INVESTIGATING THE IMPACT OF DIFFERENT WINDOW MATERIALS ON THE ENERGY CONSUMPTION OF BUILDINGS: IN THE CONTEXT OF KHULNA

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ABSTRACT

The world is going through a great energy crisis recently. The 2021-present day energy crisis is the most recent in a series of cyclical energy shortage experienced over last fifty years. Bangladesh is suffering critically due to the drastic drop in the supply of natural resources like gas and oil. The economic repercussions have been so severe that the government was compelled to obtain loans of $4.5 billion from the IMF, $2 billion from the World Bank, and $2 billion from the Asian Development Bank. The air conditioning system is one of the most energy-intensive components in buildings, particularly in tropical residences. Significant influence is exerted by the building envelope on the energy efficiency of structures. Consequently, for energy conservation, an appropriate window system is one of the essential retrofit strategies for existing buildings, given the critical role that windows play in transferring heat and cold between the interior and exterior environments. As a result, choosing the right window materials is essential to lowering energy consumption by reducing the building's need. This paper aims to identify the most energy-efficient window materials by comparing the energy performance of various varieties made from multiple materials. For this a building in Khulna was selected and modeled using sketch up then the energy analysis was done in ECOTECT simulation software. The result shows difference in energy consumption. It will help designers to select most appropriate materials for windows in tropical residential buildings to ensure a more energy efficient and economically efficient housing.

Keywords: *Energy efficiency, energy consumption, window materials.*

1. INTRODUCTION

The contemporary period faces a significant energy crisis marked by a recurring pattern of scarcities throughout the last five decades. Bangladesh is now facing a critical scenario as there has been a substantial decline in crucial resources such as gas and oil supplies. Buildings are now an important part of the global energy usage situation as countries try to deal with the effects of their rising energy needs caused by population growth and development. More than two-thirds of all energy used and half of all power used in the world is used in the building sector, which also uses the most energy (Aidin Nobahar Sadeghifam, 2020). According to new graphs from the Intergovernmental Panel on Climate Change, the building industry uses more than forty percent of all the energy used in some countries (IPCC) (Heydari, Sadati, & Gharib, 2021) (De Gastines, Correa, & Pattini, 2019) (Choi, Ozaki, & Lee, 2022). Population growth is predicted to raise building comfort and service needs, including energy consumption, as people spend more time inside. Air conditioning systems, which manage internal temperatures and offer thermal comfort, use most energy in tropical residential structures. When it comes to energy use, the main thing to think about is the materials that are needed for the building's main parts and its covering. Choosing the right ceiling, windows, walls, roof, and floor materials can cut down on the amount of energy that homes in warm areas use by a large amount. If the shell lets a lot of heat through, the house would need a lot of cooling. The shell, walls, floors, roofs, and windows are all part of the plan for the building environment. In the majority of domestic buildings in the country, walls lose 35% of their heat, floors lose 7.5%, ceilings lose 7.5%, and windows lose 50% (Aidin Nobahar Sadeghifam, 2020). Therefore, significant heat loss by choosing good window material is a key part of reaching this goal. So, houses need to use less energy.

When glass is done right, it lowers the need for cooling and warmth, which means less energy is used overall. The frame design could use more sustainable materials and materials with the least amount of energy used to make them, like aluminium-covered wood and wood. Usually, windows are built into the front and back of a building. They let natural light in and let air flow through. Heat from the sun can easily enter a room, but it can't leave because the holes are too small (Aidin Nobahar Sadeghifam, 2020). The need for purposeful interventions to enhance energy efficiency is underscored by the significant disparities in thermal transmittance values (U-value) across windows and other elements of a structure (De Gastines, Correa, & Pattini, 2019) (Choi, Ozaki, & Lee, 2022) (Sinha & Kutnar, 2012). Furthermore, recent patterns show that the growth of both population and energy use at the same time has led to a significant rise in energy costs, too much carbon dioxide emissions, and negative environmental effects such as the ozone layer depletion, climate change, and global warming. This research examines the intricate connections between the selection of materials, the design of buildings, and energy efficiency, specifically focusing on the crucial role of windows in tropical residential architecture. The case study focuses on a structure located in Khulna, Bangladesh, chosen due to its recognition of the urgent requirement for sustainable solutions. The study aims to identify the optimal window materials for energy preservation in the specified context by conducting a comprehensive analysis using software tools such as SketchUp and the simulation application ECOTECT.

