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The influence of angular configuration of two buildings on the local wind climate

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ABSTRACT

Understanding flows in urban areas is important for a wide range of research areas. In this study the influence of different angular configurations of two buildings on the local wind climate is analysed. PIV (particle image velocimetry) measurements are conducted in an atmospheric boundary layer wind tunnel. Blocken et al. (2008a) showed that, counterintuitively, the wind speeds in the passage of diverging configurations is higher compared to converging configurations. Blocken et al. focused on the wind climate at pedestrian level. The results of this new study show that from the ground to the roof level the wind speeds in the passage are increasing with increasing angles between the buildings for the converging cases, while they are decreasing for the diverging cases. For all cases the highest turbulent kinetic energies can be found downstream of the passage. For the converging cases these regions are located downstream of the buildings and mostly above the pedestrian level, while for diverging cases these regions are located between the buildings at the pedestrian level, where the probability that pedestrians are present is higher.

1. Introduction

Due to high building densities in urban areas, the wind in cities is often forced to flow in passages between buildings. Depending on the building configuration, the wind speed in the passage is increased or decreased, which has an influence on the (i) wind comfort, (ii) thermal comfort, (ii) pollutant dispersion, (iii) convective heat and mass transfer at building envelopes, (iv) wind-driven rain in urban areas and (v) wind loads on building façades. Furthermore, locations with increased wind speeds could have a potential for wind power generation. A large number of studies on flows in passages between buildings can be found in literature. Most of them focus on the pedestrian wind comfort. Mochida and Lun (2008) and Blocken and Stathopoulos (2013) present in their papers an overview of literature on pedestrian-level wind conditions around buildings.

Wiren (1975) conducted wind tunnel measurements and found that wind speeds in passages between buildings are increasing with increasing building heights. His results also showed that wind speeds are higher, if the wind flows in a passage through a single building compared to the wind speeds in a passage with the same dimensions between two buildings. Beranek (1984) studied the wind speed amplification for a large number of single building configurations and groups of buildings in a wind tunnel. Based on the large number of measurements he could derive some rules, which can predict the amplification for a number of different building configurations. Other wind tunnel studies on wind flows in passages between buildings were for example conducted by Stathopoulos and Storms (1986) and Tsang et al. (2012). Dutt (1991) conducted a field measurement and could also find overspeeds in passages between buildings at full scale. Besides wind tunnel and field measurements also CFD (Computational Fluid Dynamics) simulations have been conducted to study the wind flows between buildings. Stathopoulos (2006) compared results from CFD simulations and wind tunnel studies for different cases. CFD studies with different building configuration were for example conducted by Blocken et al. (2007), Rizk and Henze (2010), Tutar and Oguz (2002) and Hong and Lin (2015). The winds in urban areas are also important for ventilations. Asfour (2010) studied, which configuration of four buildings is optimal to increase the heat removal by wind to increase the passive cooling

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potentials of the buildings. While increased wind speeds in urban areas have a negative impact on the wind comfort of the pedestrians, they could be used for wind power generation. Awan et al. (2015) showed that small vertical axis wind turbines could be used to generate electricity in urban street canyons with increased wind speeds. The potentials of wind power generation in urban areas or for single high-rise buildings are discussed for example by Simoes and Estanqueiro (2016) and Li et al. (2013). Kubilay et al. (2014) studied the influence of local wind flow pattern between buildings on the wind driven rain impact on building facades. Due to the high complexity of the flow structures, it is difficult to drive general rules from the large number of studies on flow between buildings, which could be used by urban planners and architects to improve the urban microclimate. Reiter (2010) summarized some of the most important flow phenomena in urban areas to be used for this purpose.

The increased wind speed in passages between buildings is often referred to as the Venturi effect (e.g. Gandemer, 1975; Lawson, 1980). Blocken et al. (2008a) showed that, counterintuitively, the wind speeds are higher in diverging compared to converging building configurations with wind tunnel measurements, where they measured the wind speed at pedestrian height on the centre line in a passage between building models with a hot-wire anemometer. Blocken et al. (2008b) obtained similar results from CFD simulations, where they also showed that the air flow rates are higher in diverging compared to converging building configurations. Blocken et al. (2008a, 2008b) explained this phenomenon by the fact that the Venturi effect was originally applied to flows in closed channels (Venturi, 1799), whereas the flow between buildings involves an open domain. They showed that a large amount of the oncoming air is flowing over or around the buildings, what they call the wind-blocking effect (Blocken et al., 2008a, 2008b). This blocking is more pronounced for converging compared to diverging passages and therefore the wind speeds are higher in diverging passages. Blocken et al. (2008a, 2008b) also compared the results of studies from literature that were conducted for this kind of flows (mainly focusing on Wiren (1975), Beranek (1984) andLawson (1980)) and found that some conclusions of these studies seem to be contradicting. Li et al. (2015) confirmed the results by Blocken et al. (2008a, 2008b) with CFD simulations. Their results support the statement that the Venturi effect is unsuitable to describe the outdoor passage flow with open boundaries. Also Li et al. (2015) focused on the pedestrian wind comfort, but they used a large number of different angles between the buildings. They also found that the wind speeds in the passage between two buildings is dependent on the drag coefficient of the buildings. Both Blocken et al. (2008b) and Li et al. (2015) determined flow rates (or fluxes) thought different planes to analyse, how much air is flowing over the buildings and how much air is flowing through the passage between the buildings.

