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Uncertainty analysis of the computer model in building performance simulation

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ABSTRACT

A large number of studies in building performance simulation have analysed several types of uncertainties, i.e., physical, occupation, weather, algorithms; however, the modelling uncertainty is a poorly addressed topic. Thus, the objective of this paper is to analyse how the computer models can influence the results of heating and cooling energy consumption in a building. Three types of analyses were performed: (1) deterministic, (2) parameter variation and (3) parameter uncertainty. Fifteen computer models were created to represent the real building. Such models differ in relation to external geometry, grouping of internal zones and internal thermal mass. The simulations were performed using the EnergyPlus programme, for three climates in Brazil. The model represents the real building properly when the simulation run time was reduced, and the results were close to the base case. For the deterministic analysis, the modelling uncertainties ranged from −16.0% to 8.3% for energy consumption in Florianópolis climate. As for the cooling energy consumption, the uncertainty was lower, i.e., up to 7.4%. These uncertainties are relatively high, and should be accounted for in calibration or even in computer simulations.

1. Introduction

Building simulation is very useful to accurately determine the thermal performance and energy consumption of buildings, especially for improving buildings at the design stage [1]. However, the results predicted by the simulations are only valid if the model is properly calibrated [2].

Calibration means technical and operational adjustments of the computer model that represents the building. For this purpose, many techniques have been developed, which are based either on long or short term measurements of some building parameters. It is a laborious process, in which the user has to insert several input parameters in the simulation programme and, at the same time, collect responses from the actual building operation [3].

According to Heo et al. [1], the purpose of a calibration is not just to find the ideal combination of factors that generates results closer to measurements. Calibration should consider the uncertainties in the input parameters (at least in the most important ones), uncertainties in the measurement methods and in the theoretical conception of the algorithm used.

There is a topic that is poorly addressed in the literature in dealing with calibration analysis, which corresponds to the model itself used in the performance simulations. Such models should represent the physical behaviour of the building correctly [4]. High levels of detail may affect modelling time and the simulation steps [3]. However, large amounts of simplifications, without considering the thermal and physical phenomena involved, may lead to erroneous conclusions.

Calibration and uncertainty analysis techniques should be applied in computer models, since these models represent a simplification of reality. With these techniques, one can determine the level of imperfection of the models, before performing forecasting and decision making [5].

There are few studies that deal with the analysis of computer models. In this study the word "model" means the geometry characteristics and shape of the building. Such models do not need to represent a building as it is architecturally, but rather its thermal behaviour.

According to De Wit [6], the modelling uncertainties arise from commonly applied physical assumptions and simplifications in a computer model.

Some authors have proposed various methods of simplification, trying to reproduce the physical behaviour of a building in a few representative parameters [7].

Chlela et al. [8] proposed a method for designing buildings with low energy consumption through simulations using the statistical Design of Experiments approach. A meta-model was created for preliminary studies of prediction, optimization, sensitivity

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analysis and interaction analysis in computer simulation of buildings. For the application, the authors have considered a three-floor commercial building for three different climates in France. Thirteen parameters were varied in two to five levels (depending on the method used), which were related to the envelope properties, like thermal transmittance and thermal capacity, thermal bridges, solar heat gain coefficient of the glass, percentage of openings in the facade, solar orientation, and different strategies of infiltration and natural ventilation. The simulations were performed using the SIMBAD programme. The effectiveness of different methods of Design of Experiments (which require different numbers of simulation runs) was evaluated by using the mean and standard deviation. The results showed that the meta-models are very useful and can replace the computer simulations, which are very laborious. The meta-models have shown good results for heating demand and the total energy consumption. However, less accurate results were obtained for the cooling demand. The more complex physical phenomena involved, the lower the accuracy of the meta-model.

