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A Study on Energy Efficiency of a 3 Storey Office Building in Senai Airport City Johor

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Abstract

The Malaysian government is prioritizing energy efficiency to address rising global energy consumption and greenhouse gas emissions. Office buildings are significant energy consumers due to various factors such as building design, operational needs and occupancy rate. The Energy Efficiency and Conservation Act (EECA) and the Green Building Index (GBI) are designed to reduce energy intensity and promote environmental goals. Incentives for renewable energy use, such as Net Energy Metering (NEM) program, streamline the sale of surplus solar energy to utility firm like Tenaga Nasional Berhad (TNB). The Sustainable Energy Development Authority (SEDA) advocates for NET Zero Energy Buildings (NZEB) to promote sustainable development and mitigate environmental impact. This study seeks to examines the energy consumption profile of a 3 storey office building in Senai, Johor, identify opportunities for energy saving, aims to improve electrical energy efficiency. The energy efficiency solutions included roof insulation, LED lighting, a multi-split variable refrigerant flow (VRF) air conditioning system, precise control of temperature setting, enhanced energy efficiency, and the incorporation of solar energy system is essential in lowering building energy intensity (BEI) significantly. By employing these measures, office buildings can decrease electricity usage, minimize operation expenses, and mitigate carbon footprint emissions.

1. Introduction

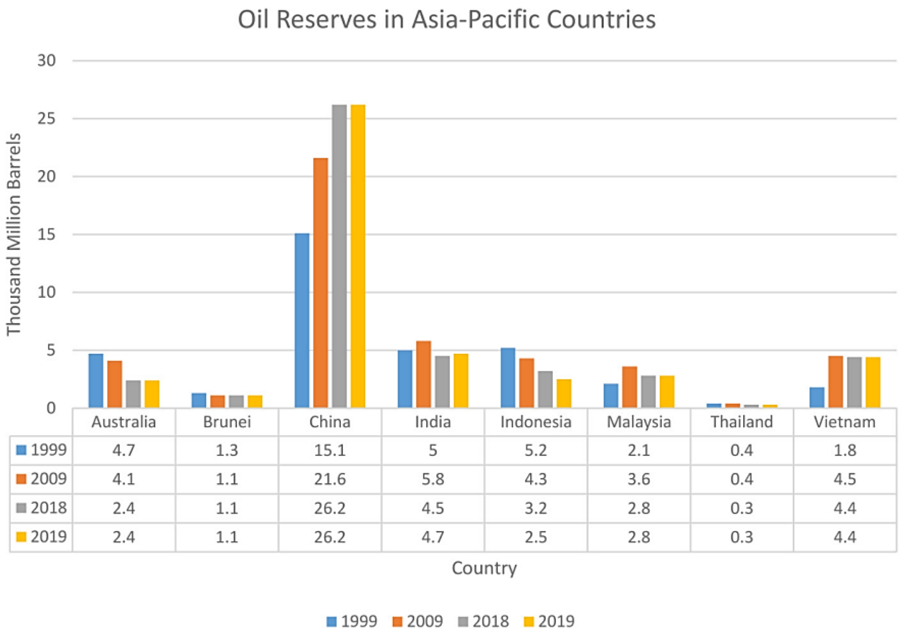
Malaysian government is focusing on energy efficiency to reduce dependence on fossil resources and greenhouse gas emissions. Energy Efficiency and Conservation (EECA) and National Energy Transition Roadmap (NETR) aim to promote energy conservation and low carbon economy. Several implications for building efficiency include energy audit, energy efficient design, high performance insulation, and using renewable energy. Malaysia has also taken steps in green building constructions, such as Green Building Index (GBI) rating based on energy efficiency, indoor environment quality, sustainable site planning, water efficiency, materials and resources and innovation. Office buildings normally consume a significant amount of electricity. Lighting systems, air conditioning and mechanical ventilation systems (ACMV) require high electricity demand in buildings [1] – [3]. Addressing this issue, the Malaysian government has provided many means to support sustainable energy practices in dealing with rising costs of electricity [4]. This study involves analyzing current energy consumption patterns, identifying potential energy efficiency measures, and assessing their cost effectiveness is essential nowadays for high electricity consumes. Additionally, it will explore the investment costs and payback periods for implementing energy efficiency measures and solar energy system.

2. Literature Review

The literature review includes studies on energy scenario in Malaysia, energy demand in Malaysia, energy diversification in Malaysia, commercial building energy consumption distribution, energy efficiency measures, potential energy saving method and assessment of net zero energy building requirements.

2.1 Energy Demand in Malaysia

Renewable energy (RE) reduces greenhouse gas emissions, fossil fuel reliance and ensures Malaysia's energy sustainability. Oil reserves in Asia-Pacific nations have fallen during previous decade, while China's have increased. Malaysia must speed its RE program and Renewable Act implementation to maintain its energy export revenue [5].



	Australia	Brunei	China	India	Indonesia	Malaysia	Thailand	Vietnam
1999	4.7	1.3	15.1	5	5.2	2.1	0.4	1.8
2009	4.1	1.1	21.6	5.8	4.3	3.6	0.4	4.5
2018	2.4	1.1	26.2	4.5	3.2	2.8	0.3	4.4
2019	2.4	1.1	26.2	4.7	2.5	2.8	0.3	4.4

Fig. 1 *Oil reserves in Asia-Pacific countries (Energy Commission, January 2016)*

Malaysia has an unconditional goal to reduce carbon intensity against GDP by 45% by 2030 [6]. The government is pursuing renewable energy targets via large-scale solar projects and biomass power plants, concentrating on economic feasibility and competitive market forces to expand solar power penetration. Furthermore, the Energy Commission (EC) promotes energy security and efficiency in national energy policy and enforcing rules. 11th Malaysia Plan's National Energy Efficiency Master Plan (NEEMP) 2011-2020 aims to increase energy efficiency by 10% by 2020 [6].

The National Energy Efficiency Plan (NEEAP) targets industrial, commercial, and household power consumption to conserve electricity and decrease demand. The strategy seeks to conserve 52,233GWh of energy, reducing electricity demand by 8% [7]. Easing renewable energy supply infrastructure restrictions can improve Malaysia's energy supply security and reduce greenhouse gas (GHGs) emissions. The proposal is expected to reduce GHGs by 38 million tons of CO_2 equivalent [8], [9].

