BUILDING INFORMATION MODELING (BIM)-BASED DESIGN OF ENERGY EFFICIENT BUILDINGS

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ABSTRACT: With the increased awareness of energy consumption as well as the environmental impact of building operations, architects, designers and planners are required to place more consideration on sustainability and energy performance of the building. To ensure most of those considerations are reflected in the building performance, critical design decisions should be made by key stakeholders early during the design development stage. The application of BIM during building energy simulations has profoundly improved the energy analysis process and thus this approach has gained momentum. However, despite rapid advances in BIM-based processes, the question still remains how ordinary building stakeholders can perform energy performance analysis, which has previously been conducted predominantly by professionals, to maximize energy efficient building performance. To address this issue, we identified two leading building performance analysis software programs, Energy Plus and IES <Virtual Environment>, and compared their effectiveness and suitability as BIM-based energy simulation tools. To facilitate this study, we examined a case study on Building Performance Model (BPM) of a single story building with one door, multiple windows on each wall, a slab and a roof. We focused particularly on building energy performance by differing building orientation and window sizes and compared how effectively these two software programs analyzed the performance. We also looked at typical decision-making processes implementing building energy simulation program during the early design stages in the U.S. Finally, conclusions were drawn as to how to conduct BIM-based building energy performance evaluations more efficiently. Suggestions for further avenues of research are also made.

***Keywords**: Building Information Modeling, LEED, Energy Efficiency, High Performance Building, Scope Definition, PDRI, Whole Building Design*

1. INTRODUCTION

According to the U.S. Environmental Protection Agency (EPA), buildings account for 39 percent of the energy use and 68 percent of the total electricity use in the United States. Moreover, data from the U.S. Energy Information Administration (EIA) illustrates that buildings are responsible for nearly half of all greenhouse gas emissions annually. Therefore, through adoption of stringent building codes, industry standards, and the green building rating systems such as Leadership in Energy & Environmental Design (LEED) [1], efforts are being made to significantly reduce the use of fossil fuel-based energy over the next two decades, to the point of net zero energy use by 2030 [2]. However, continuing the current practices of designing buildings and systems in which all the segments of the building – architecture, HVAC, and electrical system, etc. – are designed independently from each other, will keep us from achieving our energy saving goal [2]. Current design, construction, and operation practices are typically too fragmented to allow the timely and effective implementation and integration of energy efficiency methods and technologies on construction of new building or renovation projects [3].

Yet, technologies and knowledge exist that could be used to create better, high-performance buildings. In fact, the potential for energy saving is significant if energy efficiency measures, combined with a better systems integration, are incorporated at the design stage,. It is apparent that a facility built through the ongoing collaboration of all stakeholders is more likely to achieve optimal energy efficiency than one based on a succession of hand-offs

2. BARRIERS TO ENERGY EFFIECIENT BUILDINGS

Poor scope definition in building construction is recognized by industry practitioners as one of the leading causes of project failure, adversely affecting projects in the areas of cost, schedule, and operational characteristics [4]. Numerous studies have shown that early planning is poorly performed in the building industry with insufficient or incomplete scope definition, frequently leading to changes that result in significant cost and schedule overruns [5], [6]. Without complete scope definition, decision making in early project phases, when the impact on overall project performance is highest with minimum expenditures, is mostly based on variables that can be quantified relatively easily (such as first cost and aesthetics) [2]. This practice limits consideration and incorporation of broader lifecycle knowledge, such as methods and technologies for energy efficiency into the planning and design process in a consistent and predictable manner [3]. Most importantly, in spite of the recent efforts toward sustainability, lifecycle energy efficiency and the resulting value and corresponding cost savings are not key criteria in the building development process, resulting in lost opportunities to maximize the use of energy efficient building design and technology options [3]. Energy and performance analysis are typically performed after the architectural design and construction documents have been produced, if at all. This lack of integration into the design process leads to an inefficient process of retroactively modifying the design to achieve a set of performance criteria [7]

In addition, traditional CAD-based planning environments do not support the possibility of early planning and decision making process.

3. OVERCOMING THE BARRIERS

Incorporate Practices of Preproject Planning and Building Project Scope Definition

Previous studies have shown that greater preproject planning efforts, encompassing all the tasks between project initiation to detailed design, lead to improved performance in the areas of cost, schedule, and operational characteristics [8], [9]. One of the major subprocesses of the preproject planning process is the development of the project scope definition, the process by which projects are defined and prepared for execution. It is at this crucial stage where risks associated with the project are analyzed and the specific project execution approach is defined [4]. Success during the detailed design, construction, and start-up phases of a project is highly dependent on the level of effort expended during this scope definition phase [8].

This study of preproject planning and critical scope-defining elements resulted in a comprehensive scope development tool called Project Definition Rating Index (PDRI) for buildings [4]. The PDRI for buildings is a weighted checklist of 64 critical scope definition elements presented in a score sheet format that provides simple and easy-to-use tool for measuring the degree of scope definition for completeness. Owners, designers, engineers, and contractors, working together to measure the completeness of project scope development using PDRI, can better achieve business, operational, and project objectives.

