INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH
Ahsan M.M. et al., Vol.9, No.1, March, 2019

Reducing the Operational Energy Consumption in Buildings by Passive Cooling Techniques Using Building Information Modelling Tools

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Received: 01.01.2019 Accepted:26.02.2019

Abstract- Enormously increased energy consumption makes it inevitable to upgrade the energy efficiency of the existing stock of buildings which share a substantial part of the overall energy consumption worldwide. Being an effective tool for analyzing energy performance, Building Information Modelling (BIM), is used to enhance the energy performance of the buildings. This study, therefore, investigates the effectiveness of applying passive cooling techniques using BIM and focuses on developing recommendations on feasible and optimized retrofitting techniques for existing buildings. Moreover, it gives an economic comparison between initial investment and returns based on the quantitative results of energy retrofitting. Thermal simulation software Autodesk Ecotect has been used to simulate annual energy consumption of one case building. Different passive cooling techniques have been applied according to Building Energy Codes of Pakistan. The input parameters are, thus, type of insulating material, the thickness of insulating materials, single and double glazing of windows and window to wall ratio. Results indicate that the annual energy consumption of selected building can be reduced up to 35 % when building incorporates passive cooling techniques with a calculated payback period of 3 years and 2 months.

Keywords Retrofitting, Building Information Modelling, Energy Efficient Buildings, Passive Cooling Techniques.

1 Introduction

The ever-increasing energy demands and continuously depleting non-renewable energy resources along with challenges posed by climate change have inevitably drawn World's attention towards the design of energy efficient methods, equipment and buildings [1]. Thereby, promoting the use of renewable energy resources and improvement of energy efficiency are now key components of energy policies and country-specific guidelines all over the globe.

Buildings are reported to be the major consumer of energy consuming roughly half of the globe's electricity and are responsible for one third carbon emission on the planet [2-5]. Most of the energy utilized in buildings in the form of electricity is used for space heating and cooling. In many countries, energy consumption in buildings is 25-40% of the total energy consumption [6]. The number of newly constructed building that incorporate energy efficient measures are very small (1%) as compared to the existing buildings that were constructed without considering energy conservation measures pointing a huge potential in existing buildings to save energy [7-12]. According to International Energy Agency (IEA) substantial part of total energy can be saved by improving the efficiency of the buildings [3]. On one hand, with focus on quite promising renewable energy resources; the research is also accelerated on the other hand on improving the energy efficiency of existing buildings in order to mitigate emissions and reduce energy consumption. Refurbishment of existing stock seems a better solution for improving energy efficiency and environmental performance of building sector as explicated by Poel et al. [13]. Refurbishment of existing building, for reducing energy consumption, by operational or physical modification and change in its energy consuming equipment under the title of Energy Retrofitting may offer sustainable benefits including improved human health, improved thermal comfort and reduced maintenance [14-19].

When it comes to environmental impact regarding waste and materials, retrofitting has been proved a suitable candidate compared to demolishing and reconstructing of existing buildings [20, 21]. Since the existing stock of buildings is expected to be in use for next 50 to 100 years as argued by Love, P at el.[22] without escalating work on retrofitting of this stock, "green building & design" will have very little impact in reducing energy consumption and tackling global warming as pointed by Steemer [23]. Therefore, a lot of work has been done as an effort to improve energy efficiency of existing buildings by retrofitting techniques [24-37].

In a simulation study, the building envelope in the presence of daylighting in offices was evaluated for the optimum window to wall ratio as well as the windows glazing methods. The results indicated that by decreasing window to wall ratio from 50 to 30 % significant amount of energy could be saved. And by applying suitable window glazing, 83% of the heating load could be saved [35]. In another work, the usefulness of applying passive cooling techniques to ameliorate thermal performance and lessen energy utilization in residential buildings was evaluated in barren and scorching climate of Dubai. Different passive cooling techniques were applied and the cooling load was reduced by improving natural ventilation system of the building, reducing heat gains of building envelope by shading and changing the glazing methods of windows [36]. Olufolahan and Michael investigated various divergent research approaches that have been formerly embraced to analyze advantages and confrontations of Building Information Modeling (BIM). They investigated different possible what-if scenarios on a selected building and concluded that BIM could provide the necessary information required for optimum design and orientation and performance of buildings [38].

