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1st International Conference on Trends in Advanced Research
March 4-7, 2023 : Konya, Turkey

ICTAR

Sustainability in Building Design: A Comparative Study of Conventional and Energy Efficient Designs using BIM in Lahore, Pakistan

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Abstract –Global energy consumption is increasing rapidly. Pakistan is also facing a severe energy crisis. Lahore, second-largest city in Pakistan, experiences extreme weather conditions, leading to high demand for cooling energy and increased energy consumption. This paper aims to explore the use of energy-efficient practices and building designs to mitigate the impact of energy consumption. It presents a methodology for energy simulation modelling of a residential house using Revit for BIM and GBS for energy analysis. It details the process of modelling the house in Revit, making energy settings, exporting Revit model to a gbxml file, and then analyzing the energy model using GBS. After finalizing best design alternative, modifications are made to the Revit model. Finally, the impact of photovoltaic analysis on energy consumption and cost is determined. The results demonstrate the effectiveness of energy conservation measures (ECMs) in improving energy efficiency of buildings. Incorporating best design alternative resulted in a 40% increase in sustainability and cost-effectiveness, with a saving of PKR.113K/year. Furthermore, the installation of solar panels resulted in a cost saving of PKR.76K/year. Making all the changes collectively, including insulation of roofs and walls, shading and glazing of windows, occupancy and daylight sensors, and solar panels, resulted in total saving 65% of the annual energy consumption, which supports this study despite the cost increment of 1.1 million in initial investment cost. The findings can be used as a basis for developing sustainable building designs that can contribute to a greener environment and promote a sustainable future.

Keywords – Building Information Modeling (BIM), Energy Efficiency, Green Building Studio (GBS), Energy Conservation Measures (ECMs), Solar panels, insulation

I. Introduction

The world's energy consumption is growing fast, mainly due to a rising population. However, using traditional energy sources like fossil fuels is no longer feasible as they are running out quickly, which could lead to an energy crisis worldwide. Jun Chang et al. found out that construction is the primary source of greenhouse gas emissions in many countries, using over a third of the country's total energy resources [1]. Ahmed Sohail et al. studied that Pakistan, one of the world's most energy-deficient countries, derives about 70% of its energy from inefficient thermal sources, resulting in significant energy waste [2]. Lahore, Pakistan's second-largest city, faces extreme weather conditions, with high demand for cooling energy, which amplifies overall energy consumption.

To deal with this, implementing green building practices is essential in reducing the environmental impact of buildings and promoting energy efficiency. Sustainable materials, technologies, and design strategies are used to achieve this goal. Developed countries have been at the forefront of researching and implementing green building practices in recent decades. BIM has also been increasingly used with energy modeling tools to achieve comprehensive and ambitious energy efficiency improvements. Xiao-guang Zhao et al. studied the adoption of green building practices by developed countries which includes using sustainable materials, technologies, and design strategies to reduce the environmental impact of buildings and promote energy efficiency [3]. Masood R. et al. found that BIM can identify potential conflicts in design and construction, improve quality, and reduce rework during construction. However, low adoption and awareness of BIM were revealed among stakeholders in the Pakistani construction industry [4]. Tatjana Vilutiene et al. emphasized the importance of enhancing energy efficiency in buildings, specifically in residential and public structures, to lessen global energy consumption. They highlighted BIM as a tool that can help achieve comprehensive and ambitious energy efficiency improvements by using energy modeling tools and a standard-based approach to manage information across the whole life cycle of built assets [5]. Abdelazim A. A. S. et al. found that BIM technology can improve the performance of buildings and achieve sustainable public and housing buildings, maintaining the life cycle of cities and providing a suitable quality of life for inhabitants [6]. Mushref et al. studied sustainable construction in Saudia Arabia and suggested that BIM can improve sustainable design, but adoption is challenged by issues such as technology and cultural impacts [7].

During building an energy-efficient house, there may be upfront costs associated with thermal design, but the benefits of reduced energy bills in the long run can outweigh those costs. Po-Han Chen et al. found that although the initial construction cost is usually higher, energy savings can offset the additional cost, which accounts for the largest part of the lifecycle cost. [8]. In a case study, Qibo Liu et al. evaluated green performance tools for a library, resulting in a 47.4% reduction in annual loads and meeting national energy efficiency standards for public buildings. The heating load was notably reduced by 59.1%, and the cooling load was reduced by 21.5% [9].

