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Energy Use Intensity Benchmarking and Decarbonization Pathways in Student Residential Buildings: Evidence from a Multi-Hostel Campus Study

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ABSTRACT

Student residential buildings in higher educational institutions represent a high-intensity yet under-optimized segment of campus energy management. This study presents an equipment-level energy audit of six hostel buildings at Jawaharlal Nehru Technological University Kakinada, India, integrating load inventory analysis, lux-based illumination measurement, twelve-month electricity billing data, LPG consumption assessment, and techno-economic evaluation. The hostel complex recorded an annual electricity consumption of 2573.2 MWh across 8,000 m^2, gives an Energy Use Intensity (EUI) of 321.6 kWh/m^2·year and a per capita consumption of approximately 1170 kWh. Residential rooms contributed nearly 50% of the total demand. The disaggregated analysis identified lighting and ceiling fans as dominant fixed loads, while cumulative plug loads were also significant. The kitchen operations consumed approximately 30,000 kg of LPG annually. Scenario analysis indicates electricity reduction potential through LED retrofitting (24–38%), high-efficiency fan replacement (16-18%), and motion-sensor automation (10%). Rooftop solar photovoltaic integration could offset up to 100% of annual electrical demand. Using a grid emission factor of 0.82 kg CO_2/kWh, baseline emissions were estimated at 2,110 tCO_2/year. Sensitivity analysis confirms the economic robustness of solar PV under ±10% variation in cost and tariff parameters. The findings highlight an integrated efficiency–renewable pathway toward low-carbon campus residential energy systems.

Keywords: *Energy auditing; Academic institutions, Hostel building, Energy efficiency, LPG usage, Walk-through audit.*

1. Introduction

The sustainable development of modern society is fundamentally dependent on the availability and efficient use of energy [1]. National energy consumption is projected to grow at an annual rate of approximately 4.2% through 2035, placing increasing pressure on conventional energy resources. This sustained growth underscores the need for improved energy efficiency alongside accelerated adoption of renewable energy systems[2]. Rising electricity costs further reinforce the importance of systematic energy audits as a practical tool to identify inefficiencies and reduce avoidable energy consumption [3]. In this context, energy conservation refers to the efficient utilization of energy by minimizing wastage without compromising functional performance[4].

Within this broader energy challenge, public and educational buildings represent a critical yet under-addressed segment [5]. While despite the recognized importance of energy efficiency, many academic institutions in India continue to operate without systematic energy management practices[6]. Student hostel buildings, in particular, exhibit high energy consumption due to continuous occupancy, extensive lighting usage, and centralized cooking facilities [7]. However, energy use in such facilities is rarely quantified in a structured manner, and decisions related to equipment selection and operational practices are often made without reliable energy performance data [4], [8]. The absence of regular energy audits, sub-metering, and post-implementation monitoring further limits the ability of institutions to identify inefficiencies, prioritize interventions, and verify actual savings, resulting in significant unrealized energy-saving potential and avoidable operational costs [9].

In response to these gaps, the present study conducts a structured energy audit of hostel buildings at Jawaharlal Nehru Technological University Kakinada to evaluate equipment-wise electricity and LPG consumption patterns. Accordingly, the methodology adopted in this study is designed to systematically capture energy consumption data, assess end-use efficiency, and evaluate feasible conservation measures using standardized audit procedures and economic performance indicators [6], [10], [11].

2. Data Collection & Methodology

2.1 Energy Audit Methodology

2.1.1 The Proposed Energy Audit Phases

The proposed energy audit in this study was carried out in three distinct phases. Previous studies have shown that simplified audit tools can support local administrators in assessing the energy performance of educational buildings through basic data inputs and in identifying suitable energy efficiency measures. An energy audit of a commercial building by adopting an equipment-wise energy consumption analysis approach. Following similar principles, the energy auditing methodology adopted in the present study consists of the following phases:

1. Data Collection:

In the primary data collection phase, comprehensive information was gathered using various methods such as on-site observations, interactions with key personnel, and direct measurements of energy-consuming equipment[12].

2. Data Analysis:
The collected data were subjected to detailed analysis to evaluate energy consumption patterns. The database generated during this phase was further used to develop graphical representations for better interpretation of the results[4], [8].

3. Recommendations:
Based on the outcomes of data analysis and field observations, appropriate measures for reducing power consumption were proposed. These recommendations were formulated to ensure energy savings without affecting occupant comfort and satisfaction, and were supported by cost analysis [1], [9].

2.1.2 Methodology Adopted for the Audit

The energy audit methodology adopted in this study comprises the following steps:

1. Visual survey of the specific areas
2. Visual inspection and data collection
3. Observation of the general condition of the facility and equipment, along with quantification
4. Identification and verification of energy consumption and other parameters through measurements
5. Detailed calculations, analysis, and assumptions
6. Validation of results
7. Identification of potential energy-saving opportunities
8. Implementation of recommended measures

The collected data are used to diagnose weak points in the building energy usage system, identify latent energy-saving potential, and present a detailed energy audit assessment. Through systematic investigation of energy consumption, the audit mainly concentrates on equipment-wise energy use, with particular emphasis on lighting systems, electronic equipment, fans, and miscellaneous electrical loads[10], [13], [14].