Architects and engineers may enhance their design process, simulation capabilities, and building performance visualization by integrating Building Information Modelling (BIM) with energy simulation tools like ENERGYPLUS and TRANSYS. The International Energy Agency (IEA) estimates that energy efficiency could increase by 80%; therefore, intelligent design decisions are crucial. In tropical locations, air conditioning systems in residential constructions primarily depend on windows to regulate energy consumption and maintain appropriate temperatures. Choosing appropriate materials for components such as flooring, walls, ceilings, windows, and roofs is essential to minimize energy consumption (Sinha & Kutnar, 2012) (Choi, Ozaki, & Lee, 2022).

2. METHODOLOGY

This study uses a thorough quantitative research method to look into the complicated effects of different window materials on how much energy houses use in Khulna. The primary thrust of this investigation revolves around the meticulous execution of energy simulations, facilitated by the integration of ECOTECT software. Recognized as a preeminent tool in the realm of assessing building performance and energy efficiency, ECOTECT provides a sophisticated platform for the precise evaluation of how distinct window materials influence the overall energy dynamics of structures in the unique climatic conditions prevalent in Khulna. The integration of ECOTECT not only ensures a robust analytical framework but also positions this study at the forefront of methodological rigor in unravelling the intricate relationship between window materials and energy consumption within the specified locale.

2.1 Study Area

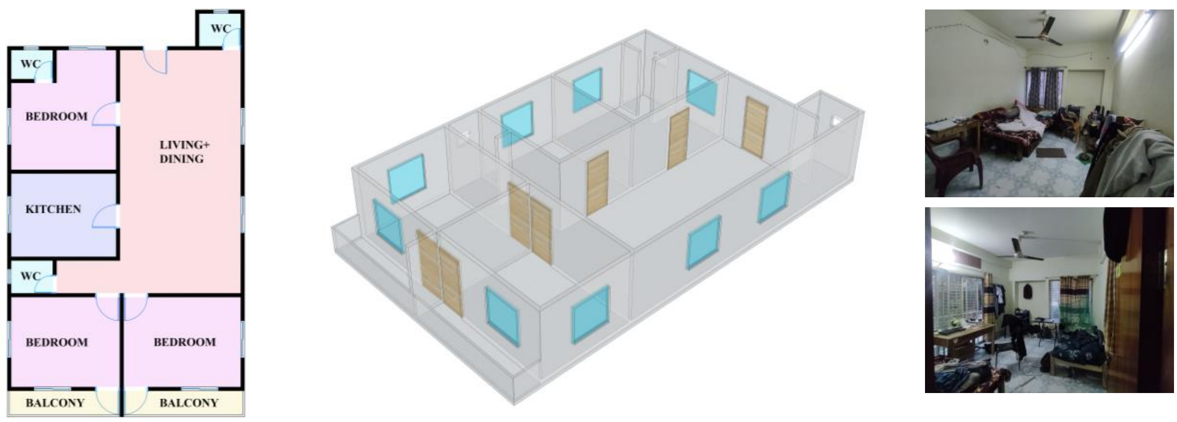
The research site selection in Khulna is based on an analysis of the region's varied climatic conditions. The selected site offers a representative subset for evaluating the energy efficiency of structures situated in a tropical environment. The simulation will utilize a four-story system comprising two units per floor, which illustrates a traditional residential building located in the Sonadanga residential locality of Khulna. The longitude is 89.5663° E, and the latitude is 22.8129° N.

