Energy Performance Evaluation and Retrofitting Strategies for Sustainable Hostel Buildings in Pakistan

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Abstract

The building sector is a significant contributor to global energy consumption and carbon emissions, particularly in developing countries like Pakistan. This study presents a comprehensive energy audit of a multi-story hostel building, identifying inefficiencies and proposing sustainable retrofitting solutions to reduce energy consumption. Using simulation tools such as Ecotect, the energy performance of appliances and building components was assessed before and after retrofitting measures. The analysis revealed that replacing traditional appliances with energy-efficient alternatives, optimizing insulation, and implementing passive cooling techniques significantly reduced the building's energy consumption from 10,150.69 kWh to 6,466.93 kWh per month. The study also evaluates the economic impact of these retrofitting measures, with a payback period of 5.3 years, emphasizing their long-term financial and environmental benefits. The findings underscore the importance of data-driven energy audits and sustainable retrofitting practices to address Pakistan's energy challenges, offering practical recommendations for policymakers, building managers, and energy professionals to improve building efficiency and reduce operational costs.

Keywords—Energy Performance Evaluation, Energy Efficiency, Building Retrofitting, Energy Consumption Analysis, Passive Heat Gain Breakdown Analysis

1 Introduction

The rapid increase in global energy demand, coupled with the depletion of non-renewable resources and escalating climate change concerns, underscores the critical need for energy-efficient building designs and retrofitting solutions. Globally, the building sector contributes significantly to energy consumption, accounting for approximately 30–40% of total energy use and 28% of energy-related carbon dioxide emissions annually. A significant portion of this energy is used for heating, cooling, and lighting, making buildings a key target for reducing emissions and promoting sustainability [1].

In developing countries like Pakistan, where energy shortages frequently disrupt daily life, inefficient energy utilization exacerbates the problem. Buildings in Pakistan consume around 60% of the nation's electricity, with much of this energy wasted due to poor thermal performance and outdated equipment. In the context of effective utilization of various energy resources, the Demand Side Management tool provides the best strategic energy model for overcoming all national energy crises' solution through effective cost analysis [2], [3].

Retrofitting existing buildings with energy-efficient technologies and practices can mitigate these challenges by reducing operational energy demands, aligning with sustainability goals, and minimizing construction waste [4], [5], [6]. Retrofitting measures, including improved insulation, advanced glazing systems, and energy-efficient appliances, have proven to significantly reduce energy consumption. For example, double-glazed windows and insulated walls can cut energy losses by up to 50%, while passive cooling techniques, such as natural ventilation and shading, can lower cooling energy requirements by 30–40% [7], [8], [9].

Simulation tools, such as Ecotect, Energy Plus,

ISSN: 2523-0379 (Online), ISSN: 1605-8607 (Print)
DOI: https://doi.org/10.52584/QRJ.2301.02
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and Design Builder, have revolutionized the assessment of retrofitting strategies by providing detailed insights into their potential impacts on energy efficiency. For instance, studies demonstrate that optimizing window-to-wall ratios, using advanced insulation materials, and integrating natural ventilation systems can significantly reduce cooling loads by up to 40% in tropical climates. Similarly, daylighting integration in office spaces has been shown to achieve annual energy savings of 20%–30% while enhancing indoor comfort levels [1], [10], [11], [12].

The objectives of this paper were investigated using Ecotect software to answer the following questions:

- What is the current energy performance of each piece of equipment in the selected building, and how does this contribute to overall energy consumption?
- What are the potential benefits of implementing passive cooling techniques, and how can BIM tools be used to identify the most effective retrofitting strategies?
- How can building energy efficiency be improved through retrofitting, and what is the economic trade-off between the initial investment and long-term energy savings?

To analyze the research landscape surrounding "Energy Conservation Management within Buildings" and "Energy Audit", we conducted a bibliometric study using Open-Alex APIs due to restricted access to prominent databases such as Scopus and Web of Science. A total of 2,611 articles were retrieved and analyzed through VOS-viewer, focusing on keyword co-occurrence to identify thematic clusters and research trends. The analysis revealed three major clusters representing interdisciplinary connections (as shown in Figure 1).

Energy systems and engineering disciplines are highlighting research on energy-efficient technologies, conservation strategies, and engineering solutions within buildings, environmental economics and policy, emphasizing the role of economic frameworks and sustainable policies in promoting energy audits and conservation, and materials science and thermal energy management are focusing on advanced materials and energy storage technologies relevant to building efficiency. The centrality of terms like "energy conservation," "engineering," and "environmental science" underscores the integration of engineering innovation with environmental concerns. The study further highlighted growing research interest in renewable energy integration, sustainable building practices, and advanced auditing techniques to optimize energy usage in built environments. The visualization underscores strong interdisciplinary collaboration between fields such as mechanical engineering, computer science, and architectural engineering. Additionally, the co-occurrence of "energy engineering" and "environmental science" suggests a shared focus on developing sustainable energy technologies. Despite limitations in data accessibility, the analysis provides a comprehensive overview of interdisciplinary efforts addressing energy challenges in buildings, offering valuable insights for future research. A country-wise collaboration network was generated using VOSviewer based on data retrieved via OpenAlex APIs, encompassing 2,611 articles as shown in Figure 2.

The visualization reveals strong international research collaboration patterns, with prominent contributions from countries such as China, the United States, Germany, and the United Kingdom. These nations are central nodes in the network, reflecting their leadership roles in energy conservation management and energy audit research. China exhibits extensive links with the United States, Germany, and several European and Asian countries, indicating robust global research partnerships.

The network also highlights regional clusters, such as collaborations among Middle Eastern countries like Saudi Arabia and Turkey, and European countries including Switzerland, Italy, and Sweden. Emerging contributions from countries like Pakistan, Brazil, and South Africa indicate growing interest and participation from developing regions in addressing energy challenges. This analysis underscores the critical role of international collaboration in advancing research on energy efficiency and conservation practices, paving the way for cross-disciplinary solutions to global energy concerns. Figure 3 highlights the collaboration network among researchers in the domain of energy conservation and management within buildings, as well as energy auditing. The study focuses on this niche due to its critical importance in addressing global energy efficiency and sustainability goals. By leveraging renowned academic databases via APIs, we ensured access to high-quality, peer-reviewed publications while maintaining a comprehensive and systematic approach to data acquisition.

Figure 4 shows the flowchart that outlines the process of an energy efficiency assessment, starting with an initial assessment that involves data collection (building specifications, energy consumption, and electricity bills) and site surveys to inspect the building. Next, the energy performance evaluation analyzes energy usage patterns and economic factors, such as electricity costs and potential savings. Based on these insights, retrofitting decisions are made, including

