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Evaluation of an urban environment regarding the potential placement of wind turbines

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1 Introduction

Households in urban environments are one of the main consumers of energy. Sustainable development of these areas is a topic of increasing interest. The key to more self-sufficient, clima-neutral housing could be local energy production from renewable energies like fuel cells, solar panels and small wind turbines. What distinguishes wind energy in urban environments from open land or offshore installations is a unique surface topology. This has many implications, with the biggest being a drastic change of the wind resource itself. A good wind resource is primarily defined by high steady wind speeds. That is essential for an effective utilisation of wind turbines for power production. This becomes apparent when looking at the available wind power per unit area.

$$\frac{P}{A} = \frac{1}{2}\rho\, U^3 \tag{1}$$

The wind power scales with the cube of the wind speed. A doubling of the wind speed would lead to eight times the available wind power. This shows the relevance of a good understanding of the urban wind resource. Therefore in this study the wind field on an exemplary urban environment is examined.

2 Experimental Methods

The flow around a model of the campus Gløshaugen of the Norwegian University of Science and Technology in Trondheim is investigated experimentally with cobra probes and pressure taps at selected locations. The model is in a ratio of 1 : 320 and includes a total of 18 building complexes with a high degree of detail, spread over an area of more than 25000 m^2 in reality. This can be considered a typical representation of an urban environment. An atmospheric boundary layer is emulated in the wind tunnel by the use of triangular spires and a horizontal bar upstream of the model. The wind tunnel has a width of 2.70 m and a height of 1.80 m along a 11.15 m long test section. The model has a maximum elevation of the wind tunnel floor of 0.2 m, resulting in an overall blockage below 5%. Wind from four different directions is simulated with different orientations of the model in the wind tunnel. The inflow Reynolds number Re with regard to the highest building height and turbulence intensity u'_∞/U_∞ are held constant at $Re = 3.3\cdot 10^4$ and $u'_\infty/U_\infty = 12.4\%$ at building height. Reynolds number independency is shown in the operating range of the facilities. From previous CFD simulations promising locations regarding wind energy exploitation are selected. Velocity measurements are conducted at various heights at these locations to obtain velocity profiles and all over the urban model at a fixed height to create a comprehensive flow field. The cobra probes measure at $f = 650$ Hz and capture the velocity in all three directions within a 45° acceptance cone. These measurements are complemented by measurements of the static pressure at fixed pressure taps on three buildings and on the ground.

3 Results

At the windward edge of a flat roof building the flow generally separates and a zone of highly turbulent, partially recirculating flow results close to the roof. This region is to be avoided when placing a wind turbine due to its low wind speeds and high turbulence. Previous studies show that around a bluff body outside of the recirculation zone an acceleration of the flow can be observed. The occurrence of this effect is investigated in this experimental study. An example of a distinct overspeed region detected in the wind tunnel experiments is shown in Figure 1. It can also be observed that this beneficial area extends over a small height above the building only.

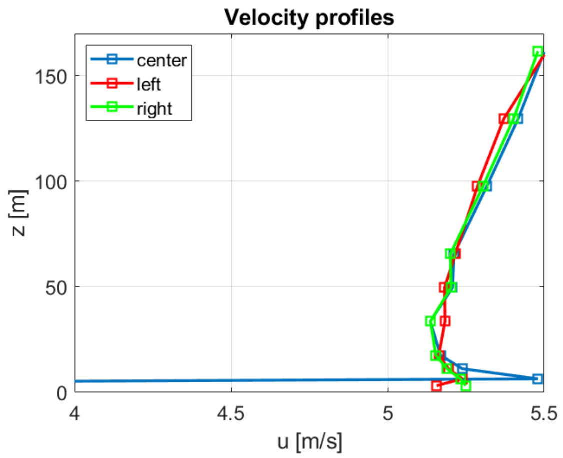

Figure 1: Overspeed region above building

It is demonstrated that obstacles upstream of a potential site mitigates flow acceleration above a building. Wakes of multiple buildings interact, resulting in large areas of low wind speeds, increased turbulence intensities and deflections of the main wind direction in the flow approaching subsequent buildings. In strongly obstructed flows this can lead to the acceleration being reduced to a negligible level. For selected buildings also the effect of different positioning on the roof is examined. It is shown that if a flow acceleration is visible it is stronger closer to the windward edge, whereas further downstream the effect washes out. The impact of these effects on available wind power is illustrated. Complete flow fields in the exemplary urban environment are analyzed with regards to the difficulties that arise for urban wind energy exploitation. The extent and complexity of building wakes can be observed in Figure 2. Large regions of reduced wind speed and strongly increased turbulence intensity occur in the presence of high buildings. These regions are to be avoided in the potential placement of wind turbines. To determine their extent and magnitude is not a simple task though, as wakes of various buildings of different geometry and size interact and merge.

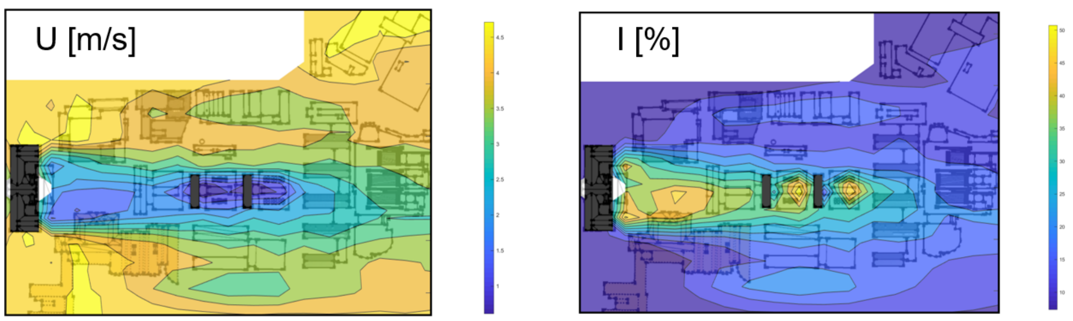

Figure 2: Velocity and turbulence field at 15 meters above the ground - wind direction North-South