Improving the insulation of a building is a key factor in reducing energy consumption. The selection of appropriate insulation materials and determining the optimal thickness are crucial to achieving cost-effectiveness and efficiency in insulation. In a study conducted by Amna Iqbal et al. in a cold region of Pakistan, three commonly available insulation materials were evaluated: glass wool, extruded polystyrene, and polyethylene. Among the three insulation materials, polyethylene was found to be the most cost-effective and efficient based on its thermal performance as well as cost, thickness and ease of application etc. [10]. Suhaib Ansari et. al. conducted a study in Hyderabad, Pakistan, comparing three insulation materials, including expanded polystyrene, extruded polystyrene, and polyurethane foam, with a conventional building without insulation. Polyurethane foam was found to be the most energy-efficient insulation material, saving 30.90-35.26% of cooling energy in roof-walls, while expanded polystyrene and extruded polystyrene saved 4.66-5.20% and 22.43-25.12%, respectively, during seasonal changes [11]. Sibgha Siddiqui et al. conducted study in Lahore, Pakistan, aimed to determine the best insulation thickness for external walls and roofs of residential buildings based on peak cooling loads. It concluded that an optimum insulation thickness of 1 inch resulted in a peak cooling load reduction of up to 40.1% [12].

One significant factor in increasing the energy efficiency of buildings is the utilization of photovoltaic panels, which should be installed in a cost-effective manner, with a reasonable payback period. Another interesting point is to consider the shading effect of solar panels on the roof, which can help prevent heat transfer and maintain lower temperatures inside the building. Aiman Albatayneh et. al. found that solar photovoltaic rooftop panels can act as shading devices, reducing heat loss in summer and boosting heat transfer in winter. [13]. Renad Albadaineh et. al. found that PV roof structure reduced heat gain by 10.87% in summer and increased heat loss by 3.8% in winter in a low-rise residential building in Amman, Jordan. It also investigated the limitations of using PV on building rooftops. [14]

Energy conservation involves simple behavior changes such as turning off lights, powering down electronics at night, and adjusting the thermostat to save energy [15]. Other factors that can affect energy conservation include the use of window shading, window-to-wall ratio, occupancy and daylight sensors, glazing, building orientation, and efficient HVAC and lighting systems.

In our research although all these factors were evaluated, only some of them were incorporated based on the project's needs and limitations. Study conducted by Safeer Abbas et al. revealed that office buildings had less energy consumption due to larger spaces for air circulation, making the window-to-wall ratio less significant. Symmetric buildings showed lower energy consumption differences based on orientation. Three-pane glass windows and wood walls without insulation demonstrated improved energy efficiency. The tested buildings were compliant with US-LEED guidelines, and the cost recovery period for each building type was estimated. Simulation tools can aid in selecting the appropriate materials for an energy-efficient building design [16]. Wei Zhou's research found that decreasing the heat transfer coefficient of outside window materials reduces energy consumption. A horizontal sunshade of 487mm was also found to be effective [17].

Numerous studies have been conducted on energy-efficient buildings, including research on the best insulation materials and thicknesses for both hot and cold regions in Pakistan. However, there is still a gap in knowledge about the combined effects of insulation, solar panels, shading, glazing, and occupancy and daylight sensors on a building's overall energy efficiency. This research aims to address this gap and provide a comprehensive understanding of the potential benefits of these measures in improving energy efficiency in buildings.

II. Materials and Method

The methodology involves using Autodesk Revit for building information modelling (BIM) and Green Building Studio for energy analysis. Revit is compatible with BIM and can communicate easily with energy software, while Green Building Studio enables information sharing between programs and is developed by Autodesk just like Revit. The Revit model is exported to a gbxml file for energy analysis in GBS.

A. *Modelling in Revit*

Creating a 3D Model of a 5 Marla house in Revit shown in “Fig. 1”.

- The Revit model is for a single-family, 5 Marla(1273ft^2) house located in Military Accounts Lahore, facing 3°East.
- The house has 2 floors, 3 bedrooms, and a garage, drawing room, and lounge on both floors.
- 2nd Floor has an open area with a parapet wall of 3ft.

