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ORIGINAL RESEARCH PAPER

Overview of whole-building energy engines for investigating energy-related systems

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ABSTRACT

With the rapid importance of high-performance energy modeling of buildings, whole-building energy simulation engines are rapidly used in the decision-making process. However, there are tens of engines in the market, which makes the choice of design engine very challenging. This article provides a comparison of the applications of whole-building energy simulation to predict a significant number of systems. As a result, the selected engines will be compared to establish their characteristics and abilities. Nevertheless, the focus will be placed on: generic criteria; envelope; lighting; service hot water; Heating-ventilation; and renewable systems. However, the authors found that an engine could be used extensively in one system and has limited capabilities in another system.

KEYWORDS

building energy, engine, environment, performance, design strategies, indoor, urban, spaces

1. INTRODUCTION

The building industry accounts for about 40% of the globe's energy consumption [1]. However, building simulation has been increasingly integrated into various mathematical models and approaches over the last few decades, from load calculations to heat and mass transfer simulations to comfort and users' behavior [2, 3].

Energy simulation software engines enable compliance with all applicable building codes while providing the users with thermal comfort by designing and implementing appropriate Heating, Ventilation, and Air Conditioning (HVAC) systems. Equivalent software has interfaces that can be used to enhance design clarification by analyzing the feasibility and efficiency of passive solar systems in housing units. There are large numbers of building performance analysis tools with distinct user features and diverse simulation software that provide these outputs. Due to the massive number of mimic engines, it is crucial to perceive the potentialities of the engines and the complications of the simulation [4–6].

Informing designers and experts on the possibility of utilizing building energy engines during the design phases is a key factor, which offers precise estimations on the performance of the building. In this paper, the authors found that no extensive comparative reviews of whole-building energy engines were conducted in the 3–5 years [7, 8]. Nonetheless, this research offers a comprehensive study that compares the features of six primary engines: EnergyPlus, TRANE, DOE-2, IES (APACHE), EQUA, and kernel TRNSYS softwares. The

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creators of these engines offer meticulous data and information on their engines' abilities and features on their websites and technical reports.

2. SYNOPSIS OF THE ENGINES

2.1. EnergyPlus

EnergyPlus is a leading energy engine in the building industry that helps building experts as well as designers to create energy-saving models for day-lighting, heat-cooling systems, and envelopes in all sorts of constructional design. Nevertheless, EnergyPlus contains several innovative analysis characteristics as three thermal comfort models, renewable systems simulation, natural and artificial lighting estimation, advanced envelope modeling, precise HVAC system analysis, electricity cost prediction, and multi-zone airflow modeling [9–12].

2.2. Trane

Trane® is a pioneer in HVAC systems, services, and solutions. Trane provides users with innovative services that advance the building atmosphere via a wide library of energy-saving HVAC components, housing units, water and energy services, components, and different sensors for residential and other buildings. Trane helps designers, engineers, and clients around the whole world with making buildings more energy-efficient and combating climate change. Moreover, with more than 1000 U.S. innovations at the time being, Trane builds convenient and eco-friendly buildings on the globe [13, 14].

2.3. DOE-2

DOE-2 is a building energy analysis engine that was developed to help designers and engineers in performing energy-related constructional design investigations of whole-building energy via real weather information. The purpose of an engine like DOE-2 is to estimate the thermodynamic performance of the housing units by roughly solving the mathematical equations. The "plain" DOE-2 tool is a "Command Prompt" interface that needs extensive knowledge to apprehend how to use it appropriately at the same time providing engineers and scientists with remarkable resilience [15, 16].

2.4. IES

IES exists to create innovation that can altogether decrease the effect that buildings and cities have on the environment by diminishing energy consumption and making zero-carbon targets attainable. By looking at buildings and urban spaces as integrated environments to make sure that everybody is involved in the conceptual design, management, implementation, or utilization of any building, integrated tool for whole-building performance investigation that used via building design experts around the world [17].

2.5. EQUA

Since the early nineties, EQUA has created cutting-edge energy analysis engines for buildings. EQUA becomes a world pioneering provider and the programs have been utilized in different massive projects all around the globe. IDA ICE is a state-of-the-art all-year intensive and dynamic multi-zone analysis interface for investigating thermal comfort and indoor air quality and the energy use of the whole housing units [18–20].

