BIM-DRIVEN ENERGY OPTIMIZATION: ENHANCING THERMAL PERFORMANCE OF BUILDINGS IN ISLAMABAD'S CLIMATE

[a] *Shujahat Anwar*, [b] *Hassaan Bin Raheel**

a: Civil Engineering Dept., National University of Technology, NUTECH, Islamabad, Pakistan.
Shujahatanwar55@gmail.com
b: Civil Engineering Dept., National University of Technology NUTECH, Islamabad, Pakistan.
Hassaanraheel01@gmail.com
*Corresponding author

***Abstract*:** In contemporary architecture, energy efficiency is a key design consideration due to increasing operational energy demands and environmental concerns. Contrary to the common belief that construction costs dominate a building's lifecycle expenses, operational energy and maintenance costs impact long term sustainability. In Islamabad, a city with composite climate featuring hot summer and cold winters, poorly designed buildings often rely on HVAC systems, resulting in higher energy usage and carbon emissions. This study employs Building Information Modeling (BIM) tools, specifically Revit and Insight, to analyze and optimize the energy performance of the NIEC lab which is under construction at NUTECH University. The model incorporates real climatic data and material properties to assess how heat transfer mechanisms affect thermal efficiency. Simulation results an initial Energy Use Intensity (EUI) of 271 kWh/m²/year, which was reduced by 58% through strategic modifications, including shading devices, window glazing, and building orientation. This paper further explores the integration of renewable energy systems, such as photovoltaic panels and small wind turbines, as potential solutions for reducing grid dependency. These findings offer practical recommendations for designing thermally efficient, cost-effective and sustainable buildings tailored to Islamabad's climate.

Keywords- BIM, Energy Efficiency, Heat Transfer, Sustainable Building Design

1. Introduction

The increasing demand for energy-efficient building in Islamabad, a city having hot summers and cold winters, needs innovative design approaches to optimize thermal performance by minimizing energy consumption. Cities are growing and energy is becoming expensive so architects and engineers should use advanced tools like Building Information Modeling (BIM) to make environmentally friendly buildings.

In Pakistan traditional building design ignore passive design strategies due to which people rely on heaters and air conditioner to maintain comfort. Through which not only their operational cost increases carbon emissions also increase. To address this challenge, BIM-based energy simulations are used to assess and enhance building performance in Islamabad's climatic conditions. For that the study started with two phases, first a review of existing literature on building modeling was conducted, passive and active design strategies were carried out, and renewable energy integration was studied in detail. This provided background knowledge and highlighted sustainable practices used in construction industry widely. In the second phase, the theoretical findings were practically implemented on Autodesk Revit and Insight. These tools simulate energy consumption based on architectural features and material choices. A detailed report has been generated by Revit to assess heating and cooling loads. It showed that building uses 271 kWh/m²/year annual energy use intensity (EUI). Using Insight, the building design was enhanced by changing the size of windows, using better glass and adding shades. These changes were expected to lower energy use without putting extra loads into heating and cooling.

Architectural techniques including thermal insulation, natural ventilation and shading devices and optimal orientations that lower energy consumption without the need for mechanical equipment are known as passive design strategies. This study also investigated renewable energy integration by assessing the feasibility of photovoltaic systems and small-scale wind turbines (e.g., the Liam F1 Urban Wind Turbine). As Islamabad is high solar irradiance solar energy is the best option while compact wind turbines provide potential power in urban settings[1]. Integrating natural ventilation system and wind impedance design can also reduce dependance on cooling and heating systems[2]. To provide consistent and dependable energy supply, hybrid renewable integration combines multiple renewable energy sources such as solar photovoltaic cells with small scale wind turbines.

International case studies like Manama (Bahrain) and Phoenix (USA) emphasizes the importance of BIM in optimizing thermal performance in hot climates[3]. The Clover Project used IES-VE simulations to show the importance of digital twin technology for better building design from planning stages by focusing on performance[4].

Including these improvements Pakistan still faces some challenges. BIM is still not used widely a traditional software like AutoCAD etc. is still being used, it is due to regulatory gaps and a shortage of trained professionals. To overcome these hurdles, update construction policies, train professionals, and make BIM as common tools. This study will connect theory with the real world by using BIM models, climate friendly design ideas and check whether renewable energy works well specially for Islamabad. The findings of this study will provide an idea that how architect, engineers and policy maker can make energy-efficient design that will be comfortable in all seasons and align with Pakistan's sustainability and climate goals.

