INVESTIGATING THE USE OF A MESOSCALE MODEL AS PART OF A FEASIBILITY STUDY FOR A ROOFTOP WIND SYSTEM

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ABSTRACT

This paper presents the results of a pilot project on rooftop wind in Perth, Western Australia, that aims to gain insight into best practice for placement of rooftop wind systems. Measurements of the air flow over a local Council building in Perth are captured using an ultrasonic anemometer installed on a 6.1 m mast on the top of the building. Data collected over a period of 6 months indicates that the mean wind speeds are too low for a rooftop wind system to be feasible at this location and demonstrates the importance of conducting wind resource assessments for potential rooftop installations. The air flow around the building has been modelling using “meso- to micro-scale” forecasting software called A2C. Use of the software was investigated as an alternative to more complex, expensive, CFD codes but was found to not have sufficient resolution for accurate prediction of turbulence length scales.

INTRODUCTION

Rooftop wind turbines are receiving increasing interest as a potential micro-generation technology for households and businesses to reduce their carbon emissions (Carbon Trust (2008) and Best *et. al.* (2008)). For any wind installation, it is important to accurately predict the nature of the wind resource that the wind turbine will experience. This is particularly the case for rooftop wind installations since the low wind speeds and high turbulence characteristic of the urban environment may make a rooftop wind installation infeasible. There is a growing body of literature in this area and Dutton, A.G. *et al.*, (2005), Webb (2007) and WINEUR (2007) stress the importance of conducting a rigorous assessment of the wind regime for wind installations in urban areas.

A rooftop wind monitoring system has been installed on the roof of a local Council building for the City of Melville in Perth, Western Australia. In order to capture the highly dynamic and complex nature of the wind resource on the rooftop, a 3D ultrasonic anemometer was chosen for the project’s monitoring system. The literature contains a number of examples of using ultrasonic anemometers to measure winds in urban areas but many have focussed on research connected with air quality forecasting and the dispersion of pollutants within the urban area (e.g. Ellis and Middleton, 2000, Yee and Biltoft 2004, Dobre *et. al*. 2005). The ultrasonic anemometer described in this paper was installed specifically to measure the suitability of the wind resource on the rooftop for a wind turbine installation. The rooftop wind monitoring system was installed on February 14, 2008 and the initial results are discussed in Anderson *et al.* (2008).

Measurements can only provide data at one location on the roof and it is necessary to use computer flow modelling for a thorough assessment of the best possible location on the roof for placement of the wind turbine. Preliminary modelling work by the authors in this area used data from a meso-scale model, TAPM (Hurley 2005) as input to a Wind Atlas model, WASP (Bowen and Mortensen 1996) in order to model local flow effects (Livingston 2008, Anderson *et al.* 2008). This approach, however, could not model the detailed effect of the buildings. CFD has been used to simulate the detailed flow over both flat (Mertens 2005) and pitched (Heath *et al.* 2007) roofs. There has been a considerable variability in the results of CFD studies due to the large number of choices that must be made by the user in designing and running the model (Ketzel *et al.* 2005). In addition, CFD is expensive and time intensive and is not practical for use in assessing a range of sites and simulating a wide range of weather conditions.

This paper aims to address this problem by trialling A2C, a less expensive mesoscale model which retains some CFD capability and is typically used in pollution dispersal applications (Yamada 2004). A2C is used to model the detailed flow effects around the Council building and the results are compared with measured data from the first six months of monitoring. The parameters of particular interest are mean wind speed and turbulence intensity as they are linked to wind turbine power output and fatigue life.

THE CIVIC CENTRE

The Civic Centre is the Council Headquarters for the City of Melville in Perth, Western Australia. The Centre is a three storey building, varying in height from 12 – 14 m and is situated roughly 8km inland from the coast. The prevailing winds are mainly easterly with strong south-westerly afternoon sea breezes in summer.

Fig. 1: Image of the Civic Centre building and surroundings [Google Earth, Sept. 2008]

THE MEASUREMENT CAMPAIGN

The Monitoring System

A wind monitoring system was assembled consisting of the following main components: (1) a 3D ultrasonic anemometer, (2) a temperature and humidity probe with radiation shield, (3) a barometric pressure sensor and (4) a data logger. The ultrasonic anemometer was chosen in preference to the 2D cup anemometers used in traditional wind monitoring campaigns because of its superior response time as well as its ability to capture the 3D nature of the flow over the roof (including the vertical component of the wind, which can be significant and is related to a speed up of flow over the roof).The system was bench tested at Murdoch University and the data logger was programmed in order to run logging schedules that would capture data at 10Hz and compute 10 minute averages.

