# DESIGN AND ANALYSIS OF SUSTAINABLE CLEAN ENERGY INTEGRATION IN A MALAYSIAN HIGHER EDUCATIONAL INSTITUTION

MUHAMMAD FIRDAUS BIN MOHD ZUBLIE

INSTITUTE FOR ADVANCED STUDIES
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**MUHAMMAD FIRDAUS BIN MOHD ZUBLIE**

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Name of Candidate: **MUHAMMAD FIRDAUS BIN MOHD ZUBLIE**

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# [DESIGN AND ANALYSIS OF SUSTAINABLE CLEAN ENERGY INTEGRATION IN A MALAYSIAN HIGHER EDUCATIONAL INSTITUTION]


## ABSTRACT

The energy sector accounts for 80% of Malaysia's greenhouse gas emissions. The education sector is one of the contributors to greenhouse gas emissions. Therefore, the education sector strongly supports the government's aspirations to reduce carbon emissions. This research investigates the energy-saving potential involving five end-load in educational institutions. Typically, energy audits are conducted on end-load equipment such as fans, lights, air conditioning, and ICT equipment. However, laboratory equipment is primarily not audited. This research added laboratory equipment as one of the five end-loads to be audited. Methodology for collecting energy consumption per equipment in a residential building using a survey questionnaire. The energy audit method collects energy consumption data of academic and non-academic buildings. The saving potential is obtained through energy efficiency and feasibility analysis of the rooftop solar photovoltaics (PV) using the net energy metering (NEM) scheme. Research confirms that laboratory equipment, lighting, and air conditioning are the highest consumers of energy consumption in educational institutions. The feasibility analysis focused on energy, cost-benefit and environmental impact analysis for Politeknik Sultan Azlan Shah (PSAS). The findings of this study, through a feasibility analysis on a covered parking lot installed with solar PV. An analysis of the feasibility of energy generation at the proposed site using NEM found that the cumulative net savings estimate for PSAS over 20 years is RM 3,534,250. The percentage of energy supplied by solar, which is 21.5%, leads to a reduction in emissions of 669,078 kg of $CO_2$, equivalent to 16,727 mature trees saved from being cut down. This research supports the practice of green technology in educational institutions, especially in Polytechnic Malaysia.

**Keywords**: Energy audit, Energy efficiency, Feasibility analysis, Solar photovoltaic, Energy-saving, Carbon emission.

**[REKABENTUK DAN ANALISIS INTEGRASI TENAGA BERSIH YANG MAPAN DALAM INSTITUSI PENGAJIAN TINGGI MALAYSIA]**

## ABSTRAK

Sektor tenaga menyumbang 80% daripada pelepasan gas rumah hijau Malaysia. Sektor pendidikan merupakan salah satu penyumbang kepada pelepasan gas rumah hijau. Oleh itu, sektor pendidikan sangat menyokong hasrat kerajaan untuk mengurangkan pelepasan karbon. Penyelidikan ini menyiasat potensi penjimatan tenaga yang melibatkan lima beban akhir di institusi pendidikan. Lazimnya, audit tenaga dijalankan ke atas peralatan beban akhir seperti kipas, lampu, penghawa dingin dan peralatan ICT. Walau bagaimanapun, peralatan makmal terutamanya tidak diaudit. Penyelidikan ini menambah peralatan makmal sebagai salah satu daripada lima beban akhir yang akan diaudit. Metodologi untuk mengumpul penggunaan tenaga setiap peralatan di bangunan kediaman menggunakan soal selidik tinjauan. Kaedah audit tenaga mengumpul data penggunaan tenaga bangunan akademik dan bukan akademik. Metodologi untuk mengumpul penggunaan tenaga setiap peralatan di bangunan kediaman menggunakan soal selidik tinjauan. Manakala pengumpulan data penggunaan tenaga bangunan akademik dan bukan akademik melalui kaedah audit tenaga. Potensi penjimatan diperoleh melalui analisis kecekapan tenaga dan kebolehlaksanaan fotovoltaik suria (PV) atas bumbung menggunakan skim pemeteran tenaga bersih (NEM). Penyelidikan mengesahkan bahawa peralatan makmal, pencahayaan, dan penyaman udara adalah pengguna tertinggi penggunaan tenaga di institusi pendidikan. Analisis kebolehlaksanaan tertumpu pada analisis tenaga, kos-faedah dan kesan alam sekitar untuk Politeknik Sultan Azlan Shah (PSAS). Dapatan kajian ini, melalui analisis kebolehlaksanaan ke atas tempat letak kereta berbumbung yang dipasang dengan PV solar. Analisis kebolehlaksanaan penjanaan tenaga di tapak cadangan yang menggunakan NEM mendapati anggaran penjimatan bersih terkumpul untuk PSAS sepanjang 20 tahun ialah RM 3,534,250. Peratusan tenaga yang dibekalkan oleh solar, iaitu 21.5%, membawa kepada pengurangan pelepasan sebanyak 669,078 kg $CO_2$, bersamaan dengan 16,727 pokok matang yang diselamatkan daripada ditebang. Penyelidikan ini menyokong pengamalan teknologi hijau di institusi pendidikan khususnya di Politeknik Malaysia.

**Kata kunci**: Audit tenaga, Kecekapan tenaga, Analisis kebolehlaksanaan, Fotovoltaik solar, Penjimatan tenaga, Pelepasan karbon.

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## LIST OF SYMBOLS AND ABBREVIATIONS

**Symbols:**

| | | |
|---|---|---|
| ABS | : | Annual bill savings (RM) |
| AEC | : | Annual energy consumption (kWh) |
| C | : | Energy cost (RM/kWh) |
| CO | : | Carbon monoxide (kg) |
| $CO_2$ | : | Carbon dioxide (kg) |
| $Em_p^n$ | : | Emission factor per unit of energy generation of fuel type n (kg/kWh) |
| $EMy$ | : | Total amount of carbon emission (ton) |
| $EPy$ | : | Electricity production in the year y (kWh) |
| GFA | : | Gross Floor Area ($m^2$) |
| $GtCO_2$ | : | Giga tonnes of carbon dioxide (ton) |
| $H_a$ | : | Annual estimated operating hours (h) |
| $Havg$ | : | Average annual hour operation (h) |
| $H_d$ | : | Operating hours of the equipment per day (h) |
| $IC$ | : | Incremental cost (RM) |
| $L_f$ | : | Load factor |
| $O_f$ | : | Number of the day in 1 year that equipment in an operational state (d) |
| $O_n$ | : | Number of the day in 1 year that equipment in a non-operational state (d) |
| PBP | : | Simple payback period (y) |
| $PEy^n$ | : | Electricity generation percentage in the year y (%) |
| $P_r$ | : | Rated power of electrical equipment (kW) |
| $R_p$ | : | Percentage replacement of electrical equipment (%) |
| $tCO_2eq$ | : | Tonnes carbon dioxide equivalent |

**Abbreviations:**

| | | |
|---|---|---|
| ACE | : | ASEAN Centre for energy |
| ACSU | : | Air cooled split unit |
| AES | : | Annual energy saving |
| C | : | Canteen |
| Capex | : | Zero capital expenditure |
| CD | : | Commerce Department |
| CED | : | Civil Engineering Department |
| $CO_2$ | : | Carbon dioxide |
| COP | : | Conference of the Parties |
| COVID19 | : | Coronavirus disease 2019 |
| CT | : | Cooling tower |
| DPM | : | Fixed digital power meter |
| DSM | : | Demand side management |
| ECM | : | Energy conservation measures |
| EED | : | Electrical Engineering Department |
| EER | : | Energy efficiency ratio |
| EMS | : | Energy monitoring system |
| EMEER | : | Efficient Management of Electrical Energy Regulations |
| ESM | : | Energy saving measures |
| GBI | : | Green Building Index |
| GDP | : | Gross Domestic Product |
| GFA | : | Gross Floor Area |
| GHG | : | Greenhouse Gases |
| GoMEn | : | Government Ministries and Entities |

| | | |
|---|---|---|
| IC | : | Islamic Centre |
| JPPKK | : | Department of polytechnic Studies and College Community |
| MH | : | Multipurpose Hall |
| MoHE | : | Ministry of Higher Education |
| PSAS | : | Politeknik Sultan Azlan Shah |
| RNC | : | Residential New Construction |
| SARE | : | Supply Agreement with Renewable Energy |
| SC | : | Sports Centre |
| SDCs | : | Standards Development Committee |
| SESB | : | Sabah Electricity Sdn Bhd |
| SEB | : | Sarawak Energy Berhad |
| $SO_2$ | : | Sulfur dioxide |
| SSB | : | Sub-switch board |
| SUKIPT | : | Higher Education Institution Sports |
| TCEU | : | Training & Continuous Education Unit |
| TNB | : | Tenaga Nasional Berhad |
| TVET | : | Technical Vocational Education and Training |
| USD | : | United States Dollar |
| WCPU | : | Water Cooled Package Unit |

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# CHAPTER 1: INTRODUCTION

In 2018, the worldwide energy consumption record increased by 2.3%. Global economic factors have influenced the doubling average growth rate increase since 2010. In addition, the increase in total energy consumption is also due to higher demand for heating and cooling elements in some parts of the world. Higher energy consumption resulted in energy-related $CO_2$ emissions rising to 33.1 $GtCO_2$, with an increase of 1.7% (IEA, 2019). Much of the annual energy consumption in modern societies comes from buildings (Yang et al., 2014). The potential savings through implementing energy efficiency strategies in the building sector would significantly reduce energy consumption (de Oliveira et al.,2017). Due to the high energy consumption in public buildings, effective energy-saving management management measures must be implemented to reduce energy consumption and save resources (Zhu & Li, 2015). The Ministry of Energy, Green Technology and Water Malaysia has introduced the National Green Technology Policy. Among the main objectives of this policy is to increase the country's economic development level and, at the same time, reduce the level of increased energy consumption. The main thrust of this established energy policy aims to achieve energy independence and promote efficient energy use (Tsalikis & Martinopoulos, 2015).

As one of the leading institutions under the Technical Vocational Education and Training (TVET) system, polytechnics are educational institutions directly involved in implementing green practices on campus. Therefore, the education sector is directly involved in helping the government make this green technology policy a success. Malaysian Polytechnic comprises 36 polytechnics that offer various programs of study covering engineering, commerce, technology, agro-technology and bio-industry, tourism and hospitality, design, and visual communication (Hasan et al.,2017). Among Malaysian Polytechnic, research about educational buildings was implemented using a single case study design focusing on Politeknik Sultan Azlan Shah (PSAS) only. PSAS has been selected to represent Conventional Malaysian Polytechnic due to obtaining accreditation from Asia Pacific Accreditation and Certification Commission (APACC) in 2017 with a Gold achievement (APACC, 2017). This research will refer to the Malaysian Polytechnic POLYGreen Blueprint 2015 and SmartGreen Polytechnic Community College 2021-2026, which stated an implementation plan and strategic direction for green technology practice in polytechnics. Green TVET is implemented through the green campus framework, community, culture, and research. The research analyses the energy use of whole buildings in PSAS and covers staff residential, academic, and non-academic buildings. Efforts to optimize energy use simultaneously lead to energy savings closely related to analyzing the energy use of each piece of equipment found in the PSAS building. The findings of the analysis provide clarity on which equipment should be targeted to achieve energy-saving objectives. Besides that, the estimation of the annual energy and bill savings, payback period, and carbon emissions reduction by implementing highlighted strategies is calculated. If installed at PSAS, this research implements a feasibility analysis method for sustainable clean power generation. The final aim of this research is to estimate the cost-benefit and the impact on the environment when clean power energy is applied in PSAS.



## 1.1 Background of Research

Malaysian Polytechnic POLYGreen Blueprint 2015 has outlined a clear strategic direction, including the implementation strategy of green technology practices in all polytechnic campuses in Malaysia. Politeknik Sultan Azlan Shah (PSAS) is one of the Malaysian Polytechnics, and the PSAS campus is located in Behrang under the administration of Muallim district, Perak. The terrain of PSAS is a hilly landscape equipped with 47 buildings covering academic and non-academic buildings. PSAS is surrounded by 100 acres, with a Gross Floor Area (GFA) of 97,975m$^2$. PSAS receives incoming power from the 11kV national grid and steps it down to 415V through five PSAS Main Switch Boards (MSBs). PSAS campus installed 55 Fixed Digital Power Meter (DPM) units to measure each load's energy consumption. However, there is a need for improvement by identifying specific equipment that uses high energy. Usually, a systematic inspection called an energy audit is implemented through an audit of cooling towers, Air Cooled Split Units (ACSU), lighting systems, and IT equipment in the server room without considering laboratory equipment such as a motor or heavy machine. Identifying the energy consumption per equipment in a building or block in PSAS will give more valuable information in context to optimize energy consumption. Through a systematic evaluation method, the focus is more on the equipment which has been identified. The analysis findings will also be used to evaluate the potential and suitable types of clean or renewable energy installed in the PSAS building. Studying the feasibility of on-site will help predict the amount of energy consumption and potential energy savings that can be obtained in the future.

## 1.2 Problem Statement

Currently, energy consumption data recorded using digital power meters can only provide information about the total energy consumption in a building. Still, which equipment significantly contributes to high energy consumption cannot be identified. Also, the measured data through energy audit only involves energy consumption in kWh/month at cooling towers, Air Cooled Split Units (ACSU), lighting systems, and server room (IT equipment) without analyzing the laboratory equipment (motor or heavy machine, etc.) data in the educational building. Analyzing energy consumption per equipment in the PSAS building help in formulating effective strategies to optimize energy consumption while creating energy savings. In addition, sufficient information related to the feasibility analysis of sustainable clean power generation is provided for PSAS.

## 1.3 Research Objective

This research investigates the sustainable clean power generation for Polliteknik Sultan Azlan Shah (PSAS). The objectives of the present study have been set as below:

1. To identify and analyze the energy-consuming equipment in PSAS.

   The first objective of this research was to identify and analyze the types of equipment that use high electrical energy need to be identified.

2. To propose energy usage optimization measures and energy savings in PSAS.

   The second objective of this research is to propose an effective strategy that can be implemented in PSAS to optimize energy consumption while saving energy. Analyzing energy consumption per equipment helps identify the equipment need focused on optimizing energy usage and savings. The research needs to investigate energy consumption in three categories of buildings.

3. To investigate the feasibility of on-site energy generation based on the energy source available in PSAS.

   The third objective of this research is to evaluate the renewable energy sources that may be used at PSAS. A feasibility analysis of on-site energy generation using solar photovoltaic for PSAS referred to the NEM 3.0 mechanism called as NEM GoMEn.

4. To estimate the cost-benefit and environmental impact of renewable energy for PSAS.

   The last objective is to estimate renewable energy's cost-benefit and environmental impact based on the final analysis of the whole energy consumption at PSAS.

## 1.4 Scope of Research

This study will investigate only one polytechnic at Behrang Perak, Malaysia, Politeknik Sultan Azlan Shah (PSAS). The scope of the study involves only PSAS but will analyze in-depth the 47, which consists of academic, non-academic, and residential buildings (staff quarters).

### 1.4.1 Limitation

This study measured individual equipment and accurately measured overall total energy consumption through the TNB meter (utility bill). The measured data will be obtained from 55 Fixed Digital Power Meter (DPM) units installed at load known Sub-Switch Board (SSB). This energy meter is explicitly measured to a group of the load.

## 1.5 Methodology

This research investigates energy consumption in three segmented buildings. The academic and non-academic buildings will use the energy audit method to collect the data. The residential building will use a survey questionnaire form and semi-structured interviews to gather the data. The proposed methodologies refer to the Malaysian Standard MS 1525:2007, Code of Practice on Energy Efficiency and Use Renewable Energy for Non-Residential Buildings. The analysis of energy consumption per equipment helps determine the appropriate type of equipment to be replaced to achieve the objective of energy saving through energy efficiency. The renewable energy system will be proposed to install at specific rooftop buildings or other places in PSAS using an on-grid energy system known as net energy metering (NEM). The feasibility analysis will focus on energy analysis, cost-benefit, and environmental impact of the total energy of PSAS.

## 1.6 Significance of Research

This research will support the strategic direction in empowering green technology practices in all polytechnics in Malaysia, as stated in the document Malaysian Polytechnic POLYGreen Blueprint 2015 and SmartGreen Polytechnic Community College (PolyCC) Blueprint 2021-2026. Analyzing the energy consumption per equipment in a building through a systematic evaluation method will help propose a Template for Energy Consumption Estimation (Appendix B). The template will help top management or energy manager in other educational institutions to start their energy-saving program. The new direction of an energy audit for the educational building involved all equipment, including laboratory equipment. Provide evidence that laboratory equipment strongly correlates with high energy consumption in technical academic buildings. These equivocal findings may open up a new avenue for further study by future research.

## 1.7 Research Question

1. What are the types of equipment that consume high electricity in PSAS?
2. What effective strategy can be implemented in PSAS where it can optimize energy consumption while saving energy?
3. Does PSAS have the flexibility to install on-grid power generation from renewable energy sources that may be used in PSAS?

4. What are the cost-benefit and environmental impacts of renewable energy installed in PSAS?

## 1.8 Thesis Outline

Design and analysis of sustainable clean energy integration in Politeknik Sultan Azlan Shah have been carried out in the present research by focusing on energy saving through energy efficiency and feasibility analysis using rooftop solar photovoltaic connected net energy metering (NEM). This report comprises five chapters.

**Chapter 2** contains a comprehensive literature review of the previous research work. This chapter focuses on the literature review on energy and buildings in Malaysia and the guidelines that become research references to ensure that the research direction is correct. In addition, the literature review on Malaysia Standard (MS) is also discussed. Identify and analyze energy-consuming equipment, measures to optimize energy use and savings, the feasibility of on-site energy generation based on energy sources found in PSAS, and the cost-benefits and environmental impact of renewable energy were also discussed in detail. This chapter also compares previous literature reviews and displays a flow chart of the research process called the research framework.

**Chapter 3** contains the research methodology for collecting data using a survey questionnaire, semi-structured interview, and detailed energy audit technique. This chapter also discusses mathematical formulation to estimate energy and bill saving, measurement and verification analysis, recommended energy saving measures, and renewable energy using rooftop solar photovoltaics are presented in this chapter.

**Chapter 4** contains results and analyzes energy audit data for residential, academic, and non-academic buildings. This chapter also discusses the analysis of mixed energy audit data by zone and involves all zones, including presenting PSAS historical energy analysis. A feasibility analysis focusing on rooftop solar photovoltaics based on a case study involving two options centered on the NEM 3.0 scheme is also discussed in detail. Besides that, the cost-benefit and environmental impact of carbon emissions is also discussed.

**Chapter 5** contains a conclusion based on each research objective stated in the research. All the research objectives are achieved. This chapter also highlights the recommendation for future work for this research.

In addition to the above chapters, the survey questionnaire energy consumption in staff quarters PSAS and template of an energy audit at the educational institution have been given as Appendices A and B.

# CHAPTER 2: LITERATURE REVIEW

## 2.1 Introduction

In 2030, Malaysia aims to achieve a reduction in the intensity of greenhouse gas emissions (GHG) compared to the Gross Domestic Product (GDP) of up to 45% based on the reference value in 2005 (ST, 2015). Measures to reduce the country's carbon emissions are related to the implementation of three methods in the energy-related sector. This method is related to energy conservation measures, efforts to maintain and improve energy efficiency and further promote the application of renewable energy (JPPKK, 2015). Investigating energy consumption is significant for achieving the target of reducing carbon emissions. Monitoring energy consumption and energy efficiency developments is necessary to check and apply desired policies (Lam et al., 2016). Typically, the amount of carbon emissions has a significant relationship with the amount of energy consumption. The electricity consumption in Malaysia involves five main sectors known as industry (47.0%), commercial (30.8%), residential (21.6%), agriculture (0.4%), and transport (0.2%) (DOSM, 2019). The commercial and residential sectors focus on research because both of these sectors are directly related to educational institutions. The residential sector contributes to $CO_2$ emissions through the use of electricity through the operation of home appliances. Monitoring household energy consumption helps reduce GHG efforts through effective energy-saving strategies. Sources of power generating involving renewable energy positively impact GHG reduction. The Malaysian government enforced the Renewable Energy Act in 2011, intending to increase the amount of green energy contribution to mixed electricity generation. Implementing a program based on the Renewable Energy Act reduced energy consumption by 306.9 Gigawatt hours (GWh). It has resulted in GHG avoidance of

208,705 $tCO_2eq$ (Libunao & Peter, 2013). The Malaysian government has initiated a renewable energy (RE) policy to encourage more individuals and industries to use renewable energy-powered systems in their on-site power system applications. RE policies try to persuade societies and individuals to adopt RE as an alternative energy source (Mekhilef et al., 2014). In the latest World Energy Outlook, the International Energy Agency stated that almost half of the world's new installed capacity in 2014 was contributed by renewables (ST, 2014a). Increasing reliance on specific RE sources such as wind, solar and geothermal heat can help solve the increased use of non-renewable resources (Alzoubi & Dwairi, 2015) such as oil, coal, and natural gas. Malaysia is on the right track by setting targets for increasing the number of renewable energy resources used as a source of power generation. Starting in October 2013, 119.47 MW of renewable energy power generation capacity is already in operation (Growth, 2014). Through initial research conducted, it has helped to establish the direction of research in which focus is placed on reducing energy consumption and implementing the use of renewable energy resources in clean power generation.

## 2.2 Energy and Building in Malaysia

In 1992, Malaysia signed a declaration convention on climate change, also known as the Conference of the Parties (COP), during a meeting in Rio de Janeiro, Brazil (Balibar, 2017). Through COP21 in Paris in 2015 (ST, 2016a), Malaysia has expressed a commitment to reduce the intensity of greenhouse gas emissions for the Gross Domestic Product (GDP) by 45% in 2030 compared to 2005. Reducing greenhouse gas emissions can be achieved by implementing energy conservation measures, improving energy efficiency, and using renewable energy sources. Further studies related to efforts to increase energy efficiency and the application of renewable energy can provide valuable additional information to the Malaysian government to save money through energy conservation. An increase in energy consumption means the total fuel also burned increases. Indirectly burn the government money because fuel subsidiary by the government is directly related to total energy consumption.

### 2.2.1 Energy in Malaysia

In Malaysia, the energy sector's transition starts with depending on oil and then implements a generation mix of oil, gas, coal, and hydro. Now, the generation mix is shared with renewable energy as a source of electricity generation. The total installed capacity for the electricity generation mix in 2016 was 33,023 MW, increasing 8.5% from 2015 (ST, 2016a). The Malaysia Government set the target for the energy sector to produce electricity using a renewable energy mix by 22% in 2020, 23% in 2025, and 30% in 2030. The set target for energy efficiency is to reduce electricity consumption by 10% in 2025, following 15% by 2030 (KeTTHA, 2017). Based on statistics in 2016, electricity consumption was recorded increasing about 8.9% compared to the previous year, with a value of 144,024 GWh. The industrial sector was the highest contributor to energy consumption, with 47%, followed by the commercial industry, with 30.8%, and the residential sector is 21.6%. The other percentage was the agriculture and transport sectors, respectively, with 0.4% and 0.2% (DOSM, 2019). According to ASEAN Centre for Energy (ACE) data, Malaysia has implemented more than 15 policies focusing on the industrial, commercial, and residential sectors. The policies, including energy audits, Minimum Energy Performance Standards (MEPS), and energy labeling, refer to the star rating. Malaysia is on track to achieve the reduction of carbon emission intensity. The reduction strategy of electricity consumption in all sectors is implemented by enforcing the Efficient Management of Electrical Energy Regulations (EMEER) 2008, the Minimum Energy Performance Standards (MEPS), and boosting renewable energy deployment (ST, 2018b).

### 2.2.2 The trend of Carbon Emission in Malaysia

The first official discussion of a world energy policy to reduce gas emissions was conducted in 1972 at the United Nations Conference on the Human Environment in Stockholm. In 1992, United Nations Convention on Climate Change (UNFCCC) was held in Rio de Janeiro, Brazil (Kusumadewi & Limmeechokchai, 2017). The ultimate objective of the UNFCCC is to stabilize greenhouse gas concentrations in the climate system at a safe level (UNFCCC, 2019). Malaysia ratified the Kyoto Protocol in 1997 and committed to reducing carbon dioxide and other emissions. The target is 2050, and an expected reduction in the average global weather between 0.02°C and 0.28°C can be achieved (Kusumadewi & Limmeechokchai, 2017). Human activities produce greenhouse gas emissions (GHG) through burning fossil fuels (Habib et al., 2016). The types of greenhouse gasses such as Carbon Dioxide ($CO_2$), Sulfur Dioxide ($SO_2$), and Nitrogen Dioxide ($NO_2$) (Salahudin et al., 2013). $CO_2$ is the dominant contributor to greenhouse gases, covering 60% of total greenhouse gases. The production of $CO_2$ is mostly from energy consumption in factories, residential, and transportation (Farabi, 2019). According to the data for Malaysia provided by The World Bank from 1970 to 2014, the average $CO_2$ emission value for Malaysia during that period was 96,390 kt. In 1970, the $CO_2$ was 14,602 kt, and in 2014 increased until the maximum value was 242,821 kt. Malaysia has been identified as one of the countries with the highest rates of greenhouse gas emissions (Lean & Smyth, 2014). Based on the data on producing carbon dioxide emissions in the world, Malaysia is ranked number 21 among 192 countries which releases high amounts of $CO_2$ (TheGlobalEconomy.com, 2016). In terms of achieving economic growth, Malaysia's greenhouse gas emissions are expected to increase by 74% from 2005 to 2020. In other words, Malaysia is currently facing the challenge of decreasing the pollution level without affecting achieving economic growth (Chiang-Ching & Tan, 2018).