The construction specifications for a typical design of the house are provided in “Table I”.

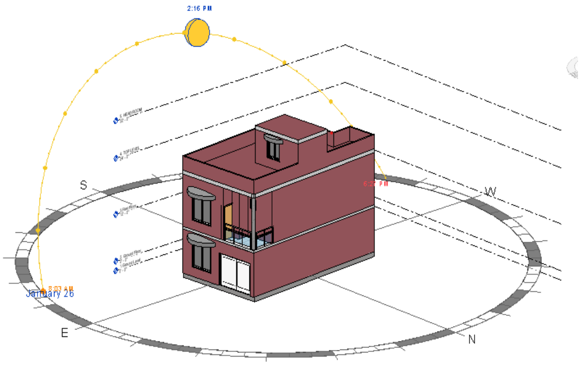


Fig.1 3D model of 5 marla house

B. *Energy Simulation Modelling*

The initial step in energy simulation of a building involves inputting fundamental energy parameters such as the building type, location, operational schedule, and ground plane. A dialogue box for energy settings is a critical element in the simulation process. Additional inputs may be required based on the model's complexity and available details. “Table II” displays the energy settings used during the simulation process. After all these settings energy model is created for the building, as shown in “Fig. 2”.

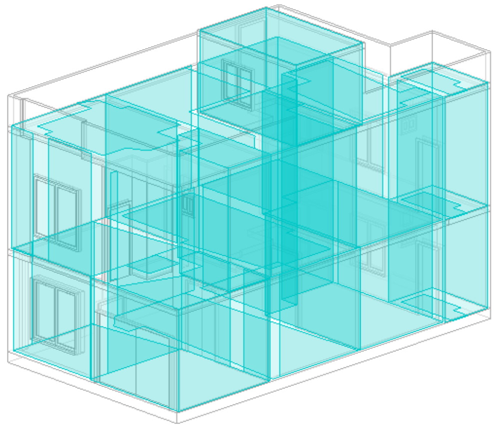


Fig.2 Energy Model created in Revit

1) *Location Settings*

The next step after modelling the house is to select the location for accurate energy analysis, which in our case is Military Accounts Lahore, Punjab.

Location is selected using the internet mapping service and inputting the coordinates to select the exact location of the house “Fig. 3”.

Table 1. Residential building construction specifications with R-value before insulation

Model	Construction Type	R value
Exterior wall	Brick Common (4.5" & 9")	1.2 & 2.4
Interior wall	Brick Common (4.5" & 9")	1.2 & 2.4
Roof	Concrete Cast in Place (6")	0.83
Floor	Lightweight concrete (1') + Acoustic Tiles (0.5")	9.5
Slab	Concrete Cast in Place (6") + Acoustic Tiles (0.5")	2.1
Glazing	Single pan clear glass (without coating)	1.5
Shade	No shading	-

C. *Exporting to gbxml file*

To analyze energy models effectively, file must be exported to the Green Building Studio (GBS) platform, which uses the gbXML file format. Exporting the energy model to GBS is a simple process that transfers all the settings made in the energy settings dialogue box.

D. *Autodesk GBS Workflow*

The process of analyzing an energy model typically involves several steps, including selecting default settings for the project, running a base analysis, conducting alternate runs, and ultimately selecting best option from those runs.

Table 2. Energy settings used in the simulation process

Energy Settings Parameters	Options selected
Mode	Use Building Elements
Ground Plane	Ground Floor
Project Phase	New Construction
Building Type	Single-Family
Building Operation Schedule	12/7
Detailed Elements	Checked

1) *Project Defaults*

To obtain accurate energy analysis results using the GBS platform, it is essential to set up a new project with accurate project details. It includes inputting the correct information and utility rates for the region, as the GBS defaults to American units and currency. For this analysis, the utility rates used for electricity and heating are PKR.14/kWh and PKR.50/therm, respectively, in Pakistan. Additionally, in the project defaults, under the subheading "Zones," the required temperature settings for heaters and air conditioners in the house can be selected.

