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Study Of Energy Saving Potential of Three Residential Building in Tun Fatimah Residential College (KKTF) By Using Energyplus Software

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ABSTRACT

Since Malaysia's growing demand for electric energy, this study examines how energy is used in residential buildings at Universiti Tun Hussein Onn Malaysia (UTHM)'s Tun Fatimah Residential College (KKTF). EnergyPlus and OpenStudio are two examples of simulation tools that will be used in the project to design and evaluate energy models of individual buildings with an emphasis on possible energy savings. Data gathering, energy-saving scenario simulations, and validation against previous energy audits are all part of the protocols. Building orientation and window features have an impact on sunlight exposure, and the EnergyPlus simulations improved our understanding of the thermal conditions, solar exposure, and energy performance of KKTF buildings dramatically. Energy-saving measures including installing photovoltaic systems, overhanging structures, and energy-efficient LED lighting have been shown to be successful by identifying patterns in daily and annual energy consumption. It's noteworthy that rooftop solar systems cut usage by 37.98% annually and as much as 41.13% monthly. These results highlight the vital role that sustainable construction techniques play in helping Malaysia achieve its environmental goals. Specifically, they highlight the ways that deliberate architectural changes improve energy efficiency, lower costs, and advance sustainability in KKTF complexes.

1. Introduction

Malaysia is largely dependent on electricity to run industrial, commercial, and residential buildings and to provide necessities like cooking, lighting, and machines. The demand for energy has significantly increased, especially in residential areas, as a result of the nation's economic expansion and population growth [1]. Malaysia's residential buildings account for a significant portion of the country's total energy consumption, with about 7.5 million residential customers [2]. The energy consumption of residential and commercial buildings increased by an astounding 2217% between 1978 and 2018, underscoring the urgent need for energy-saving measures to support sustainable development [3]. Acknowledging this tendency, the Malaysian government has been aggressively

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pushing for sustainable energy solutions through enhanced energy efficiency programmes, which might lower living expenses and even increase property prices [4].

Building utilities, electric motors, HVAC (heating, ventilation, and air conditioning) systems, lighting systems, and other components are all evaluated when determining a building's energy efficiency [5]. Using cutting-edge computational tools like EnergyPlus and OpenStudio to build energy modelling is essential to this process. These tools enable dynamic analysis of HVAC systems and guarantee adherence to energy efficiency criteria by making it easier to forecast and optimise a building's performance before it is constructed [6]. In addition, energy modelling facilitates the incorporation of renewable energy sources to further improve environmental sustainability and permits the evaluation of a building's carbon footprint. EnergyPlus and OpenStudio provide accurate assessment of energy consumption patterns and identification of possible energy-saving options in office buildings by performing comprehensive hourly and peak load simulations [5].

University facilities in Malaysia are facing a critical problem with energy usage due to ongoing expansions, rising staff and student numbers, technological integration, and administrative needs. National policies that encourage efficiency and the use of new technologies must support sustainable energy management techniques. Because of expansion and ageing infrastructure, office buildings at Universiti Tun Hussein Onn Malaysia (UTHM) are expected to have large increases in annual electricity usage [7]. Reportedly, the overall yearly electricity bill for UTHM increased from 21,378,875 kWh in 2010 to 25,477,599 kWh in 2011 [8]. This study emphasises the necessity for efficient conservation methods and well-informed decision-making using simulation-based analysis. It does this by simulating and optimising energy usage in office buildings using the EnergyPlus and OpenStudio tools.

2. Methodology

This section explores the details of a case study's methodology, which includes choosing the research topic, gathering data, and running simulations. The goal of the study is to lower energy usage. It seeks to offer precise directions and justifications for every technique used. First, the UTHM KKTF building is selected as the study area, and user trends within it are analysed. Afterwards, an electrical appliance inventory is carried out, power usage expenses are computed, and energy consumption information for three designated KKTF buildings is acquired for comprehensive examination. Next, using SketchUp, the building's plan is replicated, guaranteeing that the electrical equipment is placed precisely in the simulation design. To optimise energy usage, an EnergyPlus simulation is run and equipment modifications are made depending on data collected. Lastly, an analysis and discussion of the simulation results are conducted, and conclusions from the research are made.

2.1 Building Identification

An overview of the facilities at UTHM's Tun Fatima Residential College (KKTF) is given in this chapter, with a focus on how they may accommodate a wide range of users, including staff, students, lecturers, and guests. KKTF was founded in May 2007 and consists of three primary building types: the main building, which houses administration offices and cafés, student buildings that house up to 1240 students in separate gender dorms, and the House of Fellows, which was originally constructed for lectures. The location and internal layout of KKTF, which is close to UTHM and Tun Dr. Ismail Residential College (KKTDI), are described in detail, emphasizing the facility's significance as a case study for patterns of energy consumption, thermal comfort issues, and sustainable building techniques in residential complexes as can be seen in Figure 1. This all-encompassing strategy seeks to produce insights for maximizing energy use throughout KKTF's.

