

OPTIMIZING BUILDING ENERGY AND CARBON PERFORMANCE USING BIM: A MATERIAL-BASED THERMAL LOAD ASSESSMENT

**Mahfuzur Rahman^{*1}, Sakina Akbar Naima², Shariful Haque Sammo³, Abdey Mohimin⁴, Nadim Ahmed⁵,
Nasim Mia⁶, and Yasin Edmam Iman⁷**

¹*Mymensingh Engineering College, University of Dhaka, Bangladesh, e-mail: rmahfuzur470@gmail.com*

²*Mymensingh Engineering College, University of Dhaka, Bangladesh, e-mail: s.akbarnaima@gmail.com*

³*Mymensingh Engineering College, University of Dhaka, Bangladesh, e-mail: sammohaque@gmail.com*

⁴*Mymensingh Engineering College, University of Dhaka, Bangladesh, e-mail: raabitkhan123@gmail.com*

⁵*University of the Basque Country, Spain e-mail: nahmed002@ikasle.ehu.eus*

⁶*University of Prince Edward Island, Canada e-mail: nmia@upe.ca*

⁷*University of Dhaka, Bangladesh e-mail: edmam.ce@gmail.com*

***Corresponding Author**

ABSTRACT

The amount of energy used and carbon emitted by buildings constitutes a large percentage of the world's energy usage and carbon emissions, and hence, building sustainable design forms an important solution to combating climate change. This study evaluates the carbon footprint and energy performance of a three-story, single-family residential building in Dhaka, Bangladesh, utilizing Building Information Modeling (BIM) and Autodesk Revit's Carbon Insight tool. Two design alternatives were developed: one using standard building processes and materials, and the other utilizing sustainable resources. All building components were assigned precise thermal and mechanical values in Revit. Energy models were created and tested to determine Embodied Carbon (EC), Energy Use Intensity (EUI), Total carbon, and thermal loads for both scenarios within one year. The sustainable construction lowered embodied carbon by 45.56 percent and total carbon emissions by 34.79%. The EUI declined by 10.85%. Thermal performance improved significantly in the sustainable model. Peak Cooling Load decreased by 42.2%, while Peak Heating Load decreased from 1.59kW to 0.886 kW due to sustainable materials. Reductions achieved in component-specific EC intensity were also significant, 33% in the roof, 47% in the exterior walls, and 7% in the floor. Performance gains are consistent with those of LEED v4, giving the sustainable model a potential 3 to 4 points under MRC1 (Life-Cycle Impact Reduction) and 1 to 2 points under EA (Energy Performance Optimization). This study shows how combining BIM with carbon analytic methodologies can minimize emissions and energy consumption through material selection, contributing to climate-resistant architecture. Sustainable buildings increase energy efficiency, making them more environmentally friendly than traditional construction.

Keywords: *BIM, Revit Carbon Insight, Energy Use Intensity, Embodied Carbon, Sustainable Materials*

