BUILDING SIMULATION AND ENERGY MODELING

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Abstract
With the expanding interest in the energy efficient building design, whole building energy simulation programs are increasingly employed in the design process to help the Architects and Engineers that determines which design strategies save energy and are cost-efficient. The purpose of this research is to investigate the purpose of these programs to perform whole building energy analysis and to compare the results with the actual building energy performance. A wide variety of energy simulation softwares have been developed, enhanced and used throughout the building energy researches. There are different types of simulations viz. Energy Simulations or Energy Modelling, Thermal Simulation or Thermal Modeling, Daylight Analysis, Artificial Lighting Analysis, CFD Analysis etc. The paper introduces many energy simulation softwares such as eQuest by DOE-2, Energy Plus, IES VE, Design Builder, Trace, Trane, and so on. All of these building energy simulation softwares have their own advantages. The choice of building energy simulation software should follow the design phrase and the simulation characteristics. It is difficult to understand the output electricity consumption without analysis. These softwares and analysis give us the close results, considering the same weather condition and by taking the same proposed materials and HVAC systems.
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Intruduction

Energy Simulation programs are powerful tools to study energy performance and thermal comfort during buildings life cycle. Today numerous such tools are available and they differ in many ways; in their graphical user interface, their thermodynamic Models, their purpose of use, and their ability to exchange data with other software applications. A Building Simulation is a computational model that approximates the performance of the actual building in practice, be this for energy consumption, thermal comfort, daylight or ventilation. How closely the model approximates the real world will be governed by a variety of factors. These include the purpose of simulation, the capabilities and limitations of the simulation
software used, the weather data used, the accuracy of the model definitions, and assumptions made regarding building operation compared to actual use. A building simulation is generally a compromise between achieving absolute fidelity and delivering a cost effective and timely result. All building simulation models will apply certain assumptions and simplifications, typically around factors such as occupancy and operation schedules, external features and adjacent structures, local climate conditions, building service specifications, constructions and fitouts.

Need of Simulation:

Day by day energy consumption in the world is increasing. Use of electicity and other energy resources are increasing continuously due to the construction of big buildings and due to the development in the technology. Big malls, apartments, institutions, theatres, auditoriums etc. consumes more part of energy in form of electricity. It is known to all that the resources we are using will not be remains always available to us but we will gone violated up these resources after a certain period of time. Therefore there need arises to make such structures which reduces the energy consumption i.e. which are both energy as well as cost-efficient. Then there comes the concept of sustainable and high performance buildings in order to make the use of energy efficiently and to reduce the cost also. Green building is the practice of constructing or modifying structures to be environmentally responsible, sustainable and resource-efficient throughout their life cycle. This includes efficiently using energy, water and other natural resources, protecting occupant health, improving employee productivity and reducing waste, pollution and environmental degradation. Green buildings accounts for improving environmental footprint by reducing energy use by 30-5%, CO2 emissions by 35%, waste output by 70% and water usage by 40%. For constructing such structures there analysis is important to be done before installations. Therefore Energy Simulation is needed to be done for such structures to make them energy as well as cost-efficient.

Basic principles of energy simulation:

Energy simulation tools predict the energy performance of a given building and thermal comfort for its occupants. In general, they support the understanding of how a given building operates according to certain criteria and enable comparisons of different design alternatives. Limitations apply to almost every available tool of this kind today, thus it is necessary to understand certain basic principles of energy simulation. First of all, any simulation result can only be as accurate as the input data for the simulation. As illustrated in, the input mainly consists of the building geometry, internal loads, HVAC systems and components, weather data, operating strategies and schedules, and simulation specific parameters. Every energy simulation is based on thermodynamic equations, principles and assumptions. Since thermal processes in a building are complex and not totally understood today, energy simulation programs approximate their predictions with qualified equations and methods. Therefore, results can be arbitrarily incorrect, if certain assumptions are not satisfied in the simulation or matched in real life.