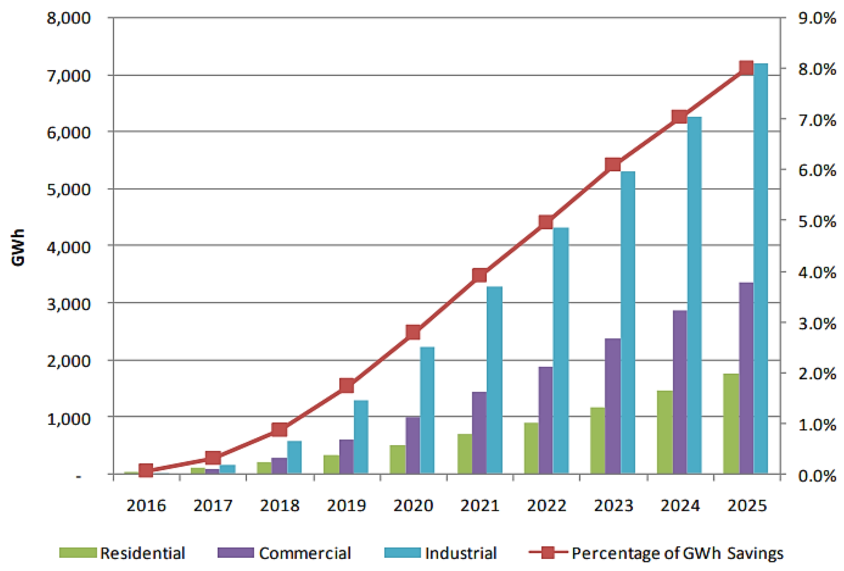


Fig. 2 *Electricity saving and percentage of savings (NEEAP, 2015)*

2.2 Energy Diversification in Malaysia

Solar energy is a rapidly growing industry in the equatorial region of Malaysia, driven by environmental pollution and government incentives. Malaysian government has implemented the NEM scheme to encourage self-generation of electricity through solar PV installations, contributing to the Renewable Energy National Target of 11% by 2020 [8]. Solar PV installations can be ground mounted, floating on reservoirs, or rooftops on residential, commercial, and industrial buildings. Other potential carbon-free energy sources include bioenergy, fuel cells, geothermal, hydropower, wind, and solar PV. The ACF roadmap aims to achieve net-zero CO_2 emissions by 2050, while the Generation Development Plan focuses on installed capacity and the Paris Agreement's NDC by 2030. Energy management in buildings involves integrating behavioral modification, modern technologies, and architectural design to maximize energy efficiency and minimize environmental impacts [10], [11].

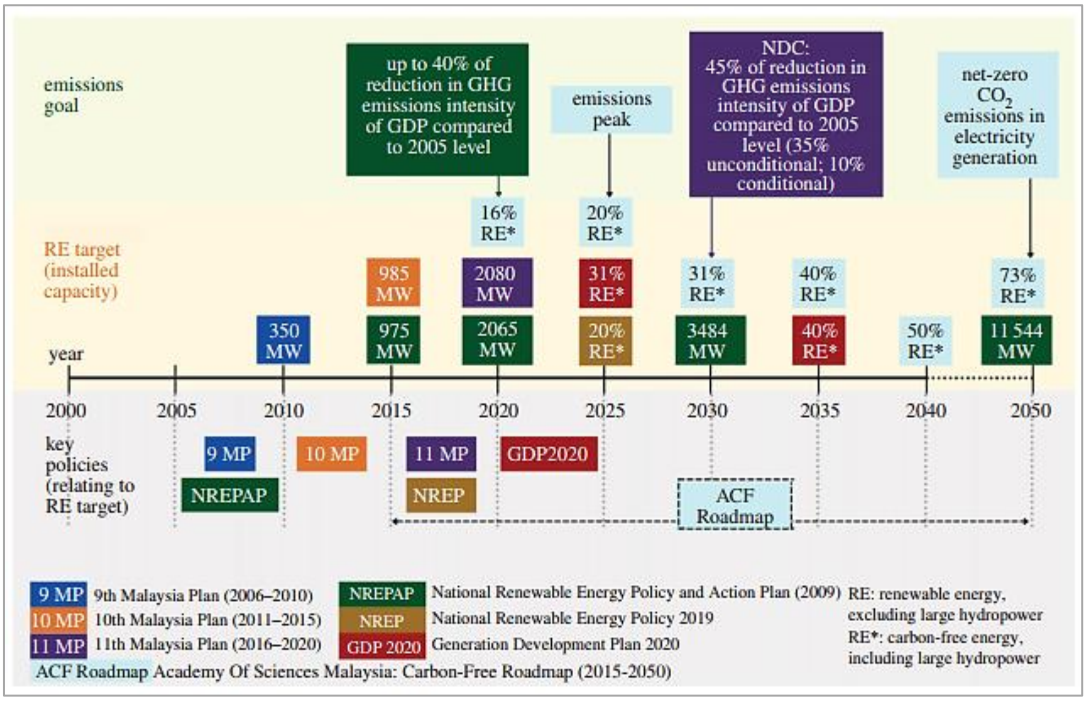


Fig. 3 *Development of national RE target in Malaysia (ACF Roadmap Academy of Science Malaysia, 2015-2050)*

2.3 Energy Policy and Transition Roadmap in Malaysia

Malaysian government has implemented several green programs to achieve energy sustainability and collective prosperity through a shift to renewable energy sources. The National Energy Policy 2022-2040 aims to reduce carbon emissions, promote a hydrogen economy, optimize energy subsidies, and ensure energy security. The National Energy Transition Roadmap (NETR) aims to achieve net-zero emissions by 2050 and a progressive increase in renewable energy proportions. Malaysian government has also organized six [5] energy transition levels into ten (10) flagship projects, which are expected to attract significant investment and create 23,000 jobs. These activities are expected to reduce greenhouse gas emissions by over 10,000 Gg CO_{2eq} (gigagrams carbon dioxide equivalent) annually. Other than that, the tax incentive packages include the introduction of new qualifying activities, namely green hydrogen, and electric vehicle charging stations.

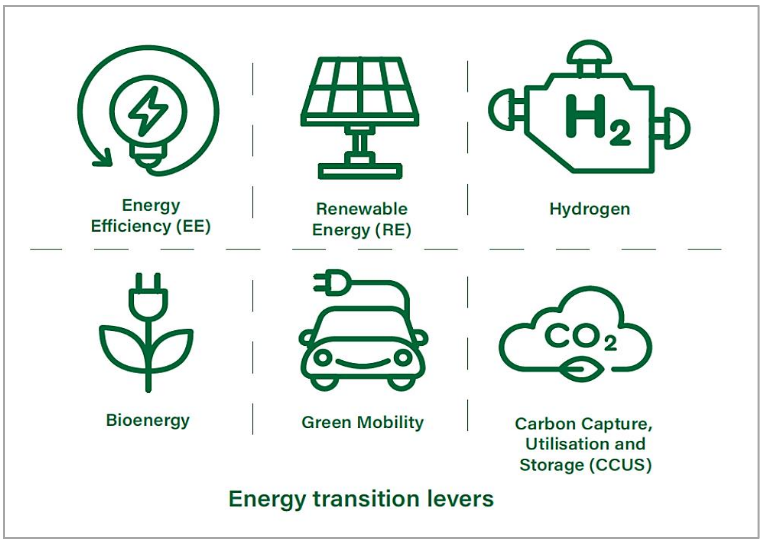


Fig. 4 *Overview of energy transition levels in Malaysia (National Energy Policy 2022-2040, NEP 2040)*

2.4 Energy Consumption and Efficiency in Building

Energy efficiency and passive design in buildings can minimize energy requirements, including residential, commercial, institutional, and industry buildings. Commercial buildings, such as offices, schools, shopping malls, hotels and hospitals, typically use over half of their energy for cooling and lighting. Therefore, energy conservation strategies include using efficient electrical equipment and appliances, high-performance insulation, and an awareness campaign for educating occupant behavior is essential to reduce energy consumption [10]. Smart thermostats and sensors can be installed on lighting systems in common areas to reduce energy waste and renewable sources like solar energy can reduce reliance on fossil fuels. The table below shows opportunities for energy conservation in various building types.

