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Exploring the Impact of Exterior Facade Materials on Energy Performance of Residential Structures in Bangladesh

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Abstract

The growing need for energy has put Bangladesh's booming economy in a state of distress. A considerable amount of solar heat gain in tropical areas, like Bangladesh, passes through a building's external walls. The most economical way to manage the outside elements and improve the comfort of dwellings is to insulate the external walls and optimize their respective building envelope parameters. We sought to investigate the effects of various external wall insulation on the energy performance of residential buildings structures. A prototype building was modeled in Autodesk Revit for our study. Design alternatives (window to wall ratio, shading height and building orientation) were simulated using Green Building Studio while considering the climate of its location. We determined the most ideal type of insulation material in residential structures based on annual electricity consumption changing various parameters. Fibre insulated wall was found to be most suitable in reducing energy consumption. Window shade at 2/3rd window height, 30% window to wall ratio and 270-degree building orientation was deemed to be the best combination for the modelled building. Our findings led us to suggest a number of energy-saving ideas that could potentially be applied to create residential buildings that are energy-efficient.

Keywords: *Wall insulation; Green Building Studio; WWR; Shading Height; Building Orientation.*

1 Introduction

The emphasis on constructing sustainable and energy-efficient residential buildings has grown significantly in recent years due to increasing energy needs, environmental considerations, and the necessity for adaptable living spaces (Nguyen, 2021). Bangladesh's metropolitan regions have grown quickly, increasing the demand for housing and the ensuing construction activity. Bangladesh's tropical climate demands careful consideration while choosing facade materials to reduce energy use for cooling and heating while still preserving occupant comfort.–The materials used on a building's exterior facade can have a significant impact on how much energy it uses. They affect solar reflectance, thermal insulation, ventilation efficiency, and heat gain or loss (Djunaedi, 2018). Despite the fact that they may not meet current energy efficiency criteria, materials of historical and cultural significance are frequently used in traditional construction methods. On the other hand, modern materials provide creative ways to improve energy performance but could ignore local availability and cultural context.
Most of the energy used for heating, ventilation, and air conditioning (HVAC) is consumed. 22.8% of the HVAC system's embodied energy was used by the cooling system, and 17.6% by the heating system (Ma et al., 2015). As a result, reducing building energy use by passive and active design will result in significant building reduction (Poerbo et al., 2017). This can be done by using retrofit envelope designs with features like shading, Window to Wall Ratio (WWR), low shading coefficient glass selection, and the use of natural light for inside lighting through building orientation (El-Darwish & Gomaa, 2017).

The goal of this study is to examine energy performance improvements made to various outside facade materials used in residential buildings in Bangladesh. This study seeks to offer insights into the potential trade-offs and benefits associated with each decision by examining a variety of materials and various envelope designs. The majority of earlier studies on facade materials didn't take the building envelope retrofit analysis into account. In order to address the energy challenges faced by residential structures in Bangladesh, it is crucial to investigate the impact of exterior facade materials and building envelope designs. This fills a significant research gap. By illuminating the intricate dynamics that affect material choice, energy use, and sustainable living in a rapidly changing urban environment, this research aims to add to the body of knowledge. A variety of materials are taken into consideration, including time-tested options like brick and concrete as well as modern substitutes like high-performance insulated panels, green walls, and advanced composite systems. Through the use of Green Building Studio, energy consumption patterns of these various facade materials are simulated under different retrofit envelope designs, providing a thorough understanding of their individual performances.

2. Materials and Methodology

2.1 Green Building Studio and Autodesk Revit

This research was conducted with energy simulation using sensitivity analysis through analytical methods with the help of Auto desk Revit and Green Building Studio. Sensitivity analysis is a study to show variations in output based on several input parameters. These parameters include the shape of the building mass, geographical location and climate data, number and area of the floor, fill material properties, and fill the characteristics of space, Shading Height, Window to Wall Ratio, type of roof, and kind of wall. A 3d base model was developed in Autodesk Revit. Figure 1(a) represents the analytical spacing of the prototype building.