The results presented by Blocken et al. (2008a, 2008b) are limited to cases with a 90° angle between the buildings, but they studied a large number of cases with different distances between the buildings, different building heights and wind directions. Li et al. (2015) kept the distance between the buildings, the building heights and the wind direction constant, but varied the angle between the buildings.

In the study presented in this paper the flow in passages for parallel, side-by-side, converging and diverging building configurations with different angles between the buildings are measured. Compared to Li et al. (2015) the distance between the buildings is smaller. Blocken et al. (2008a, 2008b) and Li et al. (2015) presented the wind speeds (almost) only at pedestrian level (2 m above the ground at full-scale). Blocken et al. (2008b) presents one vertical profile of the amplification factor in the narrowest passage between the buildings for different cases. Further also a schematic representation of the 3D flow is given in the paper. Here the results are analysed up to 2.5 times the building height. Blocken et al. (2008a) could only measure the velocity magnitude at a relative small number of locations. Flow fields with a higher spatial resolution can be measured with PIV compared with a hot-wire anemometer that was used by Blocken et al. (2008a). Further with PIV there is the possibility to measure the two velocity components in a plane. The current study improves the understanding of the flow structures of flows in passages between two buildings by presenting the flow field with high spatial resolution in a vertical plane. Because of this higher resolution, the results presented in this paper could be also used for more detailed validation of numerical simulations compared to the validation conducted by for the CFD studies mentioned above. Additionally to what was already analysed in literature (e.g. Blocken et al., 2008a, 2008b; Li et al., 2015), vertical wind speeds in the passage between the buildings (instead of flow rates at roof height), streamlines in a vertical plane, the turbulent kinetic energies and Reynolds stressed are studied in detail in this paper. Further in contrast to other studies (e.g. Blocken et al., 2008a, 2008b; Li et al., 2015), this paper does not focus on the wind speeds at pedestrian level, but presents wind speeds for all distances above the ground (up to 2.5 times the building height). Theoretically most of this information could be extracted from the CFD simulations by Blocken et al. (2008b) and Li et al. (2015), but was not presented in their papers. Instead they both presented flow fields on a horizontal plane at pedestrian height.

In this study the flow in a passage between two buildings with different angular configurations is measured. No surrounding buildings are considered and therefore this configuration does not represent an urban environment. In urban environments neighbouring buildings can have a strong impact on the flow in the surrounding areas (presented e.g. in Gerhardt and Kramer (1991) and Blocken and Persoon (2009)). Therefore the flow in the passage between the two studied buildings could strongly vary depending on the geometries of the neighbouring buildings. Here the flow between the two buildings was measured in a stand-alone configuration to get more general conclusions. To study the flow between the two buildings in a specific urban area, additional measurements have to be conducted. Comparing these results with the results of this study, it could be analysed, which effects are caused by the configuration of the two buildings and what are the impacts of neighbouring buildings.

The structure of the paper is as follows. The details of the used wind tunnel, the measurements system and the model geometries are given in Section 2. In Section 3 the results of the wind tunnel measurements are given. In a first part the measured wind speeds are presented and discussed and in a second part the results of the measured turbulence are given. In Section 4 it is discussed, which additional measurements could be conducted to study flows in urban areas for a wider range of configurations and in Section 5 the conclusions from the results of this study are drawn.

2. Experimental setup

2.1. Experimental facility and measurement system

This study was conducted in the closed circuit ETH/Empa atmospheric boundary layer wind tunnel in Dübendorf (Switzerland). The test section is 1.9 m wide and 1.3 m high. For the PIV measurements, the flow is seeded with 1 μm DEHS (Di-Ethyl-Hexyl-Sebacat) aerosol particles. The PIV images are acquired with a 12 bit CMOS camera. The camera has a maximum resolution of 2016×2016 pixels. During the measurements the images are stored locally on a 36 GB memory on the camera. At full resolution