Energy and Buildings 67 (2013) 79–87

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Uncertainties and sensitivity analysis in building energy simulation using macroparameters

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ARTICLE INFO

Article history:
Received 2 July 2013
Received in revised form 1 August 2013
Accepted 5 August 2013

Keywords:
Building energy simulations
Uncertainties
Sensitivity analysis
Detailed thermal models
Latin Hypercube sample
Macroparameters

ABSTRACT

Sensitivity analysis (SA) is usually carried out along with energy simulations to understand buildings performance and reduce their consumptions. The quality of their results mainly depends on thermal models and input data. Having accurate data about properties and operation conditions of buildings is difficult. In consequence, simulation inputs are affected by uncertainties that may have significant effects on outputs and are important to be considered. Law-driven detailed models are widely used. They ensure reliability and versatility but require a large number of input parameters.

The paper addresses the difficulties of getting information from SA using detailed models with existing techniques and proposes a methodology which solves current problems. The methodology consists of using a detailed model of the building, defining and propagating uncertainties of input parameters, calculating macroparameters that characterize the building and getting sensitivity indices. The procedure is applied to the study case of a dwelling in which weather and occupancy are found out to be the strongest parameters on its annual consumption. It should be highlighted that, keeping the structure of inputs with uncertainties required by complex models that defines buildings in detail, the method eases building performance understanding.

1. Introduction

Buildings account for approximately 40% of total energy consumption in Europe, mainly for heating and cooling purposes. It is expected that, in the coming years, a large number of buildings will undergo some form of energy retrofit, following the European directive 2010/31/EU [1]. The directive establishes a common general framework for the calculation of energy performance of buildings that includes aspects such as insulation, thermal capacity, passive solar heating, thermal bridges, etc. This leads to the use of building energy simulation models. A simulation model can predict the energy performance of a building making possible to evaluate and select the most efficient and profitable energy conservation measures. This is helpful not only for designing new buildings but also in the context of a retrofit.

Among various simulation models, a distinction can be made between law-driven and data-driven models. Following Saltelli et al. [2], a law-driven model tries to put together accepted laws which have been attributed to the system in order to predict its behaviour. Law-driven models are usually complex and try to model all the relevant energy and mass flow-paths encountered within a building. Examples for this category include widely used tools such as EnergyPlus [3], ESP-r [4] or TRNSYS [5], a.k.a. detailed building simulation models. On the opposite side, a data-driven model tries to treat the solute as a signal and to derive its properties statistically. This group includes black-box models (e.g. artificial neural network). Grey-box models are also based on a combination of prior physical knowledge (law-driven) and statistics (data-driven).

Despite the fact that black-box and grey-box models have many useful applications, detailed simulation models are nowadays the most widely used. Past efforts on verification and validation testing methods, such as BESTTEST[6] or PASSYS [7], have contributed to the current availability of mature detailed simulation software. Moreover, the ability to extrapolate, associated to law-driven models, is another reason behind their widespread use. This paper focuses on law-driven detailed building simulation models.

Furthermore, over the past few years, there has been growing interest among practitioners of building energy simulation in uncertainty analysis (UA) and sensitivy analysis (SA) techniques. In the context of a building energy retrofit, UA and SA are usually applied to assess the risk of different energy conservation measures and as a help to support decisions.

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http://dx.doi.org/10.1016/j.enbuild.2013.08.009

Nomenclature

A_j	area of a building elementj (m^2)
A_{total}	total envelope area (m^2)
C_p	specificheat(kJ/kg K)
CC	calorific capacitance of constructions (kJ/m K). Macroparameter
LHS	latinhypercube sample
Q_{inf}	infiltration flow (ach). Macroparameter
$Q_{inf,i}$	infiltration flow, zone i (ach)
$Qr_{pers,i}$	radiant internal gains of people, zone i (W)
$Qr_{equip,i}$	radiant internal gains of equipment, zone i (W)
$Qr_{ilum,i}$	Radiant internal gains of lighting, zone i (W)
$Qt_{pers,i}$	Total internal gains of people, zone i (W)
$Qt_{equip,i}$	Total internal gains of equipment, zone i (W)
$Qt_{ilum,i}$	Total internal gains of lighting, zone i (W)
R^2	Coefficient of determination
SA	sensitivity analysis
SRC	standard regression coefficient
T_{cal}	heating setpoint(C), macroparameter
$T_{cal,i}$	heating setpoint zone i (C).
T_{ref}	cooling setpoint(C), macroparameter
$T_{ref,i}$	cooling setpoint zone i (C)
U	global heat transfer coefficient (W/m^2 K), macroparameter
U_j	heat transfer coefficient of a building element j (W/m^2 K)
UA	uncertainty analysis
V_i	volume of zone i (m^3)
V_{total}	total volume (m^3)
$\overline{y}$	mean value of y
$\widehat{y}$	estimated value of y
σ_y	standard deviation of y
ρ_i	density of a building element i (kg/m^3)