Fig. 1. Location of KKTF

2.2 Building Energy Simulation

Building energy simulation, made possible by specialized software that allows for a thorough analysis of a building's energy performance, is essential to the advancement of energy saving projects within buildings. By modeling physical characteristics, thermal characteristics, and operational dynamics, architects, engineers, and building specialists can identify chances for enhancing energy efficiency through the use of computational methods. Through the process of modeling variables such as building geometry, envelope properties, and HVAC systems, interested parties can evaluate different design approaches and how they affect energy usage. These simulations aid in the integration of renewable energy sources, the optimization of occupant behavior, the deployment of energy-efficient equipment, and the formulation of well-informed decisions that support sustainability objectives. The US Department of Energy's powerful program EnergyPlus, which simulates lighting, occupancy patterns, ventilation, and material qualities unique to Malaysian residential buildings, is an excellent example of this capacity. This integrated solution improves understanding of building thermal properties and enables strategic energy planning and design decisions aimed at sustainable building practices. It is combined with SketchUp for 3D modeling and the OpenStudio plug-in for thermal simulation.

2.3 Analysing Data with Energyplus

Reliable simulation outputs in the context of energy simulation with EnergyPlus depend heavily on precise input parameters. The procedure entails carefully taking into account variables such as HVAC systems, building materials, and ambient temperatures because even small changes can have a big impact on the outcome. EnergyPlus's IDF Editor makes this easier by enabling accurate input of key parameters and guaranteeing a complete setup of the simulation. The simulation produces outputs that describe environmental factors, system performance, and energy consumption as soon as it is started. These outputs, which are frequently available in CSV and Energy Standard Output (ESO) formats, offer thorough information on energy usage throughout time periods, supporting in-depth analysis and decision-making for improving sustainability and energy-efficient building practices. For architects, engineers, and designers looking to maximize building efficiency and efficiently minimize energy usage, comprehending and understanding these outputs is essential.

2.4 Modified Characteristics

Validated energy simulation models are being developed through strategic modifications such window tinting, external shading, and set point temperature adjustments in order to increase KKTF's energy efficiency. These actions are meant to lessen the demand for cooling, use less energy, and improve environmental sustainability. By adjusting sunlight and using colored films, KKTF reduces energy use and maximizes comfort. By adjusting set point temperatures, KKTF demonstrates its dedication to sustainable construction principles while further optimizing efficiency without sacrificing occupant comfort.

2.5 Real and Modified Energy Consumption Comparison

Subsequent to validating KKTF's real energy consumption versus earlier study conducted by Azmil Asraf Hadri (2020), an extensive examination of the energy landscape is the next crucial stage. This is extended to encompass every residential building in KKTF by merging actual data on energy usage with the outcomes of simulations that incorporate altered physical attributes. Differences between actual data and revised simulation results are expected, considering the emphasis on lowering total energy consumption via structural adjustments. These differences provide a crucial viewpoint for assessing how well improvements that have been implemented throughout KKTF's residential sectors have worked. The goal of the study is to carefully evaluate how these improvements affect energy performance, providing insightful information about possible energy savings and overall environmental effects within KKTF.

3. Results and Discussion

Presenting and discussing the EnergyPlus simulation findings is the purpose of this chapter. The results are supported by data shown in tables and graphs, which are essential for verifying the goals of the study. The simulations' accuracy is guaranteed by the accompanying documentation and supporting data. The data is arranged into tables and figures, and then a thorough analysis and interpretation of the findings are given.

3.1 Building Modelling

The 3D model of the three KKTF buildings and the results of the SketchUp simulation are covered in this chapter. The model encompasses 1576 m² in total area. Throughout all buildings, rooms 1 and 2 always face east, while rooms 3 and 4 always face west that can be seen in Figure 2. The model's accuracy was checked before moving on to the simulation of the energy analysis. The simulation assessed the building's performance under several weather circumstances, including energy use, thermal comfort, and overall efficiency, using a Kuala Lumpurspecific meteorological dataset from EnergyPlus. The results offered suggestions for sustainable improvements.

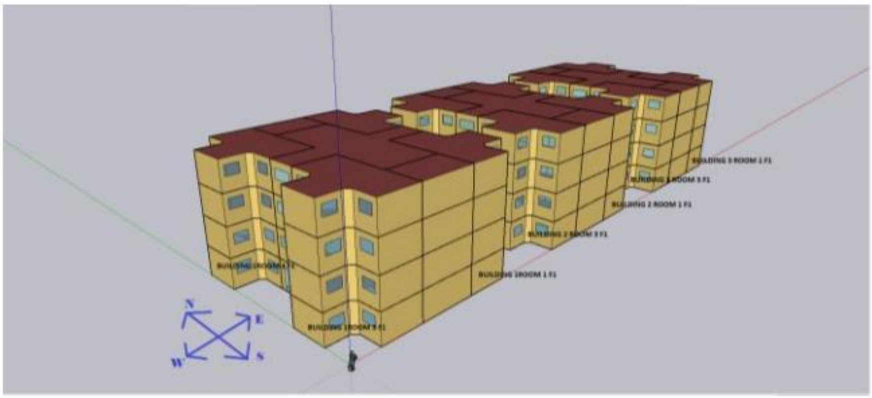


Fig. 2. Building modelling

3.2 Verification of Result Simulation

After the three KKTF buildings' EnergyPlus simulations, a thorough verification procedure was carried out. This required contrasting the results of the simulation with past studies that evaluated monthly energy consumption. This current study was verified with work reported by Hariri (2020) [9]. To ensure accuracy and relevance, the main objective was to connect the simulation results with these energy consumption measures. In particular, the simulations showed that the KKTF buildings used an aggregate of 44,507,916,000 J, or 12,363.31 kWh as shown in Table 1 with only 0.54% different from the actual data collected. The thorough verification procedure greatly increased trust in the veracity of the energy efficiency assessments carried out for the KKTF buildings.