The pattern of using daylighting instead of electrical lights was also investigated in a large size factory building located in Tianjin, China. The study compared simulated results with actual readings by switching off/dimming the lights at four different day timings for the same luminous intensity and then analyzing the thermal loads. The results suggested that there is a 35% reduction in the cooling load requirements of the building. However, heating load requirements were increased by 7 % [39]. Mohammed and Budaiwi explored the potentials of reducing the energy consumption of a Cafeteria of King Fahd University located in Saudi Arabia by evaluating its energy performance. The required data about the mechanical drawings, electrical energy consumption etc. was acquired through the simple walk through audits. Different passive cooling strategies were then implemented and results indicated that 16 % energy can be saved by the application of standards, 7 % by the use of energy efficient lighting, 3 % by use of proper insulating material and 2 % of the total energy consumption can be reduced by applying double glazing of windows [40]. In another work, Zahra et al. enquired different procedures for the retrofitting of two educational building in Iran. Buildings energy performance was assessed, and different retrofitting techniques were prioritized on the basis of simulations and payback periods. The results revealed that a significant amount of energy can be saved by the insulating roof, replacing single glazed windows with double glazed and by proper air tightening [41]. Tomas et al. investigated for a cost-effective passive retrofitting technique to renovate Swedish single-family houses and concluded that the most cost-effective renovation measure was installing an air heat pump and the least cost-effective measure was installing a window [32]. As a part of retrofitting buildings, thermal properties of window to wall connection and different positions of window openings were investigated by Marine Bouquin et al. and it was observed that proper placing the windows could reduce the linear thermal transmittance over 50% [42]. There is also a growing awareness of not just net zero but positive energy buildings [43]. Alongside these evident benefits, there are many challenges and uncertainties such climate change, services change, human behaviour change, government policy change, financial limitations and barriers and perceived long payback periods. All these challenges directly affect the selection of retrofitting technique as well as the success of retrofitting project.

Pakistan is highly energy deficient country with an average deficiency of 5000MWe resulting in severe load shedding during summer as well as winter season. Two third of the total energy is consumed by the building sector (both domestic and industrial) and roughly half of this energy is used for heating and cooling purposes [44]. After consuming such a huge amount of energy, the building sector still doesn't provide a comfortable environment during hot summer and cold winter. The situation clearly points out energy in-efficient buildings within the country. Retrofitting of existing buildings and constructing the energy efficient ones seem the only way out of this critical situation. Although there exist a number of retrofitting techniques with well-established benefits yet the guidelines regarding these techniques are available in the form of general suggestions which usually may fail to address the diversity of each retrofitting project [45]. The aim of this study is, therefore, to investigate the potential benefits of passive cooling techniques using BIM tool and recommending the most feasible retrofitting methods. The work not only focuses on improving energy efficiency rather it also gives an economic comparison between initial investments and return based on the quantitative results of energy retrofitting. The paper initially discusses energy consumption of baseline design then the retrofitting techniques have been applied and finally the results of each technique has been discussed.

2 Methodology

2.1 Overview

The study focuses on quantifying potential benefits of thermal retrofitting by considering a non-residential (institutional) building. The standard non-integrated strategy was used because of the fact that the integrated system approach for retrofitting, though more effective in reducing energy consumption, requires a higher upfront investment with quite longer payback period [34].

The building is analyzed for energy consumption considering its existing structure as baseline design and comparing it to the same after retrofitting techniques implemented.

A simulation study has been carried out to analyze both designs and to calculate thermal loads using Autodesk Ecotect 2011 [46]. The software is highly capable of performing BIM different types of analysis covering thermal, lighting, shading, acoustics and cost analysis. Buildings of different sizes, geometries and complexities can easily be handled with it. The annual energy consumption of the selected building is first calculated by performing thermal analysis. The components with the most heat gains and losses in summer and winter respectively are identified using Solar Access Analysis. Using BIM, the retrofitting techniques are then considered to evaluate their effects on reducing the building's annual energy consumption. In the second stage, the cost analysis and payback period of each retrofit are calculated.

2.2 Building Details for the Case Study

The existing building selected for the case study is double story Automotive Center of University of Engineering and Technology Lahore (Fig.1). The building is selected because it was built before implementation of Building Energy Codes of Pakistan (BECP) and falls in the category under the BECP implementation. It has a total area of 6903.6 m^2 (74312.16 ft^2) with longitudinal axis facing north-south. Further details of the building have been provided in the table.