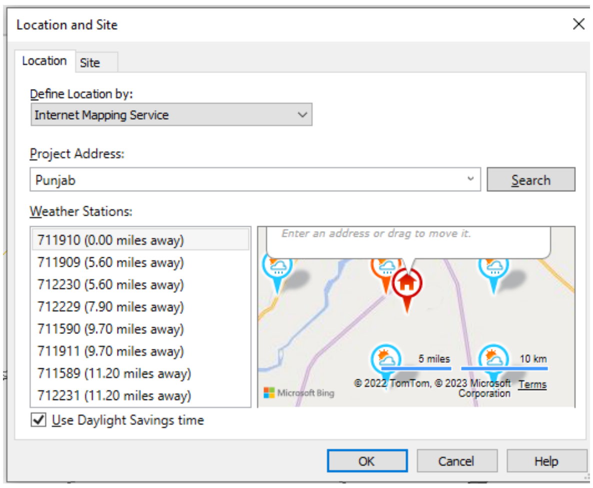


Fig.3 Location Settings

Table 3. Residential building construction specifications with R-value before insulation

Model	Construction Type	R-Value
Exterior wall	Brick Common (4") + Polyurethane (1") + Brick Common (4")	6.6
Interior wall	Brick Common (4.5" & 9")	1.2 & 2.4
Roof	Concrete Cast in Place (4") + Polyurethane Foam (1") + Earth Filling (3") + Brick Common (2")	6.1
Floor	Light weight concrete (1') + Acoustic Tiles (0.5")	9.5
Slab	Concrete Cast in Place (6") + Acoustic Tiles (0.5")	2.1
Glazing	Insulated Blue Low e	1.5
Lighting	Occupancy and Daylight Sensor added	-
Shade	2/3 of Window height	-

Collect detailed information about the building, including occupancy schedules, lighting and equipment loads, and HVAC system details. This information helps to create a realistic and accurate energy model, resulting in more effective energy-saving solutions.

2) GBS Base Run

After creating a project in GBS, the gbXML file from Revit is uploaded to generate a base run using default values determined by the software and the imported model's information. The base run results provide a comprehensive energy analysis of the building, including the yearly operating cost and the building's life cycle cost analysis.

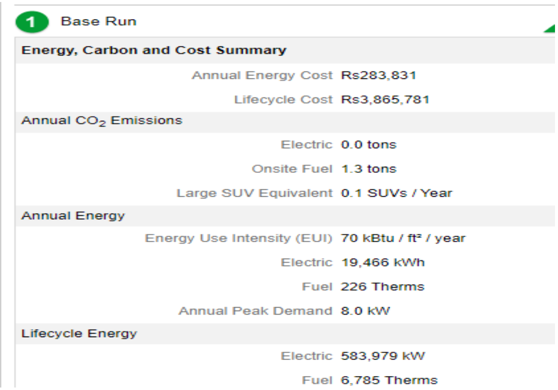


Fig.4 Summary of Energy Carbon and Cost

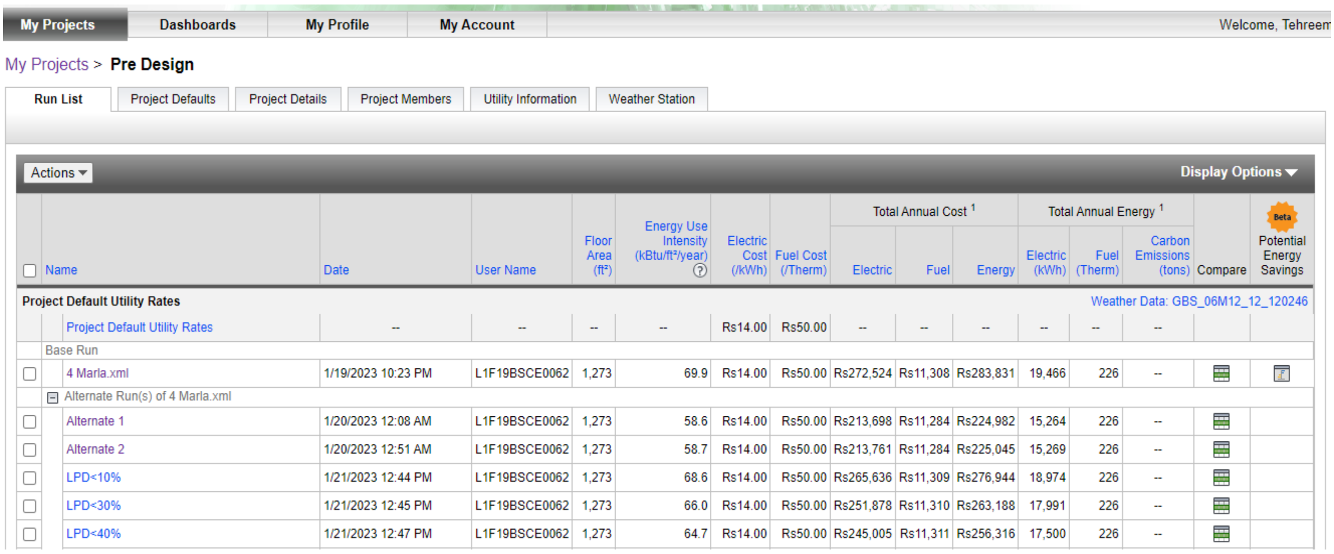
Accurate input data is crucial to ensure an accurate base run analysis, which is used as a reference point for comparing alternative options. In the case of the analyzed house, the base run without insulation, shades, solar panels and with conventional construction showed an annual energy consumption of PKR 284K and high life cycle energy costs of PKR 38.6 million "Fig. 4". This emphasizes the importance of energy-saving solutions.

