Energy and Buildings 135 (2017) 156–165

Contents lists available at ScienceDirect

Energy and Buildings

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

Development of an automatic calibration method of a VRF energy model for the design of energy efficient buildings

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ARTICLE INFO

Article history:
Received 20 January 2016
Received in revised form
24 November 2016
Accepted 28 November 2016
Available online 29 November 2016

Keywords:
Energy efficient building design
Energy simulation
Calibrated simulation
Variable refrigerant flow system

ABSTRACT

The application of whole-building energy simulation in the design and operation of buildings is limited because there are discrepancies between the actual energy consumption and the predictions obtained from energy simulation. A newly developed automatic calibration method for the variable refrigerant flow energy model, which aims to reduce the errors between simulated and measured energy consumption, has been introduced. The software that implements this method was developed for the wide use of calibrated simulations in the design of sustainable buildings. The automatic calibration method consists of parameter selection and determining boundary conditions, automatic simulation using Latin hypercube sampling, and selecting the energy models that meet the criteria for normalized mean biased error values. The developed software has been used to calibrate an energy model for a typical mid-sized office building in Korea. Comparisons between the measured energy consumption and the outcomes predicted by the software confirm that the developed calibration method can generate calibrated energy models that satisfy the criteria and the significance level of a paired *t*-test.

1. Introduction

There have been substantial advances in whole-building energy simulation programs since their advent in the 1970s [1]. There are a large number of these programs [2]; EnergyPlus [3], ESP-r [4], Trnsys [5], IES-VE [6], eQUEST, IDA ICE [7], and Trane 700 [8] are typical examples that have been continuously updated and widely used in research and practice. Earlier versions of these programs focused on indoor climate estimation, loads calculation, and energy analysis. More recently, the domain of these programs has been extended to the prediction and integration of airflow in and around buildings, natural and artificial lighting, renewable energy systems, and HVAC systems and equipment [1,9,10]. One popular application of whole-building energy simulation is predicting the performance of the energy-efficient design of buildings [11]. These types of applications include estimating the primary energy consumption for a photovoltaics-integrated building envelopes [12,13], producing decision-making information in the early stages of building design [14,15], and analyzing the effects of occupant factors on energy consumption [16–19].

The use of whole-building energy simulation in the operation and control of heating, ventilation, and air-conditioning systems is also an active area of research. Implementing a simulation program into building energy management systems (BEMSs) for simulation-assisted control was proposed in the early 2000s [20]. The Building Controls Virtual Test Bed (BCVTB) is a software environment that couples simulation programs with actual hardware [21]. This has been applied in HVAC controls to reduce operational costs [22,23].

The robustness and reliability of whole-building energy simulation programs are prerequisites before they can be widely employed in practical applications. Judkoff and Neymark [24] developed a validation and diagnostic procedure to test the ability of whole-building simulation programs; this is called the Building Energy Simulation Test (BESTEST). The BESTEST consists of empirical validation, analytical verification, and comparative testing. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 140 is based on the content of the BESTEST [25]. ASHRAE Standard 140 defines the methods used to test the technical capabilities of the whole-building energy simulation program by identifying the differences in simulation results

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http://dx.doi.org/10.1016/j.enbuild.2016.11.060
0378-7788/© 2016 Published by Elsevier B.V.

