Analysis of Energy Simulation Models

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Abstract

The building sector is responsible for approximately 40% of the overall energy consumption in the European Union (EU). Emphasis on improving the energy performance of the EU's existing and new building stock is critical. The development of Energy Simulation Models through the implementation of the BIM (Building Information Model) will allow facility managers and maintenance crews to monitor and evaluate energy systems operating in buildings, in order to optimise energy consumption and provide building performance data. Current energy simulation models are static and do not account for dynamic changes in building characteristics including occupancy and the building's external environmental conditions. This paper will examine the data formats used in energy simulation. It will describe an energy simulation of the Environmental Research Institute (ERI) building, University College Cork, and discuss potentials and limitations of available energy simulation software.

Keywords

Energy Simulation, BIM, BMS, Energy Simulation Tools, Building Lifecycle

1 Introduction

Energy simulation of the built environment involves analysis of the actual or predicted energy performance of buildings. It can also involve an analysis of the embodied energy within building materials and of methods used to construct buildings [1]. The ultimate aim of this research is to analyze simulation tools that will enhance our research focusing on energy performance and energy efficiency improvements in buildings. Energy simulation involves comparisons between actual and predicted use of building energy. Comparisons are made against benchmark parameter values used to indicate regulatory requirements, average energy consumption or best practice.

The first part of this paper discusses the basic principles of energy simulation and the input data for simulation. The second part of this paper examines the potential and limitation of simulation engines.

The final part examines the ERI building energy simulation example in detail. This simulation helps to illustrate how energy performance can be improved throughout a building's lifecycle through the use of energy efficient and renewable energy technologies in the initial design, construction, commissioning, operation and maintenance phases.

2 Basic Principles of Energy Simulation

Energy simulation tools predict the energy performance of a given building and the thermal comfort for its occupants. Such tools support the understanding of how a given building should perform under certain criteria and provide a means to compare different building design alternatives. All competing energy simulation tools have limitations, thus it is necessary to understand the basic principles of energy simulation [2].

Simulating a building's energy usage is a difficult task, requiring not only a model of the building's geometry, its components (such as insulation, windows, foundation, walls and HVAC systems), but also detailed and accurate environmental data. Environmental data includes weather conditions within the proximity of the relevant building, humidity, wind speed and external temperatures over various time periods. In addition, data supporting the building's internal electricity load (lighting devices, electronic equipment, and occupant electricity demands), heating and cooling loads are also required (see fig. 1).

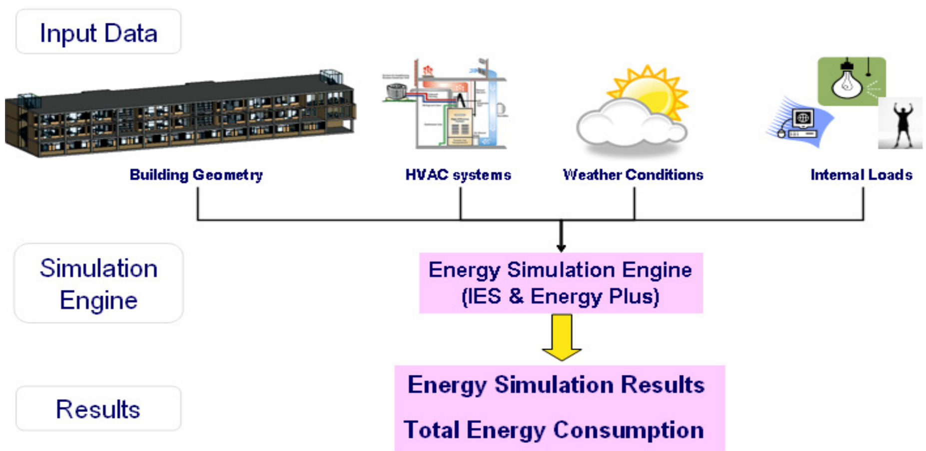

Fig. 1: Energy Simulation Process

Building geometry comprises of the basic building input for energy simulation which is created by CAD tools. There are differences between building models created by architects and the building models required for energy simulation. One of the main differences is the use of the entity *space* by architects and the use of the entity *boundary* in energy simulation models. Architectural spaces, for example, rooms, are divided by walls. In energy simulation models, such spaces are referred to as thermal spaces and are defined by space boundaries. The combination or division of architectural spaces is based on the thermal perspective and the design and layout of the HVAC systems.

