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Experimental analysis of indoor temperature of residential buildings as an input for building simulation tools

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Abstract

The Energy Performance of Buildings Directive (EPBD) requires Member States to assess the energy use of buildings. However, the results heavily depend on the correct implementation of building properties and boundary conditions. This paper challenges the average indoor temperature assumed in Quasi Steady State methods and proposes a temperature profile to improve the accuracy of the simulation. This temperature profile is derived from in-situ measurements of the indoor temperature in nine terraced houses and is characterised by the energy performance of the building, the outdoor climate and the user behaviour. Applying this new temperature profile in the energy simulation model decreases the energy performance gap between simulated and actual energy use.

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Keywords: Indoor temperature; Building simulation; Heating behaviour; Relation indoor and outdoor temperature; Energy performance gap;

1. Introduction

As a result of the Energy Performance of Buildings Directive [1], the assessment of the energy use of buildings through simulation is required. However, the results of these simulation heavily depend on the correct implementation of building properties and boundary conditions. In Belgium (Flanders), the Energy Performance Regulation (EPR) for residential buildings is stated as a one-zone model, using a Quasi Steady State method to calculate the monthly energy

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demands for a constant indoor temperature of 18 °C [2]. As an example a study of heating patterns of residential buildings in the United Kingdom demonstrates the importance of correctly implementing the indoor temperature. It showed a deviation between monitored indoor temperatures in living rooms and the assumptions for simulation models. [3] The monitored heating pattern revealed barely a difference between weekdays and weekend days, in contrast to the BREDEM simulation model (Building Research Establishment Domestic Energy Model, used in UK) [4].

In order to decrease the energy performance gap between predicted and actually achieved energy use [5], a monthly indoor temperature profile is derived in this paper, using in-situ measurements of the indoor climate of residential buildings. Several studies already assessed techniques to improve the simulation of building energy demand. A first example is the implementation of more reliable user behaviour by means of an evidence-based probabilistic behavioural model [6]. Key features of this model are a time-depended occupancy profile and space-dependent heating patterns. Other points of improvement were identified by another study, evaluating the quasi-steady state method for school buildings [7]: the implementation of more room type profiles and a revision of the efficiency of the HVAC system.

A brief review of literature reveals three key parameters that influence the indoor temperature of residential buildings. First of all, heating behaviour of inhabitants is an important indicator of the indoor temperature, with strong variation between different dwellings [3]. Secondly, the relationship between residential indoor and outdoor climate shows that the outdoor temperature has an important impact on the indoor conditions, while the influence of the outdoor relative humidity is rather small. [8] During heating season, the indoor temperature of heated rooms is independent of the outdoor temperature, but in summer indoor temperature increases with the outdoor temperature. For this reason the correlation with warm outdoor temperatures is deviating from cold outdoor temperatures, what results in a non-linear difference between the indoor and outdoor temperature. Finally, the indoor temperature is also influenced by the insulation quality of the building envelope: decreasing mean indoor temperatures during heating season are related to increasing transmission losses. [9]

In this paper, in-situ measurement data of the indoor temperature in nine terraced houses in Belgium for a monitoring period of approximately one year are used to generate a temperature profile. The three parameters discussed previously are taken into account.

2. Methodology

The temperature profile is derived from the monitoring of the dwellings in steps. Firstly, in-situ measurement data of indoor temperature are used to develop temperature profiles as a function of outdoor temperature. Then, the heating behaviour of the residents is implemented by means of heating patterns and correlations of indoor temperatures of different zones. Because previous studies [3, 8, 9, 10] only distinguished day- & night-zone of a dwelling, detailed analysis of the temperature in all rooms will be performed. As a result an overall indoor temperature profile is derived for each dwelling. Finally, these nine resulting temperature profiles are combined into a general temperature profile taking account of the insulation level of the building.

Table 1 shows the properties of the monitored dwellings sorted according increasing UA-value. This UA-value indicates the insulation quality of the building and is equal to the mean U-value of all building components multiplied with the total heat loss area A. The indoor climate of these dwellings is monitored with two types of loggers (the HOBO UX100-003 logger and the HOBO U23-001 logger [11]) with an interval of 10 minutes. This 10-minute dataset will be aggregated to hourly averages to attenuate extreme values. For the outdoor climate, weather stations within a radius of 10 km of the monitored dwellings are used. To process all data R, a language for statistical computing and graphics, is used. [12]

The indoor-outdoor correlation is analysed by means of correlation coefficients and scatter plots. The QQ-plot, the histogram-plot and the Kolmogorov-Smirnov test all showed that the dataset is not normally distributed, so the Spearman correlation coefficient has to be used to test correlations. This correlation coefficient is calculated for multiple periods, as different correlations for different seasons of the year are expected [10]: the whole year, winter, summer and the heating season. In this study, the heating season is defined as the period with a default monthly averaged outdoor temperature below 10 °C (1^{st} November to 1^{st} May). The scatter plot of the temperatures is used to further visualize the indoor-outdoor relation for each room. Four kinds of regression lines are considered. Firstly, linear regression and piecewise linear regression (PLR) are used following the methodology of an American study. [8] In addition, polynomial regression (2^{nd} degree) is performed to take the possibility of a non-linear relationship