OPTIMIZATION OF BUILDING ENERGY RETROFIT SOLUTIONS

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ABSTRACT

The building sector has the highest share of operational energy consumption and greenhouse gas emissions among all sectors. Detailed parametric analysis and measurements are required to reduce building energy usage while maintaining acceptable thermal conditions. Building retrofit is considered one of the most promising solutions for reducing this energy consumption. This research suggested a system that uses Building Information Modeling (BIM) tools to investigate the impact of building factors on energy usage and find the optimal design. We sought to investigate the effects of various retrofit solutions, such as walls and roofs, and their thickness, on the energy performance of buildings. A prototype building model was developed in Autodesk Revit for this study. Design alternatives considering shading heights, window types, wall types, and window-to-wall ratio, were simulated using Green Building Studio while considering climatic conditions in Bangladesh. This study determined the ideal retrofit solution based on annual electricity consumption changing various parameters. Window shade at $2/3^{rd}$ window height, Triple Low-E glazing window type, Insulated Concrete Form Wall 14 inch (ICF) wall type, and 30% window-to-wall ratio yielded optimum energy consumption for the modeled building. Based on this, the data and conclusions presented in this paper can provide some reference for building energy savings using retrofit solutions.

Keywords: *Energy Consumption, Retrofit, Green Building Studio, Autodesk Revit*

1. INTRODUCTION

The imbalanced availability and demand between natural resources and energy owing to resource depletion, energy conservation, and natural resources have gained international attention (Niccolò Aste, R. S. Adhikari, & Buzzetti, 2010). The building industry harms the environment through various actions, including resource depletion, CO2 and other gas emissions, and waste disposal. As per (Thibaut Abergel, 2018), published by the United Nations and the International Energy Agency, the building industry is responsible for the maximum energy consumption (36%) and emissions (39%) among all industries. Building energy usage has increased worldwide, ranging from 20% to 40% in developed countries for both residential and commercial structures (Luis Pérez-Lombard, José Ortiz, & Pout, 2008). Building energy-efficient structures is one of the best solutions for climate change and excessive carbon dioxide emissions. The building sector is pressured to reduce its environmental impact as the climate changes rapidly. A significant amount of research and actions have been carried out to conserve energy and explore new renewable energy sources to deal with environmental impact. Therefore, the development of a sustainable green concept of the built environment, or green construction, has evolved. Three aspects, according to Greendepot (Daniel Castro-Lacouture, Jorge A. Sefair, Laura Flórez, & Medaglia, 2009), support the idea: a healthy lifestyle, including air quality; careful management of energy sources and energy efficiency (both in terms of material selection and actual energy use). The process of retrofitting or customizing an existing structure to incorporate the concept involves making several improvements or modifications to its parts and facilities.

There are two categories of retrofit research: indoor component studies and building envelope systems (Mohamed Edeisy, 2017). In hot, dry conditions, Edeisy and Cecere (Mohamed Edeisy, 2017) evaluate envelope retrofit to lower dependence on air conditioners; refit using improved glass is evaluated in terms of carbon emissions and cooling load. A considerable amount of the total energy used is accounted for by heating, ventilation, and air conditioning (HVAC). The HVAC system's conditioning system used 22.8% of its embodied energy, while the heating system used 17.6% (Ma, Du, Xie, She, & Jiao, 2015). Therefore, reducing the energy consumption of HVAC and artificial lighting through passive and active design will significantly reduce the energy consumption of buildings as a whole. Combining passive design techniques could save roughly 31% on energy in office buildings (Başak Güçyeter & Günaydın, 2012). This objective can be accomplished by incorporating shading, window-to-wall ratio (WWR), glass selection with a low shading coefficient, and the utilization of natural light for indoor illumination into the envelope designs (Ingy El-Darwish & Gomaa, 2017).

The main disadvantage of single glass windows in window system design is their incapacity to provide sufficient heat resistance, which usually leads to increased energy consumption for cooling during the summer. (Kun Lai, Wen Wang, & Giles, 2017). Frequently used to increase the thermal insulation of windows (Kun Lai et al., 2017) to create a comfortable indoor environment and increase the energy efficiency of a structure, double-layer sandwich glass is frequently employed (Md Jahangir Alam & Islam, 2017) (Diane Bastien & Athienitis, 2015).

