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Bridging The Gap in Non-Process Energy Management: A Comprehensive Audit of A Power Plant Site Office in Power Generation Facilities Linked to Oil and Gas Operations

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ABSTRACT - Energy efficiency research in oil and gas and power generation facilities has predominantly focused on core process systems, while non-process energy consumption in ancillary and administrative buildings remains under-represented in both regional and international literature. Existing building energy audit studies largely emphasise standalone commercial and institutional buildings, offering limited insight into site offices embedded within industrial facilities operating under extended schedules and tropical climatic conditions. This study addresses this gap by presenting a comprehensive non-process energy audit of a site office supporting a coal-fired power generation facility linked to oil and gas operations in Malaysia. The audit follows Malaysian Standard MS1525:2019 and integrates two years of electricity consumption data (April 2023–March 2025), Building Energy Intensity (BEI) benchmarking, end-use load apportioning, and indoor environmental quality (IEQ) assessment. The seasonal analysis confirmed that electricity consumption is strongly influenced by climate-driven cooling demand, with higher peaks occurring during hotter months. However, reductions in base-load consumption during milder periods reveal opportunities for improved operational efficiency and highlight the importance of distinguishing climate effects from controllable energy use when interpreting performance in industrial office environments. The site office recorded a BEI of 172.7 kWh/m²/year, exceeding the MS1525:2019 benchmark of 135 kWh/m²/year and lying at the upper range of values reported for conventional office buildings in tropical climates. HVAC systems dominate electricity consumption (55%), followed by lighting (24%) and general equipment (14%),

indicating higher cooling dependency than typically observed in non-industrial office studies. Visual inspection revealed widespread over-illumination, while IEQ assessment identified temperature fluctuations and intermittent CO₂ exceedances, reflecting inconsistencies in environmental control. Collectively, these findings indicate that inefficiencies arise from the combined effects of HVAC operation, lighting design, and control strategies. Addressing these areas holistically offers potential to reduce BEI, flatten peak demand, and improve occupant comfort, while supporting integrated industrial energy management under Malaysia's NEEAP and EECA 2024.

Keywords: energy audit, coal-fired power plant, site office, energy management, oil and gas.

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INTRODUCTION

Malaysia's commitment to improving energy efficiency has evolved significantly since the early 2000s, driven by rising national energy demand, environmental concerns, and international climate commitments. This path has a climax in the implementation of the National Energy Efficiency Action Plan (NEEAP) and the Energy Efficiency and Conservation Act 2024 (EECA 2024), which came into force in January 2025. These frameworks position energy efficiency as a central strategy for reducing energy waste, lowering greenhouse gas emissions, and supporting sustainable economic growth across major sectors, including power generation and oil and gas (Chua & Oh 2010); Revichandran et al., 2022; Afham & Razali 2024; Sunarjanto et al., 2017. Within this policy context, the building sector has been identified as a priority, accounting for a significant share of national electricity consumption, particularly within commercial and institutional buildings.

Despite the establishment of comprehensive policies and programmes, the translation of national energy efficiency objectives into facility-level implementation remains uneven. Existing initiatives and academic research in Malaysia

largely prioritise process energy efficiency, focusing on power generation technologies, fuel optimisation, renewable energy integration, and emissions reduction within core plant operations (Abdul Latif et al., 2021); (Zamri et al., 2022); (Abdullah et al., 2019). While such efforts are critical, they have resulted in a predominantly process-centric approach to energy management, with limited attention given to non-process energy consumption in supporting infrastructure.

Non-Process Energy Inefficiencies (NPEI), which include energy use in administrative offices, control rooms, laboratories, and auxiliary facilities, represent a significant yet under-addressed source of energy demand in industrial environments. Studies on offshore oil and gas platforms have demonstrated that substantial energy losses occur outside primary process systems, with exergy analyses revealing significant inefficiencies within dedicated power generation and auxiliary services (Nguyen et al., 2012). In addition, recent research highlights that inadequate monitoring, outdated management practices, and limited integration of digital energy management tools further exacerbate non-process energy waste in oil and gas facilities (Farsi et al., 2023; Saghir et al., 2024). However, empirical assessments of administrative buildings

embedded within power generation facilities, particularly in tropical climates, remain limited.

Energy audits are widely recognised as an effective mechanism for identifying inefficiencies and guiding targeted energy conservation measures. Numerous Malaysian studies have applied energy audits to commercial, institutional, and government buildings, consistently identifying HVAC and lighting systems as the dominant contributors to electricity consumption and demonstrating significant potential for energy and cost savings (NY Dahlan et al., 2013); (Zailan & Che Kar 2018); (Mohamad et al., 2022); (Alamin et al., 2023). Nevertheless, these studies primarily focus on standalone office buildings, universities, hospitals, and municipal facilities. Such buildings operate under markedly different conditions compared to industrial site offices, particularly in terms of operational schedules, occupancy patterns, safety constraints, and thermal loads, limiting the applicability of their findings to power generation environments.

Within Malaysian power generation facilities, research and practice continue to emphasise process-side improvements, while the energy performance of site offices and ancillary buildings remains largely undocumented. Malaysia standards, such as MS1525:2019, provide Building Energy Intensity (BEI) benchmarks for non-residential buildings, yet their application to industrial administrative facilities has not been systematically examined (Department of Standards Malaysia, 2019). This lack of baseline data constrains the development of holistic energy management strategies and weakens the integration of non-process energy management into national policy objectives under NEEAP and EECA 2024 (Muhammad et al., 2021); (Aldhshan et al., 2021).

In response to this gap, this study presents a comprehensive energy audit of a coal-fired power plant site office supporting power generation operations linked to the oil and gas sector in Malaysia. The audit integrates two years of historical and experimental energy consumption data, Building Energy Intensity (BEI) benchmarking against MS1525:2019, detailed end-use load apportioning, and Indoor Environmental Quality (IEQ) assessment. By specifically focusing

on non-process energy use at the building level, this study establishes an empirical baseline for industrial administrative facilities and demonstrates how targeted energy audits can support Malaysia's broader energy efficiency and industrial decarbonisation goals under EECA 2024 and NEEAP.

Literatur Review

Energy efficiency research in power generation and industrial facilities

Energy efficiency research in Malaysia's power generation and oil and gas sectors has traditionally concentrated on process energy optimisation, including fuel diversification, generation efficiency, renewable energy integration, and emission reduction strategies. Studies analysing Malaysia's power generation mix highlight improvements in combustion efficiency and renewable penetration as the primary pathways toward decarbonisation, with limited attention given to supporting infrastructure Abdul Latif et al., 2021; Abdullah et al., 2019; Zamri et al., 2022. These findings are consistent with national policy priorities under NEEAP, which emphasise system-level efficiency improvements in energy-intensive industries (Chua & Oh 2010; Revichandran et al., 2022).

Internationally, similar trends are observed in oil and gas facilities, where research has focused on process performance and system-level inefficiencies. Exergy-based analyses of offshore platforms demonstrate significant energy destruction within power generation and process systems, reinforcing the dominance of process-centric efficiency strategies (Nguyen et al., 2012). While these studies provide valuable insights into large-scale inefficiencies, they offer a limited assessment of energy use in administrative and auxiliary buildings within industrial facilities.