1. INTRODUCTION

The building construction industry represents one of the major contributors to global energy consumption and CO₂ emissions. With economic growth and increasing urbanization, the number of residential buildings continues to rise, significantly impacting carbon emissions. Understanding the entire building lifecycle—including material extraction, manufacturing, transportation, construction, maintenance, and disposal—is essential for reducing CO₂ emissions. The energy consumed and carbon emitted by building materials throughout this lifecycle are referred to as embodied energy and embodied carbon. (Ahmed Ali & Ahmad, 2020) According to the 2021 Global Status Report for Buildings and Construction by the United Nations Environment Program, the construction industry is responsible for roughly 39% of global carbon emissions. Rapid urbanization and population growth are expected to nearly double the demand for building floor space by 2050, which will increase the environmental impact of construction and require innovative approaches to ensure sustainability. (UNEP). Assessing the embodied carbon of building materials is a key mitigation strategy with significant potential to lower the overall carbon footprint. Choosing sustainable materials can reduce a building's embodied CO₂ emissions by around 30% over its lifetime. (González & García Navarro, 2006). Various tools and approaches have been developed to reduce building-related emissions. Among them, Building Information Modelling (BIM) is a powerful tool that supports sustainable and environmentally friendly practices throughout the planning and construction of eco-friendly structures. BIM provides multiple benefits, such as sharing sustainability knowledge with stakeholders, policymakers, and project managers, and promoting the creation of high-quality, successful green buildings (Fonseca Arenas & Shafique, 2023). Additionally, Leadership in Energy and Environmental Design (LEED), which certifies sustainable green buildings, provides several recommendations for eco-friendly construction. These include optimizing building mass, incorporating green facades and vegetated roofs that reuse greywater and regulate temperatures, and installing lighting sensors to reduce energy consumption. (Keeler & Vaidya, 2016). Several recent studies have investigated strategies to improve energy efficiency and reduce carbon emissions in the building sector. (Khahro et al., 2021) highlighted the environmental impact of the construction industry, a major contributor to greenhouse gas emissions and global energy use. Using a hospital case study in Green Building Studio (GBS), the study applied BIM to improve energy efficiency through changes in orientation, materials, glazing, and HVAC systems. Expert opinions and 3D energy analysis validated the benefits of BIM, showing reductions in energy costs, CO₂ emissions, and electricity use, with a Cronbach's alpha of 0.822. (Rodrigues et al., 2018) examined the effect of lowering building envelope U-values on energy performance across eight European climates using 96,000 simulated residential buildings. Lower U-values generally reduced performance variation, but in warm/moderate climates, very low U-values increased energy consumption. The study concluded that each climate has an optimal U-value range, minimizing energy demand and allowing design flexibility. (Chen & Li, 2014) focused on Taiwan's construction industry, responsible for 27.22% of national CO₂ emissions. Using BIM, energy simulation, and Excel, they evaluated low-carbon materials based on lifecycle costs and emissions. NPV and compromise decision methods identified materials that balanced cost and carbon reduction, with results within a 5% margin of error. (Khan et al., n.d.) assessed the 60-year life cycle energy use and carbon emissions of an educational building in Peshawar, Pakistan. Changes in façade materials—including wall types, plaster, insulation, and glazing—led to significant reductions in peak cooling loads and a 63.89% decrease in embodied carbon, emphasizing the importance of material selection.

This study examines a single-family, three-story residential building situated in Dhaka, Bangladesh. The building, with a total area of 554.83 m², was modeled in Autodesk Revit 2026. To ensure an accurate comparison, both the traditional and energy-efficient versions of the model shared the same geometry, design, and functional layout. The only variation between the two was the choice of materials. The main aim of this case study is to analyze how different building materials affect energy performance and carbon efficiency. In the future, similar studies could explore a wider variety of sustainable materials, incorporate renewable energy systems, and extend the analysis to different building types and climates to provide more comprehensive guidelines for energy-efficient construction.

2. METHODOLOGY

2.1 Building Description

The case study involved a Single-family, three-story building in Figure -1, located in Dhaka, Bangladesh. The building was modelled in Autodesk Revit 2026, with an overall area of 554.83 m². The architects and engineers ensured that the geometric shapes, designs, and functional divisions of both the traditional and the energy-efficient models were identical, allowing the two to be compared equally.



Figure 1: Three-Dimensional View of Reference Building

The primary distinction of the two models was the materials. As illustrated in Table 1, the classical one employed conventional building materials such as fired clay brick, regular glass, and metal doors. The energy-efficient one was made using environmentally friendly materials such as fly ash brick, lightweight concrete, and Low-E (low-emissivity) glass with low thermal transmittance (U-values). This edifice was made to suit the climate of Dhaka, which is extremely hot and humid in summer and mild during winter. Summer also had dry and wet-bulb temperatures set at 94°F and 80°F, respectively. In case of winter, it was set at 53°F dry-bulb. It was calculated in the simulation program that the thermal comfort settings must be a cooling setpoint of 74°F and a heating setpoint of 70°F, at approximately 44% relative humidity. It was a Variable Air Volume (VAV)-Single Duct air distribution system. This has been done to ensure that the mechanical ventilation environment in both design options is made more realistic. This configuration enabled a consistent thermal and energy performance assessment of the two material systems, distinguishing the impacts of material replacement on total energy efficiency and carbon footprint.