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature °C (°F)	18.9 °C (66) °F	22.4 °C (72.2) °F	26.6 °C (79.9) °F	29.1 °C (84.4) °F	29.5 °C (85) °F	28.8 °C (83.8) °F	27.8 °C (82.1) °F	27.8 °C (82) °F	27.5 °C (81.4) °F	26.3 °C (79.3) °F	23.2 °C (73.8) °F	20 °C (68) °F
Min. Temperature °C (°F)	12.9 °C (55.3) °F	16.2 °C (61.1) °F	21 °C (69.7) °F	24.9 °C (76.8) °F	26.2 °C (79.1) °F	26.5 °C (79.6) °F	25.9 °C (78.5) °F	25.7 °C (78.2) °F	25.2 °C (77.3) °F	23 °C (73.4) °F	18.4 °C (65.1) °F	14.5 °C (58.2) °F
Max. Temperature °C (°F)	25.1 °C (77.1) °F	28.5 °C (83.3) °F	32.5 °C (90.6) °F	34.3 °C (93.8) °F	33.6 °C (92.6) °F	32 °C (89.7) °F	30.7 °C (87.3) °F	30.8 °C (87.4) °F	30.7 °C (87.2) °F	30.1 °C (86.2) °F	28.4 °C (83) °F	25.7 °C (78.3) °F
Precipitation / Rainfall mm (in)	8 (0)	20 (0)	47 (1)	113 (4)	196 (7)	319 (12)	360 (14)	301 (11)	243 (9)	143 (5)	40 (1)	11 (0)
Humidity(%)	65%	61%	61%	71%	78%	84%	86%	86%	87%	83%	71%	67%
Rainy days (d)	1	2	4	8	12	17	21	21	19	11	2	1
avg. Sun hours (hours)	9.0	9.3	9.4	8.8	8.2	7.9	7.6	7.7	7.8	8.3	8.7	8.6

Figure 1: Yearly Climate Data of Khulna (Data, 2021)

2.2 Case Study

The selected structures are presumed to be residential buildings constructed in Khulna using readily available materials as a constraint on the scope. The primary living areas of each residential building unit are situated on separate floors. These areas include a corridor, kitchen, living room, bedrooms (each with its lavatory), and bathroom. 10% of the total floor area is devoted to windows, which comprises the remaining 152 square meters of the structure for house -1.



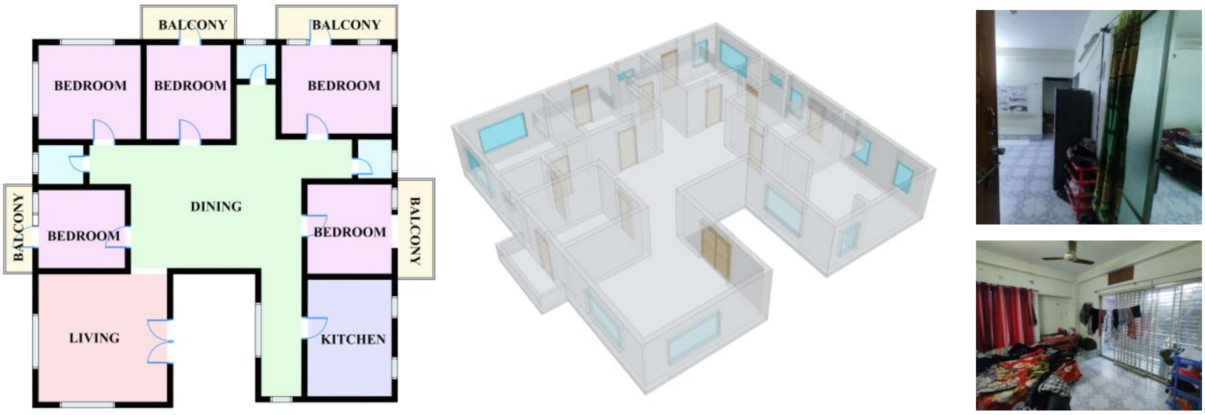


Figure 2: Plan, 3D & photos of the case study House-1 (up), House-2 (down) (prepared by author)