Energy Audits in Commercial, Institutional, and Government Buildings Energy audits are widely recognised as an effective mechanism for identifying inefficiencies and improving energy performance in buildings. In Malaysia, numerous audit-based studies have been conducted in commercial offices, government buildings, universities, and hospitals. These studies

consistently report that HVAC and lighting systems dominate electricity consumption and that targeted energy conservation measures can deliver significant energy and cost savings Saidur 2009; NY Dahlan et al., 2013; Zailan & Che Kar 2018; Mohamad et al., 2022; Alamin et al., 2023.

Building Energy Intensity (BEI) values reported in these studies typically range from below 100 to approximately 140 kWh/m²/year, depending on building type, age, and operational patterns. For example, audits of university and municipal buildings demonstrate that systematic retrofitting and operational improvements can reduce energy consumption by up to 40% while maintaining acceptable indoor environmental quality Zailan & Che Kar 2018; Mohamad et al., 2022. These findings establish a strong evidence base for the effectiveness of energy audits in non-industrial settings.

However, the majority of these studies focus on standalone buildings operating under conventional office schedules and occupancy conditions. As such, their findings are not directly representative of administrative buildings located within industrial environments, where continuous operation and stricter operational constraints significantly influence energy demand profiles.

Non-process energy inefficiencies in oil and gas and industrial facilities

Non-Process Energy Inefficiencies (NPEI), encompassing energy use in administrative offices, laboratories, control rooms, and auxiliary facilities, have been identified as a critical yet under-managed component of industrial energy consumption. In oil and gas operations, supporting infrastructure often operates continuously to maintain safety, monitoring, and administrative functions, resulting in sustained HVAC and lighting demand. Research indicates that the absence of systematic monitoring and integrated energy management frameworks exacerbates inefficiencies in these non-process loads (Farsi et al., 2023).

Recent studies highlight the growing role of digitalisation and energy surveillance tools in addressing NPEI. The adoption of real-time monitoring systems and data-driven energy

management platforms has been shown to improve energy visibility and reduce unnecessary consumption without major capital investment Farsi et al., 2023; Saghir et al., 2024. Nevertheless, these studies largely focus on system-level monitoring and do not provide detailed empirical audits of administrative buildings within power generation facilities, particularly in tropical climates.

BEI Benchmarking and Climatic Context

Building Energy Intensity (BEI) is a widely used indicator for benchmarking building energy performance. In Malaysia, MS1525:2019 establishes a recommended BEI benchmark of 135 kWh/m²/year for non-residential buildings (Department of Standards Malaysia, 2019). While extensive BEI benchmarking data exist for commercial and institutional buildings, there is limited published evidence on BEI performance for industrial administrative buildings, such as site offices within power plants.

Studies conducted in Malaysian office buildings consistently report high HVAC energy shares, often exceeding 50% of total electricity consumption, particularly under tropical climatic conditions (Saidur, 2009). Similar patterns are observed in laboratory and industrial support facilities, where HVAC systems are frequently oversized to meet safety and comfort requirements, leading to elevated energy use (Mathew et al., 2005). Despite these observations, comparable BEI benchmarks for administrative buildings embedded within power generation facilities remain largely undocumented.

Research gap and contribution of this study

The reviewed literature reveals several key gaps. First, existing energy efficiency research in power generation and oil and gas facilities remains predominantly process-focused, with limited attention given to non-process energy consumption in administrative and auxiliary buildings Abdul Latif et al., 2021; Muhammad et al., 2021. Second, while energy audits in commercial and institutional buildings are well documented, similar studies in industrial site offices are scarce, limiting the

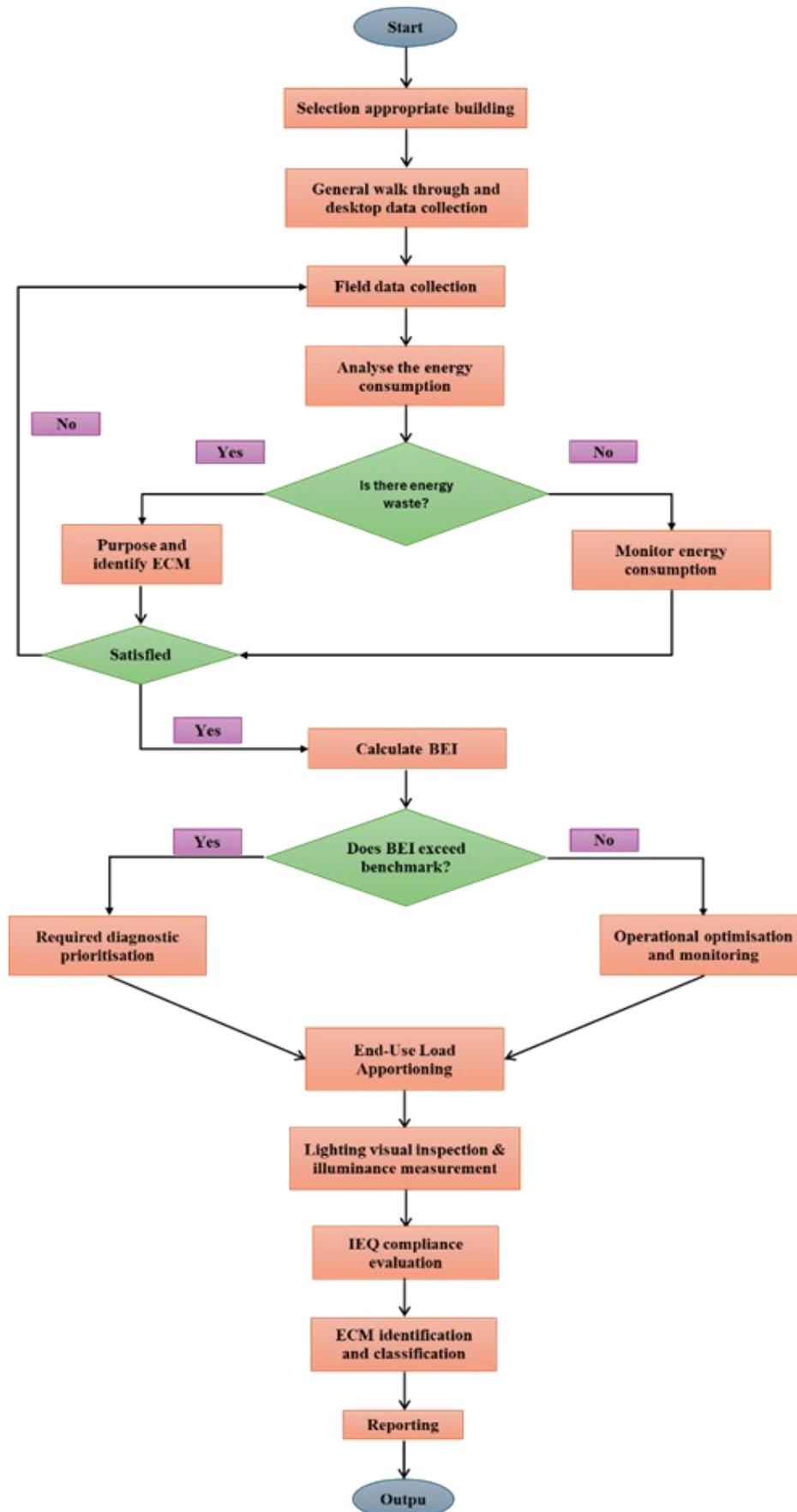


Figure 1. Generalised non-process energy audit framework for industrial administrative buildings.

transferability of established benchmarks and conservation strategies (Aldhshan et al., 2021). Third, there is a lack of empirical BEI data for industrial administrative buildings operating under Malaysia's tropical climate and MS1525:2019 framework.

