OPTIMIZING ENERGY EFFICIENCY IN GREEN BUILDINGS USING BIM-INTEGRATED ENERGY ANALYSIS TOOLS

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Abstract- The construction industry is one of the major contributors of GHG (Greenhouse Gas) Emissions, in which commercial and residential buildings play a major role. Most of these emissions are attributed to lack of energy conservation measures, outdated methods of design and construction. In this project, an analysis is made based on the comparison of energy consumption of a building constructed from conventional materials, having no sustainable design strategies. And another building that is designed with consideration to sustainable techniques such as energy efficient materials that have low thermal conductivity, lower U-value (thermal transmittance) glazing, and oriented at different angles to suit the best conditions of sun path for optimum heat transfer. A BIM-based approach is adopted. Both the models are designed in Autodesk Revit and then analyzed through the built-in Revit plug in: Autodesk Insight, which performs iterative energy analysis on cloud. The results for both the buildings are compared and conclusions are drawn based on energy and cost savings in the long run. The study concludes with the design and energy audit of a commercial plaza building, revealing the large energy and cost savings available via intelligent design decisions.

Keywords- Green Buildings, Energy Simulation, BIM, Sustainable Buildings, Energy Efficiency.

1 Introduction

Global warming is a major global issue rising rapidly and causing numerous problems for all species on Earth. One of its major contributors is Green House Gass emissions from combustion of fossil fuels for meeting energy demands. A large amount of this demand comes from operating residential and commercial buildings. Due to the rising population and intense urbanization, we have an all-time growing demand for energy. Our cities generate roughly 60% greenhouse gas emissions and account for 78% of the total energy consumption [1], where commercial buildings consume more energy than residential buildings [4]. Most of the buildings we have been constructing till recent years—especially in developing countries—did not include energy conservation strategies in their design and were unable to make energy savings. A huge amount of energy and money is wasted annually due to poor designs, inefficient materials, lack of knowledge and technical skills, and many other factors in the whole construction industry and in commercial buildings in particular.

The energy efficiency of buildings is paramount in reducing heating and cooling energy demands, with the building envelope playing a critical role by keeping the indoor temperatures at optimum[1]. Enhanced thermal resistance through improved insulation, strategic orientation, and design can significantly lower HVAC (Heating, Ventilation and Air-Conditioning) loads and overall energy consumption[2]. Extensive research has proved that green buildings outperform conventional buildings in terms of energy savings (up to 25%) and carbon emission reduction (up to 46.8%)[3]. Green buildings are more habitable and healthy for their residents[4]. Early integration of energy-saving strategies, such as passive design[5], optimal orientation, daylighting, using sustainable building materials[6] and efficient appliances, implementing BIM, can lead to substantial cost savings over time. Innovations like electrochromic windows offer increased window-to-wall ratios without sacrificing energy performance, aligning with the Net Zero Energy Building (NZEB) goal[7]. Furthermore, Computer modeling (e.g. 6D BIM), BIM tools like Revit, and whole-building design, allow us to estimate and minimize consumption in early design stages[8]. The effectiveness of these strategies is evidenced by LEED-certified buildings in North America, which report 25-30% energy savings compared to national averages[9]. There are many green building certifications worldwide such as BREEAM, LEED, HQE, NABERS, CASBEE, Green globe etc.[10]. Thanks to initiatives like "Horizon 2020", nearly €80 billion in funding is available to NZEB (Net-Zero Energy Building) cause in addition to private investments[11].