Input to energy simulation:

The building geometry constitutes the basic input for energy simulation. It is crucial to understand that there are differences between a building model that was created by an architect and a building model needed for energy simulation. The latter, often referred to as thermal building model or thermal view of the building model, is basically a simplified view of the architectural building. One of the differences is that architectural spaces can typically be aggregated into thermal spaces or in case of large open offices the architectural space can be divided into multiple thermal spaces. This conjunction or division of architectural spaces is based on the thermal perspective where spaces with the same or very similar thermal characteristics and control patterns are combined into one. For energy simulations spaces need to be defined by space boundaries, which are not necessarily the same as walls in an architectural model.

General purpose of energy simulation:

A major benefit of energy simulation in design today is the comparison of architectural design alternatives: Alternatives to the original building design are validated for both thermal comfort and energy usage. For this type of application, the validity of the discussed assumptions is less crucial. Different design alternatives are based on almost exactly the same assumptions and the common belief is that relative differences in the simulation results are reliable. However, if building usage patterns are depended on the type of design alternative, the comparison of design alternatives may provide less accurate comparison results.

The prediction of absolute energy values of an energy simulation, given the assumptions, is rarely accurate. Usually, various validation tests, such as the BESTEST (Building Energy Simulation Test) that was developed and conducted by the International Energy Agency (IEA), are performed to validate building energy simulation tools relative to each other (IEA 2007). Validation tests comparing actual measurements from test buildings can also be conducted. The differences in absolute values are mainly due to assumptions made regarding input information and the dynamic occupant usage of buildings. To obtain absolute predicted values that more closely match the actual values of the building, energy performance simulation models need to be calibrated with actual measurements. One of the biggest challenges for this comparison is the dynamic human

behavior. Typically, internal loads resulting from humans are represented with schedules in energy simulation models; the actual usage of the building, however, changes on a daily basis. It is uncommon today to keep track of occupancy for every thermal zone, and to match the simulation input of occupancy with the actual occupancy. The input of static occupancy schedules in energy simulation can not properly represent the actual building usage. Statistically derived stochastic distributions may provide a methodology to simulate the actual behavior of people in buildings more accurately, but none of the energy simulation tools provide such a functionality.

Modeling Methodology:

Different simulation programs may have different software architectures, different algorithms to model building and energy systems, and require different user inputs even to describe the same building envelope or HVAC system component. For this study, the research methodology was to identify a recently constructed existing building, and to model the identical inputs for building systems, environmental conditions, control strategies, and material components in all software programs. Also, simulation settings were kept the same or as close as possible, such as the time step and calculation algorithm. Initial simulations were completed using Vasari/GBS and Sefaira, which have been specifically developed for early conceptual design. Simulations in eQuest and EnergyPlus are currently in progress, and will be reported at later stages of the research.

Furthermore, most energy simulation tools comprise of an engine and a graphical user interface. Different calculation methods to determine space loads are being used within the engine. All available simulation tools are uniform time increment models.

While these time increments are somewhat flexible (or user-definable), they are not based on events or changes. In general, energy simulations could be applied in every stage of the building lifecycle, since the used concepts are equally valid independently of the stage of a building's life. However, so-called *design* tools are mainly focusing on the design of a building from a heating and air conditioning perspective including its passive performance, such as shading. Many of the underlying assumptions and features are primarily related to the design stage and limit capabilities for other stages of the life-cycle. In particular *design* tools are used to size HVAC equipment for worst case conditions and do not consider the overall annual performance. In contrast, *simulation* tools use more generic concepts, thus they can be used during any life-cycle phase. The latter produce more data (typically over a period of one year) that can be compared to actual building performance and, thus, they are also useful for commissioning and operations purposes.