Table 1
Power consumption of 3 KKTF per month for actual and simulation

No	Criterion	Power Consumption per month for actual (kWh)	Power Consumption per month for simulation (kWh)
1	Lighting System	1088.64	1088.64
Equipment System			
2	Ceiling Fan	6048	6048
3	Laptop Charger	2025	2025
4	Phone Charger	202.5	202.5
5	Pedestal Fan	1819.125	1801.80
6	Home Printer	0.375	0.37
7	Electric Kettle	1012.5	1080
8	Iron	72	90
9	Rice Cooker	28.8	27
	Total	12296.94	12363.31
	Difference	66.37	
Percentage Different		0.54%	

3.3 Hourly result for Energy Consumption

The results illustrated in Figure 3 offer significant perspectives for improving energy management plans customised for student accommodation in KKTF buildings. By comprehending these patterns of usage, stakeholders may improve energy efficiency, save operating expenses, and design more sustainable living spaces for students.

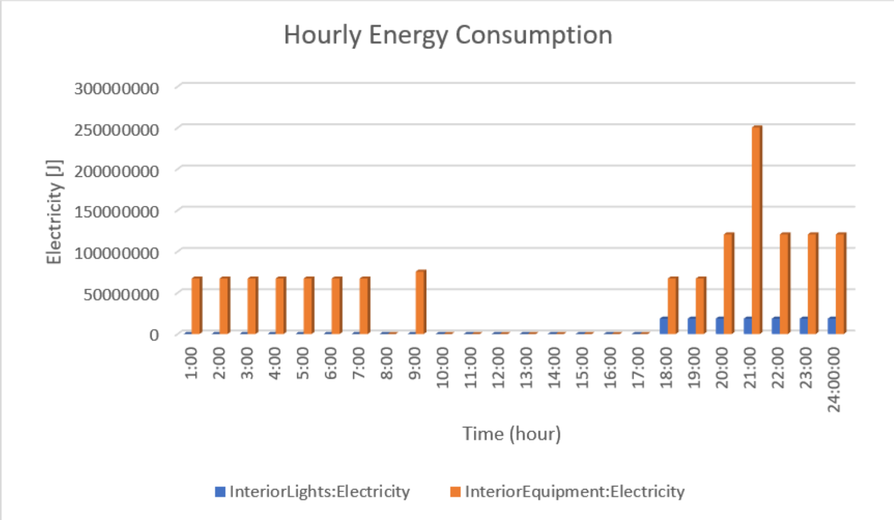


Fig. 3. Hourly energy consumption

3.4 Yearly result for Energy Consumption

The statistics on monthly energy usage show significant yearly variations in Figure 4, with July and December seeing the highest demand. On the other hand, January and October displayed somewhat reduced but stable levels of energy use. While consumption increased in April, usage increased marginally in March, May, and August. The months of February showed the lowest consumption, with June, November, and September having comparable levels. The weather and school schedules, which have an impact on occupancy levels and activities in the buildings, are probably responsible for these changes, which lead to varying electricity demand all year round.

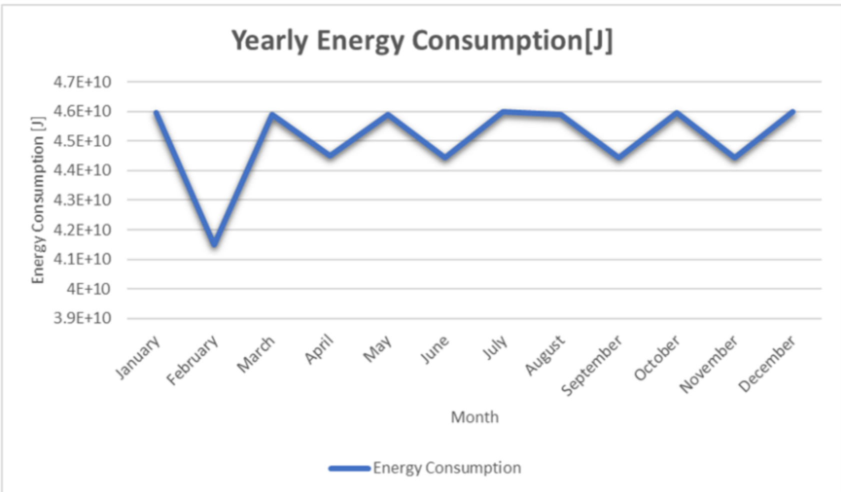


Fig. 4. Monthly and annual sum energy consumption

3.5 Sunlit Fraction on the Outside Surface

A thorough examination of the windows in Room 1 Floor 1 of the three KKTF buildings is given in this section. This study details the four strategically placed windows in Room 1 F1, which faces east, and their daily exposure to direct sunshine, with numerical values ranging from 0 to 1 that can be seen in Table 2.