Table 1: Building Energy Settings

Parameter	Value
Building Type	Single Family
Area (SF)	1,660
Volume (CF)	16,601.13
Summer Dry Bulb	94 °F

Summer Wet Bulb	80 °F
Winter Dry Bulb	53 °F
Cooling Setpoint	74 °F
Heating Setpoint	70 °F
Air Volume Calculation Type	VAV - Single Duct
Relative Humidity	44.00%
HVAC System	12 SEER/0.9 AFUE Split/Packaged Gas, 5-11 Ton

2.2 Material Data Input

In order to compare the energy and carbon performance of both types of constructions, all the material properties were carefully outlined in Autodesk Revit 2026 by adopting the Carbon Insight analytical database. Traditional and sustainable building models were the same in geometry and systems, with the only difference being the material datasets assigned. All the elements (ceiling, exterior wall, interior wall, floor, roof, door, windows, and curtain wall) had their respective thermal transmittance (U-value), specific heat, and density. With the traditional building, there were materials that represented the common construction techniques within Bangladesh, i.e., the wall using fired clay bricks, metal doors, and single-glazed steel windows, which by nature have a higher U-value and contain carbon. On the other hand, the energy-saving structure incorporates fly ash brick masonry, lightweight concrete, and Low-E Glass soda lime that offer better insulation and reduce embodied carbon. This replacement was to ensure that the building had similar mechanical strength and a more thermal performance and sustainability profile.

The material configuration for each model is summarized in Tables 2 and 3.

Table 2: Material Settings & Thermal Values of Energy Efficient Building

Materials	Description	Thermal Performance (U: W/(m ² ·K))	Specific Heat(J/(kg·°C))	Density(lb/ft ³)
Ceiling	Acoustic Ceiling tile	U: 3.59	1,340	18.10
Ex Wall	Fly Ash Brick	U: 0.88;	840	75
Interior Wall	Fly Ash Brick	U: 0.88	840	75
Floor	Concrete - Lightweight	U: 1.45	657	59.31
Roof	Concrete - Lightweight	U: 1.64	1500	10
Door	Wood Door	U: 3.128	1,260	31.84
Windows	Low-E Glass soda lime glass	U: 3.68	100	160
Curtain wall	Low-E Glass soda lime glass	U: 3.68	100	160

Table 3: Material Settings & Thermal Values of Traditional Building

Materials	Description	Thermal Performance (U: W/(m ² ·K))	Specific Heat(J/(kg·°C))	Density(lb/ft ³)
Ceiling	False Ceiling	U: 0.72	920	103.01

Ex Wall	Fired Clay Brick	U: 4.255	732	123.61
Interior Wall	Fired Clay Brick	U: 4.255	732	123.61
Floor	Concrete	U: 2.5	657	150.28
Roof	Normal Weight filled concrete unit	U: 2.5	657	150.28
Door	Metal Doors and Frames	U: 3.1286	480.	490.06
Windows	Steel frame with single glazing	U: 3.6886	840	143.58
Curtain wall	Hollow glass block	U: 3.6886	840	58.37

The greatest losses were registered in the exterior walls and roof since they involved combining fly ash brick and lightweight concrete, which have less cement and lighter density, respectively. Such material replacements had the added benefit of causing a decrease in heat transfer (lower U-values) as well as increasing the overall energy efficiency of the building envelope, which contributed to further decreases in operational carbon and the Energy Use Intensity (EUI) later observed by the simulation.

2.3 Energy Modeling and Simulation Setup

This energy model (Shown in Fig. 2) was done in Autodesk Revit with the Carbon Insight extension being used to analyze the operational and the embodied carbon emissions of the two building configurations. The analysis process was systematic, with the first stage of work, which was to define the geographical and climatic background of the project, then establish the building envelope, HVAC system, and occupancy conditions of the building, and then carry out the simulation in a one-year operational cycle.