### 2.2.3 Transformation Building toward Green

The building sector is dominant in the transition to producing clean energy. The 2018 Global Status Report shows that construction and building operations accounted for 36% of global final energy consumption. This report means it contributed almost 40% of carbon dioxide ($CO_2$) emissions into the atmosphere in 2017. Even though the power generation process for electricity consumption and commercial heat resulting emission is classified as indirect emission, this emission accounted for about 70% of total buildings-related emissions referred to as energy consumption in 2017 (IEA, 2018). One of the effective strategies to reduce energy consumption and greenhouse gas emissions is the construction of green buildings. Therefore, to meet green building standards, existing structures must be redesigned (Soon et al., 2017). Malaysia, through the Ministry of Energy, Green Technology, and Water moving forward to promote environmental sustainability by introducing the Green Building Index (GBI). In Malaysia, the GBI tools and reference guides refer to the documents known as GBI Non-Residential New Construction and GBI Residential New Construction. The research about building transformation toward green focuses on three types of buildings: office, residential, and educational buildings, using the information in green building guidelines as standards. Looking at the overview of the transformation toward green in Malaysia helps select effective strategies to reduce energy consumption.



#### 2.2.3.1 Office Building

After launching Green Building Index on 21st May 2009, the iconic building in Perdana Putra, where Malaysia's prime minister's office is located, was renovated (Mun, 2009). Perdana Putra achieved the highest level in GBI rating with a Platinum award as a good example representing green building in this country. This building is equipped with efficient technology that could reduce the building's energy intensity by 38%, $CO_2$ emissions by 30%, and water usage by 40% (Krausz, 2015). One of the elements in the

GBI rating system is energy efficiency, where renewable energy is also evaluated. There are four types of GBI classification, known as GBI rating: Platinum, Gold, Silver, and Certified (GBI, 2020). Under the building category, Non-Residential New Construction (NRNC), the Energy Commission Building was awarded Platinum in the GBI rating. Besides that, Affin Bank New Corporate HQ Kuala Lumpur was awarded a Gold rating, Mid Valley City Southpoint Office was awarded a Silver rating, and Menara Tabung Haji was awarded a Certified rating. More buildings in Malaysia have already received a GBI rating, but only four office buildings have been named as an example (GBI, 2020). Research on non-residential buildings focusing on green office buildings as a benchmark has helped researchers find effective strategies to reduce energy consumption in existing office buildings.

#### 2.2.3.2 Residential Building

According to the International Energy Agency report, the residential sector represents about 25% of global energy consumption. The residential energy sector produces about 17% of global $CO_2$ emissions (Pablo-Romero et al., 2017) and significantly impacts the global environment (Nejat et al., 2015). During the 20th century, Malaysia introduced residential buildings named flats or condominiums, terrace houses, semi-detached, townhouses, and bungalows (Hong, 2014). Until January 2016, the Malaysia Green Building Index (MGBI) already certified 340 buildings, and 667 other facilities were registered and waiting to be processed. Based on this total, 41% are under residential building categories. It shows that the demand for green housing has a significant trend in Malaysia's property market (Panasonic, 2016). Building categories under Residential New Construction (RNC) Saville @ Melawati (Pangsapuri Khidmat Melawati) have already been awarded Gold in the GBI rating, and Residensi Chymas is awarded a Silver rating. Examples of other types of residential buildings are cited in Certified ratings, such as Integrated Health Research Institute - Hostel, Hotel and Quarters Building, Student

Residence College (Jengka, Lendu, Bertam) Universiti Teknologi MARA. Universiti Teknologi Malaysia Kuala Lumpur Residence, Condominium Sierra 10 (LATHEA), Vidmau - Zero Lot Terrace house and Semi-detached house and Bungalow Neighborhood 2, Bandar Dato Onn (GBI, 2020).

#### 2.2.3.3 Educational Building

The GBI Non-Residential rating tool becomes a reference to evaluate the sustainable aspects of commercial, institutional, and industrial buildings. The educational facility is one of the institutional buildings where universities, colleges, and schools are an example of this category (Shafiei & Abadi, 2017). Research on educational facilities is directly related to the Malaysian Higher Education landscape. According to the Ministry of Higher Education statistics, Malaysia has 20 public universities with 618,180 students and an academic staff of 32,079. There are 34 polytechnics with 89,503 students and 7,916 academic staff (MOHE, 2016). These statistics do not include private universities and colleges. The number of academic and student staff at public universities and polytechnics is already enough to show why universities are identified as the highest energy consumers compared to other public buildings (Sharifah Noor Nazim et al., 2014). Research on existing educational buildings moving towards green academic buildings shows a significant decrease in energy consumption. Refurbishing existing educational buildings into green buildings can increase the sustainability of that buildings. However, renovating all conventional or academic buildings to decrease energy consumption is impractical and uneconomical to implement (Sharifah Noor Nazim et al., 2014)

## 2.3 Guidelines

The guidelines that serve as references are essential to ensure that this research direction has the right direction. Collecting several related policies will help concept development reach the research objective.

### 2.3.1 National Green Technology Policy

The world community faces two significant issues or challenges: climate change and energy security. In response to these challenges, the 6th Prime Minister of Malaysia set up a new ministry known as the Ministry of Energy, Green Technology, and Water on 9th April 2009. The Government of Malaysia is determined to continue to provide a total commitment to Green Technology. National Green Technology Policy was launched on 24th July 2009. The National Green Technology Policy is an essential guide in Malaysia's journey towards greener. This policy stated green technology as a driver to accelerate economic growth toward sustainable development. One of the policy's objectives is to minimize the increase in energy consumption, but there is an increase in economic development. The central pillar of this energy policy focuses on efforts to achieve energy independence and promote efficient utilization (KeTTHA, 2009).

### 2.3.2 Renewable Energy Policy

Malaysia set a target in the year 2030 to reduce greenhouse gas (GHGs) emission intensity against Gross Domestic Product (GDP) by up to 45% compared to the year 2005 level (KeTTHA, 2017; Raihan & Tuspekova, 2022). The Malaysia Renewable Energy Act was enforced in 2011, and its objective was to accelerate the contribution of green energy to the electricity generation mix. The program implementation based on this Act reduced energy consumption by 306.9 Gigawatt hours (GWh). This reduction has resulted in GHG avoidance amounting to 208,705 $tCO_2eq$. One of the industry's challenges is to fill the gap between energy generation and clean, sustainable, and reliable energy use (EPU, 2015). The renewable energy policy was introduced to encourage industries and individuals to apply renewable energy-powered systems in their respective power applications. These policies persuade societies and individuals to adopt renewable energy as an alternative energy source (Mekhilef et al., 2014). In the latest report inside World Energy Outlook, the International Energy Agency stated that almost half of the newly installed capacity in the world in 2014 was contributed by renewable sources (ST, 2014a). Increasing reliance on renewable energy sources such as wind, solar and geothermal heat helps solve the shortage of non-renewable resources that will be depleted in the future (Alzoubi & Dwairi, 2015), such as oil, coal, and natural gas. Renewable energy resources currently a priority in Malaysia are biomass, biogas, small-scale hydro, and solar photovoltaic (PV) (Tsalikis & Martinopoulos, 2015). The vision of this policy provides direction to achieve the target of increasing the percentage of renewable energy share in the national electricity mix.

### 2.3.3 Green Technology Master Plan Malaysia 2017 - 2030

The Green Technology Master Plan provides a strategic plan that can be implemented to support the National Green Technology Policy. This document provides an overview of how implementing green technology in vital economic sectors will help stimulate economic growth in the country. The Green Technology Master Plan also aligns with the National Green Technology Policy to spur a conducive ecosystem for green technology development. According to the Green Technology Master Plan 2017 - 2030, the electricity generation with renewable energy (RE) mix 2016 was 18.4%. The government set the target for the energy sector to increase the level of RE mix (installed capacity) to 20% by 2020, then increase to 23% by 2025 and 30% by 2030 (KeTTHA, 2017). This master plan shows the energy sector's existing initiatives and way forward in the timeline form from 2017 until 2030. In the energy sector, this document gave information about existing initiatives in electricity generation and energy efficiency and the way forward in these two aspects. The policy also aimed to encourage the efficient utilization of energy resources to reduce dependence on fossil fuels. However, the Report on Peninsular Malaysia Generation Development Plan 2019 (2020 - 2030) stated demand forecast is reviewed annually. The report indicated that to achieve Malaysia's 20% RE capacity mix target by 2025, 3,758MW of new RE capacities need to be developed in Peninsular

Malaysia starting in 2020. The latest government aspiration in 2025 for RE mix is 20% and not 23% (ST, 2020b)

### 2.3.4 Malaysian Polytechnic Polygreen Blueprint

One of the objectives stated in the National Green Technology policy is to reduce increased energy consumption while increasing economic development. The main thrust of the energy policy is to achieve energy independence while promoting efficient energy utilization. (Alzoubi & Dwairi, 2015). Therefore, the education sector is no exception in succeeding in helping the government ensure that this policy successfully achieves its objectives. As a leading institution in TVET, the polytechnic is directly involved in implementing green practice initiatives. All polytechnics in Malaysia are no exception in implementing this green campus initiative. The Polygreen Blueprint is a reference document on guidelines for implementing green practices on campus. Green TVET will be implemented by emphasizing green campuses, green technology programs, green communities, green culture, and green research (JPPKK, 2015). Ten methods or implementation strategies are stated in the Blueprint POLYgreen for the period up to 2020. One of the strategies is to run a green program in polytechnics that begins with an initiative without cost and is easy to implement. In addition, the program's implementation can involve many participants, in which the impact of its implementation can be calculated and reported. Reporting is made in terms of financial savings and reductions in carbon emission.

### 2.3.5 Part 1: Electrical Energy Audit Guidelines for Building

In the context of the development and economic growth of the country, the energy sector is a significant contributor to its success. To ensure energy sustainability in the future, the first step to be done is to implement an energy audit. This audit will assist in determining the appropriate strategies to be implemented and ensure energy consumption is efficient. Energy audits examine the energy utilization of equipment or systems intended to provide the energy being used is efficient. Two energy audits are called walk-through or preliminary audits and detailed energy audits. A walk-through audit involves a visual inspection of the building covers, lighting system, air conditioning, metering, and other factors that will affect the energy consumption of the premises. A detailed energy audit involves four main processes: data collection, end-use load apportioning, identification of energy conservation measures (ECM), reporting, and presentation. This audit will investigate the energy used, the existing equipment's current performance and identify the potential ECM (ST, 2016b). Through the energy audit, the actual energy consumption of its building can be determined, and the most effective strategies for a significant reduction also can define (Magrini et al., 2016).

### 2.3.6 General Circular Letter No.2 of 2014. Guideline on Energy Saving Methods in Office and Government Premises

The Malaysian government has decided to implement 11 measures to reduce public sector spending from 1 January 2014. Its purpose was to practice more prudent expenditures in 2014. Among the saving measures taken is the cost of electric utilities. As a preliminary step, all government premises are required to save 5% of electrical utility costs in 2014 General Circular Letter no 2 of 2014 (PMO, 2014) issued by the Prime Minister's Office has provided guidelines to government agencies on the implementation of energy conservation methods in all government buildings as a measure of a 5% government utility cost reduction. This circular aligns with the government's decision through Treasury Circular No. 2 of the Year 2014 under item 7 from the Ministry of Finance Malaysia and the Prime Minister's recommendation for civil servants to support the saving effort. The energy usage guide in the office stated in this circular is a lighting system, air conditioning, and office equipment.

### 2.3.7 Rates Tariff

In Malaysia, the authorities' electricity power generation companies are dominated by three utility companies known as Tenaga Nasional Berhad (TNB), Sabah Electricity Sdn Bhd (SESB), and Sarawak Energy Berhad (SEB). TNB has a responsibility to manage the energy demand in Peninsular Malaysia. SESB is responsible in the State of Sabah, while SEB is responsible in Sarawak. These utility companies operate independently and are not interconnected with each other (APEC, 2001). Therefore, the electricity tariff for a commercial building refers to TNB, SESB, and SEB differently (SEB, 2019; SESB, 2019; TNB, 2019b). The calculation of energy bills in this research will refer to the location of the building and current tariff rates. The research building falls under category C1, medium voltage general commercial tariff.

## 2.4 Malaysian Standard

The Department of Standards is the accreditation body in Malaysia. Malaysian Standard (MS) is a document developed by the Standards Development Committee (SDCs) and gets approval as specified in the Standards of Malaysia Act 1996 (Act 549). MS is a technical document with content adopted and aligned with international standards (DSM, 2012). There are five categories of Malaysian Standards, and the determination of the type depends on the purpose. The standard category types are divided into specifications (requirements), methods, codes of practice, terms (glossary, vocabulary, nomenclature), and guides (DSM, 2019). This research will refer to the type of Malaysian Standard named MS 2680:2017. Energy Efficiency and Use Renewable Energy for Residential Building - Code of practice and MS 1525:2014, Energy Efficiency and Use Renewable Energy for Non-Residential Building - Code of practice (second revision).

### 2.4.1 Malaysia Standard MS 2680: 2017. Energy Efficiency and Use Renewable Energy for Residential Building – Code of Practice

According to the Malaysian Standard MS 2680: 2017, this Standard guides the design, selection of materials and use of electrical appliances. It also encourages efficient energy use, especially renewable energy in an existing or new residential building. Under clause electrical appliances, there are ten types of instruments listed. It is lighting, air conditioners, fans, refrigerators, television, water heaters, washing machines, electric irons, microwaves, and an oven. In terms of choosing efficient electrical appliances, this document recommends selecting according to their energy star rating. The suggested minimum star rating level is two stars, such as the Minimum Energy Performance Standards (MEPS). The appliance should be replaced or upgraded if a more efficient hardware model exists. The replacement only can be done if the resulting energy savings can pay back the additional costs spent over a short period (DSM, 2017)

### 2.4.2 Malaysia Standard MS 1525: 2014. Energy Efficiency and Use Renewable Energy for Non-Residential Building – Code of Practice (Second Revision)

According to the Malaysian Standard MS 2474: 2017, the purpose of this standard is to promote the design, construction, operation, and maintenance of new and existing buildings that reduce energy consumption without impeding creativity in the design, building functions, and comfort of its occupants. Besides that, this document recommends using renewable energy in new and existing buildings to minimize dependence on non-renewable energy, pollution, and energy consumption while maintaining the occupants' comfort, health, and safety. This second revision MS document gives guidance on the architectural and passive design strategy, building envelope, lighting, electric power and distribution, air conditioning and mechanical ventilation (ACMV) system, energy management control system, and building energy simulation method (an alternative compliance method) (DSM, 2014). The methodology proposed in this research is developed based on this MS document to ensure the research's direction is correct and toward achieving the objective.

### 2.4.3 Minimum Energy Performance Standards (MEPS)

The Electricity Supply Act 1990 (Act 447) describes the regulation of the electricity supply industry, the supply of electricity at a reasonable price, and the licensing of any electrical installation. In addition, controlling any electrical installation plant and equipment concerning people's safety and the efficient use of electricity is also described. Under this Act Part VA about the efficient use of electricity, section 23A gives the power to Minister to determine the standards, etc. (ST, 2013). The Minister of Energy, Green Technology and Water Malaysia, on the 3rd of May 2014, gazetted the amendment to the Electricity Regulations 1994. Consequently, the Electricity (Amendment) Regulations 2013 require implementing and enforcing the Minimum Energy Performance Standards known as MEPS. This regulation lists five domestic electrical equipment: domestic fans, television, refrigerator, air-conditioner, and lighting. The minimum energy star rating value MEPS recommends is 2 Stars (ST, 2016b). Five Malaysian Standards documents are enforced when referring to MEPS. Regarding Energy Management Development and Service Quality from Energy Commission Malaysia, the MEPS code numbers MS 2574:2014 refers to the domestic fan, MS 2576:2014 for television, MS 2595:2014 for refrigerators, MS 2597:2014 for air conditioners, and MS 2598:2014 for lamps.

## 2.5 Identify and Analyze the Energy-Consuming Equipment

In modern society, buildings are identified as contributing a large portion of annual energy consumption. (Yang et al., 2014). Globally, buildings account for nearly 40% of the total end-use of energy (Akram et al., 2022). Identifying and analyzing the energy-consuming equipment is a step toward understanding the energy usage pattern per equipment. Exploring the data will help select the best strategies to reduce annual energy consumption involving equipment inside the building. Several studies are implementing an energy audit strategy to collect energy-consuming data at educational institutions. An example of these institutions is schools and universities. Research conducted in a primary school in Malaysia focuses on different high-energy-consuming equipment to calculate potential energy savings. The data collected from the energy audit has been analyzed (Roslizar et al., 2014). Another research carried out in school has been investigating and evaluating the energy consumption of five different school buildings in Southern Italy. The measurement, monitoring, and diagnosis activities use energy audit data (Rospi et al., 2015). The previous research work by (Ali et al., 2021; Paucar et al., 2017; Zublie et al., 2021) concludes implementing an energy audit is the best strategy for gathering data about high energy-consuming equipment inside the educational building. A study conducted by (Al-Daraiseh et al., 2015; Escobedo et al., 2014; Habib et al., 2016; Kaya & Alidrisi, 2016; Roslizar et al., 2014) reveals the research focusing on energy consumption per equipment is more effective in achieving the energy-saving target. Most researchers set the target equipment for lighting, cooling, heating, ventilation, air conditioning, motors, and other appliances. In this research, an energy audit was carried out on similar target equipment as mentioned in previous research work. However, laboratory equipment was added as a new highlight in an energy audit process at an educational institution. Identifying and analyzing equipment that uses energy will indicate which types of equipment should be targeted to obtain adequate energy savings. The case study with a single-case design is applied to analyze the energy audit data collected. An example of a single case study is performed at the College of Engineering in Rabigh, Saudi Arabia (Sait, 2013). Another research performs in Higher Educational Building at King Saud University, Saudi Arabia (Al-Daraiseh et al., 2015). A case-study method of upwards educational building was also conducted in the Post Graduate Centre at Heriot-Watt (HW) University, Edinburgh, Scotland (Gul & Patidar, 2015) to identify the energy usage patterns. The single case study and energy audit strategy were implemented in this research. However, collecting data for energy usage at a residential building in an educational institution uses the survey questionnaire form and semi-structured interviews. Besides, the collected data apply the quantitative and qualitative data collection methods through interviews and surveys (Bulut et al., 2015). Identifying and analyze energy-consuming equipment will indicate the types of equipment that should be highlighted for energy saving purpose.

## 2.6 Energy Usage Optimization Measure and Energy Saving

Evaluating the potential energy saving is the key to tackling the future energy target. Energy usage optimization measures will affect energy saving in educational buildings. Energy-saving is related to the use of energy-efficiency equipment. The energy-saving potential of air conditioning and refrigeration systems has been investigated. The author demonstrated that money could be saved on the air conditioner and chiller systems by installing higher-efficiency air conditioners, higher-efficiency chillers, duty cycling of air conditioning units, and utilizing existing economizers on air conditioning units (Kaya & Alidrisi, 2016). Another research found that the implementation of efficient energy use through better lighting system design and improved operating hours resulted in an energy reduction of 9.1% reduction in energy (Roslizar et al., 2014). However, this study only focused on the lighting system without focusing on the air conditioning system, which has been identified as equipment that uses the highest energy. The research conducted in the Faculty of Electrical Engineering, Universiti Teknologi Malaysia, supports the view that using new equipment with high efficiency reduces power consumption (Aliyu et al., 2015). Many countries opted for energy usage optimization measures through energy efficiency strategies in public buildings to achieve energy-saving targets (la Cruz-Lovera et al., 2017)

## 2.7 Feasibility of On-Site Energy Generation based on Energy Source Available

Many pieces of research propose effective strategies to reduce energy consumption at an office or educational building by enhancing energy efficiency. However, other effective methods exist to reduce building energy consumption through installing sustainable clean energy systems. Sustainable clean energy sources are energy sources from the natural and come from our environment. Examples include hydropower, bioenergy, direct solar, wind, geothermal, and ocean energy (Owusu & Asumadu-Sarkodie, 2016). The researcher must consider the institution's position and location before exploring suitable renewable energy sources to supply power in PSAS. Malaysia's geographic location is in an area that experiences hot and humid weather and receives a large amount of rain throughout the year. Most sites receive high solar radiation throughout the year, where most places receive average daily solar radiation of 4.7–6.5 kWh/$m^2$ (Petinrin & Shaaban, 2015). Weather conditions and average rainfall in PSAS are according to the abovementioned range. PSAS is located in Behrang and can be accessed via coordinates 3.770015 and longitude 101.450107 (Distancesto, 2021). Based on the geographical location of PSAS, the clean energy sources that can be considered for use are direct hydro and solar energy only—installation of solar systems based on the potential of solar energy in the proposed location. Information about the solar energy potential in the selected location is determined from the global radiation values (kWh/$m^2$/day), PV-type area energy generation (kWh/year), and sunshine duration (hours) (Owusu & Asumadu-Sarkodie, 2016). Although the institution has only a small lake, hydropower can be considered a clean energy option for PSAS. Since there is no river around the campus, the mini hydro generation project cannot be implemented. Because of that, with the support of geographical factors, solar energy is the best option for power generation in PSAS. This energy has been gaining popularity in Malaysia due to the good climate in this country. Therefore, the goal of reducing energy consumption in government educational institutions can be achieved through a solar system installation project and it is a practical solution at this time (Tsalikis & Martinopoulos, 2015).

In the latest World Energy Outlook, the International Energy Agency stated that almost half of the world's new installed capacity in 2014 was contributed by renewables (ST, 2014b). Currently, the building sector is where most practices are installing solar energy generation systems in government buildings to reduce energy consumption (Tsalikis & Martinopoulos, 2015). Research conducted on universities in Indonesia found that most educational institutions install solar energy systems that are not connected to the national grid system, known as off-grid. In this research, the author performed a feasibility analysis of installing a photovoltaic solar system using the energy software HOMER (Kristiawan et al., 2018). Installing an off-grid solar power generation system is one of the practical solutions to reduce the amount of energy used in educational institutions. The research by (Kristiawan et al., 2018) presents the feasibility of installing solar photovoltaic systems with an off-grid system. However, this reliance on off-grid solar energy systems will cause problems as these systems cannot effectively meet electricity demand. This off-grid system depends on weather factors where the power output is variable and inconsistent. This off-grid solar system needs to be supported by traditional sources of power supply from fossil fuels (Lofthouse et al., 2015). Installing a hybrid solar system involving a power supply source from the utility and a solar system is one of the practical solutions for off-grid generation systems. The research using a case study of an office building with an integrated PV system is conducted in Norway. The authors demonstrate that the solar potential analysis in the early stage is essential for choosing the performing system (Good et al., 2014). Solar energy development is an experimental stage to provide an alternative power supply to meet the energy consumption in buildings.

## 2.8 Cost-Benefit and Environmental Impact of Renewable Energy

Many cities worldwide are installing building-integrated with rooftop photovoltaic (PV) systems to generate electricity (Bódis et al., 2019; Byrne et al., 2015; Gómez-Navarro et al., 2021; Khan & Arsalan, 2016). Many pieces of research discuss cost-benefit analysis involving renewable energy sources using solar PV systems. Making a cost analysis for a rooftop solar PV system must apply an analysis of the installation and maintenance costs of the system according to its lifespan. In addition, the cost of PV generation and the impact on environmental benefits also need to be analyzed (Shukla et al., 2016). Some researchers present the economic viability assessment of electricity production using a cost-benefit analysis technique. The payback period calculation must first assess the economic viability of renewable energy sources such as solar PV (Alrawi & Al-Ghamdi, 2020; Atănăsoae et al., 2019). The payback time is calculated by dividing the total investment by the money saved (Gómez-Navarro et al., 2021). Another study mentioned the cost analysis for the solar project needs to consider the region's solar radiation, system sizing, the whole solar system, and the type of panel and inverter technology to be used (Ozcan & Ersoz, 2019). Different sensitivity analyses are conducted but support the point of view of analyzing the PV system cost (Fina et al., 2020). Much of the literature explores the environmental impact of renewable energy systems installed in various places, including the residential sector. Researchers make assessments and future predictions related to increased $CO_2$ emissions and potential mitigation to achieve a total target reduction of 30% for $CO_2$ emissions. The research by (Imu et al., 2021; Panahian et al., 2017; L. Tang, 2021) proved through assessments that the use of solar power generation would result in carbon emission savings. Research has been conducted on the residential sector involving Indonesia and Thailand, where renewable energy scenarios are used to calculate and analyze energy consumption and carbon emissions. The results confirm that if there is an increase in energy efficiency and the application of renewable energy sources will reduce $CO_2$ emissions (Kusumadewi & Limmeechokchai, 2017). There are also studies on housing in Korea and China.