2. Research Methodology

2.1 Research Methodology

In this study simulation was conducted using Building Information Modelling (BIM) to evaluate and enhance the energy performance of buildings within Islamabad's composite climate. The architectural modeling of NIEC (NUTECH Incubation & Entrepreneurship Centre) Lab Building, currently under construction, was used as a case study and using Performance based energy analysis was carried out using Autodesk Revit and Insight. Figure 1 illustrates the methodology flowchart followed to carry out this research.

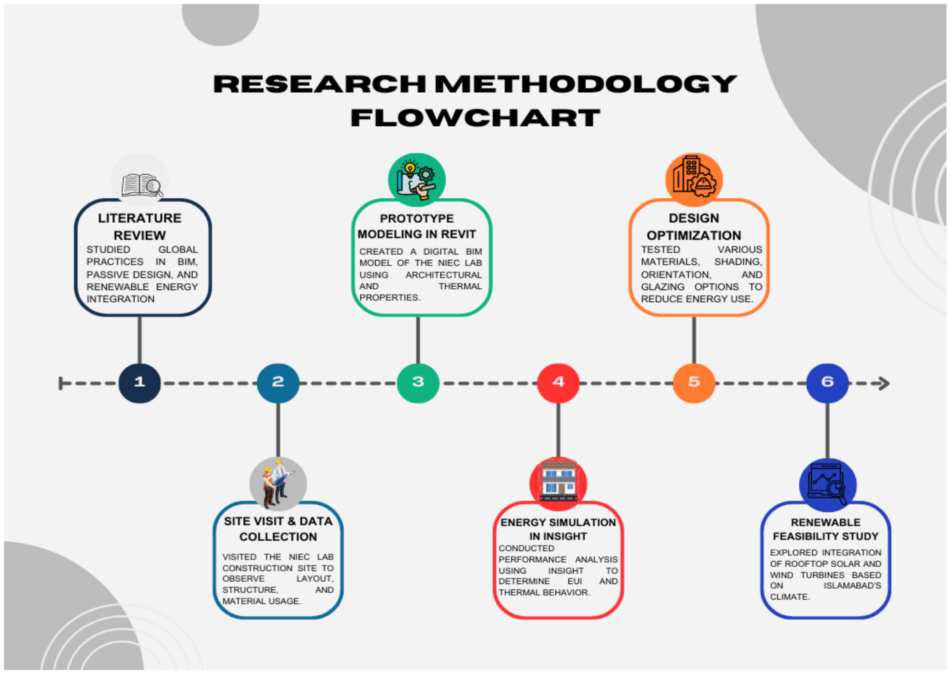

Figure 1 Research Methodology Flowchart

2.2 Prototype Building Model – NIEC Lab (NUTECH Campus)

Through site visits, drawings and onsite observations, a 3D model of a building was developed using Autodesk Revit. This model incorporates actual site conditions and specific material used during construction to enhance simulation. This model is used as a base to test how architectural and material design can affect thermal and energy performance.

Key Modeling Steps in Revit:

- **Site Location**: The project's geolocation was set to Islamabad, for accurate solar and climate date.
- **Architectural Layout**: Model is created just like representing actual model of the NIEC lab with focusing on zones like corridors and open communal areas. Figure 2(a) shows the architectural model of NIEC lab created using Revit.
- **Assumptions**: Peak occupancy was assumed to peak during working hours i.e. 9:00 AM to 4:00 PM. Standard equipment loads were considered based on typical lab usage, including lighting, plug loads, and HVAC systems. Moreover, it is assumed that the windows are operable under moderate weather conditions.
- **Material Selection**: Construction material used on site were assigned with thermal properties like R-Value, SHGC etc. to represent real-world building performance during simulations. Figure 2(b) shows the material properties of walls; Figure 3(a) shows the door material properties and 3(b) shows the windows properties.
- **Glazing & Envelope Detailing**: For studying daylighting and heat transfer effects, the actual window-to-wall ratios (WWR) were determined using site data specifically on southern and western facades
- **Orientation of Building**: Orientation of the building was designed as per its actual north-facing to assess the heat gain and shading potential during different seasons.

