CORRELATION OF MEASURED WIND DATA

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ABSTRACT

The overall aim of the project is to develop new knowledge, integrated solutions, and technologies of small/micro wind turbines. Different measurement devices were used for measuring wind velocity, wind direction, power output and vibration in 5 minute intervals on the rooftop of a test building. Wind data was also collected from two weather stations nearby. The results were collected by a data logger on the roof and periodically tracked out on a computer. The wind performance was investigated and documented followed by an analysis of the correlation between measured climate data at the installation site and the two nearest meteorological stations. The results show that wind speed on top of the building was much less than measurements from two meteorological stations nearby.

Measured wind conditions on the roof of the building were very different from expected wind conditions. The location of the measurement devices and the wind turbines in the case study were not optimized. Much lower wind velocities were measured on the rooftop than at the other measurement stations. Correlations show a 40% lower wind velocity on the roof than at the measurement stations. The equivalent wind speed would be even lower if the height of the wind turbine is considered (in accordance with the wind shear power law). This should be taken into consideration when planning to install wind turbines in the built environment.

Keywords: wind measurements, correlation, data analysis

INTRODUCTION

Wind power can be used to generate electricity in an urban environment. This trend has mainly been seen in Europe, where the integration of small/micro wind turbines in the built environment is being actively discussed [2]. New wind turbines are under development for this application, which is looking mainly for quiet and efficient devices under turbulent and skewed wind flow [5].

The overall aim of the project is to develop new knowledge, integrated solutions, and technologies of small/micro wind turbines. As well as the installation of wind turbines around and on buildings, there is also interest in ‘building-augmented’ wind turbines, where the turbine is part of the building structure or façade. The design of the building in this case is augmented in order to get the optimum out of the wind power. Comprehensive monitoring of pilot installations and analysis of the measurement results are used to demonstrate the technology and concepts developed in the project and serve as a testing ground for the design of construction and operation of building integrated or even building augmented wind turbines. Investigation of a number of existing state-of-the-art building augmented wind turbines realised in Norway and abroad was conducted with respect to building design, technologies applied, and resulting energy performance, cost and other significant experiences. The problem is to get good data about wind conditions on and around buildings. Thus pilot installations of vertical axis micro wind turbines were installed and measured on top of a building during the project period of one year.

METHOD

Different measurement devices were used for measuring wind velocity, wind direction, power output and vibration in 5 minute intervals. Since vibration was not considered the vibration measurements were not calibrated. The results were collected by a data logger on the roof and periodically tracked out on a computer. A web-based software that works with the HOBO Remote Monitoring System was used to collect the measured data [4]. The results document discrepancies between the theoretical and the actual performance of the systems, including both system solutions and management.

Figure 1 shows the measurement device installed next to the North facing row of wind turbines. The schematic representation of the whole measurement setup is shown in Figure 2.

Figure 1 – Wind measurement devices [3]

Wind data was also collected from two weather stations nearby. The following parameters were examined:

- Actual local wind speed and direction [4]
- Actual temperature and rain/snow fall
- Actual wind speed and direction at next meteorological station [6]
    - mean wind speed last 10 minutes before observation (FF)
    - highest 10 minute average wind for the last hour (FX_1)
    - maximum gust (3 seconds) last hour (FG_1)

This monitoring campaign allowed to collect and compare wind availability on-site and at two meteorological stations within the city centre [6]. The wind performance was investigated and documented followed by an analysis of the correlation between measured climate data at the installation site and the two nearest meteorological stations (Blindern and Alna). The wind measurements (velocity and direction) were performed continuously for one year. Measurement results from 5 minute intervals were processed; wind direction was vectorised, and summarized to hourly, weekly, monthly and annual data.

Correlations between wind measurements from different sources were calculated.

$$Correl(X,Y) = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sqrt{\sum (x-\bar{x})^2 \sum (y-\bar{y})^2}} \qquad (1)$$

where

X is sample array 1, Y is sample array 2

x and y are the samples, $\bar{x}$ and $\bar{y}$ sample means AVERAGE(array1) and AVERAGE(array2).

