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Projections of design implications on energy performance of future cities: A case study from Vienna

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ABSTRACT

This paper presents the results of a research project involving a new urban development project in the city of Vienna. Given the expected long life-cycle of this project, the developers requested scientifically-based information concerning the projected extent of the microclimatic changes in the development area and their potential ramifications for open urban spaces and the planned buildings' energy and thermal performance. To address this inquiry, the first stage of the research involved capturing both the current state and future projections of the climatic conditions of the area. As a next step building performance simulation models were used to evaluate alternative building designs (specifically various surface and layout design options and degrees of vegetation) in view of their mitigation effectiveness vis-à-vis climate change projections. The simulated implications of the assumed climate change trend suggest that the future heating loads will be lower, whereas cooling loads will significantly increase. The results help providing qualified estimations of the extent to which certain surface and building design features influence future cooling and heating loads. Furthermore results show the importance of taking microclimatic conditions of the relevant area into account.

1. Introduction

Reducing energy consumption and CO_2 emissions in cities is one of the top priorities of the European Union. A great amount of energy is used for conditioning buildings, which in turn is also indicated as one of the key parameters in reducing the energy consumption. A large part of buildings are already constructed, but due to growing population and rising living space per capita, demand for constructing new buildings is still existing. The fact that more and more people tend to live in cities results in densification of city quarters and the development of new settlements. In recent years master plans of new settlements and districts foresee to be constructed in a sustainable way, aiming to ensure the sustainability of natural systems and the environment including energy efficient buildings while providing comfortable conditions for the inhabitants. The energy performance of buildings is dependent on multiple factors but one significant factor is the surrounding. Not only the surrounding microclimate of a building has a direct effect on the buildings heating, cooling, and ventilation loads, but also inter-reflections between the building and external surfaces influences the performance. The magnitude of that strongly depends on factors such as building configuration, building and open space surfaces and their properties, prevailing wind situation, degree of vegetation, and sources of anthropogenic heat emission (Ali-Toudert and Mayer, 2006, Hagen, 2011). The effects are typically more pronounced in urban areas compared to rural surroundings, creating the urban heat island effect (Rosenzweig et al., 2005). Past research investigated temperature differences up to 12 K in different urban areas (Okeil, 2010). These differences may be advantageous or disadvantageous for human comfort depending on geographic location and prevailing weather conditions (Gartland, 2008). According to Taha, 1997, heat islands in the areas of high latitudes cause fewer problems since they reduce the energy demand for heating. Urban heat island effects are particularly unwanted in regions of low and mid-latitudes because they contribute to an increase in cooling loads (Rosenzweig et al., 2005). Vienna, which has a latitude of 48° is dominated by heating

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loads but also cooling loads are rising, resulting in an increased use of air conditioning. Extensive use of air conditioning worsens in turn the urban microclimate by rejecting waste heat into open spaces (Alcoforado and Andrade, 2008; Priyadarsini, 2009). These circumstances may become even more critical due to the projected global warming effect and the associated rise in temperature (De Wilde and Coley, 2012; Ouedraogo, Levermore and Parkinson, 2012; Robert and Kummert, 2012). Climate models assume rising mean annual temperatures of about 1.5 °C by the year 2050 (De Wilde and Coley, 2012).

These effects show that adapting the built environment is next to mitigating effects increasingly important.

In this context, this paper presents the results of a research project involving a new urban development project in the city of Vienna (Aspern, 2012). Given the expected long life-cycle of this project, the developers requested scientifically-based information concerning the projected extent of the microclimatic changes in the development area and their potential ramifications for open urban spaces and the planned buildings' energy and thermal performance. The goal of the project was to derive planning and design guidelines for the development of climate-responsive and energy efficient city planning and to optimize micro-climatic conditions within this development area. Thereby, the current climate and the effects of climate change on the performance of buildings and the comfort ramifications of open spaces was taken into account. The first stage of the research involved capturing both the current state and future projections of the climatic conditions. Thereby, mean and extreme conditions were predicted for a time horizon of fifty years. Starting from these data, building-relevant weather information was derived on a more resolved spatial scale by applying microclimate simulations. Representative areas within the project boundaries were selected and investigated by means of simulations with respect to the microclimatic effects of the current and future climate on the performance of urban open spaces and the performance of the adjacent buildings.

