Energy and Buildings 147 (2017) 14–26

Contents lists available at ScienceDirect

Energy and Buildings

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

Investigation of the correlation of building energy use intensity estimated by six building performance simulation tools

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ARTICLE INFO

Article history:
Received 20 October 2015
Received in revised form 22 February 2017
Accepted 24 April 2017
Available online 1 May 2017

Keywords:
Building performance
Energy modeling
Energy performance prediction
Net zero energy

ABSTRACT

This paper reports the investigation of the correlation of building energy use intensities, estimated by six building performance simulation programs and, based on findings, establishes formulas for conversion of each program to another in selected simulation tools. The data used for the analyses was collected from 15 residential projects and 180 simulation runs in two construction modes: as-built and code compliance (California's Title 24 Standard), using six different simulation tools. The data set included heating and cooling energy use intensities, multiple building attributes, and climate conditions. The results were compared by various program combination sets to analyze and determine the correlation of estimated energy use intensities (EUIs).

The statistical analysis of the collected data revealed that heating EUI conversion formulas were more robust than those of cooling EUIs, and a project case generating moderate or high EUIs generated lower error rates than that with low EUIs. Since building energy performance always generates significant discrepancies, depending on the simulation tools adopted, the outcome of this study will help building performance stakeholders understand the estimated energy performance of one tool as compared to that of another. The result will also be helpful for designing a high performance building without a technical mishap.

1. Introduction

Buildings in the U.S., which account for 70% of the use of electricity, 35% of total energy expended, and 39% of carbon emissions, have the greatest impact on climate change in the world [1,2]. In order to minimize the negative impact of buildings on the environment, considerable effort has been made to design eco-friendly buildings. To verify design performances and estimate their impact on the environment, energy simulation software has been the key factor in evaluating building energy consumption in order to attain a high performance building and Net-Zero-Energy construction. Based on use of the most popular simulation engines, such as DOE-2 and EnergyPlus, more than 20 types of energy modeling software have been developed to test and validate the projected performances of buildings to be constructed. However, each individual program's result has been different from that of the others, and there has also been significant inconsistency between each individual program's estimates and accuracy [3].

This technical condition of current simulation software makes it very difficult to select an appropriate program because of the fact that each program provides a different estimation result; and the accuracy of these results depends on the resolution of input data that every software allows, depending on the algorithms that have been adopted [4]. The more default options that the simulation software adopts could increase the uncertainty and result in inaccurate performance results. In addition, individual simulation programs adopt different building energy modeling programs (BEMPs), such as DOE-2 and EnergyPlus from the U.S. Department of Energy, and ESP-r from the University of Strathclyde in the U.K. [4]. These technical limitations create a significant inconsistency in building performance estimation, especially when simulation outcomes, generated by different simulation engines or programs, are compared to each other. This could possibly result in a poor design and plan for a high performance building and subsequent failure.

Multiple research efforts by professional organizations have established building simulation standards and guidelines for the validation process, which include IEA (International Energy Agency) The Building Energy Simulation Test (BESTEST) [5] and ASHRAE Standards 140 [6]. In addition, many studies have investigated simulation engines (i.e., BEMPs) that have been adopted

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http://dx.doi.org/10.1016/j.enbuild.2017.04.078
0378-7788/

Table 1
Basic performance of selected seven types of software [13].

	HEED	eQuest	IES	DesignBuilder	BEopt	EnergyPro	IES-VE Pro
Usability	Medium (Med)	Med	High	Med	Med	High	Med
Intelligence	Med	Low	Med	Med	Med	Med	High
Interoperability	Low	Low	Med	Med	Low	Low	Med
Process adaptability	Low	Med	Med	Med	High	High	High
Accuracy	High	High	Low	High	High	High	High

by different software and compared the technical features of each program [3,4].

Most current research and studies focused on identifying the differences between various types of software and the functionality of the technical performance. This could limit the identification of a feasible solution in professional and/or academic fields when people question how to convert the simulation outcome of one type of software to that of another. Therefore, this paper reports the study of relationships between different simulation programs that have been the most popular and have been adopted in the building science and engineering community. Further, it describes a conversion formula that was developed based on the use of two sets of performance data for 15 houses, as estimated by the six types of software selected for this study. Comparisons were conducted based on the use of simulation data generated from 30 project cases, and the relational formulas were established using a statistical data-driven approach. The results of this study could be used as a possible conversion factor for translating a building performance result of one software to that of another. Therefore, this study's outcome will contribute to an understanding of the unique simulation features of each type of software and will contribute to decision making concerning high performance building design, without being confused by diverse energy performance estimations by multiple software.