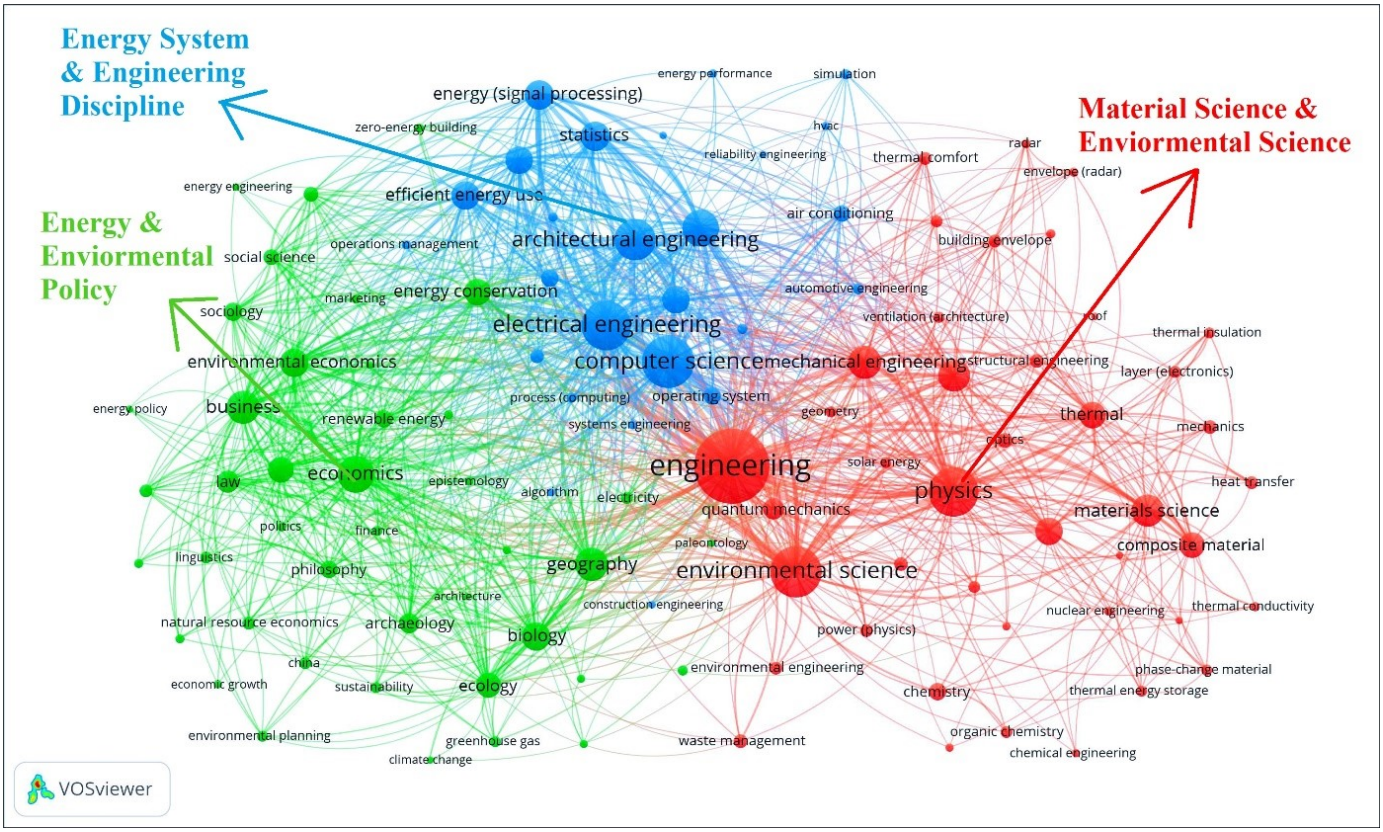

Fig. 1: Keywords network

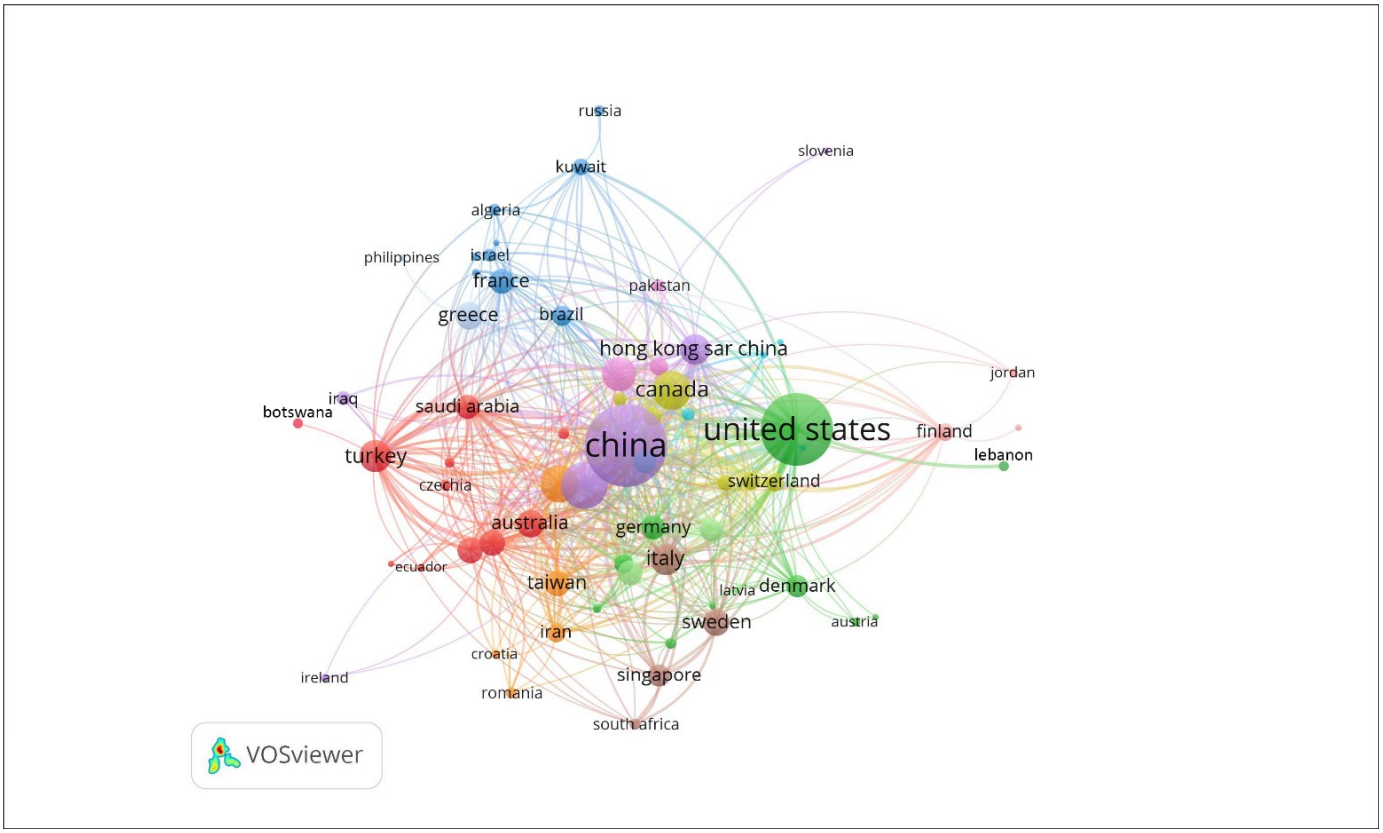

Fig. 2: Network analysis of countries

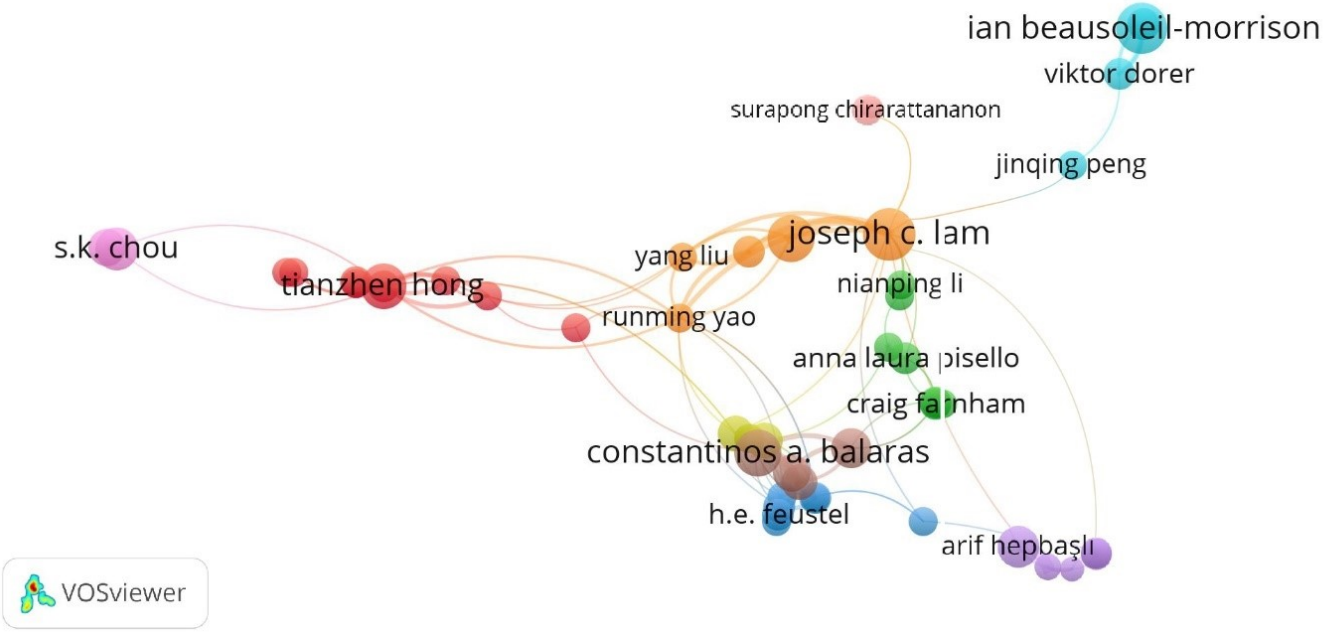

Fig. 3: Network analysis of authors

appliance upgrades, efficient lighting, and structural improvements like insulation and window upgrades. Finally, the implementation Outcomes assess the sustainability impact of the changes and establish guidelines for replicating similar improvements elsewhere.

2 Methodology

Figure 5 shows the methodology of this paper involving a systematic approach to assessing and improving the energy performance of a hostel building. This paper presents a comprehensive energy audit and performance analysis conducted on a multi-story hostel building in Pakistan. The study assesses energy usage patterns, cost implications, and potential areas for efficiency improvement. We quantify potential savings by evaluating current consumption against energy-efficient alternatives and propose targeted solutions to reduce energy usage. Our findings underscore the importance of data-driven energy audits in enabling better decision-making around retrofits and equipment upgrades, which could ultimately contribute to lowering operational costs and carbon emissions.

Passive heat gains play a vital role in sustainable building design by utilizing natural warmth to reduce heating costs and improve energy efficiency. Key contributors include solar radiation through windows, which is influenced by glazing type and building orientation, particularly south-facing in the northern hemisphere. Heat conduction through walls, roofs, and floors depends on insulation properties, with low U-value materials providing effective thermal resistance. Internal heat from occupants, lighting, and appliances also enhances indoor warmth, particularly in well-insulated spaces. Together, these factors optimize passive heating, minimizing reliance on active heating systems and supporting energy-efficient design.

Energy assessments offer valuable insights for policy-makers, building managers, and energy professionals in Pakistan, supporting the drive towards a more energy-efficient and sustainable future. Buildings globally consume substantial energy, with Pakistani buildings accounting for nearly two-thirds of the nation's total consumption, much of it used inefficiently for heating, cooling, and lighting. Given Pakistan's energy deficit, which averages around 5000 MWh, optimizing energy usage in existing structures has become essential to reduce costs and mitigate environmental impact.

This study presents an energy audit and performance analysis of a three-story hostel building, assessing its daily energy consumption of 338.97 kWh and monthly consumption of approximately 10,150.69 kWh. By comparing existing appliances with energy-efficient alternatives, potential monthly savings were identified, reducing the estimated consumption from

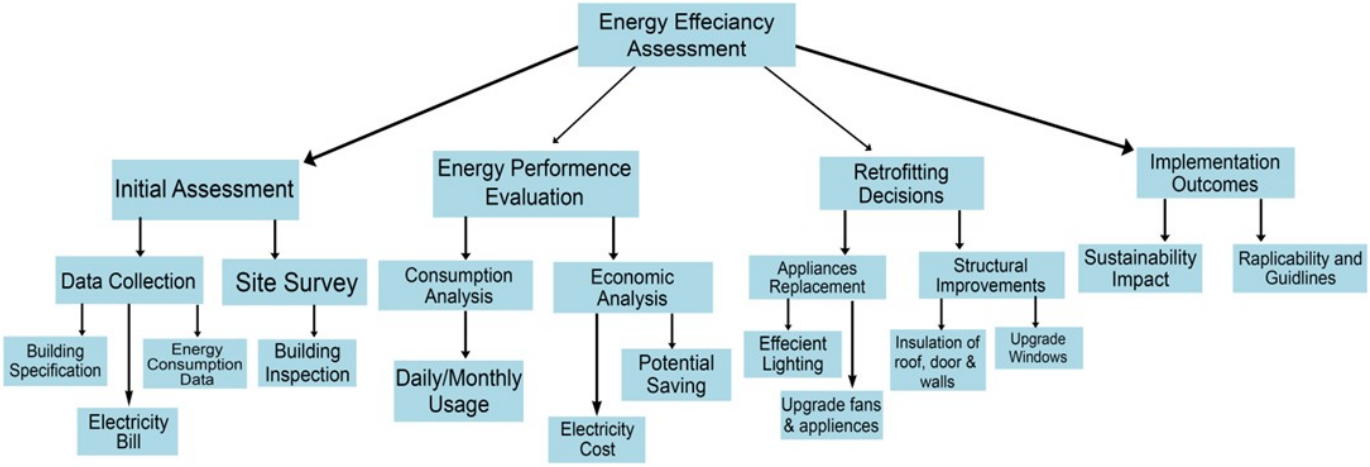

Fig. 4: Workflow diagram.

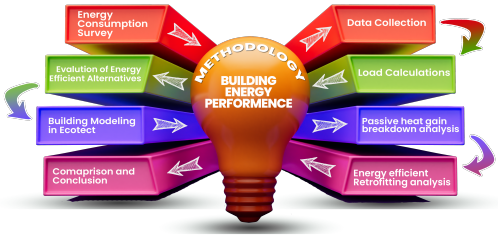

Fig. 5: Methodology chart

10,150.69 kWh to 6,466.93 kWh through targeted retrofits and upgrades. This analysis highlights actionable strategies for lowering operational costs and serves as a model for enhancing energy efficiency in Pakistan's building sector, with broader implications for energy policy and sustainable development.

We chose a hostel building; it is a 3-story building. Figure 6 shows that the hostel block is a modern, thoughtfully designed building that blends comfort, functionality, and energy efficiency. With its spacious 12355 m^2 area, the building is equipped to accommodate 195 residents, providing ample space for each individual. The carefully planned window-to-wall ratio of 0.58 ensures optimal natural lighting, while the 6187.599 m^2 of exposed area brings in ample daylight, creating an inviting and well-lit environment.