Regarding WWR, Pathirana (Shakila Pathirana, Asanka Rodrigo, & Halwatura, 2019) reported that as the percentage of WWR increased, solar heat absorption increased from 20% to 50%. (Seyedeh Hadiseh Sedigh Ziabari, Hassan Zolfagharzadeh, Farzaneh Asadi Malek Jahan, & Salavatian, 2019) Showed that the largest energy consumption occurred when WWR increased by more than 20% in a westward direction. However, regarding ventilation, 25% of WWR does best in the northern face. On the south face of the structure, there is a 30% WWR indication, and another 20% goes east.

Energy conservation and indoor comfort optimization should be the goals of shading device design (Ayca Kirimtat, Ondrej Krejcar, Berk Ekici, & Tasgetiren, 2019). This is another instance of a complex, high-dimensional, multi-objective optimization problem. Liu (Sheng Liu, Yu Ting Kwok, Kevin Ka-Lun Lau, Pak Wai Chan, & Ng, 2019) assessed how different overhang arrangements affected the energy usage of common Hong Kong public rental buildings, focusing attention on how best to use shading devices on opaque facades. The research investigated the impact of overhang length, quantity, and inclination. The results suggest that installing a sun visor on the west facade can save 8.0% of energy. Sghiouri (Haitham Sghiouri, Ahmed Mezrhab, Mustapha Karkri, & Naji, 2018) investigated the impact of exterior shading on indoor comfort and concluded that it is a highly effective method for enhancing thermal comfort.

Axaopoulos (Ioannis Axaopoulos, Petros Axaopoulos, Gregoris Panayiotou, Soteris Kalogirou, & Gelegenis, 2015) conducted a comparative analysis of insulation materials utilized in external walls to determine the differences between various thicknesses of expanded polystyrene, extruded polystyrene, and mineral wool. It was discovered that mineral wool insulation was more effective than polystyrene insulation (Ioannis Axaopoulos et al., 2015). Experimentally, Serrano-Jiménez (Antonio Serrano-Jiménez, Carmen Díaz-López, Konstantin Verichev, & Barrios-Padura, 2023) demonstrated that incorporating polyurethane foam insulation into the carpentry profiles of windows in Spanish buildings increased thermal performance by 25% and reduced interior temperature by 4%.
This study examines how different outer facade materials used in Bangladeshi residential structures have improved energy performance. This study looks at a range of materials and envelope designs to provide insights into the possible trade-offs and benefits connected with each choice. Most past research on facade materials did not consider the building envelope retrofit study. Examining the effects of building envelope designs and external façade materials is essential to addressing the energy issues that Bangladeshi residential buildings face. This addresses a big research gap. This project intends to contribute to the body of knowledge by providing insight into the complex dynamics that influence material choice, energy usage, and sustainable living in a fast-changing urban environment. A range of materials are considered, including more contemporary alternatives like high-performance insulated panels, green walls, innovative composite systems, and tried-and-true options like brick and concrete. Energy consumption patterns of these various facade materials are simulated under various retrofit envelope designs using Green Building Studio, giving a comprehensive insight into their individual performances.

2. METHODOLOGY

2.1 Green Building Studio and Autodesk Revit

The current study used energy simulation tools, specifically sensitivity analysis, together with analytical methods enabled by Auto Desk Revit and Green Building Studio (GBS). Sensitivity analysis is a research method that demonstrates how modifying a few input parameters has an impact on the result. A few of the parameters include the building mass configuration, location, climate, number and size of floors, fill material qualities, fill space characteristics, shading height, type of roof, window glass type, wall composition, and insulation materials. A 3D base model was created with Autodesk Revit. (Fig:1)

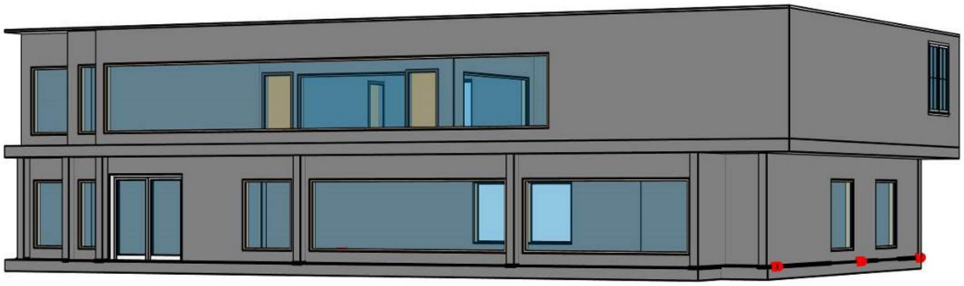


Figure 1: 3d based model of the Prototype Office Building

Revit® software, a BIM tool, enables qualified designers to create and manage better-quality, more energy-efficient structures. In order to develop projects more quickly, engineers and architects can collaborate earlier in the design phase by using the information from Revit-designed models. Every design modification made to a Revit plan, elevation, or cross-section automatically updates the model as a whole, maintaining consistency and dependability between designs and documentation (Autodesk).