An assortment of widely utilized materials from the area was considered to examine the effects of window materials and their impact. Examples of such structures are single-glazed aluminium and timber frameworks, double-glazed aluminium frames, and energy-efficient materials. Each material's thermal conductivity, solar heat gain coefficient, and overall insulation properties are evaluated. A comprehensive dataset about the chosen structure was gathered through a field survey, encompassing its precise measurements, orientation, and raw materials. SketchUp is utilized to model the desired format, which is subsequently simulated with ECOTECT, an efficient software application designed specifically for dynamic building simulation. The model incorporated meteorological conditions and local climate data unique to Khulna. Simulations are performed to examine various circumstances, altering the window materials accordingly. Energy consumption metrics, including heating and cooling demands, are analysed for each scenario.

Table 1: Thermal Properties of the selected windows (ECOTECT)

Thermal Properties	**Single Glazed Timber Frame (W1)**	**Single Glazed Aluminium Frame (W2)**	**Double Glazed Timber Frame (W3)**	**Double Glazed Aluminium Frame (W1)**
U-Value (W/m2. k)	5.10	6	2.26	2.41
Admittance (W/m2. k)	5	6	2.2	2.380
Solar Heat Gain Coeff.	0.94	0.94	0.75	0.75
Visible Transmittance	0.737	0.753	0.639	0.611
Refractive Index of Glass	1.74	1.74	1.74	1.74
Alt. Solar Gain (Heavyweight)	0.47	0.47	0.21	0.21
Alt. Solar Gain (Lightweight)	0.64	0.64	0.29	0.29

The thermostat was set between 18 and 26 degrees Celsius for optimal thermal comfort. When choosing the sample windows for the simulation, the physical properties of the U-factor, solar heat gain coefficient (SHGC), visible transmittance (VT), and emissivity were considered. In contrast to the window properties that were altered during the simulations, the walls, roofs, and other components maintained their original characteristics to ascertain window types' influence on cooling burdens. All simulations were subsequently executed to determine the annual stresses of the selected structures.

3. FINDINGS AND ANALYSIS

Our research was centred on a comprehensive examination of the energy usage patterns of buildings in Khulna. Our study examined the correlation between window materials and their influence on key performance indicators such as the refractive index of glass, U-value, admittance, and solar heat gain coefficient (SHGC). The four window materials scrutinized in this study were single-glazed timber frame, single-glazed aluminium frame, and double-glazing.

From Table 2 we can see that the energy consumption per year for the house-1 featuring Single Glazed Timber Frame windows was determined to be 356611 watt-hours. On the contrary, the energy consumption of the house featuring single-glazed aluminium frame windows was marginally more significant at 360,154 watt-hours. Variations in U-Values may account for this discrepancy; mainly, the aluminium frame increases thermal conductance, resulting in a more substantial energy requirement. Additionally, fluctuations in the solar heat gain and admittance coefficient may impact the energy dynamics. An extensive examination unveiled those residences outfitted with Single Glazed Timber Frame windows exhibited an annual energy consumption of 356,711 watt-hours. In contrast, those equipped with Double Glazed Timber Frame windows demonstrated a notable decrease of 346,625 watt-hours). The reduced energy consumption observed can be attributed to the enhanced insulating characteristics of double glazing, which manifest as a reduced U-value and heightened resistance to heat transfer.