2.1 DOE-2:

The DOE-2.1E engine was developed by the Lawrence Berkeley National Laboratory and is one of the most widely used thermal simulation engines today. The engine was designed to study energy performance of the whole building during the design phase (Birdsall et al. 1990). The last official LBNL release of DOE-2.1E in 1994 included knowledge and expertise gained over a development process of 30 years. Due to its long presence on the market several user interfaces have been developed for DOE-2. Two user interfaces, RIUSKA and eQUEST, are described in Section 4 in this paper. Both user interfaces were selected for a review here due to their capability of data exchange with CAD applications. The following subchapters describe DOE-2's major functionalities, its architecture, applicability during the life-cycle, interoperability, and limitations. The DOE-2 engine is able to simulate the thermal behavior of spaces in a building, where heat loads, such as solar gain, equipment loads, people loads, lighting loads, and air conditioning systems can be modeled and simulated with the engine. The geometry for the simulation needs to be fairly simplified from the real geometry of the building. DOE-2 first calculates loads in a space considering only external and internal loads. Based on the temperature difference between two adjacent spaces heat transfer is determined according to the so-called weight factor method which accounts for thermal mass. In the next step the resulting loads are used as input for the HVAC system calculations, and the simulation engine tries to satisfy space loads with the defined HVAC system, if possible. There is no feedback from the HVAC system calculation to the load calculation. As mentioned in the general simulation chapter, this process does not include feedback (data flow is only forward). This approach assumes that the loads in each space can be satisfied at every time step of the simulation. If loads cannot be satisfied with the systems the temperature in the space changes and has an effect on further steps of the calculation. The air and water systems (as part of the SYSTEMS subprogram) can be modeled based on different predefined system definitions, which include some optional components or variations the user is able to select.

2.2 eQUEST:

eQUEST is a publicly-available, easy to use building energy analysis tool, which provides results by combining a building creation wizard, an energy efficiency-measure wizard and a graphical results display module with an enhanced DOE-2.2 derived building energy simulation program. The building creation wizard walks a user through the process of creating abuilding model. Within eQUEST, DOE-2.2 performs an hourly simulation of the building based on inputs that describe its construction, occupancy patterns, equipment load, plug loads and lighting loads, as well as heating and cooling systems. eQUEST allows users to create multiple simulations and view the alternative results in side-by side graphics. eQUEST provides two design wizards, the so called Schematic Design (SDW) and Design Development Wizards (DDW). Both represent well-known stages during design that differ significantly in the level of detail they contain. Both wizards can be used to simplify data input through usage of default parameters. It is possible to convert from wizards with less detail to more detailed descriptions of the building. The underlying concept of eQUEST is the detailed mode, where all available parameters can be defined and changed according to definitions contained in the DOE-2 engine. Once in the detailed mode of eQUEST, the user can convert back only to DDW and will loose any detailed information modified within the detailed mode. The Energy-Efficiency Measures provides another functionality of this tool, which enables fast comparisons of specific input parameters (e.g. capacity values of a coil). This wizard allows one to change almost every parameter that is present in the related wizard, but can only be used in SDW or DDW mode. eQUEST wizards contain several wizard screens which lead the user to input and/or change data. These screens include predefined default values (identified by green font) to which the user can make appropriate changes.

2.3 EnergyPlus:

EnergyPlus is one of the most advanced, publicly-available building energy simulation programs, whose development begun in 1996 with funding from the U.S. Department of Energy. While the program borrows what was effective from BLAST and DOE-2, it contains a number of innovative features, including sub-hourly time steps, user-configurable modular HVAC systems that are integrated with a heat and mass balance-based zone simulation, as well as input and output data structures that can facilitate third party module and interface development. Graphical user interface has recently been developed and released for EnergyPlus (OpenStudio), and a software development kit has been developed to simplify the creation of applications that use simulation models. Although results from eQuest and EnergyPlus are not included in this paper, they are important in the overall research since these applications are more robust and would be valuable addition to the available body of knowledge on relationships between simulated an actual building energy performance data.