The building operates during hours conducive to students or residents, offering a quiet, peaceful atmosphere from 4 pm to 8 am. The lighting level of 400 lux provides perfect illumination for studying and daily activities, ensuring comfort without over-illumination.

Fig. 6: Hostel building chosen for case study

3 Phase of Energy Consumption Evaluation

Inefficiencies in energy consumption patterns are identified through an in-depth energy audit of residential buildings [4], [13], [14]. Systematic utilization of energy analysis tools and audits provides a strong background for practical implementation of cost-effective measures to reduce the energy demand and lower utility bills [6], [14], [15], [16], [17]. We used the approach of an energy audit for energy consumption evaluation. It consists of the three phases, as Figure 7 shows the detailed description of each phase. In the first phase, we selected a suitable building for a case study and then collected the data related to the building and did a preliminary site assessment. And in the second phase, we did the energy performance evaluation, in which we calculated the initial load and suggested the

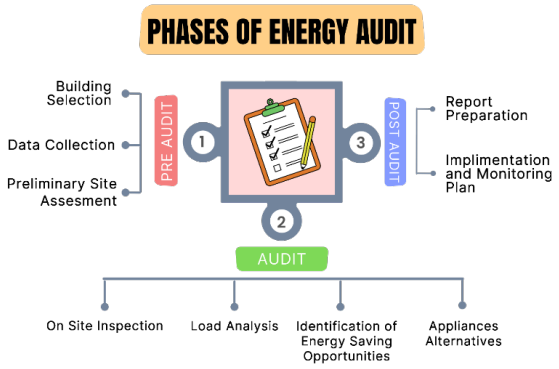

Fig. 7: Phase of energy audit

best alternative for current appliances. And in the third phase, we made the report and presented it to the concerned authorities.

Figure 8 shows the checklist in which we collected the basic data regarding the building to evaluate further energy performance of the building, which included the data of previous bills, description of building rooms, and operation hours.

Figure 9 shows the description of the building, solar path, climate graph data, and electricity demand graph over the years. Table 1 shows the building description.

TABLE 1: Building Description

Sr. No.	Parameter	Description
1	Building orientation	Face toward the West
2	Number of stories	3
3	Total area	12,355 m^2
4	Total volume	44,478 m^3
5	Total area of exposed walls	6,187.599 m^2
6	Total windows area	497.403 m^2
7	Floor height	3.6576 m
8	Indoor design temperature	18–26 °C
9	Operating schedule	4 p.m.–8 a.m.
10	Occupancies	195
11	Lighting level	400 lux

3.1 Ground Floor Data

Figure 10 shows that the walkway data for the ground floor of the hostel is equipped with 28 tube lights, providing essential illumination throughout the space. To ensure adequate ventilation and natural light, there are 8 open windows, promoting a fresh and airy environment. In addition, 11 windows are guarded, likely for security purposes, allowing airflow while maintaining safety. The ground floor also supports modern connectivity with 2 internet devices, ensuring that residents have access to the necessary network services for their studies and daily needs. Figure 10 shows that the ground floor of the hostel has 8 washrooms (W-101 to W-108), with each washroom equipped with 1 tube light, 2 LED lights, 1 exhaust fan, 2 windows, and 1 door. These washrooms are designed to provide adequate lighting, ventilation, and privacy for the resident.

And ground-floor rooms of the hostel are equipped with various appliances to ensure comfort and convenience for the residents. Room 101 is minimalistic, lacking tube lights, fans, irons, laptops, mobile chargers, and kettles, with only 1 window and 1 door. Rooms 101 to 116, on the other hand, have 3 tube lights and 2 fans each, with most rooms also featuring laptops and mobile chargers. Room 102 has the full set of appliances, including an iron and a kettle, while Rooms 103, 104, and 105 have laptops and mobile chargers but no iron or kettle. Room 106 has laptops and mobile chargers but lacks an iron and a kettle. Rooms 107 and 108 are similar, with 1 iron and 1 kettle in each. Room 109 includes an iron and laptops, but no kettle, while Room 110 has laptops, mobile chargers, and a kettle, but no iron. Rooms 111 to 113 have laptops and mobile chargers, along with a kettle in most, but lack irons in certain cases. Room 114 and Room 115 have 2 laptops and 1 kettle, with no iron, while Room 116 has only 2 laptops and no kettle or iron. Overall, the rooms are well-equipped with essential lighting, ventilation, and technology to cater to the needs of the residents.

TABLE 2: Sitting area data

Sitting Area	Sections	Fluorescent Lights	LED Lights
S-01	6	4	4
S-02	6	4	4
S-03	6	4	4
S-04	6	4	4

Table 2 highlights that ground-floor sitting areas of the hostel are well-equipped with lighting to ensure a bright and welcoming environment. Each of the four sections (S-01 to S-04) is furnished with 6 fluorescent lights and 4 Light Emitting Diode (LED) lights. The combination of fluorescent and LED lights offers both energy efficiency and sufficient illumination for the outdoor spaces.

3.2 First Floor Data

Figure 11 shows that the first floor of the hostel has 8 washrooms (W-201 to W-208), each equipped with 1 tube light, 2 LED lights, 1 exhaust fan, 2 windows, and 1 door. These features provide essential lighting, ventilation, and privacy for the residents, ensuring that the washrooms are functional and well-equipped for daily use.

Site Name		**Boys Hostel Building**	
City: Narowal	**District:** Narowal	**Date:** 3-April-2024	**Time of Audit: 10:02am**

Season: Summer	**Wind Speed:** 6.3 mph
Covered Area: 12355 m²	**Wind Direction:** From West

Architectural Plan Attached	**Yes**	**No** ☑
Monthly Electricity Bill Attached	**Yes** ☑	**No**

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
KWh	8531	8789	8900	9315	10245	Nill	Nill	Nill	9833	9521	8687	8123

Monthly Gass Bill Attached	**Yes**	**No** ☑

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MBTU												

Orientation of Building	Face Towards West	**Coordinates of Building**	3QR9+667, Narowal, Punjab, Pakistan

Outdoor Temperature: 33.9 °C	**Design Temperature:** 18 – 26 °C
No. of Occupants: 195	**Lightening Flux:** 400
Building Type: Residential	**Building Operation Schedule**: 7-Days

14h	14h	14h	14h	14h	24h	24h

General Description:

Floors	**Rooms**	**Washrooms**	**Sitting Area**
Ground Floor	16	8	4
First Floor	16	8	0
Second Floor	16	8	0

Fig. 8: Data collection checklist

The first-floor rooms of the hostel are well-equipped with essential amenities for comfort and convenience. And each room has 3 tube lights and 2 fans to ensure proper lighting and ventilation. Rooms like 201, 202, 204, 212, and 214 are equipped with an iron, while others, such as Rooms 203, 205, and 206, do not have one. Laptops are provided in most rooms, with the number varying from 1 to 4, depending on the room, and mobile chargers are available in all rooms, ranging from 2 to 5. Kettles are present in several rooms, such as Rooms 201, 203, 205, and 210, but not in others. All rooms are designed with 1 window and 1 door. Overall, the rooms are equipped to meet the needs of the residents, providing a mix of electronics, appliances, and basic furniture for a comfortable stay.

3.3 Second Floor Data

Figure 12shows that the second floor of the hostel contains 8 washrooms (W-301 to W-308), each equipped with 1 tube light, 2 LED lights, 1 exhaust fan, 2 windows, and 1 door.

Figure 12 shows that the second-floor rooms of the hostel are similarly equipped with 3 tube lights and 2 fans for adequate lighting and ventilation. Most rooms feature laptops and mobile chargers, ranging from 2 to 4 laptops and 4 to 5 mobile chargers per room. Kettles are present in some rooms, including Rooms 302, 305, 307, 312, and 315, but are not available in others. Irons are provided in some rooms, such as Rooms 303, 304, and 316, but not in others. All rooms are designed with 1 window and 1 door, ensuring proper access and light.

4 Energy Consumption Analysis

The energy consumption of the hostel appliances across three floors is carefully distributed, ensuring optimal usage throughout the day. Table 6 shows the energy consumption analysis for one day. Starting with the tube lights in the rooms, each floor uses 48 tube lights for 12 hours a day, consuming 0.036 kWh each, which adds up to a total of 62.208 kWh across all floors. The washrooms are similarly equipped

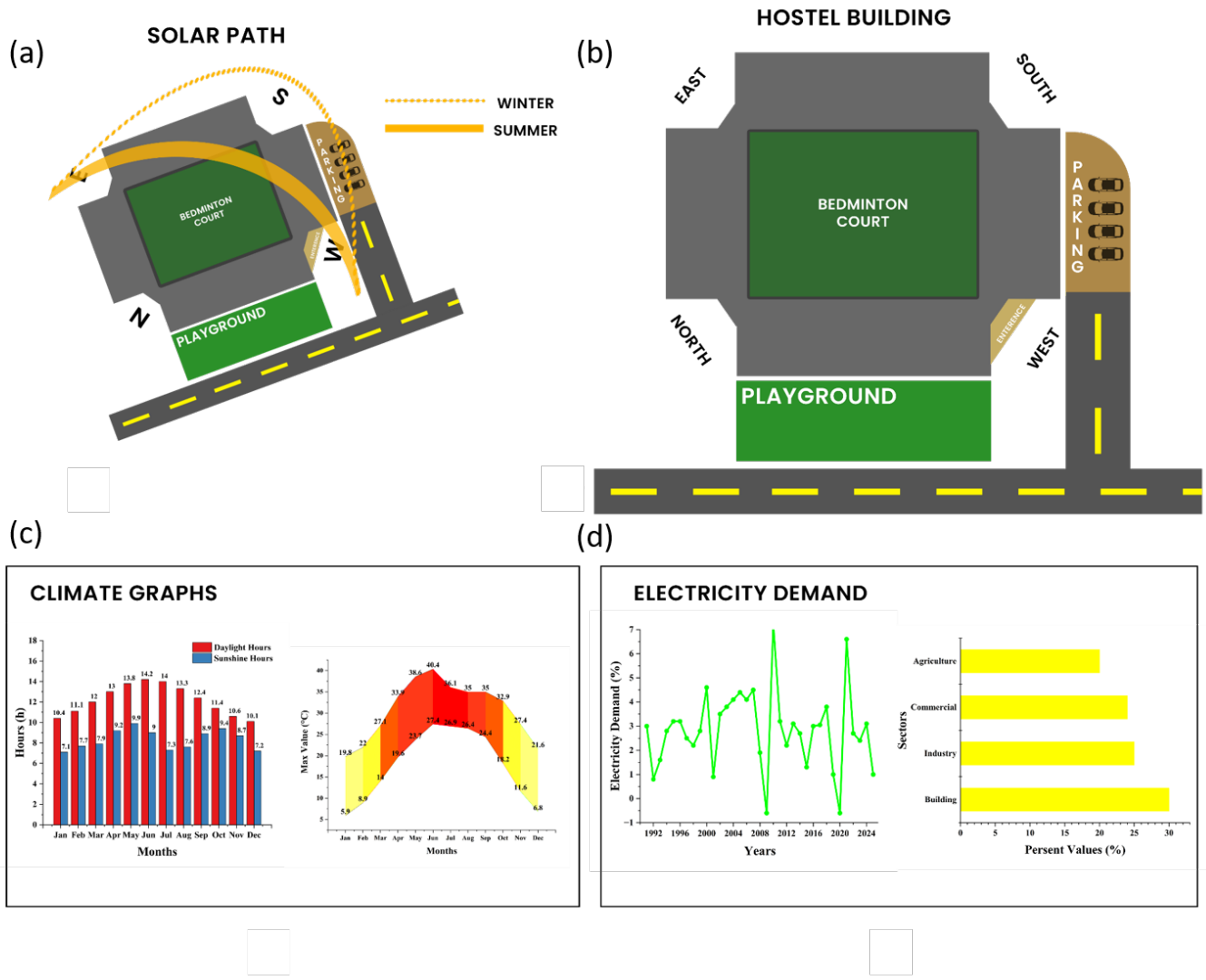

Fig. 9: (a) Solar path (b) hostel building description. (c) Climate graphs. (d) Electricity demand graphs

with tube lights, contributing 10.368 kWh to the daily consumption, while the corridor lights, essential for navigating the building, consume 36.288 kWh. To further illuminate the washrooms, LED lights are used, accounting for 13.824 kWh, offering an energy-efficient alternative to traditional lighting.