Table 2
Window orientation for Room 1 F1 for 3 KKTF Building

No	Room name	Window name	Window orientation
1	Room 1	Window 1 Room 1 F1	North
2	Room 1	Window 2 Room 1 F1	East
3	Room 1	Window 3 Room 1 F1	East
4	Room 1	Window 4 Room 1 F1	South

Based on the examination of sunny surface fractions for windows in Room 1 on the ground floor of Buildings 2 and 3 within the 3 KKTF complex, building 2 as can be seen in Figure 5 receives very little direct sunshine until 8:00, peaks around 9:00, and varies throughout the day with sporadic intervals of shade. With the exception of the morning and early afternoon hours, Window 3 and Window 4 are mostly shaded during the day. Window 3 receives maximum sunshine until 14:00, while Window 4 receives sunlight until 15:00.

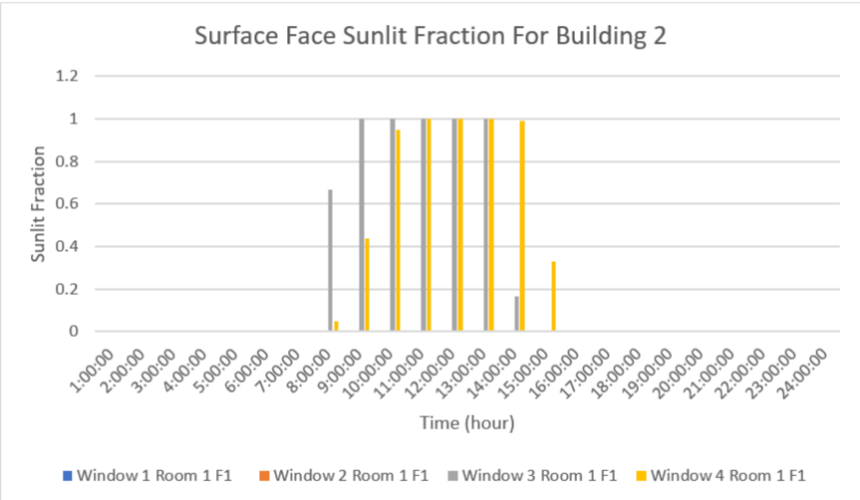


Fig. 5. Surface outside Face Sunlit Fraction building 2

The sunny percent study for Window 2 on Floor 1 in Building 3 indicates that sunshine increases starting at 8:00, peaks at 9:00, and then decreases to zero by 12:00. Sunlight at Window 3 of Room 1 increases from 8:00 to 9:00, peaks till 13:00, and then decreases to zero at 15:00. As shown in Figure 6, sunlight entering Window 4 in Room 1 increases steadily from 8:00, peaks at 9:00, and continues until 14:00, when it declines and reaches zero by 16:00.

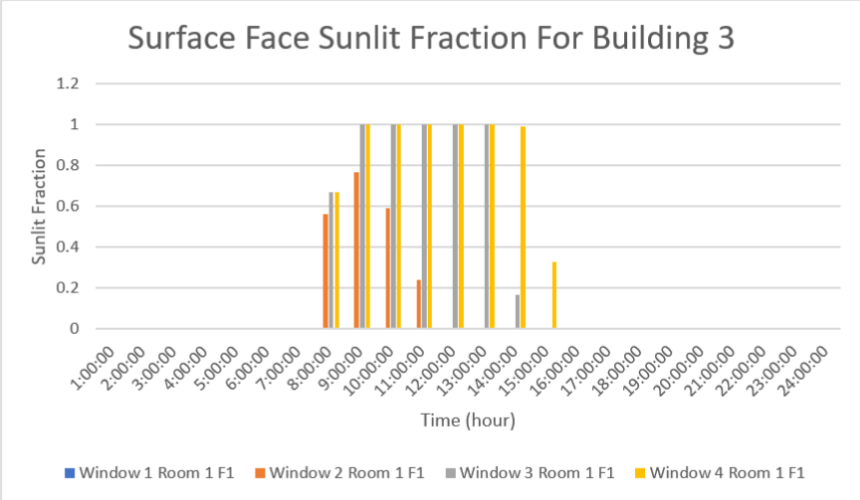


Fig. 6. Surface outside Face Sunlit Fraction building 3

3.6 Improvement on The Building Characteristics

The 3 KKTF Building's next stage of energy efficiency improvements will centre on the integration of rooftop solar systems, the strategic placement of shade structures, and the optimisation of lighting options. By utilising renewable energy sources, enhancing indoor comfort through improved thermal regulation, and optimising natural light while minimising the use of fluorescent lighting and air conditioning, these actions seek to reduce overall energy consumption and promote sustainability.

3.7 Installing a Photovoltaic System on a Rooftop Building

The choice to install a 9.4 kWp solar system on the 3 KKTF Building struck a balance between the requirement for efficient energy output and upfront expenses. This size was selected with the goal of maximising energy capture while controlling initial costs, improving long-term sustainability, and lowering dependency on traditional energy sources. Figure 7 shows the installation of the PV system at the building.