2.1.3 Energy Audit Instruments Used

Energy auditing requires accurate identification and quantification of energy consumption, which necessitates field measurements using appropriate instruments. These instruments should be portable, durable, easy to operate, and relatively inexpensive. Some of the commonly used instruments in energy audits include lux meters, infrared thermometers, tachometers, and leak detectors. Based on availability and audit requirements, a lux meter was used in the present study to measure illumination levels at various locations within the hostel buildings[15], [16].

2.1.4 Payback Period

The payback period is defined as the amount of time required to recover the initial investment. When all other factors remain constant, a project with a shorter payback period is considered more favourable, as the investor can recover the invested capital in a shorter duration. The payback period is calculated using Equation (1):

$$T = \frac{\Delta K}{\Delta \phi} \text{ ………. } [1]$$

where,
T = payback period (years)
ΔK = capital investment (Rs)
Δφ = net annual cash inflow (Rs)

2.2 Building Location and Description

The study was conducted at the Jawaharlal Nehru Technological University Kakinada (JNTUK), Kakinada, Andhra Pradesh, India. The university hostels containing multiple residential buildings accommodating both undergraduate and postgraduate students. The hostels are distributed across a built-up area of approximately 8,000 m^2 and consist of six separate buildings, including four boys' hostels and two girls' hostels. The undergraduate boys' hostels are primarily two-storey buildings with varying accommodation capacities: Nataraja Hostel (600 students), Narendra Hostel (350 students), Nalanda Hostel (400 students). The girls' hostel complex includes Nagavali and Nagavali Extension, Nivedhitha Hostel, with a combined capacity of approximately 450 students, and Nagavali Hostel (300 students). In total, the hostel facilities provide around 800 residential rooms.

Each hostel room is typically equipped with two tube lights and one ceiling fan. Common sanitation facilities are provided, with five toilets located at each corner of the hostel buildings. A centralized mess and dining hall facility serves the residents and is located within the hostel premises. The ground floor of the each hostel having one common hall, is utilized for recreational purposes, including indoor games and a television hall [17].

2.3 Data Collection

Data collection was carried out to obtain a comprehensive understanding of the existing energy usage patterns in the hostel buildings. Both primary and secondary data sources were collected to ensure reliability and completeness of the information. Primary data collection involved on-site inspections, visual surveys, and interaction with facility management personnel to document building characteristics, occupancy patterns, and operating schedules. An inventory of energy-consuming equipment, including lighting systems, fans, electronic appliances, and kitchen facilities, was prepared for each hostel building. Secondary data were collected from institutional records, including monthly electricity bills and tariff structures, which were used to establish baseline energy consumption[2], [18], [19].