Building performance simulations and energy efficiency optimization can be done earlier in the design process with the help of GBS, a flexible cloud-based service that makes it possible to design high-performance buildings more quickly and affordably than with traditional methods. (Studio)
Revit was used as a BIM tool to help with the model's design process. Every element was created by incorporating every layer with its unique set of thermal and physical characteristics, in line with the mass model's representation of actual material properties. Revit performed better during the redraw process, navigating models more smoothly and constantly without having to wait for the software to finish drawing elements at each stage, even when several scenarios were tried. The 3D views and portions of the model were automatically updated. Because Revit and GBS can function together, once the energy analysis button is pressed, the findings appear in both applications. (Ahmad Alothman, Shimaa Ashour, & Krishnaraj, 2021) I also performed an energy performance analysis of a building using these BIM tools.

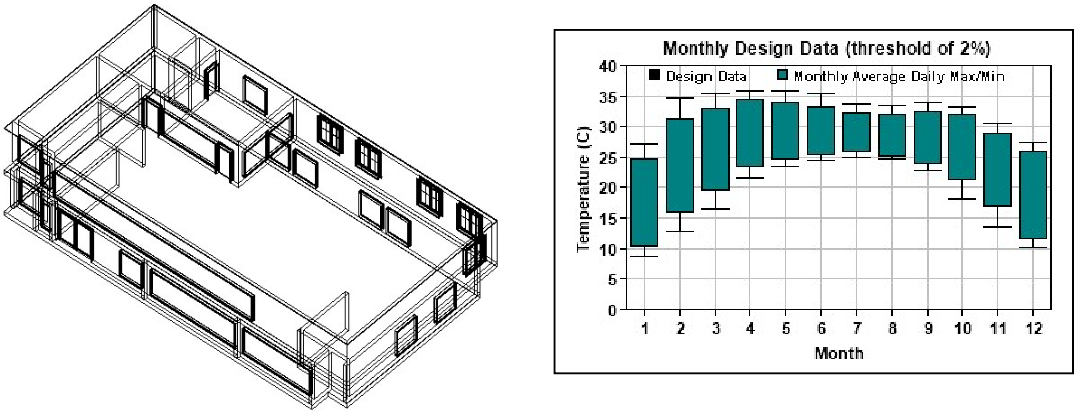


Figure 2 (a)
Figure 2 (b)

Figure 2: (a) Analytical Space of Prototype Building (b) Monthly design data of our location generated by GBS

2.2 Energy Analysis Process

The entire method of evaluating energy performance is carried out in Figure 3. Influencing factors and energy analysis are the two categories under which the total energy evaluation system falls. Here, the occupant, design, and climate are the influencing factors. As the location is assigned, occupancy and climate data are added to the BIM tool. Building kinds and orientation all affect design factors, such as whether it's an office or residential building. The gbXML file format is used to extract and import the material information into the energy analysis tool (GBS) that was utilized to prepare the building's 3D model in Revit-2023.

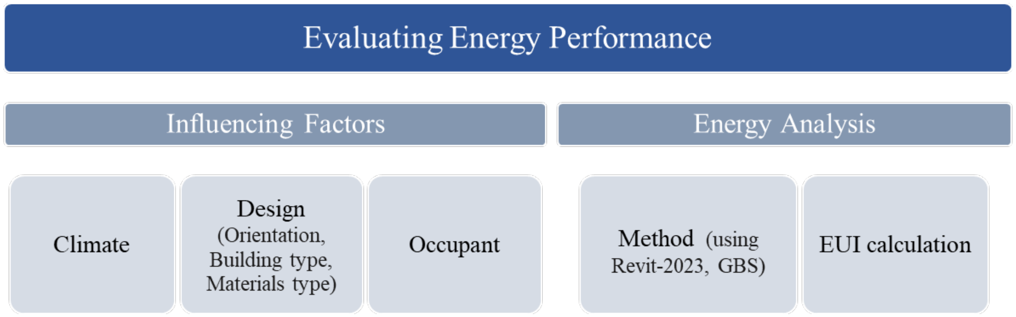


Figure 3: Energy Analysis Process

The second category of energy performance evaluation is energy analysis. As two BIM tools, Revit-2023 and GBS, were used to analyze the energy performances of the building, this method was used to determine the Energy Use Intensity (EUI) or annual electricity use.