Table 1 *Opportunities for energy conservation and renewables*

Energy Hierarchy	Domestic	Non- Domestic
Reduce Demand	• Well-designed layout • Passive solar design • Life cycle analysis of materials • High levels of insulation • High energy efficiency label	• Well-designed layout • Passive solar design • Life cycle analysis of materials • High levels of insulation • High energy efficiency label • BREEAM

Energy Hierarchy	Domestic	Non- Domestic
Energy Efficient	• Energy efficient white goods and lighting • Good heating controls • Influence behaviours	• Building Energy Management System • Energy efficient appliances and equipment • Energy efficient/ Natural ventilation • Influence behaviour
Renewable Energy	• Passive solar design • Solar water/air heating • Photovoltaic • Small scale vertical axis wind turbines	• Passive solar design • Solar water/air heating • Photovoltaic • Small scale hydro • Small scale wind

2.5 Significance of Net Zero Energy Building

Net Zero Energy Building (NZEB) is a concept designed to attain zero greenhouse gas emissions by supplying buildings with sufficient energy from renewable sources to fulfil their annual energy needs. The primary benefits of NZEB are the reduced utility expenses and less environmental footprint. Nevertheless, the initial capital expenditure renders it economically unfeasible for several property owners globally. To facilitate the execution of NZEB, three (3) critical areas must be emphasized which are passive design techniques, energy efficiency system design, and renewable energy systems design [9].

2.5.1 Passive Design Techniques

Passive design solutions directly influence the energy requirements of mechanical and electrical systems in buildings and indirectly impact renewable energy production. These tactics include optimizing natural sunshine and minimizing artificial illumination [11].

2.5.2 Energy Efficiency System Design

Energy efficiency (EE) is crucial for decarbonizing the energy industry and enhancing electrification. Malaysian government supports energy efficiency initiatives to effectively realize NZEB, since it conserves limited energy resources, lowers expenses, and may decrease CO_2 emissions. High efficiency technologies such as LED lighting and energy efficient electrical devices are essential for enhancing energy efficiency in buildings.

Fig. 5 *Overview of ST 5-star energy efficiency labelling*

2.5.3 Renewable Energy System Design

Renewable energy technologies, including solar photovoltaic and solar water heating, are crucial for net zero energy buildings to diminish and counterbalance thermal energy requirements. NZEBs must balance energy demands using active energy production methods and renewable energy technologies to fulfill the NZEB target. Incorporating renewable energy into smart grid systems offers a sustainable energy source, mitigating global warming and environmental degradation [12], [13].

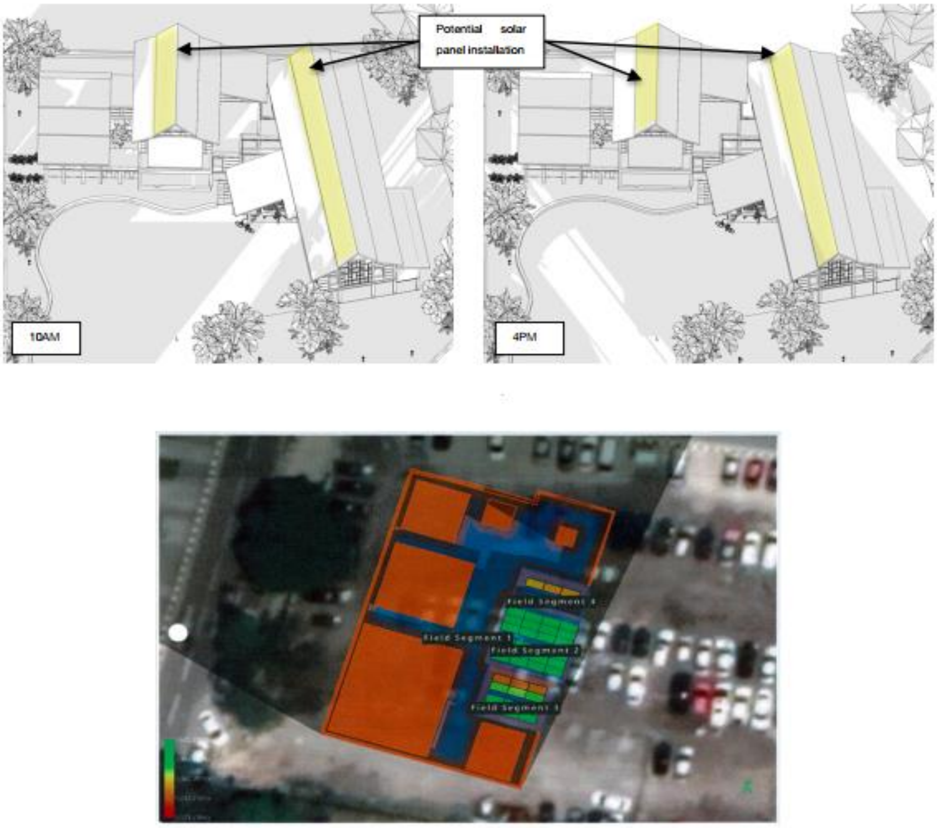


Fig. 6 *Rooftop solar PV analysis (KL LCBC 2023)*

2.6 Grid Emission Factor (GCF) in Malaysia

GEF is the GHG emission per unit of electricity generation from all generating power plants, including those producing Renewable Energy Certificates. It is used to assess the environmental impacts of electricity consumption, promote sustainability, cost efficiency, and regulatory compliance.

Table 2 *Grid emissions factors in Malaysia*

	Grid Emission Factor (Gg CO2/ GWh)		
Year	Peninsular	Sabah	Sarawak
2022	0.774	0.525	0.199
2021	0.757	0.524	0.198
2020	0.821	0.503	0.203
2019	0.753	0.548	0.222
2018	0.797	0.500	0.193
2017	0.767	0.530	0.213

2.7 Building Energy Index (BEI)

Building Energy Index (BEI) is a global metric for assessing energy consumption in buildings, developed in the 1970s to address the energy crisis 98]. The Energy Commission of Malaysia has implemented a BEI labelling initiative for public structures, including government office buildings, universities, hospitals, and schools in Putrajaya. Buildings with BEI score below 100 receive a 5-star grade, indicating better energy efficiency. The

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Green Building Index (GBI) is another established energy index administered by the Energy Commission, recommending an energy consumption index of 150-180 kWh/m^2/year for existing buildings [14]. Furthermore, Building Energy Intensity (BEI) measures the amount of energy consumed by a building relative to a specific parameter, often per unit of floor area. It is typically expressed in units of kWh/m^2/year. A lower BEI suggests that the building is using energy more efficiently. TBEC is total building energy consumption, CPEC represents carpark energy consumption, GFA represents gross floor area and WHO is weighted weekly operating hours in the office.

$$BEI = \frac{(TBEC - CPEC)x\,(52)}{(GFA\;x\;WOH)} \tag{1}$$

2.8 Building Energy Audit

An energy audit is a process that evaluates a building's energy consumption characteristics, aiming to identify strategies to reduce energy consumption in industrial and commercial sectors. Professional equipment is required, and studies suggest that energy audits can improve building electrical energy efficiency [15]. This process can be conducted in small to large seize buildings.