The data collected from the different hostel blocks are presented in the below

Table 1: Energy Consumption patterns in hostels

Name of the Hostel	Type of Equipment	Quantity	Wattage per unit(W)	Total wattage(W)	Average daily operating hours(h)	Daily Energy consumption (kWh)	Monthly Energy consumption (kWh)	Annual Energy consumption (kWh)
Narendra	Lights	109.0	20.0	2180.0	8.0	17.44	523.20	6278.40
	Fans	64.0	100.0	6400.0	10.0	64.00	1920.00	23040.00
	Geysers	6.0	2000.0	12000.0	6.0	72.00	2160.00	25920.00
	Cell Phones	350.0	80.0	28000.0	18.0	504.00	15120.00	181440.00
	Laptops	100.0	250.0	25000.0	10.0	250.00	7500.00	90000.00
	Water Cooler	2.0	400.0	800.0	18.0	14.40	432.00	5184.00
Nataraj	Lights	242.0	20.0	4840.0	8.0	38.72	1161.60	13939.20
	Fans	108.0	28.0	3024.0	10.0	30.24	907.20	10886.40
	Geysers	6.0	2000.0	12000.0	6.0	72.00	2160.00	25920.00
	Cell Phones	500.0	80.0	40000.0	18.0	720.00	21600.00	259200.00
	Laptops	300.0	250.0	75000.0	10.0	750.00	22500.00	270000.00
	Water Cooler	4.0	400.0	1600.0	18.0	28.80	864.00	10368.00
Nalanda	Lights	128.0	20.0	2560.0	8.0	20.48	614.40	270000.00
	Fans	56.0	100.0	5600.0	10.0	56.00	1680.00	10368.00
	Geysers	6.0	2000.0	12000.0	6.0	72.00	2160.00	7372.80
	Cell Phones	400.0	80.0	32000.0	18.0	576.00	17280.00	20160.00
	Laptops	250.0	250.0	62500.0	10.0	625.00	18750.00	25920.00
	Water Cooler	2.0	400.0	800.0	18.0	14.40	432.00	207360.00
Nagavalli	Lights	434.0	40.0	17360.0	8.0	138.88	4166.40	49996.80
	Fans	373.0	100.0	37300.0	10.0	373.00	11190.00	134280.00
	Geysers	6.0	2000.0	12000.0	6.0	72.00	2160.00	25920.00
	AC	2.0	1200.0	2400.0	6.0	14.40	432.00	5184.00
	Washing machines	6.0	410.0	2460.0	12.0	29.52	885.60	10627.20
	Systems	12.0	200.0	2400.0	6.0	14.40	432.00	5184.00
	Cell Phones	300.0	80.0	24000.0	18.0	432.00	12960.00	155520.00
	Laptops	200.0	250.0	50000.0	10.0	500.00	15000.00	180000.00
	Water Cooler	2.0	400.0	800.0	18.0	14.40	432.00	5184.00
Nagavalli Extension	Lights	200.0	20.0	4000.0	8.0	32.00	960.00	11520.00
	Fans	84.0	100.0	8400.0	10.0	84.00	2520.00	30240.00
	Geysers	6.0	2000.0	12000.0	6.0	72.00	2160.00	25920.00
	AC	2.0	1200.0	2400.0	6.0	14.40	432.00	5184.00
	Washing machines	6.0	410.0	2460.0	12.0	29.52	885.60	10627.20
	Systems	12.0	200.0	2400.0	6.0	14.40	432.00	5184.00
	Cell Phones	300.0	80.0	24000.0	18.0	432.00	12960.00	155520.00
	Laptops	200.0	250.0	50000.0	10.0	500.00	15000.00	180000.00
	Water Cooler	2.0	400.0	800.0	18.0	14.40	432.00	5184.00
Niveditha	Lights	294.0	20.0	5880.0	8.0	47.04	1411.20	16934.40
	Fans	126.0	100.0	12600.0	10.0	126.00	3780.00	45360.00
	Geysers	6.0	2000.0	12000.0	6.0	72.00	2160.00	25920.00
	AC	2.0	1200.0	2400.0	6.0	14.40	432.00	5184.00
	Washing machines	9.0	410.0	3690.0	12.0	44.28	1328.40	15940.80
	Systems	10.0	200.0	2000.0	6.0	12.00	360.00	4320.00
	Cell Phones	400.0	80.0	32000.0	18.0	576.00	17280.00	207360.00
	Laptops	250.0	250.0	62500.0	10.0	625.00	18750.00	225000.00
	Water Cooler	4.0	400.0	1600.0	18.0	28.80	864.00	10368.00
Central Mess (Girls Hostel)	Grinders (10 L)	5.0	750.0	3750.0	2.0	7.50	225.00	2700.00
	Mixers	5.0	550.0	2750.0	2.0	5.50	165.00	1980.00
	Water Dispenser	2.0	300.0	600.0	18.0	10.80	324.00	3888.00
	Water Motors	1.0	100.0	100.0	5.0	0.50	15.00	180.00
	Lights	50.0	20.0	1000.0	18.0	18.00	540.00	6480.00
	Fans	20.0	100.0	2000.0	10.0	20.00	600.00	7200.00
	Exhaust Fans	5.0	75.0	375.0	4.0	1.50	45.00	540.00
A Mess - (Boyes Hostel)	Grinders	5.0	750.0	3750.0	2.0	7.50	225.00	2700.00
	Mixers	5.0	550.0	2750.0	2.0	5.50	165.00	1980.00
	Water Dispenser	2.0	300.0	600.0	18.0	10.80	324.00	3888.00
	Water Motors	1.0	100.0	100.0	5.0	0.50	15.00	180.00
	Lights	50.0	20.0	1000.0	18.0	18.00	540.00	6480.00
	Fans	20.0	100.0	2000.0	10.0	20.00	600.00	7200.00
	Exhaust Fans	5.0	75.0	375.0	4.0	1.50	45.00	540.00
O Mess - (Boyes Hostel)	Grinders	5.0	750.0	3750	2.0	7.50	225.00	2700.00
	Mixers	5.0	550.0	2750	2.0	5.50	165.00	1980.00
	Water Dispenser	2.0	300.0	600	18.0	10.80	324.00	3888.00
	Water Motors	1.0	100.0	100	5.0	0.50	15.00	180.00
	Lights	50.0	20.0	1000	18.0	18.00	540.00	6480.00
	Fans	20.0	100.0	2000	10.0	20.00	600.00	7200.00
	Exhaust Fans	5.0	75.0	375	4.0	1.50	45.00	540.00
Total		**5227.0**	**21548.0**	**4100226.5**	**440.0**	**7010.52**	**210315.60**	**2573971.20**

1.4 Energy Consumption Pattern

The energy consumption pattern of the hostel building was examined in detail through a combination of reference electricity bills and on-site measurements using appropriate instruments. This approach ensured that both recorded consumption and actual operational conditions were adequately captured. The results of the assessment are discussed under the following subsections[6], [20], [21].