The fans across all floors, running for 16 hours a day, consume 138.24 kWh in total, providing comfort and ventilation. Laptops and mobile chargers, widely used by residents, contribute 28.665 kWh and 5.04 kWh, respectively, as each laptop consumes 0.065 kWh and each mobile charger uses 0.035 kWh. The irons, used on a smaller scale but still significant, account for 15.6 kWh, while the kettles, used for brief periods, consume 3.24 kWh.

For internet connectivity, two devices per floor run 24 hours a day, consuming 4.1472 kWh. Security lights ensure safety by operating for 12 hours, consuming 11.52 kWh. Additionally, the windows' lights, which enhance the ambiance, consume 9.216 kWh, contributing to the overall energy efficiency of the hostel.

The energy consumption of hostel appliances is calculated across three time periods: one hour, one day, and one month, providing a comprehensive view of how much energy each item consumes, as highlighted in Table 3. Starting with tube lights in rooms, each light uses 0.036 kWh per hour. With 48 lights on each floor, this results in a daily consumption of 62.208 kWh. Over the course of a month, this totals 1,866.24 kWh. Similarly, tube lights in washrooms and corridor lights also consume 0.036 kWh per hour, adding 10.368 kWh per day and 311.04 kWh per month for washrooms, and 36.288 kWh per day and 1,088.64 kWh per month for the corridor.

The LED lights in the washrooms consume less energy, at 0.024 kWh per hour, totaling 13.824 kWh

Walk Ways Data	Tube Lights	Open Windows	Guarded Windows	Internet Device
	28	8	11	2

Washrooms Data	Washrooms No.	Tube Lights	LED Lights	Exhaust Fans	Windows	Doors
	W-101	1	2	1	2	1
	W-102	1	2	1	2	1
	W-103	1	2	1	2	1
	W-104	1	2	1	2	1
	W-105	1	2	1	2	1
	W-106	1	2	1	2	1
	W-107	1	2	1	2	1
	W-108	1	2	1	2	1

Rooms Data	Room No	Tube Lights	Fans	Iron	Laptops	Mobile	Kettles	Windows	Doors
	101	3	2	0	0	0	0	1	1
	102	3	2	1	3	4	1	1	1
	103	3	2	0	3	4	0	1	1
	104	3	2	0	3	4	1	1	1
	105	3	2	0	3	4	1	1	1
	106	3	2	0	4	4	0	1	1
	107	3	2	1	3	3	1	1	1
	108	3	2	1	3	4	1	1	1
	109	3	2	1	4	4	0	1	1
	110	3	2	0	4	4	1	1	1
	111	3	2	0	3	4	1	1	1
	112	3	2	0	4	4	0	1	1
	113	3	2	0	4	4	1	1	1
	114	3	2	0	2	4	1	1	1
	115	3	2	0	3	4	1	1	1
	116	3	2	0	2	4	0	1	1

Fig. 10: Ground floor data

daily and 414.72 kWh monthly. Fans, operating for longer hours, consume 0.09 kWh per hour. With a daily consumption of 138.24 kWh, the fans total 4,147.2 kWh monthly, making them one of the largest energy consumers. Laptops use 0.065 kWh per hour, which adds up to 28.665 kWh per day and 859.95 kWh per month, while mobile chargers use 0.035 kWh per hour, resulting in 5.04 kWh daily and 151.2 kWh monthly.

The iron, being used less frequently but still energy-intensive, consumes 1.2 kWh per hour, amounting to 15.6 kWh per day and 468 kWh per month. Kettles, which use 0.4 kWh per hour, contribute 3.24 kWh per day and 97.2 kWh per month to the overall energy consumption.

For internet devices, running 24 hours a day, the consumption is 0.0288 kWh per hour, leading to 4.1472 kWh daily and 124.416 kWh monthly. Security lights, operating 12 hours a day, use 0.08 kWh per hour, contributing 11.52 kWh per day and 345.6 kWh per month. Windows lights, with 0.048 kWh per hour usage, consume 9.216 kWh daily and 276.48 kWh monthly. In total, the hostel consumes 338.9712 kWh of energy in one day, and 10,150.686 kWh over the course of one month. These figures highlight the significant energy usage of various appliances, with fans, tube lights, and laptops being some of the highest consumers of energy. Table 6 shows the Hourly, Daily, and Monthly Energy Consumption. Figure 13 shows the graph for the daily and monthly consumption.

Walk Ways Data	Tube Lights	Open Windows	Guarded Windows	Internet Device
	28	8	11	2

Washrooms Data	Washrooms No.	Tube Lights	LED Lights	Exhaust Fans	Windows	Doors
	W-201	1	2	1	2	1
	W-202	1	2	1	2	1
	W-203	1	2	1	2	1
	W-204	1	2	1	2	1
	W-205	1	2	1	2	1
	W-206	1	2	1	2	1
	W-207	1	2	1	2	1
	W-208	1	2	1	2	1

Rooms Data	Room No	Tube Lights	Fans	Iron	Laptops	Mobile	Kettles	Windows	Doors
	201	3	2	1	3	4	1	1	1
	202	3	2	1	3	4	0	1	1
	203	3	2	0	4	4	1	1	1
	204	3	2	1	4	5	0	1	1
	205	3	2	0	3	4	1	1	1
	206	3	2	0	2	4	1	1	1
	207	3	2	0	4	4	0	1	1
	208	3	2	0	3	5	0	1	1
	209	3	2	0	1	4	0	1	1
	210	3	2	0	3	4	2	1	1
	211	3	2	0	4	4	2	1	1
	212	3	2	1	3	4	1	1	1
	213	3	2	0	4	5	1	1	1
	214	3	2	1	1	4	1	1	1
	215	3	2	0	3	4	1	1	1
	216	3	2	1	4	4	0	1	1

Fig. 11: First floor data

4.1 Economic Analysis of Tariffs and Costs

Table 4 outlines the electricity tariffs in Pakistan for the year 2024, based on consumption levels. These tariffs vary with the number of units (kWh) consumed, reflecting a tiered pricing system to encourage energy conservation and ensure affordability for lower usage brackets.

For consumers using up to 100 units, the tariff is set at Rs. 12.21 per kWh. Those consuming between 101 and 200 units face a slightly higher rate of Rs. 14.53 per kWh. For 201 to 300 units, the price rises significantly to Rs. 31.51 per kWh, indicating a larger increase in cost with higher usage. Consumers using between 301 and 400 units are charged Rs. 38.41 per kWh, while for 401 to 500 units, the rate is Rs. 41.62 per kWh. This tariff structure shows a marked jump in cost as consumption increases, reaching Rs. 43.04 per kWh for 501 to 600 units and Rs. 44.18 for 601 to 700 units. Consumption beyond 700 units is charged at Rs. 49.10 per kWh, the highest rate, emphasizing the premium on high electricity use.

These rates reflect the current energy pricing framework for 2024, which may change in the future depending on government policies, energy demand, production costs, and economic factors.

Table 5 provides an overview of electricity costs for

Walk Ways Data				
Tube Lights	Open Windows	Guarded Windows	Internet Device	
28	8	11	2	

Washrooms Data					
Washrooms No.	Tube Lights	LED Lights	Exhaust Fans	Windows	Doors
W-301	1	2	1	2	1
W-302	1	2	1	2	1
W-303	1	2	1	2	1
W-304	1	2	1	2	1
W-305	1	2	1	2	1
W-306	1	2	1	2	1
W-307	1	2	1	2	1
W-308	1	2	1	2	1

Rooms Data								
Room No	Tube Lights	Fans	Iron	Laptops	Mobile	Kettles	Windows	Doors
301	3	2	0	2	4	0	1	1
302	3	2	0	3	4	1	1	1
303	3	2	1	3	4	0	1	1
304	3	2	1	4	4	0	1	1
305	3	2	0	3	4	1	1	1
306	3	2	0	4	4	0	1	1
307	3	2	0	3	5	1	1	1
308	3	2	0	3	4	0	1	1
309	3	2	0	4	4	0	1	1
310	3	2	0	4	4	0	1	1
311	3	2	0	3	4	0	1	1
312	3	2	0	4	4	1	1	1
313	3	2	0	4	4	0	1	1
314	3	2	0	2	5	0	1	1
315	3	2	0	3	4	1	1	1
316	3	2	1	2	4	0	1	1

Fig. 12: Second floor data

specific consumption levels, calculated for one day and one month. For a one-day consumption of 338.9712 kWh, the total cost amounts to Rs. 18165, while for one month at 10,150.686 kWh, the expense is significantly higher at Rs. 70,398,0.

Comparing this to the tiered tariff system in Table 4, it is evident that such high consumption levels push costs into the highest tariff brackets, where per-unit rates increase sharply with usage. For instance, after surpassing 700 units, the rate is Rs. 49.10 per kWh. With a daily usage of 338.9712 kWh, even a single day of consumption far exceeds the 700-unit threshold, placing it firmly within the most expensive tariff category for most of that consumption. This trend amplifies the overall expense over a month, where high daily usage at these premium rates results in substantial cumulative costs.

Table 6 compares the power consumption of current household appliances with more energy-efficient alternatives. The goal is to highlight potential energy savings by switching to lower-consumption devices.

