Energy and Buildings 107 (2015) 11–25

Contents lists available at ScienceDirect

Energy and Buildings

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

Development procedure of an air-source heat pump base-case simulation model for a code-compliant residential building

Sung Lok Do[a,*], Jeff Haberl[a,b]

[a] Energy Systems Laboratory, Texas A&M Engineering Experiment Station, The Texas A&M University System, College Station, Texas, United States
[b] Department of Architecture, Texas A&M University, College Station, Texas, United States

ARTICLE INFO

Article history:
Received 23 April 2015
Received in revised form 12 July 2015
Accepted 2 August 2015
Available online 4 August 2015

Keywords:
Building energy simulation
Building energy code
DOE-2.1e
eQUEST
Code-compliant software

ABSTRACT

Computer simulation is widely used for analyzing building energy performance. A building simulation model is often verified by comparing the simulation results of the same building using different simulation programs, and thus developing a same building simulation model for different programs is inevitable for the comparative verification. This study proposed a step-by-step input parameter change procedure to develop a residential building model that complies with the 2009 International Energy Conservation Code (IECC). By implementing the procedure, this study developed the code-compliant residential air-source heat pump base-case model using two whole-building simulation programs: DOE-2.1e and eQUEST. The simulation results from DOE-2.1e and eQUEST at each step in the procedure were compared. To evaluate the accuracy and comparability of the final base-case model developed with the procedure, this study compared the simulation results of the same base-case model using Residential Energy Services Network (RESNET) accredited programs. The comparison showed that the differences in the annual total site energy use among the simulation programs were well-matched within 4.7%.

1. Introduction

Increasing worldwide use of the fossil fuels contributes to increasing levels of atmospheric CO_2 and results in higher energy prices [1]. Concerns about climate change from increased CO_2 levels and higher energy prices have focused attention on improving the Heating, Ventilating, and Air-Conditioning (HVAC) system efficiency in buildings since significant amounts of energy are used in buildings for various purposes (e.g., cooling, heating, ventilation, and hot water). To analyze energy use in buildings, hourly whole-building computer simulation programs are widely used since energy modelling can help analyze and optimize complex building energy performance before and after construction. In this way, hourly whole-building computer simulation programs such as DOE-2.1e [2], eQUEST [3], and others are widely accepted in building energy research.

However, the hourly whole-building simulation programs are not always allowed to be used for the purpose of the building energy code-compliance. Building energy codes and standards are used for a measure of new building's energy efficiency, providing guidance and requirements to builders, designers, and energy modelers. In the United States (US), a number of energy codes and standards have been developed and adopted. In the US residential sector, the International Energy Conservation Code (IECC) [4–6] is used in almost 40 states to determine if a home meets the state energy code requirements [7]. To comply with the IECC performance-path approach, IECC compliance software tools accredited by the Residential Energy Services Network (RESNET) should be used [8].

When building energy performance is evaluated using a computer simulation program, its simulation model needs to be verified or validated. To accomplish this, the simulation results of the same building using different simulation programs are often compared. Therefore, the development of the same building simulation model for different programs is inevitable for the comparative verification. For developing the base-case building model, this study proposed a step-by-step input parameter change procedure that complies with the standard reference design and requirements as defined in the 2009 IECC [4]. The input parameter change procedure helps to identify resultant changes and sensitivity by modifying input values for each step, and allows to confidently compare the simulation results of the same building with different simulation programs.

In addition, this study evaluated the accuracy and comparability of the developed code-compliant base-case models using hourly whole-building computer simulation programs in comparison to the RESNET accredited tools. DOE-2.1e and eQUEST were selected for the hourly whole-building computer simulation programs, and

* Corresponding author. Tel.: +1 979 862 7536; fax: +1 979 862 8687.
E-mail address: sunglokdo@tees.tamus.edu (S.L. Do).

http://dx.doi.org/10.1016/j.enbuild.2015.08.005
0378-7788/

their base-case models were developed using the entire step-by-step input parameter change procedure. Next, the inputs for the final DOE-2.1e and eQUEST base-case models were used to develop base-case models using the RESNET accredited tools [8]: REM/Rate [9], EnergyGauge [10], and International Code-Compliance Calculator (IC3) [11]. The simulation results from all of the base-case models were then compared.

2. Simulation programs

The US Department of Energy (DOE) currently provides information on 416 building software tools for evaluating energy efficiency, renewable energy, and sustainability in buildings [12]. Of these 416 tools, two simulation programs related to whole-building energy simulation were selected for this study: the DOE-2.1e and eQUEST programs. In addition, this study used three IECC code-compliance software tools, which were accredited by RESNET in 2013 [8]: REM/Rate, EnergyGauge, and IC3.

2.1. DOE-2.1e and eQUEST

The DOE-2.1e and eQUEST programs are a well-known hourly building energy analysis program which uses DOE-2's building description language (BDL) to describe the building layout, construction, schedules, HVAC systems, plant, and utility rates.