3. Methodology

This chapter uses a preliminary energy audit with relevant documents such as electricity bills, equipment datasheets, construction drawings, electrical single line diagrams and a detailed energy audit to investigate energy consumption pattern, performance and potential energy conservation measures. The study involves a workflow chart, building characteristics, desktop analysis and reports with relevant information. Several approaches and measures have been selected and explained in the process flow shown in Fig. 8 in order to complete this project.

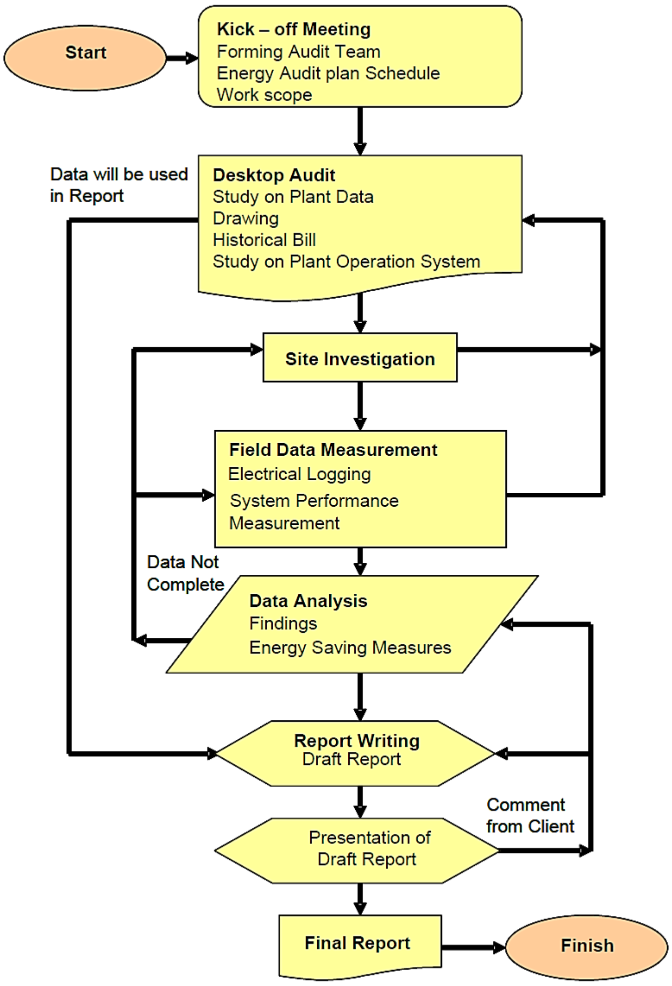

Fig. 7 *Workflow chart*

3.1 3-Storey Office Building in Senai Johor

This study was conducted in a 3-storey office building, located in Senai Johor. The office building was built in 2020, total land area is approximately equivalent to 15,293.60 m^2, while total gross floor area is equivalent to 6,154.25 m^2. Fig. 9 shows the Google Maps location and table 3 describe office building information.

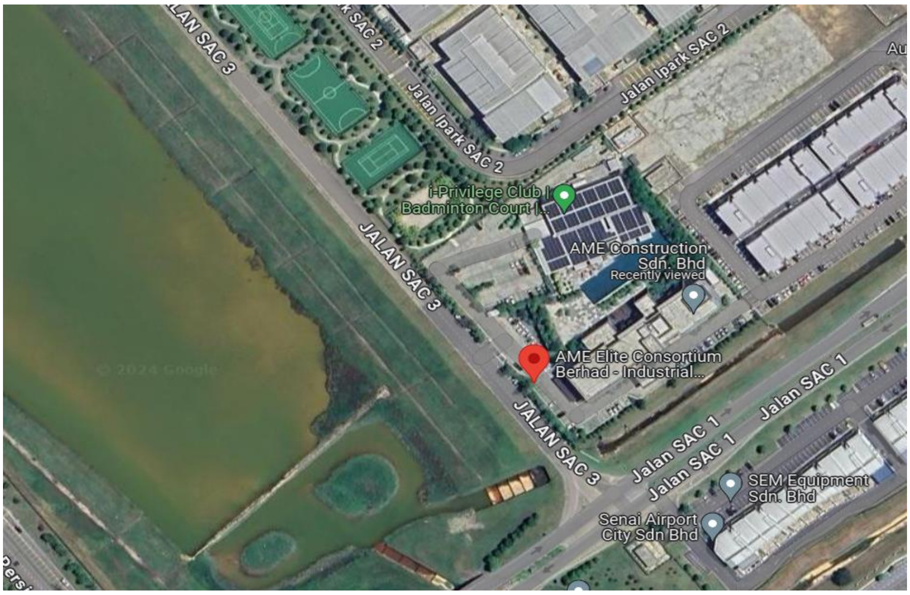

Fig. 8 *Google map location of office building*

Table 3 *Technical information of office building*

Type of building	Commercial Office building
Year of establishment	2019
Year of the last construction ended	2020
GPS coordinate	1.5961049 Latitude and 103.6774474 Longitude
Number buildings	1 block 3 store-office, 1 block guardhouse, 1 block TNB substation, 1 block utility room, and 1 block recreation hall
Operation hour	Monday to Friday: 8.00 AM to 5.00 PM
Land area	15,293.60 m^2
Floor area	6,154.23 m^2
Total of Employees:	Approximately 400 occupants

3.2 Energy Audit

Desktop analysis is used for energy audit to analyse data such as reviewing TNB bills, construction drawings and equipment datasheet to identify important parameter such as power and interview building operators to understand the operation hours. The detailed energy audit involves data collection, power load apportioning and identify energy efficient measures and presentation.

Table 4 *Measurement tools for energy audit*

No	Measuring Tool	Function	Photo
1	Three phase energy logger, energy analyzer, electrical network analyzer, power quality analyzer, energy meter	kW, kVAR, PF, time and other data relevant to building and main end-uses power supplies	
2	Lux meter	Light intensity of lit areas	
3	Temperature and Humidity meter	Measures both temperature and humidity	

3.3 Building Energy Index (BEI)

Building energy index (BEI) is used to measure office building electricity efficiency and performance. A lower BEI rating indicates better efficiency for the building. Gross Floor Area (GFA) is the total area of lobbies, corridors, staircase, office rooms, pantries etc. Net floor area (NFA) is usable area within building envelop. It can be measured with construction drawing. Following table defined the NFA of the office building [16].

3.4 Selection of Emission Factors

National and international factors such as grid electricity emissions for Peninsular Malaysia, Sabah and Sarawak provide data on CO2 emissions in specific units. The calculation formula is shown in below, activity data is electricity consumption in kWh, while emissions factor is 0.771Kg/kWh [17].

$$Emission\ (Ton) = Activity\ Data\ x\ Emission\ Factor \qquad (2)$$

3.5 Energy Data Collection

Power data logger will be used to measures electrical parameters like voltage, current, power, and energy consumption over time. This is useful information to analyse electrical energy consumption patterns in specific period. Maximum power consumption normally during weekday and daytimes, minimum power consumption normally during weekend and nighttime.