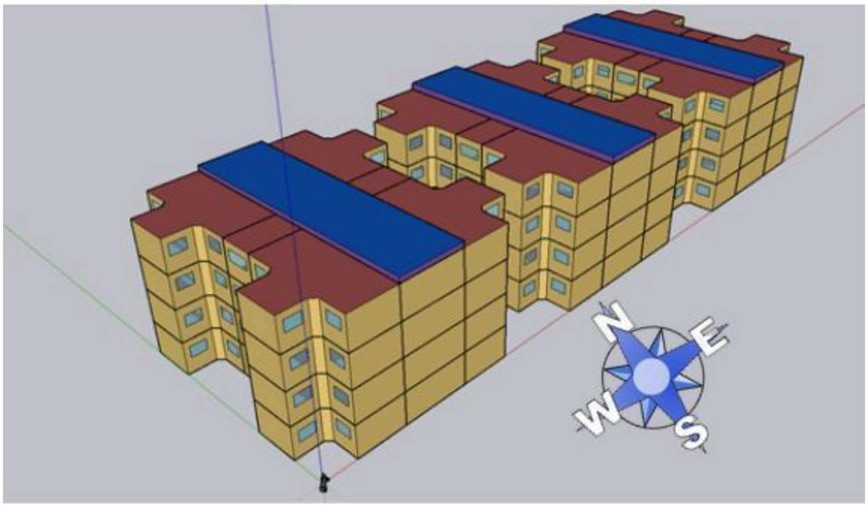


Fig. 7. Installing a Photovoltaic System on a Rooftop Building for 3 KKTF

The 3 KKTF Building's photovoltaic (PV) system installation has resulted in notable and steady annual reductions in energy consumption. Table 3 show the savings percentage fell by 37.98% on average annually, from 37.72% in January to 41.13% in March. December produced the lowest savings at 34.66%, despite small variations. These findings demonstrate how well PV technology works to improve sustainability and energy efficiency in all three of the KKTF complex buildings.

Table 3
Monthly energy consumption after Photovoltaic installation

Month	Monthly Energy Consumption before Photovoltaic Installation [J]	Monthly Energy Consumption after Photovoltaic installation [J]	Saving percentage (%)
January	45,977,482,374	28,632,728,399	37.72
February	41,493,218,018	25,015,627,416	39.71
March	45,901,945,381	27,018,695,457	41.13
April	44,518,643,585	26,905,526,030	39.56
May	45,901,945,381	28,894,967,111	37.05
June	44,432,369,593	27,711,074,882	37.63
July	45,988,219,372	28,723,962,950	37.54
August	45,901,945,381	28,218,126,113	38.52
September	44,443,106,592	27,191,106,737	38.81
October	45,977,482,374	28,772,591,899	37.42
November	44,432,369,593	28,322,582,069	36.26
December	45,988,219,372	30,047,174,612	34.66
Annual Sum	540,956,947,016	335,454,163,675	37.98

3.8 Cost Impact of Installing Photovoltaic Systems

According to the Tenaga Nasional Berhad PV system calculator (2023), the installation cost of a 9.4 kWp photovoltaic (PV) system for the 3 KKTF Building is RM38,200 per system. This price reflects the sophisticated technology found in premium, effective solar panels as well as the difficulties of installation, which need for specialised labour and tools. These financial components are depicted in Figures 8 and 9, and the data supplied aids in determining the energy needs and expenses for each of the three KKTF complex buildings.

Tariff C1, which is RM 0.365 per kWh according to Tenaga Nasional Berhad (2024), can be used to compute the monthly total energy demand for the 1 and 3 KKTF buildings after installing a photovoltaic system.

Total Cost for 1 Building before PV Installation:
$=4121.10 \times RM\ 0.365$
$=RM\ 1504.20$

Total Cost for 1 Building after PV installation:
$=2565.75 \times RM\ 0.365$
$=RM\ 936.49$

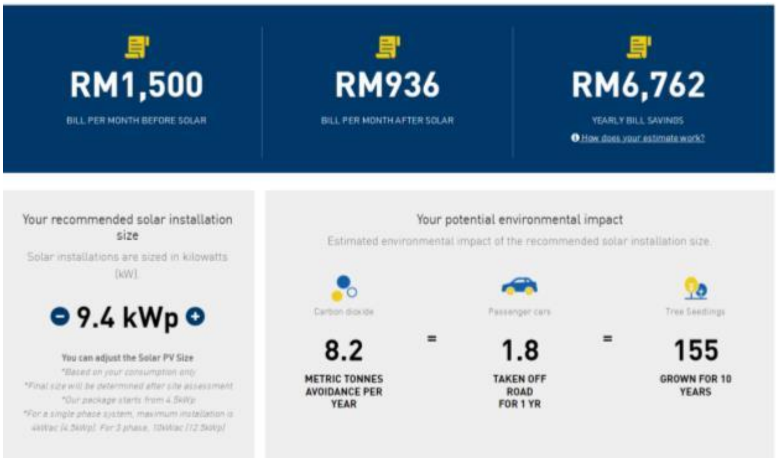


Fig. 8. details of size of PV system by Tenaga Nasional Berhad ,2024

Fig. 9. The cost of Install PV system

The results verify that the calculations match Tenaga Nasional Berhad's photovoltaic calculator. The energy savings employing three PV panels for the full 3 KKTF complex were then computed.