2.4.1 Annual Electricity Consumption Pattern of the Hostel

The annual electricity consumption pattern of the hostel is illustrated in Figure 1. The total yearly electricity consumption was found to be 2573.2 MWh, with an average per capita energy consumption of 1170 kWh. Electricity is primarily utilized to meet the requirements of lighting, ceiling fans, water coolers, pumps, computers, and other equipment associated with hostel and mess operations.

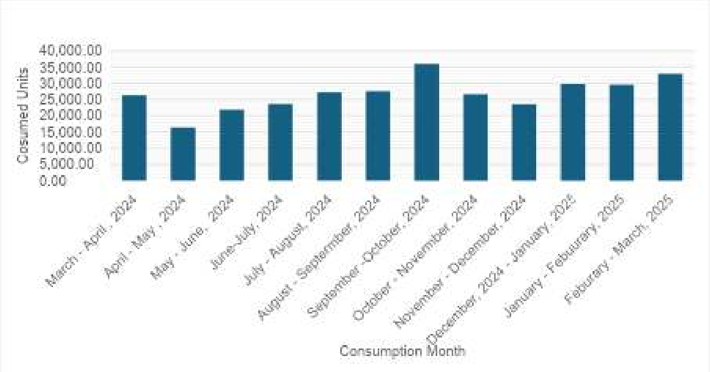

Figure 1: Energy Consumption Vs Month

Table 2: Energy Consumption in Hostels

S No	Month	Electrical Consumption (Kwh)
1	March - April , 2024	26,330.00
2	April - May , 2024	16,382.00
2	May - June, 2024	21,803.00
4	June-July, 2024	23,666.00
5	July - August, 2024	27,289.00
6	August - September, 2024	27,637.00
7	September -October, 2024	35,958.00
8	October - November, 2024	26,692.00
9	November - December, 2024	23,580.00
10	December, 2024 - January, 2025	29,864.00
11	January - February, 2025	29,519.00
12	February - March, 2025	32,977.00

***Source:** Campus Electricity Bills*

To understand temporal variations in energy use, monthly electricity consumption data for the preceding 12 months were collected and analysed. These data were used to assess changes in energy demand over an annual cycle and are summarized in Figure No. 2. The analysis indicates that the average annual electricity consumption during the period from February 2024 to March 2026 was 2573.2 MWh.

From Graph No. 1, it is evident that electricity demand increases substantially during the Winter months, which can be attributed to the increased requirement for operating fans and other electrical equipment to maintain thermal comfort within the hostel buildings. This seasonal trend highlights the influence of climatic conditions and occupancy-related usage on overall electricity consumption.

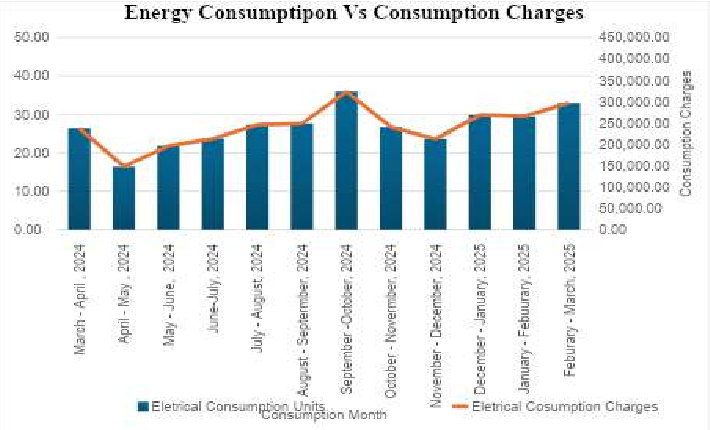

Figure 2: Annual Energy Consumption

2.4.2 Location-Wise Power Consumption Analysis

The location-wise distribution of electricity consumption within the hostel premises is illustrated in Fig. No. 3. This analysis was carried out to identify the functional areas contributing most significantly to the overall energy demand. As evident from Fig. No. 3, residential rooms and the hostel mess emerge as the major power-consuming zones.

Residential rooms account for approximately 50% of the total electricity consumption, making them the most critical area for energy efficiency improvement. This high share can be attributed to the continuous use of lighting, ceiling fans, and personal electrical appliances over extended periods. The hostel mess also contributes a substantial portion of the total consumption due to the operation of kitchen equipment and supporting electrical systems.

The results of the location-wise analysis clearly indicate that energy conservation measures targeted at residential rooms and the mess facility are likely to yield the maximum reduction in overall electricity consumption. This finding supports the need for location-specific interventions rather than uniform energy-saving measures across all areas of the hostel.

