Cairo University

EVALUATING BUILDING SYSTEMS ENERGY PERFORMANCE USING BIM AND SUPERIORITY AND INFERIORITY RANKING

By

Ibrahim Gamal Abdel-Basset Mohammed

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
STRUCTURAL ENGINEERING

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Under the Supervision of

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Title of Thesis:

Evaluating Building Systems Energy Performance Using BIM and Superiority and Inferiority Ranking

Key Words:
Building Information Modeling (BIM); Superiority and Inferiority Ranking (SIR); Indoor Air Quality (IAQ); Energy Analysis;

Summary:
Today, the demand of sustainable buildings is getting higher. The main purpose of buildings is to provide a comfortable living environment to their occupants, considering different aspects including thermal, visual and acoustic comfort as well as Indoor Air Quality. Decreasing carbon foot print and energy consumption rates while increasing comfort level can help to achieve better living and working environment for building users. This research proposes a framework that aims at improving environmental concerns and evaluating building systems energy using building information modeling during buildings' design stage by evaluating different alternatives for the installed systems in buildings. The building systems are evaluated considering four main criteria; operating cost savings, total energy consumption per year, Lifecycle cost savings, and carbon emissions. A Multiple Criteria Decision Making (MCDM) technique is applied using Superiority and Inferiority Ranking (SIR) to study different alternatives behavior. Sensitivity analysis is performed to detect the criticality and effectiveness of the different defined criteria that influence environmental concerns and systems energy performance in buildings. A case study is presented to demonstrate the use of the proposed framework.

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Abstract

Today, the demand for sustainable buildings is getting higher. The main purpose of buildings is to provide a comfortable living environment to their occupants, considering different aspects including thermal, visual and acoustic comfort as well as Indoor Air Quality. Decreasing carbon foot print and energy consumption rates while increasing comfort level can help to achieve better living and working environment for building users. This research proposes a framework that aims at improving environmental concerns and evaluating building systems energy using building information modeling during buildings' design stage by evaluating different alternatives for the installed systems in buildings. The building systems are evaluated considering four main criteria; operating cost savings, total energy consumption per year, Lifecycle cost savings, and carbon emissions. A Multiple Criteria Decision Making (MCDM) technique is applied using Superiority and Inferiority Ranking (SIR) to study different alternatives behavior. Sensitivity analysis is performed to detect the criticality and effectiveness of the different defined criteria that influence environmental concerns and systems energy performance in buildings. A case study is presented to demonstrate the use of the proposed framework.

Chapter 1. Introduction

1.1 General

Today, the demand for sustainable buildings is getting higher. The main purpose of buildings is to provide a comfortable living environment to their occupants, considering different aspects including thermal, visual and acoustic comfort as well as Indoor Air Quality. Decreasing carbon foot print and energy consumption rates while increasing comfort level can help to achieve better living and working environment for building users.

Building Information Modeling is becoming the leading process in design, construction and all the other phases through the whole asset's life cycle. Implementing BIM in our research was very effective in improving the results and increase efficiency in performing the research. The open environment of BIM maintains flexibility in applying different types of analysis in various ways with the aid of different types of software. Also BIM reflected in our research as it provides a well-structured database called COBIE –Construction Operation Building Information Exchange- as the thesis model is using COBIE as a hub for collecting all measurements and transferring them to the analysis stage.

The thesis idea was originated at the ICIM (Interoperable Carbon Information Modelling) project as it was performed as an online tool to facilitate carbon assessment of a building by informing designers regarding their decisions and impact of their decisions throughout the building life cycle. The idea is to perform any new project that enhances the building design and management system with more data assessment for humidity, temperature (for the user's comfort sense) and energy consumption improving the building life cycle as a result of a better material usage and rapid responses for different systems' defects.

The idea mainly depends on the As-built BIM Model as it has to give instant alerts for the Operator who has the responsibility of the Facility management; these alerts are coming from an external data base that receives its data from accurate measurements performed by special types of equipment which are responsible for these rapid measurements and monitoring depending mainly on different types of sensors attached to these equipment. The different building states could be given different rates to express the overall building performance in correspondence to environmental challenges.