Energy simulation modeling of HVAC systems is accommodated significantly by all energy simulation tools. However, HVAC systems can be modeled to reflect the actual system if the energy simulation tool provides enough flexibility. To define a realistic representation of a real HVAC system within a building structure can be challenging. The HVAC operating schedule is a key input for energy simulations of this nature. Operating schedules define the behavior of HVAC components, such as peak or off-peak time periods, for all of the HVAC systems.

Weather conditions are extremely important for energy simulation models. The weather data format includes basic location information; name, state/province/region/country, latitude, longitude, time zone, elevation, peak hot and cold temperatures. In addition, daylight savings, average and extreme temperature periods are also included as input data. The collected weather data are not used to reflect weather conditions for a specific year, but rather to provide statistical references for typical weather parameters for a specific location.

Internal loads, such as energy consumed by occupants, lighting devices and electronic devices depend on the actual usage of a relevant space within a building and the behavior of its occupants. Assumptions have to be made about the quantity of internal loads in a given space within a building for energy simulations.

All of the above mentioned parameters provide basic input data for energy simulation. Energy simulation is enhanced by including additional input parameters that become more relevant to specific phases of a building’s lifecycle. In addition, different types of simulation engines will also influence a building’s energy simulation results.

3 Thermal Simulation Engines & Energy Simulation Tools

As already mentioned, energy simulation of buildings is essential when researching energy efficiency in buildings. Computer simulation programs are effective analytical

tools for building energy research and evaluation of architectural design. There are a number of energy simulation tools that this research has examined for their potential and limitations.

3.1 IES

The Integrated Environmental Solution Virtual Environment (IES<VE>) performance analysis software suite allows architects and engineers to facilitate a sustainable design process by offering quantitative feedback on the environmental performance of different design options [3]. On average, green buildings use 30% less energy than conventional buildings, although through the use of IES software the potential is much higher [4]. It is a robust energy analysis tool that offers a high degree of accuracy and interoperability with the BIM model. The drawbacks are its current complexity for the user and the relatively expensive cost of the tool suite.

3.2 EnergyPlus

EnergyPlus is a modularly structured software tool based on the previous capabilities of BLAST and DOS-2.1E. It is a simulation engine, which uses text files for input and output. It was developed to provide an integrated simulation for accurate temperature and comfort prediction. It calculates heating, cooling, plant and electrical system response, with a variable time step. It allows users to evaluate realistic system controls, moisture absorption and desorption in building elements, radiant heating and cooling systems, and inter-zone air flow. A day lighting module calculates daylight luminance and glare, and calculates electric lighting reduction for the heat simulation tool. EnergyPlus is open source software, and since its launch in 2001 it has become the most used simulation tool. However it has a poor user interface which is difficult to use and demands specialist knowledge to interpret results. DesignBuilder and IDF Generator are a comprehensive user interface for the EnergyPlus dynamic thermal simulation engine.

Tab. 1 shows the major functionalities between IES and EnergyPlus. IES is older than EnergyPlus and it is a commercial product supporting standard graphical user interfaces and standalone weather file formats. IES and EnergyPlus both support 3-D geometry input and can interconnect with other tools. Although EnergyPlus includes a variety of links to other simulation engines (COMIS, SPARK), several limitations apply to the usage of these links.

Energy Simulation Tool	IES	EnergyPlus
Release year	1994	2001
Licence	Commercial	Open source
Weather file format	CIBSE	EPW
Complexity of geometry	Simplified 3-D geometry	Simplified 3-D geometry
Data exchange	GBXML	IFC/IDF
Software technologies	Not applicable	Engine based on text file input and output Modular approach
Interconnectivity to other tools	Autodesk Revit	Links to COMIS and SPARK

Tab. 1: Comparison of functionality between IES and EnergyPlus

4 ERI Lifecycle Energy Performance Model

Buildings often do not perform as well in practice as expected during pre-design planning, nor as intended at the design stage, nor even as measured during commissioning and maintenance operations. While this statement is generally considered to be true, it is difficult to quantify the impacts and long-term economic implications of a building in which performance does not meet expectations. This leads to a building process that is devoid of quantitative feedback that could be used to detect and correct problems both in an individual building and in the building process itself [5, 6]. Fig. 2 shows the different stages of the building energy lifecycle.

