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Energy performance and comfort in residential buildings: Sensitivity for building parameters and occupancy

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ABSTRACT

Energy performance simulation is a generally used method for assessing the energy consumption of buildings. Simulation tools, though, have shortcomings due to false assumptions made during the design phase of buildings, limited information on the building's envelope and installations and misunderstandings over the role of the occupant's behaviour. This paper presents the results of a Monte Carlo sensitivity analysis on the factors (relating to both the building and occupant behaviour) that affect the annual heating energy consumption and the PMV comfort index. The PMV results are presented only for the winter (heating) period which is important for energy consumption in Northern Europe. The reference building (TU Delft Concept House) was simulated as both a Class-A and a Class F dwelling and with three different heating systems. If behavioural parameters are not taken into account, the most critical parameters affecting heating consumption are the window U value, window g value and wall conductivity. When the uncertainty of the building-related parameters increases, the impact of the wall conductivity on heating consumption increases considerably. The most important finding was that when behavioural parameters like thermostat use and ventilation flow rate are added to the analysis, they dwarf the importance of the building parameters. For the PMV comfort index the most influential parameters were found to be metabolic activity and clothing, while the thermostat had a secondary impact.

1. Introduction

Building performance simulation has been established as a widely accepted method of assessing energy consumption during the design process for buildings that are either due to be renovated or are going to be built new. Modern buildings are highly complex and have high performance requirements relating to sustainability, making simulations a necessity.

Building simulation tools have shortcomings, however, and are believed to be unreliable at predicting the energy performance of buildings. The reasons for these failings could be technical, such as weather variations and false assumptions during the building design phase [1,2]. Also limited information on the building's envelope and installations (especially when the buildings are very old and there are no records of the materials used) may also play an important role in the discrepancies between simulated and actual energy use. As a result, large differences are observed between predicted and actual energy performance, ranging from 30% up as far as 100% in some cases [1–6]. In Majcen and Santin [3–5], it was also shown that predictors are much worse for buildings with a lower energy class (generally older stock) than those with a higher energy class (generally the more recently built stock). Another important reason is related to a misunderstanding or underestimation of the role of the occupant's behaviour [1,6,7]. Current simulation software fails to take into account the energy-related behaviour of the occupant and his behaviour towards indoor comfort. There are numerous studies that emphasize the need to take proper account of the occupant's behaviour during the design phase, or even during the refurbishment stage, in order to generate better building energy performance predictions [1,2,6,8,9].

The energy models that are used to predict the energy performance of buildings are sensitive to specific input parameters. These most sensitive parameters should be modelled with care in order to represent the building as accurately as possible [10–12]. Accordingly, in order to improve the quality of the prediction of building energy performance, it is important to understand its

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sensitivity to the various input parameters, and in this particular case, changes in a combination of the building envelope and the occupancy behaviour parameters. This can be done through sensitivity analysis and specifically using the method of Monte Carlo analysis (MCA) [13].

Several studies can be found in literature with sensitivity analysis performed on the effects of technical and physical parameters on the energy consumption of buildings [12–18]. However, occupancy-related parameters that could reflect the behavioural pattern of occupants have rarely been studied and moreover, the majority of studies have involved commercial or office buildings and not residential buildings, which are the main object of the present study.

The international standard ISO 7730 is a commonly used method for predicting the thermal sensation (PMV) and thermal dissatisfaction (PPD) of people exposed to moderate thermal environments. The PMV model predicts the thermal sensation as a function of activity, clothing and the four classical thermal environmental parameters: air temperature, mean radiant temperature, air velocity and humidity. Activity means the intensity of the physical activity of a person and the clothing is the total thermal resistance from the skin to the outer surface of the clothed body. Many widely used building simulation programs such as ESP-r, TRYNSYS and Energy+ use ISO 7730 [19] to calculate comfort levels inside a building. One main criticism of the PMV/PPD method is that it disregards the effect of adaptations, the changing evaluation of the thermal environment due to changing perceptions. There are three different forms of adaptation, which are all interrelated and affect one another [20]: psychological adaptation relates to a person's thermal expectations based on his past experiences and habits [21–23]; physiological adaptation (acclimatization), relates to how an individual adapts to a thermal environment over a period of some days or weeks, behavioural adaptation relates to all the modifications or actions that an individual might make, consciously or unconsciously; and changes in the heat and mass fluxes governing the body's thermal balance [20]. These modifications may be personal adjustments [24–26], technological or environmental adjustment [27].