2.3 Building Parameters

As annual energy modeling for the building was done with Green Building Studio, this involved adding hourly meteorological data particular to each site to the prototype model. Figure 2(b) displays the monthly design data that GBS produced.

The structure is a well-equipped, two-story office building used for banking activities situated in Khulna, Bangladesh. This has a Tropical wet and dry climate. Here, the annual high temperature is 32.47ºC (90.45ºF), and the annual low temperature is 23.21ºC (73.78ºF) with 28.66ºC (83.59ºF) yearly temperature and 62.72% yearly humidity. Table 1 provides important information about occupancy, schedules, materials, floor area, HVAC systems, and other critical factors required for energy simulations in each zone. Additional parameters are provided below:

Table 1: Analytical Properties of Building

Building Type	Office
Location	Khulna (Latitude = 22.9167, Longitude = 89.5333)
Floor Area	419 m^2
Occupancy Schedule	12/5 facility
Occupant Number	17
Shading device	No shading devices
Window wall ratio	North Side = 0.30, South Side = 0.95, East Side = 0.30 and West Side = 0.25
Window Type	Double Glazing-1/4 in blue-green/low-E
HVAC System	Residential 17 SEER split unit
Average Lighting Power Density	10.76 W / m^2
Average Equipment Power Density	13.99 W / m^2
Specific Cooling	7 m^2 / kW
Specific Heating	5 m^2 / kW
Total Cooling Capacity	59 kW
Total Heating Capacity	86 kW
Annual Electricity Use	84017.07 KWh

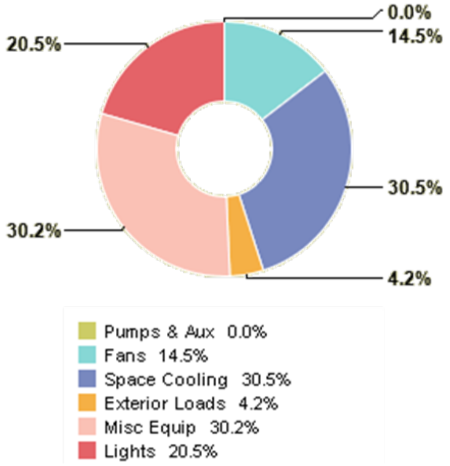


Figure 4: Annual Electric End Use Generated by GBS

2.4 Simulating Parameters

The building's conceptual mass was reconstructed in order to analyze energy utilization. In order to conduct an energy assessment, the required modifications were made to the façade features, including increasing the Window Wall Ratio (WWR), changing wall types and insulation, and adjusting shade heights and window glass materials. The prototype building was simulated using GBS, adjusting the WWR, wall types, window types, and shading heights to see how each affected energy use. The various window and wall materials utilized for the external windows and walls are listed in Tables 2 and 3, along with their corresponding U-values.

The U-value evaluates the rate of heat gain or loss through all of the combined thicknesses of the parts that go into making up a wall, floor, or roof in a building. Watts per square meter in Kelvin, or W/m^{2}K, is the unit of measurement. It is a method of calculating a building element's insulating qualities. More heat transmission results from a greater U-value, and less heat transfer results from a lower U-value, which indicates a better-insulated structure. The higher the energy efficiency when it comes to building components, the lower the U-value (Abdullah Halim, Anas Zafirol and Talkis, Nor Azizah and Wan Ali, Wan Nordiana and Majid, & Fareh, 2022). Solar heat gain coefficient (SHGC) is the percentage of solar radiation that is directly or indirectly transmitted, absorbed, and then released as heat through a window, door, or skylight. One of the factors that affect the cooling load in a building is the SHGC of the windows. Less solar heat is transmitted, and more shade capacity is provided by a lower SHGC.