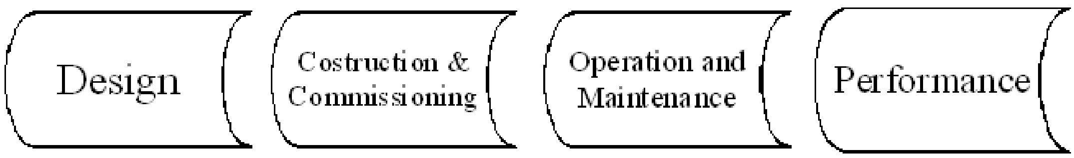

Fig. 2: Building Energy Lifecycle

The design stage of a low energy building typically involves the use of CAD drawings, steady state and dynamic simulation tools to estimate the building's energy performance, and influence the design to achieve a predefined performance objective. The energy consumption rate is expressed in kWh/m^2 of treated floor area.

The construction and commissioning of HVAC and electrical equipment is usually performed to achieve ± 10% of the peak design flows in the case of air and water commissioning. Typically optimization of equipment as part loads does not occur.

The ongoing operation of an energy efficient building involves the use of a Building Management System (BMS) to actively control and monitor the buildings environment. This system can be extended into a Building Energy Management System (BEMS). Typically maintenance of building systems prioritizes the functional well-being of mechanical and electrical components in order to prolong their working life. Unfortunately the energy function of such systems is not the primary concern although not an unrelated consequence.

There is a need for an integrated lifecycle energy performance model to provide feedback that can be used to optimize systems' operation, detect and correct problems for an individual building as well as provide design feedback to improve the design and construction of future buildings.

Our research has modeled the ERI building through the development of an integrated computer-based Building Information Model (BIM) by implementing a building lifecycle approach. The BIM includes benchmarking, simulated and real-time operation data relating to the energy performance of the building. It also provides data concerning the building's geometry, materials used, occupancy schedules, environmental conditions as well as operational data. The BIM, combined with data from the BMS, contributes to an accurate energy simulation of the ERI building [10]. This research is one of the focus areas concerning the Informatics Research Unit for Sustainable Energy (IRUSE). IRUSE has research teams based in the Civil and Environmental Engineering Department, University College Cork and the Civil Engineering Department, National University of Ireland Galway.

The ERI (Fig. 3) is a three storey research building containing offices, computer laboratories, microbiology laboratories, and controlled temperature rooms. The Informatics Research Unit for Sustaining Engineering (IRUSE-Cork), Department of Civil and Environmental Engineering, University College Cork, use the ERI as a living laboratory to conduct research into the use of ICT to enhance energy efficiency and operation of green buildings. The ERI has been designed to achieve a "Very Good" Building Research Establishment Environmental Assessment Method (BREEAM) rating [7]:

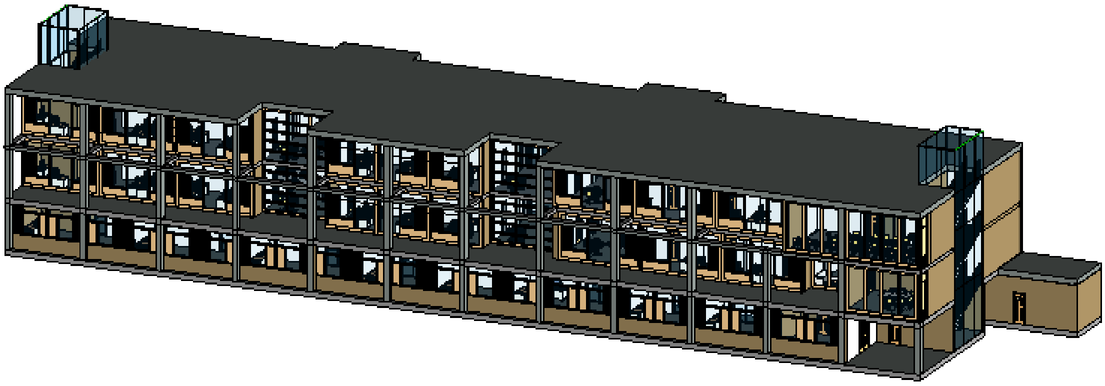

Fig. 3: ERI Dynamic Building Simulation Model

Tab. 2 shows the internal equipment and occupant parametric load which was used for the ERI energy simulation. Equipment considered for this simulation included lighting devices, personal PCs, refrigerators and a water cooler. The total internal load is easily calculated and provides one of the most important input parameters for the energy simulation model.