This study addresses these gaps by presenting a comprehensive energy audit of a coal-fired power plant site office in Malaysia. By integrating BEI benchmarking, end-use load apportioning, and indoor environmental quality assessment over two years, the study extends existing audit literature beyond repetitive commercial case studies. The findings provide a replicable framework for managing non-process energy use in industrial administrative facilities and support the broader objectives of Malaysia's NEEAP and EECA 2024.

METHODOLOGY

This paper study adopts and extends the concepts of MS1525:2019 by reorganising traditional energy audit practices into a decision-making and transferable non-process energy audit system applied to industrial administrative buildings in the setting of power generation and the oil and gas industry. Instead of offering a linear, site-specific audit sequence, the proposed framework adds the contextual normalisation, climate-sensitive energy interpretation and performance-based decision nodes as tools for ensuring diagnostic prioritisation. The metrics used (Building Energy Intensity (BEI), end-use load apportioning, and Indoor Environmental Quality (IEQ)) are not only used as descriptive measures, but they also serve as analysis drivers to define the degree of further assessment. This abstraction facilitates replication between facilities with varying operational profiles without repeating ad-hoc or trial and error audit processes, and thus seeking to fill a identified gap in non-process energy management of industrial administrative buildings.

Detailed Energy Audit

The detailed energy audit involves in-depth investigations into how the energy is currently being consumed, the current performance of the

existing systems and the identification of various potential ECMs. It also gives the estimated cost and simple payback periods for all recommended ECMs. The detailed energy audit involves the following four (4) main processes: 1). Data collection; 2). End-use load apportioning; 3). Identification of ECMs; 4). Reporting and presentation.

Generalised non-process energy audit workflow for industrial site offices

To address the need for a transferable and decision-oriented approach to non-process energy management, this study conceptualises the applied MS1525:2019 and Electrical

Energy audit guidelines for building based audit into a generalised non-process energy audit workflow suitable for industrial administrative buildings such as power plants and oil and gas site offices. While the fundamental audit elements, energy consumption analysis, Building Energy Intensity (BEI), load apportioning, and Indoor Environmental Quality (IEQ) are well established, this study reorganises them into a structured diagnostic sequence that supports replication across facilities with differing operational profiles. Unlike conventional linear audit practices that primarily document site-specific findings, the proposed workflow introduces contextual normalization and performance-based decision nodes. Energy consumption data are first evaluated temporally to distinguish climate-driven peak demand from controllable base-load consumption, enabling more accurate interpretation of energy performance in facilities subject to extended operating hours and tropical climatic conditions. This distinction ensures that higher peak consumption during extreme weather periods is not misinterpreted as inefficiency, while reductions in base-load demand are emphasised as indicators of improved operational efficiency.

Next, BEI benchmarking is applied not merely as a compliance indicator but as a screening metric to prioritise further investigation. Facilities

exceeding the MS1525:2019 benchmark are directed toward detailed end-use load apportioning, where dominant energy consumers typically HVAC and lighting systems are identified and ranked. Visual inspection and IEQ assessments then serve as diagnostic validation tools, linking quantitative energy data with system operation, occupant comfort, and environmental performance.

The final stage of the workflow translates diagnostic findings into tiered energy conservation measures (ECMs), categorized by investment level and payback period. This structured progression from normalized consumption analysis to performance-based intervention selection provides a replicable audit logic that can be applied to other industrial administrative buildings without reliance on ad-hoc or trial-and-error procedures.

By abstracting standard audit practices into a generalised workflow, this study extends existing building energy audit literature beyond descriptive case studies and contributes a practical framework for managing non-process energy consumption in industrial facilities. The approach is particularly relevant for supporting Malaysia’s EECA 2024 and NEEAP objectives, where scalable and repeatable energy management strategies are required across diverse industrial support infrastructures.

Experimental area and equipment list

A coal-fired power plant site office, located at Johor, Malaysia, has been selected as a suitable building for conducting an energy audit. A coal-fired power plant's site office is a suitable building to analyse the energy consumption pattern and provide energy-saving measures for minimising energy consumption in the building. A walk-through audit was performed on a coal-fired power plant's site office to determine the number of rooms and electrical components in each room. The Department of Planning and Site Services also provided architectural plans for the structures and appliance requirements. Energy consumption data was collected for two years from April 2023 to March 2025. The readings were recorded to

compare energy use for the HVAC, lighting system and other electrical equipment analysis systems. All data gathered were evaluated, compared, and addressed.

Good lighting for the comfort of the building's occupants and supporting several activities depends mostly on the lighting system. Energy consumption is largely influenced by the lighting choices. Two types of lighting, with different power per fixture as shown in Table 1, are utilised in a coal-fired power plant site office. An air conditioning system is essential in any facility to keep users comfortable. This air conditioning system regulates the temperature and humidity of the air in the building by collecting heat from the internal air and releasing it to the outside. A coal-fired power

Table 1. The area in a coal-fired power plant's site office uses a specific type of lighting

Lighting types	Power per fixture (Watt)	Area
T8 Fluorescent	36	Ground Floor Office, Parking Area
LED Lamp	50	Meeting Room, Manaer Room
T8 Fluorescent	23	Server Room
T8 Fluorescent	20	Rest Room

Table 2. The area in the coal-fired power plant site office uses a specific type of air conditioning.

Air-conditioning types	Capacity (kW)	Area
HVAC	5	Ground Floor Offices, Meeting Rooms
Split AC	2	Manager Room
Split AC	7.5	Server Room

Measurement equipment

The description of the listed measurement equipment is explained in the following Table 3.