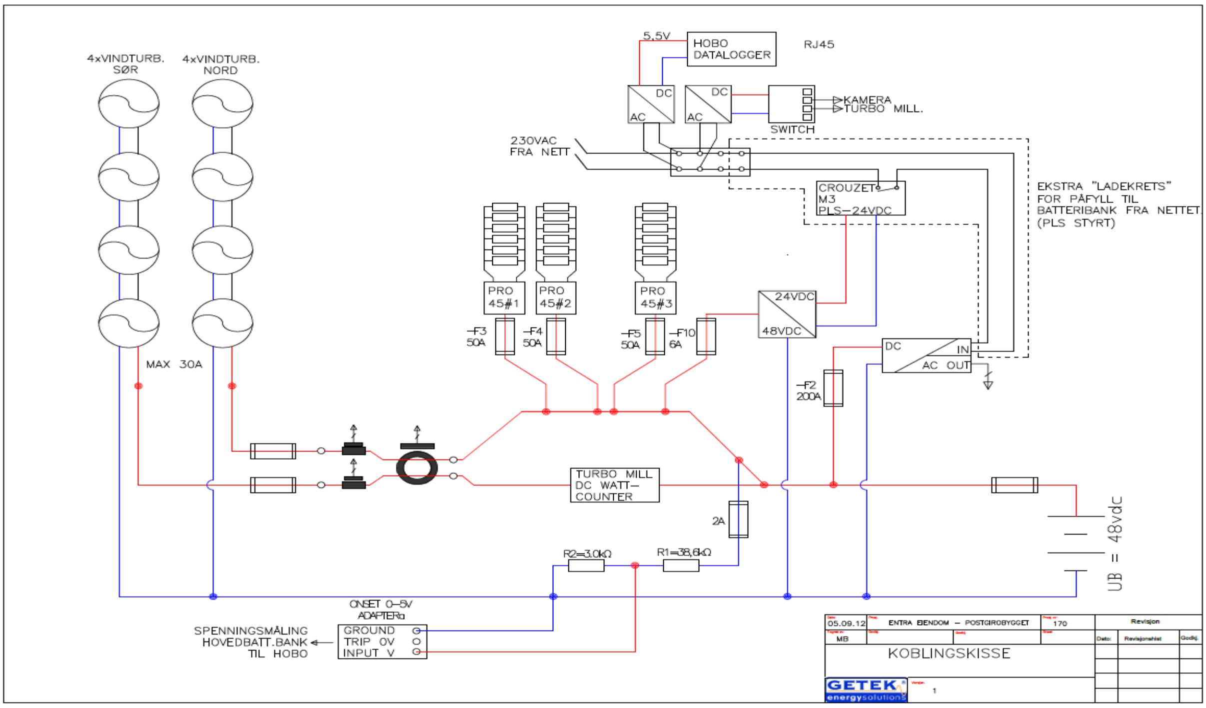

Figure 2 – Monthly wind velocities of different measurement stations [3]

RESULTS

Wind velocity

The results shown in Figure 3 illustrate that wind speed on top of the building was much less than historic data of nearby meteorological stations in Alna and Blindern.