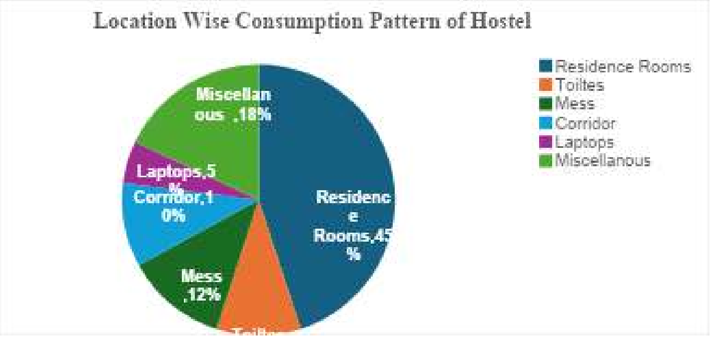

Figure 3: Location Wise Energy Consumption details

3.1.3 Equipment-Wise Analysis of Power Consumption

An equipment-wise analysis of power consumption was carried out to identify the relative contribution of individual electrical equipment operating within the same functional areas of the hostel buildings. This analysis aims to determine which equipment categories consume higher amounts of electricity compared to others under similar application conditions [22].

By examining energy consumption at the equipment level, it becomes possible to distinguish dominant energy-intensive devices from those with relatively lower impact, thereby supporting targeted energy conservation planning. The results of the equipment-wise power consumption analysis for the hostel buildings are summarized in Table 2, expressed in terms of energy consumption (kWh).

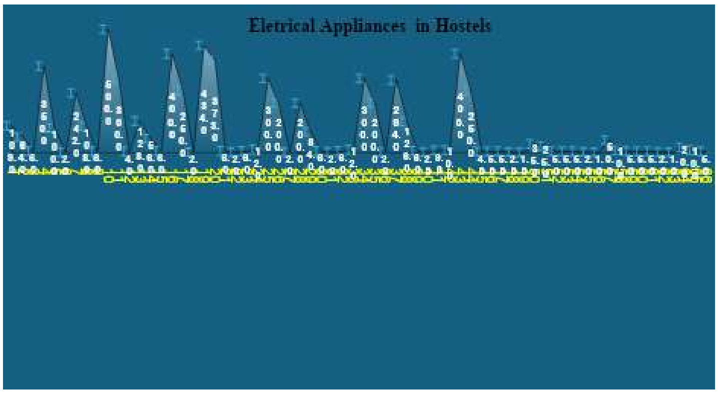

Figure 4: Equipment wise energy consumption patterns

3.1.4 Energy Usage in Hostel Kitchen

The hostel operates a common mess facility catering to both undergraduate and postgraduate students. Energy usage in the kitchen is primarily associated with cooking activities and is met through liquefied petroleum gas (LPG). Based on operational records, the hostel kitchens consume approximately 100-150 LPG cylinders per month, with each cylinder having a net weight of 19 kg.

Accordingly, the monthly LPG requirement of the hostel mess is estimated to be approximately 2850 kg, resulting in an annual LPG consumption of about 30,000 kg. This level of consumption indicates that cooking energy represents a significant and continuous energy demand within the hostel facilities. The quantified LPG usage provides a clear baseline for evaluating potential fuel-saving measures and alternative cooking energy options aimed at improving overall energy efficiency in hostel kitchen operations [23].

2.5 Audit Energy Load

2.5.1 Audit of Lighting Load

An audit of the lighting load was conducted to quantify the contribution of lighting systems to the overall energy demand of the hostel building. To determine the total installed lighting load, a physical count of all lighting fixtures was carried out across different floors and functional sections of the building. This survey provided an accurate inventory of lighting equipment in operation.

The inspection revealed that the lighting system predominantly consists of 40 W T12 fluorescent tube lights, 36 W T8 fluorescent tube lights, and 20 W compact fluorescent lamps (CFLs). These fixtures are distributed across residential rooms, corridors, common areas, and service spaces. To assess the adequacy of lighting levels and identify potential over-illumination, an accurate digital lux meter was used to measure illumination at representative locations within the building.

The illumination measurements obtained during the audit were compared with recommended lighting standards, and the observed values are summarized in Table 3. This assessment forms the basis for evaluating lighting efficiency and identifying opportunities for reducing lighting energy consumption without compromising visual comfort.

Table 3: Lighting inventory and illumination level measurement

S No	Location	T12	T8	CFL	illumination Levels(Lux)
	Residence Rooms	520.0	215.0	90.0	90.0
1	Cooking Area	20.0	5.0	4.0	115.0
3	Dinning Area	55.0	20.0	8.0	85.0
4	Toilets	45.0	25.0	12.0	95.0
5	Varandah	62.0	18.0	12.0	80.0
6	Reading Table	15.0	12.0	14.0	60.0
7	**Total**	717.0	295.0	140.0	1152.0

2.5.2 Audit of Fan Load

An audit of the fan load was carried out to assess its contribution to the overall electrical energy consumption of the hostel building. During the survey, it was observed that the hostel is equipped with a total of 982 ceiling fans, each having a rated power consumption of 100 W. These fans are primarily installed in residential rooms and common areas and are operated for extended durations on a daily basis. In addition to ceiling fans, the survey identified the presence of 25 No's exhaust fans installed in the kitchen area and bathroom areas of various hostel buildings. These exhaust fans operate for long hours during cooking periods and contribute to avoidable energy consumption due to their low efficiency. The detailed inventory of fans, including their type, quantity, and rated power, is presented in Table 4. This assessment highlights the potential for reducing fan-related energy consumption through efficiency improvements and equipment replacement.

