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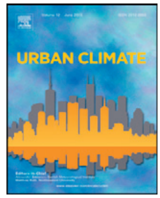

Simulations of local heat islands in Zürich with coupled CFD and building energy models

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ABSTRACT

Due to the urban heat island (UHI) effect the air temperatures in urban areas are most of the time higher compared to the temperatures in rural areas. Further the wind speeds are lower due to wind sheltering. In the past decades cities and therefore also the urban heat islands have been continuously growing. The local microclimate has a strong impact on the energy demand of buildings and the human comfort and health. Only few guidelines exist for urban planners to mitigate UHI effects or its impacts. This study aims at simulating the effect of new buildings on the local urban microclimate for a building site in Zürich (Switzerland). One-way coupled CFD and building energy simulations are conducted to determine the increase in air and surface temperatures due the presences of new buildings. The daytime local air temperatures for weather conditions with high ambient air temperatures, which are considered to be most critical for thermal comfort, are studied. The results show that the formation of local hot spots strongly depend on the building geometries, building materials, the strength of buoyancy and the wind directions and wind speeds.

1. Introduction

The microclimate in urban areas differs significantly from the climate in rural areas. Wind speeds are lower due to wind sheltering leading to less removal of heat and pollutants from urban areas (Oke, 1987) and air temperatures are higher due to the urban heat island effect. In London measurements showed up to 7 K higher air temperatures at night-time in the city compared to measurements outside the city (Watkins et al., 2002).

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The mean heat island intensity exceeds 10 K (Santamouris et al., 2001) in Athens. Also for cities in Switzerland significant urban heat island intensities were measured (Wanner and Hertig, 1984). For the city of Zürich maximum urban heat island intensities of 5–7 °C (Basel: 5–6 °C, Berne: 5–6 °C, Biel: 4–5 °C, Freiburg: 3–5 °C) were already observed by Wanner and Hertig (1984) about 30–35 years ago. The urban microclimate influences strongly the energy demand for space cooling and heating of buildings (e.g. Allegrini et al., 2012a; Bouyer et al., 2011), and it has also a large impact on the thermal comfort (e.g. Saneinejad et al., 2014) and health (e.g. Robine et al., 2008) 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. It was shown by Li and Bou-Zeid (2013) that the combined effect of UHI and heat waves is larger than the sum of the two individual effects. This can reduce the potential for night cooling significantly, what might have a strong impact on the space cooling demands in Switzerland, where mainly passive night ventilation is used to cool the buildings (Frank, 2005).

Knowledge of the detailed urban microclimate is important to predict space cooling demands or the thermal comfort. To get accurate results from building energy simulations, accurate microclimatic data at the building site are needed. Further, city planners need finely resolved information on the local microclimate to improve the exterior thermal comfort for planning new urban areas with high thermal comfort. Numerical simulations can be used to predict and study the local microclimate at the neighbourhood scale. A large number of numerical studies on the microclimate can be found in literature. Overviews of microclimate studies are given by Arnfield (2003), Mirzaei and Haghighat (2010) and Moonen et al. (2012). The local urban microclimate is numerically studied with different degrees of complexity in literature. In a large number of studies ENVI-met (Bruse and Fleer, 1998) is used to simulate the urban microclimate (e.g. Ali-Toudert and Mayer, 2006; Perini and Magliocco, 2014; Taleghani et al., 2014). ENVI-met is a model to simulate flows around buildings, model turbulence, exchange processes of heat and vapour at buildings and vegetation, bioclimatology and pollutant dispersion (Bruse and Fleer, 1998) with rather low spatial resolution. To get a higher spatial resolution and to be able to determine the convective heat transfer at the building façades Saneinejad et al., 2012 conducted CFD (Computational Fluid Dynamics) simulations coupled with a detailed radiation model and a detailed heat and moisture transport model for a two-dimensional urban street canyon. They studied local heat island mitigation measures with their coupled simulations. Studies with a similar approach have been conducted to investigate the influence of the local microclimate on the space cooling demand of buildings in urban areas (e.g. Allegrini et al., 2012a and Bouyer et al., 2011). The authors of these studies concluded that it is important to account for the local urban microclimate when simulating energy demands of buildings with building energy simulations. Allegrini et al. (2012a) conducted their study for a simplified urban street canyon configuration, while Bouyer et al., 2011 studied the energy demand for an urban neighbourhood with complex geometries.

Recent microclimate studies based on CFD simulations have been conducted e.g. by Toparlar et al. (2015), Gromke et al. (2015) and Allegrini et al. (2015a,b). Allegrini et al. (2015a) studied the impact of different urban morphologies on the local microclimate in urban neighbourhoods. Their results showed that building geometries strongly influence the formation of local heat islands. High local heat island intensities can mainly be found in areas with decreased ventilation (e.g. inside courtyards). They also found a strong impact of buoyancy on the local air temperature for weather conditions with calm winds. Buoyancy was found to increase the ventilation and therefore leading to decreased air temperatures. Therefore counterintuitively they found lower local air temperatures at the pedestrian level for lower wind speeds. The results from the same simulations were used in a second publication (Allegrini et al., 2015b) to study heat fluxes in urban areas. By studying the heat fluxes, they could better understand how heat is removed from urban areas. They found that turbulence is an important mechanism to remove heat for weather conditions with high wind speeds, because in this case heat is transported by turbulence through shear layers that are formed around buildings. For weather conditions with low wind speeds the shear layers are less important, because the flow is mainly driven by buoyancy and therefore convective heat fluxes are more important for these weather conditions. In Allegrini et al. (2015a,b) an approach with on-way coupled CFD (computational fluid dynamics) and building energy simulations (BES) is used to determine the air and surface temperatures. The surface temperatures determined in the BES are used in the CFD simulations as temperature boundary conditions. The same approach is also used in this paper. In this paper geometries of an urban neighbourhood together with existing designs for new buildings are used instead of the generic urban morphologies presented in Allegrini et al. (2015a,b).