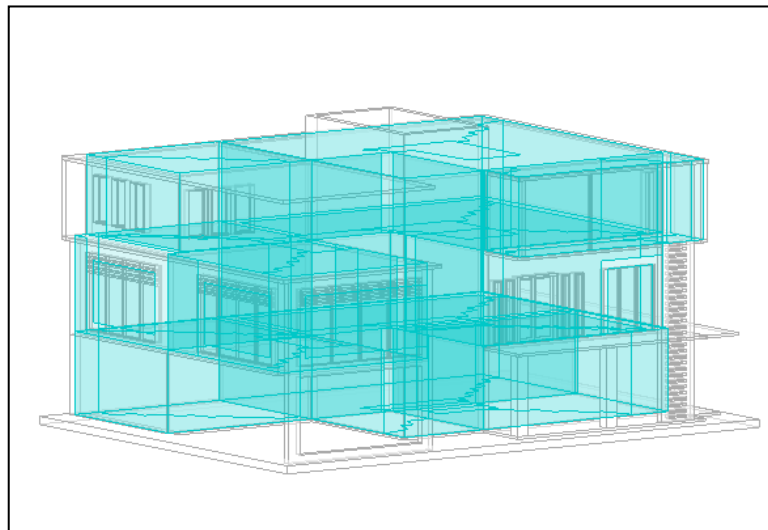


Figure 2: Energy Model

In each model, HVAC was a Variable Air Volume (VAV) - Single Duct system that constantly adjusted airflow to maintain thermal comfort using minimal power. The amount of air volume, thermal zones, and load parameters was generated automatically based on the Revit model geometry to make sure that the simulation reflected actual performance in operation. In Carbon Insight, the building envelope parameters were associated with the material parameters that would be used, which enabled the tool to approximate the Energy Use Intensity (EUI), Embodied Carbon (EC), Operational Carbon (OC), and

Total Carbon Emissions. Both models were run at the same occupancy, use schedules, and system efficiencies, therefore isolating the effects of material substitutions.

After the simulation, the quantitative results offered by Carbon Insight were annual EUI (kWh/m²*yr) and total embodied carbon (kg CO₂e). These measures were compared to identify the difference in performance of the traditional and sustainable application of materials. The resulting dataset provided an overall basis for the assessment of the environmental and energy impact of the material optimization using BIM-based simulation.

2.4 Evaluation Metrics

To analyze and evaluate the performance of the two building configurations, four main indicators were used: Embodied Carbon (EC), Operational Carbon (OC), Total Carbon Emissions (TC), and Energy Use Intensity (EUI). The indicators were obtained straight from Autodesk Revit's Carbon Insight module, which combines life cycle assessment (LCA) with energy simulation data to measure the environmental impacts of both materials and operations.

1. Embodied Carbon (EC):

Embodied Carbon represents the total carbon dioxide equivalent (CO₂e) emissions generated throughout the extraction, processing, manufacturing, and transportation of construction materials. It was computed automatically from the Revit material database and expressed in kilograms of CO₂ equivalent (kg CO₂e). The calculation follows:

$$EC = \sum_{i=1}^n (Q_i \times EF_i) \quad (1)$$

where Q_i is the quantity of material i , and EF_i is the corresponding emission factor obtained from the Carbon Insight database.

2. Operational Carbon (OC):

Operational Carbon accounts for emissions associated with the building's energy use during its functional life. Carbon Insight estimates OC based on the predicted annual energy consumption and the local carbon intensity of energy generation, using:

$$OC = E_{annual} \times CF \quad (2)$$

Where E_{annual} is the annual energy demand (kWh), and CFCFCF is the carbon factor of the regional grid (kg CO₂e/kWh).

3. Total Carbon Emissions (TC):

Total Carbon represents the sum of both embodied and operational components over the analysis period:

$$TC = EC + OC \quad (3)$$

This metric provides a holistic indicator of the building's full environmental impact, reflecting both material selection and operational performance.

4. Energy Use Intensity (EUI):

EUI measures the total energy consumed per unit floor area over one year, expressed in kWh/m²*yr. It provides an energy efficiency benchmark independent of building size and is calculated as:

$$EUI = \frac{E_{annual}}{A_{floor}} \quad (4)$$

where A_{floor} is the gross floor area of the building. Lower EUI values indicate more energy-efficient designs.

In this study, these metrics were used to establish a comprehensive comparison between the traditional and sustainable building models.

2.5 Comparative Assessment

The comparative evaluation between the traditional and sustainable building models was carried out to determine the influence of material optimization on energy efficiency and carbon performance. Both models were developed in Autodesk Revit 2026 under identical geometric, operational, and climatic conditions to ensure that variations in results were solely attributable to differences in material thermal and environmental properties.