The analysis of energy efficiency can be conducted concurrently with measurement of scope development. The analysis of energy efficiency can be incorporated as part of the building/project design parameters analysis concurrent with the constructability analysis.

Apply Whole Building Design Approach

In order to achieve high-performance buildings, Whole Building Design takes an integrated design approach and an integrated team process as two major components [2]. It involves all the stakeholders throughout the building's life cycle, from planning to operations and maintenance of the building. Whole Building Design requires an integrated team process in which the design team and all affected stakeholders work together throughout all project phases and to evaluate the design for cost, future flexibility, efficiency, and overall environmental impact, among other items [2]. The integrated design team identifies the project goals early on while the team evaluates, appropriately applies and coordinates all interrelated, interdependent building systems from the planning and programming phase. Use of a energy modeling, BIM and intensive coordination among the design team members is imperative to achieving the designated energy consumption goal, not just for grass root projects but for energy retrofit of existing buildings as well [2].

Use EPA Energy Design Guidance

The U.S. EPA has provided Energy Design Guidance mainly for designing commercial buildings to achieve ENERGY STAR certification. Specifically, it is a management approach with a set of suggested actions for building owners and design professionals to establish energy efficiency goals and to ensure that energy consumption is addressed at all levels of the projects.

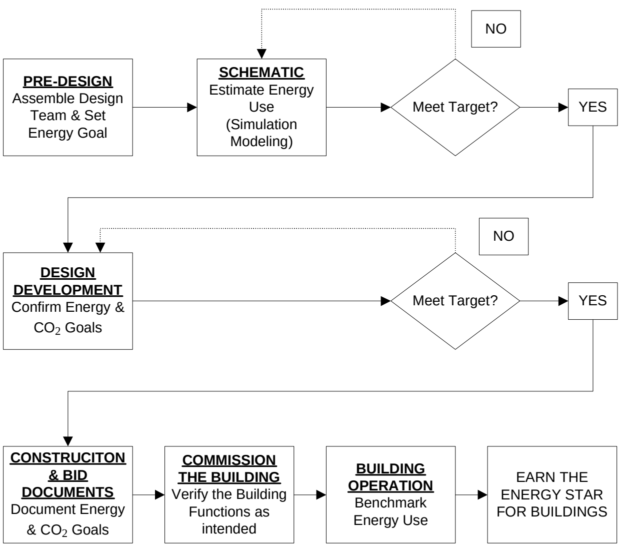

Figure 1: Incorporating energy targets, analysis, and tracking during design and operating phases of the building (modified from the EPA Energy Design Guidance) [10]

According to this guidance, as summarized in Figure 1, EPA encourages following best practices for energy design as part of the overall design, construction, and operation process to translate design intent into buildings that perform and earn the ENERGY STAR certification [10]. Among the processes outlined in Figure 1, it is at the Schematic Design phase, as design concepts take shape, where preliminary calculations and/or simulations to estimate the energy use of various design strategies [10]. Energy analysis of design concepts can take place using appropriate design tools, such as BIM interfaced with various energy simulation models. Design can be constantly improved based on analyses of relative efficiency of energy strategies. Design strategies can be refined during the Design Development phase when achievable energy performance goals – energy use and CO_2 goals – are confirmed and included in specification language.

4. ENERGY SIMULATIONS

As alluded to in the previous section, it is most effective to make decisions related with sustainable design of a building facility in the early design and preconstruction stages. Access to a comprehensive set of knowledge regarding the building's form, materials, context, and technical systems is required in order to realistically assess building performance in the early design and preconstruction phases. Because BIM allows multi-disciplinary information to be superimposed within one model, it creates an opportunity for sustainability measures and performance analysis to be performed throughout the design process [7], [11], [12].

In this study, two of the most commonly used energy simulation software packages, EnergyPlus and IES <VE>, were used to perform energy simulations and to evaluate energy performance of a Building Performance Model (BPM).

Energy Simulation Solutions

EnergyPlus is a whole building simulation program developed by the Department of Energy [13]. It provides an integrated (loads and systems) simulation for temperature and comfort prediction at a user-specified time step. It is also capable of evaluating realistic system controls, moisture adsorption and desorption in building elements, radiant heating and cooling systems, and interzone air flow.

IES<VE> was developed by Integrated Environmental Solution [14]. It evaluates thermal insulation (type and placement), building dynamics and thermal mass, building configuration and orientation, climate response, glazing, shading, solar gain, solar penetration, casual gains, air-tightness, natural ventilation, mechanical ventilation, mixed-mode systems, and HVAC systems.

The Building Performance Model (BPM)

The BPM evaluated is a single story building with one door, multiple windows on each wall, a slab foundation and a roof (Figure 2).