Table 2: Glazing Types of Window

Window Type	**U-Value (W / (m²-K)**	**SHGC Value (W / (m²-K)**
Single Clear (Sgl Clr)	6.17	0.81
Double Clear (Dbl Clr)	2.74	0.70
Double Low-E (Dbl LoE)	1.99	0.73
Triple Low-E (_Trp LoE)	1.55	0.47

Table 3: Types of External Wall Material

Wall Type	**U-Value (W / (m²-K)**
R13 Metal Frame Wall	0.88
R13 Wood Frame Wall, Wood Shingle	0.46
R13 + R10 Metal Frame Wall	0.32
Insulated Concrete Form Wall 14 inch (ICF)	0.19
R38 Wood Frame Wall	0.15
R2 CMU Wall	1.21
Structurally Ins. Panel (SIP) Wall 12.25 in (311mm layers)	0.15

In the winter, a single pane of glass loses a lot of heat through the glass due to its extremely poor insulation. Air is trapped between two (or three) panes of glass in double or triple glazing, which reduces heat loss by twice as much as single glazing. With double or triple glazing, significantly less heat is lost through the window because air is a poor heat conductor. Applying a transparent Low Emissivity (Low E) coating to one or more interior panes can help to reduce heat loss further by reflecting heat back into the room. (nulook)

R13 Metal Frame Wall is a type of wall that is built with metal studs, and this insulation type has an R-value of 13 m^{2}K/W. The thermal resistance rating, or R-value, of an insulation material is a measurement of its resistance to heat flow. Greater resistance to heat transmission, along with a greater insulating effect and consequent energy savings, are all indicated by higher R-values. Similarly, the R13 Wood Frame Wall with Wood Shingle type wall is made with wood studs along with wood shingles on the exterior and insulated with R-13 insulation, whereas the R38 Wood Frame

Wall is insulated with R-38 insulation. In the R13 + R10 Metal Frame Wall, an additional R-10 insulation is provided to the exterior of the wall. Insulation and thermal bulk contribute to the effectiveness of insulated concrete forms in preserving a constant temperature in an Insulated Concrete Form Wall. Again, the R2 CMU Wall is made with concrete masonry units (CMUs), and the SIP wall has panels for insulation that have facer material (wood) on both sides.

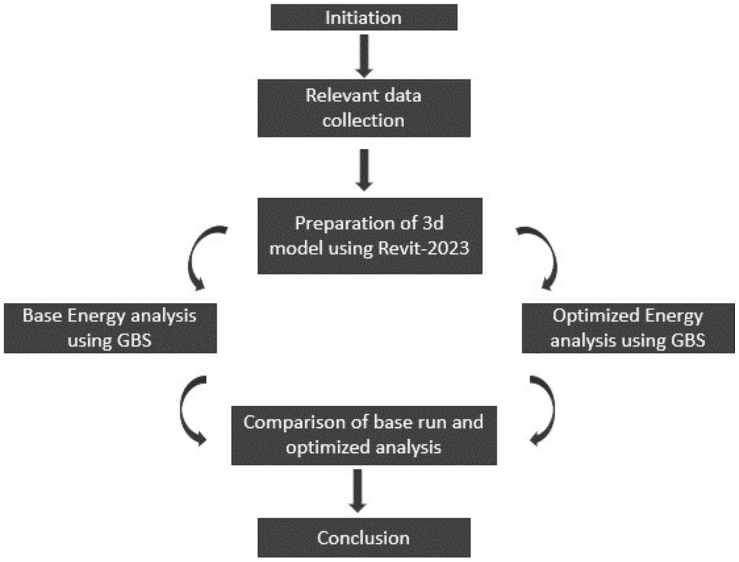
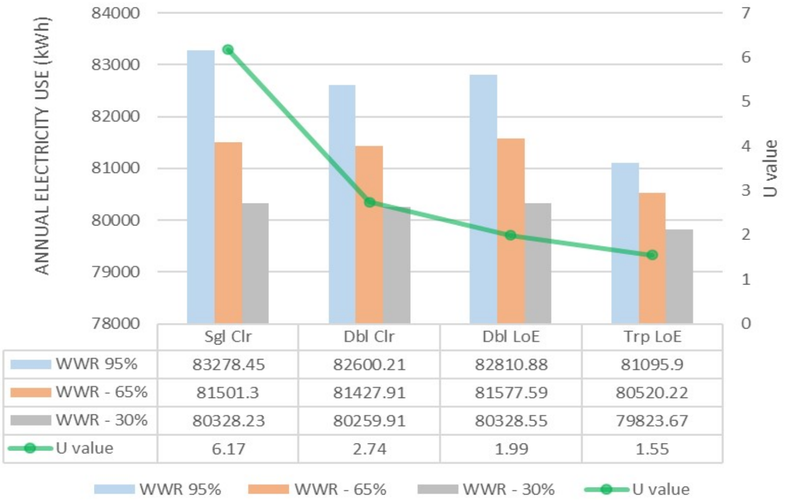