1.2 Problem Statement

Sustainable building design, construction and operation require innovations in both engineering and management areas at all stages of a building's life. Through this lifespan, essential requirements are generated from considerations of social, environmental, and economic issues for high efficient energy-saving building systems in compliance with building codes and regulations. Energy consumed and greenhouse gas emitted during the buildings life cycle is considered one of the most significant environmental problems.

1.3 Research Objectives

The main objective of this research is to propose a framework that aims at improving building systems energy performance using Building Information Modeling during buildings' design stage by evaluating different alternatives for the installed systems in buildings. The building systems are evaluated considering four main criteria; operating cost savings, total energy consumption per year, Lifecycle cost savings, and carbon emissions. To achieve this main objective, the following sub-objectives are defined.

- A COBIE (Construction Operation Building Information Exchange) spread sheet is created to support the Superiority and Inferiority Decision Making process with the inputs reached from the Indoor Air Quality (IAQ) and environmental analysis.
- A Multiple Criteria Decision Making (MCDM) technique is applied using Superiority and Inferiority Ranking (SIR) to study different alternatives behavior.
- Sensitivity analysis is performed to detect the criticality and effectiveness of the different defined criteria that influence environmental concerns and building systems energy performance.

1.4 Research Assumptions and Limitations

In developing the proposed framework that aims at improving building systems energy performance, the following assumptions are made:

1. The research considers four main criteria for evaluation which are temperature, humidity, energy consumption and carbon emissions.
2. Superiority and Inferiority Ranking (SIR) as a Multiple Criteria Decision Making (MCDM) is adopted.

1.5 Research Methodology

The research methodology is explained briefly as follows:

1. Create a sufficient as-built 3D model in a standard manner of the building objects' definition
2. Export the model in interoperable file extension (Industry Foundation Classes or IFC) in the facility management developed mode (COBIE that stands for Construction Operation Building Information Exchange) that is supported with excel spread sheet in an organized standard form that can give a high level of awareness with the model objects and spaces and providing unique IDs to every single object
3. Perform thermal analysis on an educational building, and validating the results obtained from sensors located in this building
4. Update the COBIE spread sheet with data provided by the equipment instantaneously
5. Perform well designed response plans to all scenarios that may occur over the building's life cycle
6. Propose new design alternatives to be compared with the initial building design.

7. Apply Multi Criteria Decision Making tools to reach the best design alternative with respect to energy consumption, carbon emissions and Initial costs
8. Apply sensitivity analysis on the MCDM process to detect its efficiency and criticality

1.6 Thesis Organization

The thesis is composed of six chapters, where these chapters are organized in a manner that shows the research's logical sequence.

Chapter 1 provides the reader with a generic idea about the thesis structure and its main points. The chapter started with stating the problem that is supposed to be solved in the research, then showing the objectives that have been identified in order to solve that problem in addition to the constraints and limitations that were figured out, and finally with the methodology applied in order to perform this research.

Chapter 2 provides the different efforts, ideas and concepts related to the different research sections including the Building Information Modeling, Multi Criteria Decision Making, thermal Comfort and Energy Analysis. The chapter presents the current research gap and the importance of the research.

Chapter 3 explains model's structure and general idea, then illustrates the model framework and it also illustrates all the model components and analysis.

Chapter 4 illustrates the facility management process and the use of COBIE in the research.

Chapter 5 describes the use of SIR (Superiority and Inferiority Ranking) in the process of choosing the best design alternative. A case study is worked out to illustrate the application of SIR and a sensitivity analysis to test the results.

Chapter 6 presents the summary for the research, the research contributions and recommendations for future researches.

Chapter 2. Literature Review

2.1 General

Green building concept has been adopted by the construction industry as a response for the global environmental challenges leading to successful results. (Abbaszadeh, et al., 2006)[1] found that thermal comfort, air quality, furnishing, cleaning and maintenance achieved higher rates for satisfaction in LEED-certified green buildings compared to those non-green counter parts. On the other hand, clients are looking for the added benefits coming from applying the concept of sustainable buildings as they have to increase the capital cost invested to perform their projects (Paul & Taylor, 2008)[2].

Green buildings tend to reduce harmful impacts of buildings on the environment and inhabitants, considering four main aspects: 1) efficient energy use, 2) healthy indoor air environment, 3) use of sustainable materials and resources, and 4) efficient use of water. On the other hand, sustainable buildings consider broader aspects in addition to environment such as financial and social aspects over a long period of time. Previous research concluded that the aspect of sustainable and green buildings will become the most common among people when they realize the benefits and financial gains achieved from their projects as a result of the occupants improved productivity (Zou & Zhao, 2014)[3]. This improved productivity attributed comfortable and satisfying environment provided for their users.