Table 3. Description of the listed measurement equipment

No	Equipment Type	Diagram
1	Three-phase energy logger: To perform power measurement at DBs	
2	Lux meter: to measure lighting lux level	
3	Anemometer: to determine wind speed or air velocity	
4	CO ² Meter: to measure the CO ² level in particular areas	

RESULT AND DISCUSSION

Energy consumption pattern

The monthly electricity consumption of the coal-fired power plant site office was analysed over two consecutive periods, which are the historical period (April 2023–March 2024) and the experimental period (April 2024–March 2025), in order to evaluate seasonal behaviour and the impact of implemented energy efficiency measures. Figure 2 illustrates the historical monthly electricity consumption of the site office from April 2023 to March 2024. The data reveal clear seasonal variability influenced by climatic

conditions and operational activity, with consumption ranging between 37,000 kWh and 43,000 kWh. A clear seasonal pattern is observed, with the lowest consumption recorded in May 2023, coinciding with milder ambient conditions, and the highest consumption occurring in August 2023, during peak summer months. This trend reflects the strong influence of outdoor temperature on cooling demand, particularly given that HVAC systems represent the dominant energy load in the building. During the experimental period, as shown in Figure 3, monthly consumption exhibited a wider range, between approximately 35,000 kWh and 45,500 kWh, indicating increased energy

responsiveness to both climatic and operational conditions. Notably, the lowest consumption in May 2024 ($\approx 35,000$ kWh) represents a reduction of approximately 2,000 kWh ($\approx 5.4\%$) compared to May 2023. This reduction during a climatically comparable month suggests an improvement in base-load efficiency, likely attributable to the implementation of energy conservation measures and improved operational control during non-extreme weather conditions.

While the experimental period recorded a slightly higher peak demand in August 2024 ($\approx 45,500$ kWh) compared to the historical peak ($\approx 43,000$ kWh), this increase should not be interpreted as reduced efficiency. Higher peak demand during extreme summer months is likely climate-driven, reflecting intensified cooling requirements rather than inefficient operation. Importantly, the simultaneous reduction in base-load consumption during milder months demonstrates that the building operated more efficiently overall, with energy use becoming more responsive to external conditions rather than remaining uniformly high throughout the year.

From September to December in both periods, energy consumption stabilised within the range of approximately 39,000–42,000 kWh, indicating

consistent operational demand and controlled energy use during transitional weather conditions. However, the experimental year showed smoother month-to-month variations, suggesting improved energy management and reduced unnecessary fluctuations. In the final quarter of the experimental period, consumption again declined, with March 2025 recording approximately 36,500 kWh, corresponding to a reduction of about 3,500 kWh ($\approx 8.8\%$) relative to higher-demand months.

Overall, both periods show similar seasonal patterns characterised by higher energy use during hot months and lower consumption during milder conditions. However, the experimental year demonstrates measurable efficiency gains at the base-load level, with electricity savings of approximately 5–6% during favourable climate months, despite slightly higher climate-driven peaks. This indicates that the applied efficiency measures were effective in reducing avoidable energy consumption without compromising operational requirements, particularly during non-extreme weather periods. The results confirm that seasonal peak demand is primarily influenced by cooling loads, while reductions in base-load consumption serve as a more reliable indicator of improved energy efficiency.

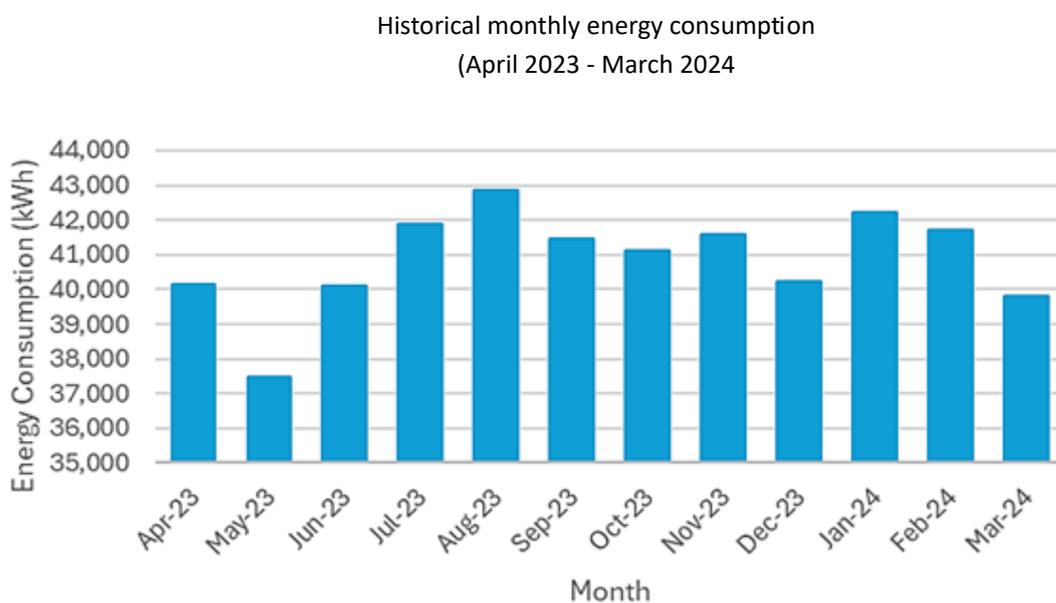


Figure 2. Historical monthly energy consumption (kWh) (April 2023-March 2024)

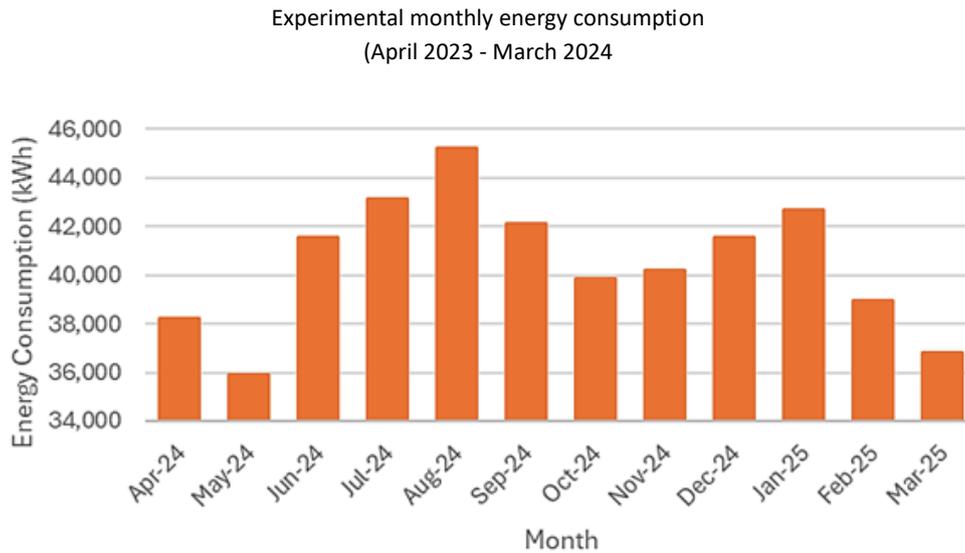


Figure 3. Experimental monthly energy consumption (kWh) (April 2024-March 2025)

Building energy intensity (BEI)

Table 4 summarises the building energy intensity (BEI) performance of a coal-fired power plant’s site office in 2024. BEI is a key performance indicator that represents the annual energy consumption of a building normalised by its gross floor area (expressed in kWh/m²/year). It is widely applied to assess building energy efficiency, benchmark performance against Malaysia standards, and evaluate progress in energy management initiatives.