Installation and Operation of the Monitoring System

The monitoring sensors were installed on a 6.1 m mast on the roof of the Civic Centre on February 14, 2008 (see Figure 2).

Fig. 2: Rooftop wind monitoring system on the Civic Centre and (inset) close up of the monitoring equipment

The anemometer was aligned using a compass. The temperature and humidity probe was inserted into a radiation shield to protect from direct sunlight and placed on the North side of the mast to avoid shading issues. Cables from the sensors were fed through the roof to a room inside the building where the data logger was situated. The barometric pressure sensor was also positioned in this room rather than on the mast to avoid instrument error due to dynamic pressure changes across the pressure sensor, as suggested by Bailey et al. (1997). Data were recorded during the period February 18 to

August 6 2008. Data were downloaded from the logger to a USB drive and transferred to a PC for analysis.

THE COMPUTATIONAL MODELLING

For the preliminary simulations with A2C it was decided to model the obstacles closest to the Civic Centre and simplify the obstacles that were further away as surface roughness. The obstacles closest to the Civic Centre were a 30 m tree at the southeast corner of the Centre, a Cinema Complex and a Library. Various references (Rampach *et al*. 1991, Hanna & Chang 1992, Grimmand & Oke 1999) were consulted to in order to establish descriptions of surface roughness distributions for the area.

The TAPM data from the previous meso-scale modelling by the authors, referred to above, was used as input to A2C. Livingston (2008) used synoptic weather data from the years 1997 to 2006 from the Climate Data Assimilation System (CDAS) (Kistler 2001) to produce hourly data of meteorological parameters, including wind speed and direction. This hourly data was referenced to a series of 3D grids centred on the Civic Centre with increased resolution in the vicinity of the Centre. The 10 years of hourly TAPM data for the grid cell located directly above the Civic Centre at an altitude of 250 m was binned into 16 wind sectors and wind speed frequency distributions were computed for each wind sector. Matlab was used to take the binned TAPM data and produce steady state wind shear profiles based on an average surface roughness value for the area surrounding the Civic Centre. These wind profiles were used as input to A2C to produce flow visualisations of the wind flow over the roof of the Civic Centre and surrounding buildings (see Figure 3). Matlab was again used to read the output data from A2C and investigate the flow parameters at the location of the mast on the roof.

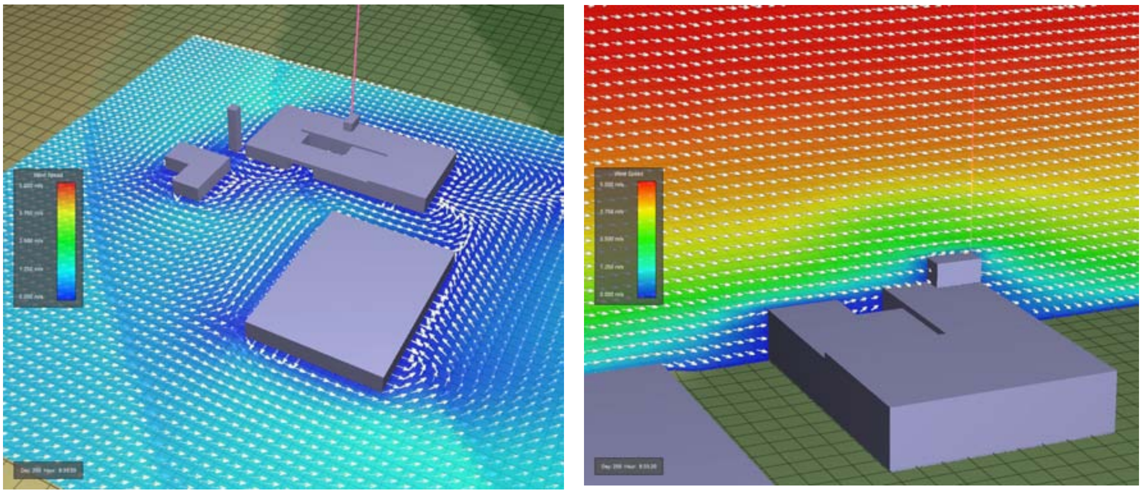

Fig. 3: Examples of the flow visualisations from the A2C modelling looking at cross-sections of the wind speed vectors in the horizontal plane (left) and in the vertical plane (right).

