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Proceeding Paper

Identification of Energy Efficiency Improvement Measures of an Existing Residential Building Using Audit-Assisted Energy Simulation and Analysis †

Farrukh Arif [1,2,*], Rabia Khalid [1] and Nida Azhar [3]

1 Department of Civil Engineering, NED University of Engineering & Technology, Karachi 75270, Pakistan; khalid3903045@cloud.neduet.edu.pk
2 Virtual Reality Center, NED University of Engineering & Technology, Karachi 75270, Pakistan
3 Department of Urban and Infrastructure Engineering, NED University of Engineering & Technology, Karachi 75270, Pakistan; nazhar@cloud.neduet.edu.pk
* Correspondence: farrukh@cloud.neduet.edu.pk
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Abstract: Depleting energy sources are forcing humans to preserve energy and utilize it wisely. Globally, researchers are working to find ways to manage the energy crisis. Residential buildings are considered to be in the most energy demanding sector. Therefore, efforts are being made to reduce the increasing energy consumption and make the buildings energy efficient. The paper focuses on finding ways to retrofit the existing residential buildings into energy efficient buildings. This study evaluated the energy performance of a G+2 residential building with a total of 3 floors covering an area of 991.68 sq. meters, to identify relevant potential improvement measures. An energy analysis of the building was performed using information modeling assisted with energy audit data for accurate and realistic analysis. It was found that there is potential for the reduction of the annual energy usage and annual energy cost up to 2.33% and 4.54% respectively, by making improvements in the window to wall ratio. Another potential energy cost saving of 14.8% can be achieved by changing Heating, Ventilation, Air Conditioning (HVAC) type, and 7.62% of a reduction in cost can be achieved through modification in lighting fixtures. Moreover, installing solar photovoltaic panels can save up to PKR 1 million, and natural ventilation could result in saving more than PKR 0.2 million annually.

Keywords: energy efficient buildings; energy performance analysis; information modeling; energy audit; improvement measures

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1. Introduction

Energy efficient buildings are buildings that are designed or refurbished to reduce the energy demand, especially for space and cooling, regardless of the source of energy [1]. Energy efficiency in buildings serves as a significant strategy to achieve reduction in energy usage and energy cost, since energy consumed in the building sector corresponds to one-third of total energy consumption [2]. Energy performance assessment of the buildings is carried out to evaluate the energy usage of the buildings, and helps in identifying the potential areas for energy efficient improvements. There are two strategies for making the existing buildings energy efficient, which include active and passive strategies. Active strategies comprise of heating and cooling systems, while passive design strategy includes building orientation, building envelope, air sealing, continuous insulation, daylighting, and natural ventilation opportunities [3]. The application of the right combination of active and passive strategies results in a substantial reduction in energy consumption and cost. In Pakistan, very little has been done in this regard. In collaboration with Pakistan Engineering Council (PEC), ENERCON has finalized the Building Energy Code of Pakistan Energy Provisions 2011, but the provisions can only be applied to buildings;

that have a total connected load of 100 kW or greater, contract demand of 125 kVA or greater, conditioned area of 900 m^2 or greater, and unconditioned buildings of covered area of 1200 m^2 or more [4]. The paper aims to develop guidelines comprising of relevant potential improvement measures that can be applied to the existing residential buildings of a relatively smaller area. The paper describes the overall process of energy analysis of the reference existing residential building using BIM software, followed by the identification and recommendation of potential cost effective, energy improvement measures.

2. Literature Review

In order to determine the building energy performance, there are six important factors to be considered, which are; climate, building envelop, building services and energy systems, building operation and maintenance, occupants' activities and behavior, and indoor environmental quality provided [5]. Wang et al. have classified energy assessment into three types; 1. Calculation based method which involves the energy assessment of the buildings through simulation engine, 2. Measurement based method is the measurement of the energy consumption of the buildings using devices like meters or simply by utility bills, 3. Hybrid method is the combination of the first two methods which involves the measurement of the energy usage, as well as energy analysis using a simulation engine i.e., energy analysis software [5]. This study adopts the hybrid method. The purpose of the energy assessment is to find out the potential spaces in the buildings for modification that can reduce the energy usage of the buildings. Different studies have identified different effective energy efficient techniques, and have been applied to the buildings to investigate their end results. These techniques include; reducing window to wall ratio [6], double or triple glazing of the windows [6], different types of glazing including tinted, shaded, reflective, low e-coatings [7], improvement of roof tops that involves insulation techniques, reflective techniques, and radiant barrier techniques [8], wall insulation i.e., different levels of thermal resistance can be achieved by adding extruded polystyrene (EPS) or rigid styrofoam thermal insulation board on the inside, in the middle or on the outside surface of the wall [7], and the insulation of doors and windows.