Table 1 Building Description

Sr. No.	Parameter	Value/Description
1	Building Orientation	Long Axis facing North-South
2	Number of story's	2
3	Total Area	6903.6 m2
4	Total Volume	10666 m3
5	Total Area of Exposed Walls	640 m2
6	Total Windows Area	368.6 m2
7	Window to Wall Ratio	0.58
8	Floor Height	9.15 m (30 ft.)
9	Indoor Design Temp.	260 C
10	Operating Schedule	8 am- 8 pm (260 Days)
11	Occupancies	250 persons
12	Infiltration Rate	0.25 ACH
13	Lighting Level	400 lux
14	Appliances (Computer)	80 (Heat Output 160W/PC)

Fig. 1. Automotive Center, University of Engineering and

Technology, Lahore

2.3 Simulation Modelling of the Building

2.3.1 Baseline Design

The actual material of the baseline design of research was brick plaster for the walls, single-glazed aluminium frames for the windows, brick tiled roof, external paving for the floor, and hollow-core plywood for the doors. Following analysis were performed on existing building (baseline design) to analyze its current performance and results were then used to compare with the results of same building after applying to retrofit.

- Thermal analysis,
- Solar access analysis
- Passive Gains breakdown Analysis

Table 2 shows the U values of building construction materials and the actual window to wall ratio.

Table 2. U values of Baseline Design

Component	Material	Composition	U Value
Wall	Brick Plaster Wall	Ceramic Tiles 0.5″, Cement Plaster 3/8″, Brick Masonry 9″, Paint Coat 1/4″	1.882 W/m^2.K
Roof	Brick Tiled Roof	Paint Coat 1/4″, Cement Plaster 3/8″, Roof Tile 1″, Cement Plaster 3/8″, Paint Coat 1/4″	4.921 W/m^2.K
Window	Single Glazed Aluminium Frame	Glass Standard 5/8″	6.065 W/m^2.K
Door	Hollow-core Plywood	Plywood 1/2″, Air Gap 1″, Plywood 1/2″	2.980 W/m^2.K
Window to Wall Ratio		WWR = 0.58	

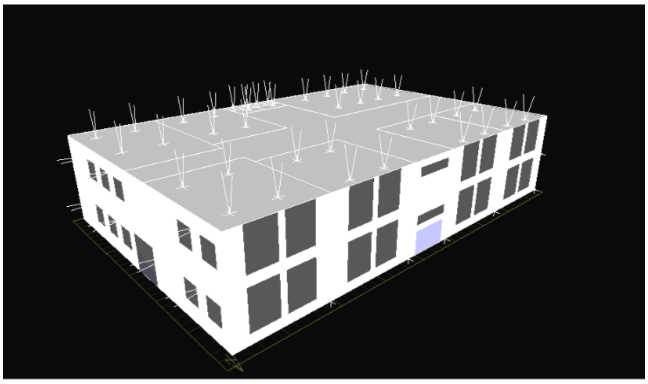

Fig. 2. 3D model of automotive Center created for simulation

2.3.2 Applying Retrofitting Techniques

After getting the results of the existing structure of the building, the following techniques were applied and then optimized to reduce the thermal loads and improve the efficiency of the building.

I. Replacement of Single Glazed Windows with Double Glazed
II. Modification of Window to Wall Ratio
III. Application of Insulation
  ▪ Selection of most efficient insulation
  ▪ Selection of optimum insulation thickness
IV. Application of Energy Efficient Lighting

All windows of the building, that were previously single glazed, are replaced with brown tinted double glazed windows while keeping other parameters constant. The consideration of replacing single glazed windows with double glazed was based on the fact that double glazed windows not only help in reducing energy consumption but also improve indoor comfort levels [47, 48]. Since, a considerable amount of energy may be saved by insulating the envelope as well as by use of energy efficient lighting [49]. The exceptionally large WWR has been optimized between 0.33 to 0.37 as recommended by Building Energy Codes of Pakistan. Moreover, the existing 40 W fluorescent tube lights have been replaced with 25W LED lights of same luminous intensity.

Initially, each modification was simulated individually by keeping all other factors constant in order to get the effects of each individual component. Then all modifications were simulated combinedly and the results of these retrofitted simulations were compared to baseline design.