For industrial administrative facilities such as a power plant’s site office, BEI provides valuable insights into how effectively energy is utilised to support operational activities and occupant comfort. In 2024, the site office recorded an annual energy consumption of 491,638 kWh, corresponding to a BEI value of 172.7 kWh/m²/year. This value exceeds the benchmark recommended by Malaysian Standard MS 1525:2019, which specifies a threshold of 135 kWh/m²/year for non-residential buildings. Consequently, the building is classified as "Below Standard", indicating higher than recommended energy consumption relative to its floor area.

The site office achieved a 2-star energy performance rating, as illustrated in Figure 4, reflecting moderate energy efficiency with

substantial room for improvement. While the BEI value does not place the building in the lowest efficiency category (1-star, BEI > 250 kWh/m²/year), it clearly indicates that the building consumes more energy than is desirable under current Malaysian guidelines. This performance level suggests that existing operational practices and system efficiencies are not optimised.

The relatively high BEI is consistent with the dominant HVAC and lighting loads identified in the load apportioning and visual inspection analysis. Extended operating hours required to support continuous power plant operations contribute to prolonged use of air-conditioning, lighting and office equipment. In addition, the presence of high-density electronic equipment increases internal heat gains, thereby elevating cooling demand. Ageing HVAC systems and suboptimal maintenance practices may further exacerbate energy inefficiencies, leading to elevated overall energy intensity.

In summary, the BEI value of 172.7 kWh/m²/year indicates that the coal-fired power plant site office operates below the energy efficiency level recommended by MS 1525:2019. These findings highlight the need for targeted energy management measures, particularly focusing on HVAC optimisation and lighting rationalisation to

reduce energy intensity. Continuous monitoring and periodic evaluation of BEI can support progressive performance improvement, contributing to cost savings and enhanced sustainability within power generation facilities.

Table 4. Enhanced BEI comparison analysis with MS1525:2019 standard

MS1525:2019 standard	
Period	2024
Annual Consumption (kWh)	491,638
BEI (kWh/m ² /year)	172.7
MS 1525:2019 Benchmark	135
Performance Rating	Below Standard
Star Rating	2 Star

The BEI value of 172.7 kWh/m²/year recorded for the power plant site office in this study in Table 5 is particularly higher than those reported for low-energy and green office buildings in Malaysia, which typically range between 30 and 100 kWh/m²/year. Similar trends are observed in other tropical climate studies, where purpose- designed energy-efficient office buildings commonly achieve BEI values below 100

kWh/m²/year, while conventional office buildings often fall within the range of 120–180 kWh/m²/year due to higher cooling and operational demands. The BEI reported in this study lies at the upper bound of this conventional range, indicating comparatively lower energy performance despite similar climatic conditions. This contrast suggests that differences in building design intent, system efficiency, and operational practices rather than climate alone play a important role in determining energy performance. The findings highlight a performance gap between benchmark low-energy offices and industrial administrative buildings, reinforcing the need for targeted energy-efficiency assessments of non-process buildings within industrial facilities in tropical regions.

Load apportioning

Figure 5 represents the energy load apportioning of the coal-fired power plant site office, illustrating the distribution of electrical energy consumption among the major building systems. This apportioning is essential for identifying dominant energy users, supporting effective energy management, controlling operational costs, and guiding targeted energy conservation initiatives. The analysis confirms that the distribution of energy consumption accounts for 100% of total building electricity use.

Table 5. Comparison of Building Energy Intensity (BEI) values for office buildings in tropical climates

Building Type	Location/Climate	Reportad BEI (kWh/m ² /year)	Source
Green Energy Office (GEO) Building, Pusat Tenaga Malaysia Selangor	Malaysia (tropical)	30	(Sigh et al. 2021)
Low Energy Office (LEO) Building Kementrian Hijau dan Air, Putrajaya Diamond Building	Malaysia (tropical)	100	(Sigh et al. 2021)
Malaysian Energy Commisison Headquarters, Putrajaya	Malaysia (tropical)	85	(Sight et al. 2021)

Table 5. Comparison of Building Energy Intensity (BEI) values for office buildings in tropical climates (continued)

Building Type	Location/Climate	Reported BEI (kWh/m ² /year)	Source
Pusat Pertumbuhan Arkitek Malaysia (PAM Centre). Kuala Lumpur	Malaysia (tropical)	53	(Sight et al. 2021)
Menara Kerja Raya (MKR). Kuala Lumpur	Malaysia (tropical)	91	(Sight et al. 2021)
Power Plant Site Office	Malaysia (tropical)	172.7	This study



Figure 4. Building Energy Intensity (BEI) label and star rating classification system for non-residential buildings in Malaysia (Suruhanjaya Tenaga, 2024)

The heating, Ventilation, and Air Conditioning (HVAC) system represents the largest share of electricity consumption, amounting to 267,505 kWh, which corresponds to 55% of the total energy load. This dominance is typical of administrative office buildings operating in hot and humid

climates, where continuous cooling and ventilation are required to maintain acceptable thermal comfort and indoor air quality. HVAC systems are often the single largest energy consumer due to extended operating hours, continuous mechanical cooling demand and limited zoning or control optimisation.

Lighting systems constitute the second largest energy consumer, accounting 116, 689 kWh or 24% of total electricity consumption. Adequate lighting is essential to support visual comfort and workplace productivity, this load can be significantly optimised. The lighting share observed in this study suggests potential inefficiencies, particularly in areas identified as over-illuminated, which may be addressed through the adoption of energy-efficient LED luminaires, automated lighting controls and improved utilisation of daylight.

General office equipment, including computers, printers and miscellaneous appliances contribute 68,377 kWh, representing 14% of total energy consumption. This category reflects the base electrical demand associated with administrative and operational activities and remains relatively constant during the working hours. Other supporting systems account for the remaining 7%, equivalent to 33,801 kWh and include ancillary loads such as security systems, lifts, or special electrical equipment not classified under the primary categories. Although smaller in proportion, these loads can cumulatively affect overall energy performance and should not be overlooked in energy saving strategies. In summary, the load apportioning analysis clearly identified HVAC and

lighting as priority areas of energy management intervention, collectively contributing nearly 80% of total electrical consumption. This energy profile is consistent with patterns reported in oil and gas administrative and laboratory facilities, where 24- hour operations and stringent safety requirements lead to elevated HVAC and lighting demand. Previous studies have shown that HVAC loads in laboratory and industrial administrative buildings are frequently overestimated, resulting in oversized systems and unnecessary energy consumption (Mathew et al., 2005).

Given that HVAC accounts for more than half of total energy use in this facility, targeted interventions such as the implementation of variable-speed drives, improved thermostat zoning, optimised operating schedules, and enhanced maintenance practices are expected to yield the greatest energy savings. For lighting systems, recommended measures include replacing conventional luminaires with high-efficiency LED fixtures, correcting over-illumination through fixture de-rating or reduction, and installing occupancy and daylight sensors. Collectively, these measures provide practical pathways to reduce energy consumption, lower operational costs, and support sustainability objectives within coal-fired power plant administrative facilities.