The process of comparison was divided into three steps:

***Data Extraction and Normalization:**

The outputs of Carbon Insight were exported and scaled by the total floor area (m^2) to allow a reasonable performance comparison between the two design options. This standardization resulted in uniformity in measuring the energy use and carbon footprint indicators.

***Component-Level Analysis:**

All the elements of the building were considered separately, including roof, walls, floor, ceiling, doors, and windows, to determine the contribution of each of the elements to the total embodied carbon. This has enabled the high-impact areas where the material substitutes gave maximum reductions, especially in the exterior walls and roof assemblies.

***Compared to others, the organization performs poorly regarding:**

The last phase was the comparative visualization of the results by the use of graphs and tabular summaries. The parameters, including EUI (kWh/m^2*yr), total carbon ($kg CO_2e$), and peak thermal loads (kW), were plotted in order to make a clear picture of the difference in energy and emissions in each case. The findings proved that the sustainable model had a consistently better performance than the traditional configuration by showing lower embodied and operational carbon and increased thermal efficiency.

3. RESULTS AND DISCUSSION

The simulation results derived from Autodesk Revit Carbon Insight provided a comprehensive overview of the energy, carbon, and thermal performance of both the traditional and sustainable building models. The findings clearly demonstrate the substantial advantages of adopting sustainable materials within a BIM-based design workflow.

3.1 Embodied Carbon Analysis

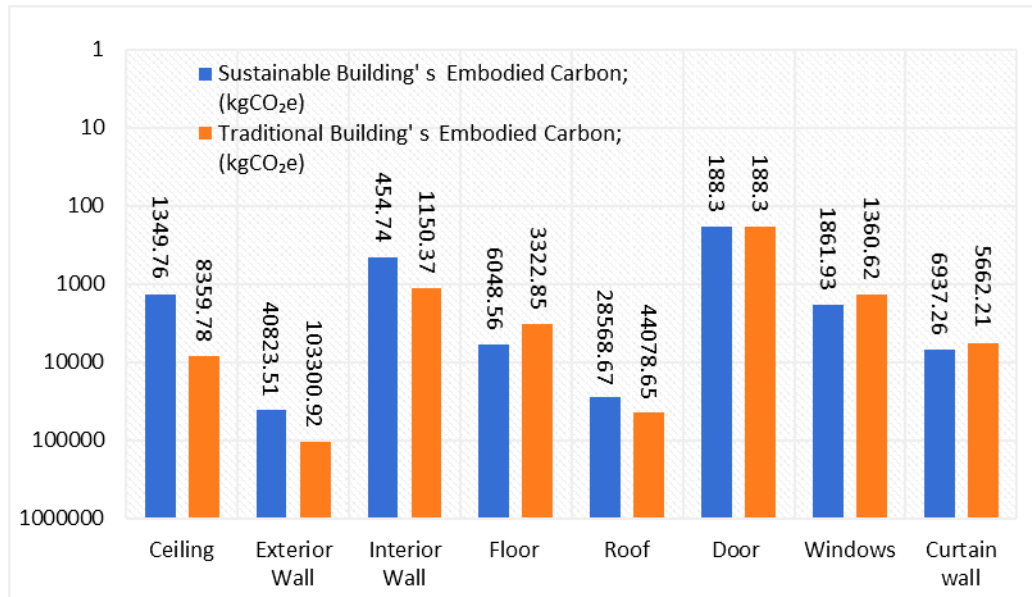


Figure 3: Embodied Carbon of Materials (kgCO₂e)

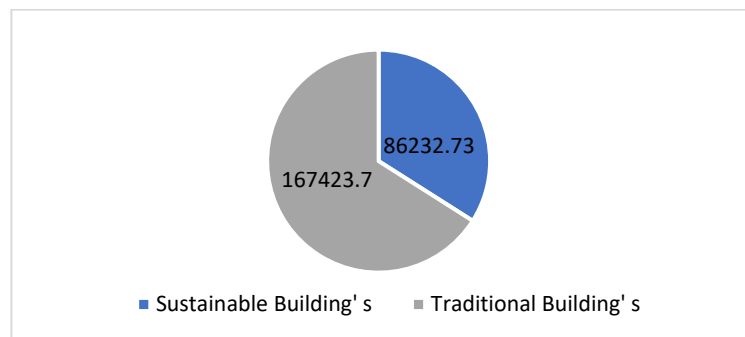


Figure 4: Total Embodied Carbon (kgCO₂e)

From figures 3 and 4 embodied carbon (EC) of the traditional building was 167,423.70 kg CO₂e compared to 86,232.73 kg CO₂e in the sustainable model, which is a 48.5% decrease. This was mainly because of the replacement of fired clay brick with fly ash brick, and lightweight concrete was to be used in the floor and roof slabs. These materials have a lower emission factor since they have less cement and also less firing energy requirements.