Table 4: Fan inventory

S No	Particulars	Values
1	Total No of Fans	982.0
2	Total No of Fans in Residence Rooms	857.0
3	No of Fans in Mess	100.0
4	Rated Power for Each Fan (W)	100.0
5	No of Exhaust Fans in Cooking Area	25.0
6	Rated Power for Each Exhaust Fan (W)	60.0

2.5.3 Audit of Gadgets and Laptop Load

An audit of personal electronic gadgets was conducted following a detailed inspection of all hostel rooms. The survey revealed that approximately 1000 -1200 students regularly use laptops, while mobile phones are used by nearly all residents, with a total of nearly 2000-2200 mobile devices identified during the audit. Laptops are typically operated for 3-4 hours per day; however, it was observed that many users do not switch off their laptops when not in active use, as shown in **Table 5.** Also, the individual power consumption of laptops and mobile chargers is significant and their widespread usage and extended operating durations contribute cumulatively to the hostel's electricity demand. The observed usage patterns indicate a combination of behavioral and operational inefficiencies, suggesting that awareness measures and improved usage practices could help reduce gadget-related energy consumption without affecting user convenience.

Table 5: Gadgets and Miscellaneous Energy Load Details

S No	Type of Equipment	Quantity	Wattage per unit(W)	Total Wattage (Kw/h)
1	Tube Lights (T8/T12/CFL)	1512.0	20.0	30.24
3	Fans	982.0	100	98.2
4	Geysers	36.0	2000.0	72
5	AC	6.0	1200.0	7.2
6	Washing Machines	21.0	410.0	8.61
7	Systems	34.0	200.0	6.8
8	Cell Phones	2250.0	80.0	180
9	Laptops	1300.0	250.0	325
10	Water Cooler	22.0	400.0	8.8
11	Grinders	15.0	750.0	11.25
12	Mixers	15.0	550.0	8.25
14	Water Motors	3.0	100.0	0.3
15	Miscellaneous	10	150	1.5

2.6 Cost–Benefit Analysis and Payback Period

Following a comprehensive analysis of the energy audit data, it was identified that several opportunities exist for improving the current energy consumption scenario of the hostel buildings. To evaluate the feasibility of the proposed energy conservation measures, a cost–benefit analysis was carried out along with an assessment of the payback period. The cost–benefit analysis was used to compare the initial investment required for implementing each energy efficiency measure against the expected reduction in energy consumption and corresponding cost savings. The payback period was then calculated to estimate the time required to recover the initial investment through these savings. This approach enabled the prioritization of energy conservation measures based on their economic viability and practical applicability, ensuring that the recommended actions are both technically and financially justified.

2.6.1 Replacement of Fluorescent Tube Lights (FTLs) with Light Emitting Diode (LED) Tube Lights

The audit revealed that the dominant lighting source in most areas of the hostel buildings is the conventional 40 W fluorescent tube light (FTL) operated with a traditional electromagnetic ballast (choke), which consumes approximately 40 W per hour. Replacing this conventional ballast-based FTL system with a T8 LED tube light offers a significant opportunity for energy conservation. The T8 LED tube light operates at a lower power rating, enabling a power saving of about 16–18 W per tube light. This replacement represents a practical and effective measure to reduce lighting energy consumption without affecting the required illumination levels.

Table 6: Cost benefit analysis of Lighting Load

S. No	Particulars	Values
1	Average number of tube lights in a corridor & toilets	120
2	Average power consumption of the tube light (W)	50W
3	Average number of motion sensors required (50 corridors and 200 toilets)	250
4	Average reduction in usage per day by motion sensor (h)	4
5	Total energy saved in corridor per year (kWh)	(120 × 4 × 50 × 365)/1000 =8760
7	Saving in **rupees** Per year	8760 × 7 = 61,320
8	Cost of installation per motion sensor	₹ 2500
9	Total cost of installing motion sensors in a corridors	2500 × 250 = 6, 25, 000
10	Payback period (years)	10.19

The simple payback period for replacing all conventional Ballast (Choke) FTLs of the hostel into LED tube light is 10.2 years and 280-350 tCO_2/year reduction.