Figure 2 BIM based Revit Model of NIEC lab building: (a). Full architectural model representing actual site layout (b). Wall material properties defined for simulation

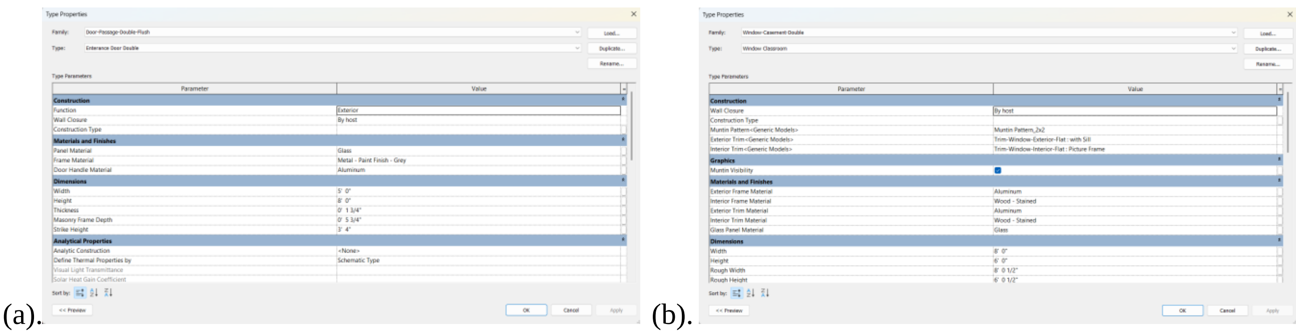

Figure 3 Thermophysical specifications for envelope components used in the BIM model: (a). wooden door R-value and composition; (b). Glazing properties including SHGC and U-values

2.3 Energy Analysis & Simulation

After completing the Revit model, dynamic energy simulations were conducted using Autodesk Insight. The workflow for simulation on Insight is as follows:

1. **Energy Settings**: For simulating the model some energy setting was done according to usage of the building such as selecting Occupancy type, operational hours, lighting and equipment loads etc. Figure 4(a) shows the selected weather station for the energy analysis and figure 4(b) illustrates occupancy type and operational hours selected for energy analysis.
2. **EUI Result**: Initial simulations results shows that Energy Use Intensity (EUI) of model was 271 kWh/m²/year, that indicates the need for improvement in building's energy performance. Figure 5(a) shows the annual energy consumption per square meter and figure 5(b) shows the annual energy cost per square meter.
3. **Design Variable**: Different parameters of building were changed to assess their impact on EUI. Figure 6 shows the zone load summary which includes the peak time, heating and cooling loads.
   - Wall Insulation for thermal resistance
   - Double glazed window type having low emissivity
   - Using shading devices
   - Natural Ventilation and thermal mass optimization through orientation of building.
4. **Final Simulations**: After several changes and testing various passive strategies, significant energy design was achieved considering comfort and daylight sufficiency.

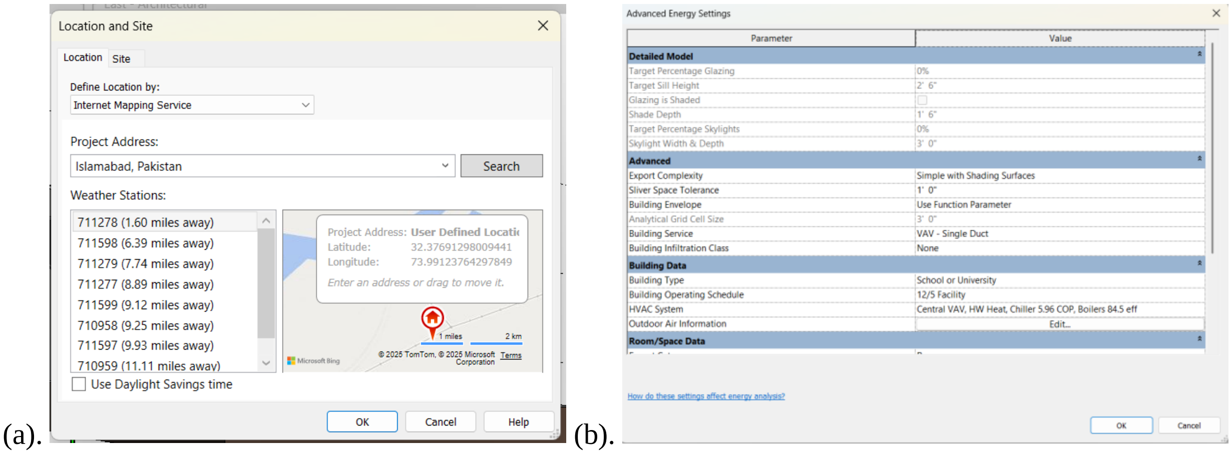

Figure 4 Building setting for simulations (a). Selecting exact location of building (b). Selecting occupancy type and operational hours