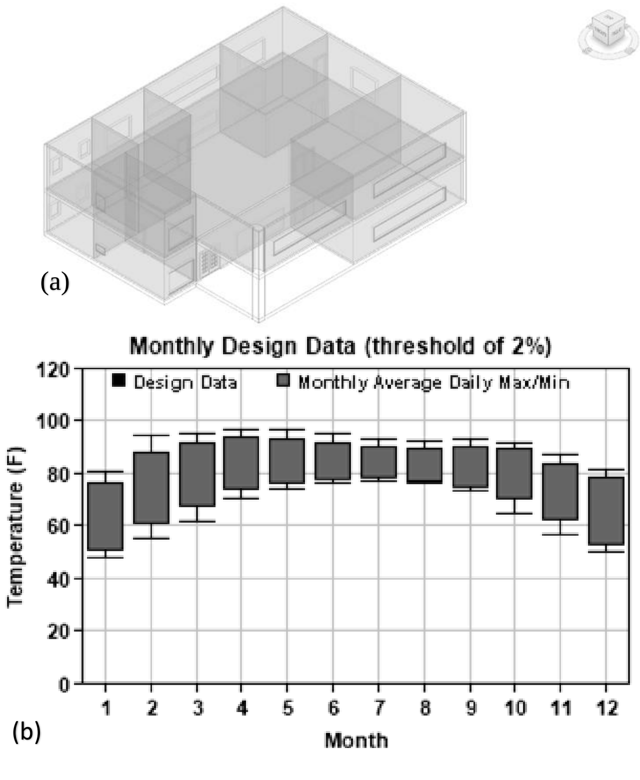


Figure 1. (a) Analytical Space of Prototype Building (b) Monthly design data of our location generated by GBS.

2.2 Building Parameters

We utilized Green Building Studio to perform annual energy modeling of the building, incorporating location-specific hourly weather data for the prototype model. The resulting monthly design data generated by GBS is presented in Figure 1(b). Table 1 provides details regarding assumed occupancy numbers, occupancy schedules, facade materials, floor area, orientation, HVAC system, and other analytical properties for each zone, essential for energy simulations.

Next, we proceeded to evaluate energy usage by reconstructing the conceptual mass of the building and making necessary modifications or additions to the facade elements for energy analysis. Using Green Building Studio, we conducted simulations of the prototype building with different wall insulation materials to assess their impact on energy consumption. Table 2 outlines the various insulation materials employed for the external walls, along with their corresponding U-values. When constructing the 8-inch external wall, we maintained a fixed insulation thickness of 3.5 inches for all insulated materials, in addition to selecting ½ inch of plaster and a 4-inch face brick.

Subsequently, we performed a comprehensive analysis of the simulation results to predict the influence of wall insulation materials on energy consumption. Furthermore, we examined the effects of shading height, wall thickness, window to wall ratio, and building orientation on the performance of insulation materials.

Table 1: Analytical Properties of Building.

Building Floor Area	708 m^2
Occupancy Schedule	24/7 facility
Roof Type	Uninsulated flat roof (U=0.2744BTU/ (h.ft^2. °F))
Exterior Wall Type	Uninsulated Brick Block Wall (U=0.2513 BTU/(h·ft^2·°F))
Interior Wall Type	Light plaster, brick, light plaster (U=0.2976 BTU/ (h.ft^2. °F))
Floor Type	8 in lightweight concrete floor deck (U=0.2397 BTU/ (h.ft^2. °F))
Exterior Window Type	Double Glazing-1/4 in blue-green/low-E (U=0.3500 BTU/ (h.ft^2. °F))
Door Type	Door-wood-hollow core (U=0.33 BTU/ (h.ft^2. °F))
HVAC System	Residential 14 Seer Split Unit
Orientation	East-West
Building Type	Residential
Location	Khulna (Latitude = 22.9167, Longitude = 89.5333)
Occupant Number	16 people

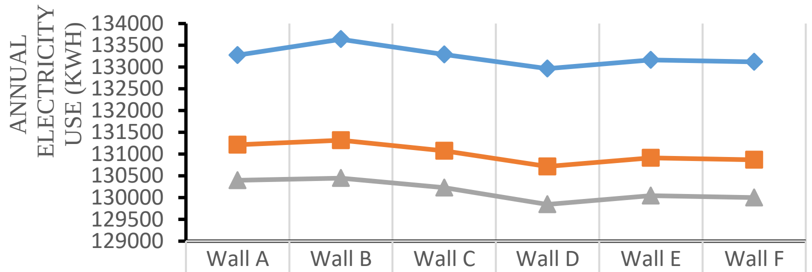
Table 2: Types of Wall Material.