The roof and exterior walls had the greatest impact component-wise, with an EC reduction of about 33% and 47%, respectively. The transition to materials with negative embodied emissions reduced not only the embodied emissions but also increased the thermal resistance of the building envelope, with operational impacts affecting the energy performance.

3.2 Operational and Total Carbon Emissions

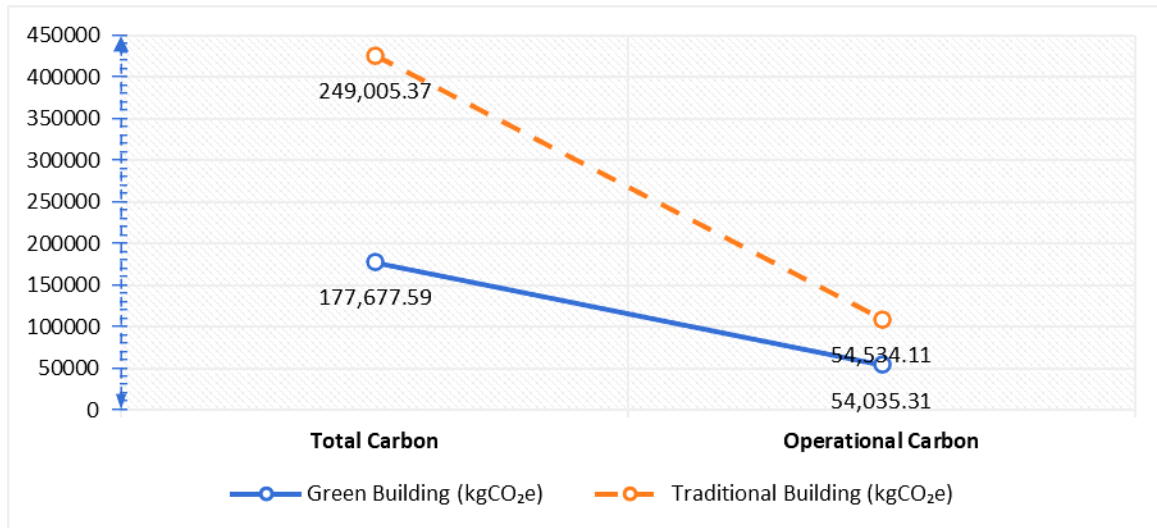


Figure 5: Emission and Operational Carbon

In Figure 5, the Operational carbon (OC) is the emission that is associated with energy consumption in the construction of buildings. The result revealed that the total carbon emissions of the sustainable model and those of the traditional model have decreased by 28.64%. This is a double effect of the better insulation and lesser heating and cooling requirements because of the lower U-values in the envelope elements. Using material-level performance and operational simulation, Carbon Insight was able to quantify combined lifecycle impacts, showing how material optimization can help to reduce the carbon footprint embodied and operational in the same BIM.

3.3 Energy Use Intensity (EUI)

The Energy Use Intensity (EUI), described in the following figure 6, which is the main indicator of energy consumption in a building, showed a reduction of 10.85% for the sustainable model compared to the traditional one. Although interior lighting and equipment loads remained identical for both models—reflecting equal usage schedules and fixture efficiencies—the envelope-driven savings in cooling and heating demonstrate the significant impact of material optimization on operational performance.