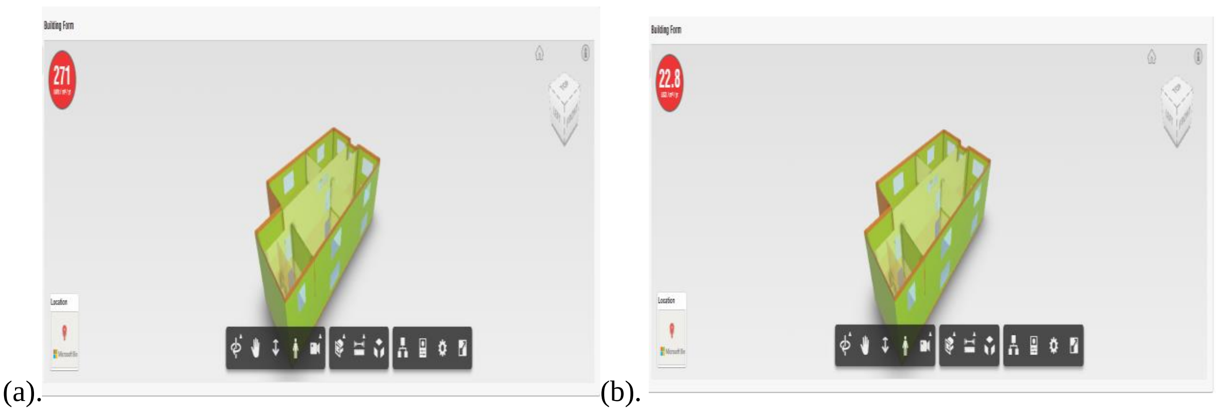

Figure 5 Initial energy analysis results from Autodesk Insight: (a). Predicted Energy Use Intensity (EUI) (b). annual energy cost per square meter

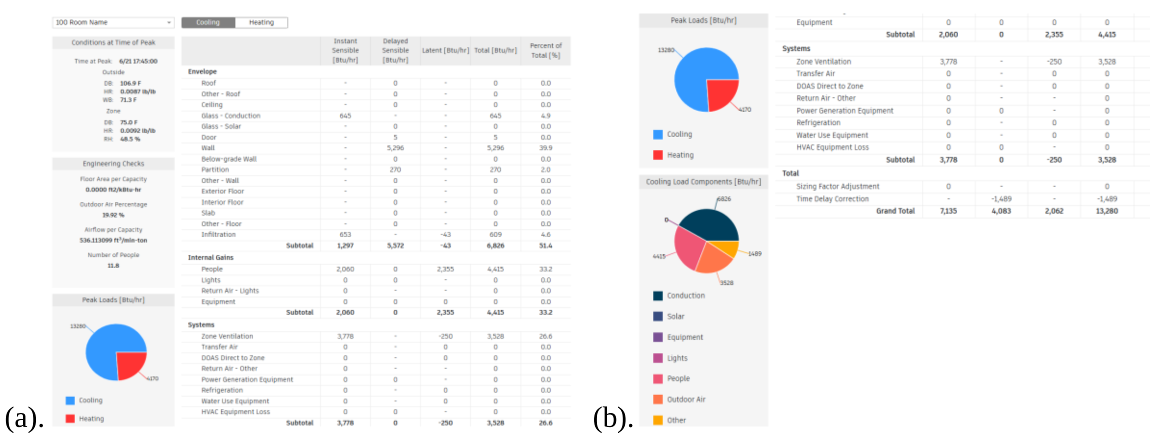

Figure 6 Peak load analysis from Insight simulation: (a). building conditions during peak time (b). distribution of cooling load components

5. **Limitations:** The tool utilized for energy analysis is Autodesk Insight which does not fully reflect the actual system behavior in extreme weather events. Moreover, it does not account for future climate scenarios as it uses predefined weather data.