2.6. TRNSYS

While the sizable majority of energy simulations are targeted at evaluating the overall performance of thermal and electric strength structures, TRNSYS can similarly properly be utilized to mimic different dynamic structures together with fluid and flow, TRNSYS is made of parts. The first is an engine (dubbed kernel) that reads and methods the enter file, iteratively solves the device, determines convergence, and plots device variables. The kernel additionally offers utilities that (amongst different things) decide thermophysical properties, invert matrices, carry out linear regressions, and interpolate outside statistics files. The 2nd part of TRNSYS is an intensive library of components, which creates the overall performance of the first part.

3. OBJECTIVES

- Reviewing of the whole building energy simulation engine applications in indoor and urban spaces;
- Informing the architects and;
- On the ability to integrate simulation software in the design process to enhance the design decision-making process and optimize the design.

4. METHODOLOGY

The article concisely described here encompasses a specific table analyzing the characteristics, capabilities and limitations of each engine in the following categories: general criteria (graphical interfaces, reliability and accuracy, cost, operating system, compatibility, visualization, training and support, compliance, baseline building design, library components, weather file/country, optimization, input file), weather and location, envelope system, lighting system, equipment choices and controls, service hot water, HVAC system, renewable systems, cost analysis, strategies, specific output, and urban studies. The materials and information of the research were taken from engine creators on their platforms, guidance, and help/support forums as well as technical reports. The six chosen software were EnergyPlus, TRANE, DOE-2, IES (APACHE), EQUA, and kernel TRNSYS. Nevertheless, it is widely recognized that simulation modeling techniques may be used correctly whilst experimental measures cannot be executed as a result of financial or environmental restrictions [20, 21, 7]. Simply, the whole-building energy simulation software method utilizes a complicated mathematical code, which is depicted and resolved by computer software. The outcomes are graphically shown as two-dimensional or three-dimensional spaces. Nonetheless, the engine's capabilities have been rated as follows: (0) not available, (1) with low capabilities and options, (2) limited alternatives, (3) moderate capabilities, (4) high alternatives and capabilities, (5) being extensive capabilities.

5. RESULTS AND DISCUSSION

Every chosen engine of the whole building energy software has certain features and specific outputs. In an attempt to better understand the specific characteristics of each engine, Tables 1–6 depict a summary table of the capabilities of every engine.

As it can be seen in Table 1 that among several whole-building energy engines EnergyPlus, IES (APACHE), and EQUA are proving to be more capable in predicting the following criteria (graphical interfaces, reliability and accuracy, average cost of educational license, availability, operating system, visualization and graphics, library components weather file/country, and lastly input files).

As it is shown in Table 2 amongst numerous energy-related engines. EnergyPlus DOE-2, EQUA, and IES (APACHE) are having the ability to forecast envelope system elements precisely. That being said, other selected engines are also able to predict the envelope systems with acceptable precision.

Table 1. Comparison of whole-building energy engines with a focus on general criteria

General criteria						
Criteria of choice	EnergyPlus	TRANE	DOE-2	IES (APACHE)	EQUA	kernel TRNSYS
Graphical Interfaces	DesignBuilder, Autodesk Green Building Studio, OpenStudio, Ladybug, Sketchup and others	Sketchup, TRACE® 3D Plus	eQUEST, Autodesk Green Building Studio,	iCD, iSCAN, iVN,VE, Autodesk Green Studio, Sketchup, rhix, grasshopper, others	IDA ICE, Sketchup	Sketchup
Average cost of educational license	Open-source, But the interface is not	2,345 $	Open-source, but the interface is not	2700 $	2,575 $	$ 2520 10-user license
Library components	Wide	Wide for HVAC, Domestic Hot Water	Wide	Wide	Wide	Wide for HVAC
Input files	XLS, Epw, gbXML	XLS, Epw, gbXML	Epw, DWG, gbXML	XLS, Epw, gbXML	gbXML, IFC, DWG	————

Table 2. Comparison of whole-building energy engines with a focus on envelope and area

Criteria of choice	EnergyPlus	TRANE	DOE-2	IES (APACHE)	EQUA	kernel TRNSYS
Envelope and area						
Walls						
Materials	5	3	4	5	2	2
Thermal bridge	5	2	2	2	5	5
Roofs						
Materials	5	3	4	5	2	2
Solar reflectance index (SRI)	3	2	2	3	3	3
Fenestrations						
Materials	5	3	5	5	2	2
Window-wall ratio (WWR)	3	3	3	3	3	3
Solar Heat Gain Coefficient (SHGC)	3	3	3	3	3	3
Visible Transmittance (VT)	3	3	3	3	3	3
Integrated photovoltaics	3	4	0	3	5	0
Floors						
Materials	5	3	3	3	2	2
Heated- Unheated	3	4	2	2	3	5
Slabs towards ground	2	3	0	0	5	3
Thermal bridge	3	3	1	2	4	3

As it is shown in Table 3 that among serval whole-building energy simulation tools Energy Plus, DOE-2, IES, and EQUA are proving to be more capable in predicting lighting system Parameters as light-to-solar-gain ratio, open partitions parallel to window walls, light source lamp efficacy (mean LPW) and, automatic controls.