Wall A	Uninsulated Brick Block Wall	(U=0.2513 BTU/(h·ft^2·°F))
Wall B	Brick, sheathing, R-11 batt insulation, gypsum	(U=0.0664 BTU/(h·ft^2·°F))
Wall C	Brick, R-5 insulation board, 8 in heavyweight CMU, gyp board	(U= 0.1106 BTU/(h·ft^2·°F))
Wall D	Brick, fiber insulation, light-weight concrete, dense plaster	(U= 0.0528 BTU/(h·ft^2·°F))
Wall E	Brick, foam insulation, light-weight concrete, dense plaster	(U= 0.0828 BTU/(h·ft^2·°F))
Wall F	Brick, polystyrene insulation, light-weight concrete, dense plaster	(U=0.0775 BTU/(h·ft^2·°F))

3 Results & Discussion

The effects of retrofit envelope designs on annual electricity use of the selected insulation types for different wall materials are presented in Figure 2, 3, and 4. It was expected that adding insulation to the wall structure would reduce the monthly energy demand (Figure 6), as insulation lowers the wall's overall heat transfer coefficient (U-value) and subsequently reduces heat gain (Budaiwi, 2011).

3.1 Impact of Shading Height on Annual Electricity use for Different Insulation Material

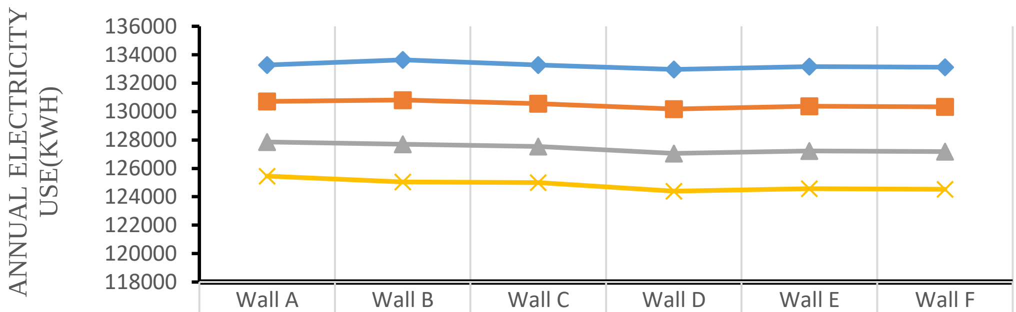


	Wall A	Wall B	Wall C	Wall D	Wall E	Wall F
No Shade	133276	133638	133285.7	132964.1	133166.5	133121.5
1/3 Win Height	131215.1	131318.9	131077.7	130716.6	130911.5	130866.3
2/3 Win Height	130399.5	130447.8	130231.6	129844	130045	129998.6

Figure 2. Impact of Shading Height on Annual Electricity use for Different Insulation Material.

The findings illustrated in Figure 2 exhibit a clear relationship between shading height and annual electricity consumption. In all scenarios, an increase in shading height corresponded to a decrease in electricity usage. For example, in the case of Wall A, the electricity consumption reduced from 133,276 kWh (No Shade) to 131,215.1 kWh (1/3 Window Height), indicating a decrease of 1.46%. Furthermore, it decreased further to 130,399.5 kWh (2/3 Window Height), demonstrating a reduction of 2.18%. Similar patterns were observed for Walls B, C, D, E, and F, highlighting the effectiveness of shading in reducing energy demands. Among these walls, Wall D exhibited the most significant improvement, with a 1.93% reduction in electricity consumption when the shading height was increased to 1/3 of the window height, and a 2.93% reduction when the shading height was increased to 2/3 of the window height. Notably, Wall D showcased a 0.426% reduction in electricity consumption compared to Wall A when shading was implemented at 2/3 of the window height. When there was no shading, Walls B and C consumed more electricity than Wall A, but the difference between the two walls fell when shading was applied. This supports Mujeebu and Ashraf's (Abdul Mujeebu & Ashraf, 2020) finding that, in high-temperature climates, improved thermal insulation of the envelope would increase the energy demand in the absence of a different plan to remove the built-up heat from the structure.