Table 5 *Data logging information*

Location	Date	Remarks
MSB (Main Building)	25 October 24– 28 October 24	With Solar PV

3.6 Investment Cost Analysis

An investment cost analysis for office building involves comparing expenses to potential savings from implementing energy conservation measures and to identify estimated costs for upgrading existing system and integration of solar energy system. Lastly, calculating ROI and payback period from the investment cost.

$$ROI = \frac{Net\ Return\ on\ Investment}{Cost\ of\ Investment}\ x\ 100\% \tag{3}$$

$$Payback\ Period = \frac{Initial\ Investment}{Annual\ Cash\ Inflow} \tag{4}$$

4. Results and Discussion

This chapter evaluated energy consumption data from January 2022 to December 2024 for the office building in Senai Johor. And discussion regarding the Building Energy Intensity (BEI) and strategies for improving energy efficiency. A lower BEI indicates better efficiency, reducing operational costs and environmental impacts.

4.1 Electricity Bill

Electricity bills for the past 3 years (2022 to 2024) were analyzed for the office building. Average electricity consumption from Jan 2022 to December 2022 is 46,294 kWh. Average electricity from solar is 19,380 kWh. In addition, average electricity consumption from Jan 2023 to December 2023 is 45,184 kWh, average solar energy consumption is 20,043 kWh. In 2024, average monthly electricity consumption is 44,184 kWh, average solar energy consumption is 18,850 kWh. There is a slight reduction in total electricity consumption over the 3 years (from 46,294kWh in 2022 to 44,184 kWh in 2024), which suggests effort towards energy efficiency or changes attitude in operation usage. However, the solar energy contribution fluctuates, showing an increase in 2023 but a decrease in 2024. This may be due to intermittent in solar energy generation.

Table 6 *Electricity consumption 2022*

Month	Year 2022			
	Total Electricity Consumption (kWh)	Electricity Consumption from TNB (kWh)	Electricity Consumption from Solar (kWh)	Solar Contribution (%)
January	44,853.00	44,853.00	0.00	0%
February	45,154.00	45,154.00	0.00	0%
March	46,326.00	46,326.00	0.00	0%
April	46,404.00	46,404.00	0.00	0%
May	47,122.00	47,122.00	0.00	0%
June	48,418.00	48,418.00	0.00	0%
July	48,406.00	22,104.00	19,618.00	41%
August	46,404.00	28,218.00	18,186.00	39%
September	47,122.00	24,913.00	22,209.00	47%
October	47,498.00	26,131.00	21,367.00	45%
November	46,064.00	26,096.00	19,968.00	43%
December	41,755.00	26,815.00	14,940.00	36%
Total	555,538.00	432,554.00	116,288.00	21%

Table 7 *Electricity consumption 2023*

Month	Year 2023			
	Total Electricity Consumption (kWh)	Electricity Consumption from TNB (kWh)	Electricity Consumption from Solar (kWh)	Solar Contribution (%)
January	41,755.00	24,158.00	17,596.00	42%
February	45,154.00	24,836.00	20,317.00	45%
March	46,326.00	25,955.00	20,370.00	44%
April	43,355.00	23,452.00	19,902.00	46%
May	52,617.00	27,827.00	24,789.00	47%
June	49,958.00	29,133.00	20,825.00	42%
July	45,105.00	26,212.00	18,893.00	42%
August	45,382.00	25,777.00	19,604.00	43%
September	43,240.00	22,871.00	20,368.00	47%
October	46,386.00	23,608.00	22,777.00	49%
November	42,764.00	24,514.00	18,250.00	43%
December	40,160.00	23,331.00	16,829.00	42%
Total	542,202.00	301,674.00	240,520.00	44%

Table 8 *Electricity consumption 2024*

Month	Year 2024			
	Total Electricity Consumption (kWh)	Electricity Consumption from TNB (kWh)	Electricity Consumption from Solar (kWh)	Solar Contribution (%)
January	44,434.550	26,499.420	17,935.130	40%
February	42,011.560	22,667.020	19,344.540	46%
March	46,967.050	25,212.620	21,754.430	46%
April	45,438.580	25,940.950	19,497.630	43%
May	46,853.980	29,120.860	17,733.120	38%
June	42,098.480	23,998.470	18,100.010	43%
July	49,726.870	28,082.880	21,643.990	44%
September	41,195.030	22,428.820	18,766.210	46%
October	44,688.770	25,449.660	19,239.110	43%
November	42,840.390	26,896.250	15,944.140	37%
December	39,433.480	22,545.660	16,887.820	43%
Total	530,205.32	303,979.91	226,225.41	43%

4.2 Building Energy Intensity Analysis

The building energy intensity (BEI) was calculated for a 3-storey office building using gross floor area data in Table 9 and energy usage data in Table 8.

Table 9 *Net floor area of office building*

No.	Level	Floor area (m^2)
1	Ground	2,192.41 m^2
2	Level 1	2,062.41 m^2
3	Level 2	1,899.41 m^2
	Total	6,154.23 m^2

The 3-storey office building's energy consumption and performance from 2022 to 2024 showed significant improvements. In 2022, the building's BEI was 70.3 kWh/m^2/year, primarily from the TNB grid. In 2023 and 2024, the BEI dropped to 49.0 kWh/m^2/year and 49.4 kWh/m^2/year, respectively. The integration of 44% solar energy, LED lights, ACMV optimization, and better insulation contributed to the decrease. Table 10 shown BEI from 2022 to 2024.

Table 10 *Net building energy intensity 2022 to 2024*

Description/Year	2022	2023	2024
Electricity consumption from TNB (kWh)	432,554.00	301,674.00	303,979.00
Gross floor area (m^2)	6,154.23	6,154.23	6,154.23
Annual BEI (kWh/m^2/ year)	70.3	49.0	49.4

4.3 Results from Energy Performance Assessment

A comprehensive energy performance assessment was conducted on October 25, 2024, using methods such as a walk-through audit, direct measurement, interviews, and data collection from the building manager, Mr. Yusuf. The audit examined aspects like building envelope, indoor comfort levels, energy-consuming equipment, operation hours, and power supply systems. Data was obtained from building manager such as electricity bills and equipment datasheet. The audit also included a power logger for recording actual power load profiles and lux meter for checking lux intensity.

Table 11 *Office building detail 2024*

Description	Details
Building Name	3-Storey Corporate Office Building
Location	No 2, Jalan I-Park SAC 1/1, Taman Perindustrian I-Park SAC, Senai Johor
Type of Building	Commercial Type
Total Floor Area	6,154.23 m^2
In Operation Since	October 2021
Average Occupancy	275
Energy Source	Electricity- Supplied from TNB (Tariff B)

4.3.1 Indoor Comfort Level

Overall, the office environment provides adequate comfort level for ventilation, lighting, air quality and noise level. The average noise level recorded was around 45dBA in open space area and around 37 dBA in closed office area. The average lighting level recorded was acceptance level. The average relative humidity and temperature in the office room was 66.8% and 24.3°C. Maximum relative humidity and temperature was 80.0% and 28.1°C, minimum relative humidity and temperature was 43.0% and 21.2°C.

