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A BIM Based Model for Energy Efficient Retrofitting of an Existing Building – A Case Study

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Abstract

Construction sector is responsible and accounted for 40% of the energy consumption globally. As one of the largest energy consumers of the world, buildings have great potential to save energy (Liu & Ning 2019). It is also predicted that around half a million tons of CO_2 emission, each year is accredited to the energy use by the residential buildings; the use of retrofitting strategies for better energy efficiency of the existing buildings is the way forward. The improvement of the energy consumption of the already existing buildings represents a key challenge in the past but the modern technology and techniques provide a good platform to analyze what impacts any specific retrofitting strategy will have on an existing building. This research focused on to perform a detailed analysis of retrofitted strategies implemented on a 3D model of a library building (base model) of main campus of NED University. It is aimed to give a complete set of information about the 3D model development, energy analysis and life cycle cost analysis of different retrofitted energy efficient models. Retrofitted models that showed a payback period of the initial cost of the retrofitting, within six years were highly encouraged.

Keywords

Building Information Modeling (BIM), Retrofitting Strategies, Energy Analysis, LCCA, 3D Modeling

1. Introduction

It is recognized globally that there is necessity to pay more attention towards the way buildings are designed and then constructed for better or optimized energy consumption (Akande & Olagunju, 2016). In the context of retrofitting and for the purpose of sustainability the engineers and architects are eyeing for global optimization of energy consumption of already built buildings. With excessive consumption of energy, demand for saving strategies is increased. Over the last decade, a drastic increase in the energy consumption in public buildings is observed. Without compromising on functional needs, better comfort in buildings can be achieved by applying retrofitting strategies on features of diverse buildings envelope (Akande & Olagunju, 2016). Thermal, visual and acoustical, that are part of comfort needs can reduce energy consumption. Some major measures applied in the retrofitting technique of the building envelope for reduction in energy consumption include air tightness, wall insulations, windows glazing type and solar shading (Akande & Olagunju, 2016). LEDs lighting equipment are nearly 70% more energy efficient than any other system (Hermoso-Orzáez et. al, 2017). Application of these simple retrofitting strategies can result in thermal load improvements and cost reduction for buildings (Habibi et. al., 2020)

The construction sector was found responsible for 40% to 50% of the final energy consumption in the countries taking part in the research conducted by El-Darwish & Gomaa (El-Darwish & Gomaa 2017). In the European Union (EU) energy related needs for new buildings are on rise. The betterment in energy performance of the existing building play a vital challenge (El-Darwish & Gomaa 2017). Overcoming this challenge needs to identify cost optimum retrofit techniques and strategies to gain maximum reduction in energy consumption and emission of greenhouse gasses through and within building restoration. The rising number of building retrofit extending the needs of modern building standards is a pointer for the convenience and possibility of energy efficient technologies. Buildings efficiency capabilities and cost curves of building envelope assesses new buildings (El-Darwish & Gomaa 2017). In the scenario of building renovation, there is often object specific extra cost for incorporating energy related retrofit measures into existing buildings, and that give rise to an increased cost range and to doubts related to rusting costs of the building retrofit.

Green retrofits are an upgradation for an existing building either partially or completely for improvement of energy and environment performance, optimized water use, improved quality and comfort of the spaces in terms of natural or artificial light, quality of air and noise. It can be simply equal to as putting new HVAC system or installing solar panels on roof. For sustainability, the greening of existing buildings is one of the leading approaches at relatively low cost and high utilization rates. Even though there are a variety of retrofitting techniques and technologies easily available but ways to identify the most cost effective retrofit measures for projects is still a main technological challenge (Ungureanu et. al., 2013). Various attempts, around the world, have been made in developed countries like UK, USA and Australia towards improving the energy efficiency of existing buildings. Such attempts include methods such as provision of policy guidance, technical and financial support to apply energy efficient measured. Similarly, considerable number of works by many authors have been conducted to find energy efficiency through varied avenues directed to improve performance in energy use of existing buildings (Ungureanu et. al., 2013). Global environment concerns and modern computational tools and techniques have significant impact on how the buildings are designed (Montiel-Santiago et. al, 2020). This research is aimed for cost-optimized BIM models that are sustainable and energy efficient. The study facilitated in the selection of optimized sustainable building envelope alternatives and should improve the operating function of the building that would reduce the need for maintenance.