3. Results

This section presents the overall results after energy simulation and analysis using Autodesk Revit and Insight plugin. Various design improvements were implemented in the model to evaluate performance by assessing energy use intensity (EUI) and estimated operational costs.

3.1 Initial Model Analysis

The initial model was developed in Revit without any design improvement and was simulated using Insight. The simulation represents the following results:

- **Energy Use Intensity (EUI):** 271 kWh/m²/year
- **Operational Cost:** 22.8 USD/m²/year

These results represent inefficiencies in building envelopes, HVAC systems, lighting setup and how buildings will be operated in daily schedule.

3.2 Changes applied for optimization

Several modifications in model were made to improve energy efficiency. Some of those modifications are as follows:

- Upgrading building envelope insulations.
- Enhancing HVAC system performance.
- Lighting system is optimized using daylighting and LED solutions.
- For better sealing-controlled infiltration is done.
- Adjusting operating schedules according to actual use.
- Integrated daylight and occupancy sensors.

3.3 Impact of Design changes on Energy Performance

After doing the above measures, we re-simulated the model in Insight. The results after simulations were as follows:

- **Reduced Energy Use Intensity:** 127 kWh/m²/year
- **Reduced Operational Cost:** 9.49 USD/m²/year
- **HVAC System Cost Range:**
    - **Minimum:** 7.85 USD/m²/year
    - **Maximum:** 18.24 USD/m²/year
    - **Mean Value:** 11.68 USD/m²/year

These results indicate a successful reduction in the energy cost by over 58% demonstrated that early-stage design analysis and optimization can lead to significant long term energy savings for the building. Figure 7(a) shows the annual energy consumption per square meter after the changes are applied and figure 7(b) shows the annual energy cost per square meter after the changes are applied. Figure 8 illustrates the model history for different systems.

(a). 

(b). 

Figure 7 Upgraded Energy Analysis Report (a). Annual Energy Consumption per square meter (b). Annual energy cost per square meter

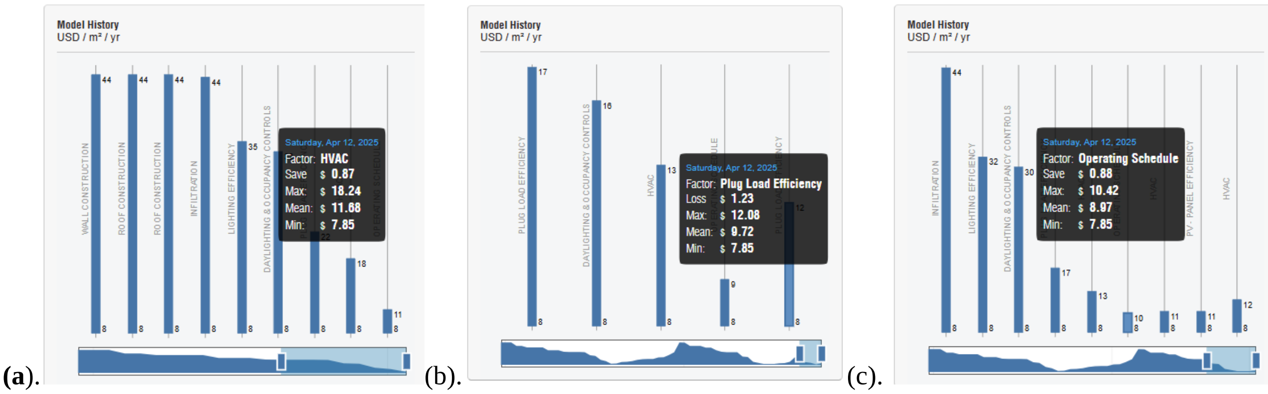

Figure 8 Model history (a). HVAC System Cost Range (b). Plug Load Efficiency System Cost Range (c). Operation Schedule system Cost Range

Summary Table of Energy Results

Comparison of results before and after making various changes in the designed model are shown in Table 1.