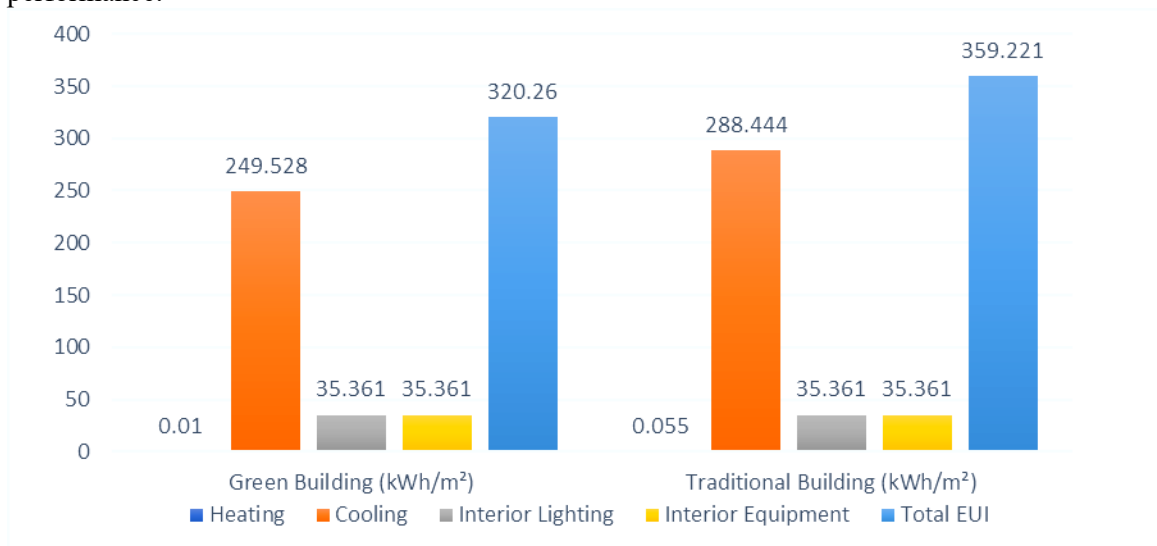


Figure 6: Annual Energy Use Intensity (kWh/m²)

Overall, the sustainable building's lower EUI confirms that thermal envelope enhancement is a critical factor in improving building energy efficiency in warm-humid climates like Dhaka.

3.4 Environmental Performance and LEED Correlation

To assess the sustainability performance of proposed building models, a correlation was made with the LEED v4.1 BD+C framework established by the U.S. Green Building Council. Two key credit categories were analyzed: MRc1 – Building Life-Cycle Impact Reduction and EA – Optimize Energy Performance. The sustainable model demonstrated a 48.5% reduction in carbon intensity compared to traditional buildings, potentially qualifying for the maximum 4 points under MRc1.(USGBC, n.d.-a) This reduction was primarily due to the use of fly ash brick masonry and lightweight concrete. Additionally, the model achieved a 10.85% reduction in Energy Use Intensity (EUI), indicating eligibility for 1–2 points under the EA category.(USGBC, n.d.-b) facilitated by improved thermal insulation and lower cooling demand.

The study demonstrates that material-level decisions significantly impact a building's environmental footprint when combined with BIM-integrated analytics. It reveals that using environmentally responsible materials can lead to notable carbon and energy savings without changing geometry or HVAC systems. The BIM–Carbon Insight framework facilitates efficient lifecycle assessment and carbon quantification in the design process, thereby enhancing decision-making. Ultimately, the results showcase a sustainable building model's environmental benefit, emphasizing the BIM-based carbon assessment's role in promoting climate-resilient architectural design in tropical regions like Bangladesh.

4. LIMITATIONS

Whereas the study has managed to show the prospects of the BIM-integrated carbon and energy analysis, a number of limitations must be referred to. The data on the embodied carbon was acquired via the Autodesk Carbon Insight database, which mainly utilizes the global averages with limited consideration of the local manufacturing, transportation, and material makeup in Bangladesh. In addition, the buildings were tested over a one-year time span, that is, in the condition of constant occupancy and weather conditions, without considering the long-term climate fluctuations and the dynamic users. The operational carbon estimates were also inaccurate, and the grid emission factors and efficient HVAC were assumed to be constant. It may be possible in future research to combine local life-cycle databases and dynamic simulation software to enhance local precision and flexibility.

5. CONCLUSION

This paper has used a Building Information Modeling (BIM) methodology where Autodesk Revit 2026 Carbon Insight was implemented to compare the energy and carbon performance of two building designs: one that is built using conventional materials and another that is built using sustainable materials. As a result of the analysis, it turned out that the replacement of the traditional materials with the fly ash brick, a lightweight building material, and low-E glass greatly contributes to the energy efficiency and decreases environmental impact.

