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Impact of building design and occupancy on office comfort and energy performance in different climates

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ABSTRACT

The building sector has a significant share in a county's total greenhouse gas emissions, and as a reaction to the Kyoto commitment most countries are constantly adjusting building energy requirements in order to reduce greenhouse gas emissions and mitigate the climate change. While it is easier to set standards for the building fabric and for technical systems, the impact of occupants on comfort and energy performance in buildings has proven to be important, but is a lot harder to account for. This paper therefore aims to investigate the magnitude of influence of occupants in relation to climate and architectural design on thermal comfort and CO_2 emissions in offices in different climate zones of the world. The aim is to identify typical patterns and key parameters for optimisation.

For this purpose, a parametric study for a typical cellular office room has been conducted using the simulation software EnergyPlus. Two different occupant scenarios are each compared with three different architectural design variations and modelled in the context of three different locations for the IPCC climate change scenario A2 for 2030. The evaluation of the results is focused on two different modes of operation. For natural ventilation adaptive thermal comfort according to ASHRAE Standard 55 has been evaluated, and for mixed mode operation final energy consumption and resulting CO_2 emissions. The results indicate a first approach to estimate comfort levels based on climatic data, architectural design priorities and occupancy. Additionally, warmer climates seem to have larger optimisation potential for comfort and energy performance in offices compared to colder climates.

1. Introduction

In the context of the climate change, buildings have to provide satisfying comfort levels for occupants with minimum energy consumption in order to reduce resulting greenhouse gas emissions. This is a particular challenge in office buildings where significant internal heat gains are caused by occupancy, while at the same time the building is exposed to solar heat gains from the sun.

With the climate change decreasing cold stress and increasing heat stress can be expected which will increase the cooling energy demand especially in warm climates to maintain comfort under summer conditions [1]. As indicated by Wan et al. [2] for the Chinese context, CO_2 emissions are likely to increase with the climate change, and significant mitigation potential is related to energy efficient lighting, higher cooling set points and a cleaner fuel mix for electricity generation. This suggests that in order to mitigate the climate change a combination of different strategies needs to be considered which balances the specific climate, the building design and occupancy.

Based on the climate change scenario A2 of the Intergovernmental Panel on Climate Change [3] for the year 2030, this paper aims to compare the impact of building design and occupancy on comfort and energy performance in offices in order to derive optimisation strategies. It is based on a parametric study using the simulation software EnergyPlus [4] for a typical cellular office room to investigate the balance of architectural design and occupancy in three different climates. Simulations are run over a whole year, however the evaluation of the results is focused on summer conditions by considering a particularly hot year with similar characteristics to a year in the past decade with major heat waves. The aim is to investigate whether patterns of comfort and energy performance can be identified, that could be helpful for design considerations in early design stages.

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The study is conducted to compare three different climate zones of the world, the moderate climate of Hamburg, Germany, the Mediterranean climate of Athens, Greece and the hot and dry climate of Alice Springs in Australia. These locations allow for a comparison of the share of heating, cooling and lighting on the total final energy consumption in different climates.

In order to evaluate the impact of building design different parametric prototypes have been developed for this study. For comparability these prototypes had to be similar for all locations, but also reflect the variability of building design that can occur within one context. This has been achieved by focussing on the design priorities on the real estate market. Although the architecture of a building is a response to a multitude of influences, ranging from climate, urban and social and cultural context, occupancy parameters, comfort expectations, economic situation of the client, etc., mechanisms of the real estate market are similar in most countries and design priorities can be identified. In this study these are "prestige" reflecting a more luxurious office configuration, "low-cost", reflecting lowest initial costs, and "green" reflecting a more sustainable configuration. These configurations have been developed in a previous publication and more details on the development of these variations can be found in Roetzel et al. [5,6].

As with building design, the behaviour of occupants in buildings is extremely various and context dependent [7,5]. The magnitude of impact and influencing parameters has been discussed more in depth in a previous literature review [5], however the main conclusion is that average standard values that are typically assumed in norms and regulations do not reflect the influence of occupants on comfort and energy performance to a satisfying level. In order to address this issue different suggestions have been made. One of those is to model occupant behaviour precisely based on observations in field studies as proposed by Wilke et al. [8] for residential buildings. As investigated by Widén et al. [9] for domestic context, if sufficiently detailed time-use data are available, occupancy patterns with an unlimited degree of detail can be generated and modelled. However they also raise the question which degree of detail would be necessary for different applications. Another difficulty with occupant behaviour modelling based on field data is that results valid for one context are not necessarily as valid in another context, as indicated by Schweiker et al. [10] comparing occupant interactions with windows in Switzerland and Japan.