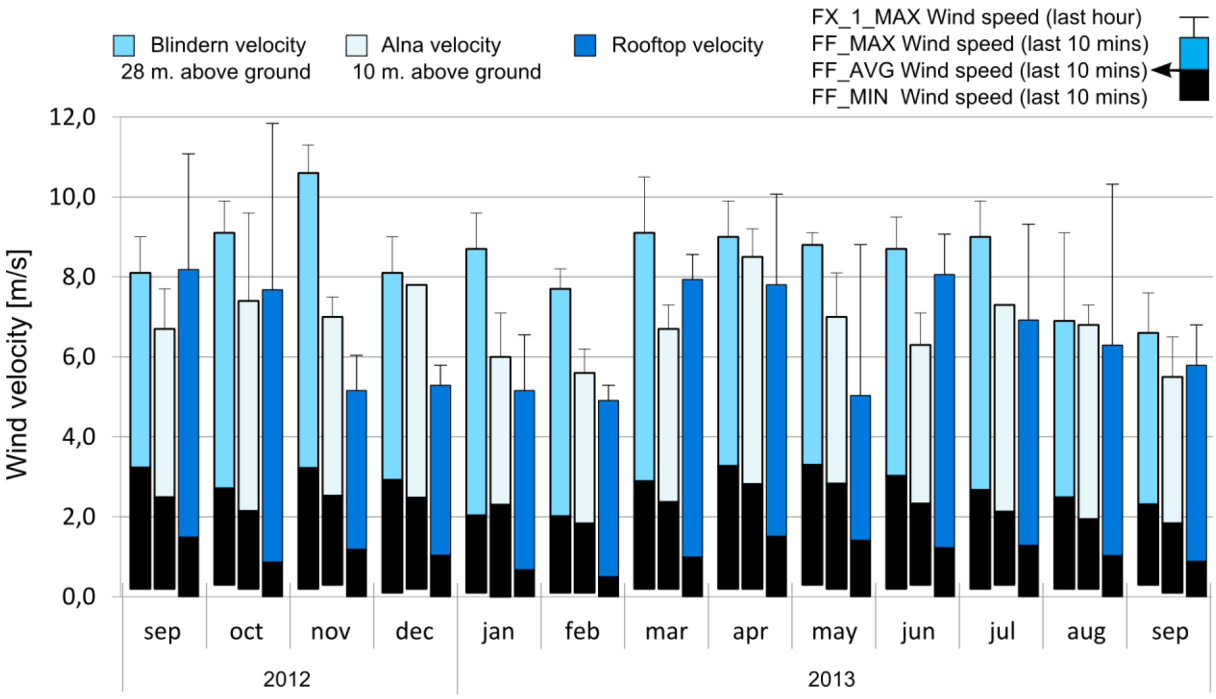

Figure 3 – Monthly wind velocities of different measurement stations

Figure 3 illustrates that mean wind velocity on the roof was much lower than measured at other the stations at Blindern and Alna in Oslo. In average, wind velocities on the roof were only 42% of the average measured at Blindern and Alna.

Wind direction

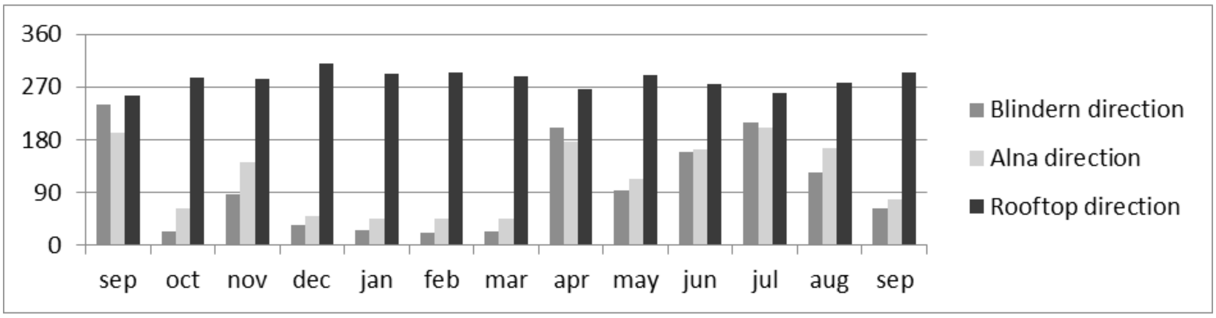

Figure 4 – Monthly wind direction for different measurement stations

Figure 4 illustrates the main wind directions for three different locations in Oslo. Measurements results on the roof of the test building show very different wind directions than those registered at Alna and Blindern weather stations. There were distinct differences in wind direction between summer (April–August) and winter (October–March). This difference in wind direction was not registered by the measured location on the roof of the test building. Here, the prevailing wind direction remained the same throughout the year.