3) GBS Design Alternatives

GBS has a design alternative feature that allows adjustments to base model assumptions to simulate their impact on energy efficiency. To improve energy efficiency, modifications were made to

- Lighting efficiency and control
- Roof and wall construction
- Shading, Glazing type and HVAC equipment

Although orientation has a significant impact on energy analysis, it cannot be altered in our case. To enhance energy efficiency, 45 design alternatives were created by adjusting the aforementioned elements, with an additional 8 alternatives produced by combining modifications for optimal simulation. "Fig. 5" displays some of these designs and their comparison to the base run, the total list comprises of approximately 50 options. The most suitable alternative is chosen from this list based on both energy efficiency and initial investment cost



Name	Date	User Name	Floor Area (ft²)	Energy Use Intensity (kBtu/ft²/year)	Electric Cost (/kWh)	Fuel Cost (/Therm)	Total Annual Cost [1]: Electric	Total Annual Cost [1]: Fuel	Total Annual Cost [1]: Energy	Total Annual Energy [1]: Electric (kWh)	Total Annual Energy [1]: Fuel (Therm)	Carbon Emissions (tons)	Compare	Beta Potential Energy Savings
Project Default Utility Rates														Weather Data: GBS_06M12_12_120246
Project Default Utility Rates	--	--	--	--	Rs14.00	Rs50.00	--	--	--	--	--	--		
Base Run														
4 Marla.xml	1/19/2023 10:23 PM	L1F19BSCE0062	1,273	69.9	Rs14.00	Rs50.00	Rs272,524	Rs11,308	Rs283,831	19,466	226	--		
Alternate Run(s) of 4 Marla.xml														
Alternate 1	1/20/2023 12:08 AM	L1F19BSCE0062	1,273	58.6	Rs14.00	Rs50.00	Rs213,698	Rs11,284	Rs224,982	15,264	226	--		
Alternate 2	1/20/2023 12:51 AM	L1F19BSCE0062	1,273	58.7	Rs14.00	Rs50.00	Rs213,761	Rs11,284	Rs225,045	15,269	226	--		
LPD<10%	1/21/2023 12:44 PM	L1F19BSCE0062	1,273	68.6	Rs14.00	Rs50.00	Rs265,636	Rs11,309	Rs276,944	18,974	226	--		
LPD<30%	1/21/2023 12:45 PM	L1F19BSCE0062	1,273	66.0	Rs14.00	Rs50.00	Rs251,878	Rs11,310	Rs263,188	17,991	226	--		
LPD<40%	1/21/2023 12:47 PM	L1F19BSCE0062	1,273	64.7	Rs14.00	Rs50.00	Rs245,005	Rs11,311	Rs256,316	17,500	226	--		

Fig.5 Alternate Runs

4) *Photovoltaic Analysis*

According to the Solar panels available in market and selecting one out of them following changes are made in GBS.