For lighting, tube lights in rooms, washrooms, and corridors currently consume 36W each but could be replaced with LED lights that use only 20W, reducing energy usage significantly. Similarly, a 24W LED light in the washroom could be replaced by an 18W LED bulb. Security lights and window lights currently consume 80W and 48W, respectively, but LED replacements would reduce their consumption to 48W and 36W. In terms of appliances, traditional fans consum-

TABLE 3: Hourly, daily, and monthly energy consumption

Appliances	Hourly Consumption (kWh)	Daily Consumption (kWh)	Monthly Consumption (kWh)
Tube Lights (Rooms)	0.036	62.208	1866.24
Tube Lights (Washroom)	0.036	10.368	311.04
Tube Lights (Corridor)	0.036	36.288	1088.64
LED Light (Washroom)	0.024	13.824	414.72
Fans	0.090	138.24	4147.20
Laptops	0.065	28.665	859.95
Mobiles	0.035	5.040	151.20
Iron	1.200	15.60	468.00
Kettles	0.400	3.240	97.20
Internet Devices	0.0288	4.1472	124.416
Security Lights	0.080	11.52	345.60
Windows Lights	0.048	9.216	276.48
Total Daily Consumption		**338.3562**	
Total Monthly Consumption			**10150.686**

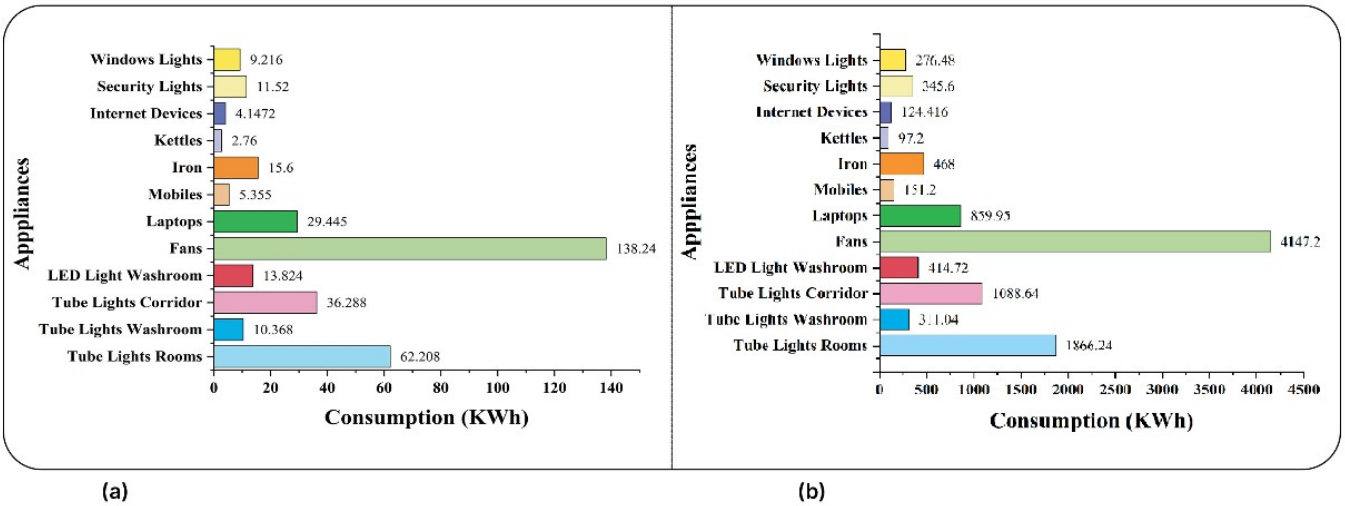

Fig. 13: (a) Daily consumption (b) Monthly consumption

TABLE 4: Tariff per unit

No. of Units	Price/Tariff per Unit (Rs/kWh)
001–100 units	12.21
101–200 units	14.53
201–300 units	31.51
301–400 units	38.41
401–500 units	41.62
501–600 units	43.04
601–700 units	44.18
Above 700 units	49.10

ing 90W could be replaced by GFC Fan Deluxe Saver models using only 50W. The iron's power usage could also be reduced by switching from a 1200W model to a more efficient 1000W Panasonic iron. Certain devices, such as laptops (65W), mobiles (35W), kettles (400W), and internet devices (28.88W), currently have no available energy-efficient alternatives and remain unchanged in this comparison. By replacing the current high-consumption appliances with these alternatives, substantial energy savings could be achieved across household usage.

Figure 14 illustrates a comparison of energy consumption (in watts) between current appliances and more energy-efficient alternatives across different devices in a building setting. For lighting fixtures such as tube lights in rooms, washrooms, corridors, and an LED light in the washroom, the alternatives show a slight reduction in power usage, likely due to replacing conventional tube lights with LED lights or other efficient lighting solutions. Fans also demonstrate a modest decrease in energy consumption with energy-efficient models, though the savings are not as substan-

TABLE 5: Daily and monthly electricity prices before analysis

Description	Daily Consumption Bill	Monthly Consumption Bill
Units Consumed (kWh)	338.9712	10150.686
Total Cost of Electricity (Rs.)	13270.7230	495759.5040
Electricity Duty (Rs.)	207.92	7701.81
General Sales Tax (GST) (Rs.)	2766	99890
Advance Income Tax (Rs.)	0	49112
PTV Fee (Rs.)	35	35
Fixed Charges (Rs.)	200	1000
FC-Surcharge (Rs.)	1094.8770	32786.7160
AQTA (Q-Trf-Adj) (Rs.)	590.9	17694.68
Current Bill (Rs.)	18165	703980
Arrears (Rs.)	0	0
Amount Within Due Date (Rs.)	18165	703980
L.P. Surcharge (Rs.)	1516	54724
Amount After Due Date (Rs.)	19681	758704

TABLE 6: Daily and monthly electricity prices before analysis

Description	Daily Consumption Bill	Monthly Consumption Bill
Units Consumed (kWh)	338.9712	10150.686
Total Cost of Electricity (Rs.)	13270.7230	495759.5040
Electricity Duty (Rs.)	207.92	7701.81
General Sales Tax (GST) (Rs.)	2766	99890
Advance Income Tax (Rs.)	0	49112
PTV Fee (Rs.)	35	35
Fixed Charges (Rs.)	200	1000
FC-Surcharge (Rs.)	1094.8770	32786.7160
AQTA (Q-Trf-Adj) (Rs.)	590.9	17694.68
Current Bill (Rs.)	18165	703980
Arrears (Rs.)	0	0
Amount Within Due Date (Rs.)	18165	703980
L.P. Surcharge (Rs.)	1516	54724
Amount After Due Date (Rs.)	19681	758704

tial.

Among the appliances, the iron has the highest power consumption, with the alternative model showing only a minor decrease in wattage, indicating that energy-efficient irons can offer some savings, though they still remain high-energy devices. Kettles also consume significant power, and the alternative model provides a slight reduction, underscoring that more efficient kettle models can contribute to energy savings, albeit to a limited extent. Internet devices also exhibit a small reduction in power usage with more efficient hardware, though the savings are relatively modest. For security and window lights, the graph shows a minor decrease in energy consumption when switching to alternative models, likely due to the use of energy-efficient lighting technology. Overall, the chart indicates that replacing high-consumption devices like irons and kettles with energy-efficient alternatives provides noticeable energy savings, while lighting replacements and other small devices contribute moderate savings. This data supports the conclusion that adopting energy-efficient appliances can reduce total energy consumption, although the impact varies depending on the type of appliance.

Table 8 presents the hourly, daily, and monthly energy consumption of various appliances, including lighting, fans, laptops, and other devices. It highlights the total daily energy usage as 215.56 kWh and the total monthly usage as 6466.93 kWh, providing insights into consumption patterns. Table 8 shows the daily and monthly electricity consumption bills based on 215.56 kWh and 6466.93 kWh usage, respectively. It includes costs such as electricity charges, taxes, and surcharges, totaling Rs. 10,152 daily and Rs. 448,973 monthly.

TABLE 7: Hourly, daily, and monthly energy consumption after analysis

Appliances	Hourly Consumption (W)	Daily Consumption (W)	Monthly Consumption (W)
Tube Lights Rooms	0.02	34.56	1036.8
Tube Lights Washroom	0.02	5.76	172.8
Tube Lights Corridor	0.02	20.16	604.8
LED Bulbs Washroom	0.018	10.368	311.04
Fans	0.05	76.8	2304
Laptops	0.065	28.665	859.95
Mobiles	0.035	5.04	151.2
Iron	1	13	390
Kettles	0.4	3.24	97.2
Internet Devices	0.0288	4.1472	124.416
Security Lights	0.048	6.912	207.36
Windows Lights	0.036	6.912	207.36
Total Daily Consumption = 215.5642 kWh			
Total Monthly Consumption = 6466.926 kWh			

TABLE 8: Daily and Monthly Consumption Bills after Analysis

Description	Daily Consumption Bill (Rs.)	Monthly Consumption Bill (Rs.)
Units Consumed	215.5642 kWh	6466.926 kWh
Total Cost of Electricity	7385.23	315844.6660
Electricity Duty	116.42	4906.77
General Sales Tax (GST)	1543	63704
Advance Income Tax	0	31321
PTV Fee	35	35
Fixed Charges	200	1000
FC-Surcharge	696.2720	20888.1710
AQTA (Q-Trf-Adj)	375.77	11273.14
Current Bill	10152	448973
Arrears	0	0
Amount Within Due Date	10152	448973
L.P. Surcharge	846	34901
Amount After Due Date	10998	483874

5 Energy Analysis Through Ecotect

Figure 15 shows the image of a building that is used for further analysis in Ecotect. Solar radiation through windows significantly impacts indoor warmth, particularly in south-facing buildings in the northern hemisphere. Glazing type influences how much solar heat is retained indoors, with double-glazed or low-emissivity glass being more effective in managing solar gain without excessive heat loss [18].

Heat conduction through walls, roofs, and floors depends on material insulation properties, typically measured by U-values. Materials with low U-values, like insulated concrete or brick walls, provide thermal resistance, moderating indoor temperatures and reducing heat loss [19].

Heat generated by occupants, lighting, and appliances can add to the internal warmth, reducing dependency on external heating sources. In high-efficiency buildings, internal gains can significantly contribute to overall heating, especially in well-insulated spaces [20].

5.1 Sun-Path Diagram

The sun path diagram in Figure 16 is often very useful in determining the period of the year and hours of the day when shading will take place at a particular location.

5.2 Passive Heat Gain Breakdown Analysis

Passive heat gains are essential in sustainable building design, providing natural warmth from external sources to reduce heating costs and improve energy efficiency. Passive gains primarily come from solar radiation entering through windows, conduction through walls, and even occupants and appliances. Figure 17

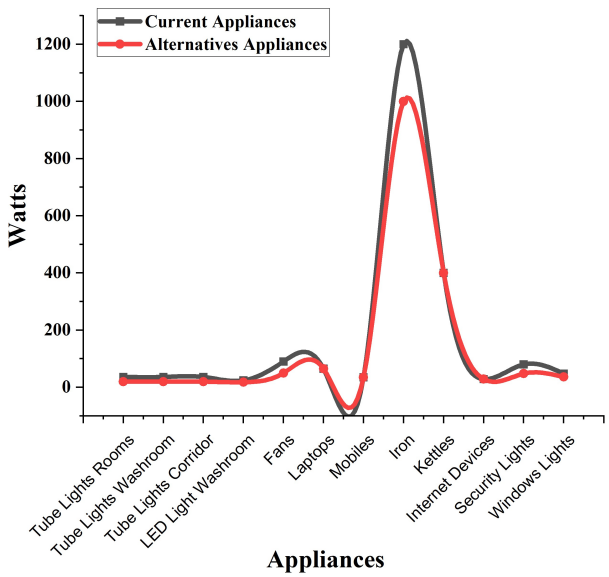

Fig. 14: Comparison between current and alternative appliances

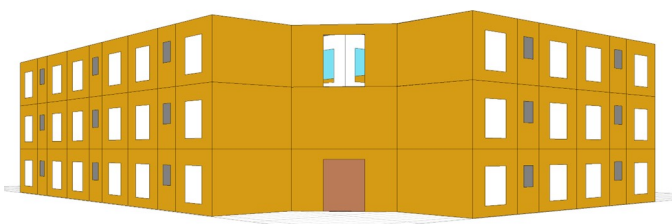

Fig. 15: Hostel building model in Ecotect

shows the graph of passive grain breakdown analysis before applying retrofitting, and we see that a major loss of heat is due to conduction, so we target the conduction to optimize the energy consumption. Figure 18 shows the hourly building temperature graph before retrofitting.