2. Objectives and Scope

Following are the objectives of the paper:

1. To develop BIM based models for energy optimization through retrofitting strategies.
2. To perform life cycle cost analysis of the retrofitted energy efficient models.

3. Methodology

The research methodology consists of the following steps:

1. Identification of retrofitting strategies through literature review.
2. Development and Energy Analysis of a 3D BIM model.
3. Development and Energy Analysis of retrofitted models.
4. Comparative energy consumption analysis of base model and retrofitted models.
5. Evaluation of Life cycle cost analysis.

Thermal comfort plays a major role in energy consumption and can be achieved by adding slight modifications to original building (base model) by the use of the selected building envelope features which include outer walls, roof, windows and doors based on their efficiency and

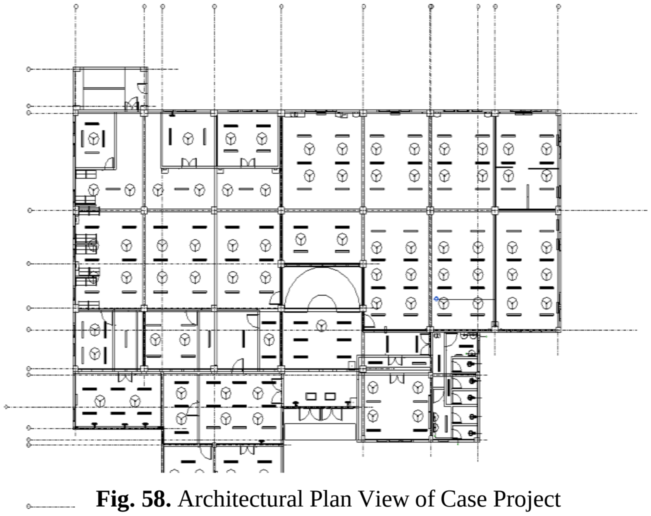


Fig. 58. Architectural Plan View of Case Project

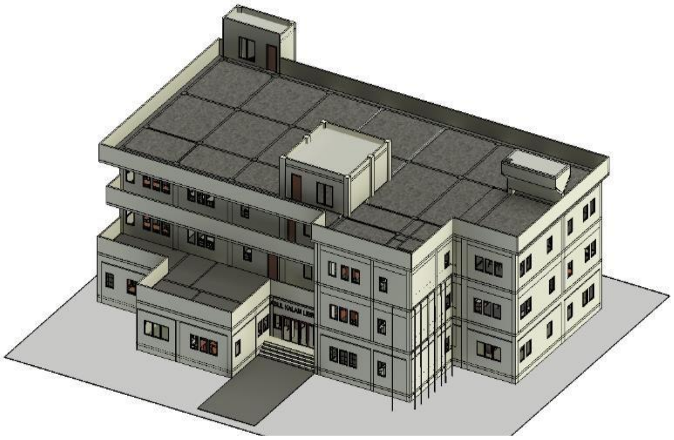


Fig. 2. 3D View of Model

feasibility for retrofit. Various retrofitted strategies were identified through literature and considering local industry practices and classified into various categories.

3.1 Development of BIM Model

Autodesk Revit was used for modeling the building of Project especially for 3D modelling due to the availability of a wide range of library of building elements, materials and other items. Figures 1 & 2 show the Architectural Plan and 3D View of Model of the case building.

4. Analysis

After the development of base model, Energy Analysis was done and the annual electrical consumption of base model was calculated. Various retrofitted strategies were applied on the base model to perform the energy analysis of the different models for optimization purpose.

A comparative analysis between the electrical consumption of the base model and the retrofitted optimized model was concluded and are shown in Table 1. Finally, the LCCA evaluation of the payback period of the initial investment was calculated.

Energy and LCCA analyses of both the base model and the retrofitted models were conducted and the computed results were compared. The annual energy consumption of the base model was calculated to be 151 MWh. The energy consumption of the retrofitted models was compared to the base model as shown in Table 1. The same table showed the individual retrofitting strategies with a drastic change in annual electrical consumption.