- Single-crystal solar panels are chosen that have an efficiency of 13.8%.
- An initial cost of PKR.120/watt is estimated, which includes the cost of the panels and labor.
- The same assumed electricity cost is used for analysis, which is PKR.14/kWh.
- A maximum payback period of 6 years is set.

All of these settings are shown in "Fig. 9".

E. *Making Changes in Revit*

Following the selection of the most suitable alternative design, necessary modifications were implemented on the Revit model to assess the impact on energy cost and consumption.

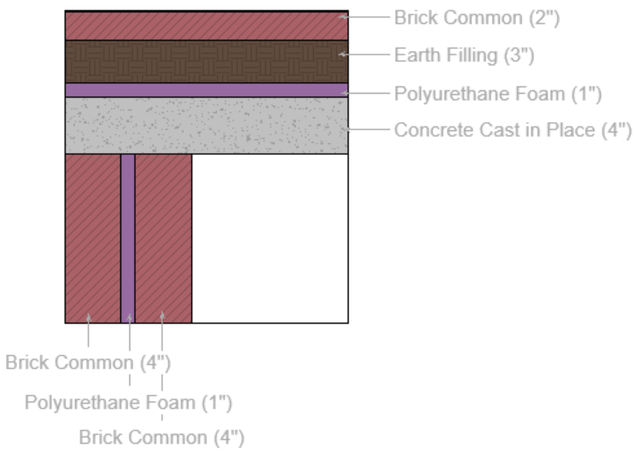


Fig.6 Insulated Walls and Roof x-section

A comprehensive record of these changes has been presented in "Table III", which will be useful as a reference during the implementation phase. Polyurethane is chosen as the insulation material due to its superior efficiency compared to other options, and a thickness of 1" is deemed which is shown in x-section of walls and roof "Fig. 6".

F. *Cross Check in GBS*

After making the optimal design changes in REVIT, the gbxml imported file is re-evaluated in GBS to confirm the potential cost savings of incorporating insulation, window shading, solar panels, and glazing. The results of this evaluation are approximately close to those obtained from the best alternative runs, as shown in "Fig. 7".

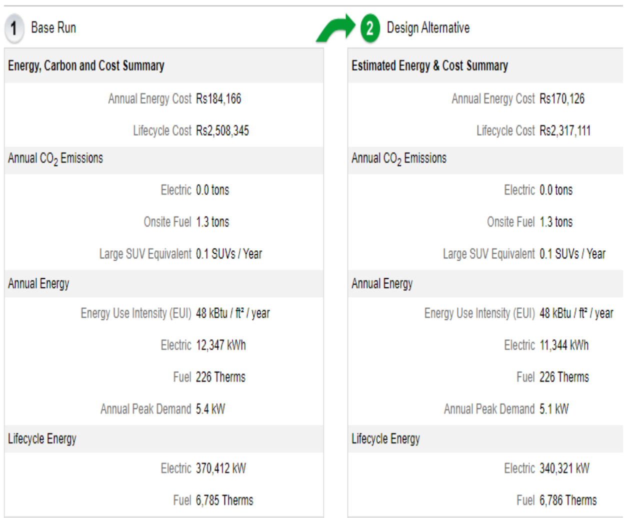


Fig.7 Cost Summary after adding Insulation, shading and Sensors

III. RESULTS

This presents outcomes of multiple simulations on the base and Energy simulation models using GBS. Adjustments are made to construction materials and to reduce energy demand and gauge financial impact.

The basis for evaluating the results is:

- Energy Consumption &
- Energy costs

The simulation results show that after selecting best design alternative, it results in 39% cost saving. Consequently, the final outcome yields a saving of PKR 113K, which is equivalent to 40% of the total yearly energy consumption cost after incorporating insulation, shading, and light and occupancy sensors, as shown in “Fig. 7”

A. *Without Insulation*

Before insulation is installed, space cooling accounts for 43.7% of energy consumption (“Fig. 8”) indicating its significant energy usage and high cost. Miscellaneous equipment and lights consume the same amount of energy, with both accounting for 21.5% of total energy usage “Fig. 8”.