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Table 12 *Illuminance level 2024*

Task and Applications	Recommended Illuminance (Lux)	Actual Illuminance (Lux)
Office	300-400	307
Sales Gallery	100	214
Toilet	100	105
Meeting Room	200	235

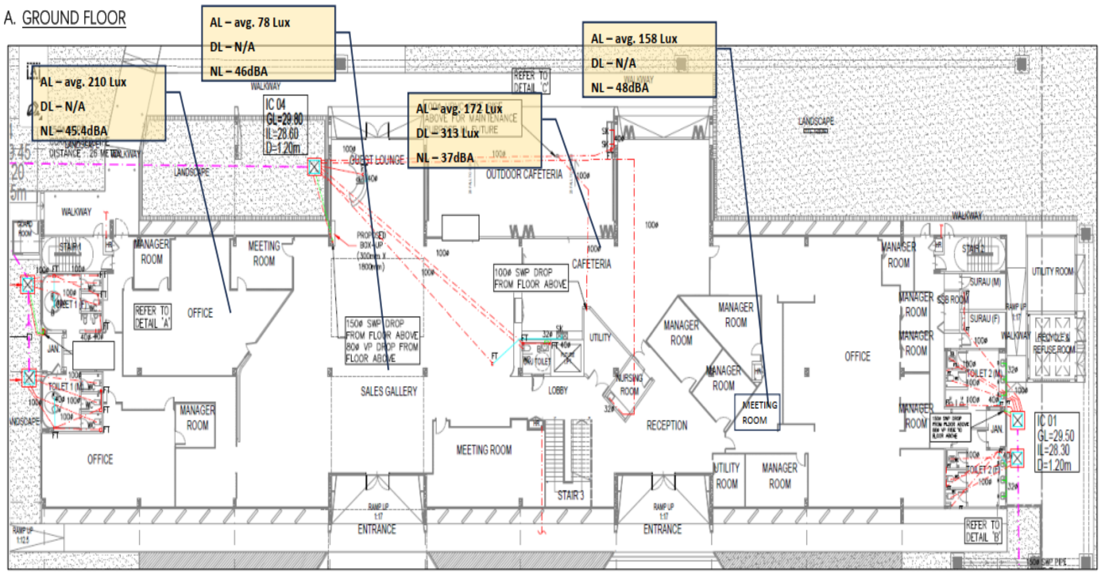

Fig. 9 *Lighting level and noise level*

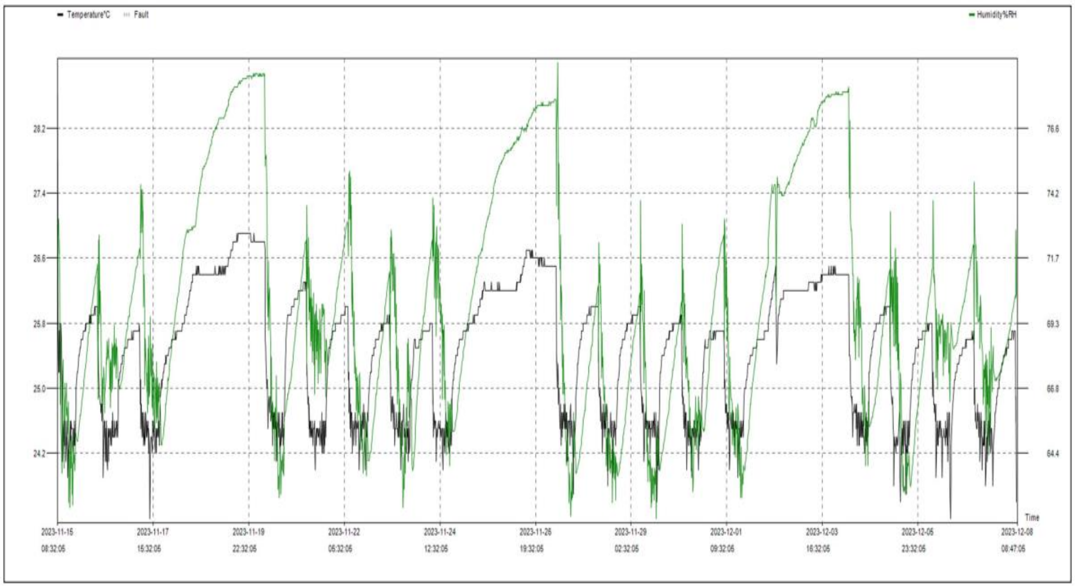

Fig. 10 *Humidity (%RH) and temperature (°C) level*

4.3.2 Electrical System

Office building is connected to the Tenaga Nasional Berhad power grid and has a rooftop solar system. The energy performance is assessed through a building energy index, and the baseline electricity consumption and cost are determined using historical electricity bills.

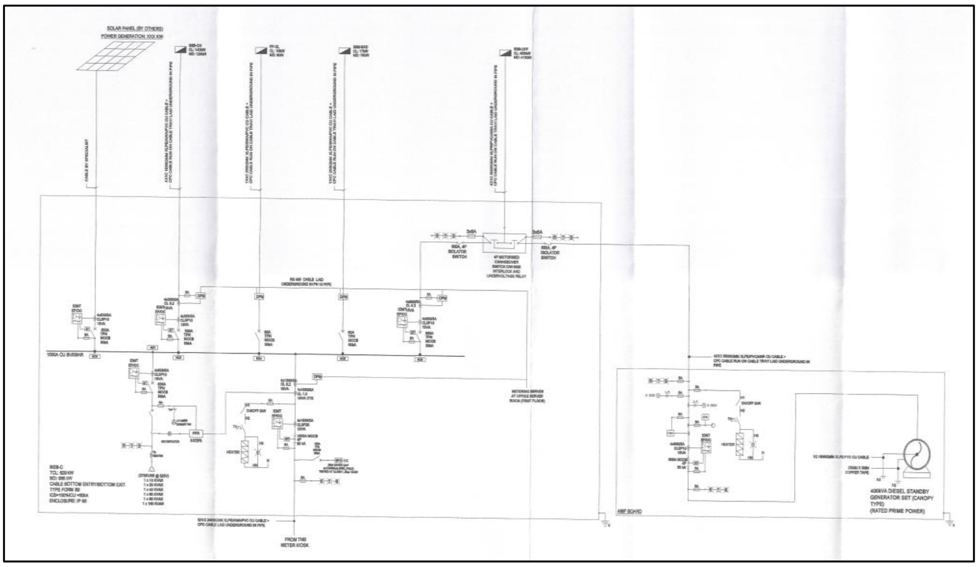

Fig. 11 *Electrical single line diagram*

4.3.3 Electricity Tariff

The Senai Johor office, with a 3-storey structure, uses a low voltage commercial tariff (B) with a flat energy charge of RM0.509/kWh. The building requires ICPT charge, SST, and a renewable energy fund contribution for electricity consumption.

Table 13 *Electricity bill information 2024*

Component	Charge
Energy charge	Flat rate 0.509 Sen/kWh
Minimum monthly charge	RM600
(ICPT) Imbalance Cost Pass-Through	0.027 Sen/kWh
Note: ICPT charge is reviewed and adjusted every 6 months in Peninsular Malaysia	
(KWTBB) Renewable energy fund contribution	1.60%

4.3.4 Electricity Cost

The electricity tariff in effect from 2022 to 2024 will determine the cost of electricity for that period. The average electricity cost over these three years was around RM 188,953.00.