3 Results and Discussion

3.1 Baseline Design

3.1.1 Annual Energy Consumption of Baseline Design

The baseline design of the case building involving the aforementioned materials is simulated to find out the annual energy consumption. The obtained dataset has been presented graphically (Fig. 3 and Fig. 4). The energy consumption throughout the year to keep the building's temperature between 20 and 26 °C based on these materials is 476.024 MWh. It can be seen, that the highest amount of energy consumption occurs in the month of May i.e. 88.867 MWh. On the other hand, energy consumption in December, January and Feb is the lowest, in between 1.5-2.5 MWh. In fact, due to the location of the building in the hot area, most of the energy is required for cooling purposes and winter season lasts only for 2 to 3 months.

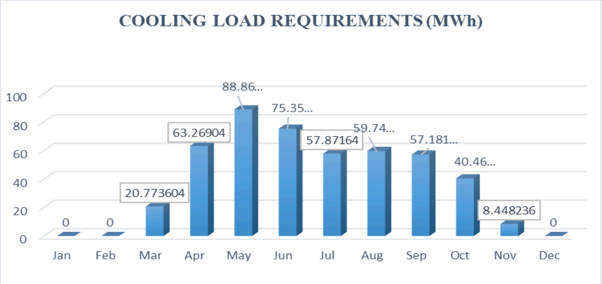

Fig. 3. Monthly Cooling Load Requirements

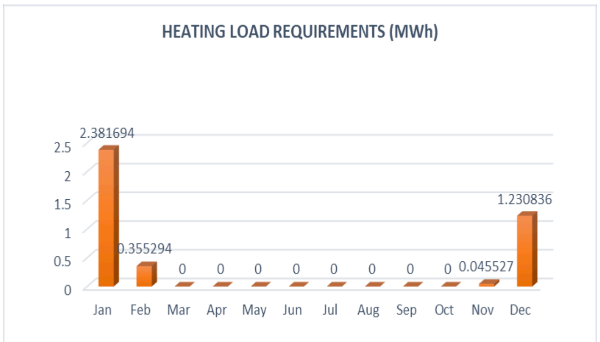

Fig. 4. Monthly Heating Load Requirements

3.1.2 Solar Access Analysis of Baseline Design

Areas of the buildings exposed to solar radiation and/or getting maximum heat have been identified by solar access analysis of the baseline design. Different sections of the building were turned into a spectrum of different colours ranging from yellow to blue, showing the maximum and minimum solar energy absorption by the envelope of the building (Fig. 5).

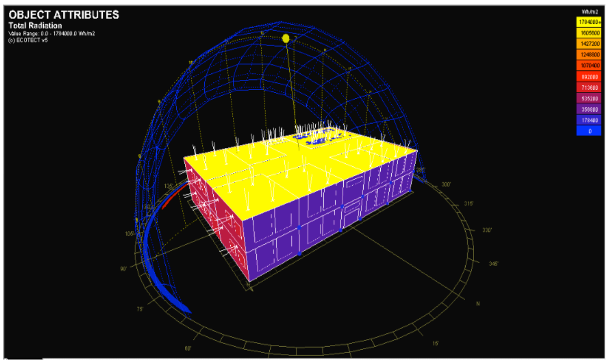

Fig. 5. Building Solar Access Analysis

From solar access analysis, it is evident that the most exposed component of the building was a roof, which was highlighted as yellow and heat gains from the roof were maximum. Moreover, South wall was also responsible for the considerable amount of heat gains. But the South wall was coloured as red which shows lesser heat gains than yellow and orange coloured range. So, the cooling load can be considerably reduced by insulating the roof along with some suitable insulating material and at most the South wall also.

3.1.3 Passive Gains Breakdown Analysis of Baseline Design

The categorization of the passive gains is obtained as an Illustration of the contribution of each building component in heat gains and losses as shown in Fig. 6. It is apparent that conduction has the largest impact on building losses and conduction together with the internal gains are majorly responsible for building heat gains. It might be possible to reduce heat gains and losses by conduction to some extent by applying insulation.