Total Cost for 3 Building before PV Installation:
=12363.31×RM 0.365
=RM 4512.60

Total Cost for 3 Building before PV Installation:
=7697.26×RM 0.365
=RM 2809.49

The projected outcomes of installing photovoltaic (PV) systems for the 3 KKTF Building are displayed in Table 4, which demonstrates a significant drop in energy consumption from 12,363.31 kWh to 7,697.26 kWh. With current expenses falling from RM 4512.60 to RM 2809.49, this reduction equates to significant cost reductions, yielding savings of RM 1703.11. This demonstrates a noteworthy 37.74% decrease in energy-related expenses, highlighting the PV systems' financial advantages.

Table 4
Comparison between current usage vs after implementation of PV system for 3 KKTF Building

Criteria	Power consumption per month (kWh)		Estimated Cost per month (RM)
Energy Consumption	Current	12363.31	4512.60
	Future	7697.26	2809.49
Saving Value		4666.05	1703.11
Saving percentage (%)		37.74	

Following the installation of photovoltaic (PV) systems for the 3 KKTF Building, Table 4.9 demonstrates a notable decrease in energy usage and associated costs. Monthly expenses reduce from RM 4512.60 to RM 2809.49, while monthly energy consumption decreases from 12,363.31 kWh to 7,697.26 kWh. This leads to RM 20,437.32 in annual savings, which will partially offset the RM 114,600 initial investment for 3 PV system.

Initial cost for 3 PV system:
=RM38,200×3
=RM114,600

Payback Period for 3 PV System:

$$Payback\ Period = \frac{Initial\ Investment}{Annual\ Saving}$$

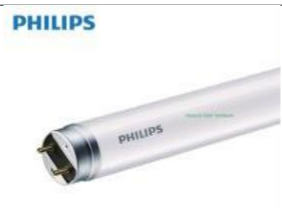
$$Payback\ Period = \frac{\text{RM114,600}}{\text{RM20,437.32}}$$

$$Payback\ Period = 5.6\ years$$

3.9 Enhancing and Replacing the Types of Lamps in Student Buildings

Three KKTF buildings, housing 48 student rooms with four or more inhabitants each, have all been equipped with energy-saving features. Over-illumination in rooms with more than six lights and four ceiling fans led to excessive energy use, according to a review. To tackle this problem, fewer lights have been installed, and energysaving LED lights have taken the place of inefficient fluorescent ones that be show on Table 5. Five 16-watt LED lights are now installed in each room. Increased energy efficiency is anticipated as a result of this adjustment. By using less energy and constructing an eco-friendly home, the initiative highlights KKTF's dedication to sustainability.

Table 5
Example of LED tube with specification

No	Criteria	Specification
1	Model	Phlips LED ECOFit tube 1200mm
2	Energy Efficiency label	A+
3	Power (w)	16
4	Price	RM11.30
5	Proposed	240
6	Picture	

3.10 Cost Analysis of Changing Lamp Types

Comprehensive details regarding the LED tubes utilised in the project are given in Table 6. Included is also the overall cost of replacing each of the 48 rooms' five LED light tubes.

Total cost:
=240 pieces × RM11.30
=RM2712.00

Table 6
Lighting equipment cost with LED lamp

No	Equipment	Cost per lamp (RM)	Quantity (pcs)	Estimated cost (RM)
Light Equipment				
1	Recessed type fluorescent 1 light fitting	11.30	240	2712.00

The total electrical energy used for the lighting system after the LED tubes were installed in place of the fluorescent lights is shown below. This calculation was made using Tariff C1 and RM 0.365 per kWh (Tenaga Nasional Berhad, 2024).

Total Cost:
=806.40kWh × RM 0.365
=RM 294.33

Table 7 shows the projected outcomes of using LED tubes in place of traditional lights, comparing actual lighting usage with those results. With LED tubes, energy consumption and prices are reduced by 25.9%, from RM 397.35 and 1088.64 kWh to RM 294.33 and 806.40 kWh, saving 282.24 kWh and RM 103.02.

Table 7
Comparison of current consumption and after LED tube replacement

Criteria		Power consumption (kWh)	Estimated Cost (RM)
Lighting system	Current	1088.64	397.35
	Future	806.40	294.33
Saving Value		282.24	103.02
Saving percentage (%)		25.9	

The payback period for switching to LED tubes is roughly 2.2 years, during which time energy cost savings will return the initial RM 2712.00 expenditure. This illustrates the investment's financial viability in relation to the benefits in energy efficiency.

Payback period:

$$Payback\ Period = \frac{Initial\ Investment}{Annual\ Saving}$$

$$Payback\ Period = \frac{2712.00}{1236.24}$$

$$Payback\ Period = 2.2\ years$$

3.11 Overhang Structure Implementation

The installation of overhang shading on all windows in the three KKTF buildings is shown in Figure 10. The goal of this installation is to improve energy efficiency by efficiently controlling natural light. This programme naturally maintains suitable indoor temperatures by reducing heat gain and glare, especially during the hours of greatest sunlight. By taking this proactive stance, KKTF supports sustainability initiatives, saves a significant amount of energy, and creates an atmosphere that is conducive to learning and living at all of its locations.