Figure 5: A schematic flow diagram of the study

3. RESULTS AND DISCUSSION

Retrofit envelope design has a significant effect on annual electricity consumption using variations in shading height, different window glass types on different window-to-wall ratios (WWR), and different kinds of insulation and wall materials, as shown in Figures 6, 7, and 8. Since insulation lowers the wall's total heat transfer coefficient (U-value) and thus reduces heat gain, it was anticipated that adding insulation to the wall construction would minimize the monthly energy demand. (Budaiwi, 2011).

3.1 Impact of Window Glass Type on Annual Electricity Use for Different Window to wall Ratio



	Sgl Clr	Dbl Clr	Dbl LoE	Trp LoE
WWR 95%	83278.45	82600.21	82810.88	81095.9
WWR - 65%	81501.3	81427.91	81577.59	80520.22
WWR - 30%	80328.23	80259.91	80328.55	79823.67
U value	6.17	2.74	1.99	1.55

Figure 6: Impact of Window Glass Type on Annual Electricity Use for Different Window-to-Wall Ratio

Reduced annual percentage energy consumption for various window glass types (Sgl, Dbl, Dbl LoE, Trp LoE) used in (WWR-95%, WWR-65%, WWR-30%) is illustrated by the findings in Figure -6. In the instance of (WWR-95%), there was a decrease in electricity consumption of 0.81%, from 83278.45 kWh (Sgl Clr) to 82600.21 kWh (Dbl Clr). There was also a decrease of roughly 0.56% and a large decrease of 2.62% in (Sgl to Dbl LoE and Sgl to Trp LoE). In a similar manner, the percentage in (WWR-65%) dropped by roughly 0.08%, rose by 0.09%, and then dropped by 1.20% once again. The percentage variation for a comparable pattern for (WWR-30%) reduced by 0.08%, remained unchanged, and decreased by roughly 0.62%. Relevant findings about the interaction of glazing kinds on the building envelope were noted by (Md Jahangir Alam & Islam, 2017). In comparison to advanced glazing, they observed that single clear glass has the maximum heat gain. Each case showed a reduction in annual electricity use from the building's current annual electricity consumption of 84017.07 KWh. Here, it is found that in every instance, there was an apparent reduction in the energy demand as the U-value dropped. It is observed higher annual energy consumption for Dbl LoE (U-value: 1.99) than for Dbl Clr (U-value: 2.74), in spite of having a lower U-value. This is because Dbl LoE has a higher SHGC value (0.73 W/m2-K) than Dbl Clr's SHGC value (0.70 W/m2-K). SHGC (solar heat gain coefficient) indicates the fraction of solar radiation transmitted through the Window. As Dbl LoE has a higher SHGC value than Dbl Clr glazing type, it allows more heat gain, which results in increasing cooling energy consumption. A similar kind of scenario was mentioned by (de Gastines & Pattini, 2020). So, it is found that the best way to lower the annual energy consumption is to reduce SHGC, which is followed by lowering the window's U value. (Takeshi Ihara, Arild Gustavsen, & Jelle, 2015) mentioned this similar kind of founding.