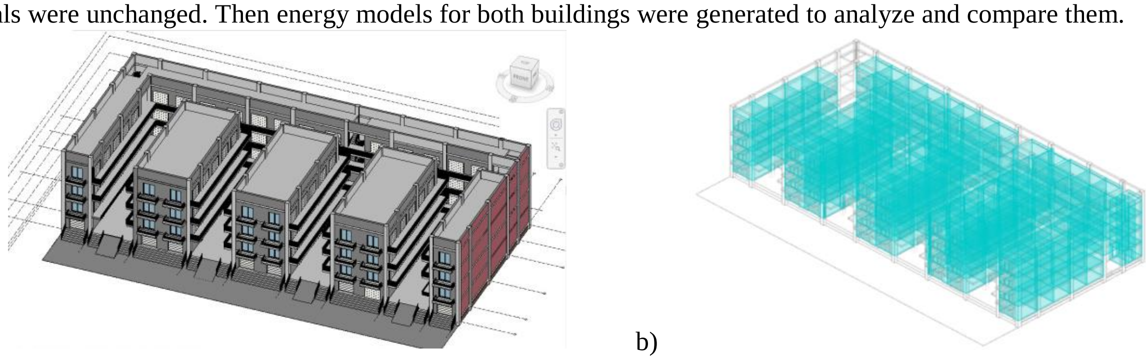
In this work, a deeper dive has been taken to address this issue and examine numerous aspects such as using sustainable materials, improving building orientation, glazing, and sun-shading to minimize energy demand of buildings while also trying to quantify the effects of various parameters on energy efficiency of buildings using BIM based approach.

2 Research Methodology

A conventional commercial plaza building was designed in Autodesk Revit using architectural drawings, then necessary energy settings were applied to perform its energy analysis in Autodesk Insight, then its energy model was generated in Revit and analysed in Insight. After that, the same process was repeated for another model of the same size, shape and form, and other structural and architectural features but with a more energy efficient wall material CLC (Cellular Lightweight Concrete) with Fiberglass insulation and double-glazed windows. Then the model was analysed with different iterations to come up with the most efficient scenario.

2.1 Model

A 3D Revit model of a Commercial Plaza (Fig. 1, a) assumingly located in Lahore using real architectural drawings was developed, which is 4 storeys high with 212 shops and having approximately 208x90 (ft^2) covered area. 12" First Class Brick Masonry wall with 20mm Cement Sand plaster (U=1.736 W/m^2K) with no insulation material. Single-pane, glass windows with wooden frames were installed as glazing material (U=3.688 W/m^2K). The floor and roof are made of 12", cast-in-place concrete (U=3.4318 W/m^2K). Then a replica of that model was created but with a sustainable approach. For walls, 12" Cellular lightweight Concrete with 20mm cement sand plaster (U=1.0716 W/m^2K) was used and Fiberglass was used as insulation material (U=0.187 W/m^2K). Double-glazed windows were installed (U=1.2 W/m^2K). Floor and roof materials were unchanged. Then energy models for both buildings were generated to analyze and compare them.



a) b)

Figure 1: a. Revit Building Model, b. Revit-Generated Energy Model

2.2 Analysis

First, energy settings such as thermal properties of all material components of the model and weather data were configured, then both the energy models were analyzed using Autodesk Insight. With the energy analysis model (Fig. 1, b) in place, energy consumption and performance simulations were conducted. Using the specified occupancy schedules, lighting fixtures, HVAC systems, and other energy-related parameters, the building's energy usage and performance was simulated over time. After the energy simulations were completed, the results provided by Autodesk Revit were reviewed and analyzed. Energy consumption data, including energy use intensity (EUI), heating and cooling loads, and energy cost estimates were examined. The performance of different design options, such as varying building orientation, wall-to-window ratios, and glazing types, was compared to identify energy-saving opportunities.

3 Results

3.1 Initial Cost Comparison of Conventional and Green Building

The capital cost for both models was calculated in Revit Schedule of Rates, and rates were taken from MRS-2022 (Market Rate System). The cost comparison is enlisted below. It can be seen in Table 1 that the initial cost of Green building is $125,221 higher than that of conventional building. Which is equivalent to 45.7% increase in initial cost.

Table 1: Initial Cost Comparison of Conventional and Green Building

Building Type	**Walls Cost (USD)**	**Roof & Floor Cost (USD)**	**Doors Cost (USD)**	**Windows Cost (USD)**	**Total Cost (USD)**
Conventional	100,009	169,097	3,907	1,067	274,080
Green	224,616	169,097	3,907	1,680	399,301

3.2 Energy Consumption and Performance Simulation

Using specified occupancy schedules, lighting fixtures, HVAC systems, building orientation, window-to-wall ratios etc., annual energy consumption cost per square feet of the energy model was calculated in Autodesk Insight. The energy consumption cost of the Conventional model was calculated to be 2.76 USD/ft^2/yr. (Fig. 2, a). Multiplying this with the floor area of the building, which is 30316 ft^2, the annual consumption cost was found to be 83,672 USD/yr.