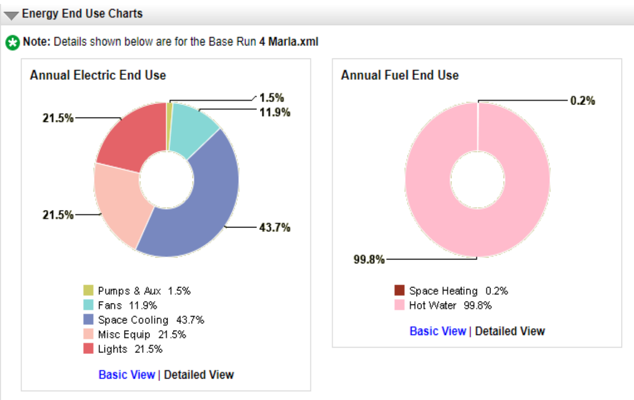


Fig.8 Without Insulation Energy End use charts

B. *With Insulation*

The addition of roof insulation, wall insulation, window shades, and Low-e windows reduces energy consumption for space cooling by almost 20% (from 43.7% to 24%). See “Fig. 9” for details.

C. *Solar Panels*

GBS has determined that installing a solar panel for PKR. 457K and 297 ft^2 will produce 5.4 MWh of energy annually, resulting in a cost savings of PKR.76K. “Fig. 9” shows areas with payback periods less than 6 years, annual energy production, and cost savings.

All the above-mentioned changes, including insulation of roofs and walls, shading and glazing, occupancy and daylight sensors, and solar panels, save 65% of the annual energy consumption, resulting in significant savings.

A. *Cost Estimation*

“Table IV”, displays the net price increase in the project's initial investment cost if insulation is added to both walls and roofs. The total cost of insulation is **PKR 0.67 million**, and adding solar panels of **PKR 0.45 million** increases the cost to **PKR 1.1 million**. Despite the cost increment, the **65%** energy saving every year supports the research.

Table 4. Cost Increment in Initial Investment Cost after Insulation and Solar Panels

Sr. No.	Description of items	Cost (PKR)	Increment in cost (PKR)
1	Walls before Insulation	923216	482101
2	Walls after Insulation	1405317	
3	Roof before Insulation	303897	189868
4	Roof after Insulation	493765	
5	Solar Panels	457044	457044
Total Increment in Initial Investment Cost (PKR)			1129013

IV. DISCUSSION

GBS is utilized to compare the energy efficiency impact of different energy conservation measures (ECMs) by analysing simulation results. The simulation produces an energy chart consumption (“Fig. 8”) for the house, indicating which building features have the most significant impact on energy savings.