3.2 Impact of Shading Height on Annual Electricity Use for Different Window-to-Wall Ratio

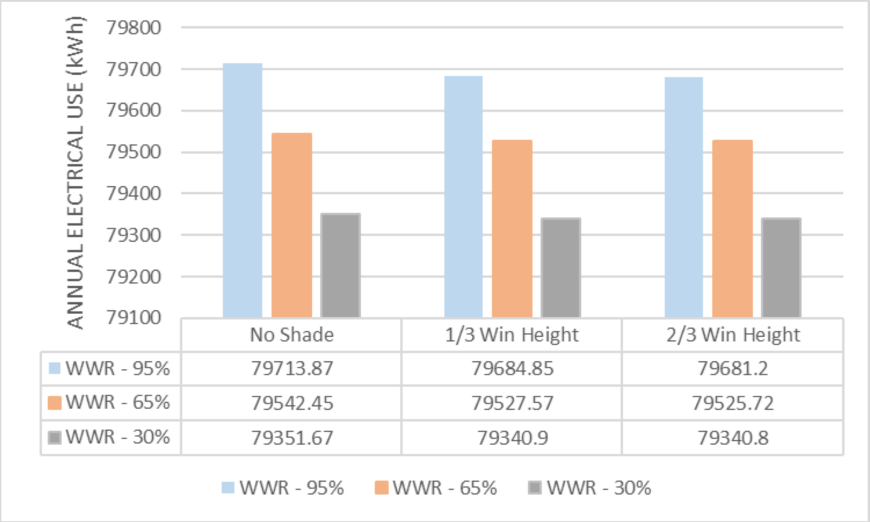


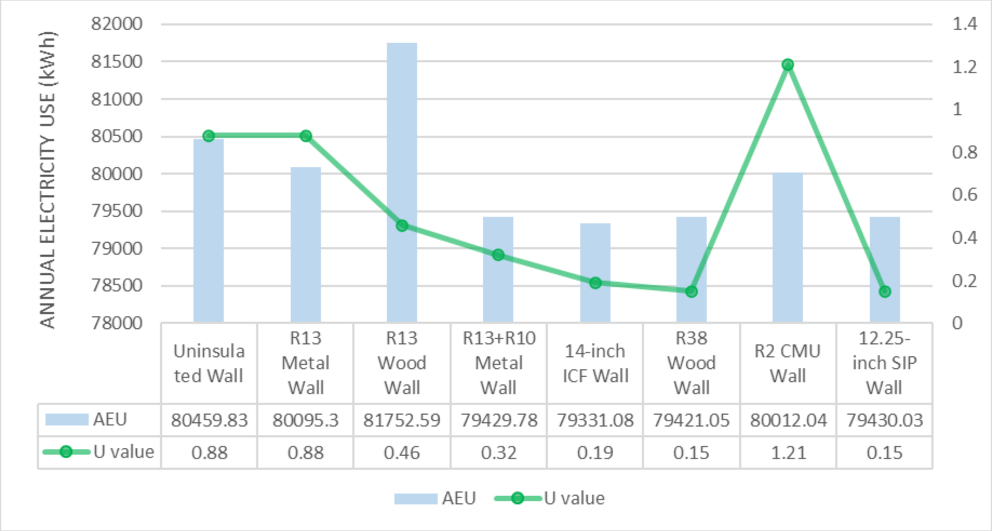
Figure 7: Impact of Shading Height on Annual Electricity Use for Different Insulation Materials

As shown in Figure 7, this study showed a relationship between the annual electricity use and the shading height. There was usually a positive correlation between rising shading height and falling electricity use. For example, the wall with (WWR-95%) exhibited a 0.03% decrease in power consumption, going from 79713.87 kWh (No Shade) to 79684.85 kWh (1/3 Window Height). Then, it slightly decreased to 79681.2 kWh (2/3 Window Height), indicating a 0.041% loss. Walls with (WWR-65%) followed next, showing how shade can significantly reduce energy use. The reduction in electricity usage was 0.019% for (WWR-65%) when the shade height was extended to 1/3 of the window height, 0.021% when it was expanded to 2/3 of the window height, and 0.013% for (WWR-

30%) when compared to the no shade state, where the reduction in electricity usage was 0.014% in 2/3 of the window height. This analysis validates the findings of Mujeebu and Ashraf (Muhammad Abdul Mujeebu & Ashraf, 2020) that, in high-temperature conditions, increasing the thermal insulation of the exterior will increase energy consumption in the absence of a backup plan to release the building's stored heat.

3.3 Impact of different types of wall material and insulation on Annual Electricity use

This study demonstrates that utilizing various wall materials and insulation can result in noticeable annual energy use variations (figure 8).