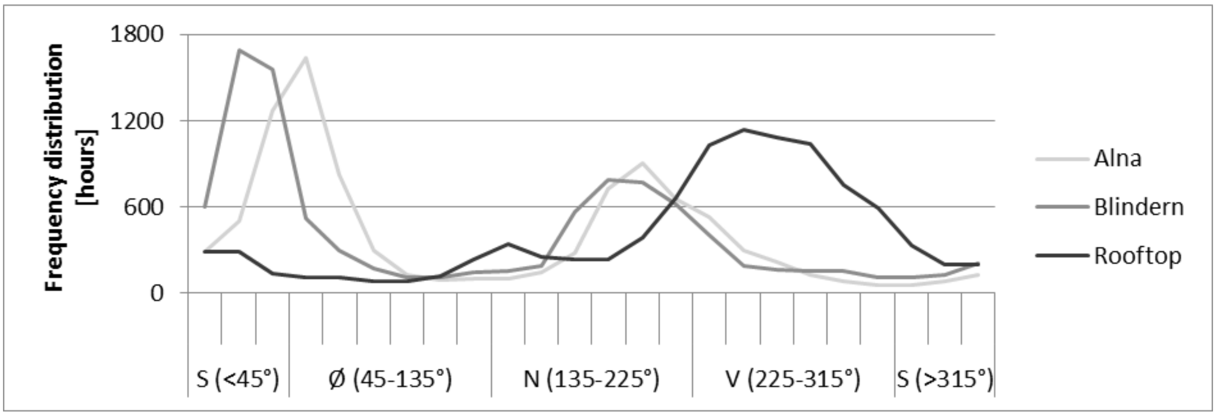

Figure 5 – Annual wind direction for different measurement stations with frequency distribution (year)

It can be seen in Figure 5 (frequency distribution, below) that measured wind directions from the weather stations at Alna and Blindern were dominating from North and North-North-East (30–60'). The measured wind direction on the test building shows dominance from South-West (270 '). This is difficult to explain. One reason for this mismatch could be local «conditioning» and redirection of wind due to the building geometry and the surroundings.

What might have a major impact is turbulence around the building which would lead to higher gut velocities but lower average wind velocities. The different wind directions support the presumption that turbulent wind conditions affect the results.

The measurements of wind velocity and direction were taken in periods from September 2012 to September 2013. Table 1 shows the monthly correlation factors between Alna/Blindern, Blindern/rooftop and Alna/rooftop. It can be seen that correlation between the weather stations is higher than rooftop. Wind gusts have a higher correlation than average wind speed.

date		Alna/Blindern velocity			Blindern/rooftop velocity			Alna/rooftop velocity		
year	**month**	**FF**	**FX_1**	**FG_1**	**FF**	**FX_1**	**FG_1**	**FF**	**FX_1**	**FG_1**
2012	sep	0.794	0.855	0.875	0.690	0.694	0.843	0.678	0.664	0.866
	oct	0.755	0.805	0.831	0.672	0.692	0.866	0.630	0.677	0.827
	nov	0.737	0.771	0.775	0.742	0.739	0.855	0.714	0.731	0.805
	dec	0.656	0.697	0.766	0.657	0.694	0.768	0.692	0.735	0.822
2013	jan	0.441	0.541	0.657	0.588	0.638	0.744	0.583	0.638	0.788
	feb	0.667	0.733	0.789	0.674	0.713	0.841	0.657	0.711	0.846
	mar	0.714	0.787	0.843	0.665	0.722	0.846	0.674	0.694	0.839
	apr	0.788	0.831	0.863	0.738	0.767	0.883	0.785	0.766	0.875
	may	0.715	0.792	0.844	0.657	0.720	0.845	0.732	0.731	0.821
	jun	0.746	0.815	0.854	0.758	0.715	0.848	0.706	0.719	0.845
	jul	0.769	0.835	0.868	0.709	0.748	0.870	0.664	0.703	0.840
	aug	0.736	0.814	0.837	0.708	0.742	0.861	0.689	0.722	0.833
	sep	0.635	0.741	0.825	0.666	0.693	0.838	0.667	0.697	0.821

Table 1: Monthly correlation coefficients for measurement period. FF is the mean wind speed last 10 minutes before observation. FX_1 is the highest 10 minute average wind for the last hour and FG_1 is maximum gust (3 seconds) last hour.