2.6.2 Replacement of Existing Fans with Energy-Efficient DU Brushless Super Fans

Another major energy-consuming equipment category in the hostel buildings is ceiling fans, which are extensively used to meet cooling and ventilation requirements. The audit identified a total of 982 conventional ceiling fans installed across the hostels. Most of these fans are operated using resistance-type regulators, which further increase energy losses during speed control[24]. Measurements conducted during the audit revealed that each existing ceiling fan consumes approximately 100 W per hour during operation. Energy efficiency can be significantly improved by replacing these conventional fans with 5-star rated (BEE) energy-efficient DU brushless super fans. Such fans typically operate at substantially lower power ratings, resulting in an estimated power saving of about 30-50 W per fan when compared to the existing ceiling fans. This replacement provides a highly effective means of reducing fan-related energy consumption while maintaining the required level of thermal comfort with 5 star rating (BEE) energy-efficient super fan**.**

Table 7: Cost benefit analysis of Fan Load

S No	Particulars Value	Value
1	Total number of fans in hostel	982
2	Average power consumed by each fan (W/h)	100
3	Average power consumed by each super fan (W/h)	40
4	Average utilisation of fan in a day (h)	10
5	Average utilisation of fans in a year (h)	280 × 10 = 2800
6	Total Power consumption (kW/h)	39.28
7	Total Energy consumption per year (kWh)	9427.2
8	Net annual cash inflow (Total Energy consumption per year × cost per unit of electricity/Local Triff)	65990.4
9	Expenses should be spent replacing one fan into super fan	2000
10	Total expenditure in replacing all existing fans (982 × 2000)	1964000
11	Resale value of existing fan	400
12	Total Resale value of all existing fans	392800
13	Initial investment	1571200
14	Payback period (years)	23.80

The payback period for replacing existing fans into superfan is 23.8 years. Hence, this would reduce the consumption of power in a large portion and 120-160 tCO_2/year mitigation.

2.6.3 Installation of Solar PV Power System at the Hostel

Table 8: Cost benefit analysis of PV Solar Installation

S. No	Particulars	Values
1	Total Power load demand (kWh/day)	7010. 52 * 1.3(discharge loss) = 9114 kWh/day
2	Total PV module capacity	9114 kWh/6 h (Max expected sunny hours per day) = 1520 kW
3	PV module capacity	250 kWp
4	No. of solar panels need	1520kW/550W = 2764
5	Size of solar inverter (maximum conveyance of load at any instant)	200 kW (4 No's)
7	Total space required (m^2)	11,000
8	Initial Investment (Rs)	1,30,00,000
9	Life span of system (years)	25 - 35
10	Net annual cash inflow (Rs)	22,51,879.00
11	Payback period (years)	5.7

For the past 45 years, the hostel has been predominantly dependent on grid-supplied electrical energy to meet its overall energy requirements. The average annual electricity consumption of the hostel is approximately 2573.2 MWh, which results in an average annual electricity expenditure of about ₹ 22, 51, 879. This continuous reliance on grid electricity contributes significantly to the operational energy cost of the hostel. One of the most effective approaches to reduce, or potentially eliminate, dependence on conventional grid electricity is the installation of a solar photovoltaic (PV) power system. The adoption of a solar PV system would allow on-site generation of renewable electricity, thereby off-setting a substantial portion of the hostel's annual electricity demand and reducing overall electricity expenditure. The payback period for installing a solar power system in the hostel is 5.7 years. Within 5.7 years the investment should be recovered successfully. After 5.7 years and up to remaining period 19.3 years system will produce power with free of cost with little periodic maintenance and 2,110 tCO_2/year reduction.

2.6.4 Implementation of Motion Sensors in Toilets and Corridors

A significant amount of electrical energy can be conserved through the implementation of automation systems in common areas such as toilets and corridors. These spaces are typically characterized by intermittent occupancy; however, lighting in these areas often remains switched on continuously, leading to unnecessary energy consumption. While by installing motion sensors, lighting systems in toilets and corridors can be automatically switched on or off based on occupant movement. This demand-based operation ensures that lights are used only when required, thereby substantially reducing the connected load and operating hours in these areas. The adoption of motion sensor–based lighting control represents an effective and low-cost energy conservation measure with minimal impact on user convenience.

Table 9: Cost Benefit analysis of Motion Sensor Installation

S. No	Particulars	Values
1	Average number of tube lights in a corridor & toilets	120
2	Average power consumption of the tube light (W)	50W
3	Average number of motion sensors required (50 corridors and 200 toilets)	250
4	Average reduction in usage per day by motion sensor (h)	4
5	Total energy saved in corridor per year (kWh)	(120 × 4 × 50 × 365)/1000 =8760
7	Saving in Rs. Per year	8760 × 7 = 61,320
8	Cost of installation per motion sensor	₹. 2500
9	Total cost of installing motion sensors in a corridors	2500 × 250 = 6, 25, 000
10	Payback period (years)	10.19

The payback period for installing motion sensors in corridors & toilets is 10.19 years. It would reduce energy consumption in a considerable quantity and 7 tCO_2/year reduction.