The sustainable model recorded 48.5%, 28.64%, and 10.85% reduction in the embodied carbon, total carbon emissions, and Energy Use Intensity (EUI), respectively, in comparison with the traditional model. These results confirm that the material-level design optimization can have a significant effect on both the embodied and operational energy performance, without changing the geometry or configuration of the building structures. The findings are also in compliance with LEED v4 sustainability requirements, which means that they may receive 3-4 points on MRc1 (Life-Cycle Impact Reduction), and 1-2 points on EA (Energy Performance Optimization).

All in all, the combination of BIM and carbon analytics technologies would present an efficient digital design analysis at the initial stage of design and allow the architect and engineer to make responsible choices to balance the performance, cost, and environmental responsibility. The method is specifically applicable to tropical/subtropical climatic conditions, where the material heat transfer properties are critical in the building energy behavior.

DECLARATION OF USE OF AI

The authors indicate that AI-based tools, such as ChatGPT Plus and QuillBot, were applied solely for grammar checking, paraphrasing, and enhancing the readability and clarity of the manuscript. The methodology, research design, data analysis, interpretation of results, and formation of scientific content did not employ these tools. The authors are fully responsible for the work, originality, and integrity of the work.

REFERENCES

- Ahmed Ali, K., & Ahmad, Y. Y. (2020, September 10). Issues, Impacts, and Mitigations of Carbon Dioxide Emissions in the Building Sector. <https://www.mdpi.com/2071-1050/12/18/7427>
- Chen, P.-H., & Li, Y.-C. (2014). BIM-based integration of carbon dioxide emission and cost effectiveness for buildings in Taiwan. *Society of Social Management Systems Internet Journal*, 12, 1–6.
- Fonseca Arenas, N., & Shafique, M. (2023). Recent progress on BIM-based sustainable buildings: State of the art review. *Developments in the Built Environment*, 15, 100176. <https://doi.org/10.1016/j.dibe.2023.100176>
- González, M. J., & García Navarro, J. (2006). Assessment of the decrease of CO₂ emissions in the construction field through the selection of materials: Practical case study of three houses of low environmental impact. *Building and Environment*, 41(7), 902–909. <https://doi.org/10.1016/j.buildenv.2005.04.006>
- Keeler, M., & Vaidya, P. (2016). *Fundamentals of Integrated Design for Sustainable Building*. John Wiley & Sons.
- Khahro, S. H., Kumar, D., Siddiqui, F. H., Ali, T. H., Saleem Raza, M., & Khoso, A. R. (2021, March 25). Optimizing Energy Use, Cost, and Carbon Emission through Building Information Modelling and a Sustainability Approach: A Case-Study of a Hospital Building. <https://www.mdpi.com/2071-1050/13/7/3675>
- Khan, F. A., Ullah, Z., Aashan, M., Ahmad, F., Saad, M., & Azhar, M. (n.d.). Life cycle assessment and energy efficiency of building façade materials: A case study of an educational building in Pakistan—Khan—2025—The Journal of Engineering—Wiley Online Library. <https://doi.org/10.1049/tje2.70047>
- Rodrigues, E., Fernandes, M. S., Soares, N., Gomes, Á., Gaspar, A. R., & Costa, J. J. (2018). The potential impact of low thermal transmittance construction on the European design guidelines of residential buildings. *Energy and Buildings*, 178, 379–390. <https://doi.org/10.1016/j.enbuild.2018.08.009>
- UNEP - UN Environment Programme. (n.d.). Retrieved November 5, 2025, from <https://www.unep.org/>
- USGBC. (n.d.-a). U.S. Green Building Council, LEED v4.1 Building Design and Construction: MR Credit—Building Life-Cycle Impact Reduction, Washington, D.C., USA: USGBC, 2019. [Online] from <https://www.usgbc.org/credits>
- USGBC. (n.d.-b). U.S. Green Building Council, LEED v4.1 Building Design and Construction: EA Credit—Optimize Energy Performance, Washington, D.C., USA: USGBC, 2019. [Online].from <https://www.usgbc.org/credits>