup anemometer and a propeller anemometer in order to develop a three-dimensional wind profile, however the different output types and characteristics of the two anemometers cast doubt on the accuracy of the data. The two primary limitations of cup anemometers are that they are subject to over-speeding and that the output is degraded at fast sample rates due to pulse counting demodulation [10, 11]. The over-speeding effect has been well documented as far back as the 1920s and in general is "a consequence of the property of the anemometer that responds more quickly to an increase in the wind speed than to a decrease of the same magnitude" [12]. Thus the anemometer tends to be biased toward the high side of the mean. Output degradation is a function of the pulse-counting demodulation most commonly used in cup-anemometers to extract the wind speed data. At fast sampling rates these devices suffer from discretization error such that the output is not useful for calculating turbulence. Prop-vane anemometers have a tendency to register lower wind speeds in turbulent environments largely because they are unable to maintain alignment with the instantaneous wind direction [10]. As Kirstensen (1998) states, "the vane is always lagging behind the instantaneous wind direction" [12]. The response time of these rotational anemometers to sudden changes in wind speed and direction is slow such that much of the dynamic nature of the wind does not get recorded. When used in the highly dynamic and constantly changing wind environment of a rooftop, a significant amount of valuable data could be lost while the devices respond to change. When selecting an anemometer one must consider the intended application, the starting threshold, the distance constant, and the reliability of the device. Thus for the purpose of rooftop wind resource analysis the traditional cup anemometer may not always be appropriate in all cases.

In order capture the true nature of the wind resource, a three-dimensional ultrasonic anemometer was chosen for the project's monitoring system. The main advantages of this type of anemometer are that it can detect the vertical component of the wind and has a response time that is virtually instantaneous. Another key advantage is that it has no moving parts to be serviced or maintained. The particular 3D ultrasonic anemometer chosen was a Gill Instruments WindMaster (see Figure 3 below).

Figure 3: Gill Instruments WindMaster ultrasonic anemometer.

Unlike rotational anemometers that convert the mechanical rate of rotation into wind speed, ultrasonic anemometers use time of flight theory to convert ultrasonic pulses into wind speed and wind direction values. The measured parameters (time and signal velocity) are resolved into wind speed and wind direction in three-dimensions. The U and V vectors are the horizontal component of the wind, often referred to as the longitudinal and lateral component. The W vector is the vertical component [13]. Figure 4 shows the orientation of the U, V, and W vectors when the anemometer is oriented to North. These three vectors (which represent the magnitude and direction of the air flow) can then be resolved into one resultant vector that is the true wind speed and direction.

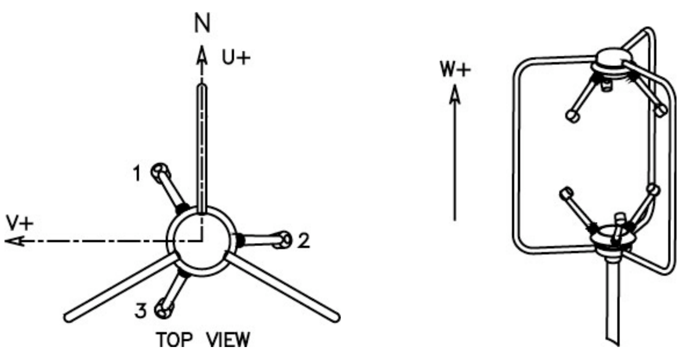

Figure 4: Views of WindMaster showing U,V,W vectors.

In order to measure ambient temperature, relative humidity, and barometric pressure, other sensors must be used. A Vaisala HMP50 Humidity and Temperature probe was chosen for this monitoring system. This sensor measures temperature and relative humidity in an integrated sensor. The output format is in voltage which is then scaled into the two weather variables (i.e. 0.01V per degree Celsius or % humidity).