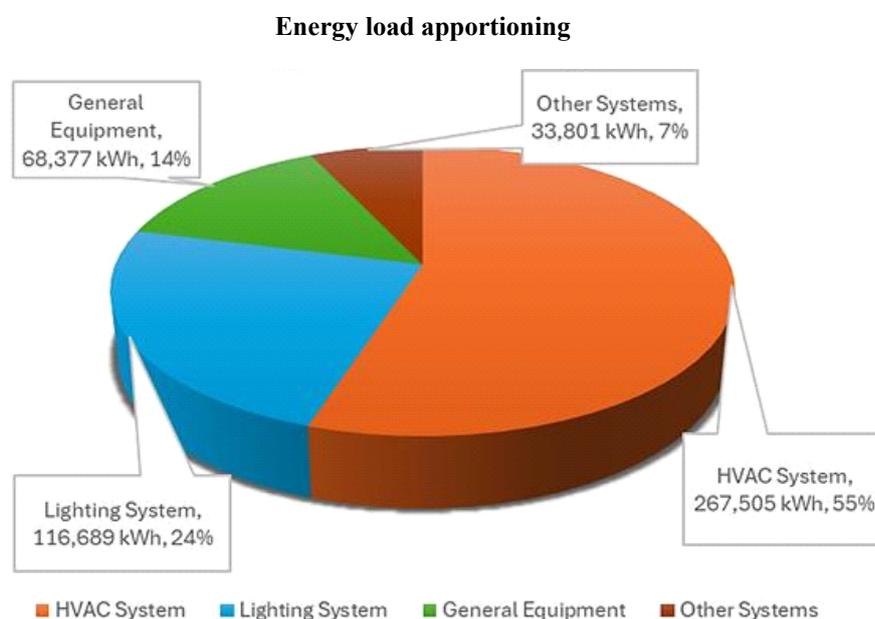


Figure 5. Energy use is heavily concentrated in the HVAC system, which consumes more than half of the total office load , significantly exceeding lighting and equipment demands

Visual inspection

The research carried out on the energy audit of the site office of a coal-fired power plant indicated some results based on visual inspection. It was revealed during the inspection that there were LED lamps and T8 fluorescents installed and utilised in different locations. It is well known that LED lighting is more energy efficient, has a longer life cycle, and heats less than the conventional incandescent or fluorescent lighting systems. This option demonstrates the will to use energy in a sustainable manner, and it is in line with the current energy-conserving trends. The Malaysian Standard, MS1525:2019, gives the recommended illuminance (lux) of different indoor spaces to ensure acceptable visibility, safety, and comfort as well as reduce energy consumption (Department of Standards Malaysia, 2019).

According to the figures in Table 6, the experiment determined the lux in different locations and compared them to the following standards. Table 5 and Figure 6 display an evaluation of the light levels (in lux) in some of the functional areas within a facility against the suggested values given in the MS1525:2019 standard. Such an assessment plays a vital role in determining the over-illuminance and under-illuminance areas, and this assessment has an impact on the energy efficiency, comfort, and safety of the user.

Based on the findings, most of the areas are over-illuminated and are above the recommended maximum lux levels. Ground Floor Office, Meeting Room and Manager Room have an average lux of 485-520 each, compared to the suggestion of 300-400 lux in MS1525:2019. Such excessive lightings are not only causing unnecessary consumption of energy but can also cause occupants to experience visual discomfort or glare. Likewise, the Server Room that needs approximately 100 lux measured 195 lux, as well as illuminance. This implies that there can be a chance of saving on energy by lowering the intensity of lighting, particularly in areas with limited human activities.

The Parking Area, with a measured value of 275 lux against a recommendation of 100 lux, is

significantly over-illuminance. The opportunities available to conserve energy through the utilisation of motion sensors or dimmable lights during periods of low activity consist of outdoor or semi-outdoor spaces such as parking areas.

As compared to this, the Restroom had the lowest mark as under-illuminance because lux was measured at 85, which was below the recommended 150 lux. Poor restroom lighting may reduce the hygiene perception and comfort of the users, and thus, it should be improved.

Correcting over-illumination in five out of six assessed areas presents substantial potential for lighting energy reduction without compromising visual comfort. The use of controls as the retrofitting of the lights with LEDs, dimming systems, or task lights, can not only bring the levels to the same level as the requirements but also save energy and money.

Table 6. Comparison of luminance for a coal fired power plant's site office

Areas	Average lux {measured}	Lux level {MS1525}	Remark
Ground Floor office	520	300-400	Over lit
Meeting room	485	300-400	Over lit
Manager room	485	300-400	Over lit
Server room	195	100	Over lit
Restroom	85	150	Under lit
Parking area	275	100	Over lit

*Remark: Over/under lit mean over/under illuminance

Indoor environmental quality

Table 7 compares the measured environmental parameters to the Malaysian Standard (MS) 1525:2019 and determines their adherence in a particular setting (Department of Standards Malaysia, 2019). These parameters are the temperature, relative humidity, CO₂ content, illuminance, and air speed, all of which are essential to indoor environmental quality, especially when it comes to building energy and comfort conditions.

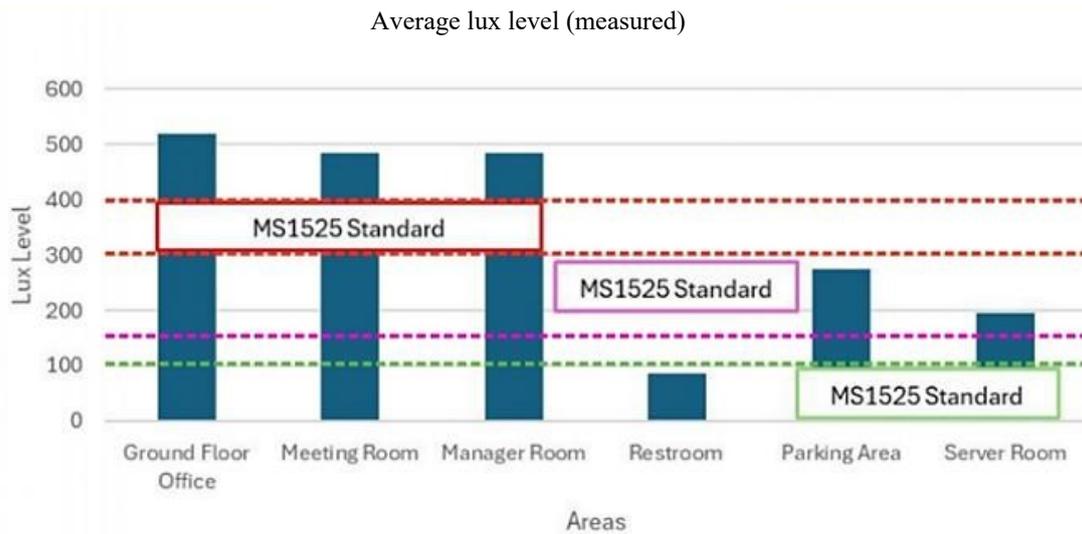


Figure 6. The measured illuminance levels in most areas exceed the MS1525:2019 recommended standards, while the restroom falls below the required levels