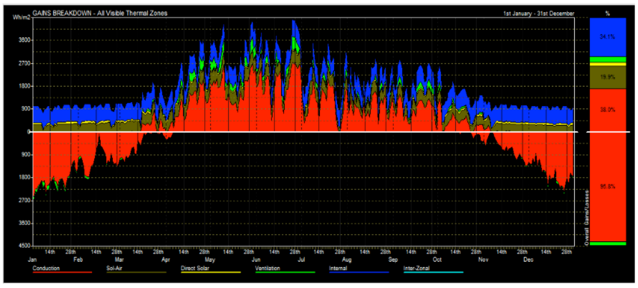

Fig. 6. Passive Gains Breakdown Analysis

3.2 Retrofitted Simulation Results

3.2.1 Load Savings from Modification of Windows (Modification 1)

The replacement of single glazed windows with brown tinted double glazed windows, while keeping other parameters constant has given a total reduction in annual thermal loads of 4.17% as depicted by the figure below (Fig. 7). The input U values of two types of windows have been given below.

Table 3. Input Parameters Double Glazed Windows

Material	U Value
Single Glazed Aluminium Frame Windows	6.065 W/m2.K
Double Glazed Aluminium Frame Windows	2.0 W/m2.K

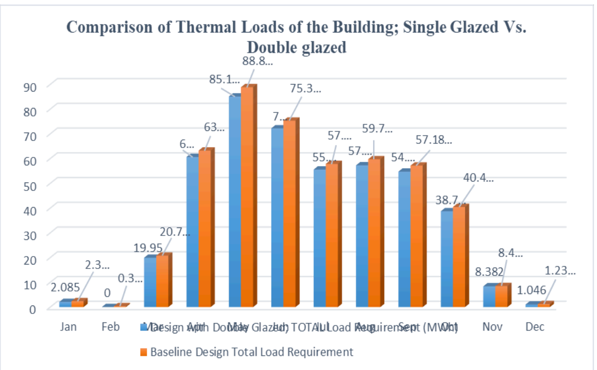

Fig. 7. Reduction in Thermal Loads by Double Glazed Windows

Annual Load with Single Glazed Windows = 476.024 MWh

Annual Load with Brown Tinted Double Glazed Windows = 456.150 MWh

Load Saving = 4.1683%

3.2.2 Load Savings by Standard Window to Wall Ratio (Modification 2)

Following the guideline of Building Energy Codes of Pakistan, the total area of windows is reduced from 368.6 m^2 to 237 m^2 and shading is applied on the remaining windows. The optimum value of window to wall ratio at minimum thermal loads is observed to be 0.37. All other parameters like U value for walls, windows and roof are kept constant.

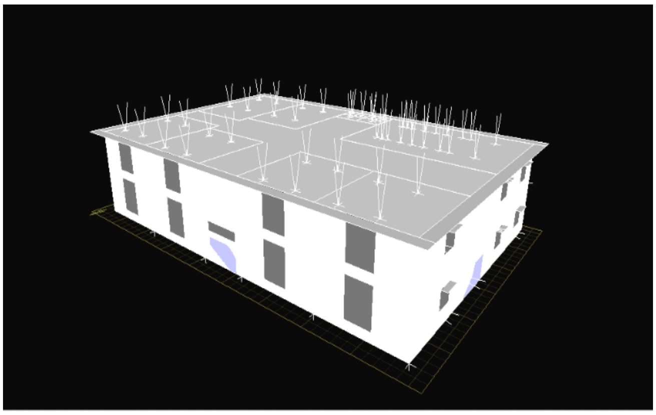

Fig. 8. Building View with Optimized WWR

Total Thermal loads obtained after optimizing the window to wall ratio are compared below with the baseline design. (Fig. 9) The results show a decrease in energy consumption of 1.96%.

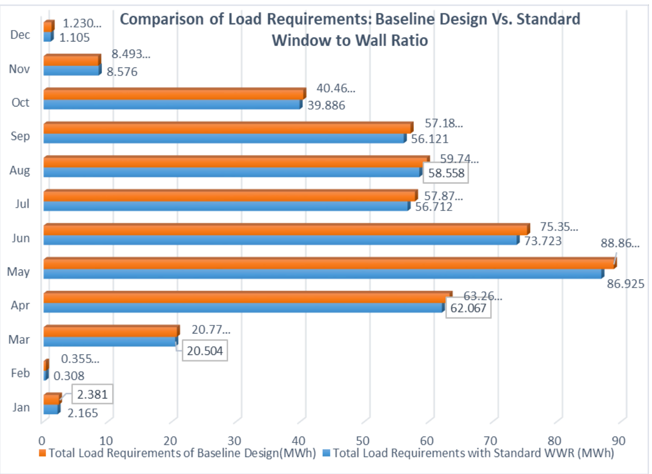

Fig. 9. Thermal Load Comparison of Standard Window to Wall Ratio with Thermal Loads of Baseline Design