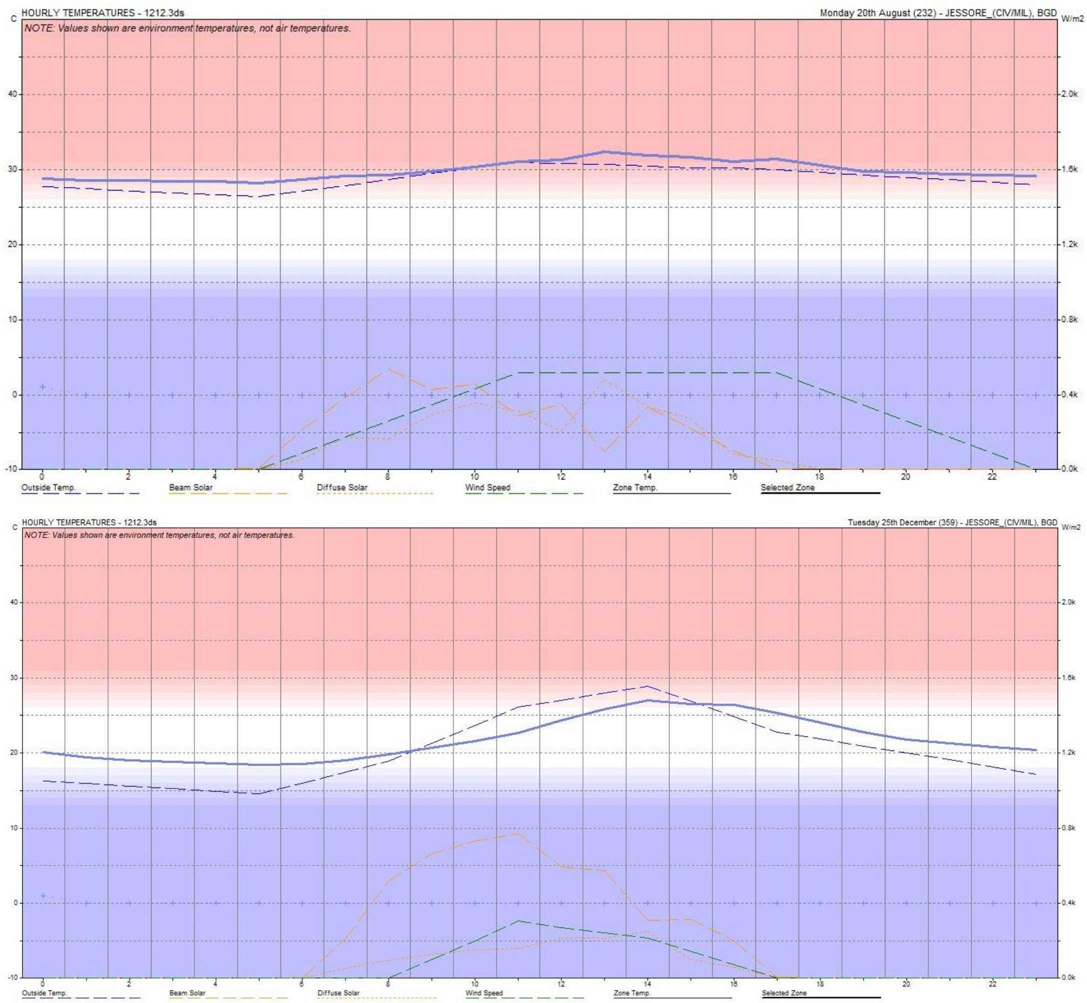


Figure 3: Thermal Analysis of Houses, 20th August (up), 25th December (down)