	Uninsulated Wall	R13 Metal Wall	R13 Wood Wall	R13+R10 Metal Wall	14-inch ICF Wall	R38 Wood Wall	R2 CMU Wall	12.25-inch SIP Wall
AEU	80459.83	80095.3	81752.59	79429.78	79331.08	79421.05	80012.04	79430.03
U value	0.88	0.88	0.46	0.32	0.19	0.15	1.21	0.15

Figure 8: Impact of Different Insulted Walls on Annual Electricity Use

These wall constructions include (uninsulated wall, R13 Metal, R13 Wood, R13+R10 Metal, 14-inch ICF, R38 Wood, R2 CMU, and 12.25-inch SIP). Using the following materials and compositions, these constructed walls consumed 80459.8 kWh, 80095.3 kWh, 81752.6 kWh, 79429.8 kWh, 79331.1 kWh, 79421.1 kWh, 80012 kWh, and 79430 kWh of electricity annually. According to this analysis, the top three energy-efficient walls were made of the following materials: R13+R10 Metal, 14-inch ICF, and R38 Wood. These walls used around 1.28%, 1.41%, and 1.29% less energy yearly than uninsulated walls. The quality of insulation and its ability to prevent heat absorption is better when the U-value of specific building materials is lower (Abdullah Halim et al., 2022). Type "R13 Wood Frame Wall, Wood Shingles" wall shows higher electricity consumption, though it has a lower U-value than R13 metal frame wall. Because the R13 Metal Wall has a higher thermal mass than the R13 Wood Wall, as metal can gain and release heat slowly, it leads to low energy consumption at a closed space in hot climate region. Again, wood shingles are less air-tight than other cladding materials. This leaky wall of "Wood Shingles" type leads to higher heating and cooling energy needs than others because it allows more heat loss and air infiltration, which increases electricity consumption.

4. CONCLUSIONS

- Lowering the Window-to-Wall Ratio (WWR) reduced the amount of energy used as it reduced the heating caused by solar radiation. 30% WWR consistently exhibits the lowest electricity consumption among all WWR values with variations in shading heights and window types. Between these two varied scenarios of window types and shading heights, 30% WWR with variable shading heights exhibits the lowest electricity usage. Hence, a WWR of 30% emerged as the most suitable action. Compared to other orientations of the following office building, its south-facing wall has a greater window-to-wall ratio. Because windows have already been installed on north, east, and west-oriented walls in accordance with the optimal amount of WWR, the only option to apply the optimum percentage of WWR is on the south-oriented wall for this building.

- In comparison to advanced glazing for different window types, the most favorable glazing is Triple Low-E (Trp LoE), facilitating consistently visible light transmittance while managing lower solar heat gain. The lowest annual electricity use for Trp LoE was found to be 30% WWR. So, this can be the optimum window type for all variations of WWR changes while considering electricity consumption. This optimum condition consumes 5% less electricity annually compared to the building's present condition. Again, Double Clear (Dbl Clr) window glazing is the second lowest for annual electricity use among all the types of window glazing with changing variations of WWR. Again, the analysis of windows' energy efficiency usually depends on their thermal characteristics, such as U-values and SHGC values. Reducing SHGC is the most effective strategy to minimize annual energy usage compared to U-values reduction.
- Optimal shading was observed at 2/3rd of the window height. At this level, all variations of WWR exhibited lower electricity consumption compared to the no-shade state and shading at 1/3rd of the window height state. The findings illustrate that shading at 2/3rd of window height reduces 0.014 % of electricity consumption compared to no shading state for 30% WWR. This emerged as optimum action by reducing the need for artificial lighting and minimizing solar heat gain. Compared to the building's current state, this optimum shading height uses 5.5% less electricity annually. These results also demonstrate how effective 30% WWR is at lowering energy use, especially when combined with higher shade heights.
- The results show that among eight types of wall variations, Insulated Concrete Form Wall 14 inch (ICF) showed the lowest electricity consumption annually, which saves 5.57% electricity annually compared to the current building. Insulation and thermal bulk contribute to the effectiveness of insulated concrete forms in preserving a constant temperature. It was found that using insulating materials combined with retrofit design techniques greatly improved the building's energy efficiency.
- The optimal retrofitting technique varies greatly depending on the location and climate, as solar control is an essential strategy for energy savings in the analysed context. The results of this study are helpful in developing effective façade materials and components for energy-efficient buildings, taking into account the challenges presented by the interaction between facade characteristics and design considerations.
- Future research should consider to explore additional factors affecting energy performance efficiency, such as other combinations of facade properties, behavior, window types, building types, dynamic facade properties, and retrofitting strategies. These retrofitting strategies can be applied to a broader context like Bangladesh's tropical wet and dry climate for ensuring the validity of the results.

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