## 2.9 Comparison of Previous Literature Review

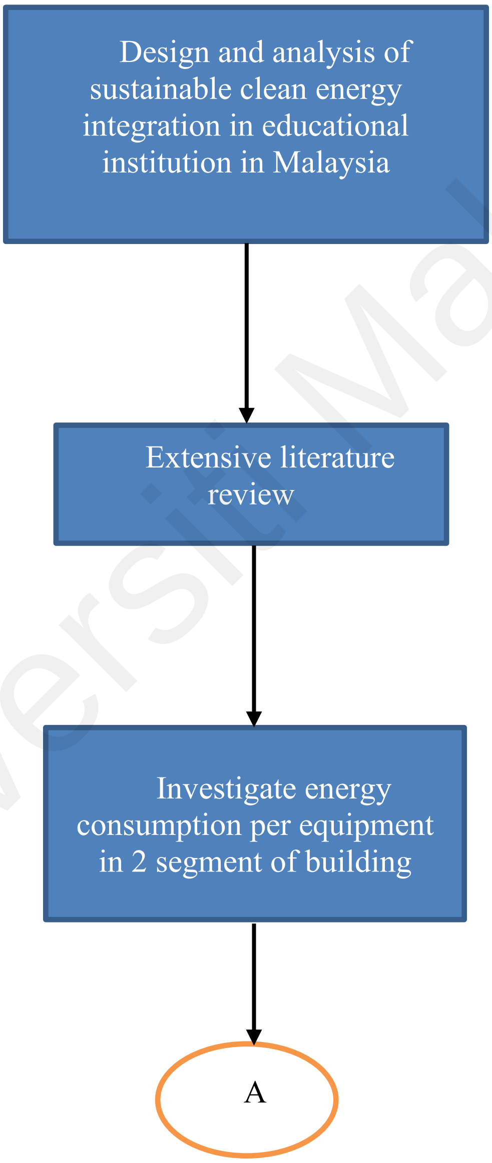
$CO_2$ is one of the significant contributors to the total amount of greenhouse gases covering 60 per cent. $CO_2$ is mainly generated by energy consumption in transportation, factories, and residential industries (Farabi, 2019). Based on World Bank data from 1972 to 2021, it was found that Malaysia's $CO_2$ emissions in 1972 amounted to 14.7 million tons and increased to 251.6 million tons in 2021 (Knoema, 2022). The residential sector in Malaysia has shown a trend of increasing energy and $CO_2$ consumption from 1975 to 2011 (Azlina et al., 2015). Research findings conclude that increased energy efficiency or the application of renewable energy is one of the factors influencing the reduction of $CO_2$. The research conducted by (Chunark & Limmeechokchai, 2015) in Thailand supports statements related to energy-efficient appliances used in the residential sector that are essential in reducing $CO_2$. Another study that compared two countries, Indonesia and Thailand, confirmed that improving energy efficiency reduces $CO_2$ emissions. The research states that in 2050, $CO_2$ emission rates in Indonesia and Thailand can be reduced by 16% and 13.36%, respectively, when energy savings of 27.6% and 15.5% occur. The authors decided to implement the research methodology only focusing on specific energy-efficient equipment such as lighting, refrigerators, air conditioners, and televisions. (Chunark & Limmeechokchai, 2015).

Other research (Thuy & Limmeechokchai, 2015) also involves the residential sector but focuses on Vietnam and Thailand using demand-side management (DSM) scenarios to analyze energy consumption. This research also focuses on appliances similar to the type from the study (Chunark & Limmeechokchai, 2015), except for televisions, which are replaced with cooking appliances that can improve energy efficiency. This study also considers renewable energy (RE) use when analyzing energy consumption and total carbon emissions. Other research also surveyed residential in Korea and China, providing make future predictions about the increasing quantity of $CO_2$ emissions and the potential to reduce them. A study of these two countries shows that using cooking appliances and water heaters with highly energy-efficient technology reduces $CO_2$ emissions by 30%. Based on the literature review mentioned above, further research on energy consumption per equipment in a residential building located at an educational institution has been carried out. The goal is to prove that $CO_2$ reduction is also related to residential buildings. Besides, the limited literature review on energy consumption per equipment was carried out in residential because most previous literature focuses only on an office building at the educational institution.

Several researchers (Escobedo et al., 2014; Habib et al., 2016; Kaya & Alidrisi, 2016; Roslizar et al., 2014) set similar target equipment types to implement the energy audit process covering equipment such as lighting, cooling, water heating, motors, and other equipment. Therefore, this study is extended by using the same type of equipment for energy auditing but equipped with laboratory equipment as a new highlight in the energy audit process in academic institutions. This research analyses the energy consumption per equipment, indicating the type of equipment that should be targeted as it has energy-saving potential. This energy-saving can be achieved by applying energy-efficiency equipment and renewable electricity generation.

## 2.10 Research Framework

Determining building categories is crucial to ensure that the methodology for data collection is correct. The research framework in Figure 2.1 displays the flow chart of the research process. This flow chart shows movement and actions taken to achieve the research objective.



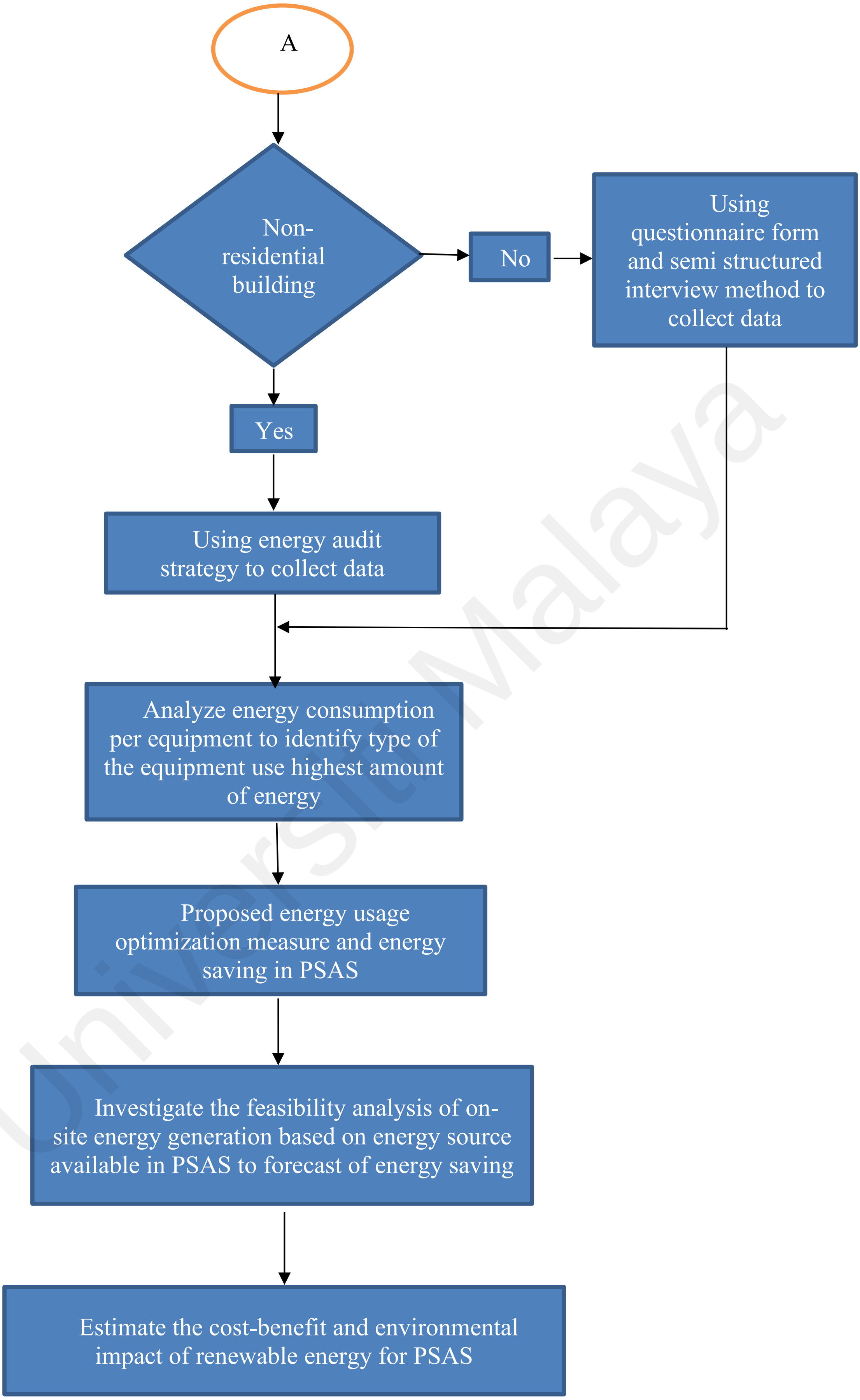



**Figure 2.1: Flow Chart of Research Framework**

## 2.11 Conclusion

Identifying and analyzing the energy-consuming equipment is a step to understanding the energy usage pattern per equipment. The research focusing on energy consumption per equipment is more effective in achieving the energy-saving target. Implementing an energy audit is the best strategy for gathering data about high energy-consuming equipment inside the educational building. The single case study and energy audit strategy were chosen to implement this research. However, collecting data for energy usage at a residential building in an educational institution is a new highlight in this research. The collected data apply the quantitative and qualitative data collection methods through survey questionnaires and semi-structured interviews. Research on the office building implements the energy audit strategy, focusing on laboratory equipment as a new highlight in an energy audit process at an educational institution. Identifying and analyzing equipment with high energy consumption will clarify the types of equipment that should be targeted for energy savings. Other effective strategies are to reduce building energy consumption by installing renewable energy systems. The best choice for PSAS is to reduce energy consumption by installing a solar power generation system due to geographical factors. This energy has also been gaining popularity in Malaysia. Installing a hybrid solar system is a practical solution to overcoming the lack of off-grid power generation systems. This research uses a "best-case" and a "worst-case" scenario to analyze the data to tackle uncertainty in estimating and calculating data. The best-case method is known as the NEM, while the worst-case scenario is the self-consumption (Gómez-Navarro et al., 2021).

# CHAPTER 3: METHODOLOGY

## 3.1 Introduction

This chapter clarifies the application method to collect the data for residential and non-residential buildings. The detailed methodology implemented in this research is discussed. The study conducted always refers to the relevant Malaysia Standard.

## 3.2 Research Approach

This research will investigate energy consumption in three segments. The residential buildings will use a survey questionnaire form and semi-structured interviews to gather the data. Non-Residential buildings (academic and non-academic buildings) will collect the data using the energy audit method. The methodology proposed always refers to the Malaysian Standard MS 1525:2007, Code of Practice on Energy Efficiency and Use Renewable Energy for Non-Residential Buildings. The manual equipment and building layout document were also evaluated during the energy audit process. The interview session is conducted with the person in charge to understand the equipment's function and usage. Figure 3.1 shows the PSAS campus view from the top. Figure 3.2 shows the site plan of PSAS, divided into six zones.

**Figure 3.1: The PSAS campus view from the top.**

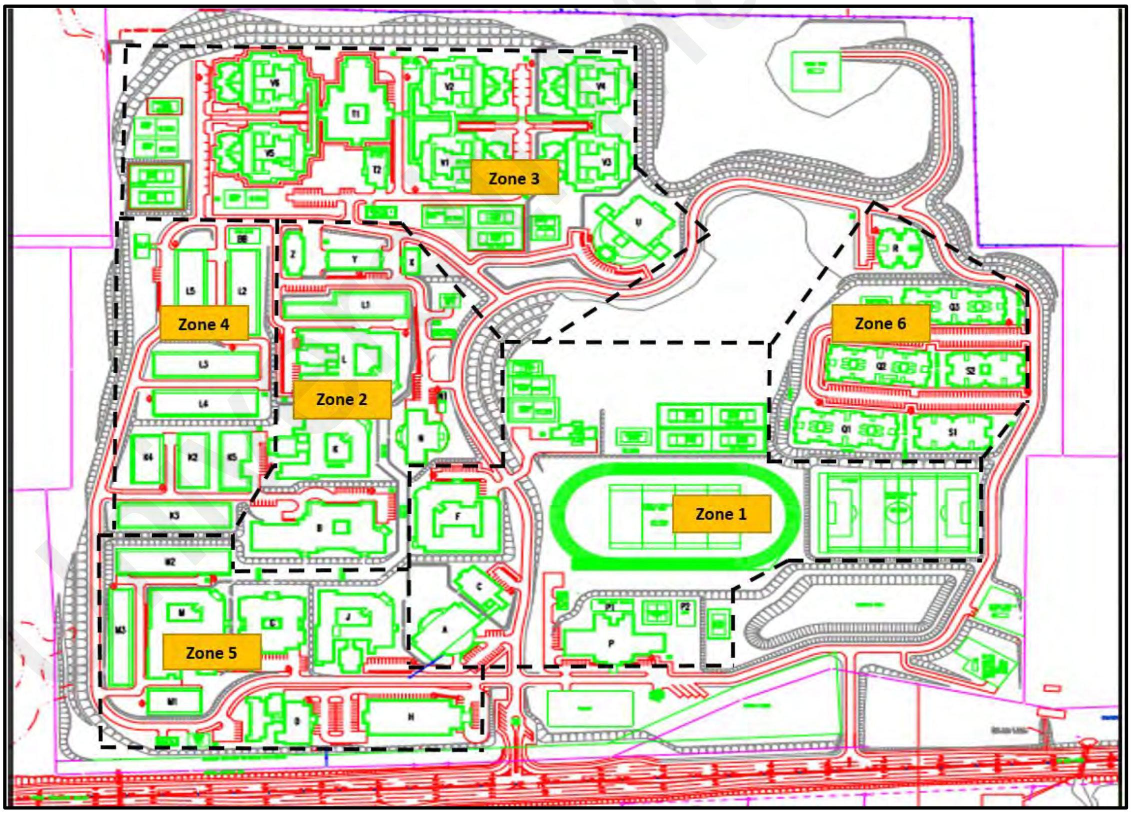



**Figure 3.2: Site Plan of PSAS**

## 3.3 Survey Questionnaires and Semi-Structured Interviews

Research focusing on staff residences in Zone 6 PSAS is carried out, and the data has been collected using the survey questionnaire form and semi-structured interviews. Data collection from the residential block involves all categories of blocks. Since energy usage is influenced by how a facility is operated and utilized, collecting data on occupancy rates (hour/day) is necessary. Estimated data on energy consumption levels will be collected. This paper focuses on energy consumption per equipment in a residential building located at an educational institution.

### 3.3.1 Data collection and characteristics of the residential building

A survey was conducted on the residents of the residential quarters at the Politeknik Sultan Azlan Shah (PSAS), Malaysia, using a questionnaire form shown in Appendix A. The residential quarters consist of four main block categories: block C is for top management, block D is for institutional officers, block F is for support staff, and block W is for hostel wardens. A survey was carried out on a class C category house consisting of an R block and three blocks of class D consisting of Q1, Q2, and Q3. Next, 2 class F blocks consisting of blocks S1, S2, and nine houses from block W. The distributed questionnaire contains 21 main questions. 13 focused on home electrical appliances. The total number of questions in this questionnaire, including sub-questions related to home electrical appliances, is 36. This survey questionnaire will collect information about the profile of respondents' backgrounds, such as their names, address, and departments or units working at PSAS. Respondents must state the number of family members who live together, the quarter class type, and the total number of rooms.

In addition, respondents were also asked about using any other energy sources to turn on electrical equipment. The survey also collects data on average monthly energy consumption (kWh) and monthly electricity bill (RM), types of electrical equipment, and an estimate of operating hours of home electrical appliances. This questionnaire involved

143 respondents in 7 different blocks, namely Q1, Q2, Q3, S1, S2, R, and W. Home electrical appliances are divided into 11 categories: kitchen appliances, televisions, cooling and heating, washing machines, irons, appliances small kitchens, lamps, computers, mobile accessories, domestic well-pumps, and other appliances. This questionnaire obtains the type of electrical appliances, quantity, and estimation of operation hours duration for equipment. The collection of information on the ownership of at least one home electrical appliance was also made. This study also uses a semi-structured interview method through a face-to-face or phone interview. This interview method aims to ensure the validity of the obtained data. This interview session usually takes 10 minutes for each respondent. Questions asked ranged from how the respondent estimated the time of use of the electrical appliance. The information about their control of the ON-OFF time of electrical equipment is vital to ensure the estimated operating hours of equipment specified in the questionnaire are valid and accepted. This interview method ensures the quality of the obtained data has reliability. Estimated operating hours of equipment submitted by respondents are by the routine use of their residence and can be verified. Table 3.1-3.3 shows the respondent background, average data for electricity consumption and electricity bill costs, and details on the home appliance type, quantity, capacity, and operating hour duration of home electrical appliances within one day.

**Table 3.1: Background information on the residential building in 2018**

| | |
|---|---|
| Total Floor Area | 30,422 $m^2$ |
| Number of quarters | 143 unit |
| People live in quarters | 603 people |
| Number of room | 634 room |

**Table 3.2: Average monthly electricity usage and cost of electricity usage for a different block in 2018**

| Block | Electricity usage (kWh) | Cost of electricity usage (RM) |
|---|---|---|
| Q1 | 5,766.00 | 1,386.96 |
| Q2 | 6,270.98 | 1,552.16 |
| Q3 | 5,515.00 | 1,409.04 |
| S1 | 5,321.00 | 1,347.88 |
| S2 | 6,035.10 | 2,048.4 |
| R | 795.00 | 254.27 |
| W | 3,694.00 | 1,159.32 |
| **Total** | **33,172.08** | **9,158.03** |

**Table 3.3: Quantity, the capacity of power, and operating hours in 2018**

| Home appliance type | Appliances | Quantity | Power (W) | hour/day |
|---|---|---|---|---|
| Kitchen Appliances | Refrigerator (20L-450L) | 88 | 170 | 14 |
| | Refrigerator (456L-650L) | 64 | 260 | 14 |
| | Refrigerator (760L-more) | 8 | 400 | 14 |
| | Microwave (< 1 cubic) | 28 | 600 | 0.4 |
| | Microwave (1-1.5 cubic) | 28 | 800 | 0.4 |
| | Microwave (1.6 - 2 cubic) | 1 | 1000 | 3 |
| Television | TV (14"-35") | 77 | 180 | 6.2 |
| | TV (36"-55") | 74 | 120 | 7.5 |
| | TV (60"- more) | 1 | 190 | 8 |
| Cooling & heating | Air conditioner (1hp) | 29 | 944 | 8 |
| | Air conditioner (1.5hp) | 12 | 1252 | 8 |
| | Air conditioner (2hp) | 3 | 1913 | 8 |
| | Ceiling Fan | 535 | 75 | 12.7 |
| | Stand Fan | 108 | 50 | 7.4 |
| Washer | Washing Machine (<=6kg) | 25 | 585 | 1.5 |
| | Washing Machine (6.1-8kg) | 86 | 600 | 1.5 |
| | Washing Machine (> 8.1kg) | 30 | 650 | 1.5 |
| Iron | Iron (small) | 102 | 600 | 0.25 |
| | Iron (medium) | 46 | 800 | 0.25 |
| | Iron (large) | 2 | 1000 | 0.2 |

| | | | | |
|---|---|---|---|---|
| Small kitchen appliances | Rice cooker (3 - 4 cups) | 82 | 450 | 2 |
| | Rice cooker (5 - 6 cups) | 54 | 550 | 2 |
| | Rice cooker (8 - 10 cups) | 14 | 650 | 2 |
| Lighting | Lighting (0 - 2W) | 1 | 1 | 8 |
| | Lighting (3 - 5W) | 1 | 4 | 8 |
| | Lighting (6 - 11W) | 0 | 9 | 8 |
| | Lighting (12 - 25W) | 686 | 16 | 8 |
| | Lighting (26 - 50W) | 1396 | 36 | 8 |
| Computer | Notebook | 140 | 250 | 3.5 |
| Mobile Accessories | Phone charger | 355 | 5 | 2.5 |
| Domestics Well Pump | Pump (0.5- 1 hp) | 3 | 746 | 0.5 |
| | Pump (< 5hp) | 1 | 1125 | 0.5 |
| | Pump (> 5hp) | 1 | 3730 | 0 |
| Other equipment | Wifi router | 58 | 20 | 6 |
| | Clothes dryer | 1 | 1600 | 0.4 |
| | Popcorn maker | 1 | 1040 | 0.4 |
| | Hairdryer | 24 | 320 | 1.5 |
| | Coffee maker | 1 | 600 | 0.5 |
| | Water heater | 36 | 3400 | 4 |
| | DVR player | 38 | 100 | 3 |
| | Alarm clock radio | 6 | 5 | 8 |
| | Printer | 57 | 175 | 1 |
| | Kettle | 76 | 1800 | 0.1 |
| | Stereo | 17 | 380 | 4 |
| | Vacuum | 80 | 400 | 0.4 |
| | Toaster | 71 | 600 | 0.1 |
| | Incandescent Bulb | 6 | 20 | 4 |
| | Oven | 74 | 600 | 0.4 |
| | Dishwasher | 0 | 1800 | 0 |
| | HD Receiver | 14 | 45 | 10 |
| | Hot tub | 0 | 4700 | 0 |
| | Humidifier | 6 | 65 | 8 |
| | Dehumidifier | 2 | 280 | 8 |
| | Aquarium | 9 | 50 | 24 |

| | | | | |
|---|---|---|---|---|
| | | | | |
| | Satellite dish | 77 | 55 | 8 |
| | Blu-ray player | 10 | 145 | 2 |
| | Blender | 124 | 450 | 0.1 |

**Table 3.4: Summary of the data collected for home appliances and their quantity according to the residential block group.**

| Home appliance types | Appliances | Quantity | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|
| | | Q1 | Q2 | Q3 | S1 | S2 | R | W | |
| Kitchen Appliances | Refrigerator (20L-450L) | 16 | 17 | 15 | 19 | 15 | 1 | 5 | 88 |
| | Refrigerator (456L-650L) | 11 | 11 | 8 | 11 | 15 | 1 | 7 | 64 |
| | Refrigerator (760L-more) | 1 | 2 | 1 | 1 | 3 | 0 | 0 | 8 |
| | Microwave (< 1 cubic) | 11 | 3 | 6 | 0 | 2 | 0 | 6 | 28 |
| | Microwave (1-1.5 cubic) | 6 | 8 | 6 | 1 | 5 | 2 | 0 | 28 |
| | Microwave (1.6 - 2 cubic) | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Television | TV (14"-35") | 14 | 12 | 13 | 18 | 18 | 1 | 1 | 77 |
| | TV (36"-55") | 12 | 14 | 13 | 12 | 12 | 2 | 8 | 73 |
| | TV (60"- more) | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| Cooling & heating | Air conditioner (1hp) | 8 | 3 | 4 | 1 | 4 | 1 | 8 | 29 |
| | Air conditioner (1.5hp) | 0 | 4 | 3 | 2 | 1 | 1 | 1 | 12 |
| | Air conditioner (2hp) | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 3 |
| | Ceiling Fan | 97 | 111 | 79 | 93 | 108 | 11 | 36 | 535 |
| | Wall Fan | 17 | 24 | 16 | 23 | 18 | 2 | 8 | 108 |
| Washer | Washing Machine (<=6kg) | 4 | 3 | 5 | 7 | 5 | 0 | 1 | 25 |
| | Washing Machine (6.1-8kg) | 16 | 21 | 12 | 16 | 14 | 2 | 5 | 86 |
| | Washing Machine (> 8.1kg) | 5 | 3 | 6 | 3 | 9 | 0 | 4 | 30 |
| Iron | Iron (small) | 19 | 20 | 20 | 20 | 16 | 1 | 6 | 102 |
| | Iron (medium | 9 | 9 | 7 | 9 | 9 | 1 | 2 | 46 |
| | Iron (large) | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 2 |
| Small kitchen appliances | Rice cooker (3 - 4 cups) | 19 | 16 | 11 | 15 | 14 | 0 | 6 | 81 |
| | Rice cooker (5 - 6 cups) | 4 | 10 | 12 | 13 | 11 | 2 | 2 | 54 |
| | Rice cooker (8 - 10 cups) | 4 | 1 | 3 | 2 | 2 | 0 | 2 | 14 |
| Lighting | Lighting (0 - 2W) | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| | Lighting (3 - 5W) | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | Lighting (6 - 11W) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Lighting (12 - 25W) | 122 | 139 | 116 | 124 | 127 | 13 | 45 | 686 |
| | Lighting (26 - 50W) | 246 | 269 | 230 | 259 | 268 | 30 | 94 | 1396 |
| Computer | Notebook | 36 | 34 | 32 | 15 | 12 | 3 | 8 | 140 |
| Mobile Accessories | Phone charger | 63 | 71 | 64 | 67 | 56 | 8 | 26 | 355 |
| Domestics Well Pump | Pump (0.5- 1 hp) | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 3 |
| | Pump (< 5hp) | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| | Pump (> 5hp) | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Other equipment | Wifi router | 14 | 12 | 12 | 6 | 8 | 0 | 6 | 58 |
| | Clothes dryer | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| | Popcorn maker | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| | Hair dryer | 5 | 3 | 5 | 5 | 3 | 1 | 2 | 24 |
| | Coffee maker | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | Water heater | 8 | 6 | 6 | 6 | 4 | 2 | 4 | 36 |
| | DVR player | 6 | 4 | 5 | 9 | 10 | 1 | 3 | 38 |
| | Alarm clock radio | 5 | 0 | 0 | 0 | 0 | 0 | 1 | 6 |
| | Printer | 11 | 13 | 14 | 5 | 3 | 2 | 9 | 57 |
| | Kettle | 16 | 12 | 11 | 12 | 16 | 2 | 7 | 76 |
| | Stereo | 3 | 4 | 2 | 4 | 3 | 0 | 1 | 17 |
| | Vacuum | 15 | 19 | 18 | 12 | 9 | 2 | 5 | 80 |
| | Toaster | 12 | 13 | 10 | 19 | 8 | 3 | 6 | 71 |
| | Incandescent Bulb | 2 | 2 | 1 | 1 | 0 | 0 | 0 | 6 |
| | Oven | 14 | 14 | 15 | 14 | 8 | 2 | 7 | 74 |
| | Dishwasher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | HD Receiver | 2 | 2 | 2 | 2 | 3 | 0 | 3 | 14 |
| | Hot tub | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Humidifier | 3 | 1 | 1 | 0 | 1 | 0 | 0 | 6 |
| | Dehumidifier | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 2 |
| | Aquarium | 1 | 3 | 3 | 0 | 1 | 0 | 1 | 9 |
| | Satellite dish | 15 | 15 | 13 | 15 | 16 | 2 | 1 | 77 |
| | Blu-ray player | 1 | 1 | 1 | 1 | 1 | 0 | 5 | 10 |
| | Blender | 22 | 25 | 25 | 21 | 20 | 3 | 8 | 124 |

## 3.4 Energy Audit

The data collection from office buildings will involve all enlisted structures. Since energy usage is influenced by how a facility operates and is utilized, data is necessary to collect occupancy rates (hour/day). The researcher will collect estimated energy consumption data while investigating the equipment manuals and building layout. An interview session will be conducted with the person in charge at the laboratory or non-academic block to understand the equipment's use and function. The collection of energy consumption data through energy audit in this research involves 47 buildings located in PSAS. However, this study does not show all the details of the data for each building listed individually. The detailed energy data from the rest buildings that are not shown will be included in each zone's overall data summary. All data from the 47 buildings involved are included in the analysis, but not all data details are shown.