Uncertainty analysis (UA) takes into account uncertainties due to inherent simplifications of any model and lack of information with regard to input data. A common approach to conduct UA is to use a deterministic model but assign probability distributions to the uncertain input parameters. These distributions characterize a degree of belief as where appropiate value of each variable is located [8]. UA has been typically used to assess the uncertainty associated to decisions in the building design process, such as summer overheating risk in naturally ventilated buildings [9,10], architectural design choices [11,12], ventilation strategies in buildings [13] or HVAC system sizing [14].

On the other hand, sensitivity analysis (SA) consists of modifying model inputs in order to see their effects on model outputs. SA can determine the relation between independent and dependent variables to get a better understanding of the building performance. SA has been used in building design, retrofit, stock or impact of climate change on buildings (see [15–24]). SA and simulation tools can be used together to support design decisions [25].

Detailed law-driven models are very suitable for UA and SA due to their ability to analyze the influence of any physic parameter of the building. However, some difficulties still remain. Detailed building models are overparametrized and usually require a large number of inputs (for a standard dwelling model this number may be above 100). Moreover, these inputs have different scale. There are inputs that may be called "micro-parameters", e.g. the density of a material layer that belongs to the composition of a particular wall of the building. On the other hand, other inputs are lumped parameters or "macro-parameters", e.g. the infiltration level described as air changes per hour. The impact of a variation of these parameters on the performance of the building (typically energy consumption) will have different order of magnitude, making difficult the interpretation of a sensitivity analysis.

As the input structure required by the main building simulation programs cannot be easily modified, this work proposes to carry out a postprocess to lump microparameters into macroparameters, after running simulations and before conducting SA. For example, the global heat transfer coefficient (U W/m^2 K) would be a macroparameter which is calculated from the properties of the constructions and whose effects are expected to be comparable to others such as infiltration level, weather or occupancy.

Therefore, these macroparameters perform a double function: they decrease the number of parameters in SA and they make possible a fairer comparison of variables in SA as their effects on the model outputs have a similar order of magnitude. This approach will ease SA comprehension as well as will improve building performance understanding, since macroparameters have physic meaning.

The objective of this paper is to show the proposed methodology. It consists of using a detailed model of the building which is implemented in EnergyPlus [3]; defining and propagating uncertainties of the input parameters using the Latin-hypercube technique; running simulations by means of the parametric tool called jEplus [26]; aggregating macroparameters, and finally calculating sensitivity indices for the macroparameters in order to know which of them have more influence. The proposed methodology gives quite valuable information about building performance and solves some limitations of current techniques.

A case study is used to illustrate the methodology. Some remarkable conclusions about the most influential macroparameters will be found. Specifically, weather and occupancy turn out to be the strongest macroparameters. This paper is organized into four others sections. In Section 2, the example is described. In the third one the methodology is explained, then results are shown and finally conclusions are discussed.

Table 1
Construction of the building envelope.

Construction	Layers (starting from external side)
Exterior wall	Mortar cement 1.5 cm/brick 12 cm/mineral fiber rock 4 cm/walls air gap/brick 9 cm/gypsum 1.5 cm
Interior wall	Gypsum 1.5 cm/brick 7 cm/gypsum 1.5 cm/
Ceiling and floor	Pavement 5 cm/concrete 31 cm/pavement 5 cm
Door	Door exterior agglomerate 3.5 cm
Windows	Glass 4 cm/windows air gap 6 cm/glass 4 cm
Ceiling and floor thermal bridges	Mortar cement 1.5 cm/brick 7 cm/concrete 31 cm
Pillars thermal bridges	Mortar cement 1.5 cm/brick 7 cm/reinforced concrete 30 cm/gypsum 1.5 cm
Blinds thermal bridges	Aluminium thermal bridge

2. Case study

The case study is an intermediate flat located in Malaga, a Mediterranean city in the South of Spain (36°40′N, 4°29′W).The dwelling has two bedrooms, the study room, the living-room, the kitchen and the corridor. Its total surface is 155 m^2 and its main facade has South orientation. See Fig. 1 for its distribution and boundary conditions, and Fig. 2 for the EnergyPlus model. Constructions of the building envelope are summarized in Table 1. All zones are conditioned with the exception of the corridor. They