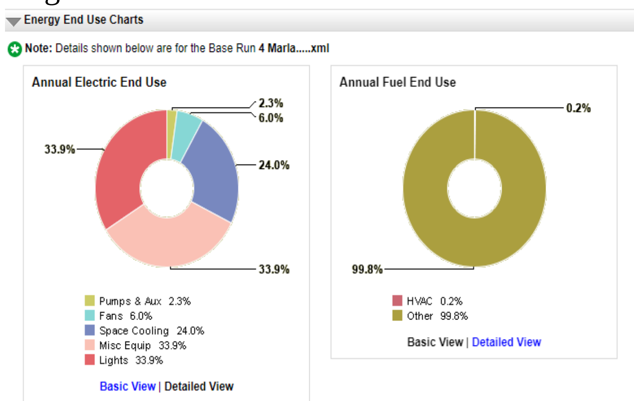


Fig.9 With Insulation Energy End use charts

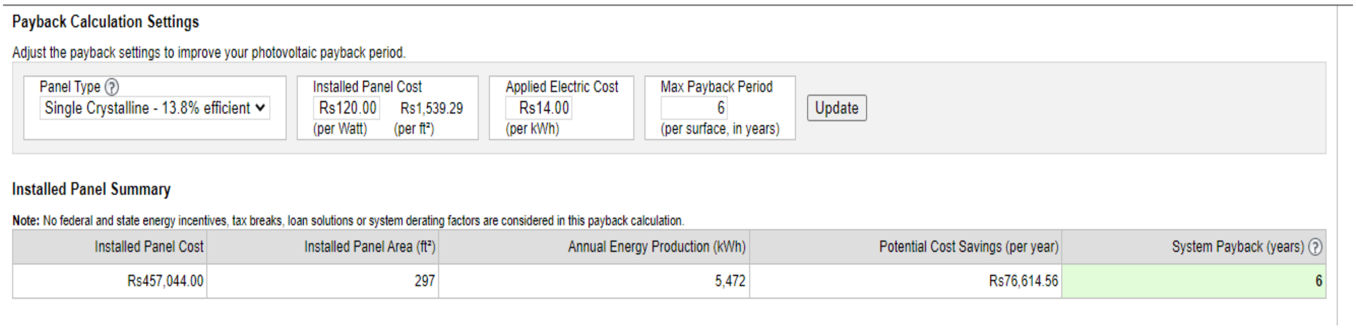


Fig.10 Photovoltaic Analysis

The results emphasize on the significant impact of ECMs on enhancing energy efficiency and cost savings in buildings. Prior to the installation of insulation, space cooling is the primary energy consumer, accounting for 43.7% of energy consumption because of extreme weather in Lahore during the summers. Without insulation R-value of walls and Roofs is low ("Table 2") allowing a greater amount of heat to transfer inside the house and ultimately resulting in increased energy costs.

However, the implementation of insulation and shading reduces the energy consumption for space cooling by almost 20%, indicating the importance of insulation as well as shading. Providing the 1" Polyurethane insulation increases the R-value (thermal resistance) of the house and ultimately saving a considerable amount of PKR 113k/ year consequently, building owners can achieve considerable cost savings.

The integration of solar panels, which incur a cost of PKR. 457k generates an estimated annual energy production of 5.4 MWh. This results in a cost savings of PKR 76K out of PKR 284K per year, which is equivalent to 27% of the total energy savings. This indicates that although there is a great initial investment cost for solar panels but it lower downs the annual energy consumption by 27% and payback for its cost in the coming 6 years making a must-use renewable energy source.

Moreover, insulation is ranked second in terms of cost savings, with an estimated annual saving of PKR 53K, accounting for 19% of the total savings.

The net cost of implementing all these measures, including insulation and solar panels, is estimated at PKR 1.1 million. Incorporating various ECMs, including roof and wall insulation, shading, glazing, occupancy, and daylight sensors, and solar panels, result in incorporating various ECMs, including roof and wall insulation, shading, glazing, occupancy, and daylight sensors, and solar panels, result in a significant reduction of energy consumption by 65%. This highlights the significance of considering ECMs in building design to increase energy efficiency and reduce energy costs. Overall, the findings of this study underscore the importance of implementing energy conservation measures to enhance the sustainability of buildings

V. Conclusion

From the research studies mentioned, it is clear that improving energy efficiency in buildings is crucial for reducing energy consumption and promoting sustainability. Improving insulation, utilizing photovoltaic panels, and adopting simple behaviour changes such as turning off lights and adjusting the thermostat are also effective ways to improve energy efficiency in buildings. While there may be upfront costs associated with these improvements, the long-term benefits of reduced energy bills and a more sustainable future outweigh the initial investment.

The simulations conducted using GBS to evaluate the energy efficiency impact of different energy conservation measures (ECMs) show significant savings in energy consumption and costs. The best design alternative result in a saving of PKR.113K of the total yearly energy consumption cost. The implementation of insulation and shading reduces the energy consumption for space cooling by almost 20%. The integration of solar panels generates an estimated annual energy production of 5.4 MWh, resulting in a cost savings of PKR.76K or 27% of the total energy savings. The incorporation of various ECMs, including insulation, shading, glazing, occupancy and daylight sensors, and solar panels, all at the same time result in a significant reduction of energy consumption by 65%. The total cost of implementing all these measures is estimated at PKR.1.1 million. Despite the high initial investment costs, the long-term cost savings and energy efficiency benefits of these ECMs justify their incorporation into building design.

ACKNOWLEDGEMENT

We would like to express our sincere appreciation and gratitude to the University of Central Punjab for the support and resources that have enabled us to undertake this project. We would like to extend special thanks to the Department of Civil Engineering and the faculty members within this department, whose expertise and guidance have been instrumental in the success of this project. We would also like to thank all, those who have contributed to this project in various ways, including providing feedback, support, and encouragement. We are deeply grateful for your contributions and commitment to excellence.

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