5.3 Solar Gains

Ecotect calculates solar gains primarily from direct, diffuse, and reflected solar radiation using hourly climate data and geometric analysis. The equation below is used for solar gain on surface calculations:

$$Q_{\text{solar}} = A \times S \times \tau \times \cos(\theta) \tag{1}$$

where:

- A = area of the surface (e.g., window)
- S = solar irradiance (W/m^2), includes direct + diffuse + reflected
- τ = solar transmittance of glazing
- $\cos(\theta)$ = cosine of the angle of incidence of solar rays on the surface

The total solar heat gain through glazing is computed using the following equation:

$$Q_{\text{solar glazing}} = A \times G_t \times \text{SHGC} \tag{2}$$

where:

- G_t = total solar irradiance on the glazing
- SHGC = Solar Heat Gain Coefficient

5.4 Conduction

For heat transfer through walls, roofs, and floors, Ecotect uses Fourier's Law of Heat Conduction simplified for one-dimensional (1D) steady-state conditions:

$$Q_{\text{cond}} = U \times A \times (T_i - T_o) \tag{3}$$

where:

- Q_{cond} = heat transfer rate (W)
- A = area of the surface
- T_i and T_o = indoor and outdoor temperatures (°C or K)
- U = overall heat transfer coefficient (W/m$^2 \cdot$ K)

5.5 Internal Heat Loads

Ecotect estimates internal heat gains by using the following equations:

$$Q_{\text{people}} = N \times q_{\text{person}} \tag{4}$$

where:

- N = number of people
- q_{person} = sensible + latent heat gains per person (W), depending on activity level

For lighting, the following equation is used:

$$Q_{\text{lighting}} = W_{\text{light}} \times \text{Usage factor} \tag{5}$$

with consideration of lighting load in W/m^2 or total W, and corresponding usage schedules.

5.6 Ventilation & Infiltration Heat Transfer

Ventilation and infiltration heat transfer can be calculated as follows:

$$Q_{\text{vent}} = \rho \times C_p \times \dot{V} \times (T_i - T_o) \tag{6}$$

where:

- ρ = air density (≈ 1.2 kg/m^3)
- C_p = specific heat of air (≈ 1005 J kg^{-1} K^{-1})
- $\dot{V}$ = air flow rate (m^3/s)