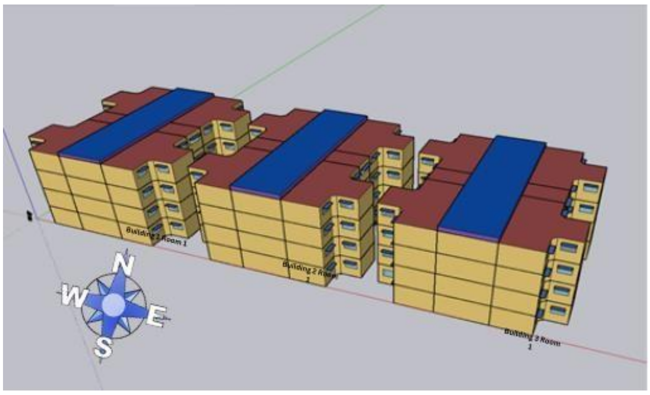


Fig 10. 3 KKTF building after implementation of overhang structures

The effects of installing shade structures on Building 2's patterns of solar exposure are examined in Figures 11 and 12. Prior to installation, there was never direct sunshine shining through Windows 1 and 2 in Room 1 Floor 1. On the other hand, Window 3's exposure progressively grew from 0 at 7:00 to a maximum of 1 from 9:00 to 13:00, and by 14:00, it had dropped to 0.167. Variable exposure was seen in Window 4, with values beginning at 0.051 at 8:00, rising to 1 by 11:00, staying at that level until 13:00, falling to 0.99 at 14:00, and finally reaching 0.327 by 15:00.

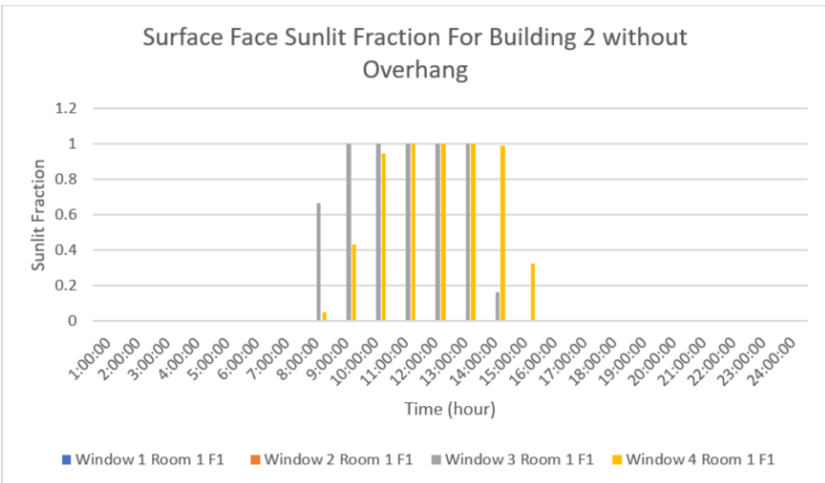


Fig 11. Surface face-sunlit fraction for Building 2 without overhang

Window 1 and Window 2 in Room 1 Floor 1 had no sunlight exposure after shade structures were installed (Figure 12), suggesting efficient shading. The noon exposure in Window 3 decreased from 1 at 12:00 to 0.237 at 13:00, and the morning sunshine declined from 0.667 at 8:00 to 0.636 at 9:00. At eight in the morning, Window 4 had complete shade (0.051), peaked at one by eleven, decreased to 0.327 by fifteen, and reached zero by sixteen. The KKTF building's daylight management was enhanced and solar radiation was largely reduced by the shade structures.

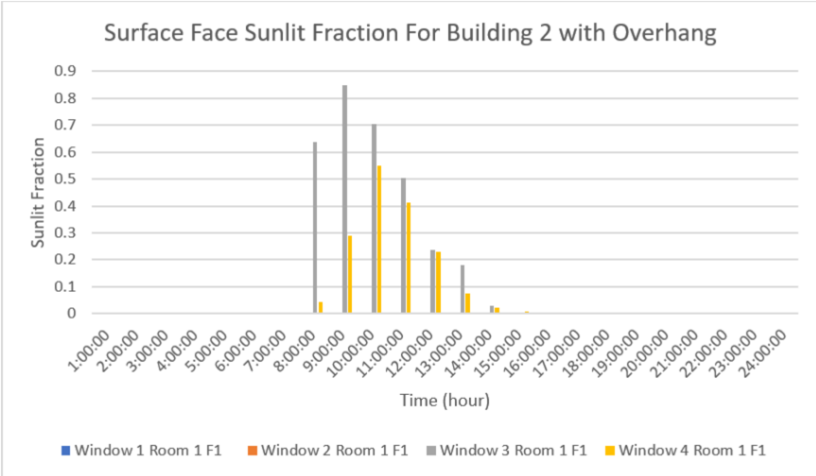


Fig 12. Surface face-sunlit fraction for Building 2 with overhang

The patterns of solar exposure in Building 3 prior to the installation of the shade structure were as follows on Figure 13: Throughout the day, Window 1 in Room 1 Floor 1 was not exposed to sunlight. Window 2 began at 0 at 7:00 and increased its exposure to sunshine steadily, reaching 0.764 at 9:00. At 7:00, Window 3 had no exposure; at 8:00, it had climbed to 0.667; by 9:00, it had reached full exposure (1); and by 14:00, it had fallen to 0.167. Parallel to this, Window 4 began at 0.667 at 8:00, reached its peak at 1 by 9:00, continued to be fully exposed until 13:00, then declined to 0.99 by 14:00, and ultimately settled at 0.327 by 15:00.