3.2 Impact of WWR on Annual Electricity use for Different Insulation Material

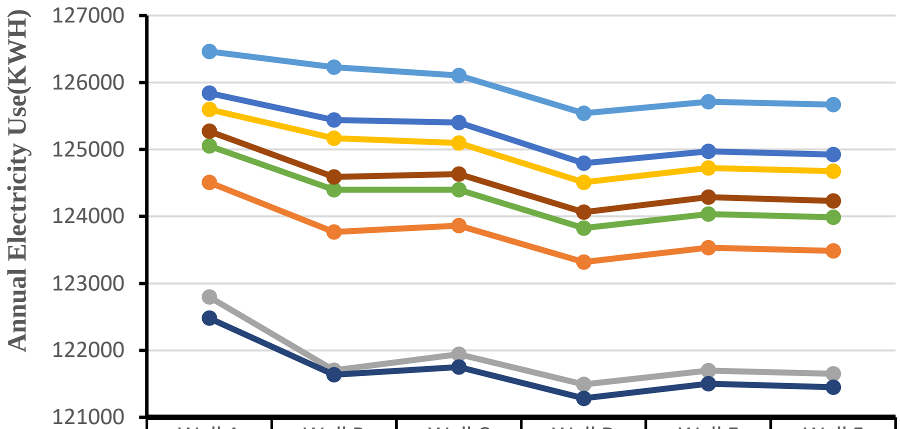


	Wall A	Wall B	Wall C	Wall D	Wall E	Wall F
WWR 95%	133276	133638	133285.7	132964.1	133166.5	133121.5
WWR 65%	130707.5	130813.4	130552.1	130178	130367.1	130322.7
WWR 30%	127858	127691.2	127545.8	127053.8	127232.5	127192.1
WWR 0%	125455	125043.4	125003.6	124395.2	124576.7	124530.6

Figure 3. Impact of WWR on Annual Electricity use for Different Insulation Material.

The findings presented in Figure 3 indicate that reducing the Window-to-Wall Ratio (WWR) has a significant impact on reducing electricity consumption across various wall configurations. Regardless of the wall type (A to F), decreasing the WWR from 95% to 0% resulted in substantial reductions in annual electricity usage. The percentage reductions in electricity consumption varied, ranging from 2.08% (Wall D, WWR 65%) to 6.80% (Wall B, WWR 0%). These results highlight the potential for energy savings and improved sustainability in buildings by optimizing the WWR. Notably, the WWR of 0% yielded the highest reduction in annual electricity consumption among all the walls. Specifically, Wall D exhibited the lowest electricity usage with a WWR of 0%, resulting in a 0.84% reduction in annual electricity consumption compared to Wall A. These findings emphasize the significance of WWR as a design parameter to enhance energy efficiency in building envelopes.

3.3 Impact of Building Orientation on Annual Electricity use for Different Insulation Material



	Wall A	Wall B	Wall C	Wall D	Wall E	Wall F
0 degree	125841.5	125439	125402.6	124794.5	124970	124924
45 degree	124507.7	123768.2	123863.9	123318.7	123532.4	123483.4
90 degree	122797.4	121700.9	121942.4	121491.1	121695.4	121649.7
135 degree	125598.1	125168.9	125096.9	124510.1	124725.3	124676.5
180 degree	126463	126228.6	126105.1	125540.9	125712.4	125671.1
225 degree	125052.8	124399.2	124399.9	123825.8	124034.5	123989.3
270 degree	122479.5	121634.6	121749.9	121284	121499.4	121446.8
315 degree	125270.8	124591.2	124634.3	124063.2	124288.1	124231.1

Figure 4. Impact of Building Orientation on Annual Electricity use for Different Insulation Material.