Building performance simulation models were used to evaluate alternative building designs (specifically various surface options and degrees of vegetation) in view of their mitigation effectiveness vis-à-vis climate change projections and improvement of the microclimatic conditions. The results help providing qualified estimations of the extent to which certain building and open space design features could mitigate projected consequences of climate change.

2. The case study

The case study which is presented concerns a new development area "Seestadt Aspern" in the city of Vienna. A master plan has been developed for an area of 240 hectares, which will be constructed on an old airfield. The realization of the master plan should be finalized by the year 2028, whereby several construction phases are foreseen. About 40% of the surface area is devoted to apartments for 20,000 people, 15,000 office places, and additional 5000 working places in trade, research and development. The remaining 60% of the surface area includes roads, green areas such as parks, sports facilities and an artificial lake. The master plan divides the area into a business district, an industrial area, a research and development district, and residential areas with different density. The future buildings are required to fulfill relatively high construction standards in terms of energy efficiency.

In a first step, reference areas of 500 by 500 m were defined to investigate the microclimatic conditions of typical urban situations of the "Seestadt Aspern".

Three reference areas were selected (T1–T3, see Fig. 1). T1 in the southern part is devoted to research and development and includes a technology center and the southern railway/metro station. T2 is located in the west of the development area and includes low and uniformly distributed residential perimeter blocks with typical residential yards, streets, district parks and squares. T3 covers a highly dense urban area within the settlement and shows a strong variation in building height.

3. Climatic ramifications

Climatic effects impact the performance of buildings such as that they influence heating, cooling, and internal loads (people, light, and equipment) (Crawley, 2008). In building performance simulations, typically standardized weather files are used based on long-term weather records as derived from weather stations. These weather files represent typically the past, but do not take future climate change into account. Moreover weather station data are not available for all building block locations, but are rather limited to a number of few spots within a city. Actual (building block level) microclimatic conditions may substantially deviate from those at the weather station locations. For more consistent energy use predictions, we thus need micro-climatic data, that have better resolution both spatially (block-level) and temporally (embody future climate projections). In this context site related weather station information was retrieved for the current as well as future climate conditions. In a next step microclimatic simulations were conducted to consider influences of specific locations, urban structures, and the urban heat island effect.

3.1. Future climate projections

To project future trends of climatic conditions so-called "General Circulation Models" (GCM) are deployed, which simulate the general circulation of a planetary atmosphere (and ocean) based on Navier–Stokes equations considering the energy sources (radiation and latent heat). Global weather dynamics are modeled by discretizing fluid motion and energy transfer equations into spherical grids of discrete "cells," which are integrated over time. Dynamics between cells are calculated iteratively, processes within a cell – like convection – occurring on scales too small to be resolved are parameterized at cell level. The atmosphere surface interactions are taken into account by integrating an ocean model, an elevation model as well as a soil and a land cover model into the GCM. These GCMs deliver minute-wise results on atmospheric pressure, wind speed, temperature, humidity, radiation, cloud cover, precipitation, snow cover and various more, which are averaged to hourly values for spherical grid cell layers (100 by 100–250 by 250 km at ground level) staggered in the vertical to model the atmosphere volume covering the entire planet. As these gridded 100 km × 100 km results are too coarse to describe local climate, regional climate simulations are conducted by nesting a further climate model with higher grid resolution into a cut out of the gridded GCM. The GCM results are used as boundary conditions for the higher resolved atmosphere simulations which are calculated for smaller grid cells. To consider regional land and ocean effects (albedo, moisture exchange, surface roughness etc.) higher resolved terrain, soil- and land cover models are applied. Giorgi and Mearns, 1991 or Laprise, 2008 provide amongst other authors a comprehensive descriptions on regional climate modeling.

For the case study area, regional climate model results were extracted from the reclip:century simulations results, carried out for the greater Alpine area at 10 km × 10 km grid spacing and stored as hourly averages (Loibl, Züger, & Köstl, 2011; Loibl, Tötzer, Köstl, Züger, & Knoflacher, 2011; Loibl, 2010,2011). The reclip:century simulations have been carried out with the regional climate model COSMO CLM (Rockel et al., 2008). The current and future regional