Another approach to occupant modelling is the definition of different occupant types, e.g. Parys et al. [11] suggested an approach to consider the variability in behaviour amongst individuals by defining representative active and passive users. Such an approach comes with higher levels of uncertainty for the results, however the applicability of the model might be increased since it is less dependent on individual building context.

This paper does not aim to model occupant behaviour precisely, but the approach is also based on the definition of different occupant types. The inclusion of specific contextual data seemed contradictory to the nature of the parametric study the investigation is based on. And also the focus of this work was to develop a simplified methodology that can be used in early design stages of an architectural project. This is the building stage where the optimisation potential is largest and where even a rough estimate of occupant's influence on comfort and energy performance can make a difference. This influence of occupants has been considered in this study by using extreme cases such as an ideal and a worst case scenario. Rather than precise predictions, the aim is to indicate the magnitude of influence that occupants can have on comfort and energy performance in buildings, and to derive recommendations for optimisation in early design stages.

This paper is the continuation of two previous publications. The first sets up the comparison of occupant behaviour, building design and climate [5]. It provides a more detailed literature review on occupant behaviour, more details on the development of the simulation models, and a more detailed description of input parameters for EnergyPlus. The second paper [6] as well as this third paper are updates of the initial simulation model, changes and additions have been made to suit the different focus of the studies. In this present paper, only the changes made to previous modelling assumptions have been described, for further details the reader is referred to the previous publications.

2. Development of the simulation models

2.1. Selection of weather data

In order to compare the impact of building design and occupants, three locations in different climate zones of the world have been chosen. They were selected to represent a moderate, a Mediterranean and a hot climate, and all three locations are in climate zones without extreme humidity, which makes comfort evaluation based on temperatures only more reliable. On the updated world Koeppen-Geiger climate classification map [12] Hamburg, Germany is classified as 'temperate, warm summer, without dry season' (Cfb), Athens in Greece as 'temperate, with hot dry summer' (Csa), and Alice Springs in Australia as 'arid, hot desert climate' (BWh).

In order to reflect these climate characteristics in building simulation, the selection of the weather data set is very important. And while national bureaus of meteorology offer a range of climate data observations and forecasts, these are very rarely available in a file format that can be used for building simulation. Additionally, there is no standardised input format, but different software requires different input file types and data content.

For use with the software EnergyPlus the weather file needs to be in ".epw" format, and a common source such weather files for many locations in the world is available from the EnergyPlus website [13]. These files are ready for use in simulation but they are based on data from the past. Additionally real time measurements from recent years are available for download [14], however they can have gaps of recording or the amount of recorded parameters can be limited. As such, they cannot be directly used as input for simulation, however in most cases they provide enough data to identify e.g. major temperature characteristics in a certain year.

For this study, the real time weather data from the EnergyPlus website have been used to get an overview of the main temperature characteristics for the hottest year in the past decade for the three locations Hamburg, Germany, Athens, Greece and Alice Springs, Australia. The hottest year has been defined as the year that has been associated with major heat waves, which had impact on human health as well as on the environment (bushfires), and is likely to be used as a reference year for comfort predictions due to expectations of increasing heat stress in summer in a future warmer climate [1]. For the location of Hamburg this is the year 2003, in Athens it was the year 2007 and in Alice Springs the year 2009, and all three countries apply different criteria to identify extreme heat. In Germany there is no official definition of a heat wave but the German Meteorological Service [15] issues a warning for the day when the perceived temperatures (related to temperature, humidity, wind speed and radiation) exceeds a threshold between 32 and 38 °C. In Athens, the Greek meteorological service defines a heat wave as a series of at least three consecutive days with a maximum daily temperature >37 °C [16]. Australia has no common definition of a heat wave, and different state emergency services issue heat warnings based on different thresholds. The Northern Territory does not have a specific threshold for such warnings, but