De Wit [6] analysed modelling uncertainties in a case study of a three-storey office building, with heavy internal walls, double glazing, shading of windows and without a cooling system. The scenario conditions were assumed constant for elaboration of the modelling. Fourteen parameters were adopted, such as convection coefficients, wind reduction factor, pressure coefficient data, albedo, convective fraction of the internal loads and model used to calculate the internal and external convection. The authors used two programmes separately, the ESP-r and BFEP. For the sensitivity analysis the method of Morris [9] was used with the elementary effects at four levels of variation in all parameters. The variable analysed was the thermal comfort of the space. The parameters related to the deviation of external air temperature from the weather file value, the wind reduction factor, the database of wind pressure coefficients, and coefficients of internal heat transfer were the most influential parameters in the thermal comfort performance. As a conclusion, in order to reduce the uncertainty of some parameters, wind tunnel measurements for the pressure coefficients determination could be used. For reducing the temperature stratification uncertainty, CFD models could be used. The second order effects were considered to be unimportant.

Melo et al. [10] conducted a validation study of a simplified model for determining the energy performance of commercial buildings. The analysis involved the comparison of the code developed, which was based on multivariate linear regression, with the BESTEST applicable by ASHRAE Standard 140 [11] and the results of validated simulation programmes, in different typologies and climates. It was verified that the simplified model generally underestimates the energy consumption of the building, due to the difference between the typologies used in its design and conception.

Pan et al. [12] verified the use of simplified models for modelling of atrium in buildings. A glazed atrium shows complex heat transfer phenomena, which causes difficulty in calculating the heat load due to temperature stratification. They found that conventional models for energy analysis, with uniform internal temperature throughout the height of the atrium, without considering stratifications lead to large errors in the calculation of the thermal load. The authors developed three simplified models, differing by the number of nodes in which internal air temperatures are calculated. The three models divisions depend on the height of the atrium, which were compared with results of CFD models, in various heights.

Most of the studies assessed how the simulation results differ from results measured through calibration methods that include all types of parameters (physical, internal loads, usage and occupancy schedules, weather). However, one should also consider the simplifications in the same geometric model used, because they generate uncertainty that should be accounted for.

Thus, the objective of this paper is to analyse the uncertainties in the computer model in the cooling and heating energy consumption in a public building with complex geometry, through building performance simulation.

Table 1
Thermal properties of the construction components.

Variable	Walls and partitions	Roof	Floor
Thermal transmittance [W/m^2 K]	2.27	1.13	5.56
Thermal capacity [kJ/m^2 K]	146	2.18	129
Solar absorptance [–]	0.5	0.15	–
Long wave emissivity [–]	0.9	0.1	–

Table 2
Internal loads for each activity.

Activity	Equipment (W/m^2)	Lighting (W/m^2)	People (occupants/m^2)
Classroom	4.74	12.24	0.2034
Laboratory	8.73	12.24	0.1063
Reception	4.63	7.20	0.1122
Bathroom	1.56	6.00	0.2316
Corridor	1.83	8.52	0.1065
Office	10.49	14.28	0.0979
Computer cluster	27.81	12.24	0.2313

2. Method

The first part of this study refers to the description of the actual building and considerations about geometry, physical properties, usage, occupancy and internal loads. The second part refers to the general settings of the computer simulation, common to all models. The third part refers to three analyses performed successively, i.e., (1) deterministic analysis, (2) parameter variation analysis, with screening sampling technique, and (3) uncertainty analysis, with the Latin Hypercube sampling technique.

In all analyses, there is a base case model that represents a simulation model which contains the greatest amount of details possible, named model 1. Fig. 1 summarizes the method developed for this study.

2.1. Building description

The building model was based on the design of the Department of Architecture and Urbanism of the Federal University of Santa Catarina, shown in Fig. 2. The building is located in Florianópolis-SC, southern Brazil. It is an educational building, with 4800 m^2 of built area, distributed on three floors. The main facade faces North.

The floor plan of the building has the shape of an arch, which is complex in terms of modelling heat transfer phenomena, as each infinitesimal element of the facade has a slightly different solar orientation.

Table 1 shows the thermal properties of the construction components adopted in the study. The walls are of brickwork, with cement mortar, the floors are of concrete and the roof is metallic with PVC ceiling. The windows are 3 mm glass with a Solar Heat Gain Coefficient (SHGC) of 0.87. The metallic roof has low thermal capacity.

Table 2 shows the internal loads, which were defined for each thermal zone of the building. The internal loads of equipment and occupants density have been adopted according to ASHRAE Standard 90.1 [13]. For lighting loads, values 20% higher than required in the same standard were taken to avoid considering a high performance building model. The metabolic rate was set to 108 W/person, regardless of activity.