2.6.5 Recommendations for Gadgets and Laptop Load

Energy consumption associated with personal electronic gadgets and laptops can be reduced through increased energy conservation awareness among students and hostel staff. Educating occupants on responsible usage practices, such as switching off laptops and chargers when not in use, can contribute to noticeable reductions in electricity consumption. In addition, regular inspection of hostel buildings is necessary to monitor compliance with energy-efficient usage practices. The introduction of penalties or fines for defaulters may serve as an effective enforcement mechanism to discourage misuse and promote responsible energy behaviour. These measures, when combined, can help minimize avoidable energy consumption from personal electronic devices without affecting user convenience.

2.6.6 Replacement of LPG Gas Stove Cooking with Steam Cooking

Energy consumption for cooking in the boys' hostel is primarily dependent on liquefied petroleum gas (LPG), as the hostel mess operates continuously throughout the year. Based on operational records, the hostels consume approximately 100-150 LPG equivalent cylinders per month, with each cylinder weighing 19 kg. This corresponds to a monthly LPG requirement of about 2850 kg and an annual consumption of approximately 30, 000 kg. At present, the cost of each LPG cylinder is around ₹1,700-₹1800, inclusive of taxes and delivery charges, resulting in an annual LPG expenditure of approximately ₹30.99-32.40 lakh. One of the most effective approaches to reducing LPG consumption is the replacement of conventional LPG-based cooking with a steam cooking system. The college campus possesses abundant natural resources in the form of trees, and regular tree maintenance through pruning is essential for healthy growth. The biomass generated from pruning activities can be effectively utilized as fuel for a steam boiler, thereby supporting steam-based cooking operations.

The implementation of a steam cooking system would significantly reduce dependence on LPG while simultaneously enabling the productive utilization of locally available natural resources. This approach not only lowers recurring fuel costs but also contributes to sustainable energy management within the campus by integrating waste biomass into the cooking energy system.

2.6.7 Replacement of Inefficient Kitchen Appliances

The energy audit revealed that the hostel kitchen is currently using old and inefficient manual defrost-type refrigerators, which contribute significantly to avoidable electricity consumption. Measurements indicate that the existing refrigerator consumes approximately 4.8 kWh of electricity per day, resulting in substantial annual energy usage. To reduce this energy consumption, it is recommended to replace the existing refrigerator with a 5 star-rated, energy-efficient, self-defrosting refrigerator. Such refrigerators are designed to operate with lower power consumption and improved thermal efficiency, thereby reducing daily and annual energy usage. The replacement of inefficient kitchen appliances with high-efficiency alternatives represents a practical and effective measure for improving overall energy efficiency in hostel kitchen operations.

2.6.8 Creating Awareness Among Workers and Students

The energy audit revealed that many workers and students in the hostel are not fully aware of the importance of energy conservation and efficient energy use. This lack of awareness contributes to avoidable energy wastage through improper operation of electrical equipment and inefficient usage practices. Conducting proper orientation and training programs can help educate occupants on simple yet effective energy-saving practices, such as switching off equipment when not in use and following efficient operating procedures.

These awareness initiatives are expected to play a supportive role in sustaining the effectiveness of technical energy conservation measures implemented in the hostel.

3. Conclusions

This study establishes a structured, equipment-disaggregated energy auditing framework for institutional residential buildings and applies it to a multi-hostel university campus.

1. The hostel complex consumes 2573.2 MWh annually across 8,000 m^2, resulting in an Energy Use Intensity (EUI) of 321.6 kWh/m^2·year.

2. When compared with typical academic residential building benchmarks (200–300 kWh/m^2·year), the campus operates at the higher end of consumption intensity, confirming the presence of substantial efficiency improvement potential.

3. The estimated annual electrical carbon footprint of approximately 2,110 tCO_2 (based on 0.82 kg CO_2/kWh grid emission factor) underscores the environmental significance of targeted interventions. Equipment-level analysis identifies lighting and fans as primary controllable loads, while plug loads contribute cumulatively to demand growth.

4. The quantified intervention impacts are summarized as follows:

I. LED retrofitting: ~55.5% reduction in lighting load; ~14–18% reduction in total electricity; potential carbon reduction of ~280–350 tCO_2/year.

ii. High-efficiency brushless fans: ~30–50% reduction in fan load; ~6–8% reduction in total electricity ~120–160 tCO_2/year mitigation.

iii. Motion sensors (corridors & toilets): ~8,760 kWh/year savings (~0.3% total); ~7 tCO_2/year reduction.

iv. Rooftop solar PV (250 kWp system): capable of offsetting up to 100% of annual electrical demand; potential mitigation of ~2,110 tCO_2/year.

5. From an economic standpoint, solar PV integration demonstrates the strongest financial performance (simple payback ≈ 5.7 years), followed by lighting retrofits (moderate payback), while fan replacement yields long-term technical savings but extended financial recovery (≈23.8 years under current tariff conditions)

6. Solar PV payback is moderately sensitive to tariff escalation but remains financially attractive under ±10% cost variation.

Future research should incorporate real-time sub-metering, dynamic load profiling, life-cycle cost analysis, and comprehensive carbon accounting (including LPG substitution impacts) to further enhance decision-making precision and climate impact assessment.

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Conflict of Interest

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