ANALYSIS

Data from the Monitoring Campaign

For each 10 minute data record collected over the period from February to August 2008, the average components of wind velocity (u, v, w) and associated standard deviations (σ_u, σ_v, σ_w) were used to calculate the turbulence intensity along each of the three axes e.g. longitudinal or north-south (I_x), traversal or east-west (I_y) and vertical (I_z) as well as the overall mean wind speed (U), turbulence (σ_U) and turbulence intensity (I). In addition, the longitudinal (u) and traverse (v) components of wind velocity were used to calculate the wind direction (θ) in the horizontal plane.

Sixteen wind sectors were defined and the calculated values from all the 10 minute data records were binned with respect to wind direction and averaged. For each bin, the averaged value was multiplied by the frequency of occurrence for winds in that bin to produce density roses. Summation of the values for each “petal” of the density rose yields the weighted averaged value for the parameter. Figures 4 and 5 provide examples of density roses for the parameters of wind speed and turbulence intensity, respectively.

The measured mean wind speeds on a sector by sector basis is in the range 2 m/s – 3.5 m/s. Figure 4 shows that the most significant wind speeds i.e. those with the greatest combination of strength and frequency of occurrence are from the east with significant winds also from east-southeast and south-southwest. The traversal component is dominant while the vertical wind speeds make a very small contribution to the overall wind speed. These vertical wind speeds are in the range 0.2 – 0.3 m/s and, at least at the measurement height, are not indicative of a “speed up of flow” over the building.

The turbulence intensity of the measured wind speeds on a sector by sector basis is in the range 25% - 40%. Figure 5 shows that across the sectors the vertical winds have the most significant turbulence intensity i.e. those with the greatest combination of turbulence and frequency of occurrence. The variation in vertical wind speeds is actually less than half the variation in longitudinal and traversal winds but produces significant turbulence intensity values due to the low wind speeds in the vertical direction. The longitudinal winds with the most significant turbulence intensity occur when the wind blows in the traversal direction and there are low longitudinal wind speeds, and vice versa for traversal winds. The variation in traversal winds dominates the overall turbulence and is consistent with the greater roughness values in the traversal direction due to e.g. the presence of the shopping centre in the eastern sector.

Data from the Computational Model

A Matlab script was used to take the output from the A2C simulations and extract the weighted average values of various parameters with respect to altitude at the location of the mast. Figures 6 and 7 show the weighted average wind speed and turbulence intensity profiles, respectively. The measurement height of the ultrasonic anemometer is shown on the plots for comparison.

From Figure 6 the weighted average wind speed at the measurement height is 2.76 m/s and compares favourably with the value of 2.69 m/s from measurement. The longitudinal and traverse components of wind speed are seen to have roughly equal contributions to the magnitude of overall wind speed and at the measurement height have values of around 1.68 m/s and 1.75 m/s, respectively, comparing reasonably well with the values from measurement of 1.60 m/s and 1.98 m/s, respectively. The magnitude of the vertical wind speeds at the measurement height is predicted by A2C to be around 0.5 m/s, higher than the 0.2 m/s - 0.3 m/s values recorded by the anemometer. This suggests that A2C is over-predicting the influence of the building on the air flow.