Generally speaking, the environment inside a residential dwelling is not as constant as that of an office and the range of behaviour of occupants and their interactions with building components is wider than in office buildings. All forms of thermal adaptation can be applied in residential dwellings: changing the level of activity and clothing, adjusting the thermostat, opening or closing windows and window shades, etc. It is suspected that user behaviour plays a much more important role in determining the comfort range, which may also be much wider than in office buildings, which are often more uniformly conditioned by HVAC and individuals have much less potential for changes and adaptations.

There is a significant gap in the literature when it comes to sensitivity analysis of physical, technical and occupancy parameters in the residential sector of areas with a maritime climate such as the Netherlands. Few studies have evaluated these parameters with a complete sensitivity analysis method which reflects the occupant's energy-related behaviour such as ventilation and thermostat settings as well as physical parameters for heating consumption and comfort index.

This paper presents the results of a sensitivity analysis study that was performed for a single residential housing unit in the Netherlands. The analyses were performed for the technical/physical properties of the building only – i.e. the thermal conductivity of the walls, floor and roof, window U and *g* values, orientation, window frame conductivity and indoor openings. The simulations were carried out with the following variations: multi-zone and single-zone versions of the building; two different grades of insulation; three different types of HVAC services; the occupant's behavioural characteristics (thermostat level, ventilation behaviour, metabolic rate, clothing and presence which in simulation terms is the heat emitted by people). The sensitivity of the above-mentioned parameters was gauged for the yearly total heating demand of the building and the hourly PMV comfort index. The present paper focuses on the heating period which is of importance in the Netherlands.

2. Methodology

The goal of the study is to make recommendations for:

(I). The effect of the accuracy of measurements relating to the building's physical properties on predicting the energy consumption of the building;
(II). we will seek to answer the following questions:
   (1). Which are the most critical parameters (physical and behavioural) that influence energy use in residential dwellings for heating according to whole building simulation software?
   (2). Which parameters have the most critical influence on the PMV comfort index?
   (3). How do the most important parameters for heating and PMV relate to each other?
   (4). Is the sensitivity different for dwellings with different physical qualities and different energy classes?
   (5). What do the results mean for the modelling techniques for predicting the energy consumption in dwellings (simple versus more complicated models)?

First, a sensitivity analysis will be carried out to determine the most important physical parameters for the energy consumption of the dwelling. Next, the behavioural parameters (heat emission due to tenants' presence, thermostat and ventilation) are added to the sensitivity analysis in order to compare the effect of the physical parameters and the behavioural parameters on the total energy consumption for heating. At the same time, another sensitivity analysis will be carried out in order to assess the most important parameters for the thermal comfort index (PMV). Possible overlap between the most influential parameters for the total energy consumption and the comfort index could reveal possibilities for improvement that could lead to reduced energy consumption and higher comfort levels.

2.1. Sensitivity analysis

The technique of sensitivity analysis is used to assessing the thermal response of buildings and their energy consumption [13]. The goal of a sensitivity analysis is to study the response of the model simulated by EnergyPlus with respect to the variations of specific design parameters.

In general, a sensitivity analysis is able to determine the effect of a building's design variable on its overall performance (for example, the demand for heating or cooling) of the building. It can be used to assess which set of parameters has the greatest influence on the building performance variance, and at what percentage.

Sensitivity analyses can be grouped into three classes: screening methods, local sensitivity methods and global sensitivity methods. Screening methods are used for complex, computationally intensive situations with a large number of parameters, such as in sustainable building design. This method can identify and rank in qualitative terms the design parameters that are responsible for the majority of the output variability e.g. energy performance. These methods are called OAT methods (one-parameter-at-a-time) and the impact of changing the values of each parameter is evaluated