Table 1. Energy Consumption of Individual Retrofitted Models

Retrofitted Strategies	Building Components	Energy Consumption (MWh)
Base Model (Library Model)	-	151
EPS 2” Foam	Interior Walls	131
Lasani Acrylic Wood Board	Interior Walls	133
EPS 1.5” Foam	Interior Walls	133
EPS 1” Foam	Interior Walls	137
Insulating Panels	Interior Walls	142
Thermopore Blue	Exterior Walls	121
Isothane Insulation	Exterior Walls	127
Weather Shield Paint	Exterior Walls	146
XPS 1 Inch Board	Interior/Exterior Walls	137
XPS 2 Inch Board	Interior/Exterior Walls	131
XPS 1.5 Inch Board	Interior/Exterior Walls	134
LED Bulb	Electrical	124
LED Tube Lights	Electrical	134
Insutile	Roof, Floor	142
Gravel Roof	Roof	146

After simulating individual models of different strategies, some combined strategies were tested for more improved energy consumption and indoor thermal comfort. Efficient combinations of retrofitting strategies were taken into consideration with respect to least implementation costs, operating and maintenance costs and efficient energy consumptions.

Since LED Tube lights had the least implementation cost, other retrofitting strategies were implemented with combination to LED Tube lights. Figure 3 showed a concise representation of annual electrical consumption with respect to combine retrofitted strategies implemented on a based model.

4.1 Life Cycle Cost Analysis (LCCA)

Life Cycle Cost Analysis for the electrical consumption of the base model was done. Later, for electrical consumption of the retrofitted models was done when different strategies were implemented.

The case project fell under the category c-3(b) of K-Electric's tariff revised in 2020. The tariff schedule has different kWh rates for peak and off-peak hours. The case project is generally operated on weekdays between 8:30 AM to 5:00 PM. This schedule fell under the peak hours as revised by K-Electric. Hence rates of Rs. 21.60 kWh were considered. Figure 4 shows the K-Electric tariff for category C and it represents the cost with respect to building type.

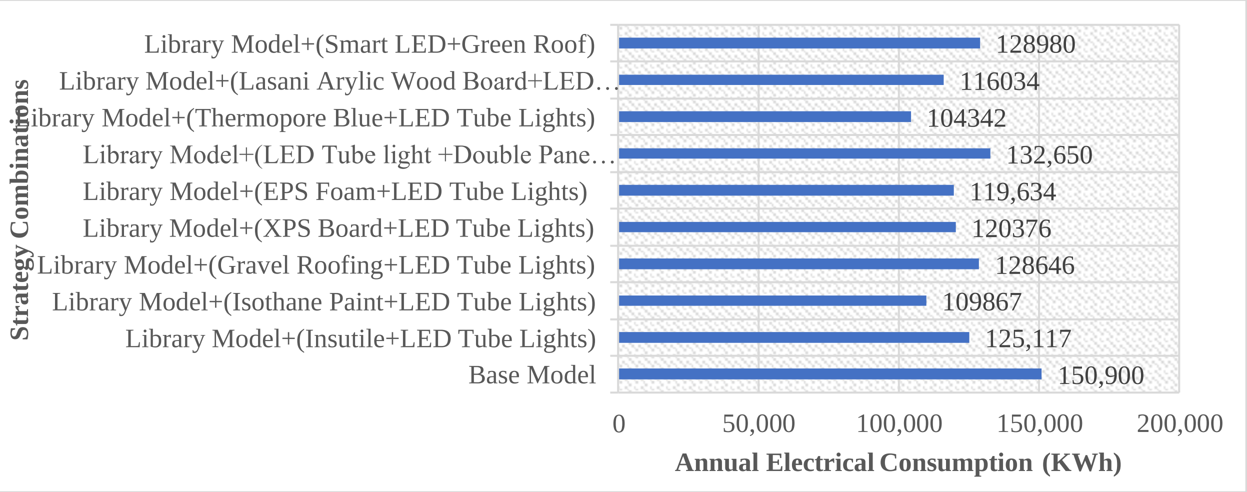
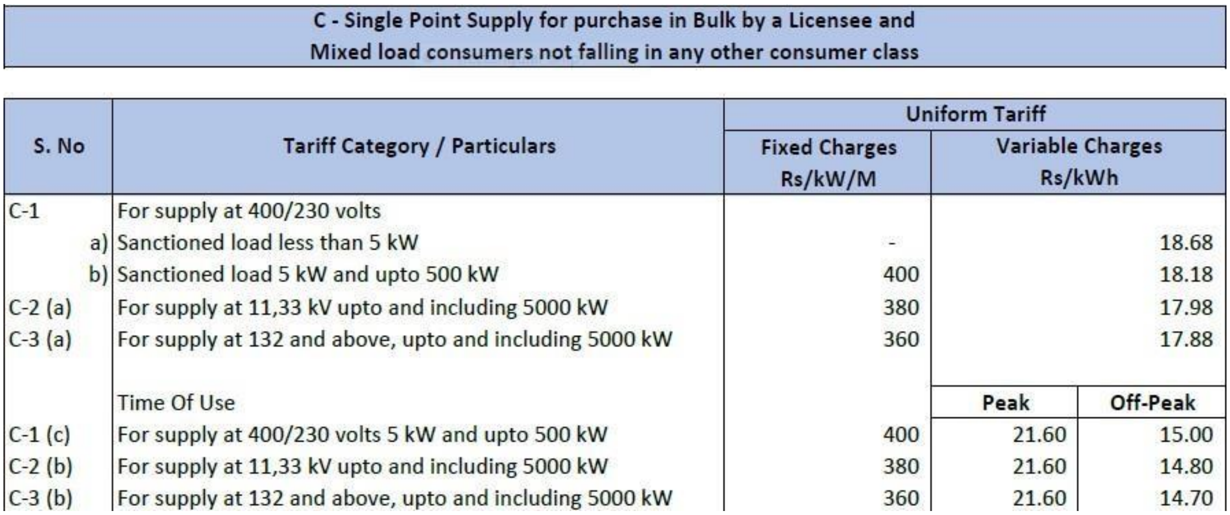


