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Evaluation of a multi-stage guided search approach for the calibration of building energy simulation models

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ABSTRACT

This paper is focused on increasing the knowledge on methods for calibrating BES models and to get more insights of different approaches for the optimization of the calibration process. The paper will be centred in the evaluation of a multistage guided search approach. It defines an iterative optimization procedure which starts with the assignment of probabilistic density functions to the unknown parameters, followed by a random sampling and running batch of simulations. It then finishes with an iterative uncertainty and sensitivity analysis combined with a re-assignment of the ranges of variation of the strong parameters. The procedure converges when no new influencing parameters are found. This method is applied to a real case study consisting of an unoccupied office building located in Lleida (Spain). The measured indoor temperature has been used to determine the uncertainty and precision of the method. The effect of the size of the sampling, the number of iterations and the parameters of the global sensitivity method are analyzed in detail. The results of this paper exemplify the degree of accuracy of multistage guided search approaches, and illustrate the reasons how these analyses can contribute to the improvement of more refined calibration methods.

1. Introduction

The calibration of forward Building Energy Simulation (BES) models plays a fundamental role in building energy performance analysis and is a critical factor for proper evaluation of energy savings produced by energy conservation measures. In order for BES models to be used with any degree of confidence, it is necessary that the existing model closely represents the actual behaviour of the building under study. Therefore, the purpose of model calibration is to reduce the discrepancies between building energy simulation (BES) and measured building energy performance. The need for calibration of building models is not an indication of the limited capacity of prediction of buildings models; it is, instead, a manifestation of the limited knowledge that the model developer has on the operational parameters of the building, as well as on the stochastic nature of the building-users behaviour and on the lack of control of the pathologies generated in construction or operation of the buildings. Calibration can be understood as the process of "fine-tuning" the values of the unknown parameters of a model in order to minimize the differences between the predicted outputs and the observed data. Due to the large number of unknown input parameters in a detailed BES model, calibration is a complex procedure characterized by a non-unique solution [1] and high uncertainties. In many engineering fields, a model is usually calibrated by implementing a maximization/minimization of one of the statistical indicators of goodness of fit, through a computer code, and by exploring the input space until convergence is reached. However, this can be cumbersome and complicated, especially in the case of complex and/or over parameterized models [2] such as BES. Unfortunately, there is substantial work associated with the detection of influencing parameters in over parameterized models and this cannot be done in a straightforward manner. As highlighted by Reddy and Maor [3], it is almost impossible to identify the exact solution to the calibration problem of BES models. Under this particular circumstance, there is a need to look for alternative strategies which can be

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n	number of parameters in the model (–)
y_i	measured indoor temperature (°C)
$\hat{y}_i$	predicted indoor temperature (°C)
$\overline{y_i}$	mean indoor temperature (°C)
z	random value of the parameters (–)
r	is the number of parameters (–)
N	is the sample size of trials (–)
M	vector solution matrix (–)
V_w	velocity of the wind (m/s)

more appropriate for these models and that can give the users additional information to better understand the insights of BES models.

A review of current literature on this topic has revealed that there is no generally accepted method for calibration of BES following other approaches. Some authors [4,5] addressed calibration methodologies based on manual refinement of the BES models. These methodologies followed clearly defined standards [6,7] for laying down the maximum tolerances of residuals and for measuring and verification of energy savings, however, the refinement of the BES models was addressed based on the experience of the analyst and no systematic approach was taken into account.