The indoor air temperature fluctuated between 22.1°C and 26.4°C with an average of 24.2°C. According to the MS 1525:2019 standard, the recommended temperature range is 24°C to 26°C. Although the measured average falls near this range, the wider measured variation observed indicates only partial compliance with the standard. Such fluctuations suggest inconsistent HVAC control, which may affect both occupant thermal comfort and energy efficiency performance. Maintaining indoor temperatures consistently within the designated range is essential to ensure stable comfort conditions while avoiding unnecessary cooling energy consumption. In addition, the Industry Code of Practice (ICOP) 2010, issued by the Department of Occupational Safety and Health (DOSH) Malaysia, specifies an acceptable air temperature range of 23°C to 26°C for workplace environments (DOSH, 2010); (Buyamin, Syahrudin, et al). This slightly broader range accommodates variations in building usage and occupant preferences while maintaining safe and comfortable conditions. Nevertheless, sustained operation outside the optimal control band may indicate opportunities for improved HVAC regulation and demand-responsive control strategies.

Relative humidity readings ranged from 55% to 72%, averaging 63.5%. The standard specifies a range of 50% to 70%, to which the measurements

generally comply, affirming suitable moisture control. Similarly, the ICOP 2010 guidelines by DOSH Malaysia specify an acceptable RH range of 40% to 70% DOSH 2010; Razali et al.,. Maintaining appropriate humidity levels is important for occupant comfort and preventing issues like mould growth. However, the MS1525:2019 and ICOP guidelines allow up to 70%, which is likely considered specific local climate and building conditions.

Carbon dioxide (CO₂) concentrations measured within the site office varied between 420 ppm and 1,250 ppm, with an average of 785 ppm. According to the MS standard, the recommended upper limit for acceptable indoor air quality is 1,000 ppm. While the measured average CO₂ concentration remains within this limit, the recorded maximum exceeds the standard, indicating intermittent periods of inadequate ventilation or elevated occupancy levels. Such exceedances suggest that ventilation performance may not consistently respond to variations in occupancy or usage patterns. To ensure that CO₂ concentrations are maintained within acceptable limits, efficient and demand-responsive ventilation mechanisms are required. Improving ventilation control strategies would enhance indoor air quality, occupant comfort, and overall operational efficiency. The illumination measured between 185 lux, 625 lux with an average of 445 lux (but the normal range is

Table 7. Indoor environmental quality measurements

Parameter	Measured range	Avarage	MS 1525:2019 Standart	Compliance
Temperature (°C)	22.1 - 26.4	24.2	24-26	Partial
Relative Humidity	55 – 72	63.5	50-70	Yes
CO ₂ Level (ppm)	420 – 1,250	785	<1,000	Yes
Illuminance (lux)	185 - 625	445	300-500	Partial
Air Velocity (m/s)	0.05 0.25	0.12	0.15-0.50	Yes

Table 8. Low-cost energy conservation measures

Measure	Description	Investment (RM)	Annual Savings (kWh)	Annual Cost Savings (RM)	Payback Period (Years)
ECM-1	Implement energy awareness program	2,500	24,319	11,555	0.23
ECM-2	Install programmable timers for lighting	5,200	17,502	7,876	0.66
ECM-3	Optimize HVAC temperature settings	1,000	26,756	12,040	0.08
ECM-4	Enable power management on computers	800	9,275	4,174	0.19
ECM-5	Regular maintenance of AC filters	3,600	13,391	6,026	06
Total		13,100	91,243	41,064	0.32

300-500 lux). This demonstrates a partial adherence because not all measurements will be within the minimum or maximum. Adequate lighting will also contribute to the ease of the eye and to the economy of energy, should the lighting be well planned.

The velocity of air was between 0.05 and 0.25 m/s with an average value of 0.12 m/s, which is similar to the normal range of 0.15 to 0.50 m/s. This parameter is well in line, which means that there is proper air flow, and drafts are not present in the house, and there is enough air circulation to keep the thermal comfort level.

Conclusively, the indoor environmental quality assessment indicates that the site office generally demonstrates good correspondence with the requirements of MS 1525:2019 standards. Full compliance was observed for relative humidity, CO₂ concentration, and air velocity, although intermittent exceedances in CO₂ levels were recorded. Partial compliance was identified for

indoor temperature and illuminance, primarily due to observed fluctuations beyond the recommended control ranges. These findings highlight specific areas for improvement, particularly the fine-tuning of HVAC temperature control strategies to minimise variation and the optimisation of lighting design and usage to remain within the preferred lux levels. Addressing these aspects would enhance occupant comfort while improving energy efficiency in building operations. Furthermore, this assessment provides a critical foundation for continued energy consumption modelling and environmental optimisation of site office or similar non-process facilities.

Energy conservation measures

Based on the comprehensive energy audit findings, a series of Energy Conservation Measures (ECMs) have been identified and categorised into low-cost, medium-cost, and high-cost interventions.

Low-cost measures

Table 8 summarises five proposed Energy Conservation Measures (ECMs) along with their investment costs, annual energy and cost savings, and payback periods. All ECMs demonstrate positive economic performance, where a shorter payback period indicates better financial viability.

ECM-1 (Energy awareness program) requires a low investment of RM 2,500 and achieves annual savings of 24,319 kWh (RM 11,555), resulting in a short payback period of 0.23 years. ECM-2 (Programmable lighting timers) involves an investment of RM 5,200 and delivers annual savings of 17,502 kWh (RM 7,876) with a payback of 0.66 years. ECM-3 (Optimising HVAC temperature settings) requires only RM 1,000 yet provides the highest annual energy savings of 26,756 kWh (RM 12,040), yielding the shortest payback period of 0.08 years, making it the most cost-effective measure. ECM-4 (Power management on computers) also shows strong performance, with an RM 800 investment, 9,275 kWh annual savings, and a payback of 0.19 years. ECM-5 (Regular AC filter maintenance) requires RM 3,600 and achieves 13,391 kWh savings annually, with a payback period of 0.60 years.

Overall, all ECMs are financially viable with rapid payback periods. When implemented together, the total investment of RM 13,100 results in annual savings of 91,243 kWh and RM 41,064, corresponding to an overall payback period of 0.32 years, highlighting the strong economic justification for implementation.

Medium-cost measures

Table 9 presents five additional Energy Conservation Measures (ECMs), ECM-6 to ECM-10, detailing their investment costs, annual energy and cost savings, and payback. All measures show positive economic outcomes, where shorter payback periods indicate better financial performance.

ECM-6 (Occupancy sensors for lighting) requires an investment of RM 18,500 and achieves annual savings of 23,338 kWh (RM 10,502), with a payback period of 1.76 years. ECM-7 (LED lighting upgrade – Phase 1) involves a higher investment of RM 45,000 but delivers the highest energy savings at 52,411 kWh annually (RM 23,585), resulting in a payback period of 1.91 years, indicating strong long-term financial viability. ECM-8 (Smart thermostats) requires RM 15,600 and provides 32,147 kWh of annual savings (RM 14,466), yielding the shortest payback period in this group at 1.08 years. ECM-

9 (Window film installation) shows a longer payback period of 3.29 years with annual savings of 18,904 kWh (RM 8,507), reflecting a more long-term investment. ECM-10 (Variable speed drives for ventilation) has the longest payback period at 4.53 years, despite achieving 15,678 kWh in annual savings (RM 7,055).