Fig 3. Annual Electrical Consumption of Combined Retrofitted Energy Models



C - Single Point Supply for purchase in Bulk by a Licensee and Mixed load consumers not falling in any other consumer class

S. No	Tariff Category / Particulars	Uniform Tariff		
		Fixed Charges Rs/kW/M	Variable Charges Rs/kWh	
C-1	For supply at 400/230 volts			
a)	Sanctioned load less than 5 kW	-	18.68	
b)	Sanctioned load 5 kW and upto 500 kW	400	18.18	
C-2 (a)	For supply at 11,33 kV upto and including 5000 kW	380	17.98	
C-3 (a)	For supply at 132 and above, upto and including 5000 kW	360	17.88	
	Time Of Use		Peak	Off-Peak
C-1 (c)	For supply at 400/230 volts 5 kW and upto 500 kW	400	21.60	15.00
C-2 (b)	For supply at 11,33 kV upto and including 5000 kW	380	21.60	14.80
C-3 (b)	For supply at 132 and above, upto and including 5000 kW	360	21.60	14.70

Fig 4. K-Electric Tariff for Different Buildings and Timings

Life Cycle Cost Analysis (LCCA) of the base project and retrofitted models were calculated. The escalation and discount rates for LCCA was taken from Statista's inflation rate estimates for Pakistan. The payback period of any strategy was calculated by superimposing the LCCA graph of the strategy over the LCCA graph of the base model.

Figure 5 shows how the two graphs are superimposed and the interaction of the graphs shows the payback period of the initial investment. As indicated LED Tube lights showed payback period of two years and it reduced the total annual consumption from 151 kWh to 134 kWh.

Since LED Tube Lights had a life of 6 years, the strategy needed to be implemented twice in the span of 15 years costing 2 hundred and 50 thousand rupees each time. Due to less investment, the return period was achieved early at about 1 year.

Similarly, payback periods of different individual retrofitted strategies were calculated in Table 5 which shows the concise representation of it.