### 3.4.1 Active Equipment in Building

This research focuses on five active equipment: laboratory equipment, fan, lighting, air conditioning, lighting, and information & communication technology (ICT). The PSAS building is mainly served by two various air conditioning systems: The centralized Water-Cooled Package Unit (WCPU) and the Air-Cooled Split Unit (ACSU), where a cooling tower (CT) fits all the WCPU. However, air conditioning has a different kind of system to audit.

### 3.4.2 Baseline Data

The baseline data refer to the information on energy consumption measured using a Fixed Digital Power Meter (DPM) installed in each academic and non-academic building at PSAS. Reference data relates to energy consumption (kWh) data measured by Digital Power Meter for 2019, from January 2019 to December 2019. The calculated energy consumption value should be compared with the baseline value to minimize the error percentage between the measured and calculated data. To ensure the measured data using DPM and calculation does not exceed the actual energy consumption at PSAS. However, the analysis's estimation value is compared with DPM's measured data. The calculation data does not correspond with utility data because the utility data show the whole energy consumption for PSAS without revealing the amount of energy consumption by section or zone. The Energy Monitoring System (EMS) version 2.1 (v2.1), as shown in Figure 3.3, is an interface to view energy consumption readings at specific loads in real time. However, EMS v2.1 is an online system that only certain people with permission can access this system.

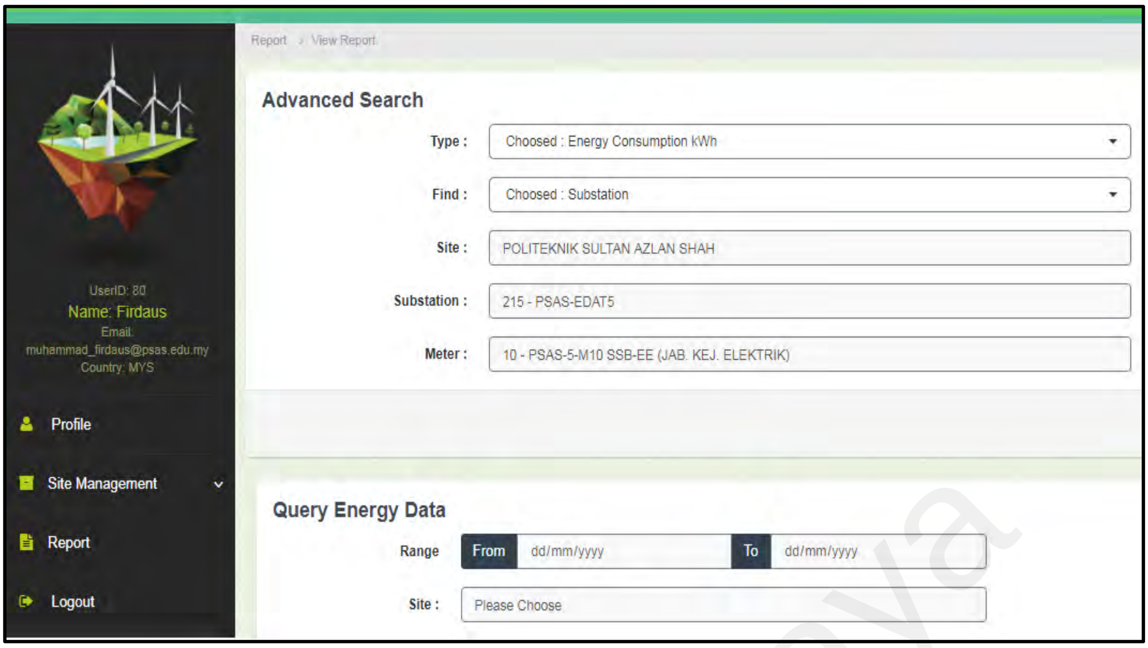



**Figure 3.3: The interface of EMS v2**

### 3.4.3 Data collection and characteristics of the non-residential building

This research measured data from 55 DPM units installed on each Sub-Switch Board (SSB) in the PSAS campus. The meter measures the total energy consumption in each associated block. In addition, the calculated data was obtained from the audit process. The data involving the number of class days is about the PSAS academic calendar year. Data gathering follows the methodology (Habib et al., 2016), where the PSAS energy auditing process was carried out in academic and non-academic buildings. Most researchers (Kumar et al., 2015; Paucar et al., 2017; Rahman Saidur et al., 2009; Zublie et al., 2021) implement energy auditing methodology to identify types of equipment with high energy consumption. This research focuses on five kinds of end loads that use the most energy in academic and non-academic buildings. The walk-through energy audit collects various information, including the type of equipment, quantity, power, and operating hours of the equipment. The academic and non-academic buildings will collect the data according to five categories: laboratory equipment, fan, lighting, air-conditioning, and Information and Communication Technology (ICT) equipment. Examples include academic buildings such as the Electrical Engineering Department and the Mechanical Engineering Department. The non-academic buildings include Islamic Centre, Sports Centre, and Multipurpose Hall. Collecting data in the academic building involves five main categories of equipment: laboratory equipment, fans, lighting, air conditioning, and ICT equipment. While for non-academic buildings also collect the same data as academic buildings, except that it does not involve laboratory equipment and ICT equipment. This research places equipment other than those mentioned above for non-academic buildings under "other equipment" categories.

The detailed energy audit report written here involves all five zones except zone 6, where this zone report has been discussed in the residential building section. The data collected refer to the average energy consumption data (kWh) from PSAS utility bills for 60 months from January 2016 to December 2020, shown in Table 3.5. Figure 3.4 shows an example of the data output generated from the Energy Monitoring System (EMS) for Zone 2. All the measured data is extracted via PSAS's online Energy Monitoring System (EMS). Table 3.6 shows the baseline data for energy consumption in 2019 imported from EMS, where the recorded data are readings for Main Switch Board (MSB) 1 to 5. However, some loads are not installed with an energy meter and make a measured energy consumption error of around 10%. Even the DPM operates in digital mode, but if a disruption to a few meters in the MSB occurred, which stems from an imbalance phase (phase unbalance) at some time, it would not be able to read meter data kWh. The meter also could not record data perfectly when the trip. The data from this MSB involves the usage data of several buildings placed under a particular zone without applying the data for the energy consumption of each piece of equipment. For example, for all MSB data values, MSB 1 represents data values for zone 1, MSB 2 for zone 2, and so on. Future predictions for total energy consumption and savings that PSAS could achieve were estimated based on baseline data.

Table 3.7 shows the PSAS building or block by zone. Table 3.8 shows that the PSAS buildings list and code involve 47 buildings, including staff residences, with a total gross floor area (GFA) of 131,997 $m^2$. Most of the buildings are two to five-story buildings. Table 3.9 shows the baseline data for academic buildings imported from EMS (2019).


**Figure 3.4: Example of the data output generated from EMS for zone**

**Table 3.5: PSAS utility bill data for five years (2016 - 2020)**

| Month | The year 2016 | | The year 2017 | | The year 2018 | | The year 2019 | | The year 2020 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Energy Consumption [kWh] | Maximum Demand [kW] | Energy Consumption [kWh] | Maximum Demand [kW] | Energy Consumption [kWh] | Maximum Demand [kW] | Energy Consumption [kWh] | Maximum Demand [kW] | Energy Consumption [kWh] | Maximum Demand [kW] |
| January | 422,190 | 1,769 | 354,637 | 1,519 | 416,075 | 1,739 | 412,109 | 1,710 | 362,478 | 1,540 |
| February | 376,300 | 1,661 | 330,167 | 1,529 | 349,936 | 1,757 | 327,293 | 1,537 | 361,757 | 1,554 |
| March | 479,303 | 1,715 | 419,218 | 1,549 | 423,761 | 1,773 | 396,652 | 1,523 | 265,364 | 1,541 |
| April | 363,330 | 1,371 | 332,449 | 1,384 | 335,091 | 1,434 | 409,313 | 1,581 | 89,752 | 181 |
| May | 330,633 | 1,354 | 295,169 | 1,184 | 274,444 | 1,341 | 274,323 | 1,133 | 149,894 | 875 |
| Jun | 344,652 | 1,622 | 299,394 | 1,526 | 232,579 | 1,198 | 238,018 | 1,253 | 229,280 | 1,018 |
| July | 316,239 | 1,523 | 425,681 | 1,705 | 421,593 | 1,720 | 402,746 | 1,606 | 207,737 | 987 |
| August | 401,431 | 1,548 | 387,551 | 1,577 | 404,195 | 1,771 | 360,350 | 1,524 | 337,101 | 1,487 |
| September | 345,435 | 1,557 | 372,177 | 1,673 | 349,138 | 1,720 | 412,774 | 1,717 | 341,540 | 1,449 |
| October | 366,035 | 1,503 | 401,418 | 1,661 | 437,352 | 1,715 | 405,410 | 1,626 | 265,782 | 1,149 |
| November | 296,903 | 1,177 | 337,893 | 1,536 | 292,351 | 1,260 | 278,121 | 1,240 | 278,500 | 1,116 |
| December | 327,808 | 1,435 | 340,508 | 1,667 | 334,021 | 1,589 | 314,303 | 1,408 | 278,598 | 1,090 |
| **Average** | **364,188** | **1,512** | **358,022** | **1,543** | **355,878** | **1,585** | **352,618** | **1,488** | **263,982** | **1,166** |

**Table 3.6: Baseline data for the year 2019 imported from EMS**

| Month | Zone 1 MSB 1 (kWh) | Zone 2 MSB 2 (kWh) | Zone 3 MSB 3 (kWh) | Zone 4 MSB 4 (kWh) | Zone 5 MSB 5 (kWh) |
|---|---|---|---|---|---|
| January | 97,053 | 84,420 | 57,939 | 3,558 | 132,487 |
| February | 90,518 | 76,163 | 46,957 | 2,668 | 105,135 |
| March | 108,807 | 90,108 | 64,703 | 3,824 | 120,969 |
| April | 85,624 | 64,818 | 43,935 | 1,961 | 92,877 |
| May | 85,878 | 68,649 | 23,027 | 1,789 | 95,326 |
| Jun | 81,054 | 74,278 | 43,176 | 2,445 | 81,054 |
| July | 82,417 | 66,406 | 46,007 | 3,482 | 77,878 |
| August | 96,947 | 96,087 | 60,730 | 4,396 | 100,400 |
| September | 87,865 | 79,072 | 48,636 | 3,170 | 90,162 |
| October | 92,626 | 81,679 | 60,395 | 2,809 | 85,345 |
| November | 82,372 | 65,141 | 31,325 | 1,839 | 74,897 |
| December | 93,804 | 77,392 | 32,970 | 3,272 | 47,299 |
| **TOTAL** | **1,084,965** | **924,213** | **559,800** | **35,213** | **1,103,829** |

**Table 3.7: PSAS Building by Zone**

| Zone 1 (MSB 1) | Zone 2 (MSB 2) | Zone 3 (MSB 3) | Zone 4 (MSB 4) | Zone 5 (MSB 5) | Zone 6 (Individual Meter) |
|---|---|---|---|---|---|
| Block A | Block B | Block T1 | Block K2 | Block D | Block Q1 |
| Block C | Block K | Block T2 | Block K3 | Block G | Block Q2 |
| Block F | Block L | Block U | Block K4 | Blok H | Block Q3 |
| Block P | Block N | Block V1 | Block K5 | Blok J | Block R |
| Block P1 | Block X | Block V2 | Block L1 | Blok M | Block S1 |
| Block P2 | Block Y | Block V3 | Block L2 | Blok M1 | Block S2 |
| | Block Z | Block V4 | Block L3 | Blok M2 | Block W |
| | | Block V5 | Block L4 | Blok M3 | |
| | | Block V6 | Block L5 | | |
| | | | Block X1 | | |

## Table 3.8: PSAS Buildings List and Code

| NO | BUILDING | | NO OF FLOOR | GROSS FLOOR AREA |
|---|---|---|---|---|
| | CODE | NAME | | $m^2$ |
| 1 | A | Administration | 2 | 1,967 |
| 2 | B | Library | 2 | 3,774 |
| 3 | C | Main Lecture Hall | 1 | 650 |
| 4 | D | Training & Continuing Education Unit | 2 | 1,647 |
| 5 | F | Department of Computer, Sains and Mathematics & Department of General Studies | 3 | 6,600 |
| 6 | G | Canteen | 1 | 1,850 |
| 7 | H | Multipurpose Hall | 1 | 1,960 |
| 8 | J | Department of Commerce | 3 | 5,738 |
| 9 | K | Department of Civil Engineering | 3 | 4,677 |
| 10 | K2 | Workshop / Laboratory of Civil Engineering | 1 | 810 |
| 11 | K3 | Workshop / Laboratory of Civil Engineering | 1 | 1,404 |
| 12 | K4 | Workshop / Laboratory of Civil Engineering | 1 | 702 |
| 13 | K5 | Workshop / Laboratory of Civil Engineering | 1 | 751 |
| 14 | L | Department of Mechanical Engineering | 4 | 8,480 |
| 15 | L1 | Workshop / Laboratory of Mechanical Engineering | 1 | 1,188 |
| 16 | L2 | Workshop / Laboratory of Mechanical Engineering | 1 | 1,296 |
| 17 | L3 | Workshop / Laboratory of Mechanical Engineering | 1 | 1,296 |
| 18 | L4 | Workshop / Laboratory of Mechanical Engineering | 1 | 1,296 |
| 19 | L5 | Workshop / Laboratory of Mechanical Engineering | 1 | 1,323 |
| 20 | M | Department of Electrical Engineering | 5 | 10,722 |
| 21 | M1 | Workshop / Laboratory of Electrical Engineering | 1 | 648 |
| 22 | M2 | Workshop / Laboratory of Electrical Engineering | 1 | 1,404 |
| 23 | M3 | Workshop / Laboratory of Electrical Engineering | 1 | 972 |
| 24 | N | Department of Student Affairs | 2 | 993 |
| 25 | P | Sports & Co-curricular Unit | 1 | 1,548 |
| 26 | P1 | Sports Unit Store | 1 | 250 |
| 27 | P2 | Sports & Co-curricular Office | 1 | 225 |
| 28 | Q1 | Staff Quarters | 5 | 7,039 |
| 29 | Q2 | Staff Quarters | 5 | 7,039 |
| 30 | Q3 | Staff Quarters | 5 | 7,039 |
| 31 | R | Staff Quarters | 5 | 2,533 |
| 32 | S1 | Staff Quarters | 5 | 5,186 |
| 33 | S2 | Staff Quarters | 5 | 5,186 |
| 34 | T1 | Cafetaria Hostel (Kamsis) | 1 | 2,080 |
| 35 | T2 | Warden Office | 1 | 587 |
| 36 | U | Islamic Centre | 2 | 1,486 |
| 37 | V1 | Kamsis & Warden House | 4 | 4,727 |
| 38 | V2 | Kamsis & Warden House | 4 | 4,727 |
| 39 | V3 | Kamsis & Warden House | 4 | 4,727 |
| 40 | V4 | Kamsis & Warden House | 4 | 4,727 |
| 41 | V5 | Kamsis & Warden House | 4 | 4,727 |
| 42 | V6 | Kamsis & Warden House | 4 | 4,727 |
| 43 | W | Guard Post | 1 | 26 |
| 44 | X / BB | Construction & Maintenance Unit | 1 | 185 |
| 45 | X1 | Central Store | 1 | 230 |
| 46 | Y | Main Store | 1 | 486 |
| 47 | Z | Garage | 1 | 362 |
| **TOTAL** | | | | **131,997** |

### 3.4.4 Detailed Energy Audit at Academic Buildings

At this research stage, an energy audit only is focused on four significant academic buildings known as the Mechanical Engineering Department (MED), Civil Engineering Department (CED), Electrical Engineering Department (EED), and Commerce Department (CD) without showing detailed energy audit data in support departments such as the Department of Science, Mathematics & Computer and the Department of General Studies. Details of energy consumption data in these supporting departments are not shown as these two departments do not have classrooms and students in the buildings to supervise. Energy audits in academic buildings will collect data based on five categories of active equipment: laboratory equipment, fans, lighting, air conditioning, and ICT equipment. Figure 3.5 shows the location of the four foremost academics in PSAS buildings from the top view.

**Table 3.9: Baseline data for academic buildings imported from EMS (2019)**

| Meter No. | Building | Annual Energy Consumption (kWh) |
|---|---|---|
| | | 2018 |
| PSAS-2-M1 | Mechanical Engineering Department **(MED)** | 251,110 |
| PSAS-2-M5 | Workshop / Laboratory Mechanical Engineering L1 | 35,283 |
| PSAS-4-M2 | Workshop / Laboratory Mechanical Engineering L2 | 6,841 |
| PSAS-4-M11 | Workshop / Laboratory Mechanical Engineering L3 | 11,634 |
| PSAS-4-M1 | Workshop / Laboratory Mechanical Engineering L4 | 9,025 |
| PSAS-4-M10 | Workshop / Laboratory Mechanical Engineering L5 | 13,431 |
| | **Total MED** | **327,324** |
| PSAS-2-M6 | Civil Engineering Department **(CED)** | 151,085 |
| PSAS-4-M9 | Workshop / Laboratory Civil Engineering K2 | 5,703 |
| PSAS-4-M7 | Workshop / Laboratory Civil Engineering K3 | 1,473 |
| PSAS-4-M6 | Workshop / Laboratory Civil Engineering K4 | 9,411 |

| | | |
|---|---|---|
| PSAS-4-M8 | Workshop / Laboratory Civil Engineering K5 | 5,796 |
| | **Total CED** | **173,468** |
| PSAS-5-M10 | Electrical Engineering Department **(EED)** | 356,635 |
| PSAS-5-M5 | Workshop / Laboratory Electrical Engineering M1 | 33,822 |
| PSAS-5-M8 | Workshop Electrical Engineering Department M2 | 14,643 |
| PSAS-5-M1 | Workshop Electrical Engineering Department M3 | 65,489 |
| | **Total EED** | **470,589** |
| PSAS-5-M2 | Commerce Department **(CD)** | **201,878** |
| | Total Energy Consumption 4 main department | **1,173,259** |

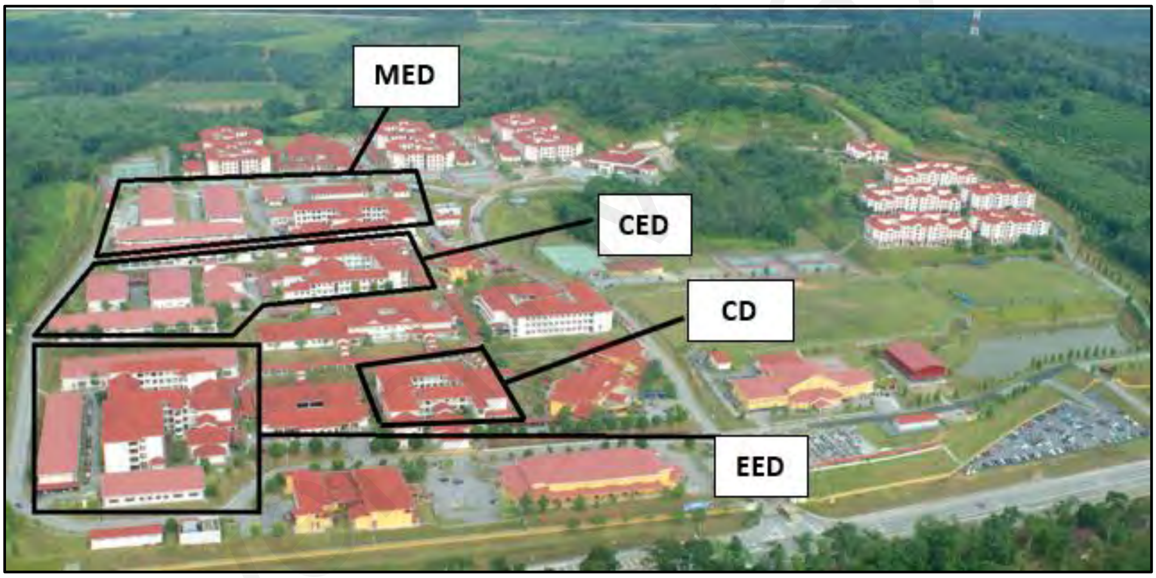



**Figure 3.5: The location of 4 foremost academics in PSAS buildings from the top view**

### 3.4.4.1 Data collection at Mechanical Engineering Department

Tables 3.10, 3.11, 3.12, 3.13, and 3.15 show the details of the collected data related to the type, quantity, power consumption, and estimated operating hours per year for the equipment located in MED. These data refer to MED's laboratory equipment, fan, lighting, air-conditioning, and Information and Communication Technology (ICT). The estimated operating hours for laboratory equipment in Table 3.10 have been calculated using equation (3.2). The working hour for equipment per day is acquired from the Head of the Program and lecturers MED. The calculation of the number of operating equipment days (ON) in a year is based on 32 weeks of lectures without considering days on weekends. Public holidays during the relevant lecture sessions should be considered when making the analysis. In 2019, only three public holidays fell during the lecture session. The estimated operating hours for fan and lighting in Tables 3.11 and 3.12 has been calculated based on the total time the active equipment operates daily is 8 hours. The number of days in 1 year of operation of fans and lights (ON) is calculated based on the next 32 weeks of lectures plus four weeks of the final exam period.

However, the total estimated operating hours must assume half because not all the fans run simultaneously. The estimated operating hours for air-conditioning (ACSU) in Table 3.13 and Table 3.14 has been calculated based on the active period of equipment operation for a day is 9 hours, while 8 hours for WCPU (8.30 am until 4.30 pm). The total number of days in 1 year for air-conditioning operation (ON) is calculated based on 52, 42, and 32 weeks, referring to the capacity (horsepower) and their consumer group. The total number of public holidays for the 52 and 42-week lecture sessions is the same, which is 14 days. Table 3.14 shows the code, power, and estimated operating hours for the Air Handling Unit (AHU) - WCPU under Cooling Tower no. 2. The daily active period of air conditioners is counted only half because not all air conditioners are turned on at the same time. Table 3.16 summarises the data collection summary for five types of active equipment at MED. The estimated operating hours for fan, lighting, air-conditioning, and ICT equipment in other academic departments will follow the same value applied to MED.

