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Coupled CFD and building energy simulations for studying the impacts of building height topology and buoyancy on local urban microclimates

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A B S T R A C T

The temperatures in cities are increased due to the urban heat island effect. Heat can be removed from urban areas by wind and buoyancy driven ventilation. Building geometries have a strong impact on the wind flow patterns and heat removal in urban areas. The microclimate is analysed for a generic urban area with 23 buildings. Six different urban topologies are studied, where only the building heights of the individual buildings are changed. The local air temperatures are studied with coupled CFD and building energy simulations. The results show that the building height topology has a minimal impact on the mean air temperatures, but influences local air temperatures and the size of local heat islands. An analysis based on a comparison of simulations with/without buoyancy, shows a strong impact of buoyancy on the mean and local air temperatures. Further, correlations are found showing that the normalized increase in local air temperature is linked to the local air volume flow rates and thermal diffusivities. With higher volume flow rates and thermal diffusivities more heat can be removed from the environment. Based on these correlations an approach to evaluate the local heat island formation risk using isothermal CFD simulations is proposed.

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1. Introduction

It is well known that the microclimate in urban areas differs significantly from the climate in rural areas. Air temperatures are higher due to the urban heat island effect and wind speeds are lower due to wind sheltering leading to decreased removal of heat and pollutants from urban areas (Oke, 1987). Measurements in London showed up to 7 K higher air temperatures at night-time in the city compared to measurements outside the city (Watkins et al., 2002). In Athens the mean heat island intensity exceeds 10 K (Santamouris et al., 2001). The urban microclimate influences strongly the energy demand for space cooling and heating of buildings, and it has also a large impact on the thermal comfort and health of the people living in urban areas. Global warming and associated heat waves (Schär et al., 2004; Fischer and Schär, 2009) may further increase the temperatures in urban areas and can e.g. reduce the potential for night cooling significantly. Li and Bou-Zeid (2013) showed that the combined effect of UHI and heat waves is larger than the sum of the two individual effects. The UHI effect has a large impact on the thermal comfort (e.g. Saneinejad et al., 2014) and health (e.g. Robine et al., 2008) of pedestrians and on energy demand of buildings in urban areas (e.g. Allegrini et al., 2012a; Bouyer et al., 2011).

Knowledge of the detailed urban microclimate is important for a wide number of applications. A wide range of numerical studies on the microclimate can be found in literature. Arnfield (2003), Mirzaei and Haghighat (2010) and Moonen et al. (2012) give overviews over such microclimate studies. In the literature the local urban microclimate is numerically studied with different degrees of complexity and for different length scales, different numerical models are applied. Computational Fluid Dynamics (CFD) simulations are often used for microclimate simulations at the neighbourhood scale due to its high spatial resolution. For larger scales these simulations get computationally too expensive. As an example we mention recent microclimate studies based on CFD simulations e.g. by Toparlar et al. (2015), Gromke et al. (2015), Allegrini et al. (2015a) and Allegrini et al. (2015b).

Two types of microclimate or wind flow studies can be found in literature: studies with generic building configurations (a list of a number of studies is given in Ramponi et al., 2015) and studies for existing mostly complex building configurations (e.g. Toparlar et al., 2015, Van Hooff and Blocken, 2010). For most of the studies with generic building configurations, all buildings have the same building height and the influence of non-uniform building heights in an array of buildings is not analysed in detail (except flows around high-rise buildings).

A number of studies, where the impact of non-uniform building heights on the flow in urban areas is studied, can be found in literature. Tominaga (2012) conducted a CFD study, where he first analysed the ventilation efficiency in a generic urban area with non-uniform building heights, before he studied the ventilation for a real urban configuration. For the generic cases he kept the average building height constant. He found lower wind speeds and higher temperatures for building configurations with uniform (lower) building heights, compared to the cases with high-rise buildings surrounded by low-rise buildings. He reported that the high-rise buildings have a positive effect on the ventilation potential of an urban area. Also Hang et al. (2012) studied the influence of building height variability on ventilation in urban areas. They mainly focused on pollutant dispersion. As Tominaga (2012), they conducted their study with a generic building configuration with block-type buildings, which had variable building heights. The results of this study show improved ventilation for urban areas with non-uniform building heights. Boppana et al. (2010) conducted a similar study, but used a staggered configuration of the building blocks instead of the configuration, where the buildings are aligned as it was used by Hang et al. (2012). They used LES (Large Eddy Simulations) to account for the unsteady flow structures and found that the ventilation is influenced by the higher turbulence intensities caused by the non-uniform building heights. Gan and Chen (2016) analysed the influence of different building height topologies on the wind flow patterns within the urban areas. They found a correlation between the rugosity of the urban area and the wind speed at the pedestrian level.

Besides studies that focus on the wind flow patterns and on pollutant dispersion also a number of studies have been conducted, where the influence of the building height topology on the air temperatures in an urban environment and the removal of heat was investigated. Pillai et al. (2010) and Pillai and Yoshie (2015) used CFD simulations to analyse the heat removal from generic urban areas with uniform and non-uniform building heights. The results showed increased heat transfer for cases with non-uniform building heights. They further used their results for urban canopy models in mesoscale meteorological models for better urban heat island predications. Deng et al. (2016) used ENVI-met (Bruse and Fleer, 1998) to study the thermal comfort

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