2. Background information

Numerous building software programs are available in the domain of building performance and engineering. The Building Energy Simulation Test (BESTEST) [5,7] has been established by the Department of Energy in the U.S., to provide a method for testing, diagnosing, and validating the capabilities of building energy simulation programs. However, even though those programs' functional features are fundamentally based on building physics and thermos-dynamics, and are also validated by a government agency (i.e., the U.S. Department of Energy), their evaluation results vary depending on those programs' embedded assumptions and calculation formula algorithms [8,9]. For these reasons, some programs are more specialized and appropriate for a residential building, while others may concentrate on complicated mechanical systems for a larger or smaller scale building. In some cases, however, there is no such application rule for building types. Therefore, it is very challenging to compare the results from different programs, even those from the same project in practice. One recent research study evaluated and reported the discrepancies in simulation results from multiple programs, including HEED, Energy Pro, BEopt, eQuest, DesignBuilder, and IES-VE Pro. The discrepancies in the results were mainly from various mathematic parameters [3,10,11]. Crawley et al. ran all of the selected programs for the same construction and the outcomes varied from 47.6 KWh/m^2 to 189.3 KWh/m^2. This was in spite of the fact that the same project encoded was in each program [3,12]. Based on the research, Attia summarized individual program functional features as follows (Table 1).

Discrepancies were analyzed that resulted from any input data, including weather data, observation errors, unknown deterioration effects, and simulation solutions [13]. One major difference between these types of software can be attributed to the simulation engines adopted. EnergyPlus is a powerful simulation engine that has been widely adopted by many software manufacturers, including DesignBuilder, IES, and BEopt. On the other hand, another popular engine, DOE-2, is used in eQuest and other software [3]. These two simulation engines are different in many aspects, such as the thermal comfort estimation principle, seasonal heat and cold storage, HVAC load estimation, integrated simulation of loads and systems, radiant exchange, etc. [14–18]. For example, DOE-2 uses hourly recorded weather data for simulation while EnergyPlus's calculation is based on 10-min time steps. In addition, DOE-2 processes the energy simulation per hour while EnergyPlus runs a simulation with a higher resolution that ranges from 1 to 60 min [3]. Since all of the computational processes are time-sequential, such simulation time resolutions affect the sequential estimation process and result in different simulation outcomes as a consequence of the simulation. Obviously, the higher the resolution is, the longer the simulation takes to implement [19].

Apart from different simulation engines, the functional features in each program vary greatly. The capability to create a digital model is one of the most important steps in the energy modeling process [20]. Various types of software, including DesignBuilder, IES-VE Pro, and eQuest, have very powerful transaction ability and can import digital models from design tools like AutoCAD, SketchUp, and Revit. On the other hand, a tool like EnergyPro, is a stand-alone software that does not need a digital model for energy simulation. The existing uncertainty in the simulation process has many origins since each simulation tool may deploy its own computational feature for preprocessing calculation. For example, IES-VE Pro and eQuest take the beam solar radiation that passes through interior windows in their calculations; however, HEED does not consider this in its simulation process [21,22]. In addition, eQuest, for example, does not take an iterative non-linear system solution while other tools do [23].

As discussed above, current Building Energy Simulation software programs have their own advantages and weaknesses. Consequently, on the one hand, it is difficult to completely trust the results from only one program and to disregard others. On the other hand, building professionals and architects are plagued by the lack of standardized features in available simulation tools, during the decision phase that addresses more of a building's geometry and envelope [3]. Under the current trend of Integrated Project Delivery [24], it is critically important to adopt an energy simulation tool in the early design stage, so that the tool can serve to create an energy efficient scheme throughout the entire project. Therefore, it is necessary to study the uniqueness of each of the selected software and to analyze their performance so that a comprehensive comparison of the different types of software can be made. The relation between the various types of simulation software will need to be determined so that a predicted standard baseline can be derived to assure higher simulation accuracy in energy performance predictions.

Many studies have already been conducted to investigate and identify limitations of the available software. One technical report compared ten different programs and their performance, including usability, intelligence, interoperability, process adaptability, and accuracy of each selected tool [13]. The actual function and usage of each tool, as well as its performance in a real project, were studied