Annual Load with WWR of 0.58 (existing) = 476.024 MWh

Annual Load with WWR of 0.37 (after retrofitting) = 466.651 MWh

Load Saving = 1.962%

3.2.3 A Load Savings from Roof Insulation (Modification 3)

Since the solar access analysis in section 3.1.2 shows highest heat gains from the roof of the building particularly due to the high value of the overall heat transfer coefficient of roof material. The roof is insulated to minimize the heat gains and cooling load of the building. For this, the optimum insulating material is selected by insulating the roof with four different types of insulating materials. These materials are cellulose, polystyrene, polyurethane foam and rock wool respectively. For the purpose of comparison, the thickness of insulation is taken to be 2 inches and it is applied on both sides (i.e. outside and inside) of the roof. Table 4 shows the U value and other properties of different available insulation materials while table 5 gives a comparison of thermal loads as calculated after simulation. Though the results show Polystyrene foam (high density) to be the most effective insulating material but being highly flammable it always requires fireproof coating material. Commonly it is treated with fireproofing chemical called Hexabromocyclododecane [50]. Rock wool doesn't have additives to make it fire resistant making it poor for use in extreme hot situations, though it is not combustible. Polyurethane foam uses CFC gas as a blowing agent which damages the ozone layer. Cellulosic insulation is the most eco-friendly insulating material amongst all selected ones. It is also fire resistant and suitable for use in extreme weather conditions. So, cellulosic insulation was selected as suitable insulating material [50].

Table 4. Properties of Insulating Materials

Type of Insulation	U value (W/ m^2.K)	Density (kg/m$^{3)}$	Specific Heat (J/kg.K)	Conductivity (W/m.K)
Cellulose	0.380	43	1380	0.042
Polystyrene Foam	0.077	46	1130	0.008
Polyurethane Foam	0.370	60	1757	0.042
Rock Wool	0.313	200	710	0.034

3.2.4 Optimizing Insulation Thickness (Modification 4)

Analysis to optimize the insulation thickness has been performed by varying the insulation thickness from 0.25 inch to 8 inches with an increment of 0.25. The annual load savings and costs of insulating material are evaluated. Then, optimum thickness is selected on the basis of cost. The varying U-values and annual load savings with increasing thickness of insulation have been depicted graphically. (Fig. 10 & Fig. 11).

Table 5. Comparison of Thermal Loads of Building Using Different Insulating Materials

Month	Total Load (MWh)			
	Cellulose	Polystyrene Foam	Polyurethane Foam	Rock Wool
Jan	0.358	0.309	0.358	0.343
Feb	0.003	0.959	0.003	0.002
Mar	15.288	15.011	15.288	15.21
Apr	44.8	43.91	44.8	44.551
May	62.17	60.884	62.17	61.81
Jun	52.8	51.714	52.8	52.497
Jul	42.275	41.524	42.275	42.065
Aug	44.301	43.557	44.301	44.093
Sep	42.075	41.347	42.075	41.871
Oct	29.953	29.442	29.953	29.809
Nov	7.933	7.837	7.933	7.906
Dec	0.361	0.367	0.361	0.122
Grand Total	342.317	336.861	342.317	340.279
Percentage Load Saving	28.132%	29.293%	28.132%	28.50%

The graph shows a considerable increase in annual load savings (10%) up to 4 inches of thickness. After that, the load saving does not increase significantly (0.6% up to 8 inches) and all end up is adding the cost of insulation. So, the optimized insulation thickness has been selected as 4 inches.