DISCUSSION

The measurement of wind conditions were continuously monitored between the 4th of September 2012 and end of September 2013. Wind conditions on top of the test building were compared with measured wind data from weather stations nearby. The wind velocity and direction differ greatly from measurements taken at weather stations in Oslo (Blindern and Alna).

Wind conditions were measured at different heights. Alna weather station is measuring 10m above ground, while Blindern is measuring 28m above ground. The rooftop measurements were taken at 89m height. To compare these wind speeds there are some correlation equations where the height and the roughness of the surroundings has to be measured and considered (wind shear power law). This has not been done because the roughness of the surroundings could not be measured. In addition, the test building influenced the local wind conditions so that the wind speed at that height was obstructed and thus lower. The results with such adjustments would lead to lower correlations for the rooftop (since it is much higher than the weather stations).

The roughness of the terrain remains an important parameter as it shows high sensitivity of the wind speed. More detailed measurements are necessary in order to be able to confirm actual roughness of the surroundings (terrain factors). Local wind conditions on top of the high-rise building test building must be greatly influenced by the building and its surroundings. More detailed measurements are necessary in order to be able to explain this.

Measured wind conditions in Oslo (in all three locations) show average wind speeds that are much lower than what is required for electric operation from the wind turbines. The wind turbine product showed good results on the data sheet (power curve). Since these data depend on standard test conditions it is advisable to be careful with transferring them to local situations. It is very important to make local measurements of wind conditions (velocity and directions) prior to installation. This can help to select wind turbines that fit to the local wind profile.

After a couple of weeks of testing the product failed to function during strong wind gusts. The producer had to retrofit the windmills with a brake unit in order to solve this problem. Unfortunately it turned out to be a long and tedious process to receive these retrofit units. The first units delivered did not fit. This was a major setback in the testing, and it took many months to get the windmills up and running again.

CONCLUSION

Measured wind conditions on the roof of the building were very different from expected wind conditions. The location of the measurement devices and the wind turbines in the case study were not optimized. Much lower wind velocities were measured on the rooftop than at the other measurement stations. Correlations show a 40% lower wind velocity on the roof than at the measurement stations. The equivalent wind speed would be even lower if the height of the wind turbine is considered (in accordance with the wind shear power law). This should be taken into consideration when planning to install wind turbines in the built environment.

Accurate prediction of the wind velocity represents the basis for economic performance and is essential to calculate the electricity output of small and micro wind turbines (MWT). Wind evaluation presents challenges due to the expensive wind measurement tools in urban environments.

The shading and turbulence effect of surrounding obstacles produces inconsistent and unpredictable wind patterns below 30 m. Traditional wind resource maps are rarely available or are inadequate as wind conditions are evaluated at an altitude of 50 m (or 80 m) [1].

The following aspects of the wind resource in the built environment are poorly understood:

- Turbulence and directional variability
- Wakes, eddies, and separation zones
- Three-dimensional wind velocity profile and distribution
- Existing wind resource maps do not translate to the built environment.

As a result, the urgent demand for inexpensive and efficient methods of predicting and collecting local wind data is another key driving factor that requires further development and cost reduction.

REFERENCES

1. As, 2003. Norwegian Wind Atlas. NVE / ENOVA.
2. BLANCH, M. J. 2002. Wind energy technologies for use in the built environment. Wind Engineering, 26, 125-143.
3. Haase, M., Skeie, K.S., Tronstad, T.V., 2014. Building integrated vertical wind turbines: Experiences from the roof of Biskop Gunnerus gate 14 in Oslo. Oslo: SINTEF akademisk forlag (ISBN 978-82-536-1383-3) 59 s. SINTEF Fag(19)
4. HOBO: Remote Monitoring System, http://www.onsetcomp.com/live_systems, Access date: September 2012
5. MERTENS, S., (2006). Wind Energy in the Built Environment - Concentrator Effects of Buildings, PhD thesis, TU Delft.
6. Weather station data from the climate database of the Norwegian Meteorological Institute. http://eklima.met.no/