3. Energy Analysis Methodology

A multi-story residential building with a total area of 991.68 m^2 in the Staff Colony of NED University of Engineering and Technology was selected for study. Energy analysis was performed using Autodesk Revit, Insight 360, and Green Building Studio. Realistic data were required to be incorporated into the software for accurate energy analysis, which was obtained through physical walk-through energy audit. The collected data included building architectural plans, utility bills of a year, and data related to the building envelope and building energy service system. The approach is described in Figure 1.

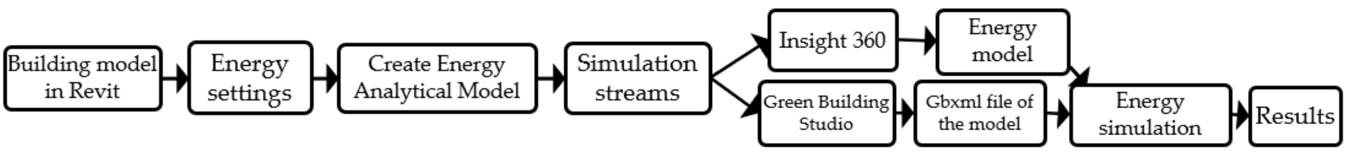

Figure 1. Energy Analysis Methodology.

The 3D model was developed in Autodesk Revit as per the architectural plan. Energy settings (thermal properties, building type, location and building system properties) were incorporated into the model, and an energy analytical model was created. Energy model was processed for energy performance assessment in Autodesk Insight 360 and was exported into a green building studio. Design alternatives were run and potential design alternatives were selected, interpreted and recommended as relevant potential energy efficiency improvement measures. Figure 2 provides an illustration of the procedure of energy analysis of case study building.

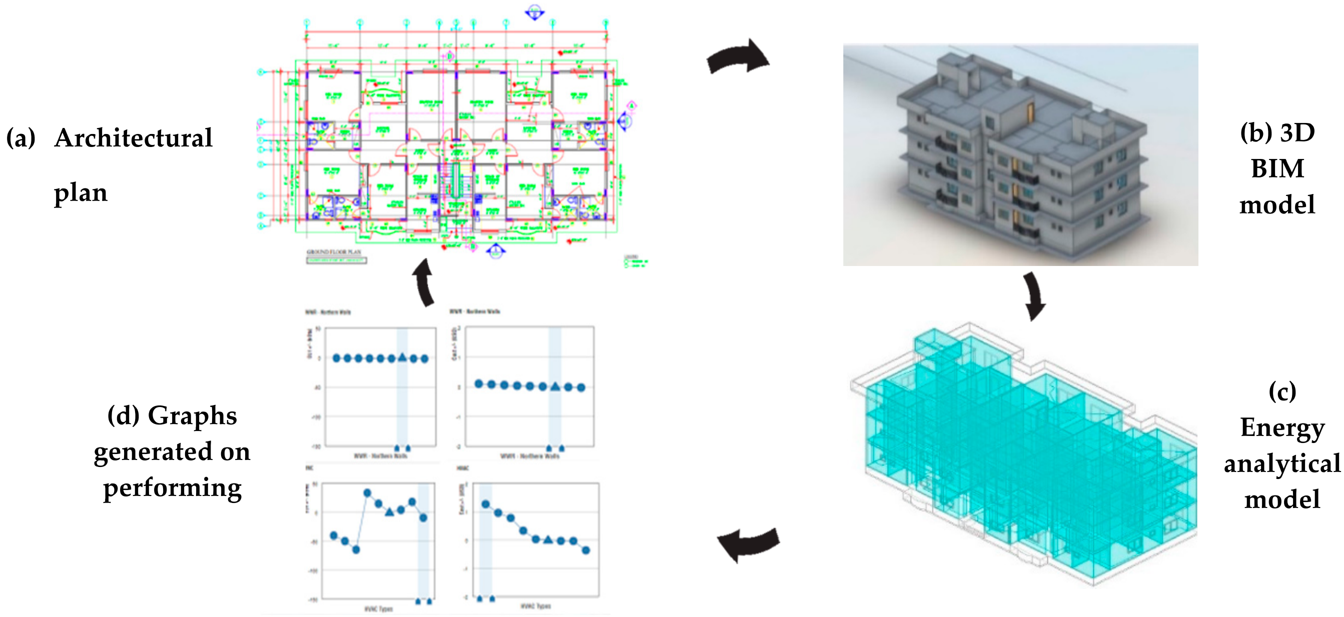

Figure 2. Illustration of Energy Analysis Procedure (**a**–**d**).