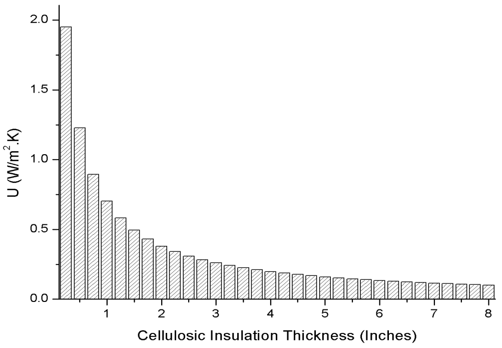

Fig. 10. U Values Varying with Insulation Thickness

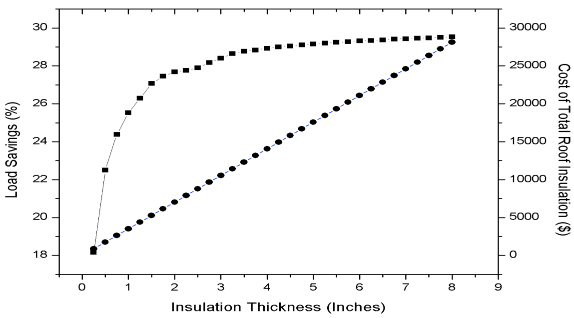

Fig. 11. Annual Load Saving and Insulation Cost Varying with Insulation Thickness

*3.2.5 Load Savings from Energy Efficient Lighting (Modification **5)***

The existing fluorescent tube lights of 40W when replaced with 25W LED lamps of the same luminous intensity, gave a total of 1.91% decrease in thermal loads (or 1.91% load saving). Thermal loads with energy efficient lights have been compared graphically with the baseline design (Fig. 12)

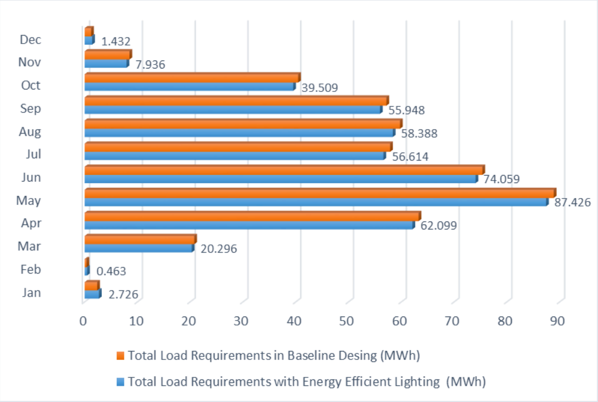

Fig. 12. Thermal Loads after using energy efficient lighting compared with the baseline design

Annual Load with 40 W fluorescent tube lights = 476.024 MWh

Annual Load with Energy Efficient 24 W L.E.D. lights = 466.896 MWh

Load Saving = 1.91%

3.2.6 *Overall Heating and Cooling Load Savings by All Techniques*

After examining the retrofits for each element of the building, the combined effect of all these retrofits on the reduction of cooling and heating load requirements of the building were studied. Table 6 shows the input parameters of energy efficient building while building's annual operational energy consumption based on the combination of all of the modifications has shown graphically. (Fig. 13) The combination has the ability to save about 167.5 MWh annually.

Table 6. Input Parameters of Energy Efficient Building

Component	**Composition After Retrofitting**	**Parameter**	**Actual Value**	**After Retrofitting**
Walls	Ceramic Tiles 0.5″, Cement Plaster 3/8″, Brick Masonry 9″, Paint Coat 1/4″	U value of Walls	1.882 $W/m^2.K$	1.882 $W/m^2.K$
Windows	Glass Standard 5/8″, Air Gap 1″, Glass Standard 5/8″	U value of Windows	6.065 $W/m^2.K$	2 $W/m^2.K$ (Double Glazed)
Roof	Paint Coat 1/4″, Cellulosic Insulation 4″, Cement Plaster 3/8″, Roof Tile 1″, Cement Plaster 3/8″, Cellulosic Insulation 4″, Paint Coat 1/4″		4.921 $W/m^2.K$	0.115 $W/m^2.K$ (Insulated)
Window to Wall ratio	Standard	WWR	0.58	0.37
Roof Insulation	Cellulosic Insulation	Insulating Material	No Insulation	4 Inch Cellulosic Insulation
Lights	L.E.D. Lights	Lights Power Rating	40 W	24 W