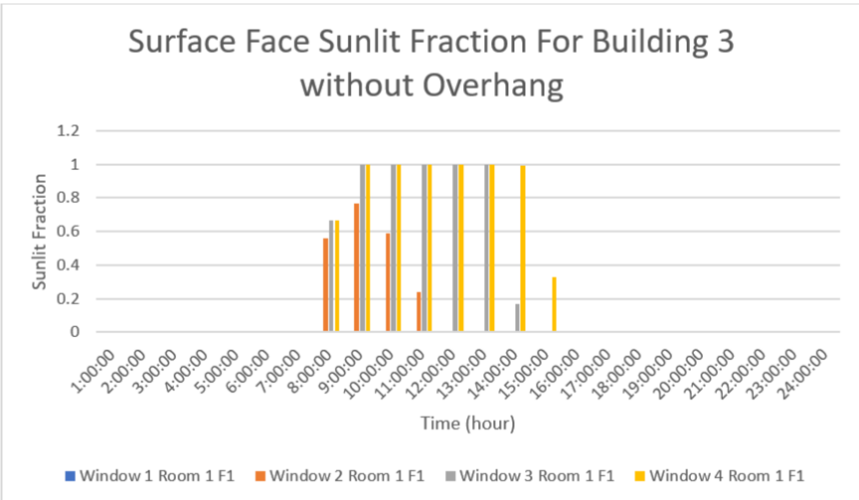


Fig 13. Surface face-sunlit fraction for Building 3 without overhang

Substantial gains were noted in Building 3 (Figure 14) after shade structures were installed. The entire day was spent with Window 1 Room 1 F1 completely shaded. Window 2 Room 1 F1 had limited sun exposure at 11:00 and decreased sun exposure from 0.559 to 0.527 at 8:00 and 0.764 to 0.618 at 9:00. The morning sunshine in Window 3 Room 1 F1 was reduced from 0.667 at 8:00 to 0.636 at 9:00. At noon, there was significant shadowing, with the amount of sunlight falling from 1 at 12:00 to 0.237 at 13:00. In Window 4 Room 1 F1, the morning sun decreased from 0.667 at 8:00 to 0.622 at 9:00. By 16:00, the sun was completely shaded, falling from 0.327 at 15:00 to 0.

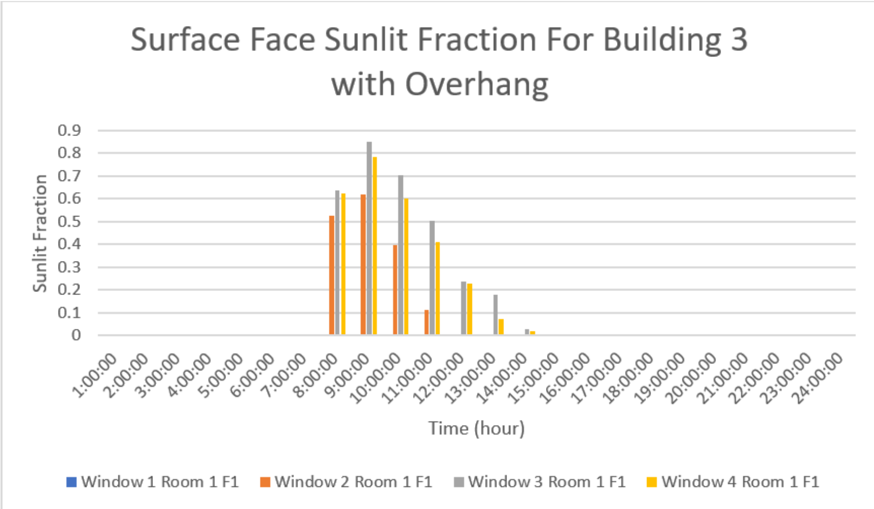


Fig 14. Surface face-sunlit fraction for Building 3 with overhang

4. Conclusion

The three KKTF buildings' solar exposure, thermal parameters, and energy performance were all carefully analysed by the EnergyPlus simulation. The daily patterns of energy use showed that the demand for power was at a baseline in the early morning, that it significantly increased at 9:00 as a result of equipment use, that it was at its lowest from 10:00 to 17:00, and that it climbed in the evening. Variations in annual energy data were associated with weather, occupancy, and academic calendars; greater intake months were associated with higher activity levels. An investigation of sunlight exposure revealed the effects of window size, orientation, glass type, and shading, which helped to maximise natural lighting and energy efficiency. Installing photovoltaic systems reduced monthly energy consumption by 34.66% to 41.13% and achieved an annual reduction of 37.98%. Replacing old bulbs with LED lighting resulted in a 2.28% monthly reduction in energy usage. Implementing overhang structures reduced sunlight exposure and heat accumulation, improving thermal comfort. This study highlights how crucial thoughtful architectural changes are to drastically cutting energy use and advancing sustainability in the KKTF buildings.

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