Parametric	**Watt**
Occupant	60W
Lighting	80W
Water Cooler	130W
PC	85-230W
Fridge	345W

Tab. 2: Internal parametric Load

The HVAC system in the ERI supports the under-floor heating system. For the weather condition data we applied Cork, Ireland (City, Country). Using Revit MEP we linked to the IES tool to calculate the total energy usage as 218.732 kW (see Fig. 4). The Energy Use Intensity (EUI) value for the ERI was calculated as follows:

Total Energy Usage (KW) / Total Area Space (m^2) / Boiler Efficiency * Operation Hours (per year)

$$\mathbf{218.732 / (2627+631) / 0.8 * 2096 = 175.625\ Kwh/m^2/yr}$$

Loads Report Summary

Powered by ies

Project Information

Project	Project4
Run Time	25/05/2009 17:22
Address	
Latitude	53° 19' 59"
Longitude	6° 14' 53"
Building Type	Office
IES Version	5.8.5.2

Building Summary

Input Data	
Total Occupied Analytical Area	2627 m^2
Total Unoccupied Analytical Area	631 m^2
Total Occupied Analytical Volume	8852.06 m^3
Total Unoccupied Analytical Volume	2272.59 m^3
Results	
Total Cooling Load	0 W
Total Heating Load	218732 W

Building Checksums

Item	Cooling	Heating
Load Density	0.00 W/m^2	83.26 W/m^2
Load / Occupied Volume	0.00 W/m^3	24.71 W/m^3
Flow Density	1.92 $L/(s \cdot m^2)$	2.43 $L/(s \cdot m^2)$
Flow / Occupied Volume	0.57 $L/(s \cdot m^3)$	0.72 $L/(s \cdot m^3)$
Flow / Load	0.00 $L/(s \cdot kW)$	N/A
Area / Load	0.00 m^2/kW	12.0110 m^2/kW
People	339.66	N/A

Weather Data

Item	Winter	Summer
Dry Bulb	-2 °C	24 °C
Wet Bulb	-5 °C	18 °C

Fig. 4: ERI Energy Simulation Report

The BMS (Building Management System) used for this research has been designed supporting data from wireless sensors measuring lighting levels, mean and radiant temperature, humidity and CO_2. In addition a number of energy meters have been installed to record energy consumption of the HVAC systems and energy consumed by electronic equipment. The BMS is capable of storing this energy real-time. Additional software techniques that we are currently researching will facilitate the detection of data patterns useful for predicting energy consumption and enhancing the building’s energy efficiency operation. The BMS will provide the operational data for the BIM [8, 9]. Tab. 3 details actual energy data from the BMS system.

GAS		ESB	
Date	**KWhrs**	**Date**	**KWhrs**
06/09/07 - 24/10/07	5676		
25/10/07 - 22/11/07	12464	Oct	58350
23/11/07 - 28/12/07	23167		
29/12/07 - 23/01/08	15889	Dec	63600
24/01/08 - 19/02/08	9833		
20/02/08 - 02/04/08	14074	Feb	70450
03/04/08 - 22/04/08	5223		
23/04/08 - 21/05/08	6397	Apr	72550
22/05/08 - 24/06/08	11630		
25/06/08 - 23/07/08	4476	June	67900
24/07/08 - 21/08/08	3595		
22/08/08 - 26/09/08	2000	Aug	67650
Total Gas: 108027		Total Electricity Consumed: 400500	
Total Energy (kWh): 508527			
ERI EUI (Kwh/m^2/yr): 181.6168			

Tab. 3: Actual energy data from the BMS system

Comparing predicted EUI with actual EUI, we have verified that the predicted EUI is the basic energy requirement for the building. The actual energy usage must be greater than or equal to the predicated EUI. By knowing the building's EUI we can optimize energy consumption and perform better building operation strategies.

5 Conclusion and future Work

This paper has highlighted the importance of energy simulation of buildings during each stage of the building lifecycle. Through accurate simulation appropriate design enhancements can be achieved focusing of energy efficient building operation. The accuracy of the simulation is influenced by the number of available input parameters. In addition, the ability of the energy simulation tool to support such input parameters is also critical to an accurate simulation. This paper examined the performance of IES and EnergyPlus simulation tools. This research preferred the use of IES.

This research is enhanced by the availability of a smart building for data analysis. Future work will see a greater quantity of data being harvested in the mentioned smart building through the expansion of its existing wireless sensor network. This will provide a greater array of input data for energy simulation. In comparison to the smart building model, IRUSE Cork has commenced analysis of their existing Civil Engineering building focusing on improving the buildings carbon emissions.

This will allow this research to focus on energy simulation concerning the retro-fitting of an old building, which was constructed in 1910, and research how energy simulation can influence the design of a retro-fit project to improve old buildings' energy consumption and contribute to the reduction of its carbon emissions.

List of Figures

List of Tables

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