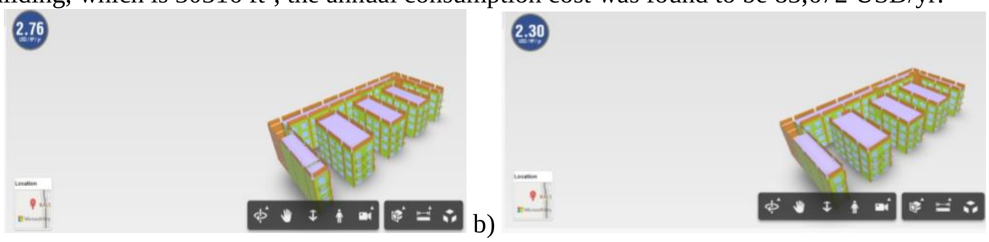
a)  b)

Figure 2: Annual Energy Consumption Cost per sq. ft., a. Conventional Building, and b. Green Building

The energy consumption cost of the Green model was calculated to be 2.30 USD/ft^2/yr. (Fig. 2, b) with only changing wall material, insulation and glazing. Hence, the annual consumption cost of this model was reduced to 69,727 USD/yr. observing a decrease of 16.7%.

3.3 Annual Consumption Cost Variation

The above model was selected as a base model and factors affecting energy consumption such as building orientation, WWR, light and plug load efficiency, and HVAC etc. were varied in multiple iterations to look for the best-case scenarios that will result in minimum energy consumption (Fig. 3). After applying all the optimum parameters, the annual energy cost was reduced to just 0.89 USD/ft^2/yr. Which totals about $27,000 per year. Hence the total annual energy consumption cost was reduced from $83,672 to $27,000; a 67.7% decrease, leading to savings of $56,672 per annum.

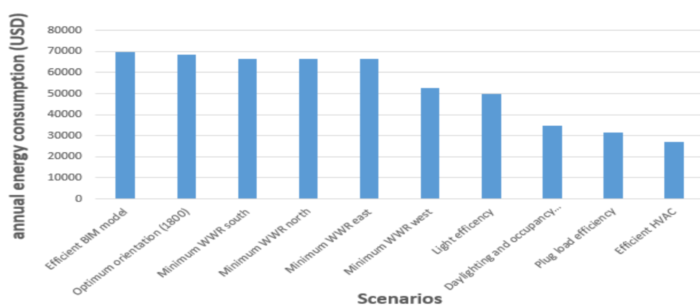


Figure 3: Annual Consumption Cost Variation with Various Factors

4 Practical Implementation

From this experiment, it is evident that there is a formidable margin for energy and consumption cost savings by applying Green building design strategies in early design stages of the project.

5 Conclusion

The following conclusions can be drawn from this work:

1 By implementing sustainable design strategies, the carbon footprint and overall lifecycle cost of buildings can be minimized which will reimburse the initial high cost through savings.

2 Using CLC (Cellular Lightweight Concrete) as wall material increases thermal resistance and minimizes heat loss, which in turn leads to reduced energy consumption required to heat or cool the building.

3 The double-glazed windows have higher initial cost but pay back their initial investment through energy savings because they have lower U-value (thermal transmittance) compared to single-glazed windows, which minimize heat loss and thermal bridging that normally lead to excessive energy consumption.

4 Building orientation also affects energy consumption based on path followed by the sun throughout the year and the heat gain that takes place when sunlight enters the interior spaces of the building.

The above results indicate further opportunities for energy efficiency and reducing carbon footprint of buildings. Next approach should be analyzing the impact of solar photovoltaics on annual energy consumption cost.

Acknowledgment

First and foremost, we want to express our gratitude to Almighty Allah for giving us the ability to finish our research, then to Dr. Qazi Samiullah, our supervisor, for his advice and thorough feedback. We would also like to acknowledge our department and the teachers who taught us well and our parents whose prayers helped us through our journey.

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