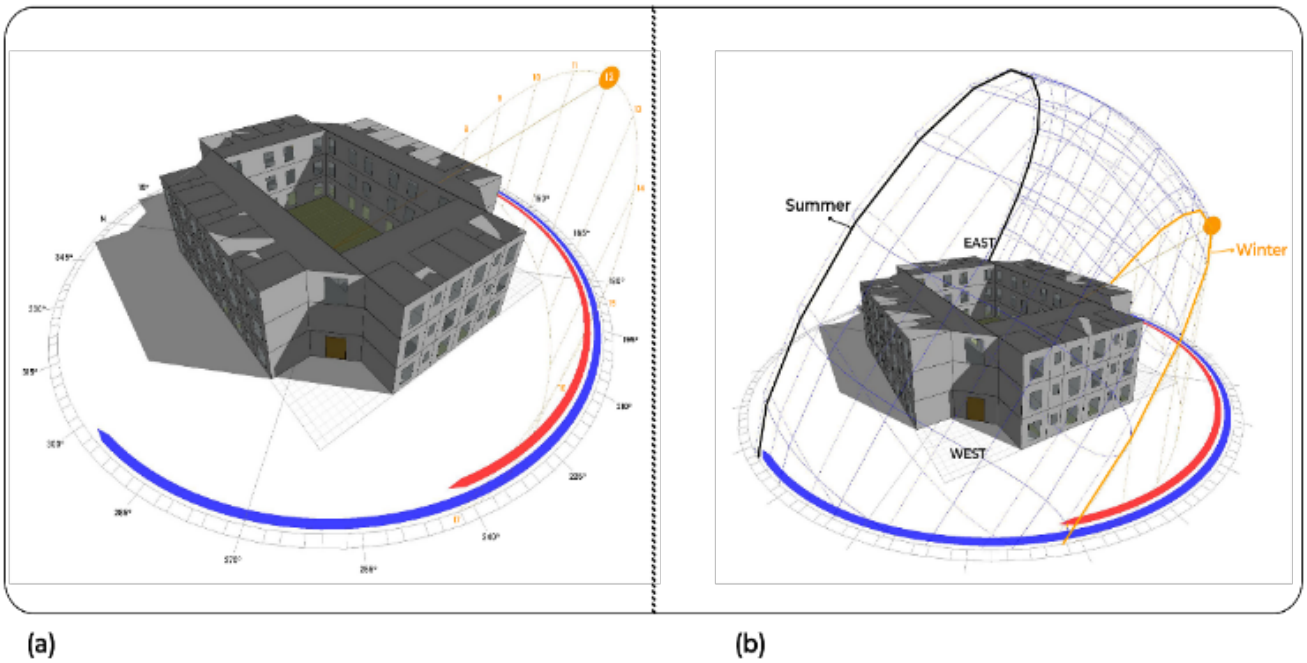

Fig. 16: (a) Hourly Sun path. (b) Annual Sun path

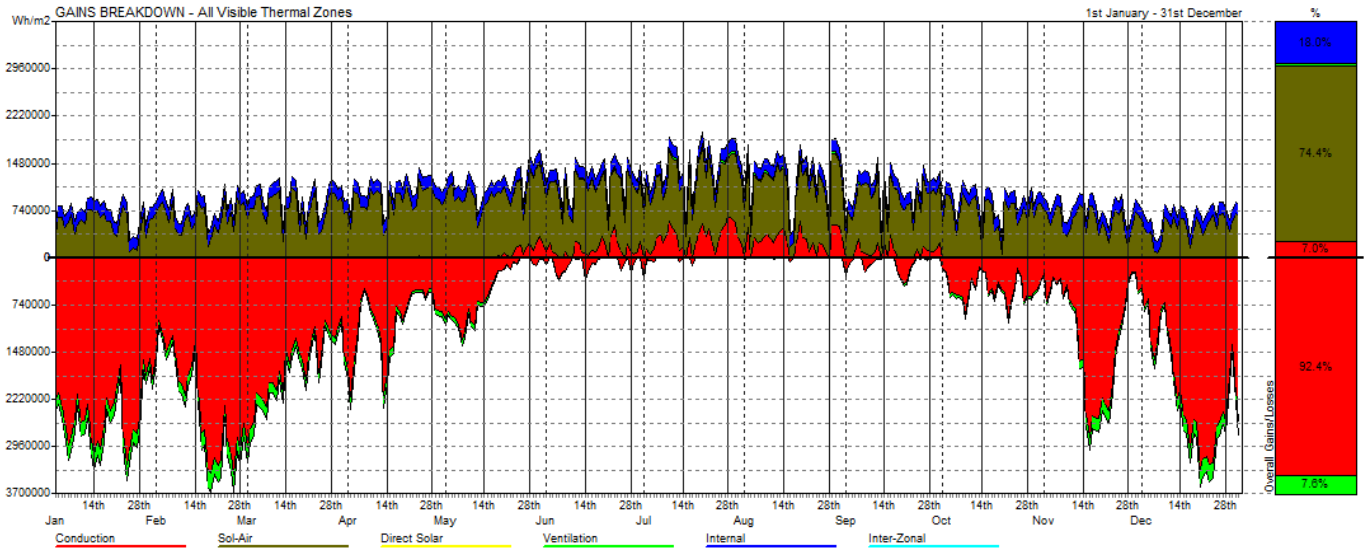

Fig. 17: Passive grain breakdown analysis before retrofitting

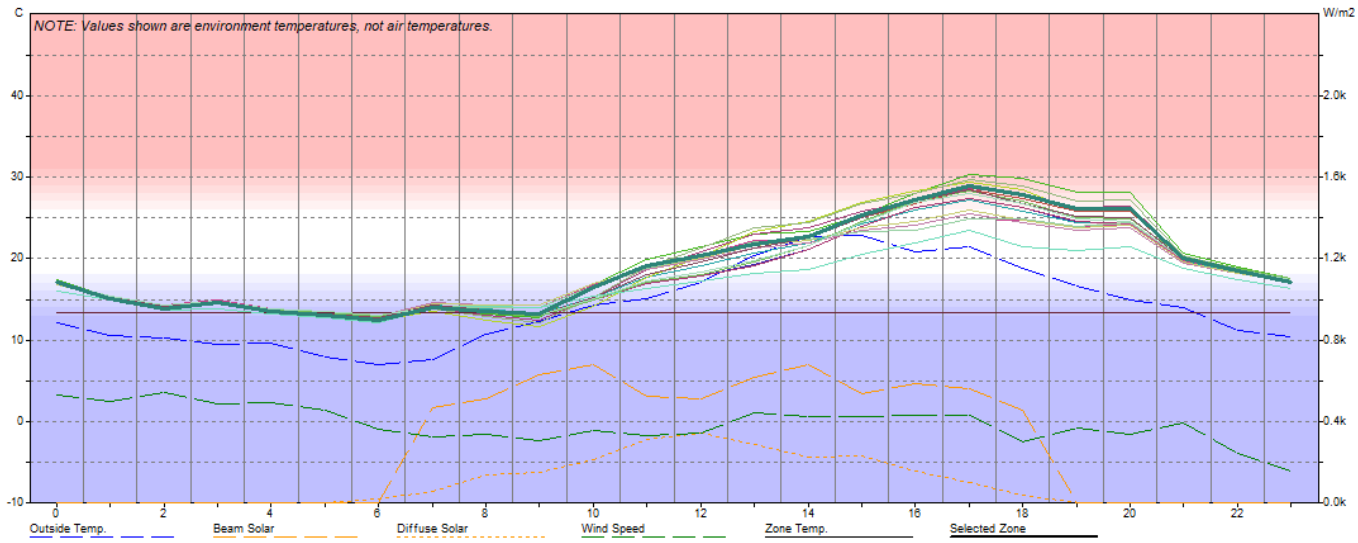

Fig. 18: Hourly temperature profile before retrofitting

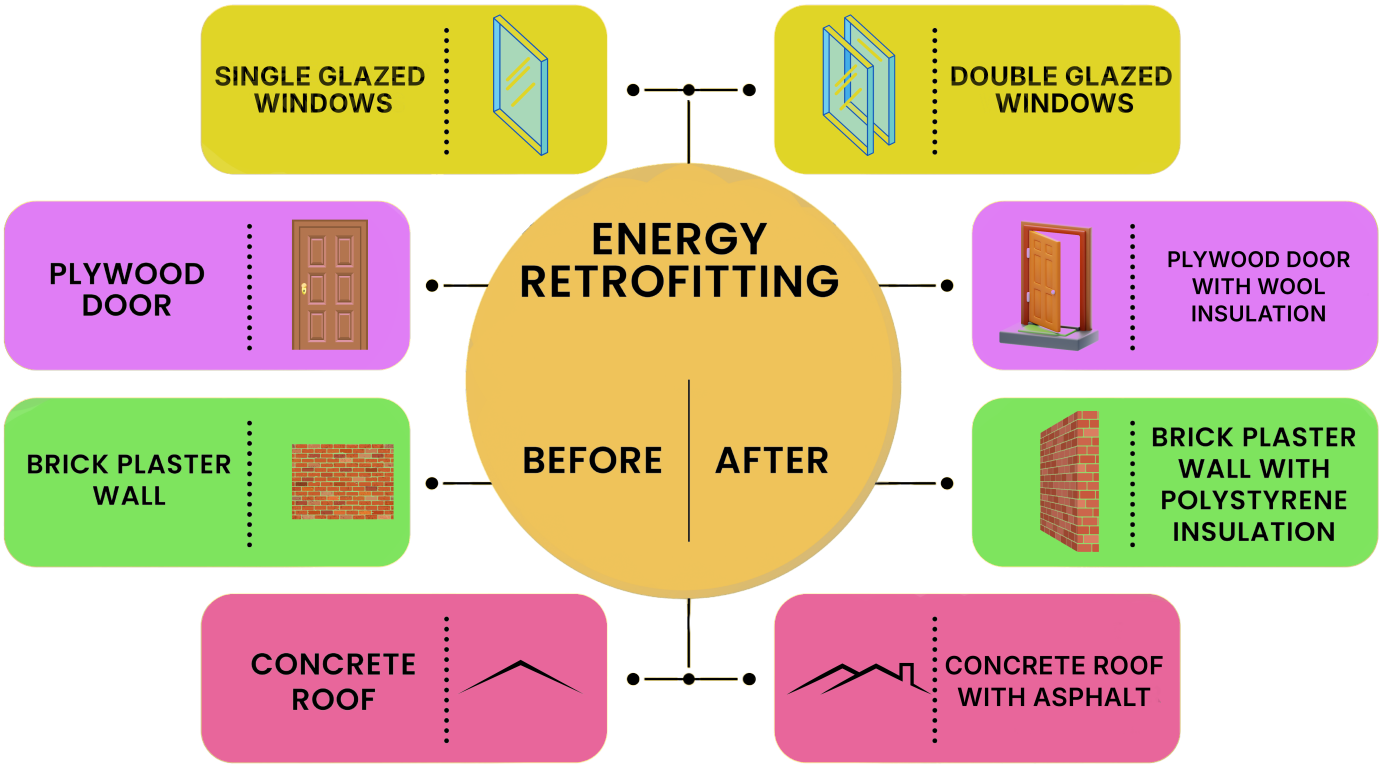

Fig. 19: Retrofitting chart

6 Retrofitting Analysis

6.1 Modifications

Figure 19 shows a retrofitting chart that shows the modifications of energy retrofitting measures, such as upgrading single-glazed windows to double-glazed, insulating plywood doors and walls, and adding asphalt to concrete roofs. These modifications enhance insulation, reduce energy loss, and improve building efficiency.

6.2 U-Values of Material

U-values, also known as thermal transmittance, measure the rate of heat transfer through a material. They quantify how well a building component (e.g., walls, windows, or roofs) conducts heat. The U-value is expressed in watts per square meter per degree Kelvin ($W/m^2 \cdot K$), and lower values indicate better insulation and reduced heat loss. Figure 20 compares the U-values of common building materials, providing insight into their insulation performance. U-value measures how well a material conducts heat, with lower values indicating better insulation. Single-glazed windows, with a U-value of 6.0, have the poorest insulation, allowing significant heat loss and making indoor spaces harder to keep warm in winter or cool in summer. Double-glazed windows, with a U-value of 2.7, offer a noticeable improvement, providing moderate insulation. Before the retrofitting, the U-value of plywood doors is 4.93, brick plaster walls is 4.48, and the concrete roof stands out with a U-value of 1.09. After the retrofitting, the U-value of plywood doors with wool insulation is 2.21, brick plaster walls with polystyrene insulation is 0.59, and a concrete roof with asphalt insulation stands out with a U-value of 1.01, offering the best insulation and helping to maintain a stable indoor temperature. Overall, selecting materials with lower U-values enhances energy efficiency, reducing heating and cooling costs and creating a more comfortable living environment.

Triple-glazed windows cost 60–70% more than double-glazed windows, and triple-glazed windows are unsuitable for hot climates like Pakistan because they are designed primarily to retain heat in cold environments, offering very low thermal conductivity (U-value) but often allowing significant solar heat gain unless specialized coatings are used. IMPs are less costly but harder to integrate into brick structures and need special detailing to prevent thermal bridging.

7 Post Retrofitting Results

As an illustration in Figure 21 of how each building component contributes to heat gains and losses, the passive gains are categorized. It is clear that the loss due to conduction has decreased to 53.3%. And decrease by almost 40%.

It is clear from Figure 18 that the temperature before insulation varies from 25-30℃ according to the zone in front of the sun. While Figure 22 shows that after the insulation temperature varies from 18-23℃. So, after the isolation, the temperature drops. So, our retrofitting technique is successful. Figure 23 shows the difference between the usage of electricity before and after the analysis. The blue bar shows the current installed appliances, and the orange bars show alternate appliance usage.

7.1 Fabrication Cost

The cost breakdown of retrofitting materials reveals that the majority of the investment was allocated to windows, amounting to $50,910.84 or 87.2% of the total cost. This reflects the significant expense and impact of installing energy-efficient double-glazed units. Roof insulation accounted for $3,690.24 (6.3%) and wall insulation for $3,495.09 (6.0%), both essential for reducing heat conduction and improving the building's thermal envelope. In contrast, door insulation represented a minimal cost of $312.11 (0.5%). This distribution underscores the strategic focus on high-impact elements—particularly glazing—to maximize energy efficiency through targeted retrofitting. Figure 24 shows the chart of fabric/material cost used for insulation.

7.2 Maintenance Cost Saving

In addition to energy cost savings, maintenance cost reductions were evaluated by replacing high-consumption appliances (e.g., traditional ceiling fans and tube lights) with energy-efficient models that require less frequent replacement and servicing compared to previously used appliances.

The tube lights were replaced with LED lights. The average lifespan of tube lights is approximately 10,000 hours, whereas the lifespan of LED lights is about 25,000 hours. The total annual saving is calculated as the difference between the annual maintenance costs before and after retrofitting.

Lights are used for 12 hours per day. Based on this, tube lights need replacement after approximately 834 days, while LED lights require replacement after approximately 2,084 days. This clearly indicates a significant difference in maintenance duration.

The cost of a tube light is 750 Rs, and the cost of an LED light is 1,450 Rs. From this, it was calculated that the maintenance cost of LED lights is approximately

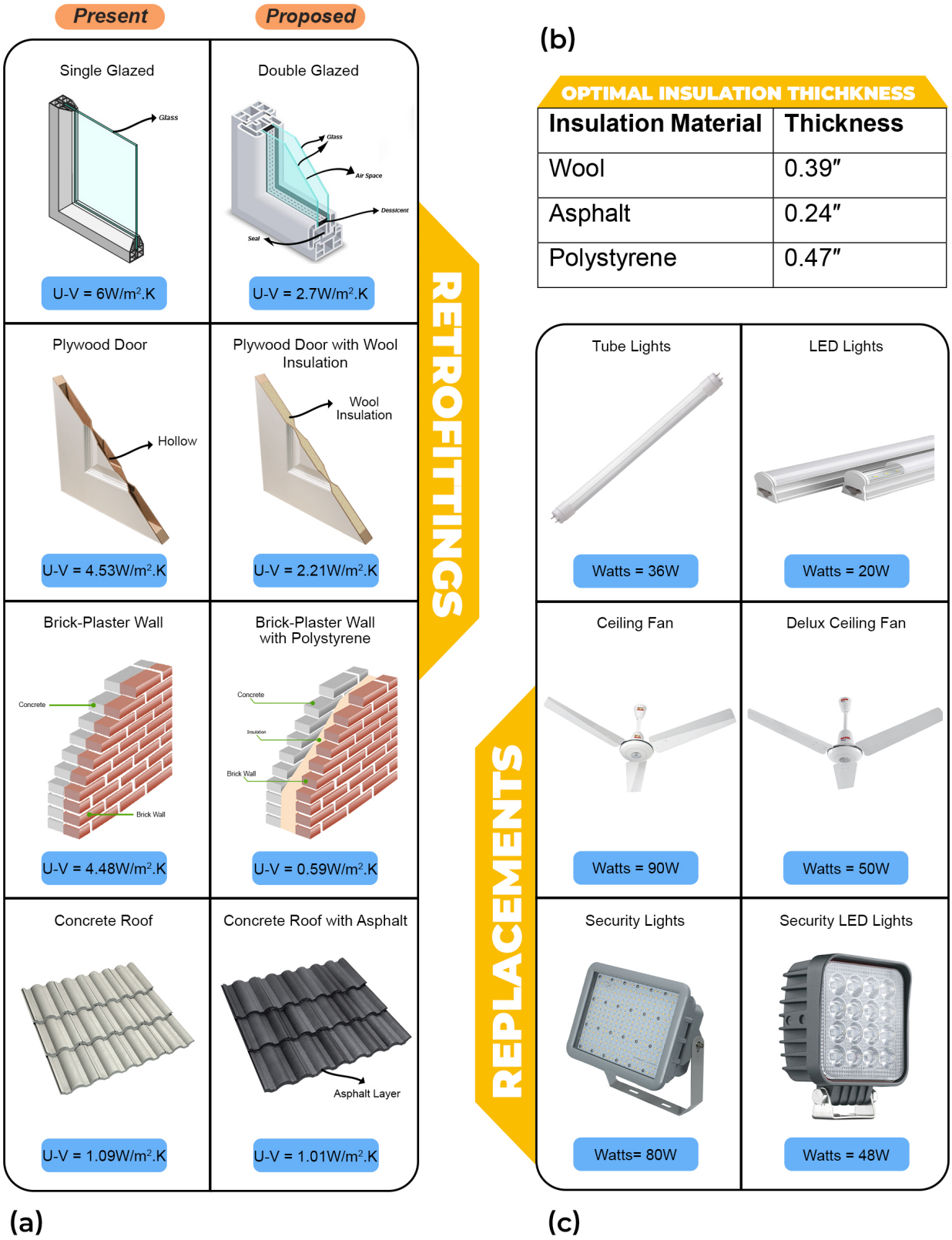

Fig. 20: (a) Retrofitting (b) Insulation thickness table (c) Appliances alternatives