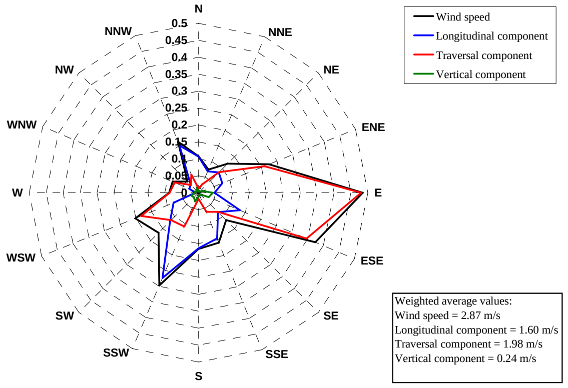

Fig. 4: Density rose of measured wind speed and its components

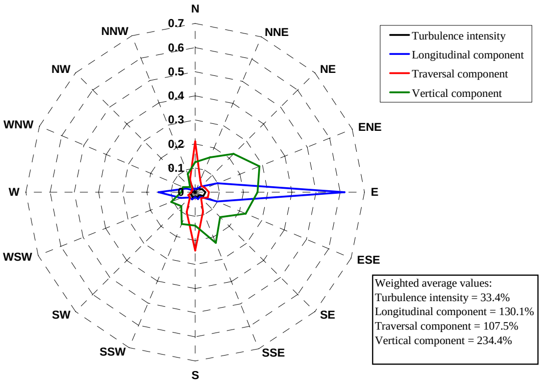

Fig. 5: Density rose of measured turbulence intensity of wind speed and components

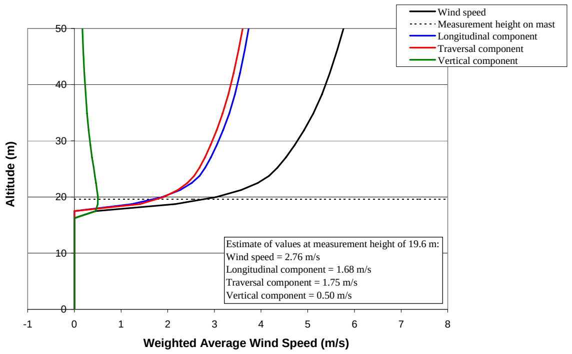

Fig. 6: Predicted wind shear profiles of wind speed at the location of the mast

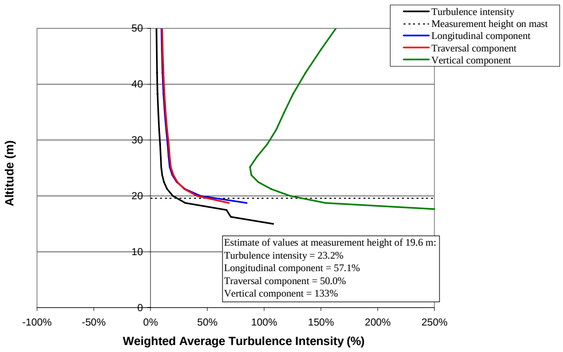

Fig. 7: Predicted profiles of turbulence intensity at the location of the mast

From Figure 7 the weighted average turbulence intensity of the wind at the measurement height is 23% compared to the value of 33% from measurement. The turbulence intensity of the longitudinal and traverse components of wind speed are seen to be roughly equal with values of around 50% and 57%, respectively and under-predict the values from measurement of 130% and 107%, respectively. The turbulence intensity of the vertical component of wind speed at the measurement height is approximately 130% and under-predicts the value from measurement of 234%. In all cases A2C is under-predicting the turbulence intensity of the wind speeds at the measurement height.

DISCUSSION

Suitability of site for turbine installation

The measured average wind speed at the measurement height of 19.6m for the data collected to date was 2.87 m/s. A2C predicted a similar value of 2.76 m/s. According to the literature [Cace 2007, Marsh 2008] rooftop wind is feasible for sites with mean wind speeds above approximately 5 m/s. Indeed in a catalogue of 57 urban wind turbines (WINEUR 2005) roughly 50% had cut-in wind speeds greater than the measured mean wind speed at the Civic Centre. One option for the Council would be to install a larger mast. The A2C predictions of Figure 6, however, suggest that you would need a mast of roughly 20 - 30 m in order to satisfy the suggested guideline from the literature. At this stage the installation ceases to be a building-integrated wind system and would have an obvious visual impact.

To gauge whether the turbulence levels measured on the roof are acceptable i.e. an installed wind turbine would be able to survive the variability in winds, a comparison is made between the measured values and the design turbulence levels as given in the wind turbine standard IEC61400-1 (2005), and calculated using

$$\sigma_{u,IEC} = \frac{I_{15}(15 + aU)}{a + 1}$$

where I_{15} is a reference hub-height turbulence intensity, a is a slope parameter and U is the mean wind speed. The IEC define a lower limit of turbulence, given by (I_{15}=16%; a = 3), and an upper limit given by (I_{15}=18%; a = 2).