The origin of the DOE-2.1e began with the Post Office Program which was the loads program (i.e., computational procedure) developed by the General American Research Division (GARD) in the late 1960s [13,14]. The GARD was one of the divisions in the General American Transportation Corporation, which was a subcontractor for the Post Office facilities division. The Computation Consultants Bureau developed the CAL-ERDA program in the late 1970s [15]. CAL-ERDA was based on the load algorithms used in the Post Office Program and utilized the equations of the ASHRAE algorithms (i.e., weighting factor method) and the NECAP program (i.e., NASA's Energy Cost Analysis Program) to develop the calculation procedure [15]. CAL-ERDA used the Building Description Language (BDL), which is a user-friendly computer input language to be used in the building's load, systems, plant, and economic sub-programs, and improved calculation speed by recompiling the code [14,15]. In 1978, the DOE-1 was released, which was a slightly enhanced version of CAL-ERDA [14,16]. DOE-2.0a in 1979 and DOE-2.1a in 1980 were released by the Lawrence Berkeley Laboratory (LBL) and the Los Alamos Scientific Laboratory (LASL). These DOE-2 series had a new BDL to more easily control the LOADS, SYSTEMS, PLANT, and ECONOMICS analysis program. In 1982, DOE-2.1b which had an option to choose metric or English units for inputs and outputs was released by the LBL and the Los Alamos National Laboratory (LANL) [17]. In addition, DOE-2.1b included the split flux method for daylight calculation. In 1984, the LBL released DOE-2.1c which included algorithms for sunspace analysis [18]. In 1989, the LBL released DOE-2.1d which improved the calculation method for diffuse solar radiation shading [19]. In 1993, the LBL and James J. Hirsch & Associates (JJH) released DOE-2.1e which is the most recent version. In this version, more HVAC system models were added including: water loop heat pump systems, water-cooled condenser for packaged units, electric and fuel meters, packaged variable volume temperature (PVVT) system, and gas heat pumps. DOE-2.1e-121, the latest version through updates and improvements from DOE-2.1e-087 in 1995, has been used for an hourly building energy analysis program since 2003.

DOE-2.1e can be categorized in two versions: the standard DOE-2.1e and the enhanced DOE-2.1e [14]. The standard DOE-2.1e series includes the versions before Version e-110, which were developed by the LBNL and JJH together. On the other hand, the enhanced DOE-2.1e series includes the versions after Version e-110, which were developed by JJH solely; and improved by fixing existing bugs and having new features. The features of the enhanced DOE-2.1e contributed to the development of DOE-2.2 [20].

The DOE-2.2 program, which was based on DOE-2.1e, has been privately supported for version updates by JJH. eQUEST, also created by JJH in 1999, uses the DOE-2.2 simulation program and provides input/output wizards with a graphical user interface (GUI) for ease-of-use [3,20,21]. It offers 2-D and 3-D display of a building geometry and a feature to import CAD files for point-and-click layout drawing. One of the improved features in eQUEST is the "Jurisdiction" function, which determines defaults for input parameters corresponding to the selected energy codes. In addition, eQUEST has been improved to have more capabilities to simulate renewable systems such as ground-source heat pump systems. The currently available version of eQUEST is 3.65; however, this study was conducted with eQUEST version 3.64.

2.2. RESNET accredited programs

RESNET has defined a suite of five software tests that must be performed by software to be a RESNET certified, code-compliant software (RESNET 2006). Test No.1 is the Tier one of the Home Energy Rating Systems (HERS) Building Energy Simulation Test (BESTEST); Test No.2 is the IECC code reference home auto-generation test; Test No.3 is the HVAC test; Test No.4 is the duct distribution system efficiency (DSE) test; and Test No.5 is the Hot water system performance tests. In 2013, three IECC code-compliance software tools were accredited by RESNET: REM/Rate Version 12.91, EnergyGauge Version 2.8, and the International Code Compliance Calculator (IC3) Version 3.12.4. In this study, all three of these programs were used for the comparison of the ASHP base-case model.

2.2.1. REM/Rate

The REM/Rate software was developed by the Architectural Energy Corporation (AEC) in Boulder, Colorado, for the Home Energy Rating Systems (HERS) providers. It is a software tool for residential energy analysis including single- and multi-family residences [9]. REM/Rate is based on a climate similarity analysis, using heat balance equations on a seasonal basis. For example, REM/Rate aggregates hourly weather data into seasonal weather data and uses this to determine heating and cooling loads. In this way, REM/Rate calculates residential system energy performance, annual energy costs, and annual net savings costs. It provides a comprehensive output by comparing the Rated Home to the Reference Home as defined in the "Mortgage industry national home energy rating systems standards" as promulgated by the RESNET, including: an energy analysis, cost analysis, air pollution reductions, and code compliance. It also calculates a HERS Index, and reports the results in tables and graphic format.

2.2.2. EnergyGauge

The Florida Solar Energy Center (FSEC) in Cocoa, Florida, developed EnergyGauge, which is a home energy simulation software package based on the DOE-2.1e program [10]. It simulates building energy performance using the DOE-2.1e program, which is an hourly whole-building energy simulation tool. It has two main versions: USA Residential EnergyGauge and Commercial EnergyGauge. The USA Residential EnergyGauge is used for residential analysis including single- and multi-family. One key feature of EnergyGauge is that it provides output for the Florida Building Energy Rating Guide, which provides HERS Index for the home [22]. In addition, it provides comprehensive reports including an Energy Star homes