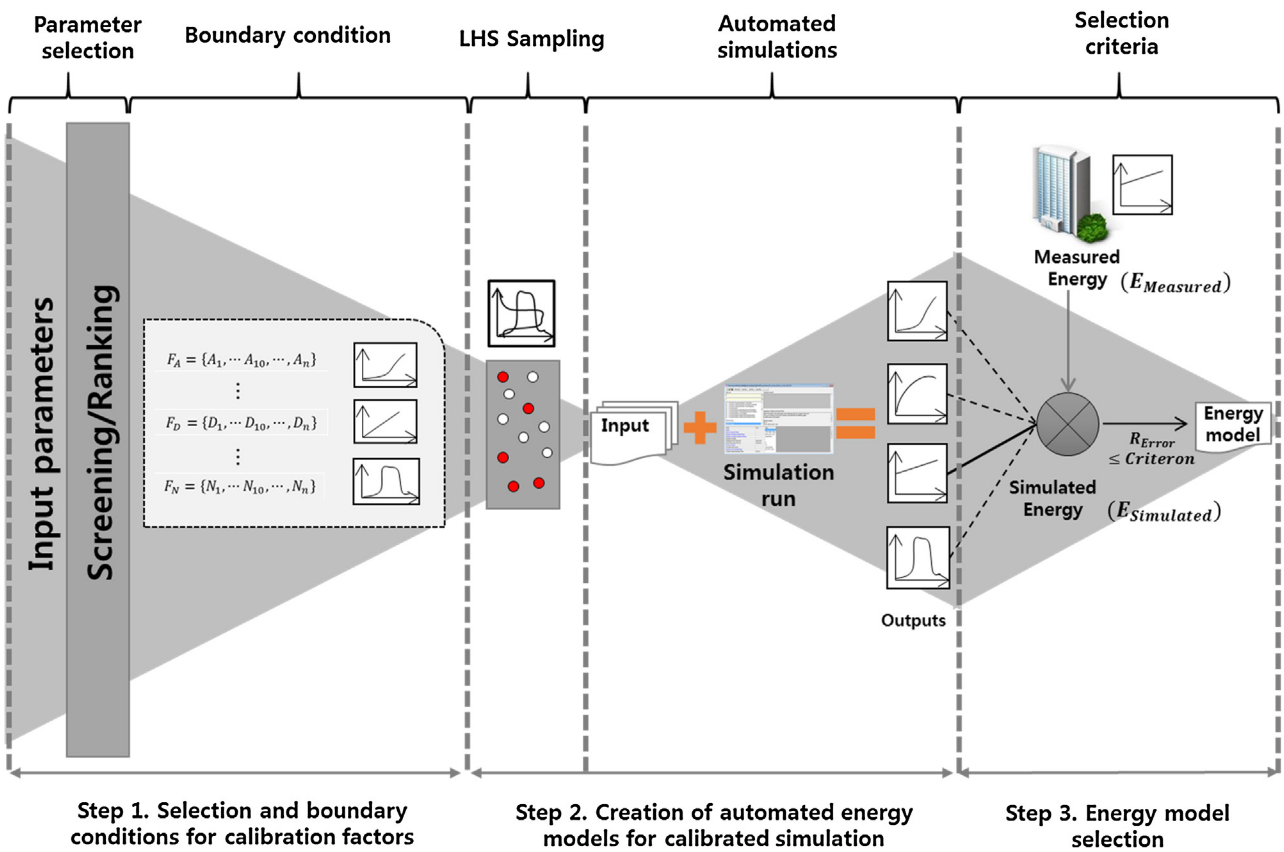

Fig. 1. Automated calibration procedure for energy simulation models using a whole-building simulation program.

that can be caused by algorithmic differences, modeling limitations, or coding errors.

On the other hand, the calibration of whole-building energy simulation programs focuses on reducing the differences between the measured energy use and the results predicted by simulation. This is done by calibrating the inputs used for modeling in existing simulation programs [26]. Previous studies [27–30] showed that there were large discrepancies between the actual energy consumption and the consumption predicted by energy simulation programs. This hinders the wide use of simulation programs during the design and operation of buildings; thus, it is critical that energy models made with whole-building energy simulation programs accurately predict the energy consumption of buildings.

The energy modelling of variable refrigerant flow (VRF) systems, which gains wide implementation in small- and medium-sized commercial buildings, is challenging because the operation of the VRF system requires to control numerous operational factors at various indoor and outdoor conditions [31]. The energy models of the VRF systems in EnergyPlus utilize a series of performances curves to accurately define their part-load performances at various operating conditions. However, an existing study shows that there existed large gaps between the measured energy consumption of the VRF system and the predicted energy use by the VRF model in EnergyPlus, particularly when heating loads were low [32]. Therefore, it is necessary to improve the prediction performance of the VRF model in order to fully realize the energy saving potentials of the VRF system in practice [33,34].

The aim of this paper is to develop and verify an automated calibration method for energy simulation models for an energy efficient building with VRF systems, which gain wide implementation in small- and medium-sized commercial buildings. After explaining the automated calibration method for the VRF energy simulation model, this paper describes the case study building that was used to develop and verify the calibration method. This paper also investigates the calibration results by analyzing the differences between the predicted and actual energy consumption in summer and winter seasons.

2. Automatic calibration

The automated calibration method developed in this study is structured in three main steps. It starts with the selection of boundary conditions for the calibration factors of the energy simulation model (Fig. 1). This is followed by automated energy simulations for calibration using Latin hypercube sampling (LHS). The final step is the selection of energy simulation models that meet the requisite calibration performance. We also develop a piece of software for automatic calibrated simulations based on the automatic calibration procedure used in this study, as shown in Fig. 2.

The first step in the automated calibration method is to define the input factors that contribute to the discrepancies between the predicted and actual energy use. Existing studies [28,35,36,37,38] revealed three main elements that cause inaccuracies in energy simulation results. The first element is related to building construction. The thermal conductivities of materials and the assumption of air-tightness used in energy simulation models may be different from the actual performance of buildings. The second element is related to the performance of HVAC systems. The cooling and heating performances of the HVAC system change depending on how a building is used; they are also influenced by indoor and outdoor environmental conditions. The modelling of HVAC systems in energy simulations can be simplified and do not necessarily represent the actual behavior of the system. The final element is how buildings are used by occupants and building managers. Occupant