All of the measured parameters are fed into a data logger for recording, scaling, and calculating into other quantities. A dataTaker DT80 was chosen to perform this function. The DT80 has the capacity to receive the serial output from the WindMaster anemometer as well as the voltage output from the HMP50 or any other sensors that may be connected in the future. It scans the sensors and records the measured parameters based on the user's specifications. The data logger was set up to scan and log the WindMaster output at ten hertz (ten times per second). The other parameters are scanned at 1Hz. Averages and other relevant statistics are recorded at one minute and ten minute intervals. The scanning rate of ten hertz was chosen in order to get a high level of detail in the data, on the recommendation of Dr. Tom Lyons of the Murdoch University School of Environmental Science. The recording interval of one minute was chosen again to reflect a high level of detail in the short-term fluctuations of the wind regime. The ten-minute recording interval was chosen because it is an industry standard for wind resource monitoring.

Results

The monitoring system was installed at the proposed wind turbine location in February 2008. To date one month of data has been extracted and analyzed (March 2008). Initial results up to April 10 indicate an average wind speed of 3.1 metres per second with the predominant wind direction being South-East (see Figure 5 below). This value is based only on the horizontal component of the wind regime (U and V vectors). This is lower than the predicted wind speed from the computer modeling process, but only incorporates one month of data. It may also indicate the inherent limitation of WAsP to predict wind speeds in an urban environment and reinforce the conclusion from WINEUR that urban wind regimes are subject to lower annual mean wind speeds, but it is too early in the monitoring campaign to make conclusions about the comparison between modeling and monitoring.

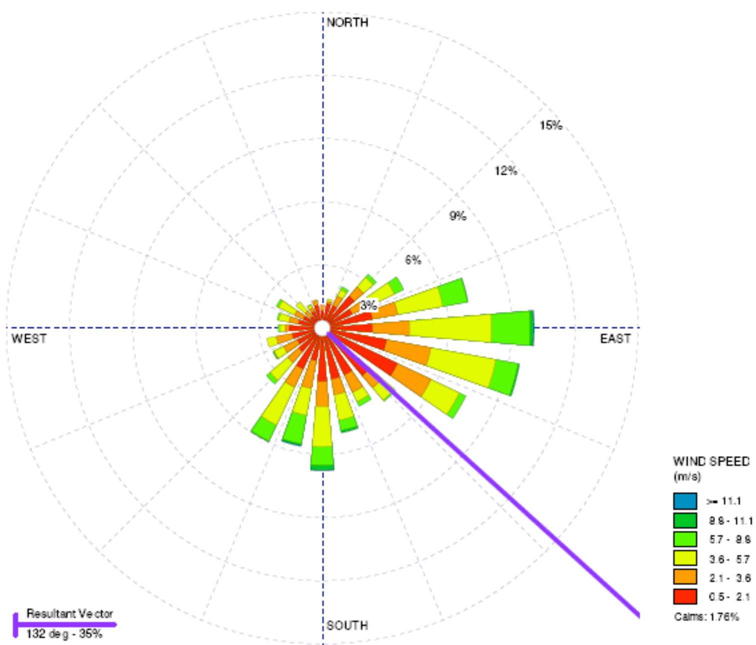

Figure 5: Monitored wind resource March/April 2008.

Ongoing Work & Conclusion

The monitoring campaign will carry forward in order to generate enough data to allow for a proper comparison of the modeled results to the monitored results. The monitored data must be analysed for turbulence and to extract the vertical component of the wind (W). The monitoring campaign may also be expanded to include a second ultrasonic anemometer at a different height in order to build up a better picture of the wind profile at different heights above the Civic Centre building. Conventional cup and prop-vane anemometers may also be included in order to conduct an analysis of anemometer performance and reliability in a rooftop scenario. Computational Fluid Dynamic (CFD) modeling is also being undertaken using advanced pollution dispersal software to feed in to the feasibility analysis and long-term goals of the project. The eventual goal of the project is to develop a portable and rapidly deployable wind resource monitoring station to generate onsite wind data that can be compared against a predicted wind climate generated from synoptic data and modeled using CFD software. If the modeling can be validated using onsite data then it may be possible to apply a measure-correlate-predict methodology to rooftop wind analysis or develop a software tool to allow installers of rooftop wind systems to predict the resource with reasonable accuracy and thus conduct feasibility analyses with confidence. In the process the researchers will develop a set of Best Practice Guidelines to help guide the domestic rooftop wind industry.

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