Table 2. Electrical Consumption of Individual Retrofitted Models

Retrofitted Strategies	**Building Components**	**Energy Consumption (MWh)**	**Life Cycle Cost (PKR in Millions)**	**Savings (PKR in Millions)**	**Payback Period (Years)**
Base Model (Library Model)	-	151	33	-	-
EPS 2” Foam	Interior Walls	131	32	1	8
Lasani Acrylic Wood Board	Interior Walls	133	29	4	9
EPS 1.5” Foam	Interior Walls	133	31	2	6
EPS 1” Foam	Interior Walls	137	31	2	5
Insulating Panels	Interior Walls	142	30	3	9
Thermopore Blue	Exterior Walls	121	30	3	6
Isothane Insulation	Exterior Walls	127	29	4	4
Weather Shield Paint	Exterior Walls	146	31	2	7
XPS 1 Inch Board	Interior/Exterior Walls	137	31	2	5
XPS 2 Inch Board	Interior/Exterior Walls	131	32	1	8
XPS 1.5 Inch Board	Interior/Exterior Walls	134	31	2	6
LED Bulb	Electrical	124	28	5	1
LED Tube Lights	Electrical	134	30	3	1
Insutile	Roof, Floor	142	34	-1	-
Gravel Roof	Roof	146	32	1	4

LCCA of combine retrofitted strategies were performed to do a comparative analysis if the combination were more effective in terms of energy reduction and payback time compared to the individual retrofitted strategies. Since LED Tube Lights were the most effective in terms of energy reduction and implementation cost, LCCA was performed on the combinations made only with LED Tube Lights. The initial investment was the sum of the initial investment of LED tube lights and the other strategy used in combination. Since LED tube lights had a life span of 6 years, only the cost of LED tube lights was reapplied in year 5 and 11 respectively.

Table 3. Electrical Consumption of Combined Retrofitted Models

Retrofitted Strategies	**Building Components**	**Energy Consumption (MWh)**	**Life Cycle Cost (PKR in Millions)**	**Savings (PKR in Millions)**	**Payback Period (Years)**
Base Model (Library Model)	-	151	33	-	-
LED Tube Lights + Lasani Acrylic Wood Board	Interior Walls	133	29	4	9
LED Tube Lights + EPS 1.5” Foam	Interior Walls	120	28	5	2
LED Tube Lights + EPS 1” Foam	Interior Walls	120	28	5	2

LED Tube Lights + Thermopore Blue	Exterior Walls	104	27	6	4
LED Tube Lights + Isothane Insulation	Exterior Walls	110	27	6	9
LED Tube Lights + XPS 1 Inch Board	Interior/Exterior Walls	120	28	5	3
LED Tube Lights + XPS 2 Inch Board	Interior/Exterior Walls	111	28	4	4
LED Tube Lights + XPS 1.5 Inch Board	Interior/Exterior Walls	116	29	4	4
LED Tube Lights + Insutile	Roof, Floor	125	31	2	9
LED Tube Lights + Gravel Roof	Roof	129	29	4	6

6. Conclusions

The 3D model of Library building of main campus of NED University was developed which was later used for energy analysis of individual and combined energy retrofitting purposes. The energy results of simulated building analysis and actual energy consumption of the existing building were similar which shows the accuracy of the model generated. After applying the retrofitting strategies, a clear reduction in the energy consumption was seen. The following table summarizes the efficient individual retrofitting strategies in terms of energy consumption.

Table 4. Efficient individual retrofitting strategies

Building Envelop	Individual Strategies & Annual Energy Consumption
For Interior Walls	EPS 2” Foam (Annual Energy Consumption = 131 MWh)
For Exterior Walls	Thermopore Blue (Annual Energy Consumption = 121 MWh)
For Electrical Appliances	LED Bulb (Annual Energy Consumption = 124 MWh)
For Roof	Insutile (Annual Energy Consumption = 142 MWh)

The top three strategies which were effective as combine retrofitted strategies are as follows;

(i) Thermopore Blue & LED Tube Lights (Annual Energy Consumption = 104 MWh)
(ii) LED Tube light & Isothane Insulation & LED Tube Lights = 110 MWh)
(iii) Lasani Arylic Wood Board & LED Tube Lights (Annual Energy Consumption = 116 MWh)

Based the energy reduction and the implementation cost, the payback time of retrofitting strategies showed that the combine retrofit models of LED lights with interior walls were proven to be an energy efficient and cost effective retrofit.

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