The lower and upper IEC limits for design turbulence are calculated for each 10 minute data record collected over the period from February to August 2008. These values, along with the previously calculated turbulence (σ_U) and turbulence intensity (I) are binned with respect to wind speed as shown in Figure 8.

Figure 8 shows that the turbulence exceeds the upper limit for wind speeds above 5.5 m/s but that only 5% of winds satisfy this condition. In fact, approximately 80% of the winds experienced on the roof are less than 3.5 m/s and for these wind speeds, the turbulence is under the lower limit and is acceptable. For wind speeds in the range 3.5 m/s to 5.5 m/s, the turbulence levels on the roof are within the upper and lower design turbulence limits for wind turbines as defined in IEC61400-1 and, according to EWEA guidelines (2005), there is a risk to the turbine and frequent inspection should be performed. The fact that wind speeds in the range 3.5 m/s to 5.5 m/s only occur approximately 15% of the time may dictate the required frequency of inspection.

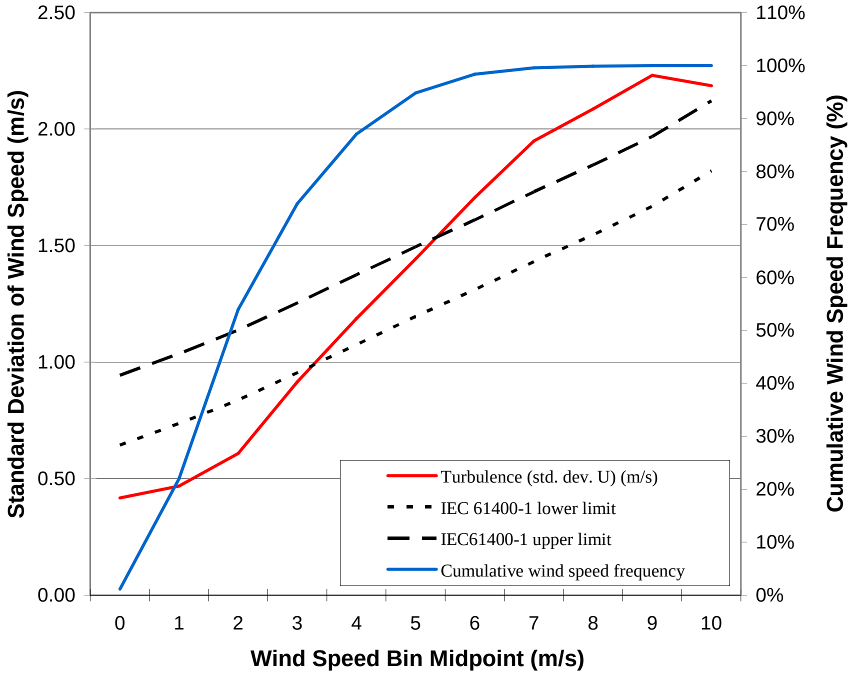

Fig. 8: Turbulence levels compared to design levels of turbulence for wind turbines

Suitability of A2C as a prediction tool

Based on weighted average values, A2C predicts wind speed and its longitudinal and horizontal components at the measurement height reasonably well although over-predicts the vertical wind speeds. In terms of turbulence, A2C predicts the basic trends from the measurements i.e. very high turbulence in the vertical direction with turbulence intensity levels in the longitudinal and traversal directions comparable. In all cases, however, A2C under-predicts the actual values of turbulence intensity.

Limitations of method

Limitations of the method include the fact that only six months of data have been collected, of which only one is in the summer months. Collecting data over the hotter months is likely to show greater south-westerly contributions due to stronger sea breezes.

In terms of the limitations of A2C, the TAPM data that was used was based on hourly values of wind speed whereas the measurements used 10 minute averaged values based on 10Hz sampling. In addition A2C permits grids of 60 x 60, which translated to a grid resolution of 5 m x 5 m for this study, too coarse for accurate prediction of turbulence length scales.

CONCLUSION

A rooftop wind monitoring system has been installed on a 6.1 m mast on the Civic Centre building in Perth, Australia. Data collected over a period of 6 months indicates that the mean wind speeds are too low for a rooftop wind system to be feasible at this location. The air flow around the building has been modelled using A2C – a mesoscale model with some CFD capability. The software was trialled as an alternative to more complex, expensive CFD codes but was found to not have sufficient resolution for accurate prediction of turbulence length scales.

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