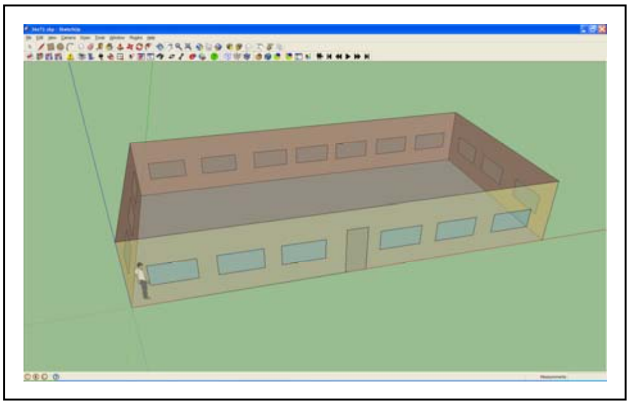

Figure 2: Building Performance Model (BPM)

Building Energy Simulation Processes

The first step was to use EnergyPlus to conduct energy simulations. The BPM was created using Google SketchUp, then its energy performance was simulated using OpenStudio, an EnergyPlus Plug-in for SketchUp. The simulation results are shown in Table 1.

IES <VE> was then used to evaluate the energy performance of the BPM. Revit Architecture was used to create the BPM, then the IES <VE> plug-in for Revit was used to conduct the energy simulation. Table 2 summarizes the simulation results.

Many design parameters have the potential to affect building energy performance. Since the goal of this study was to explore the ways energy efficiency affects the building design decision-making process, thorough research of all the design parameters was not necessary. Two design parameters were considered in the energy simulations, the orientation and window sizes.

VAV Single Duct system was chosen as the default HVAC system for energy simulations.

Energy Simulation Results and Discussions

The simulations results are shown in the tables below.

Table 1: Energy Simulation Results Using EnergyPlus

Energy Plus _ Simulation Results (VAV Single Duct System)			
Parameters		Heating (GJ)	Cooling (GJ)
Orientation (window size 48"x36")	0°	417,764.1	275,803.1
	45°	417,765.1	275,805.2
	90°	417,765.8	275,805.2
	135°	417,766.1	275,804.6
	180°	417,765.2	275,802.3
Window (Building orientation 0°)	24x36	417,755.5	275,803.1
	48x36	417,764.1	275,803.1
	72x36	417,772.9	275,803.1

As shown in Tables 1 and 2, when the BPM was at 0° and 180° orientation, the total energy consumption, including cooling and heating, was lowest. Therefore, the recommended orientation is either north or south. It was also noticed that larger windows increased the total energy consumption.

Even though the lighting conditions can be significantly improved by adding larger windows, the HVAC system will use more heating energy to heat the building, and will use more cooling energy to cool the building. Thus, larger windows will not necessary ensure a better design.

Table 2: Energy Simulation Results Using IES <VE>

IES VE _ Simulation Results (VAV Single Duct System)			
Parameters		Heating (Mbtu)	Cooling (Mbtu)
Orientation (window size 48"x36")	0°	77.8	6.4
	45°	78.0	6.5
	90°	78.3	6.5
	135°	78.3	6.5
	180°	77.9	6.3
Window (Building orientation 0°)	24"x36"	77.8	5.9
	48"x36"	77.8	6.4
	72"x36"	77.9	6.9

The HVAC system in a building accounts for the majority of heating and cooling energy consumption. During the energy simulations in this study, the default HVAC system of VAV Single Duct System was selected and no other HVAC systems were considered for altering design parameters. This explains the fact that there were no significant differences in energy consumption between the two simulation models as shown in Tables 1 and 2.

5. CONCLUSIONS

Although recent statistics show steady increases in energy and electricity consumption in the U.S. building sector, technologies and knowledge exist that could be used to create better, high-performance buildings. The potential for energy saving is significant if:

- energy efficiency measures, combined with better systems integration, are incorporated at the design stage, combined with better systems integration.
- the facilities are built through ongoing collaboration of all stakeholders rather than one based on a succession of hand-offs.
- the most effective decisions regarding energy efficiency in a building are made early in the design and preconstruction stages.
- the analysis of energy efficiency is conducted concurrently with measurement of scope development. The analysis of energy efficiency can be incorporated as part of the building/project design parameters analysis concurrent with the constructability analysis.
- an energy modeling, BIM and intensive coordination among the design team members are in place.

Designing energy efficient buildings entails comprehending results from energy simulations. There are a number of energy analysis solutions available to fulfill this need. By focusing on differing aspects of energy performance analysis, each software solution simulates energy consumptions based on various design parameters to assists stakeholders in finalizing the design.

IES <VE> and EnergyPlus are the most commonly used energy simulation solutions worldwide. IES <VE> is more user friendly in terms of its user interface and reports. It is easier to define design parameters in IES<VE>. It can also perform Computational Fluid Dynamics (CFD) analysis and Life-Cycle Cost Analysis (LCA). EnergyPlus is a powerful energy simulation tool that offers users great flexibility in defining HVAC systems and allows simulation of multiple HVAC systems for a single zone. However, extensive knowledge of HVAC systems is required to obtain accurate simulation results.

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