As it is depicted in Table 4 that among several whole-building energy engines TRANE are TRNSYS are more efficient in forecasting HVAC system packages as packaged single-zone air-source heat pumps, WSHPS with DOAS, radiant systems with DOAS and others.

As it can be seen in Table 5 that amongst numerous whole-building energy-related engines TRANE and TRNSYS are proving to be more capable in predicting renewable system features such as solar thermal systems, photovoltaic, wind turbine, micro-hydro, geothermal heat pump systems,

Table 3. Comparison of whole-building energy engines with a focus on lighting systems

Criteria of choice	EnergyPlus	TRANE	DOE-2	IES (APACHE)	EQUA	kernel TRNSYS
Lighting						
Daylighting						
Light-to-solar-gain ratio	3	3	3	4	3	3
Open partitions	3	3	3	2	3	0
Interior lighting						
Lighting power density (LPD)	3	5	3	3	3	3
lumens per watt (LPW)	4	5	2	2	4	4
Controls	3	5	3	3	5	2

Table 4. Comparison of whole-building energy engines with a focus on HVAC system

Criteria of choice	EnergyPlus	TRANE	DOE-2	IES (APACHE)	EQUA	kernel TRNSYS
HVAC						
Packaged single-zone air-source heat pumps						
Dedicated outdoor air system (DOAS) air-source heat pump	3	5	3	3	3	3
DOAS heating and cooling efficiency	3	5	3	3	3	3
DOAS energy recovery	3	5	3	2	3	2
Wshps with doas						
Unit size	3	5	3	3	3	5
Single-stage cooling and heating efficiency	3	5	3	3	3	5
Radiant systems with doas and others						
Radiant systems with DOAS	3	5	3	3	3	3
Air-cooled chiller Integrated Part Load Value (IPLV)	3	5	2	3	2	3
Condensing boiler efficiency	2	5	3	2	3	3

Table 5. Comparison of whole-building energy engines with a focus on renewable system

Criteria of choice	EnergyPlus	TRANE	DOE-2	IES (APACHE)	EQUA	kernel TRNSYS
Renewable systems						
Photovoltaic	3	5	3	3	2	3
Wind turbine	3	5	3	3	1	5
Micro-hydro	0	3	0	1	3	5
Geothermal heat pump systems	0	5	0	2	0	5
Hydrogen fuel cell systems	0	0	0	0	0	5

Table 6. Summary of whole-building simulation engines' capabilities to different systems

Engine name	Envelope System	HVAC System	Lighting System	Renewables System	Cost and Management	Urban studies
EnergyPlus	5	4	4	3	4	3
TRANE	3	5	3	4	3	1
DOE-2	4	4	4	3	3	1
IES	4	4	4	4	4	4
EQUA	5	4	4	3	3	1
TRNSYS	3	5	3	3	3	1

power plants (biomass, cogeneration), and hydrogen fuel cell systems.

As it can be seen in Table 6 that amongst several whole-building energy engines EnergyPlus, DOE-2, IES, and EQUA are proving to be more capable in predicting whole building energy performance indoor and outdoor. Nonetheless, all the selected engines are capable of performing energy simulation for different types of buildings with acceptable accuracy and covering the basic required systems.

6. CONCLUSION

There are numerous whole-building simulation engines with various ranges of complexities and capabilities to different systems. However, the selected simulation engines were EnergyPlus, TRANE, DOE-2, IES (APACHE), EQUA, kernel TRNSYS. The authors found that each engine has extensive, moderate, and low abilities in one system or another, in other words, a whole-building simulation engine could be used extensively in one system and has limited capabilities in another. As a result, the recommendations are to utilize each engine in the appropriate sub-field at the proper stage. However, all engines could be used to simulate whole-building energy performance. Nonetheless, not all engines are suitable for investigating individual systems and strategies as can be seen in this work. Moreover, the authors think that the user could select any available engine as long as the engine is permitted by the authority having jurisdiction. That being said close attention must be paid to engine compatibility with Computer-aided design and building information modeling.

7. FUTURE WORK

A comparative evaluation of engines that serve environmental indoor quality, computational fluid dynamics, and noise control is needed.

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