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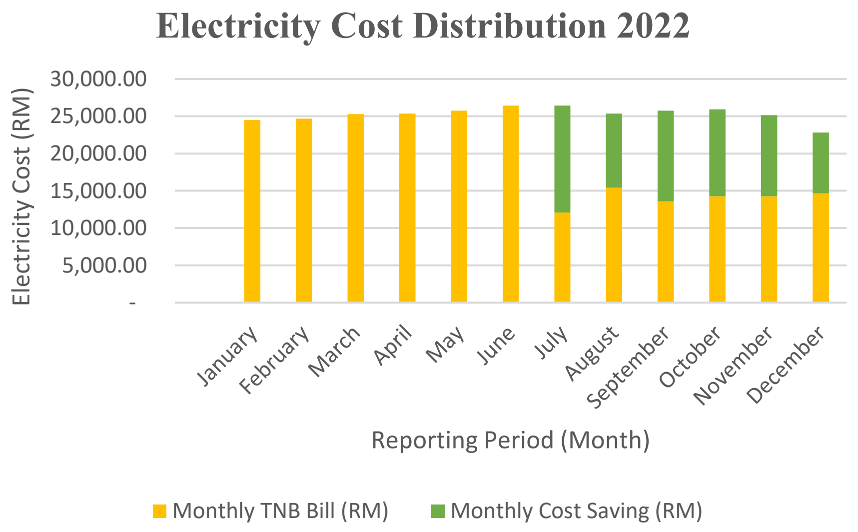

Fig. 12 *Electricity cost 2022*

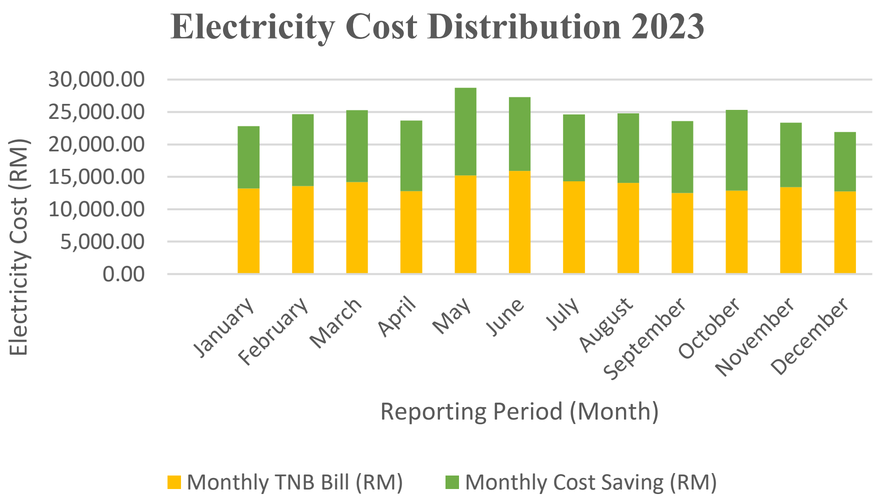

Fig. 13 *Electricity cost 2023*

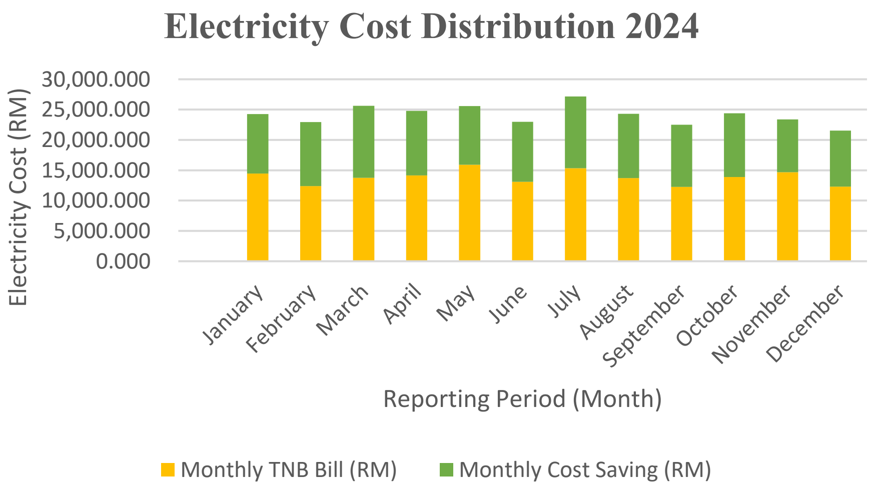

Fig. 14 *Electricity cost 2024*

4.3.5 Breakdown Energy Usage

The building consumed an average of 530,205.00 kWh of electrical energy, with the cooling system accounting for 68%, lighting accounting for 20%, and office equipment, elevators, and miscellaneous loads accounting for 12%. The building's total energy consumption was 56% from the TNB grid.

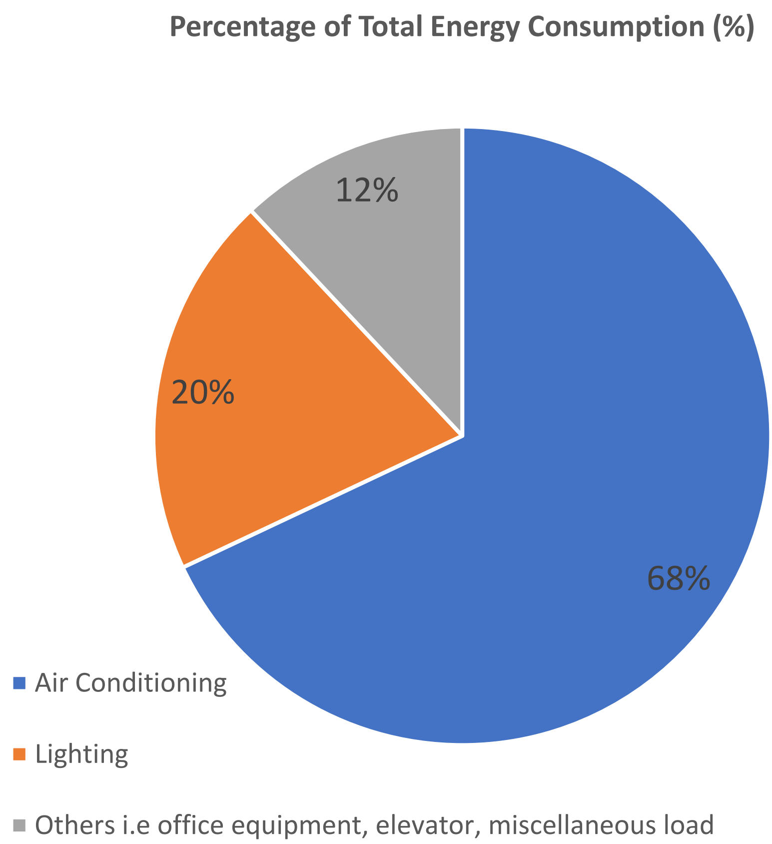

Fig. 15 *Electricity consumption distribution chart 2024*

4.3.6 Air Conditioning System

The Variable Refrigerant Flow (VRF) system is an advanced air conditioning system used to cool a 3-storey office building. It adjusts coolant flow to match zone demand, reducing energy consumption and overcooling. VRF systems use smaller coolant lines and ceiling-mounted indoor units, allowing for individual temperature settings. A total of 20 inverter-driven compressors are used in VRF systems. As compared to conventional ACMV systems, VRF systems can offer significant energy cost savings up to 50%.