Recently, the calibration of BES models has been included in a more formal framework due largely in part to the advances in the fields usually known as UA (Uncertainty Analysis) and SA (Sensitivity Analysis) that are seen more and more as prerequisites for any field that makes extensive use of model predictions. Sensitivity analysis applied to BES models calibration can help in understanding the relative influence of input parameters in the output [8]. The combination of random sampling trials and sensitivity analysis of the parameters seemed to be a good approach to perform BES calibration. Several sensitivity analyses can be used, Tian [9] divided the methods for sensitivity analysis into local and global approaches, considering the global approach as the more reliable one for BES calibration. In 2006, Reddy and Maor [3] defined a detailed procedure to afford calibration of BES models based on the Latin Hypercube Montecarlo (LHMC) method and global sensitivity analysis. The proposed methodology involved four main steps: (i) identification of a set of influential input parameters along with their better estimates and their range of variation; (ii) a coarse grid search using LHMC simulation to identify a sub-set of the most sensitivity parameters; (iii) a fine grid calibration to further refine the feasible solutions and (iv) predictions of energy savings using a small number of the top feasible solutions. This methodology was applied over three case study office buildings using monthly energy consumption data as the basis for calibration. Many doubts related to this methodology remained unclear and [3] also highlighted the need for further research in issues such as minimum sampling size evaluations, selection of one-stage or multi-stage procedures and also if the fine grid calibration was necessary or not. Corrado and Mechri [10] applied uncertainty and global sensitivity approaches to analyze the energy performance of a family house in Turin, Italy. A widespread list of 129 input data was identified and probability density functions (PDF) were assigned to each parameter. A comprehensive review of available PDF was provided and the causes of data variability were also discussed. The LHMC method was applied to generate random samplings and the Morris technique was applied to perform a sensitive analysis and to obtain the dominant parameters. This research concluded that a very small group of unknown parameters were the ones which were affecting the energy consumption of the building. In this previous research study, as well as in others [11], LHMC sampling has been used because of its efficient stratification properties which allow the extraction of a large amount of sensitivity information with a relatively small sample size [12]. In [13] it has been proved that, for the same number of simulations, the LHMC method produces a more robust result compared to the stratified method, which in turn produces a more robust result compared to the simple method. It was also concluded that the Monte Carlo uncertainty analysis in typical building simulations should use about 100 runs and simple random sampling. In 2011, Coakley et al. [14] suggested a novel methodology to calibrate BES based on LHMC sampling combined with a regional sensitivity analysis using Monte Carlo Filtering approach, as described by Saltelli [15]. The overall methodology is outlined and the first stages of the proposed calibration methodology are applied to a 700 m^2 naturally ventilated library building using short-term monitored BMS and sensor data. The paper concludes with a discussion of how this methodology differs from existing approaches and the benefits it offers over traditional calibration technique. It also highlights the need of iterative regional sensitivity analysis for those situations in which goodness of fit falls out of accepted ranges. More recently [16], a very detailed review of existing sampling techniques and sensitivity analysis was carried out in for uncertainty analyses of BES with a large number of unknown parameters (≈ 1000). The balance between computation time and accuracy of the LHMC method and of the quasi-random sampling method was analyzed, leading to the conclusion that the second one has faster convergence. This is a crucial issue in calibrations with such large number of parameters. In addition to this, an input–output sensitivity analysis, followed by a decomposition to quantify which intermediate processes were contributing the most to this uncertainty, were performed. This type of analysis, including the decomposition, is valuable for identifying which subcomponents of a model need more attention during building design or model calibrations. The same author, [17], used the results of the previous analyses to perform a methodology for meta-model optimization in BEMS. A full meta model was created and an energy performance optimization has been carried out. The creation of full order or reduced order meta-models can be understood as one step forward to the guided coarse grid search outlined by [3] since it not only leads to an improvement of the calibration, but also allows for the implementation of many different cost functions or optimization algorithms without repeating time-intensive energy simulations. The above mentioned studies highlighted that meta-models are powerful and promising approaches to allow for permanent commissioning of buildings, fault detection and control optimization, however, some of these previous studies fails in a lack of detailed analysis of the effect of the range of variation of the input parameters and of performing the coarse grid search limited to a single stage random sampling, which clearly conditions the subsequent meta model, as stated by [3]. In the previous studies, the range of variation of parameters are often arbitrarily chosen, which may of course, influence the output uncertainty as well.

In this research, a contribution to achieve more insights of the coarse grid search stage analysis is proposed for buildings in non-occupied periods. This procedure has many similarities with the methodology defined by [3], however some changes are implemented. First of all, the new procedure will be used to calibrate BES models of real buildings under free floating conditions and not under real energy consumption situations. Considering that in these situations the number of unknown parameters is substantially smaller, and assuming that the uncertainty of data coming from monitored indoor temperature is also smaller than the data coming from monthly energy consumption measurements, both the goodness of fit criteria and the parameters for the sensitivity analysis are re-defined to become more demanding than those defined in [3]. The suggested Goodness of Fit (GOF) criteria is twice as stringent as the value proposed by [3]. A multi