According to the norms of building automations, it was found that comfort is an important characteristic compared to the usual security and safety issues. It was found also that thermal comfort and air quality are very important and significant factors in deciding the building sustainability and the human comfort level (Kang & Park, 2000)[4] (Singh, et al., 2011)[5]. (Kim, et al., 2012)[6] monitored and predicted IAQ of subways.

Temperature, humidity and air pollutants were measured at a Korean subway. By assessing the different season's effect on the IAQ in metro systems using seasonal models. The seasonal effect on IAQ was detected using a multivariate analysis of variance test (MANOVA). A framework was developed by (Azhar, et al., 2011)[7] which aimed at utilizing one of BIM valuable advantages with LEED accreditation process. The authors stated that this process could be more efficient compared to other traditional methods. In this framework the BIM model was integrated to environmental solution software in order to perform different types of analysis and create LEED documentation. (Lee, et al., 2012)[8] integrated BIM with a group of sensors in order to create a navigation system that could help in blind lifting problems (e.g. crane operator).

2.2 Building Information Modelling

BIM as defined as a data-rich, intelligent, parametric digital and object oriented presentation of the facility from which data and views needs to be extracted and analyzed to manage information (ACE, 2010)[9]. This can help to improving the process of decision making and delivering the facility.

(Jack, 2009)[10] stated that BIM is a process of demonstrating graphical and non-graphical information for the building life cycle. Building Information Modeling (BIM) is considered one of the shining technologies developed to increase the efficiency of construction industry. Its function was extended to help in the facility management process by using the As-built BIM model and it is used also in monitoring the facility behavior over its life time as a way to increase the level of control on the building even in operations or maintenance.

(Smith & Tardif, 2009)[11] stated that the core attribute of BIM which makes it different from traditional design technologies is not the three dimensional geometric modeling but this difference is due to the structured organized and defined information that could be exchanged. Practical attention is concentrated on BIM implementation to use open shareable asset information through buildings and infrastructure life-cycle and this could be illustrated by the UK government motivations for using BIM in addressing cost, value and carbon issues (BIS/IWG, 2010)[12].

(Becerik-Gerber, et al., 2012)[13] stated that specialized tools of design, architecture and engineering professions join the basic functionalities such as structural analysis, scheduling, tracking progress and energy analysis. BIM uses are concentrated on preplanning, design, construction and delivering building and infrastructure projects and recently the BIM uses were improved to include refurbishment, maintenance and environmental considerations (Akbarnezhad, et al., 2012)[14] (Eastman & Sacks, 2011)[15]. These great advantages are the results of the comprehensive information stored in the model during the construction process. The functional and physical characteristics of a facility can be modeled digitally using BIM (Marzouk & Abdelaty, 2014)[16]. The aim of the study is to evaluate buildings' design using building information modeling by considering several designs of systems alternatives. Alternatives are studied relative to preset objectives using SIR as a MCDM technique in order to aid with the decision of optimized design. Also, a sensitivity analysis was performed on the problem criteria to detect the effectiveness of criteria and to support the decision making on alternatives with an increase in the efficiency of the resolution process.

COBIE (Construction Operation Building Information Exchange) is one of the IFC (Industry Foundation Classes) formats. It was developed to improve facility management through the BIM process. COBIE has become mobilized as the initial format for data transfer between packages at a series of 'data drops' to the client, as it is compliant with Building Smart Industry Foundation Classes (IFCs) (East & E., 2007)[17] . It exports all model data in a manner that helps the facility manager to apply a high level of control, understanding all the building components, improve data quality and cut costs at projects turnover. (Eastman & Sacks, 2011)[18] stated that due to the introduction of the international COBIE standard, stakeholders became able to store maintenance information in BIM models in a structured way and as a result an increased value for facility documentation. (Marzouk & Abdelaty, 2012)[19] proposed an integration between subways BIM-based models and Facility management process using a semi-automated inspection system. The system was developed using Wireless Sensor Network (WSN) inside the subway for detecting temperature and humidity.