Table 1 Summary of energy simulation results before and after design optimization, highlighting EUI, operational cost, and HVAC performance

Parameter	Initial Model	Optimized Model	Improvement
Energy Use Intensity (EUI)	271 kWh/m²/year	127 kWh/m²/year	Significant decrease
Operational Cost	22.8 USD/m²/year	9.49 USD/m²/year	↓ 58%
HVAC Cost (Mean)	18.5 USD/m²/year	11.68 USD/m²/year	Optimized HVAC system
Plug Load Efficiency (Mean)	14.77 USD/m²/year	9.72 USD/m²/year	Optimized Schedule
Operating Schedule (Mean)	10.91 USD/m²/year	8.97 USD/m²/year	Optimized Schedule
Lighting and Envelope Improvements	Not Implemented	Implemented	Contributed to savings

The Energy Use Intensity (EUI) of the building improved by 53%, which allowed the improvement of a building that formerly recorded Energy Use Intensity (EUI) of 271 and 127 kWh per m 2 per year after installing insulation upgrades, optimized glazing, and shading devices. It can be explained as improvement whose increase can be reached first of all with the help of the reducing thermal transmittance (U-value) of the building envelope lowering heat loss in winter and narrowing heat gain in summer.

Namely, solar heat gain coefficient (SHGC) is lowered when there are windows with low-emissivity coatings and the use of a double-glazing window. The introduction of shading systems prevents direct solar exposure to south, west facing elevations, which can enhance thermal comfort, and keep mechanical cooling systems at a minimum.

Moreover, the optimization of the operation schedule and occupancy settings maintains that HVAC systems are used closer to reality and become more efficient. These findings can be compared to other BIM-based studies, e.g. Chen et al. (2024) and Zhang et al. (2025), which achieve 40-60 decrease in EUI through envelope optimization and passive strategies in the hot climate.

4. Limitations:

Autodesk Insight offers useful early-stage energy analysis, accuracy may be impacted under harsh weather conditions due to its simplified HVAC models and dependence on past weather data. Furthermore, the generalizability of results is restricted in study due to the absence of sensitivity analysis. Parametric simulations, real time occupancy data and sophisticated modelling tools may all be used in future studies to confirm and improve these results.

5. Recommendations

A 58% reduction in annual operational energy cost was achieved through implementation of passive design strategies including insulation, optimizing glazing and natural ventilation etc. We can also reduce the dependency on grid electricity and promote sustainable building operations, through hybrid renewable energy integration. Through research and simulation data, recommended solutions are the solar PV system and a compact wind turbines system that are suitable for Islamabad's urban environment.

5.1 Hybrid Renewable Energy Integration

The study investigated the possibility of integrating hybrid renewable energy to further improve the building's sustainability and energy performance. In order to provide a more consistent and reliable energy supply, photovoltaic (PV) system was combined with small wind turbines, such the Liam F1 Urban Wind Turbine. This hybrid strategy improves overall system efficiency and lessens the drawbacks of depending only on one energy source particularly in the fluctuating weather conditions typical of Islamabad's composite environment.

4.1.1 Integration of Solar Photovoltaic Systems

Islamabad receives an average solar irradiance of 5.3 kWh/m²/day, which means that installing solar panels on roof top is a smart and affordable solution to meet building energy need[5]. According to Sharma et al[6]. In Islamabad using hybrid systems, especially solar systems, can reduce the dependency on fossil fuel. 1kW solar system can generate between 1460-1680 kWh/year in Islamabad, which is enough to cover residential or institutional electricity demand[7].

4.1.2 Integration of Urban Wind Energy Systems

For supporting solar system, especially in cloudy weather, compact urban wind turbines like the Liam F1 Urban Wind Turbine are the solution for generating extra power. Manufactured by The Archimedes, the Liam F1 is a 1.5m Dia, 100kg turbine having capacity of producing 300-2500 kWh/year at an average speed of 4.5 m/s[8]. Due to its aerodynamic design, it can capture upto 80% available wind energy, while operating silently at 45 decibels. Due to its built-in directional shape, it requires no additional mechanical alignment system. These features make it possible to use the roof on top of institutions like NIEC Lab, where space is limited but sustainability is priority.

According to the results of Zhang et al.[4] and Noorollahi et al.[9] wind system when used with smart grid technology or combined with solar can make energy system more stable and help in reducing carbon emissions. Chen et al. [3] highlighted how hybrid system works efficiently in dense cities like Manama and Phoenix where building-integrated renewable system reduced grid dependency upto 60%. Table 2 describes the key advantages of utilizing wind energy system.