**Table 3.10: Types, quantity, rating power, and operating hours for laboratory equipment at MED**

| No | Types of Equipment | Quantity | Power (kW) | Estimated Operating Hours (h/year) |
|---|---|---|---|---|
| 1 | Cleaning Machine | 3 | 1.1 | 314 |
| 2 | Audio Amplifier and Mixer | 2 | 0.12 | 126 |
| 3 | Lab Grinder Machine | 2 | 0.75 | 1,005 |

| | | | | |
|---|---|---|---|---|
| 4 | DC Power Supply | 14 | 0.1 | 502 |
| 5 | Microscope | 14 | 0.02 | 251 |
| 6 | Workstation Mobile for Pneumatic and Electro-Pneumatic | 3 | 0.48 | 628 |
| 7 | CNC Machine | 4 | 6 | 314 |
| 8 | Cutting Machine | 4 | 5 | 1,005 |
| 9 | Air Compressor | 5 | 2 | 628 |
| 10 | Grinding Machine | 7 | 3.7 | 502 |
| 11 | Lathe Wood Machine | 30 | 0.37 | 1,005 |
| 12 | Shears Machine | 10 | 3 | 251 |
| 13 | Milling Machine | 8 | 1 | 1,005 |
| 14 | Industry Stand Fan | 2 | 0.12 | 628 |
| 15 | Saw Machine | 1 | 2.9 | 1,005 |
| 16 | Welding Machine | 60 | 1.1 | 502 |
| 17 | Arc Welding Machine | 3 | 5 | 1,005 |
| 18 | Rapid Prototype 3D printer | 1 | 1.62 | 251 |
| 19 | Oscilloscope | 4 | 0.04 | 126 |
| 20 | Dryer | 2 | 0.2 | 251 |
| 21 | Cartesian Robot | 1 | 4 | 126 |
| 22 | Revolute Robot | 1 | 1 | 251 |
| 23 | Scara robot | 1 | 1.8 | 126 |
| 24 | Cutter Machine | 1 | 1.5 | 251 |
| 25 | Electric Hand Drill | 3 | 0.55 | 502 |
| 26 | Mechanical/Civil Engineering Set Kit | 713 | 0.1 | 126 |
| 27 | Automotive Engineering Set Kit | 120 | 0.1 | 126 |
| 28 | Wheel Alignment System | 1 | 0.37 | 502 |
| 29 | Pneumatic Tyre Changer Machine | 1 | 0.75 | 251 |
| 30 | Tester Machine | 1 | 0.38 | 251 |
| **TOTAL** | | **1022** | **45.17** | |

**Table 3.11: Types, quantity, rating power, and operating hours for a fan at MED**

| No | Types of Fan | Quantity | Power (kW) | Estimated Operating Hours (h/year) |
|---|---|---|---|---|
| 1 | Ceiling | 94 | 0.075 | 708 |
| 2 | Wall Mounted | 14 | 0.2 | 708 |
| 3 | Stand | 5 | 0.024 | 708 |
| **TOTAL** | | **113** | **0.299** | |

**Table 3.12: Types, quantity, rating power, and operating hours for lighting at MED**

| No | Types of End-load Lighting | Quantity | Power (kW) | Estimated Operating Hours (h/year) |
|---|---|---|---|---|
| 1 | T8 36W | 1209 | 0.036 | 708 |
| 2 | T8 18W | 204 | 0.018 | 708 |
| 3 | CFL 24W | 23 | 0.024 | 708 |

| | | | | |
|---|---|---|---|---|
| 4 | MH 400W | 155 | 0.4 | 708 |
| 5 | Ttube 18W | 650 | 0.018 | 708 |
| **TOTAL** | | **2241** | **0.496** | |

**Table 3.13: Types, quantity, rating power, and operating hours for air-conditioning ACSU at MED**

| No | Capacity (Horsepower) | Quantity | Power | Estimated Operating Hours |
|---|---|---|---|---|
| | | | (kW) | (h/year) |
| 1 | 1 hp | 1 | 0.746 | 2,214 |
| 2 | 1.5 hp | 4 | 1.119 | 1,764 |
| 3 | 2 hp | 20 | 1.491 | 707 |
| 4 | 2.5 hp | 11 | 1.864 | 707 |
| 5 | 3 hp | 8 | 2.237 | 707 |
| 6 | 4 hp | 5 | 2.982 | 707 |
| 7 | 5 hp | 5 | 3.729 | 707 |
| **Total** | | **54** | **14.168** | |

**Table 3.14: Code, power, and estimated operating hours for Air Handling Unit (AHU) - WCPU under CT 2 for MED**

| No | Code | Power | Estimated Operating Hours |
|---|---|---|---|
| | | (kW) | (Annual) |
| 1 | L-0-46 | 12.7 | 784 |
| 2 | L-1-47 | 14.2 | 784 |
| 3 | L-2-48 | 12.7 | 784 |
| 4 | L-0-49A | 9.5 | 784 |
| 5 | L-0-49B | 6.24 | 784 |
| **TOTAL** | | **55.34** | |

**Table 3.15: Types, quantity, rating power, and operating hours for ICT equipment at MED**

| No | Equipment | Quantity | Power | Average Operating Hours |
|---|---|---|---|---|
| | | | (kW) | (h/year) |
| 1 | Desktop (assets) | 108 | 0.036 | 628 |
| 2 | Administration Computer | 52 | 0.036 | 784 |
| 3 | Notebook | 12 | 0.024 | 784 |
| 4 | Laser Printer | 13 | 0.25 | 196 |
| 5 | Scanner | 1 | 0.032 | 392 |
| **TOTAL** | | **186** | **0.378** | |

**Table 3.16: Summary of the data collection for five types of active equipment at MED**

| No | End-load | Quantity | Total Power (kW) | Average Operating Hours (h/year) |
|---|---|---|---|---|
| 1 | Laboratory Equipment | 1022 | 45.17 | 318 |
| 2 | Fan | 113 | 0.299 | 708 |
| 3 | Lighting | 2241 | 0.496 | 708 |
| 4 | Air-conditioning (ACSU+WCPU) | 59 | 73.008 | 928 |
| 5 | ICT Equipment | 186 | 0.378 | 309 |
| **TOTAL** | | **3621** | **119.351** | |

#### 3.4.4.2 Data collection at Civil Engineering Department

Tables 3.17, 3.18, 3.19, 3.20, and 3.22 show the details of the collected data related to the type, quantity, power consumption, and estimated average operating hours per year for the equipment located in CED. These data refer to CED's laboratory equipment, fan, lighting, air-conditioning, and Information and Communication Technology (ICT). The estimated operating hours for laboratory equipment in Table 3.17 have been calculated using equation (3.2). The working hours of the equipment each day were obtained from the Assistant Engineer and the CED lecturer. Calculating the number of equipment operating days (ON) in a year refers to 13 and 42 weeks of lectures without considering days on weekends. Based on a survey, the lecturer or person in charge of the laboratory is stated for specific equipment; it operates for a short period and mainly for two experiments. Table 3.21 shows the code, power, and estimated operating hours for Air Handling Unit (AHU) - WCPU under Cooling Tower no. 2 for CED. Table 3.23 summarises the data collection for five types of active equipment at MED.

**Table 3.17: Types, quantity, rating power, and operating hours for laboratory equipment at CED**

| No | Types of Equipment | Quantity | Power (kW) | Estimated Operating Hours (h/year) |
|---|---|---|---|---|
| 1 | Universal Oven | 4 | 1.6 | 366 |

| | | | | |
|---|---|---|---|---|
| 2 | Incubator | 1 | 0.86 | 488 |
| 3 | Lab Mixer | 1 | 0.75 | 828 |
| 4 | Lab Grinder Machine | 1 | 0.75 | 828 |
| 5 | Sieve Shaker | 7 | 0.08 | 828 |
| 6 | Balance / Scaler | 4 | 0.015 | 621 |
| 7 | Dissolved Oxygen Meter | 1 | 0.1 | 621 |
| 8 | Triaxial Test Apparatus | 1 | 0.3 | 621 |
| 9 | Motorized Casagrande Device | 4 | 0.03 | 207 |
| 10 | Multi-Purpose Teaching Flume / Flow Channel | 1 | 0.65 | 244 |
| 11 | Liquid limit Cone Penetrometer | 2 | 0.1 | 183 |
| 12 | Vacuum Pump | 2 | 0.75 | 244 |
| 13 | Drilling Machine | 1 | 3.6 | 305 |
| 14 | Air Compressor | 1 | 2 | 244 |
| 15 | Hot Air Gun | 2 | 2 | 244 |
| 16 | Lathe Wood Machine | 1 | 0.37 | 183 |
| 17 | Saw Machine | 10 | 2.9 | 305 |
| 18 | Dryer | 4 | 2.1 | 183 |
| 19 | Concrete Mixer | 2 | 1.5 | 244 |
| 20 | Dowel Boring Machine | 1 | 4 | 244 |
| 21 | Electric Hand Drill | 8 | 0.55 | 244 |
| 22 | Pneumatic Angle Polisher | 2 | 0.36 | 183 |
| 23 | Field Density Apparatus | 2 | 0.04 | 183 |
| 24 | Specific Gravity Apparatus | 2 | 0.03 | 183 |
| 25 | Unconfined Compression Apparatus | 1 | 0.19 | 183 |
| 26 | Air Hammer Drill | 2 | 0.5 | 122 |
| 27 | Brick Cutting Machine | 2 | 5.5 | 244 |
| 28 | Cone Penetration | 1 | 0.1 | 122 |
| 29 | Ring and Ball Apparatus | 1 | 0.7 | 244 |
| 30 | Automatic Marshall Compactor | 1 | 0.37 | 244 |
| 31 | Marshall Specimen Water Bath | 1 | 1 | 244 |
| 32 | Flow Channel | 1 | 0.65 | 183 |
| 33 | Hydraulic Bench | 1 | 0.3 | 183 |
| 34 | Spectrophotometer | 2 | 0.01 | 122 |
| 35 | JAR Test Apparatus | 1 | 0.08 | 122 |
| 36 | Hollow Chisel Mortising Machine | 1 | 2.2 | 244 |
| 37 | Radial Arm Saw | 1 | 2.9 | 549 |
| 38 | Jointer | 1 | 2.23 | 549 |
| 39 | Thickness Planer Machine | 1 | 7.5 | 244 |
| 40 | Universal Testing Machine | 1 | 0.76 | 244 |
| 41 | Time recorder machine | 1 | 0.01 | 1863 |
| 42 | LCD Projector | 4 | 0.37 | 1656 |
| 43 | Television | 7 | 0.3 | 828 |
| 44 | Portable PA System | 1 | 0.3 | 122 |
| 45 | Domestic Refrigerator | 3 | 0.93 | 2200 |
| **TOTAL** | | **100** | **52.34** | |

**Table 3.18: Types, quantity, rating power, and operating hours for a fan at CED**

| No | Types of Fan | Quantity | Power (kW) | Estimated Operating Hours (h/year) |
|---|---|---|---|---|
| 1 | Ceiling | 93 | 0.075 | 708 |
| 2 | Wall Mounted | 8 | 0.2 | 708 |
| 3 | Stand | 8 | 0.024 | 708 |
| **TOTAL** | | **109** | **0.299** | |

**Table 3.19: Types, quantity, rating power, and operating hours for lighting at CED**

| No | Types of End-load Lighting | Quantity | Power (kW) | Estimated Operating Hours (h/year) |
|---|---|---|---|---|
| 1 | T8 36W | 404 | 0.036 | 708 |
| 2 | T8 18W | 52 | 0.018 | 708 |
| 3 | CFL 24W | 35 | 0.024 | 828 |
| 4 | MH 400W | 75 | 0.4 | 828 |
| 5 | Ttube 18W | 775 | 0.018 | 708 |
| **TOTAL** | | **1341** | **0.496** | |

**Table 3.20: Types, quantity, rating power, and operating hours for air-conditioning (ACSU) at CED**

| No | Capacity (Horse Power) | Quantity | Power (kW) | Estimated Operating Hours (h/year) |
|---|---|---|---|---|
| 1 | 1 hp | 2 | 0.746 | 2214 |
| 2 | 1.5 hp | 6 | 1.119 | 2214 |
| 3 | 2 hp | 3 | 1.491 | 2214 |
| **Total** | | **11** | **3.356** | |

**Table 3.21: Code, power, and estimated operating hours for Air Handling Unit (AHU) - WCPU under CT 2 for CED**

| No | Code | Power (kW) | Estimated Operating Hours (Annual) |
|---|---|---|---|
| 1 | K-0-42 | 14.3 | 784 |
| 2 | K-1-43 | 12.3 | 784 |
| 3 | K-2-44 | 18.7 | 784 |
| **TOTAL** | | **45.3** | |

**Table 3.22: Types, quantity, rating power, and operating hours for ICT at CED**

| No | Equipment | Quantity | Power (kW) | Estimated Operating Hours (h/year) |
|---|---|---|---|---|
| 1 | Desktop (assets) | 35 | 0.036 | 628 |
| 2 | Administration Computer | 31 | 0.036 | 784 |
| 3 | Notebook | 9 | 0.024 | 784 |
| 4 | Laser Printer | 5 | 0.25 | 294 |
| 5 | Bubble Jet Printer | 1 | 0.033 | 294 |
| 6 | Dot Matrix Printer | 1 | 0.06 | 294 |
| 7 | Plotter Printer | 1 | 0.12 | 294 |
| 8 | Scanner | 2 | 0.032 | 588 |
| **TOTAL** | | **85** | **0.591** | |

**Table 3.23: Summary of the data collection for five types of active equipment at CED**

| No | End-load | Quantity | Total Power (kW) | Average Operating Hours (h/year) |
|---|---|---|---|---|
| 1 | Laboratory Equipment | 100 | 52.335 | 430 |
| 2 | Fan | 109 | 0.299 | 708 |
| 3 | Lighting | 1341 | 0.496 | 756 |
| 4 | Air-conditioning (ACSU+WCPU) | 14 | 48.656 | 1499 |
| 5 | ICT Equipment | 85 | 0.591 | 495 |
| **TOTAL** | | **1649** | **102.377** | |

### 3.4.4.3 Data collection at Electrical Engineering Department

Tables 3.24, 3.25, 3.26, 3.27, and 3.29 show the type, quantity, power consumption, and estimated average operating hours per year for laboratory equipment, fan, lighting, air-conditioning, and Information and Communication Technology (ICT), respectively, for EED. The estimated operating hours for laboratory equipment in Table 3.24 have been calculated using equation (3.2), where the period the equipment operates in a day is obtained from the EED lecturer. The total number of days in 1 year of operating equipment (ON) is calculated based on 16 days (8 days and two sessions) and 32 weeks of lectures excluding days on weekend holidays. Table 3.28 shows the code, power, and estimated operating hours for Air Handling Unit (AHU) - WCPU under Cooling Tower no. 1 for EED. Table 3.30 summarises the data collection for five types of active equipment at EED.

**Table 3.24: Types, quantity, rating power, and operating hours for laboratory equipment at EED**

| No | Types of Equipment | Quantity | Power (kW) | Estimated Operating Hours (h/year) |
|---|---|---|---|---|
| 1 | Cleaning Machines | 9 | 1.1 | 52 |
| 2 | LCD Projector | 5 | 0.37 | 1256 |
| 3 | Speaker | 5 | 0.02 | 52 |
| 4 | Portable PA System | 1 | 0.3 | 52 |
| 5 | Universal Oven | 4 | 0.8 | 52 |
| 6 | Plotter | 1 | 0.15 | 52 |
| 7 | Isolation Transformer | 14 | 0.72 | 1256 |
| 8 | Solar Panel System | 1 | 0.23 | 628 |
| 9 | AC Power Supply | 38 | 0.15 | 1256 |
| 10 | Generating Station Simulation Lab | 1 | 0.324 | 628 |
| 11 | Mobile Radio | 1 | 0.05 | 52 |
| 12 | Audio Splitter | 3 | 0.06 | 52 |
| 13 | Mixer | 1 | 0.5 | 68 |
| 14 | Test Pattern Generator | 10 | 0.01 | 52 |
| 15 | Air Compressor | 4 | 2 | 628 |
| 16 | Grinding Machine | 3 | 1.1 | 628 |
| 17 | Electrical Machine Trainer | 8 | 0.375 | 628 |
| 18 | Pillar Drilling Machine | 4 | 0.8 | 68 |
| 19 | Digital Frequency Counter | 2 | 0.55 | 1256 |
| 20 | Signal Generator | 155 | 0.005 | 628 |
| 21 | Oscilloscope | 226 | 0.04 | 628 |
| 22 | Static Relay and Relay Protection | 3 | 0.22 | 628 |
| 23 | Motor Fault Simulator (MV 1046 3-Phase Squirrel Cage Motor) | 1 | 0.55 | 628 |
| 24 | UV Expose Units | 8 | 1 | 628 |
| 25 | Electric Machine | 14 | 0.375 | 628 |
| 26 | Electric Hand Drill | 88 | 0.55 | 628 |
| 27 | Programmable Logic Controller | 20 | 0.5 | 628 |
| 28 | Electro-Pneumatic Trainer + Portable Compressor | 3 | 1.8 | 628 |
| **TOTAL** | | **633** | **14.649** | |

**Table 3.25: Types, quantity, rating power, and operating hours for a fan at EED**

| No | Types of Fan | Quantity | Power (kW) | Estimated Operating Hours (h/year) |
|---|---|---|---|---|
| 1 | Ceiling | 68 | 0.075 | 708 |
| 2 | Wall Mounted | 20 | 0.2 | 708 |

| | | | | |
|---|---|---|---|---|
| 3 | Stand | 14 | 0.024 | 708 |
| **TOTAL** | | **102** | **0.299** | |

**Table 3.26: Types, quantity, rating power, and operating hours for lighting at EED**

| No | Types of End-load Lighting | Quantity | Power (kW) | Estimated Operating Hours (h/year) |
|---|---|---|---|---|
| 1 | T8 36W | 1260 | 0.036 | 828 |
| 2 | T8 18W | 135 | 0.018 | 708 |
| 3 | CFL 24W | 13 | 0.024 | 828 |
| 4 | MH 400W | 42 | 0.4 | 828 |
| 5 | Ttube 18W | 800 | 0.018 | 828 |
| **TOTAL** | | **2250** | **0.496** | |

**Table 3.27: Types, quantity, rating power, and operating hours for air-conditioning at EED**

| No | Capacity (Horse Power) | Quantity | Power (kW) | Estimated Operating Hours (h/year) |
|---|---|---|---|---|
| 1 | 1 hp | 1 | 0.746 | 2,214 |
| 2 | 1.5 hp | 18 | 1.119 | 2,214 |
| 3 | 2 hp | 43 | 1.491 | 1,764 |
| 4 | 3 hp | 15 | 2.237 | 1,764 |
| **Total** | | **77** | **5.593** | |

**Table 3.28: Code, power, and estimated operating hours for Air Handling Unit (AHU) - WCPU under CT 1 for EED**

| No | Code | Power (kW) | Estimated Operating Hours (Annual) |
|---|---|---|---|
| 1 | M-0-16 | 8.82 | 784 |
| 2 | M-0-17 | 12.3 | 784 |
| 3 | M-2-18 | 13.1 | 784 |
| 4 | M-1-20 | 4.09 | 784 |
| 5 | M-2-21 | 8.3 | 784 |
| 6 | M-0-24A | 12.4 | 784 |
| 7 | M-0-24B | 17.8 | 784 |
| 8 | M-1-25B | 8.4 | 784 |
| 9 | M-1-25B | 8.4 | 784 |
| 10 | M-2-26A | 8.6 | 784 |
| 11 | M-2-26B | 4.1 | 784 |
| 12 | DK-28 | 7.9 | 392 |
| **TOTAL** | | **76.93** | |

**Table 3.29: Types, quantity, rating power, and operating hours for ICT at EED**

| No | Equipment | Quantity | Power (kW) | Estimated Operating Hours (h/year) |
|---|---|---|---|---|
| 1 | Administration Computer | 42 | 0.036 | 784 |
| 2 | Lab Computer (rent) | 20 | 0.018 | 784 |
| 3 | Notebook | 2 | 0.024 | 784 |
| 4 | Laser Printer | 1 | 0.25 | 294 |
| 5 | Bubble Jet Printer | 1 | 0.033 | 294 |
| 6 | Plotter Printer | 1 | 0.12 | 294 |
| 7 | Scanner | 2 | 0.018 | 294 |
| **TOTAL** | | **66** | **0.361** | |

**Table 3.30: Summary of the data collection for five types of active equipment at EED**

| No | End-load | Quantity | Total Power (kW) | Average Operating Hours (h/year) |
|---|---|---|---|---|
| 1 | Laboratory Equipment | 633 | 14.649 | 436 |
| 2 | Fan | 102 | 0.299 | 708 |
| 3 | Lighting | 2250 | 0.496 | 804 |
| 4 | Air-conditioning (ACSU+WCPU) | 89 | 163.653 | 1375 |
| 5 | ICT Equipment | 66 | 0.361 | 588 |
| **TOTAL** | | **3140** | **179.458** | |

### 3.4.4.4 Data collection at Commerce Department

Tables 3.31, 3.32, 3.33, 3.34, and 3.36 shows details on the type, quantity, power consumption, and estimated operating hours per year for laboratory equipment, fan, lighting, air-conditioning, and Information and Communication Technology (ICT), respectively, for CD. The estimated average operating hours for laboratory equipment in Table 3.31 have been calculated using equation (3.2). The period the equipment operates actively daily is obtained from the Head of the Department himself. The total number of operating equipment days (ON) in a year is calculated based on 42 weeks of lectures because most equipment is located in the Centre of Retail Excellence (CORE). This CORE is a simulation laboratory for business programs, and its operating hours differ from other academic department laboratories. Table 3.35 shows the code, power, and estimated operating hours for Air Handling Unit (AHU) - WCPU under Cooling Tower no. 1 for CD. Table 3.37 summarises the data collection for five types of active equipment at CD.

**Table 3.31**: **Types, quantity, rating power, and operating hours for laboratory equipment at CD**

| No | Types of Equipment | Quantity | Power (kW) | Average Operating Hours (h/year) |
|---|---|---|---|---|
| 1 | Cashier Machine | 1 | 0.02 | 1,656 |
| 2 | Garment Steamer | 1 | 1.7 | 828 |
| 3 | Audio Amplifier and Mixer | 4 | 2 | 828 |
| 5 | Projection Screen | 1 | 0.287 | 414 |
| 6 | PA System | 1 | 0.3 | 1,242 |
| 7 | Microwave | 1 | 1.2 | 828 |
| 8 | Bakery Refrigerator | 1 | 0.726 | 3,598 |
| 9 | Display Chiller Refrigerator 3 Door | 1 | 2.2 | 5,110 |
| 10 | LCD Projector | 1 | 0.37 | 828 |
| 11 | TV Box | 1 | 0.05 | 1,242 |
| 12 | Electric Stoves | 1 | 1.2 | 621 |
| 13 | Water Dispenser | 1 | 1.5 | 1,656 |
| 14 | Electronic White Board | 1 | 0.5 | 1,656 |
| 15 | Chocolate Warmer | 1 | 1.2 | 1,656 |
| 16 | Food Warmer | 1 | 0.75 | 1,656 |
| 17 | Hot Water Dispenser | 1 | 0.85 | 414 |
| 18 | Chocolate Warmer | 1 | 1 | 1,656 |
| 19 | Chiller and Freezer 2 Door | 1 | 1.5 | 5,110 |
| 20 | Retail Shop Billing Machine | 1 | 0.1 | 1,656 |
| 21 | Microphone System | 12 | 0.285 | 1,656 |
| 22 | Controller video conferencing | 1 | 0.58 | 1,656 |
| **TOTAL** | | **35** | **18.32** | |

**Table 3.32: Types, quantity, rating power, and operating hours for a fan at CD**

| No | Types of Fan | Quantity | Power (kW) | Average Operating Hours (h/year) |
|---|---|---|---|---|
| 1 | Ceiling | 56 | 0.075 | 828 |
| 2 | Wall Mounted | 15 | 0.2 | 708 |
| 3 | Stand | 17 | 0.024 | 828 |

| TOTAL | 88 | 0.299 | |
|---|---|---|---|

**Table 3.33: Types, quantity, rating power, and operating hours for lighting at CD**

| No | End-load | Quantity | Power | Average Operating Hours |
|---|---|---|---|---|
| | | | (kW) | (h/year) |
| 1 | T8 36W | 534 | 0.036 | 1656 |
| 2 | T8 18W | 50 | 0.018 | 1656 |
| 3 | CFL 24W | 13 | 0.024 | 2190 |
| 4 | Ttube 18W | 450 | 0.018 | 1656 |
| **TOTAL** | | **1047** | **0.078** | |

**Table 3.34: Types, quantity, rating power, and operating hours for air-conditioning at CD**

| No | Capacity (Horsepower) | Quantity | Power | Average Operating Hours |
|---|---|---|---|---|
| | | | (kW) | (Annual) |
| 1 | 1 hp | 1 | 0.746 | 1764 |
| 2 | 1.5 hp | 6 | 1.119 | 2214 |
| 3 | 2 hp | 4 | 1.491 | 2214 |
| 4 | 3 hp | 2 | 2.237 | 2214 |
| **Total** | | **13** | **5.593** | |

**Table 3.35: Code, power, and estimated operating hours for Air Handling Unit (AHU) - WCPU under CT 1 for CD**

| No | Code | Power | Estimated Operating Hours |
|---|---|---|---|
| | | (kW) | (Annual) |
| 1 | J-0-9 | 11.4 | 784 |
| 2 | J-1-10 | 13.9 | 784 |
| 3 | J-2-11 | 13.5 | 784 |
| 4 | J-0-12A | 7.75 | 784 |
| 5 | J-0-12B | 9.09 | 784 |
| 6 | J-1-13A | 5.68 | 784 |
| 7 | J-1-13B | 7.9 | 784 |
| 8 | DK-15 | 5.3 | 784 |
| **TOTAL** | | **74.52** | |

**Table 3.36: Types, quantity, rating power, and operating hours for ICT at CD**

| No | Equipment | Quantity | Power | Estimated Operating Hours |
|---|---|---|---|---|
| | | | (kW) | (h/year) |
| 1 | Desktop (assets) | 1 | 0.036 | 1,242 |
| 2 | Administration Computer | 27 | 0.036 | 784 |
| 3 | Notebook | 2 | 0.024 | 784 |
| 4 | Laser Printer | 2 | 0.25 | 311 |
| **TOTAL** | | **32** | **0.346** | |

**Table 3.37: Summary of the data collection for five types of active equipment at CD**

| No | End-load | Quantity | Total Power | Average Operating Hours |
|---|---|---|---|---|
| | | | (kW) | (h/year) |
| 1 | Laboratory Equipment | 35 | 18.32 | 1,124 |
| 2 | Fan | 88 | 0.299 | 788 |
| 3 | Lighting | 1047 | 0.078 | 1432 |
| 4 | Air-conditioning (ACSU+WCPU) | 18 | 80.113 | 782 |
| 5 | ICT Equipment | 32 | 0.346 | 780 |
| **TOTAL** | | **1220** | **110.636** | |

**Table 3.38: Summary of the data collection for five types of active equipment at MED, CED, EED, and CD.**

| . | End-load | Department | Quantity | Total Power | Average Operating Hours |
|---|---|---|---|---|---|
| | | | | (kW) | (h/year) |
| 1 | Laboratory Equipment | MED | 1022 | 45.17 | 318 |
| | | CED | 100 | 52.335 | 430 |
| | | EED | 633 | 14.649 | 436 |
| | | CD | 35 | 18.32 | 1124 |
| 2 | Fan | MED | 113 | 0.299 | 708 |
| | | CED | 109 | 0.299 | 708 |
| | | EED | 102 | 0.299 | 708 |
| | | CD | 88 | 0.299 | 788 |
| 3 | Lighting | MED | 2241 | 0.496 | 708 |
| | | CED | 1341 | 0.496 | 756 |

| | | | | | |
|---|---|---|---|---|---|
| | | EED | 2250 | 0.496 | 804 |
| | | CD | 1047 | 0.078 | 1432 |
| 4 | Air-conditioning (ACSU + WCPU) | MED | 59 | 73.008 | 928 |
| | | CED | 14 | 48.656 | 1499 |
| | | EED | 89 | 163.653 | 1375 |
| | | CD | 18 | 80.113 | 782 |
| 5 | ICT Equipment | MED | 186 | 0.378 | 309 |
| | | CED | 85 | 0.591 | 495 |
| | | EED | 66 | 0.361 | 588 |
| | | CD | 32 | 0.346 | 780 |
| **TOTAL** | | MED | **3621** | **119.351** | |
| | | CED | **1649** | **102.377** | |
| | | EED | **3140** | **179.458** | |
| | | CD | **1220** | **99.156** | |

#### 3.4.4.5 Summary data collection at four academic buildings

Table 3.38 summarises the type, quantity, rated power, and average operating hours per year for the five end-load equipment in MED, CED, EED, and CD. The data summary for air conditioning involves two different types of systems, ACSU and WCPU, where the air-conditioning is connected to cooling tower no. 1 or 2. The estimated operating time of each listed equipment is calculated using equation (3.2). The busy time of equipment related to operating every day is obtained from interview sessions with lecturers, Program Heads, or Heads of Departments. The number of days in 1 year of operating equipment (ON) is calculated based on the total of 32 weeks of lectures without taking into account days off on weekends. In addition, public holidays that fall during the lecture week also need to be counted; in 2019, there are only three public holidays. Estimated operating hours for fans and lighting have been calculated by setting the total active operation per day for the following two appliances as 8 hours. The number of days involving the operation of fans and lighting (ON) in 1 year is calculated based on 32 weeks of lectures plus four weeks of final exams. However, the estimated operating time during the analysis is only half calculated because not all the equipment will operate simultaneously in a routine situation.