The data presented in Figure 4 displays the annual electricity consumption for different building orientations (0 degrees, 45 degrees, 90 degrees, 135 degrees, 180 degrees, 225 degrees, 270 degrees, and 315 degrees). The findings demonstrate variations in electricity consumption among Walls A to F under different orientations. Wall A consistently exhibits the highest electricity consumption across all orientations due to the absence of insulation. Conversely, Wall D consistently showcases the lowest electricity consumption, with reductions of 0.61%, 1.01%, 0.94%, 0.85%, 0.33%, 0.32%, 0.50%, and 0.30% compared to Wall A (No Insulation) for the respective orientations of 0, 45, 90, 135, 180, 225, 270, and 315 degrees. Furthermore, Wall B consistently demonstrates lower electricity consumption than Wall C, while Wall E and Wall F exhibit nearly identical energy consumption across various building orientations. The 270-degree building orientation yields the least energy consumption, closely followed by the 90-degree building orientation. On the other hand, the 0-degree building orientation results in the highest energy consumption.

4 Conclusions

- Findings indicate that insulated walls (B, C, D, E, F) outperform uninsulated (A) configurations, significantly reducing heat transfer and energy consumption. Walls with advanced insulation (D, E, F) stand out, effectively minimizing energy demand in Bangladesh's warm and humid climate. As the nation aims for sustainable development, integrating such facade materials can contribute to energy-efficient and resilient residential structures.

- Optimal shading was observed at 2/3rd of the window height. At this height, all walls except for wall B exhibited lower electricity consumption compared to wall A (uninsulated wall). Wall B with batt insulation, was found to be ineffective in reducing electricity consumption. Among all the walls, wall D, which utilized fiber insulation, demonstrated the highest reduction in electricity consumption (0.426%) compared to wall A when shading was applied at 2/3rd of the window height. These findings highlight the effectiveness of fiber insulation in wall D, particularly when combined with increased shading height, in reducing energy usage.
- Decreasing the Window-to-Wall Ratio (WWR) resulted in a decrease in energy consumption as it reduced the heating caused by solar radiation, leading to lower energy consumption. Among all the WWR values, wall D with fiber insulation, consistently exhibited the lowest electricity consumption, making it the most suitable option. When the WWR was higher, wall B consumed more electricity than wall A. However, when the WWR was reduced to 30% or less, wall B demonstrated reduced energy consumption compared to wall A. Therefore, a WWR of 30% is considered suitable.
- The optimal building orientation for the structure is 270 degrees. This orientation allows for consistent utilization of daylight while effectively managing glare along the longer sides of the building, thus reducing the need for artificial lighting. All types of walls exhibited a reduction in electricity consumption when the building was oriented at 270 degrees, closely followed by the 90-degree orientation. On the other hand, an orientation of 180 degrees is not recommended as it allows for increased solar radiation penetration, which can lead to higher energy consumption.
- This paper concludes wall D with fiber insulation as the optimum material for energy reduction in building. We found that retrofit design strategies combined with insulation materials significantly improved their energy performance.

References

Abdul Mujeebu, M., & Ashraf, N. (2020). Impact of location and deadband on energy performance of nano aerogel glazing for office building in Saudi Arabia. Building Research & Information, 48(6), 645-658. https://doi.org/10.1080/09613218.2019.1696171

Budaiwi, I. M. (2011). Envelope thermal design for energy savings in mosques in hot-humid climate. Journal of Building Performance Simulation, 4(1), 49-61. https://doi.org/10.1080/19401491003746639

Djunaedi, A., Sun, T., & Love, P. E. (2018). Energy performance of façade designs and thermal comfort in a cool temperate climate: A case study in Melbourne. Journal of Building Engineering, 20, 166-177.

El-Darwish, I., & Gomaa, M. (2017). Retrofitting strategy for building envelopes to achieve energy efficiency. Alexandria Engineering Journal, 56(4), 579-589.

Ma, J.-J., Du, G., Xie, B.-C., She, Z.-Y., & Jiao, W. (2015). Energy Consumption Analysis on a Typical Office Building: Case Study of the Tiejian Tower, Tianjin. Energy Procedia, 75, 2745-2750. https://doi.org/https://doi.org/10.1016/j.egypro.2015.07.506

Nguyen, A. T., Yang, J., & Chua, K. J. (2021). A review on energy-efficient building technologies for tropical climates. Applied Energy, 285.

Poerbo, H. W., Martokusumo, W., Koerniawan, M. D., Ardiani, N. A., & Krisanti, S. (2017). Algae façade as green building method: application of algae as a method to meet the green building regulation. IOP Conference Series: Earth and Environmental Science.