Table 2 Key Advantages of Solar + Wind Integration

Parameter	Solar PV System	Liam F1 Wind Turbine
Output (Annual)	~1,460–1,680 kWh/kW	~300–2,500 kWh/unit
Day/Night Balance	Daytime performance	Evening/Night wind compensation
Urban Suitability	Rooftop	Rooftop/wall mount (1.5 m diameter)
Noise Level	Silent	~45 dB (urban background level)
Wind Requirement	N/A	Avg. 4.5 m/s at 10m height

By implementing hybrid renewable energy strategies, building can move towards net zero operational energy use. Combining passive design with on-site renewables will not only make cost-effective future buildings but also resilient and climate-adaptive in future.

6. Conclusion

This study shows that using BIM and energy simulation tools in designing buildings will reduce the energy consumption and maintenance cost of these buildings especially in the Islamabad climate. NEIC lab at NUTECH was modeled using Autodesk Revit and Insight, and they looked at its baseline energy performance. Initially simulations result high energy use intensity (EUI) of 271 kWh/m²/year and an operational energy cost of 22.8 USD/m²/year. By making some design changes like better insulation, optimizing windows, adding shading devices, and adjusting the building's orientation we have cut the EUI down to 127 kWh/m²/year means energy consumption was dropped by 53% and cost went down by 58%. In addition to it by installing solar panels and wind turbines, it also reduces energy usage by another 22%. Through this hybrid renewable system, we could generate about 30,000 kWh/year.

This research confirms that BIM is not only for designing shapes and material but is also a tool for making smart energy decisions. As results looks favorable, but more work is needed to implement in Pakistan practically. To make BIM common in Pakistan, we need to implement it in the building rules, conduct training programs, and support. Overall, doing energy analysis with BIM early in the design process can really help create buildings that are sustainable, cost-effective, and responsive to climate challenges. The methods and results from this study can help guide architects, engineers, and policymakers in future projects that aim for energy efficiency in similar climates.

Acknowledgment

The authors would like to express gratitude to Almighty Allah who blesses us with an opportunity to carry out this extensive research. A sincere thanks to the National University of Technology, Islamabad, Civil l Engineering Department for giving a chance and support in the work. The NIEC Lab project's academics and staff deserve special recognition for providing access to site data and drawings, which were essential for creating the BIM Model. The support and direction from peers and academic mentors during the research were essential to finishing this study successfully. Lastly, the authors express their gratitude to the 7th Conference on Sustainability in Civil Engineering (CSCE'25) organizers for giving them a venue to showcase their findings.

References

[1] F. Ullah *et al.*, "A comprehensive review of wind power integration and energy storage technologies for modern grid frequency regulation," *Heliyon*, vol. 10, no. 9, p. e30466, 2024, doi: 10.1016/j.heliyon.2024.e30466.

[2] C. N. Nwagu, C. O. Ujah, D. V. V. Kallon, and V. S. Aigbodion, "Integrating solar and wind energy into the electricity grid for improved power accessibility," *Unconv. Resour.*, vol. 5, no. May 2024, p. 100129, 2025, doi: 10.1016/j.uncres.2024.100129.

[3] L. Chen *et al.*, *Green building practices to integrate renewable energy in the construction sector: a review*, vol. 22, no. 2. Springer International Publishing, 2024. doi: 10.1007/s10311-023-01675-2.

[4] X. Zhang, Y. Ge, and R. V. Patel, "Renewable Energy Integration and Energy Efficiency Enhancement for a Net-Zero-Carbon Commercial Building," *Buildings*, vol. 15, no. 3, 2025, doi: 10.3390/buildings15030414.

[5] "National Renewable Energy Laboratory (NREL), 'PVWatts Calculator,' U.S. Department of Energy, 2023.".

[6] "R. Sharma, M. Tiwari, and N. Dubey, 'Hybrid Renewable Energy Systems for Sustainable Development,' Renewable Energy Reports, vol. 2, pp. 45–56, 2023.".

[7] "EcoSpark Solar, 'Peak Sun Hours in Pakistan – A Comprehensive Overview,' EcoSpark Solar, [Online].".

[8] "The Archimedes, 'Liam F1 Urban Wind Turbine: Technical Overview,' iEnergy US, [Online]".

[9] "E. Noorollahi, D. Fadai, S. H. Ghodsipour, and M. Abedi, 'Simulation of wind power cost and integration using EnergyPLAN software,' Sustainable Cities and Society, vol. 65, p. 102607, 2021.".