Additionally, the refractive index of the glass utilized in double glazing could impact energy dynamics. When comparing the energy consumption of residences fitted with single-glazed timber frame windows and those equipped with double-glazed aluminium frame windows, the former revealed a substantial increase of 356,711 watt-hours. In contrast, the latter exhibited a marginally reduced consumption of 347,267 watt-hours. In case of house-2, house-2 with a single-glazed wood frame used 624,286 watt-hours (wh) for cooling. House-2 with a single-glazed metal frame, on the other hand, used a little more energy, 631,981 wh for the cooling load. Also, house-2 with double-glazed windows were included in the comparison, which showed some interesting trends. The cooling load energy consumption of a house with a double-glazed wood frame was 604,114 wh, which is a big drop from the single-glazed version. For the same reason, house-2 with a double-glazed metal frame used a little less energy for cooling, equal to 603,384 wh. These results show that the type of glass and window frame material have different effects on how much energy is needed to cool a home generally. The results not only show how much energy each case uses, but they also make the clear benefits of double-glazed windows, especially when paired with a wooden frame, stand out. This in-depth study adds important new information to the conversation about how to build in a way that uses less energy and shows possible ways to improve how well domestic buildings handle cooling loads. The differences seen could be because of how double glass drops the U-Value and how aluminium frames change things like the amount of light that comes in and the solar heat gain rate. Here the calculated energy consumption is only cooling load means only those devices that are used for maintaining thermally comfortable living environment. In both houses normal cooling method of using ceiling fan has been considered. Potentially exacerbating variations in visible transmittance is the refractive index of the glass. The results of our study shed light on the complex correlation between window materials and critical parameters, including the refractive index of glass, U-value, admittance, solar heat gain coefficient, and visible transmittance. The incorporation of double glazing, regardless of the material of the frame, becomes a significant contributor to the reduction of energy usage. Aluminium frames exhibit the potential to augment energy efficiency by integrating double glazing, attributable to their influence on U-values and other optical characteristics. The findings of this study not only contribute to the discourse on energy dynamics in structures and offer significant knowledge for refining architectural plans to accommodate the unique climatic conditions of Khulna. Additional research is recommended to explore the complex interrelationships among these variables to develop more all-encompassing strategies for energy-efficient construction.

Table 2: Thermal and Energy Consumption analysis (found on ECOTECT analysis)

Window	**Thermal Analysis (17th April)**	**Thermal Analysis (20th August)**	**Thermal Analysis (25th December)**	**Annual Energy Consumption (Wh) House-1 (Only Cooling Load)**	**Annual Energy Consumption (Wh) House-2 (Only Cooling Load)**
Single Glazed Timber Frame	Avg. Temperature: 30.0 C (Ground 25.8 C)	Avg. Temperature: 28.5 C (Ground 25.8 C)	Avg. Temperature: 20.4 C (Ground 25.8 C)	356711	624286
Single Glazed Aluminium Frame	Avg. Temperature: 30.0 C (Ground 25.8 C)	Avg. Temperature: 28.5 C (Ground 25.8 C)	Avg. Temperature: 20.4 C (Ground 25.8 C)	360154	631981
Double Glazed Timber Frame	Avg. Temperature: 30.0 C (Ground 25.8 C)	Avg. Temperature: 28.5 C (Ground 25.8 C)	Avg. Temperature: 20.4 C (Ground 25.8 C)	346625	604114
Double Glazed Aluminium Frame	Avg. Temperature: 30.0 C (Ground 25.8 C)	Avg. Temperature: 28.5 C (Ground 25.8 C)	Avg. Temperature: 20.4 C (Ground 25.8 C)	347267	603384