The estimated operating time of the air conditioning in this study has been calculated based on the total working hours per day, which is 9 hours. The number of days for controlled air conditioning (ON) in 1 year is calculated based on a specific lecture week of 52, 42, or 32 weeks. The number of lecture weeks is closely related to the air conditioning power capacity (horsepower) type and the user group that uses this equipment. The number of public holidays for a lecture week of 52 or 42 weeks is 14 days. The estimated operating time for air conditioners is assumed to be half because not all air conditioners are turned on simultaneously under normal conditions. The estimated operating hours per equipment for laboratory equipment, fans, lighting, air conditioning, and ICT have calculated the total energy consumption for the end load. The laboratory equipment is included equipment located in workshops. Average operating hours are the total number of active hours for each listed equipment group.

### 3.4.5 Detailed Energy Audit at Non-Academic Buildings

The research in this section aims to identify which type of equipment has the highest energy consumption in non-academic buildings. This identification process is carried out through the energy audit method on each active piece of equipment that has been set. The energy auditing process carried out on non-academic buildings is the same as the implementation in academic buildings where information collection is similar, except the other equipment replaces the laboratory equipment and does not involve ICT equipment. The energy audit analysis conducted on four end-load groups: fans, lighting, ACSU-type air conditioning, and other equipment. The study only focused on three non-academic buildings, namely the Islamic Center (IC), the Sports Center (SC), and the Multipurpose Hall (MH).

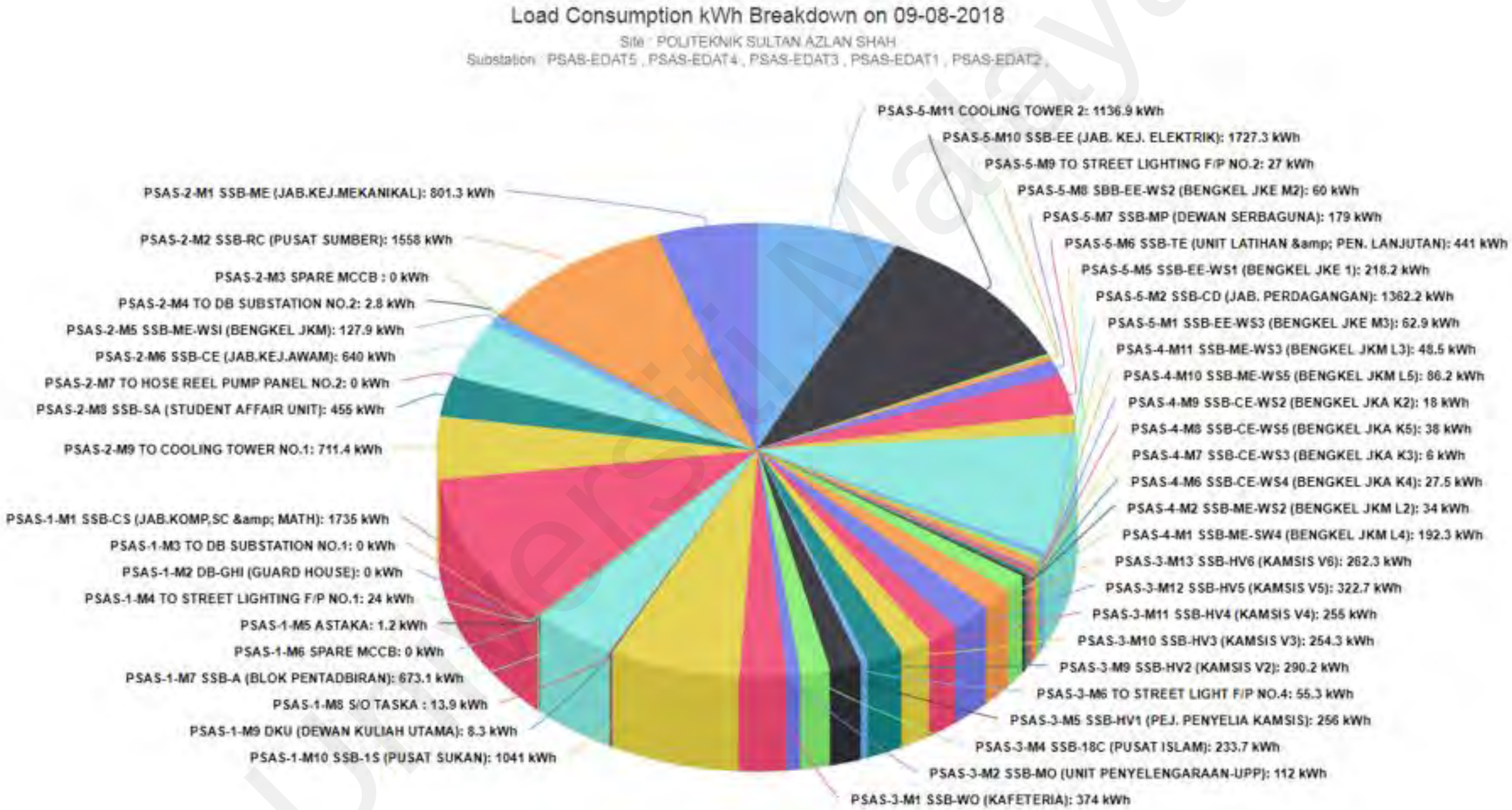



**Figure 3.6: Load consumption kWh breakdown on PSAS**

The selection of these three buildings is based on the building's operating hours, not only during office hours but also at night and on weekends. Although these three buildings are not academic, they are listed among the PSAS buildings with high energy consumption. In addition, another way to determine which non-academic building records the highest energy consumption is by referring to Figure 3.6 about load consumption kWh breakdown on PSAS. Figure 3.7 shows the location of three non-academic facilities from the top view.


**Figure 3.7: The location of 3 foremost non-academics in PSAS buildings from the top view**

#### 3.4.5.1 Data collection at Islamic Centre

Tables 3.39, 3.40, 3.41, and 3.42 show the type, quantity, power consumption, and estimated operating hours per year for fan, lighting, air-conditioning, and other equipment for Islamic Centre (IC). Table 3.43 summarises the data collection summary for four end-load types at IC.

**Table 3.39: Types, quantity, rating power, and operating hours for a fan at IC**

| No | Types of Fan | Quantity | Power (kW) | Estimated Operating Hours (h/year) |
|---|---|---|---|---|
| 1 | 26" Industrial Stand Fan | 17 | 0.18 | 708 |
| 2 | 26" Industrial Wall Fan | 23 | 0.22 | 708 |
| 3 | 16" Wall Fan | 12 | 0.05 | 708 |
| **TOTAL** | | **52** | **0.45** | |

**Table 3.40: Types, quantity, rating power, and operating hours for lighting at IC**

| No | Types of End-load Lighting | Quantity | Power (kW) | Estimated Operating Hours (h/year) |
|---|---|---|---|---|
| 1 | T8 36W | 7 | 0.04 | 828 |
| 2 | Downlight | 198 | 0.05 | 828 |
| **TOTAL** | | **205** | **0.09** | |

**Table 3.41: Types, quantity, rating power, and operating hours for air-conditioning (ACSU) at IC**

| No | Capacity (Horsepower) | Quantity | Power (kW) | Estimated Operating Hours (Annual) |
|---|---|---|---|---|
| 1 | 1 hp | 1 | 0.75 | 708 |
| 2 | 1.5 hp | 3 | 1.12 | 708 |
| 3 | 2 hp | 6 | 1.49 | 708 |
| 4 | 5 hp | 7 | 2.24 | 708 |
| **Total** | | **17** | **5.59** | |

**Table 3.42: Types, quantity, rating power, and operating hours for other equipment at IC**

| No | Types of Equipment | Quantity | Power (kW) | Estimated Operating Hours (h/year) |
|---|---|---|---|---|
| 1 | Water dispenser | 1 | 1.90 | 2200 |
| 2 | Refrigerator | 3 | 0.93 | 2200 |
| 3 | Vending Machine | 2 | 0.37 | 2200 |
| 4 | CCTV Camera | 1 | 0.06 | 2200 |
| 5 | Freezer | 1 | 0.15 | 2200 |
| 6 | Television 50" | 1 | 0.10 | 1680 |
| 7 | PA System | 1 | 0.33 | 520 |
| **TOTAL** | | **10** | **3.84** | |

**Table 3.43: Summary of types of end load, total quantity, total rating power, and average operating hours for routine activity at IC**

| No | End-load | Quantity | Total Power (kW) | Average Operating Hour (h/year) |
|---|---|---|---|---|
| 1 | Fan | 52 | 0.45 | 708 |
| 2 | Lighting | 205 | 0.09 | 828 |
| 3 | Air-conditioning (ACSU) | 17 | 5.59 | 708 |
| 4 | Other equipment | 10 | 3.84 | 1886 |
| **TOTAL** | | **284** | **9.97** | |

### 3.4.5.2 Data collection at Multipurpose Hall

Tables 3.44, 3.45, and 3.46 show the type, quantity, power consumption, and estimated operating hours per year for fan, lighting, air-conditioning, and "other equipment" for Multipurpose Hall (MH). Table 3.47 summarises the data collection summary for four types of end-loads at MH.

**Table 3.44: Types, quantity, rating power, and operating hours for a fan at MH**

| No | Types of Fan | Quantity | Power (kW) | Average Operating Hours (h/year) |
|---|---|---|---|---|
| 1 | Wall Mounted | 21 | 0.2 | 708 |
| **TOTAL** | | **21** | **0.2** | |

**Table 3.45: Types, quantity, rating power, and operating hours for lighting at MH**

| No | Types of lighting | Quantity | Power (kW) | Average Operating Hours (h/year) |
|---|---|---|---|---|
| 1 | T8 36W | 66 | 0.04 | 828 |
| 2 | T8 18W | 8 | 0.02 | 828 |
| 3 | CFL 24W | 48 | 0.02 | 828 |
| 4 | MH 400W | 20 | 0.40 | 828 |
| 5 | Ttube 18W | 125 | 0.02 | 828 |
| **TOTAL** | | **267** | **0.50** | |

**Table 3.46: Types, quantity, rating power, and operating hours for air-conditioning (ACSU) at MH**

| No | Capacity (horsepower) | Quantity | Power (kW) | Average Operating Hours (h/year) |
|---|---|---|---|---|
| 1 | 1 hp | 2 | 0.75 | 707 |
| 2 | 2 hp | 1 | 1.49 | 707 |
| 3 | 2.5 hp | 7 | 2.24 | 707 |
| 4 | 10 hp | 2 | 22.40 | 707 |
| **Total** | | **12** | **26.87** | |

**Table 3.47: Summary of types of end load, total quantity, total rating power, and average operating hours for routine activity at MH**

| No | End-load | Quantity | Power (kW) | Average Operating Hour (h/year) |
|---|---|---|---|---|
| 1 | Fan | 21 | 0.20 | 708 |
| 2 | Lighting | 199 | 0.50 | 828 |
| 3 | Air-conditioning (ACSU) | 12 | 26.87 | 708 |
| **TOTAL** | | **232** | **27.57** | |

#### 3.4.5.3 Data collection at the Sports Centre

Tables 3.48, 3.49, 3.50, and 3.51 show the type, quantity, power consumption, and estimated operating hours per year for fan, lighting, air-conditioning (ACSU), and other equipment for Sports Centre (SC). Table 3.52 summarises the data collection for four types of end-loads at SC.

**Table 3.48: Types, quantity, power, and operating hours for a fan at SC**

| No | Types of Fan | Quantity | Power | Average Operating Hours |
|---|---|---|---|---|
| | | | (kW) | (h/year) |
| 1 | Ceiling fan | 2 | 0.08 | 708 |
| 2 | Exhaust fan | 18 | 0.08 | 708 |
| 3 | 16" Wall Fan | 34 | 0.05 | 708 |
| **TOTAL** | | **54** | **0.21** | |

**Table 3.49: Types, quantity, power, and operating hours for lighting at SC**

| No | End-load | Quantity | Power | Average Operating Hours |
|---|---|---|---|---|
| | | | (kW) | (h/year) |
| 1 | T8 36W | 106 | 0.04 | 708 |
| 2 | T8 18W | 4 | 0.02 | 708 |
| 3 | High Bay light | 27 | 0.20 | 708 |
| 4 | Spotlight | 2 | 0.50 | 708 |
| **TOTAL** | | **139** | **0.75** | |

**Table 3.50: Types, quantity, power, and operating hours for air-conditioning at SC**

| No | Capacity (Horse Power) | Quantity | Power | Average Operating Hours |
|---|---|---|---|---|
| | | | (kW) | (Annual) |
| 1 | 1 hp | 6 | 0.75 | 708 |
| 2 | 1.5 hp | 3 | 1.12 | 708 |
| 3 | 2 hp | 3 | 1.49 | 708 |
| 4 | 2.5 | 5 | 2.24 | 708 |
| **Total** | | **17** | **5.59** | |

**Table 3.51: Types, quantity, power, and operating hours for other equipment at SC**

| No | Types of Equipment | Quantity | Power | Average Operating Hours |
|---|---|---|---|---|
| | | | (kW) | (h/year) |
| 1 | Water dispenser | 1 | 1.90 | 2200 |
| 2 | Amplifier | 3 | 0.05 | 520 |
| 3 | Keyboard | 1 | 0.01 | 520 |

| | | | | |
|---|---|---|---|---|
| 4 | PA System | 1 | 0.33 | 2200 |
| 5 | Guitar Electric | 3 | 0.06 | 520 |
| 6 | Equalizer | 1 | 1.00 | 520 |
| 7 | Server Internet | 1 | 0.35 | 2200 |
| 8 | Track Mill (Brad) | 1 | 1.30 | 520 |
| 9 | Track Mill BH Fitness | 1 | 1.50 | 520 |
| 10 | Indoor Exercise Bike | 3 | 0.70 | 520 |
| 11 | Computer | 18 | 0.02 | 1200 |
| **TOTAL** | | **34** | **7.22** | |

**Table 3.52: Summary of types of end load, total quantity, total rating power, and average operating hours for routine activity at SC**

| No | End-load | Quantity | Total Power (kW) | Average Operating Hour (h/year) |
|---|---|---|---|---|
| 1 | Fan | 54 | 0.21 | 708 |
| 2 | Lighting | 139 | 0.75 | 708 |
| 3 | Air-conditioning (ACSU) | 17 | 5.59 | 708 |
| 4 | Other equipment | 34 | 7.22 | 1634 |
| **TOTAL** | | **244** | **13.77** | |

### 3.4.6 Detailed Energy Audit by Zone

PSAS has been divided into six zones. There are five zones based on five main switchboards (MSB) and 1 zone representing the residential staff. According to Table 3.6, zone 5 recorded the highest energy consumption compared to other areas. Zone 5 consists of 5 main buildings known as the Electrical Engineering Department (EED), Commerce Department (CD), the Training and Continuing Education Unit (TCEU), the Canteen (C), and the Multipurpose Hall (MH). Detailed energy audit data by zone is only shown for zone 5, identified as the highest energy consumption zone. Other zones are not established detailed data in this section, but the values of the data collected in different zones are included in the overall calculation of energy consumption estimates. Summary data collection for the Training and Continuing Education Unit and Canteen shows in Tables

3.53 and 3.54. The other table needs to refer to Table 3.30 for EED, Table 3.37 for CD, and Table 3.47 for MH to summarize the data collected for zone 5.

**Table 3.53: Summary data collection for Training and Continuing Education Unit**

| No | End-load | Quantity | Total Power (kW) | Average Operating Hour (h) |
|---|---|---|---|---|
| 1 | Others Equipment | 116 | 19.05 | 493.8 |
| 2 | Fan | 24 | 0.33 | 708.0 |
| 3 | Lighting | 459 | 0.50 | 828.0 |
| 4 | Air-conditioning (ACSU) | 28 | 37.04 | 828.0 |
| 5 | ICT Equipment | 15 | 0.31 | 944.8 |
| **TOTAL** | | **642** | **57.23** | |

**Table 3.54: Summary data collection for Canteen**

| No | End-load | Quantity | Total Power (kW) | Average Operating Hour (h) |
|---|---|---|---|---|
| 1 | Fan | 48 | 0.08 | 708 |
| 2 | Lighting | 320 | 0.50 | 708 |
| 3 | Aircond | 4 | 1.49 | 707 |
| **TOTAL** | | **372** | **2.07** | |

## 3.5 Mathematical Formulation

The estimated annual amount of energy used by electrical equipment in the PSAS academic building is calculated according to the formula in equation (3.1) (Habib et al., 2016; Roslizar et al., 2014)

$$AEC = P_r \; x \; H_a \; x \; L_f \qquad (3.1)$$

AEC is the estimate of annual energy consumption in units of kWh, $P_r$ does electrical equipment use the power in units of kW, $H_a$ is the estimate of the equipment's annual operating time, and $L_f$ is the load factor of electrical equipment. Estimated operating hours, $H_a$ obtained from the equation in (3.2).

$$H_a = H_d \; x \; (O_n - O_f), \qquad O_n \neq O_f \tag{3.2}$$

$H_d$ is the operating hours of the equipment per day, $O_n$ is the number of days in 1 year of the equipment in an operational state (On-mode), $O_f$ is the number of days in 1 year of the equipment in a non-operational state (Off-mode) due to public holidays. In normal conditions, the number of days that electrical equipment is activated in educational institutions consistently exceeds the number of public holidays gazetted by the Government. The situation of $O_n$ equal $O_f$ should not happen. In other words, the variable value for $O_n$ cannot be equal to $O_f$ ($O_n \neq O_f$). The determination of the number of days this electrical equipment operates or not is based on the PSAS 2019 academic calendar. Usually, on weekends it is considered that there are no official activities related to curriculum and co-curriculum on campus. At this time, most electrical equipment is in non-operational mode. This research finds the load factors for all electrical equipment listed ideal. That means the loading factor is 1 (Roslizar et al., 2014). Calculation of the annual energy saving value for the listed equipment involves the use of equation (3.3)

$$AES = P_r \; x \; Havg \; x \; L_f \; x \; R_p \tag{3.3}$$

where AES is the annual estimated energy saving of electrical equipment (kWh), $P_r$ is the power consumption of electrical equipment, $Havg$ represents an average annual operation hour, $L_f$ is the load factor of the electrical equipment where it is set to a value equal to 1 for the worst case, and $R_p$ is the percentage replacement of electrical equipment. Energy savings for each type of energy-efficiency equipment in this study were calculated according to the percentage of different replacement quantities. Annual bill savings through conversion to energy-efficient equipment is computed using equation (3.4): (Habib et al., 2016)

$$ABS = AES \; x \; C \tag{3.4}$$

AES is the annual energy savings (kWh), C is the average energy cost (RM/kWh), and ABS is the yearly bill savings obtained in units of RM. Based on equation formula (3.5), A simple payback period has been calculated after the replacing some energy-efficient electrical appliances. (Habib et al., 2016).

$$PBP = \frac{IC}{ABS} \tag{3.5}$$

where PBP is a simple payback period, $IC$ is incremental cost (RM), and ABS is annual bill saving (RM). In Malaysia, most power plants involve fossil fuel combustion elements to generate electricity. Burning fossil fuels produces greenhouse gas emissions (GHG) such as $CO_2$, $SO_2$, and CO (Habib et al., 2016). However, based on the energy-saving strategies recommended to be implemented in academic buildings at PSAS, the reduction of GHG according to the percentage of electricity generation in Malaysia involves different types of fuel mix. In addition, the estimated calculation of GHG emissions includes the electricity rate generated by each type of fuel, such as hydro, gas, coal, and diesel, plus the emission factor in power stations in Malaysia (ST, 2017). Energy savings strategies are directly related to emission reductions and estimated value according to the types of fuel, electricity generated percentage by the specific fuel, and the fuels emission factor for producing the electricity by using the following mathematical equation (3.6) (Roslizar et al., 2014; R. Saidur, 2009; Rahman Saidur et al., 2010). The emission factor per unit of energy generation for four types of fuels has been taken from references (Roslizar et al., 2014; R. Saidur, 2009; Rahman Saidur et al., 2010) and shown in Table 3.55. The electricity generation mix in Malaysia was taken from the Malaysian Energy Statistics Handbook 2017 issued by the Energy Commission. The electricity generation mix is about 13.0%, 42.5%, 0.4%, 43.5%, and 0.6% from hydro, coal, petroleum, natural gas, and other sources for 2016 (ST, 2017).

$$EMy = EPy\ (PEy^1 \times \mathrm{Em_p}^1 + PEy^2 \times \mathrm{Em_p}^2 + PEy^3 \times \mathrm{Em_p}^3 + \ldots\ldots PEy^n \times \mathrm{Em_p}^n) \tag{3.6}$$

Where $EMy$ is the total amount of carbon emission (ton), $EPy$ is the amount of electricity production in the year $y$, $PEy^n$ is the electricity generation percentage in the year *y* according to recommended type n fuel. $Em_p^n$ is the emission factor per unit of energy generation of fuel type n.

**Table 3.55**: **Emission factor per unit of energy used for various types of fuels (Habib et al., 2016)**

| Fuels | Emission factors (kg/kWh) | | |
|---|---|---|---|
| | $CO_2$ | $SO_2$ | CO |
| Hydro | 0 | 0 | 0 |
| Coal | 1.18 | 0.0139 | 0.002 |
| Petroleum | 0.85 | 0.0164 | 0.002 |
| Natural Gas | 0.53 | 0.0005 | 0.005 |

## 3.6 Measurement & Verification Analysis

The monthly energy consumption data for PSAS is gathered from utility bills from TNB. Energy consumption in each block is measured using a Fixed Digital Power Meter (DPM) installed on each Sub-Switch Board (SSB). The number of lecture days data is based on the annual PSAS academic calendar. Measuring the energy consumption of laboratory equipment or other equipment refers to the timetable or lab sheet during the semester lecture. Energy Saving refers to estimating the reduction in electricity use (kWh) and electric demand (kW). The measurement and verification analysis will follow the Malaysian Standard recommendation.

## 3.7 Recommended of Energy-Saving Measures (ESM)

The ESM proposed to reduce energy consumption through energy efficiency improvement methods for certain ESM after specific equipment identified as among the contributors to high total energy consumption had been audited in certain aspects. For example, lighting equipment at a particular building is measured by the level of illuminance using a lux meter. The measurement value will be compared with the value of illuminance allowed under Malaysian Standard MS1525: 2007. The energy efficiency ratio (EER) data for air-conditioning was collected for a capacity of 5hp and above if the proposed ESM highlights air-conditioning. The other measurement equipment used to collect data about air-conditioning is a hygrometer to measure temperature and relative humidity and an anemometer to measure airspeed.

### 3.8 Renewable Energy

The main target of this research is to perform a feasibility analysis to produce sustainable clean power generation. Based on the geographical location of PSAS, solar energy is identified as a suitable source for power generation. The recommended system is analyzed by focusing on the forecast of future energy through feasibility analysis using rooftop solar photovoltaic (PV). Then, the calculation for energy-saving potential is made for the following years. The power generated by the solar PV system is assumed for self-consumption on campus (Rodrigues et al., 2016), and annual energy-saving (kWh) and bill-saving (RM) for specific academic and non-academic buildings are calculated. Self-consumption means that electricity is generated for its own needs and is not exported to the national grid system (Mansur, Baharudin, & Ali, 2017). The off-grid system refers to self-consumption, where the power produced by this system is used directly by buildings and typically has no energy storage.

