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RESEARCH ARTICLE

Assessment of energy utilization and leakages in buildings with building information model energy

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Abstract
Given the ability of building information models (BIM) to serve as a multidisciplinary data repository, this study attempts to explore and exploit the sustainability value of BIM in delivering buildings that require less energy for operations, emit less carbon dioxide, and provide conducive living environments for occupants. This objective was attained by a critical and extensive literature review that covers the following: (1) building energy consumption, (2) building energy performance and analysis, and (3) BIM and energy assessment. Literature cited in this paper shows that linking an energy analysis tool with a BIM model has helped project design teams to predict and create optimized energy consumption by conducting building energy performance analysis utilizing key performance indicators on average thermal transmitters, resulting heat demand, lighting power, solar heat gains, and ventilation heat losses. An in-depth analysis was conducted on a completed BIM integrated construction project utilizing the Arboleda Project in the Dominican Republic to validate the aforementioned findings. Results show that the BIM-based energy analysis helped the design team attain the world's first positive energy building. This study concludes that linking an energy analysis tool with a BIM model helps to expedite the energy analysis process, provide more detailed and accurate results, and deliver energy-efficient buildings. This study further recommends that the

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adoption of level 2 BIM and BIM integration in energy optimization analysis must be demanded by building regulatory agencies for all projects regardless of procurement method (i.e., government funded or otherwise) or size.

1. Introduction

Hsieh and Wu, (2012) divided the performance evaluation of a building into five parts: (1) building envelope, (2) air conditioning and ventilation, (3) water heating system, (4) dynamic equipment, and (5) illumination. The building envelope was recognized as the most important factor with regard to energy efficiency. The researchers believe that if the properties of the building envelope can be improved, a suitable energy saving design can be attained, thereby leading to lower energy consumption during operation, as well as lower energy waste and carbon dioxide emissions.

A defined energy amount has to be supplied for a building to operate at optimum capacity and functionality. This condition requires estimating the energy amount required and equating energy demand with energy supply. Thus, “the demand side is calculated, cumulating energy losses such as transmission and ventilation heat losses of the building envelope” (Schlueter and Thesseling, 2009). Various methods of evaluating the energy performance of buildings have been identified and employed by different researchers. A hybrid method in the energy analysis of building materials was applied (Alcorn and Baird, 1996). Previous researchers identified three types of energy analysis methods: (1) statistical analysis, (2) input-output analysis, and (3) process analysis. Statistical analysis employs published statistics to evaluate energy usage. Input-output analysis equates energy usage with the monetary flow within an economy. Process analysis deals with the systematic examination of the direct and indirect energy into a process. Similarly and in a more detailed format, energy performance analysis was classified into two types (Schlueter and Thesseling, 2009), namely, (1) physical calculation models and (2) statistical calculation models. The researchers argued that the physical calculation model provides the exact calculation of detailed performance analysis tasks, whereas the statistical calculation model applies empirical factors in the building performance analysis, thereby generating performance analysis estimates.

Although the aforementioned methods seem to have worked in the past, recent developments in computational simulations now allow for the efficient analysis of the building envelope performance. Current computational optimization methods applied to sustainable building design problems were reviewed (Evins, 2013). The author identified three types of computational optimization: (1) generic optimization, (2) multi-objective optimization, and (3) algorithm. Bazjanac (2007) stated that “the quality of developed and used simulation model depends on data available at the given stage of the project, the knowledge and experience of the modeler, available resources, and various other external conditions and pressures”.

The following factors are provided (Al-Homoud, 2001) to be considered when selecting a method/tool for performance analysis: (1) accuracy, (2) sensitivity, (3) speed and cost of learning and use, (4) reproducibility, (5) ease of use and detail level, (6) availability of required date, (7) output quality, and (8) project stage.

Key performance indices that are calculated to display the energy performance of buildings are provided (Hsieh and Wu, 2012; Schlueter and Thesseling, 2009). These indices include: (1) average thermal transmittance, (2) ventilation heat losses, (3) solar heat gains, (4) internal heat gains, (5) lightning power, and (6) resulting heat demand. The USGSA (2008) provided possible results of energy analysis as follows: (1) assessment of the space and building energy performance for compliance with regulations and targets, (2) overall estimate of the energy use by space and for the building, as well as an overall estimate of the energy cost, (3) time-based simulation of the energy use of the building and time-based estimate of the utility costs, and (4) lifecycle estimate of the energy use and cost of the building.

1.1. Justification for the study

Global warming and its consequential climate change are threatening the existence of humanity. These changes have been attributed to anthropogenic activities that largely affect a building's energy use, carbon footprint, and indoor climate, as well as lead to sick buildings. An insight into the impacts of climate change on buildings is provided (Sanders and Phillipson, 2003). The researchers identified the following major climate impacts on buildings: (1) flooding, (2) swelling and shrinking of soils that affect foundations, (3) wind actions that cause dynamic structural loading by pressure forces, and (4) driving rain that leads to weathering. Similarly, the following were identified (Camilleri et al., 2001) as significant impacts of climate change on buildings: (5) increased overheating and air-conditioning load, (6) increased greenhouse gas (GHG) emissions, and (7) increased costs due to carbon or GHG charges.

Therefore, different types of consensus have been established among built environment professionals and regulatory bodies on the need to design and construct energy-efficient buildings to reduce the negative effects of the aforementioned factors on buildings. However, the conventional method of building energy analysis provides minimal opportunities to completely evaluate the relative energy performance of alternative designs and opportunities for information sharing, as discussed (Michelle, 2009; Capper et al., 2012). Similarly, Perez-Lombard et al., (2008) believed that the probability of misinterpreting the 2D/3D CAD information is high because an energy analyst