4. Results and Discussion

Autodesk Insight 360 provides results in graphical form corresponding to different building parameters like; wall construction, roof construction, lightening efficiency and others. Table 1 shows the potential reduction in annual energy use intensity (EUI) and annual energy cost corresponding to different potential energy efficiency measures.

Table 1. Results obtained from Autodesk Insight 360.

S. No.	Result Parameters	Percentage Reduction Potential in EUI	Percentage Reduction Potential in Cost
1	Operating schedule as 12/7	27.9%	18%
2	Wall construction for R38 Wood	30%	18.87%
3	Roof construction for R60	2.2%	12%
4	Infiltration for 0.17 ACH (air changes per hour)	0.1%	0%
5	Lightening efficiency for 3.23 W/sq. m	1.03%	7.62%
6	HVAC for high efficiency packaged terminal AC	3.98%	14.8%
7	Window shades	Gives optimum results	Gives optimum results
8	Window glass	Gives optimum results	Gives optimum results
9	Window to wall ratio for the southern walls increasing WWR from 23% to 50%	2.33%	4.54%

Energy Analysis results indicated that operating the building for 12 h a day can help reduce EUI by 27.9%. It also suggested that, if the block masonary wall construction is replaced by R38 wood construction and the roof reinforced concrete slab is replaced by R60 roof construction, it may help achieve 32.2% reduction in EUI and 30.87% reduction in energy cost. However, changing the wall and roof construction was not a logically possible measure for existing residential buildings. Modifications in infiltrating areas of building i.e., air sealing the gaps in the building elements, had little or no potential for improvement in this case. Energy analysis in Green Building Studio resulted in providing a variety of design alternatives, energy usage and energy cost saving reports corresponding to electricity and gas usage, water usage, LEED daylight, photovoltaic potential, wind energy potential, natural ventilation potential, and others [9]. Results showed that natural ventilation for 1476 h can help conserve annual electricity generation of 15,076 kWh and annual energy cost of more than PKR 0.2 million, and only 7279 h of cooling would be required. Moreover, a single 4.572 m diameter turbine can generate electricity of 1079 kWh annually. Moreover, a solar panel installation up to a possible roof top area of 271.93m^2 can offer load replacement of 37%, which can produce 57,552 kWh of electrical energy annually and can help save up to PKR 1 million annually, as shown in Table 2.

Table 2. Solar Photovoltaic Panel Installation Analysis from Green Building Studio Results.

Load Replacement%	Installed Panel Area (m^2)	Installed Panel Cost PKR	Annual Energy Production (kWh)	Potential Cost Savings (per Year)
20%	157.10	87,932	31,144.8	551,784
30%	222.32	124,436	46,717.2	817,600
37%	271.93	152,204	57,552	1,017,561.58

Potential Energy Efficent Improvement Meausres

Out of all the design alternatives from energy simulation, only those alternatives are recommended which can be applied to the existing buildings to substantially reduce energy consumption, as tabulated in Table 3.

Table 3. Potential Energy Efficient Improvement Measures.

Areas For Improvement	Improvement Measures	Percent Reduction	
		EUI	Cost
Window to Wall Ratio (WRW) in Southern Walls	Increase the window to wall ratio from 26% to 50%	2.33%	4.54%
HVAC	Install highly efficient packaged terminal air conditioners, or DC inverters	3.98%	14.80%
Lighting Efficiency	Replace energy savers and tube lights with LED lights	1.03%	7.62%
	Total Percent Reduction	7.34%	26.96%

5. Conclusions and Recommendation

Hence, by increasing the WRW in southern walls, installing highly efficient terminal air conditioner, reducing lightening efficiency using LED lights, installing solar PV panels and natural ventilation for 1476 h, can together cause 7.34% and 26.96% total reduction in EUI and cost. Furthermore, these recommended improvement measures could be applied to the case study building, to experimentally validate the results.

Data Availability Statement: All the relevant data has been included in the paper.

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Conflicts of Interest: The authors declare no conflict of interest.

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