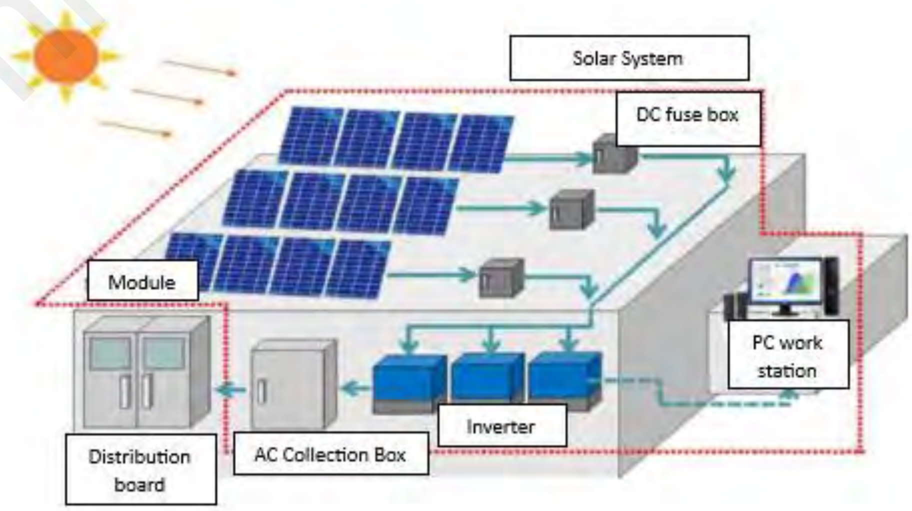



**Figure 3.8: Self-consumption layout diagram for rooftop solar power system**

Figure 3.8 shows the layout diagram for a 1 MW solar power system installed on the rooftop of a new supermarket built in Airai State, Republic of Palau, for self-consumption purposes (JCM, 2019). This research also performs feasibility analysis for an on-grid system using Net Energy Metering (NEM) 3.0 Programme, namely NEM GoMEn. NEM 3.0 Programme means the mechanism where a PSAS installed a solar PV installation on the rooftop of his premise primarily for his use. During the first ten years of NEM solar operation, if there is excess energy that is not used due to operational constraints or monthly or seasonal changes in load demand at the Premises can be exported to the National Grid system. PSAS may use credits received due to the delivery of such excess energy to offset part of the electricity bill for energy provided by the Distribution Licensee (TNB) during the applicable Billing Period. NEM GoMEn refers to a particular NEM scheme for entities under the government that have never participated in any solar program before (ST, 2021). Figure 3.9 shows the layout diagram for Net Energy Metering

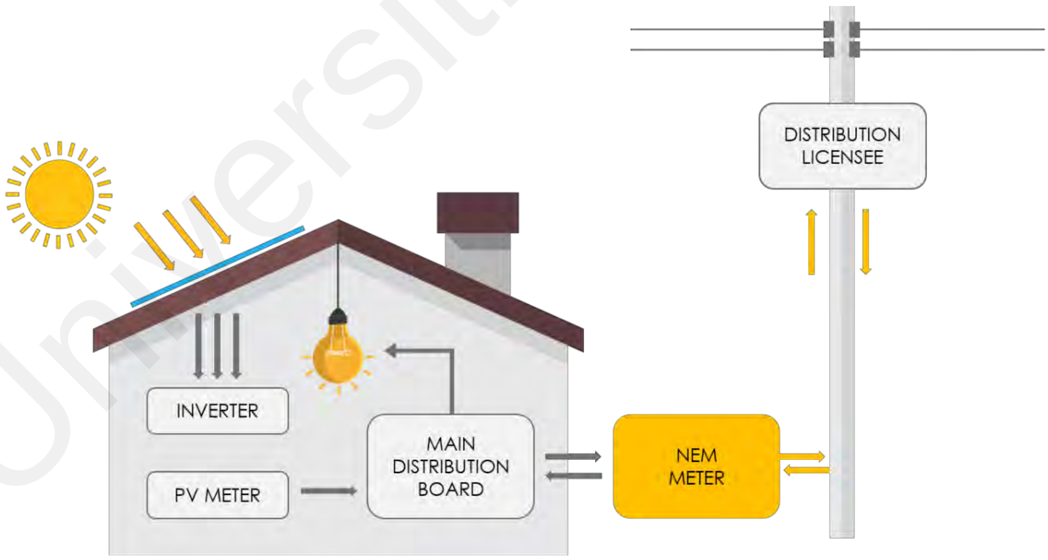



**Figure 3.9: Layout diagram for Net Energy Metering (Itramas, 2021)**

## 3.9 Existing Electricity Distribution System in PSAS

PSAS receives 11kV electricity from Tenaga National Berhad (TNB) through the National Grid System, and the power is stepped down to 415V through five Main Switchboards (MSB). Currently, the distribution system in PSAS uses a ring connection, as shown in Figure 3.10. This methodology section proposes two new model distribution system options where modifications are made based on the current distribution layout at PSAS, as shown in Figure 3.10. Both of these new distribution models are Option 1 or Option 2 models. The Option 1 modification involves a rooftop solar photovoltaic connection connected to a NEM meter and then a Sub-Switch Board (SSB), as shown in Figure 3.11. While Option 2 involves a solar photovoltaic contact connected to the NEM meter and then to the Main Switch Board (MSB), as shown in Figure 3.12. Figure 3.11 shows an example of the connection between the NEM meter and SSB in a particular block, then connected to MSB 1. However, this basic diagram does not show the complex relationship between SSB and other MSBs. The complete layout and further explanation of Figures 3.11 and 3.12 in the content of topic 4.52 related to system design is detailed in Chapter 4.

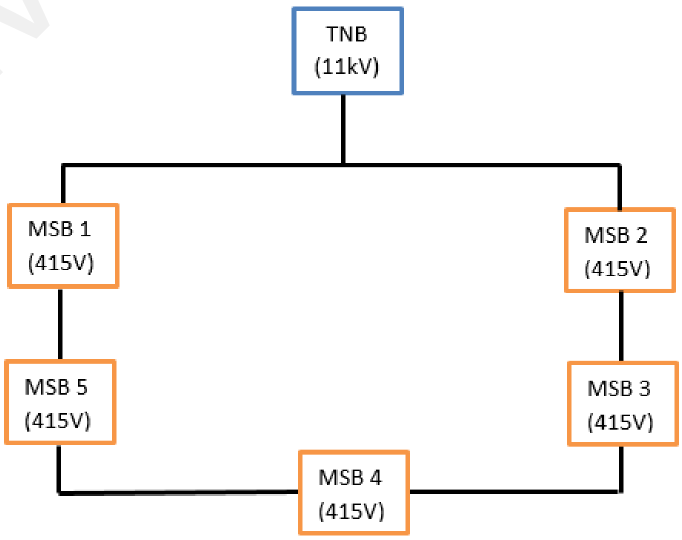



**Figure 3.10: PSAS Distribution System using ring connection**

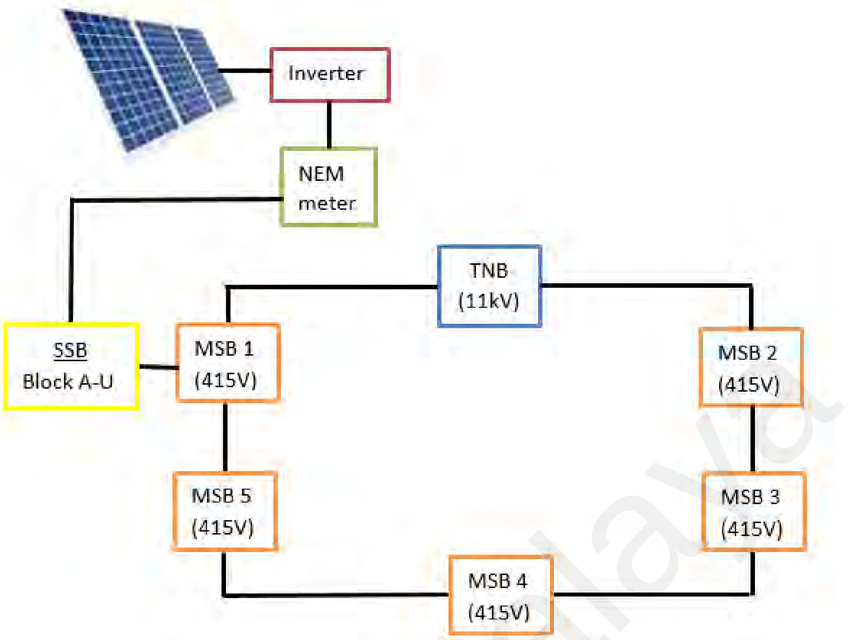



**Figure 3.11: PSAS Distribution System with modification using Option 1 distribution design**

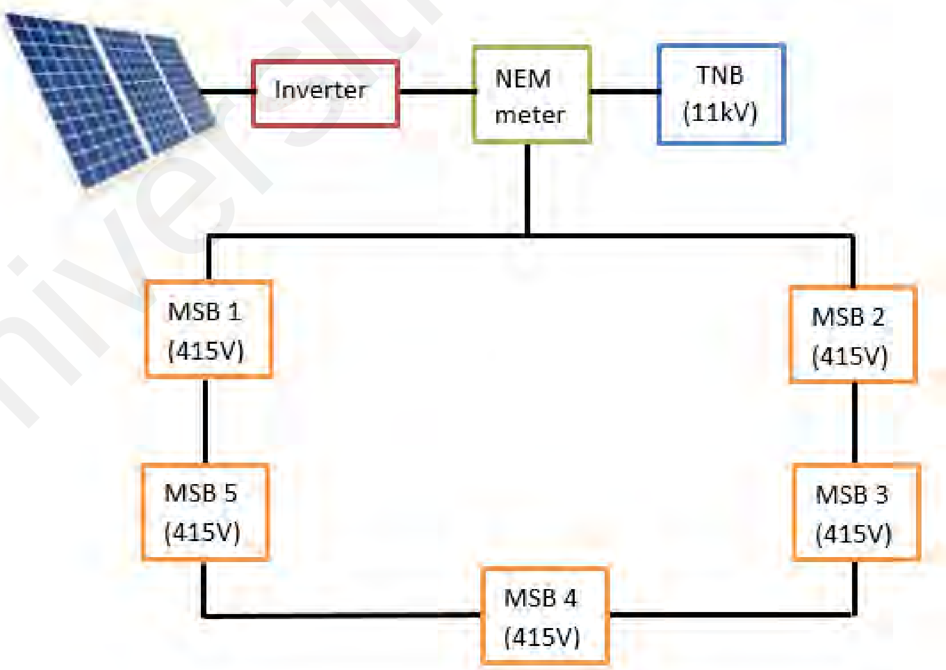



**Figure 3.12: PSAS Distribution System with modification using Option 2 distribution design**

### 3.10 Conclusion

Research at PSAS is unique because residential and office buildings can be analyzed in one research topic. The methodology for collecting data in staff residences uses survey questionnaires and semi-structured interviews, while data collection in academic and non-academic buildings uses detailed energy audit techniques. This methodology section also revolves around energy-saving formulas and bills, measurement analysis and verification, recommended energy-saving measures, renewable energy using rooftop solar photovoltaics, and modification design layout for the electricity distribution system.

# CHAPTER 4: RESULTS AND DISCUSSION

Energy audit data analysis for this research is divided into three main sections: residential buildings, academic buildings, and non-academic buildings. All the data collected in Chapter 3 has been analyzed to answer the research question and identify and analyze PSAS's energy-consuming equipment. The analysis results will be considered the main factor in recommending energy-saving measures (EMS). This recommendation will be made to top management at PSAS, focusing on improving energy efficiency. In addition, this research aims to reduce energy consumption where using renewable energy methods is a high-impact energy-saving measure, but it involves costs. Assessing renewable energy sources suitable for use in the PSAS is vital before proceeding with the ESM proposal, which involves renewable energy utilization strategies. Investigating the feasibility of on-site renewable energy generation at PSAS can provide valuable information regarding energy-saving forecasts for the future. Through feasibility analysis, it can be proved whether PSAS has the flexibility to install on-grid power generation. The final examination in this research focuses on estimating the cost-benefits and environmental impact of renewable energy for PSAS.

## 4.1 Analysis of energy audit data for Residential Building

### 4.1.1 Staff quarters, equipment, and ownership

A survey through questionnaires and interviews was conducted on the residents of the residential quarters at PSAS. This study related to residential buildings focuses on collecting information for 2018 which begins by collecting background information on residential buildings. This survey found that the total floor area was 30,422 $m^{2,}$ and 603 families lived in the residential building during the survey session. This survey involved 143 house units with different floor areas. Table 3.1 shows the background information of respondents and residential buildings. Table 3.2 shows the average amount of electricity consumption (kWh) in a month in residential buildings in PSAS is 33,172.08 kWh, with the cost of electricity consumption being RM 9,158.03. This data is obtained from the average monthly electricity bill of residents of PSAS residences issued by TNB for 2018. Table 3.3 shows the details of 11 types of electrical equipment, the quantity of equipment, and the estimated duration of operation of electricity consumption for household appliances. Table 3.4 summarizes the data collected related to home electrical appliances and the collection of such devices based on the residential block category. The percentage of ownership for different household appliances in PSAS is shown in Figure 4.1. The questionnaire's question of ownership of home appliance equipment refers to the right of at least one piece of electrical equipment owned by the respondent. Based on Figure 4.1, the home equipment in PSAS recorded the highest percentage of ownership, 95% to 100%, are ceiling fans, lighting, phone charger, refrigerator, rice cooker, iron, television, and washing machine. However, this listed home appliance does not reflect it records a high amount of energy consumption.

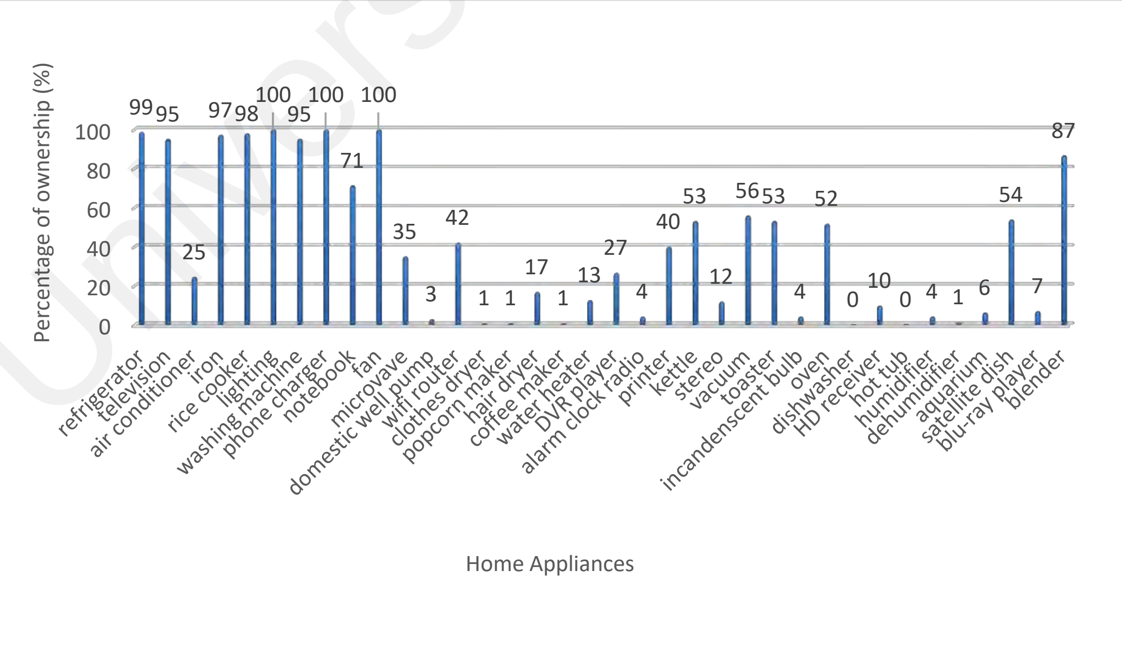



**Figure 4.1: Percentage ownership of home appliances for a residential occupant at PSAS**

### 4.1.2 Major equipment and ownership

Major equipment refers to home electrical appliances from the same category but with different capacities and equipment specifications. The analysis focused on six main types of home appliances: kitchen appliances, televisions, cooling and heating, washing machines, small kitchen appliances, and lighting. Kitchen appliances include a refrigerator and a microwave. The percentage of ownership for the different capacities of a refrigerator, microwave, television, and air-conditioning is shown in Figure. 4.2. Based on the result, the refrigerator (20L-450L) ownership records the highest percentage, about 55%. The rate of ownership of refrigerators (20L-450L) is the highest due to the majority of families living in the quarters being small families where the number of occupants in each household is less than five people. Household size is one of the critical things to consider when buying a refrigerator. The more people in that household, the greater the refrigerator capacity required. The percentage of ownership between microwaves with different abilities is (1-1.5 cubic) and (< 1 cubic) is the same as both are 49%. Results illustrated in Figure 4.2 show that most working residents prefer appliances that will help them cook quickly and save time. The microwave properties are related to heating uniformity and are relevant for food safety and quality. It is offered promptly in sterilization and pasteurization processes (J. Tang, 2015). Besides that, the percentage distribution of ownership for TV (36”-55”) and TV (14"-35") does not show a significant difference where they record 51% and 48%, respectively. These results indicate that most respondents have a TV size below 55”. Considering only 1% ownership for TVs (60”-over) means this type of TV is not the preferred one. The percentage of ownership for the different capacities of the air conditioner is also illustrated. It is shown that 66% of respondents chose a 1 hp air conditioner because it involves the total area being cooled to only 22 square meters. Referring to the chart (Department of Energy, 2019), 1 hp is identified as prefer rating for the installed air conditioner in the main bedroom of the respondent. Figure 4.3 shows the distribution percentage of ownership for a domestic fan, washing machine, and lighting. It was found that 83% of respondents installed ceiling fans in their homes. These findings are similar to studies conducted in Malaysia's residential buildings by Kubota, which show that the ceiling fan ownership level is 93% (Kubota et al., 2011). About 61% of the occupant use a 6.1-8kg washing machine. This result is in line with the characteristic of the group that inhabits this home, which consists of small families of less than five people. The 6.1-8 kg washing machine capacity accommodates this group's household use. Besides that, these results show that lighting (26 – 50W) offers the highest ownership percentage of 66% compared to (12 – 25W) only 33%. It is because most occupants use fluorescent lamps 36W as their main lighting source.

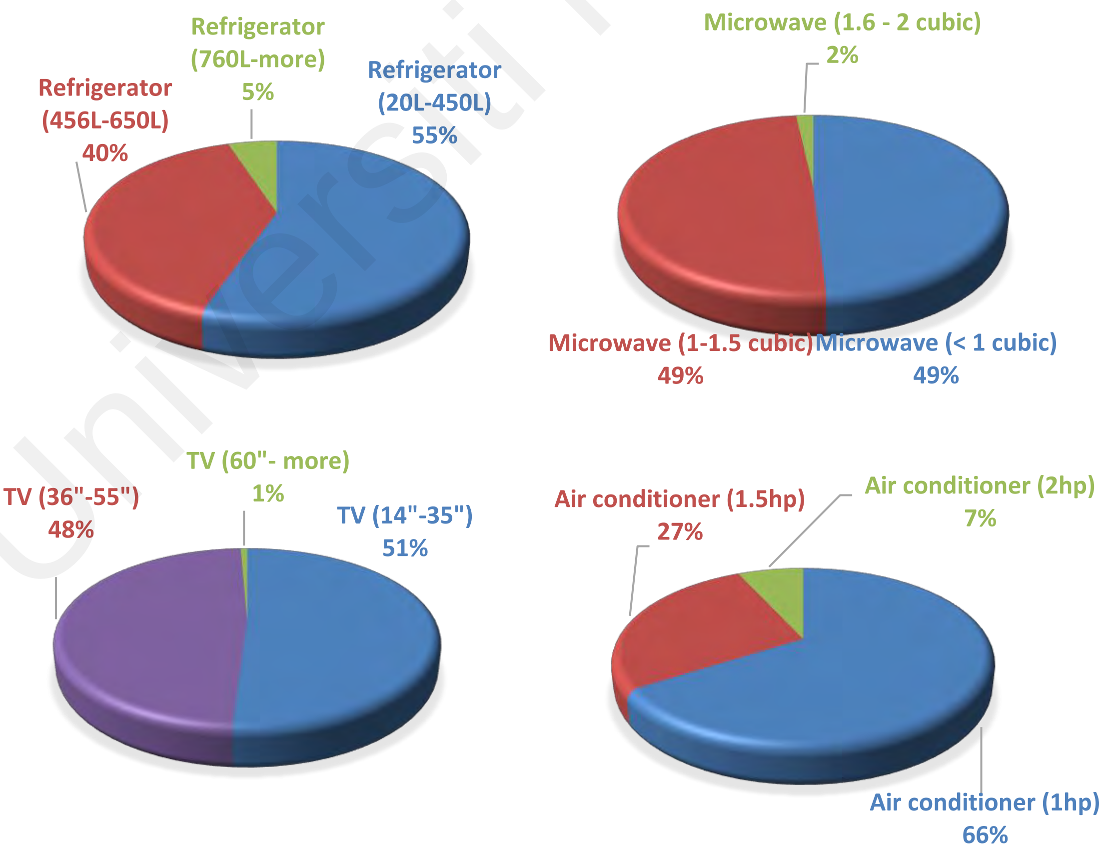



**Figure 4.2: The capacity of different types of refrigerators, microwaves, television and air conditioner in PSAS staff quarters**

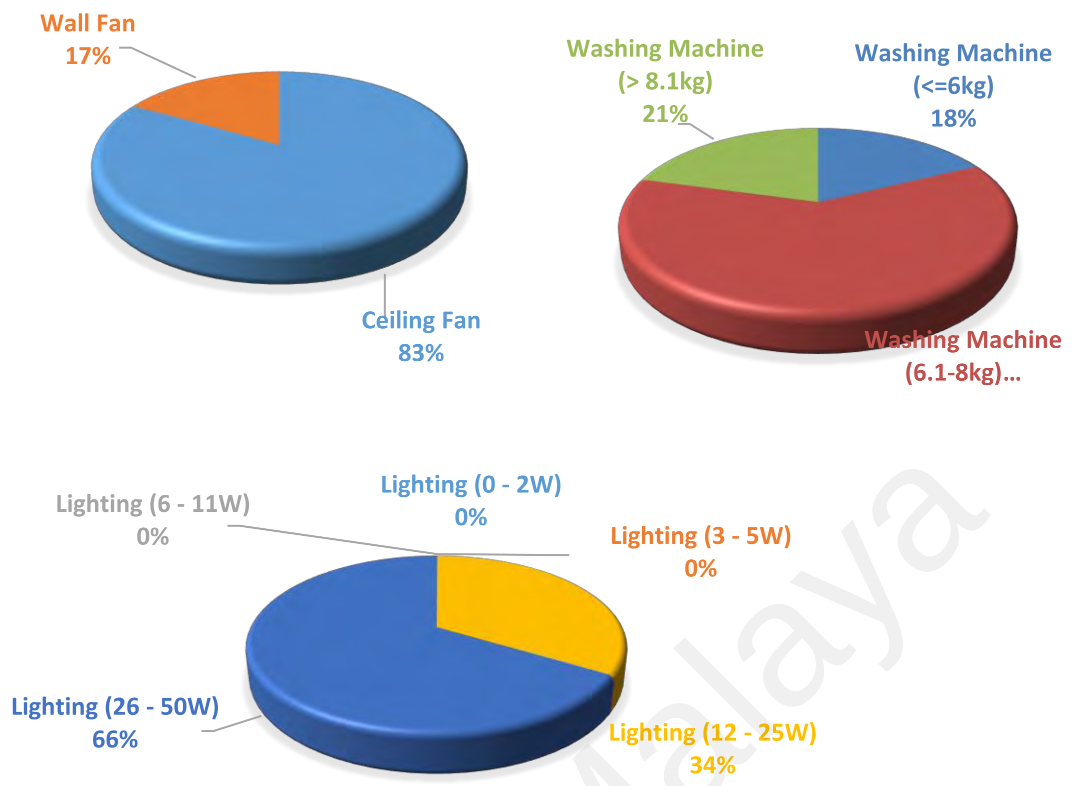



**Figure 4.3: The capacity of different types of domestic fans, washing machines, and lighting in PSAS staff quarters**

### 4.1.3 Identify and analyze the energy-consuming equipment through annual energy consumption and annual bills

Energy consumption for each type of household appliance is collected based on the type of appliance group. Equation (3.1) and data from Table 3.3 are used to calculate the annual energy consumption for all the equipment involved; then, the results are shown in Table 4.1. Table 4.1 shows the total yearly energy consumption referred to based on the type of equipment group. The estimated energy bill is calculated based on tariff and residential rates in 2018, released by TNB. The minimum monthly block rate selected for calculation purposes is 200 kWh per month with a charge rate of RM0.218 (TNB, 2019a). Table 4.2 shows the top 10 positions for home appliances arranged based on total electricity consumption. Energy-saving strategies focus on three types of equipment occupying the highest position: ceiling fans, lights, and water heaters.