Overall, the combined implementation of these five ECMs requires a total investment of RM 139,100 and is projected to yield annual savings of 142,478 kWh and RM 64,115, resulting in an overall payback period of 2.17 years. Among these

Table 9. Medium-cost energy conservation measures

Measure	Description	Investment (RM)	Annual Cost Savings(kWh)	Annual cost Savings (RM)	Payback Periods (Years)
ECM-6	Install occupancy sensors for lighting	18,500	23,338	10,502	1,76
ECM-7	Upgrade to LED lighting (Phase1)	45,000	52,411	23,585	1,91
ECM-8	Install smart thermostats	15,600	32,147	14,466	1,08
ECM-9	Window film installation	28,000	18,904	8,507	3,29
ECM-10	Variable speed drives for ventilation	32,000	15,678	7,055	4,53
Total		139,100	142,478	64,115	2,17

Table 10. High-cost energy conservation measures

Measure	Description	Investment (RM)	Annual Savings(kWh)	Annual Cost Savings(RM)	Payback period (Years)
ECM-11	Completed LED Lighting retrofit	85,000	78,547	35,346	2.4
ECM-12	Hogh-efficiency HVAC replacement	280,000	107,002	48,151	5.82
ECM-13	Building automation system	280,000	58,364	26,264	5.71
ECM-14	Solar PV system	250,000	175,200	78,840	4.44
ECM-15	Building envelope improvements	120,000	38,786	17,454	6.87
Total		985,000	457,899	206,055	4.78

measures, the LED lighting upgrade and smart thermostats stand out as particularly impactful, supporting their financial attractiveness for long-term operational cost reduction.

High-cost measures

Table 10 presents a third set of Energy Conservation Measures (ECMs), ECM-11 to ECM-15, which focus on higher-investment and large-scale interventions. The table outlines investment costs, projected annual energy and cost savings, and payback periods. All measures show positive economic results, with shorter payback periods indicating better financial performance.

ECM-11 (Complete LED lighting retrofit) requires an investment of RM 85,000 and achieves annual savings of 78,547 kWh (RM 35,346), resulting in a payback period of 2.4 years, demonstrating a relatively fast return for a high-capital project. ECM-12 (High-efficiency HVAC replacement) involves a major investment of RM 280,000 and delivers the highest savings in this group at 107,002 kWh annually (RM 48,151), though with a longer payback period of 5.82 years. ECM-13 (Building automation system) has a similar investment level and provides 58,364 kWh in annual savings (RM 26,264), yielding a comparable payback period of 5.71 years. ECM-14 (Solar PV system, 100 kWp) represents the largest investment at RM 350,000 but offers the highest energy savings across all ECMs at 175,200 kWh annually (RM 78,840), resulting in a competitive payback period of 4.44 years. ECM-

15 (Building envelope improvements) shows the longest payback period at 6.87 years, despite contributing to energy savings and potential non-energy benefits such as improved comfort.

Overall, implementing all five measures requires a total investment of RM 985,000 and is projected to yield annual savings of 457,899 kWh and RM 206,055, corresponding to an overall payback period of 4.78 years. Although these ECMs require higher capital expenditure, they offer substantial long-term energy and cost savings, with the Solar PV system standing out as the most impactful measure in this group.

CONCLUSION

This study presented a comprehensive non-process energy audit of a site office supporting a coal-fired power generation facility linked to oil and gas operations in Malaysia, addressing a notable gap in industrial energy management research that has traditionally prioritised core process systems. By integrating two years of electricity consumption data, Building Energy Intensity (BEI) benchmarking, end-use load apportioning, indoor environmental quality (IEQ) assessment, and a structured evaluation of Energy Conservation Measures (ECMs), the study provides a holistic assessment of energy performance in an industrial administrative building operating under tropical climatic conditions.

Collectively, the findings indicate that while the site office demonstrates stable operational energy behaviour and partial compliance with MS 1525

standards, inefficiencies persist in HVAC operation, lighting design, and environmental control consistency. Addressing these areas holistically would reduce BEI, flatten peak demand, and improve occupant comfort. Seasonal analysis confirmed that electricity consumption is strongly influenced by climate-driven cooling demand, with higher peaks occurring during hotter months. However, reductions in base-load consumption during milder periods reveal opportunities for improved operational efficiency and highlight the importance of distinguishing climate effects from controllable energy use when interpreting performance in industrial office environments. The calculated BEI of 172.7 kWh/m²/year exceeds the MS 1525 benchmark of 135 kWh/m²/year, confirming that the building operates below the recommended energy efficiency standard. Load apportioning analysis identified HVAC systems and lighting as the dominant contributors, accounting for 55% and 24% of total electricity consumption, respectively. Visual inspection further revealed widespread over-illumination in most functional areas, while IEQ assessment identified temperature fluctuations and intermittent CO₂ exceedances, suggesting inconsistencies in environmental control that affect both energy efficiency and occupant comfort.

These results demonstrate that energy inefficiencies in the site office are not isolated to a single system but arise from the combined effects of HVAC operation, lighting design, and control strategies. Addressing these areas holistically through improved HVAC optimisation, lighting rationalisation, and enhanced environmental control has the potential to reduce BEI, flatten peak demand, and improve indoor comfort conditions. The proposed ECMs, particularly low- and medium-cost measures, show strong economic feasibility and provide a practical pathway for immediate and long-term energy performance improvement.

Overall, this study reinforces the importance of incorporating ancillary and administrative buildings into industrial energy management strategies. By providing empirical benchmark data and a replicable audit framework aligned with MS 1525:2019, NEEAP, and EECA 2024, the findings

support a more integrated approach to non-process energy management and contribute to Malaysia's broader sustainability and decarbonisation objectives.

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GLOSSARY OF TERMS AND SYMBOLS

Terms & Symbols	Definition	Unit
MS15225:2019	Code of Practice on Energy Efficiency and Use of Renewable Energy for non-Residential Buildings	
Indoor Environmental Quality (IEQ)	Refers to the conditions inside a building that affect occupants' health, comfort, and well-being	
Building Energy Intensity (BEI)	Measures a building's annual energy consumption Relative to its size, typically in kilowatt-hours per square meter per year (kWh/m ² /year)	
National Energy Efficiency Action Plan (NEEAP)	A strategic government policy outlining targets, measure and actions to improve energy efficiency, reduce consumption, and lower greenhouse gas (GHG) emissions	

Energy Efficiency and Conservation Act 2024 (EECA 2024) Malaysia's landmark legislation effective January 1, 2025, that mandates energy efficiency standard, promotes conservation, and support national goals like carbon neutrality by 2050

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