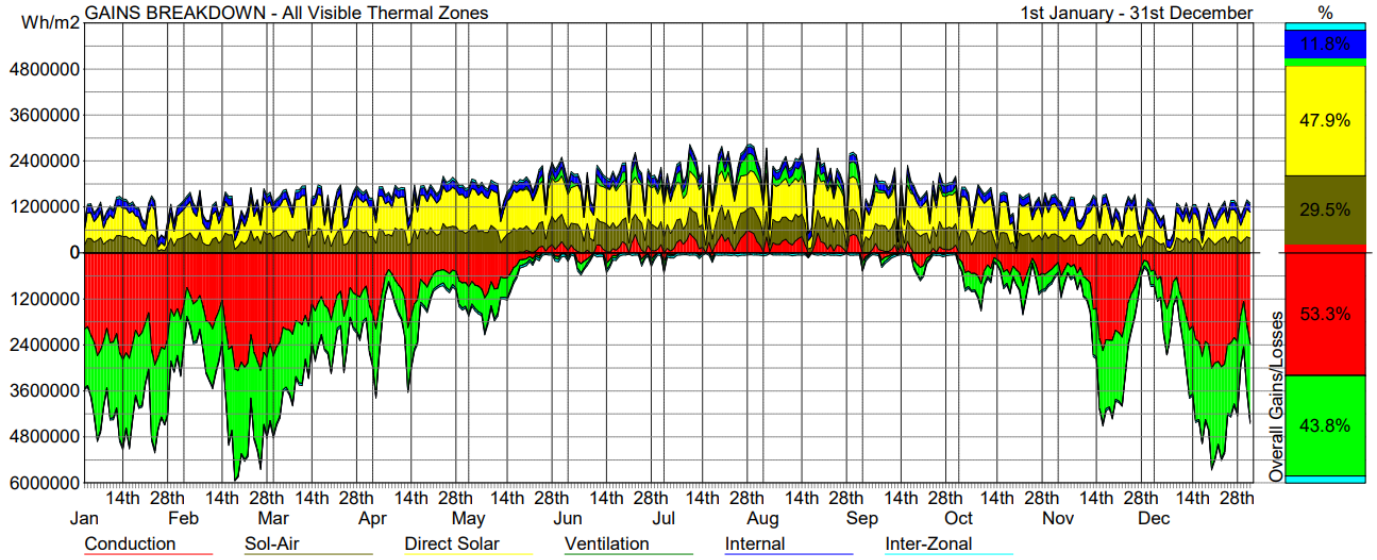

Fig. 21: Passive grain breakdown analysis after retrofitting

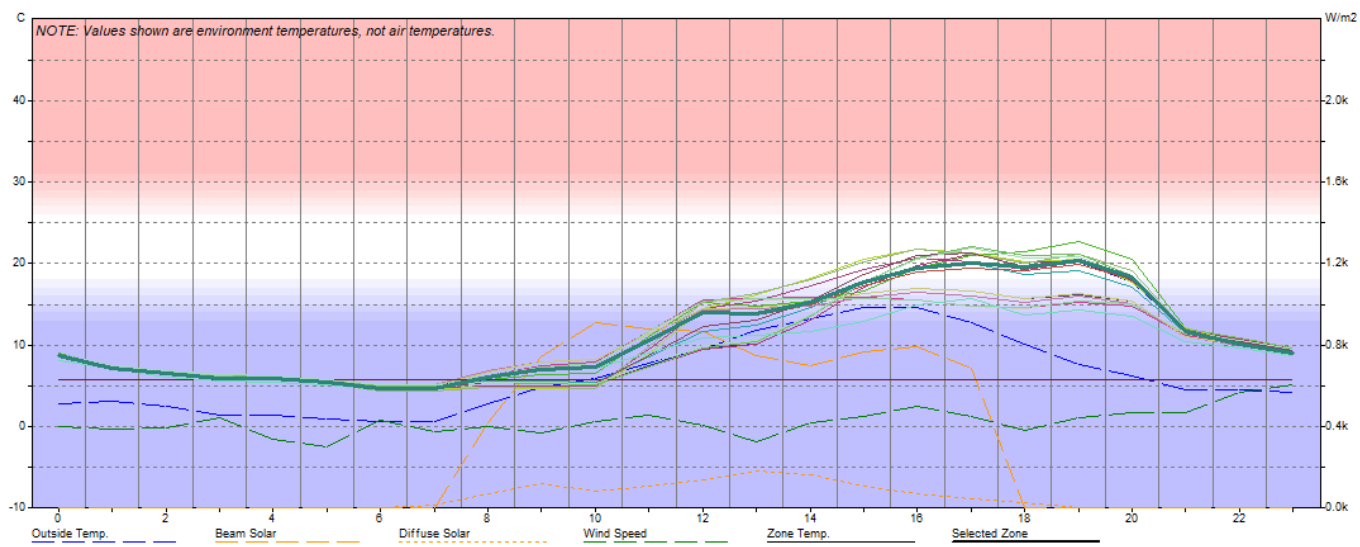

Fig. 22: Hourly temperature profile after retrofitting

365,400 Rs after every 2,084 days, whereas the maintenance cost of tube lights is 189,000 Rs after every 834 days. Considering that LED lights have an average lifespan of about 2.5 times greater than that of tube lights, the calculated annual maintenance saving after retrofitting is approximately 20,000 Rs.

7.3 Environmental Benefits

The environmental impact of energy savings was quantified using the national grid emission factor of approximately 0.46 kg CO_2/kWh for Pakistan, as reported by the IEA (2023). The reduction in monthly energy consumption from 10,150.69 kWh to 6,466.93 kWh corresponds to a decrease of approximately 1.7 tons of CO_2 emissions per month, amounting to over 20 tons annually. The relationship used for this estimation is expressed as:

$$\text{CO}_2 \text{ Emission} = \Delta E \times EF \tag{7}$$

where

$$\Delta E = 10{,}150.69 - 6{,}466.93 = 3{,}683.76 \text{ kWh/month},$$

$$EF = 0.46 \text{ kg CO}_2 \,/\, \text{kWh}.$$

Substituting these values yields:

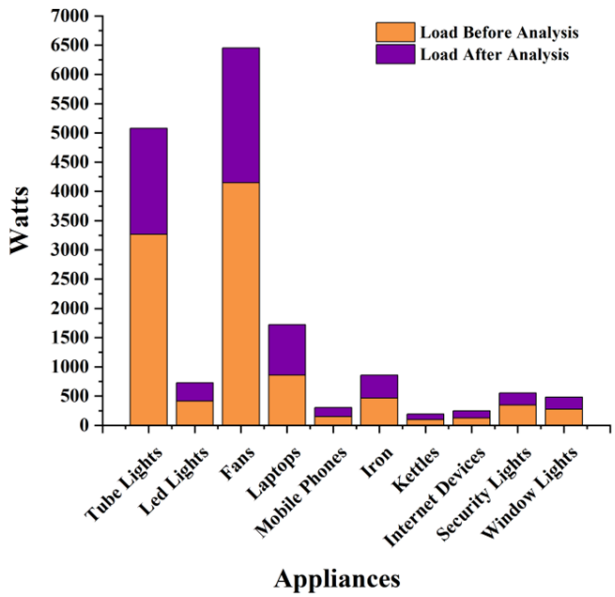

Fig. 23: Load before and after analysis

$$\begin{aligned} CO_2 \text{ Emission} &= 3{,}683.76 \times 0.46 \\ &= 1{,}694.5296 \text{ kg } CO_2/\text{month} \\ &\approx 1.6945 \text{ t } CO_2/\text{month} \\ &\approx 20.334 \text{ t } CO_2/\text{year}. \end{aligned} \tag{8}$$

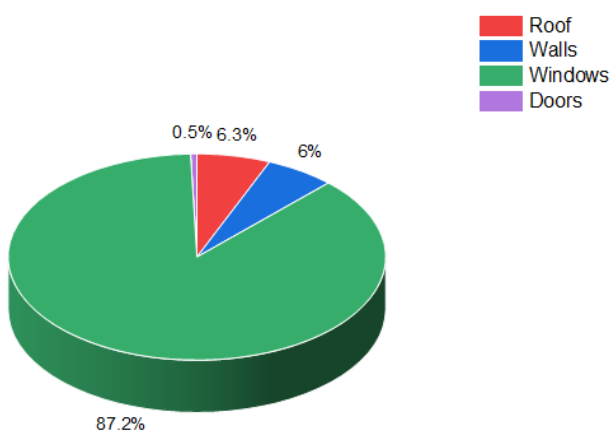

Fig. 24: Fabric cost

7.4 Payback Period

In this study, the payback period for retrofitting the hostel building was calculated to be 5.3 years, indicating that the initial investment cost will be recovered within this timeframe through energy cost savings. This payback period highlights the economic feasibility of the proposed retrofitting measures, demonstrating their long-term financial and environmental benefits. The payback period represents the amount of time required to recover the initial investment through savings in energy costs. A shorter payback period indicates a quicker return on investment, making the project more attractive.

In this study, the total investment in retrofitting measures amounted to Rs/=16,225,742, while the monthly savings in electricity costs are Rs. 255,007. This yields a payback period of approximately 5.3 years.

$$\begin{aligned} \text{Total Investment} &= \text{Rs. } 16{,}225{,}742, \\ \text{Monthly Saving} &= \text{Electricity Bill Before Analysis} \\ &\quad - \text{Electricity Bill After Analysis} \\ &= \text{Rs. } 703{,}980 - \text{Rs. } 448{,}973 \\ &= \text{Rs. } 255{,}007, \\ \text{Payback Period} &= \frac{\text{Total Investment}}{\text{Monthly Saving}} \\ &= \frac{16{,}225{,}742}{255{,}007} = 63.62 \text{ months} \\ &\approx 5.3 \text{ years.} \end{aligned} \tag{9}$$

8 Conclusion

The comprehensive analysis conducted on the energy performance of appliances in the selected hostel building has yielded valuable insights into energy consumption patterns and potential areas for improvement. By meticulously surveying and evaluating the energy usage of various equipment across different floors, we have gained a deeper understanding of the building's energy dynamics. Furthermore, the economic comparison between initial investments and returns based on the quantitative results of energy retrofitting underscores the significance of investing in energy-efficient technologies and practices. By reducing energy consumption, not only can operational costs be minimized, but also environmental impacts can be mitigated, aligning with sustainability goals. The comparison between the old and new units used by each appliance over a month reflects the success of energy conservation endeavors. The significant reduction in total energy consumption, from 10150.686 kWh to 6466.926 kWh, underscores the efficacy of the implemented measures. And the payback period is 5.3 years. In conclusion, this study highlights the importance of

proactive energy management strategies in addressing the energy challenges faced by buildings. By embracing energy-efficient technologies, adopting sustainable practices, and implementing effective retrofitting measures, we can pave the way towards a more sustainable and energy-efficient future.

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