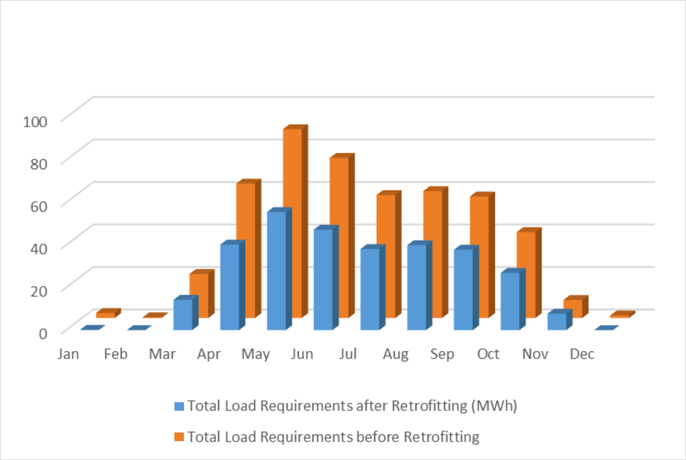

Fig. 13.a Thermal Load Requirements after applying all retrofitting techniques at once

Annual Load of building without retrofitting = 476.024 MWh

Annual Load of building after retrofitting = 308.476 MWh

Load Saving = 35.20%

Thus, from the application of these selected retrofitting techniques, we can save 35.20 % of the total annual building energy consumption.

3.3 Results of Cost Analysis

The cost of retrofitting techniques has been calculated based on a combination of online available quotes as well as the quotes† provided by the Manufacturers in Pakistan. The electricity cost is based on Lahore Electric Supply Company's general supply Tariff for commercial connections [51] while the cost of cellulose insulation per square foot and that of windows per square foot are calculated with the help of quotes available online and quotes provided by the manufacturer respectively.[52, 53] Table 7 summarizes the unit cost used in the cost analysis of retrofitting techniques while table 8 gives the details of cost analysis.

Table 7. Details of Unit Costs for Cost Analysis

Electricity price per kWh for commercial connections (inc' GST)	$ 0.15 [51]
Cost of cellulose Insulation per square foot	$ 0.4 [52]
Double glazed windows	$ 5 [53]
23 W LED bulbs (Osaka Lightings)	$ 3.07 [54]
Price of Cement bag of 50 kg	$ 4.22 [55]

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† Local Market Conversion rate ($ 1 = 122 PKR) have been applied to convert PKR to US dollar where necessary

Table 8. Details of the Cost of Retrofitting and Annual Savings

Retrofitting Technique	**Details of Cost**	**Unit Price ($)**	**Total Area to be retrofitted (ft^2) or Number of Parts/pieces Required**	**The total cost of technique ($)**	**Annual Load Saving (kWh)**	**Energy Efficiency**	**Price of electricity per (kWh)**	**Annual Electricity Saving (kWh)**	**Annual saving in terms of Electricity ($)**
Cellulosic Insulation		0.4	50209.3365	20083.7346	167506	3	0.15	55835.33	8375.3
Double Glazed Windows		5	2551	12755	19841	3	0.15	6613.667	992.05
Energy Efficient Lighting (Thermal Load Saving)		3.07	120	368.4	9083	3	0.15	3027.667	454.15
Energy Efficient Lighting (Direct Electricity Saving)							0.15	5920	888
Modification in Window to Wall Ratio and Shading	Bricks cost per piece	0.08	5000	400	9339	3	0.15	3113	466.95
	50 kg Cement bag	4.22	20	84.4					
	Estimated Labor cost			1920					
Total Cost/Saving				35611.5346	205769			74509.67	11176.45

Payback Period = 3.18 Years

Payback Period = 3 Years 2 Months

4 Conclusion

The study has focused on investigating the effectiveness of different passive cooling retrofitting techniques for existing institutional building in Lahore. The existing structure has first been simulated in thermal modelling software Autodesk Ecotect for current thermal loads and to point out the areas of improvements. Certain retrofitting techniques have then been implemented to quantify their effectiveness with respect to annual load saving and finally, the economics of these techniques have been discussed by comparing the quantified benefits with the expected initial investment.

It is evident from the results that

i. Most significant input parameter/retrofitting technique for reducing annual thermal load of the building is "application of insulation" giving a total of 28% load saving while the most feasible insulation material is cellulose with optimum thickness value of 4 inches.
ii. Being 2nd most significant technique, "replacing single glazed windows with double glazed" saves the load up to 4.16 %. While "window to wall ratio" and "use of energy efficient light" are next in the list saving 1.96% and 1.91% thermal loads respectively.
iii. When applied combinedly, all techniques save annual thermal loads up to 35%.
iv. A total investment of $ 19056.00 is required to apply all discussed retrofitting techniques while the annual cost saving in terms of electricity is $ 11176.45 giving a payback period of 3 year, 2months.

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