4. CONCLUSION AND DISCUSSION

An extensive investigation into the impact of various window materials on the energy consumption of buildings in Khulna has unveiled complex relationships between the properties of the materials and indicators of energy performance. The discourse analyses the intricate correlation among the variables: Admittance, Solar Heat Gain Coefficient (SHGC), Visible Transmittance (VT), U-Value, and the refractive index of glass. Doing so illuminates the ramifications for the design of sustainable buildings. Regarding the cooling load results, double glazed window with timber frame is showing good result in terms of cooling load, as shown by the low U-factor, which means a slow transfer rate. So, the thermophysical features are what make buildings either move or store heat. The ultimate thermophysical feature is the U-value, which tells us how fast heat moves into and out of a building and, by extension, how much energy is needed for cooling and heating. According to the U-value, a building uses how many Watts per hour in a one-meter square area where the temperature difference between hot and cold is one degree Celsius. Due to the big difference in temperature between inside and outside in a warm setting, using windows with a low U-factor can usually save a lot on cooling costs. A more comprehensive analysis of the thermal properties of single-glazed aluminium frames and single-glazed timber frame structures is warranted in light of the observed discrepancies in energy consumption. The increased energy consumption linked to aluminium frames can be ascribed to their superior thermal conductance, which impacts U-Values and Admittance. Therefore, it is critical to consider the insulating properties of the glazing and the frame material to achieve the most excellent possible energy efficiency. Energy consumption is significantly reduced when double-glazed timber frame windows are installed instead of single-glazed windows. This discovery highlights the critical significance of double glazing in improving insulation, consequently reducing U-values and alleviating heat transfer. The discourse also encompasses the possible impact that the refractive index of glass may have, which could result in modifications to visible light transmission and affect the overall energy dynamics. Similarly, comparing structures composed of single-glazed timber frames and double-glazed aluminium frames reveals noteworthy findings. Integrating double glazing and aluminium frames into a design reduces energy usage, thereby exposing a potentially fruitful pathway toward implementing sustainable construction methods. The complex mechanisms at play necessitate careful consideration of the interconnections among U-Values, admittance, and the solar heat gain coefficient, which are influenced by the crystal's refractive index.

As a whole, this research provides significant contributions to our understanding of the complex correlation between window materials and the resulting energy usage in the Khulna context. A comprehensive comprehension of the underlying dynamics has been achieved through the integration of several critical metrics, namely the refractive index of glass, U-Value, Admittance, SHGC, and VT. Regardless of the material of the frame, the results underscore the importance of double glazing in reducing energy consumption. When designing energy-efficient structures, the contrast between aluminium and timber frameworks underscores the necessity of taking thermal properties into extensive account. By judiciously selecting materials, it may be possible to attain optimal energy performance, as suggested by the potential benefits of integrating double glazing with aluminium frames. Further investigations are stimulated by these discoveries as we advance in the pursuit of sustainable architecture. Ongoing investigation is required to refine design guidelines for energy-efficient buildings in Khulna, taking into account the distinctive climatic conditions, due to the dynamic interaction between window materials and other associated properties. By fostering a path towards a more sustainable and energy-efficient built environment, this research adds to the dialogue surrounding environmentally conscious building practices.

REFERENCES

Aidin Nobahar Sadeghifam, I. K. (2020). Analysis of Windows Element for Energy Saving in a Tropical Residential Buildings in Order to Reduce the Negative Environmental Impacts. *Journal of Environmental Treatment Techniques*, 1-6.

Choi, Y., Ozaki, A., & Lee, H. (2022). Impact of Window Frames on Annual Energy Consumption of Residential Buildings and Its Contribution to CO2 Emission Reductions at the City Scale. *Energies*, 3692.

Data, C. (2021). *Arongghata*. Retrieved from en.climate-data.org: https://en.climate-data.org/asia/bangladesh/khulna-division/arongghata-1062010/

De Gastines, M., Correa, É., & Pattini, A. (2019). Heat transfer through window frames in EnergyPlus: Model evaluation and improvement. *Advances in Building Energy Research*, 138-155.

Heydari, A., Sadati, S., & Gharib, M. (2021). Effects of different window configurations on energy consumption in building: Optimization and economic analysis. *Journal of Building Engineering*, 1-15.

IPCC. (2007). *Climate Change 2007: Synthesis Report, Summ. For Policymakers*. Geneva, Switzerland: IPCC.

Sinha, A., & Kutnar, A. (2012). Carbon Footprint versus Performance of Aluminum, Plastic, and Wood Window Frames from Cradle to Gate. *Buildings*, 542-553.