2.4 Computational simulation:

The Virtual Environment (VE) v5.9.0.3 was selected to perform this case study as it allowed a single model to be used for all the required aspects of the study. The daylighting element of the analysis required the facilities to calculate Daylight factors on the working plane. The Radiance link within the VE was utilised for this aspect of the study. In order to account for the local shading effects from surrounding trees and buildings, the Suncast module of the VE combined the Apache Simulation Engine was used. For the overheating analysis the software needed to be able to model bulk air flow within the building in order to establish the effectiveness of the proposed ventilation strategy. The Macroflo module of the VE was used in conjunction with Suncast and the Apache Simulation engine for this element of the study.

2.5 DesignBuilder:

The DesignBuilder is the most comprehensive interface for EnergyPlus available today. Its current version (1.4.0.031 beta) includes a simplified CAD interface, templates, wizards, and most compact air system configurations of EnergyPlus. The workflow of DesignBuilder starts with the selection of a location and the corresponding weather through a weather file (in this case in EPW format), followed by the creation of specific thermal building model geometry with the integrated CAD

interface. This building geometry represents the definition of geometry needed for the simulation of the building's thermal performance. Additionally, one can import DXF files as footprints for the creation of the geometric model as described later in this paper. DesignBuilder provides a variety of country or region specific templates for selection of parameters (such as materials and constructions). Lists of other definable parameters include internal loads (with occupancy patterns/activities), construction types, openings (windows and doors), lighting, and HVAC systems. Once the definition of all input parameters is complete, one can perform design day and/or annual simulations. In addition, one can validate most parts of the thermal model of the building against the energy code that applies to the location of the building. An important feature of DesignBuilder is the help window that provides tips andwizards guiding the user through the creation of the thermal model. This is especially useful to novice users, as it helps them to better understand the concepts of thermal modeling. Most of the other user interfaces reviewed in this document lack such a functionality. In addition, DesignBuilder includes video tutorials with short lessons about

specific features of the program. The typical usage of DesignBuilder includes evaluation of façade options, daylighting analysis, visualization of site layouts and solar shading, thermal simulation of natural ventilation, and sizing of HVAC equipment and systems.

Conclusion:

This paper describes building thermal simulation engines DOE-2 and EnergyPlus, and some of the available user interfaces to these engines. The benefits and limitations of each tool were discussed by describing their functionality, life-cycle usage and data exchange over software boundaries. The user interfaces for DOE-2 are currently more developed in comparison to the interfaces for EnergyPlus. The lack of user-friendly, mature and comprehensive user interfaces limits the usage of building energy performance simulation in practice. Current progress on interfaces to EnergyPlus is promising and is likely to provide adequate user friendliness and functionality in the foreseeable future. Even though the development of thermal simulation tools has “eased the life” of users, the usage of such tools is not a trivial task and needs an understanding of the described limitations, as well as the knowledge of thermal processes in a building. Thus, any result is only as good as the understanding of its limitations. As outlined in the recommendations, various issues related to thermal simulation tools itself need more development and research to improve the value and accuracy of energy simulation. The strength of energy simulation today is the comparison of different design alternatives rather than predicting absolute energy consumption values. With additional research and development, these tools could also provide more accurate absolute values and provide many additional benefits to their users.

Current seamless data import of building geometry data into energy simulation tools has limitations and usually includes either a process of iteratively changing the architectural model or manual checking and fixing of the partially converted geometry.

The example building shown repeatedly in this document demonstrates the typical and frequently encountered problems with data exchange related to building energy performance simulation. Energy performance simulation tools are mostly used during design, but the use of such tools during the commissioning and operations phase has additional value. To leverage this value, data exchange must become more applicable and usable in other phases of a building’s life-cycle, not only in the design phase. Thus a closer integration of energy performance simulation with the actual performance of buildings during operation will not only improve existing simulation tools, but will also enable a more efficient operation of buildings.

4. References

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