Fig. 16 *VRF system used by office building*

4.3.7 Lighting System

The energy consumption of a building's lighting system is determined by factors like lamp wattage, working hours, and operating days. Manual switches and occupants' turning off lights can affect energy use. LED lights are used for office buildings to increase energy efficiency and long-term cost savings but have higher initial costs. The average operating hours are 12 hours. Estimated a total of 875 LED lights are currently installed in the building such as LED- T5-24W, LED-S9292-18W, LED-T5-24W-3000K, LED-82/7W, and LED-RO48-15W. Compared to conventional lighting systems, LED lights can offer significant energy cost savings of up to 50%. Apart from that, natural light is a key feature in this modern office building, and it can significantly enhance the comfort level, we also found that the building is designed with artificial lighting such as large windows.

(a) **(b)**

Fig. 17 *(a) LED light in office rooms; (b) Artificial light in pantries*

4.3.8 Solar System

The installation of a rooftop solar PV system in a 3-storey office building resulted in a 44% monthly electricity cost reduction, equivalent to RM 15,153.00. The system generated 339,250 kWh annually, reducing annual CO_2 emissions by 196.76 tCO_2.

Fig. 18 *Rooftop solar PV system (271.4 kWp)*

4.3.9 Power Data Logger

A load profile analysis of a 3-storey office building revealed that overall electricity consumption increases during the working day, with peak usage occurring during office equipment, lighting, and ACMV systems. The highest consumption was recorded in the morning, at 154 kWh, and the lowest was 15.7 kWh. Peak usage occurred between 8:30am and 5:30pm. Targeted energy-saving measures can optimize consumption, reduce costs, and improve energy efficiency. Simple actions like turning off lights during lunch and off-peak hours can contribute to sustainability efforts. The Fig. 19 below shows 4-day load profile for the office building.

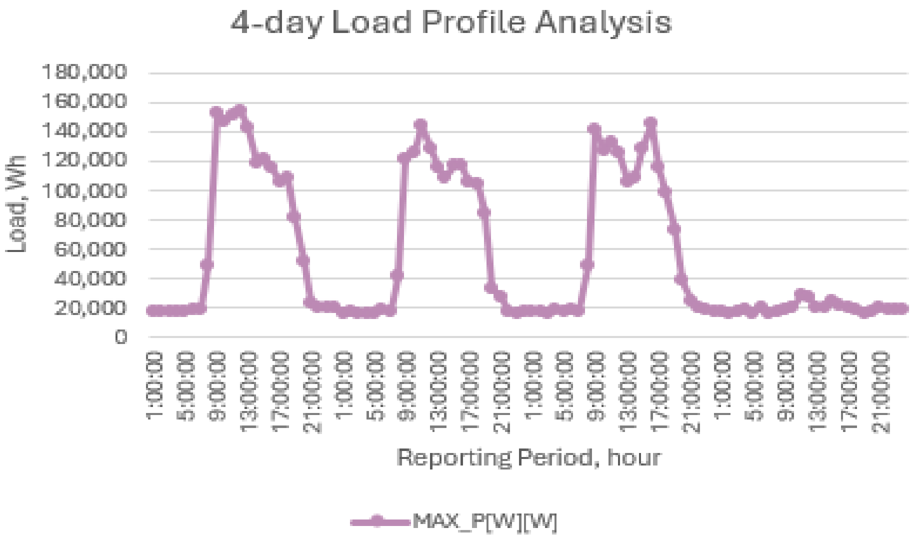

Fig. 19 *4-day load profile chart*

4.4 Results of Energy Efficiency Measures & Economic Analysis

This chapter discusses the integration of passive lighting systems, LED lighting, a variable refrigerant flow (VRF) system, and rooftop solar energy in a building. These systems optimize natural light, reduce artificial lighting, and offer efficient climate control. The VRF system allows for independent temperature settings, while solar energy offsets energy consumption, reducing grid reliance and electricity bills. This sustainable, cost-effective, and energy-efficient building demonstrates the importance of sustainability in modern green building design.

The total investment cost was estimated RM 2,273,000.00, resulting in energy cost savings of RM 469,146.00 per year and payback period is estimated 4.85 years.

Table 14 *Potential energy saving per year*

No	Measures	Energy savings (kWh/ Year)	Reduction in percentage (%)
1	LED lighting adoption	49,820	Estimated 50%
2	VRF system adoption	443,100	Estimated 40%
3	Solar energy system	339,250	Estimated 50%

Table 15 *Investment cost analysis*

Measures	Estimated Investment Cost after Tax Deduction (RM)	Energy Cost Saving Per Year (RM)	Payback Period (Year)
LED Lighting Adoption	165,000.00	26,703.00	6.18
VRF System Adoption	1,500,000.00	260,605.00	5.76
Solar Energy System	608,000.00	181,838.00	3.35
Total:	2,273,000.00	469,146.00	4.85

The economic analysis of proposed measures, as discussed in this study, is evaluated by using equations (3) and (4) as stated before. The payback period is calculated by using equation (4), where the equation is based on the initial cost and yearly return. All the values in this equation are positive, and the result of the economic analysis is positive. A smaller result showed a better result compared to a bigger result. Table 13 shows potential energy savings per year for energy efficiency implementation. Investment cost analysis is shown in Table 14.

5. Conclusion and Recommendations

The study on electrical energy consumption and efficiency in a 3-storey office building reveals significant improvements in energy efficiency. The research aimed to analyze the building's electrical energy consumption, establish the Net Building Energy Intensity (NBEI), propose energy efficiency measures, and evaluate the economic impact of these measures. The study found room for improvement in concrete insulation, lighting systems, and building management systems. The investment analysis showed an estimated cost of RM 2,273,000.00, resulting in approximate energy cost savings of RM 469,146.00 per year and a payback period of 4.85 years. The research also provided insights into the Zero Energy Building (ZEB) criteria, highlighting technologies like louvers panel, double glazing windows, high-efficiency VRV systems, LED lighting, and rooftop solar PV systems. Further research is needed to explore renewable energy technologies, ventilation strategies, and the integration of advanced energy modelling and simulation.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Teo Kok Swee, Sulastri Sabudin, Mohd Faizal Mohideen Batcha;* ***data collection:*** *Teo Kok Swee, Sulastri Sabudin, Mohd Faizal Mohideen Batcha;* ***analysis and interpretation of results:*** *Teo Kok Swee, Sulastri Sabudin, Mohd Faizal Mohideen Batcha;*

draft manuscript preparation: *Teo Kok Swee, Sulastri Sabudin, Mohd Faizal Mohideen Batcha. All authors reviewed the results and approved the final version of the manuscript.*

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