**Table 4.1: Annual energy consumption and energy bill for electrical home appliances in 2018**

| Home appliance type | Appliances | Energy consumption (kWh) | Energy bill (RM) |
|---|---|---|---|
| Kitchen Appliances | Refrigerator (20L-450L) | 76445.6 | 16665.1 |
| | Refrigerator (456L-650L) | 85030.4 | 18536.6 |
| | Refrigerator (760L-more) | 16352.0 | 3564.7 |
| | Microwave (< 1 cubic) | 2452.8 | 534.7 |
| | Microwave (1-1.5 cubic) | 3270.4 | 712.9 |
| | Microwave (1.6 - 2 cubic) | 1095.0 | 238.7 |
| Television | TV (14"-35") | 31365.2 | 6837.6 |
| | TV (36"-55") | 24309.0 | 5299.4 |
| | TV (60"- more) | 554.8 | 120.9 |
| Cooling and heating | Air conditioner (1hp)<br>Air conditioner (1.5hp)<br>Air conditioner (2hp)<br>Ceiling Fan<br>Wall Fan | 79937.9<br>43870.1<br>16757.9<br>185999.4<br>14585.4 | 17426.5<br>9563.7<br>3653.2<br>40547.9<br>3179.6 |
| Washer | Washing Machine (<=6kg) | 8007.2 | 1745.6 |
| | Washing Machine (6.1-8kg) | 28251.0 | 6158.7 |
| | Washing Machine (> 8.1kg) | 10676.3 | 2327.4 |
| Iron | Iron (small) | 5584.5 | 1217.4 |
| | Iron (medium) | 3358.0 | 732.0 |
| | Iron (large) | 146.0 | 31.8 |
| Small kitchen appliances | Rice cooker (3 - 4 cups) | 26937.0 | 5872.3 |
| | Rice cooker (5 - 6 cups) | 21681.0 | 4726.5 |
| | Rice cooker (8 - 10 cups) | 6643.0 | 1448.2 |
| Lighting | Lighting (0 - 2W) | 2.9 | 0.6 |
| | Lighting (3 - 5W) | 11.7 | 2.5 |
| | Lighting (6 - 11W) | 0.0 | 0.0 |
| | Lighting (12 25W) | 32049.9 | 6986.9 |
| | Lighting (26 50W) | 146747 | 31991.0 |
| Computer | Notebook | 44712.5 | 9747.3 |
| Mobile Accessories | Phone charger | 1619.7 | 353.1 |
| Domestics Well Pump | Pump (0.5- 1 hp) | 408.4 | 89.0 |

| | | | |
|---|---|---|---|
| | Pump (< 5hp) | 205.3 | 44.8 |
| | Pump (> 5hp) | 0.0 | 0.0 |
| Other equipment | Wifi router | 2540.4 | 553.8 |
| | Clothes dryer | 233.6 | 50.9 |
| | Popcorn maker | 151.8 | 33.1 |
| | Hairdryer | 4204.8 | 916.6 |
| | Coffee maker | 109.5 | 23.9 |
| | Water heater | 178704.0 | 38957.5 |
| | DVR player | 4161.0 | 907.1 |
| | Alarm clock radio | 87.6 | 19.1 |
| | Printer | 3640.0 | 793.7 |
| | Kettle | 4993.2 | 1088.5 |
| | Stereo | 9431.6 | 2056.1 |
| | Vacuum | 4672.0 | 1018.5 |
| | Toaster | 1554.9 | 339.0 |
| | Incandescent Bulb | 175.2 | 38.2 |
| | Oven | 6482.4 | 1413.2 |
| | Dishwasher | 0.0 | 0.0 |
| | HD Receiver | 2299.5 | 501.3 |
| | Hot tub | 0.0 | 0.0 |
| | Humidifier | 1138.8 | 248.3 |
| | Dehumidifier | 1635.2 | 356.5 |
| | Aquarium | 3942.0 | 859.4 |
| | Satellite dish | 12366.2 | 2695.8 |
| | Blu-ray player | 1058.5 | 230.8 |
| | Blender | 2036.7 | 444.0 |

**Table 4.2: Top ten energy consuming appliances types**

| Rank | Equipment type | Electricity usage (kWh) | Energy bill (RM) | Contribution to total energy consumption (%) |
|---|---|---|---|---|
| 1 | Fan | 200,584.8 | 43,727.5 | 17.5 |
| 2 | Lighting | 178,797.4 | 38,977.8 | 15.5 |
| 3 | Water heater | 177,828.0 | 38,766.5 | 15.5 |
| 4 | Refrigerator | 178,704.0 | 38,957.5 | 14.9 |
| 5 | Air conditioner | 140,565.9 | 30,643.4 | 12.2 |
| 6 | TV | 56,229.0 | 12,257.9 | 4.9 |
| 7 | Rice cooker | 55,261.0 | 12,046.9 | 4.8 |
| 8 | Washing machine | 46,934.4 | 10,231.7 | 4.1 |

| | | | | |
|---|---|---|---|---|
| 9 | Notebook | 44,712.5 | 9,747.3 | 3.9 |
| 10 | Stereo | 94,31.6 | 2,056.1 | 0.8 |
| 11 | Others | 66,915 | 14,587.6 | 5.8 |
| | **Total** | **1,155,995.6** | **252,007.0** | **100.0** |

### 4.1.4 Energy usage optimization measures using energy-efficient ceiling fans

According to the energy consumption data in Table 4.2, a fan is a piece of electrical equipment consuming the highest energy in PSAS residential. Through analysis, a fan is confirmed as electrical equipment that needs to be targeted to implement effective energy-saving strategies. Additionally, using electrical equipment labeled Energy Star Ratings issued by the Energy Commission of Malaysia helps people gain more benefits, especially home electrical equipment efficiency (Rahman et al., 2017). This recommendation refers to the document "Minimum energy performance standards" (MEPS) for a domestic fan with code MS 2574:2014. A domestic fan is one type of equipment containing an AC induction motor. The weakness of this type of motor is less efficient because there is a difference between the rotor speed and the magnetic field known as slip (Shah et al., 2015). The problem of slip can be overcome by using a brushless DC motor (BLDC) that synchronizes the movement of the rotor with the rotation of the alternating current (AC) magnetic field produced through electronic conversion. However, the price of ceiling fans with BLDC is high due to new designs with more efficient motor and electronic control. The price for a 1-unit KDK brand is RM 649 (KDK, 2019), compared with a standard ceiling fan of about RM 145. Another option is to reduce energy use on ceiling fans by replacing the existing ones with efficient ceiling fans certified with a 4-5 energy star rating. It will save more than 20% (Sameeullah et al., 2014). Annual energy and annual bill savings were calculated using Equations (3.3) and (3.4), shown in Figure 4.4, to replace old ceiling fans (80W) with new ceiling fans. This contemporary ceiling fan receives a 5-star energy rating for MEPS with a star index value of over 3.00 (ST, 2020a). The star rating label can help consumers use energy more efficiently and save energy consumption (Rahman et al., 2016). Replacing ceiling fans from the old to the new version reduces electricity usage due to reduced wattage from 80W to 65W.

Table 4.3 shows the technical specification and prices of ceiling fans for old and new designs. Most importantly, both ceiling fans supply the same airflow (cubic feet per minute or CFM) in the house. The minimum bill savings of 5% is taken from the document Blueprint Polygreen (JPPKK, 2015), which states that all government buildings must reduce their utility cost by 5%. Therefore, the PSAS residence's 5% energy reduction is set as a baseline following the document. According to Table 4.2, to reduce annual energy consumption and bill consumption by at least 5%, the energy-saving needed is about 57,799.78 kWh and RM 12,600.35, respectively. Refers to Figure 4.4, the results indicate that replacing 100% of an old ceiling fan with the new version is insufficient to achieve a 5% reduction target for the following year. This result shows another piece of equipment also needs to be replaced to ensure the 5% energy reduction target in PSAS residences can be achieved.

**Table 4.3: Detail specification of ceiling fan**

| No | Equipment | Wattage | Capacity air delivery | Star rating | Cost per unit |
|---|---|---|---|---|---|
| 1 | Old ceiling fan | 80W | 8115 CFM | - | RM 145 |
| 2 | New ceiling fan | 65W | 8122 CFM | 5 Star | RM170 |

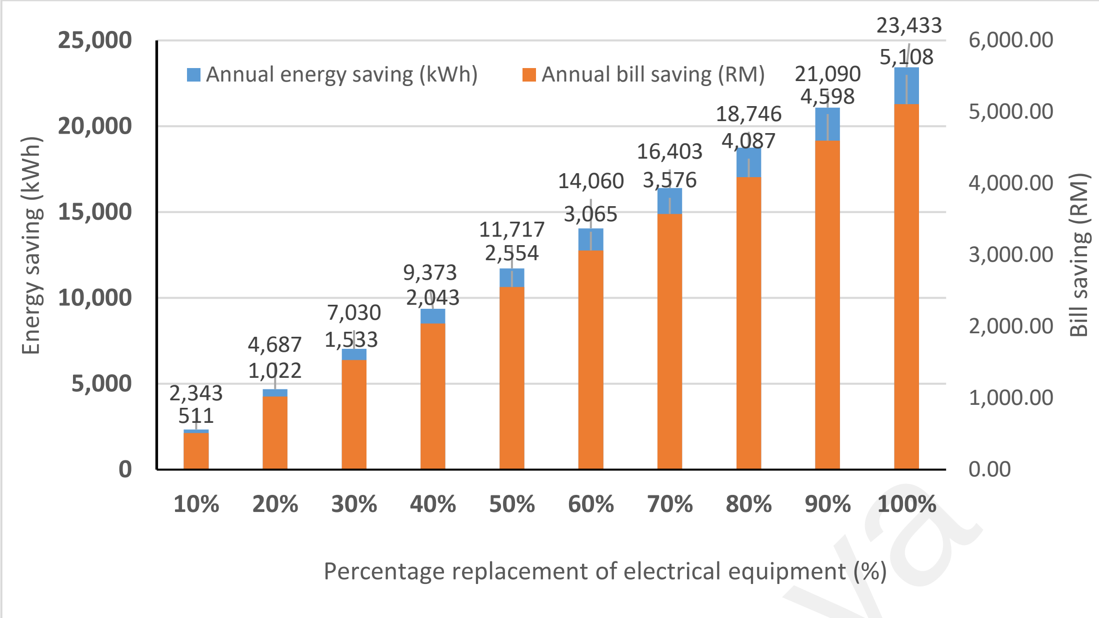



**Figure 4.4: Annual energy-saving and bill savings by using a new ceiling fan**

### 4.1.5 Energy usage optimization measures using LED lamp

Replacing fluorescent lamps (FL) with a new lighting system known as light-emitting diode (LED), lamps can increase lamp life while significantly reducing energy consumption and saving energy costs (Luewarasirikul, 2015). The lighting system uses 15.5% of the total energy and is the equipment that uses the second-highest energy, as shown in Table 4.2. Table 4.4 shows the technical specifications and price of lamps for old and new designs. The LED light for 18W nearly doubled its life span compared to the fluorescent lamps. Although LED lamps cost more than fluorescent lamps, LED and FL tubes have almost the same light efficiency in terms of lumens or brightness, where they have 1900 and 1800 lumens, respectively (Luewarasirikul, 2015). Although the total lumens of these two types of lamps are almost exact, different amounts of power are used to produce brightness. This analysis will refer to general lighting for interior spaces with surface mounting applications using the Philips brand with code LED tube 1200mm 18W and fluorescent lamps with code TMS 011 1x36W TLD. Annual energy savings and bill savings after using 18W LED lamps were calculated using Equations (3.3) and (3.4) and are further shown in Figure 4.5. The total 36W (26 – 50W) lamps is 1396 units. The analysis shows the annual energy consumption and bill savings at 80% of lamp replacement are 58,278.53 kWh and RM 12,704.72, respectively, exceeding the target to reduce at least 5% in the following year (57,799.78 kWh and RM 12,600.35).

**Table 4.4: Detail specification of lamp**

| No | Equipment | Wattage | Lumen | Average life span | Cost per unit |
|---|---|---|---|---|---|
| 1 | Fluorescent tube light | 36W | 1800 | 12,000 hours | RM 14.30 |
| 2 | LED tube light | 18W | 1900 | 25,000 hours | RM 18.40 |

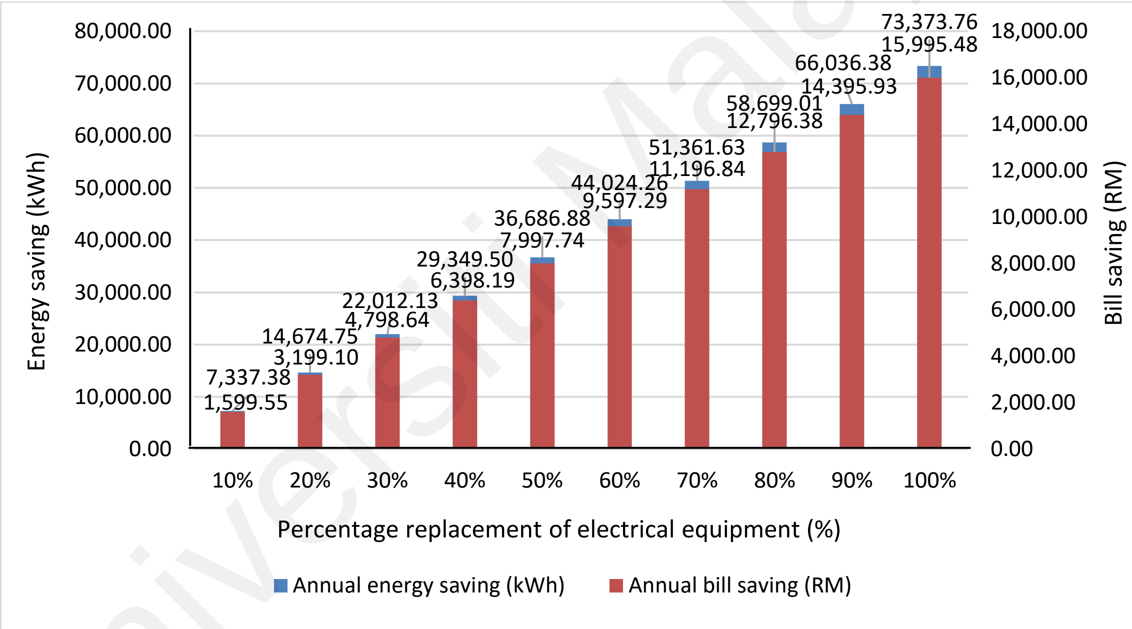



**Figure 4.5: Annual energy and bill savings by using LED 18W**

### 4.1.6 Energy usage optimization measures using Mini Solar Water Heater

The water heater is the third-highest energy consumer, about 15.5% of the total energy, as shown in Table 4.2. The average capacity of the domestic water heater used in the staff quarters is 3400W. The process of heating water using renewable energy source technologies may reduce energy consumption and utility costs. Several renewable energy-based applications exist in domestic water heaters, like solar water heaters, photovoltaic-thermal water heaters, and biomass water heaters (Hohne et al., 2019). This feasibility analysis will refer to the potential energy reduction using solar water heating applications to replace the conventional water heater in PSAS residential. Annual energy saving and bill savings of Solar Water Heater (SWH) has been calculated by using Equation (3.3) and (3.4), which are shown in Table 4.5. Refers to Table 4.5, the results indicate that replacing 40% of an old water heater with a mini solar water heater for household use (Alibaba, 2021) is sufficient and exceeds the target to reduce 5% of energy consumption and bill saving at PSAS residential.

**Table 4.5**: **Energy and bill saving using Mini Solar Water Heater.**

| Appliances | MSWH Replacement | Annual energy saving (kWh) | Annual bill saving (RM) |
|---|---|---|---|
| Mini Solar Water Heater (MSWH) | 10% | 17,870.40 | 3,895.75 |
| | 20% | 35,740.80 | 7,791.49 |
| | 30% | 53,611.20 | 11,687.24 |
| | 40% | 71,481.60 | 15,582.99 |
| | 50% | 89,352.00 | 19,478.74 |
| | 60% | 107,222.40 | 23,374.48 |
| | 70% | 125,092.80 | 27,270.23 |
| | 80% | 142,963.20 | 31,165.98 |
| | 90% | 160,833.60 | 35,061.72 |
| | 100% | 178,704.00 | 38,957.47 |

### 4.1.7 Estimated cost-benefit in Residential Building

The current market price for a new ceiling fan is RM 164 to RM170 per unit, while old ceiling fans are RM 145 per unit. The incremental cost is the difference between the price of the ceiling fans of the new version and the old version in the current market. Table 4.6 shows when the percentage of ceiling fan replacement increases, causing the payback period to be faster. This situation is due to the purchase of ceiling fans in larger quantities at one time, allowing the price of a fan unit to be lower. The payback period for the ceiling fan was calculated using Equation (3.5), where data from Table 3.4, Table 4.3, and Figure 4.4 were entered into the following equation. The total additional cost is calculated by multiplying the cumulative price per 1 unit by the number of ceiling fan replacements out of 535 units. The payback period shown in Table 4.6 is less than three years (1.99 to 2.62 years).

The payback period for the lamp is calculated using Equation (3.5). Data from Tables 4.2 and 4.4 are entered into the equation. The total additional cost is calculated by multiplying the accumulated price per 1 unit by the number of LED replacements from 1396 units (18W), shown in Table 4.7. The payback period shown in Table 4.7 is less than half of the year (0.31 to 0.36 years).

The payback period for the water heater was calculated using Equation (3.5). Data from Table 4.2 and Table 4.5 are entered into the equation. The total additional cost is calculated by multiplying the accumulated price per 1 unit for MSWH (RM 606) with the number of mini solar water heater replacements from 36 units (RM 350/unit) shown in Table 4.8. The payback period is between 7.83 to 9.11 years, and this duration is quite long.

**Table 4.6**: **Payback period for replacing a new ceiling fan**

| Appliances | Fan Replacement | Incremental cost (RM)/1 unit | Payback period (y) |
|---|---|---|---|
| Fan (65W) | 10% | 25.00 | 2.62 |
| | 20% | 25.00 | 2.62 |
| | 30% | 23.00 | 2.41 |
| | 40% | 23.00 | 2.41 |
| | 50% | 23.00 | 2.41 |
| | 60% | 21.00 | 2.20 |
| | 70% | 21.00 | 2.20 |

| | | | |
|---|---|---|---|
| | 80% | 21.00 | 2.20 |
| | 90% | 19.00 | 1.99 |
| | 100% | 19.00 | 1.99 |

**Table 4.7: Payback period for replacing by LED 18W**

| Appliances | Lighting Replacement | Incremental cost (RM) | Payback period (y) |
|---|---|---|---|
| Lighting (36W) | 10% | 4.10 | 0.36 |
| | 20% | 4.10 | 0.36 |
| | 30% | 3.90 | 0.34 |
| | 40% | 3.90 | 0.34 |
| | 50% | 3.90 | 0.34 |
| | 60% | 3.70 | 0.32 |
| | 70% | 3.70 | 0.32 |
| | 80% | 3.70 | 0.32 |
| | 90% | 3.50 | 0.31 |
| | 100% | 3.50 | 0.31 |

**Table 4.8: Payback period for replacing by using Mini Solar Water Heater**

| Appliances | MSWH Replacement | Incremental cost (RM) | Payback period (y) |
|---|---|---|---|
| Mini Solar Water Heater (MSWH) | 10% | 256.00 | 9.11 |
| | 20% | 256.00 | 9.11 |
| | 30% | 256.00 | 9.11 |
| | 40% | 256.00 | 9.11 |
| | 50% | 256.00 | 9.11 |
| | 60% | 220.00 | 7.83 |
| | 70% | 220.00 | 7.83 |
| | 80% | 220.00 | 7.83 |
| | 90% | 220.00 | 7.83 |
| | 100% | 220.00 | 7.83 |

## 4.2 Analysis of energy audit data for Academic Building

Analysis of energy audit data for five end-loads has been conducted in 4 main academic buildings known as Mechanical Engineering Department (MED), Civil Engineering Department (CED), Electrical Engineering Department (EED), and Commerce Department (CD). Equipment quantity, operating power (kW), operating hours, energy consumption, and energy costs are calculated. Energy consumption and energy bills in a year for all types of final loads listed are calculated based on equation (3.1). The estimated calculation for the energy bill is based on the TNB tariff rate issued in 2018. PSAS under the medium voltage general commercial tariff category that uses the C1 tariff, where all kWh per month are charged at a fixed charge rate of RM0.365 (TNB, 2019b)

### 4.2.1 Identify and analyze the energy-consuming equipment at MED

Using data from Tables 3.10, 3.11, 3.12, 3.13, 3.14, 3.15 and calculated using Equation (3.1), then the detail of annual energy consumption and annual bill for each type of equipment listed under five end-loads in MED are shown in Tables 4.9, 4.10, 4.11, 4.12, 4.13, 4.14. Estimated energy bill calculation using the fixed tariff rate issued by TNB in 2018. According to the tariff, the annual energy consumption (kWh) is multiplied by the charge rate of RM 0.365 to get the value of the annual energy bill (RM) (TNB, 2019b).

**Table 4.9: Annual energy consumption and annual bill for laboratory equipment at MED**

| No | Types of Equipment | Annual Energy Consumption (kWh) | Annual bill (RM) |
|---|---|---|---|
| 1 | Cleaning Machine | 1,036 | 378 |
| 2 | Audio Amplifier and Mixer | 30 | 11 |
| 3 | Lab Grinder Machine | 1,507 | 550 |
| 4 | DC Power Supply | 703 | 257 |
| 6 | Microscope | 70 | 26 |
| 7 | Workstation Mobile for Pneumatic and Electro-Pneumatic | 904 | 330 |

| | | | |
|---|---|---|---|
| 8 | CNC Machine | 7,536 | 2,751 |
| 9 | Cutting Machine | 20,096 | 7,335 |
| 10 | Air Compressor | 6,280 | 2,292 |
| 11 | Grinding Machine | 13,012 | 4,749 |
| 12 | Lathe Wood Machine | 11,153 | 4,071 |
| 13 | Shears Machine | 7,536 | 2,751 |
| 15 | Milling Machine | 8,038 | 2,934 |
| 16 | Industry Stand Fan | 151 | 55 |
| 17 | Saw Machine | 2,914 | 1,064 |
| 18 | Welding Machine | 33,158 | 12,103 |
| 19 | Arc Welding Machine | 15,072 | 5,501 |
| 20 | Rapid Prototype 3D printer | 407 | 149 |
| 21 | Oscilloscope | 20 | 7 |
| 22 | Dryer | 100 | 37 |
| 23 | Cartesian Robot | 502 | 183 |
| 24 | Revolute Robot | 251 | 92 |
| 25 | Scara robot | 226 | 83 |
| 26 | Cutter Machine | 377 | 138 |
| 27 | Electric Hand Drill | 829 | 303 |
| 28 | Mechanical/Civil Engineering Set Kit | 8,955 | 3,269 |
| 29 | Automotive Engineering Set Kit | 1,507 | 550 |
| 30 | Wheel Alignment System | 186 | 68 |
| 31 | Pneumatic Tyre Changer Machine | 188 | 69 |
| 32 | Tester Machine | 95 | 35 |
| **TOTAL** | | **103,223** | **37,676** |

**Table 4.10: Annual energy consumption and annual bill for lighting at MED**

| No | Types of Lighting End-load | Annual Energy Consumption | Annual Bill | Load Apportionment |
|---|---|---|---|---|
| | | (kWh) | (RM) | (%) |
| 1 | T8 36W | 30,815 | 11,247 | 36 |
| 2 | T8 18W | 2,600 | 949 | 3 |
| 3 | CFL 24W | 391 | 143 | 0 |
| 4 | MH 400W | 43,896 | 16,022 | 51 |
| 5 | Ttube 18W | 8,284 | 3,024 | 10 |
| **TOTAL** | | **85,985** | **31,385** | **100** |

**Table 4.11: Annual energy consumption and annual bill for a domestic fan at MED**

| No | Types of Fan | Annual Energy Consumption | Annual Bill | Load Apportionment |
|---|---|---|---|---|
| | | (kWh) | (RM) | (%) |
| 1 | Ceiling | 4,991 | 1,822 | 71 |
| 2 | Wall Mounted | 1,982 | 724 | 28 |

| | | | | |
|---|---|---|---|---|
| 3 | Stand | 85 | 31 | 1 |
| **TOTAL** | | **7,059** | **2,576** | **100** |

**Table 4.12: Annual energy consumption and annual bill for air-conditioning (ACSU) at MED**

| No | Capacity (Horse Power) | Annual Energy Consumption | Annual Bill | Load Apportionment |
|---|---|---|---|---|
| | | (kWh) | (RM) | (%) |
| 1 | 1 hp | 1,652 | 603 | 2 |
| 2 | 1.5 hp | 7,896 | 2,882 | 10 |
| 3 | 2 hp | 21,068 | 7,690 | 26 |
| 4 | 2.5 hp | 14,486 | 5,287 | 18 |
| 5 | 3 hp | 12,644 | 4,615 | 16 |
| 6 | 4 hp | 10,534 | 3,845 | 13 |
| 7 | 5 hp | 13,173 | 4,808 | 16 |
| **Total** | | **81,451** | **29,730** | **100** |

**Table 4.13: Annual energy consumption and annual bill for air-conditioning (WCPU) under CT 2 for MED**

| No | Code | Annual Energy Consumption | Annual bill |
|---|---|---|---|
| | | (kWh) | (RM) |
| 1 | L-0-46 | 9,956.8 | 3,634.2 |
| 2 | L-1-47 | 11,132.8 | 4,063.5 |
| 3 | L-2-48 | 9,956.8 | 3,634.2 |
| 4 | L-0-49A | 7,448.0 | 2,718.5 |
| 5 | L-0-49B | 4,892.2 | 1,785.6 |
| **TOTAL** | | **43,386.6** | **15,836.1** |

**Table 4.14: Annual energy consumption and annual bill for ICT equipment at MED**

| No | Equipment | Annual Energy Consumption | Annual Bill | Load Apportionment |
|---|---|---|---|---|
| | | (kWh) | (RM) | (%) |
| 1 | Desktop (assets) | 2,442 | 891 | 51 |
| 2 | Administration Computer | 1,468 | 536 | 31 |
| 3 | Notebook | 226 | 82 | 5 |
| 4 | Laser Printer | 637 | 233 | 13 |
| 5 | Scanner | 13 | 5 | 0 |
| **TOTAL** | | **4,785** | **1,746** | **100** |

Table 4.15 summarizes the energy consumption and bill cost for the five types of end loads found in MED. According to Table 4.15 and Figure 4.6, air conditioning (ACSU and WCPU) recorded the highest energy consumption and annual energy bills in MED, about 38%. These results support the findings of a study conducted by previous authors (Balbis-Morejón et al., 2021), where air conditioning systems consume the highest amount of electrical energy in the educational building. Views by other authors also support the finding that most of the power has been used by the cooling system in an office building (Almogbel et al., 2020). The results obtained about air-conditioning is similar to the worldwide finding by other authors. However, the new highlight of this research is to explore the extent to which laboratory equipment significantly influences the amount of energy consumption in educational institutions. Table 4.15 and Figure 4.6 show that MED laboratory equipment is the second-highest energy consumer, about 32%. The difference in the percentage of load distribution between the air conditioner and the laboratory equipment was found to be only 6%. It means that laboratory equipment, such as air conditioners, is enormously significant to the energy consumption in MED. The result relates to the MED condition, where this department uses the heavy machine during practical sessions or experiments. Besides, these findings align with what the researchers (Shang et al., 2019) mentioned: the heavy-duty machine tool typically consumes much more power but receives less attention regarding energy saving. Using a heavy machine load, as stated in Table 4.9, such as a CNC machine, lathe wood machine, or welding machine, will increase the total energy consumption of the place where the equipment is used. This point of view is supported by research conducted at Hospitals in Norway (Rohde & Martinez, 2015). Their results confirm that sizeable electrical equipment with high rating power, such as Large Medical Technical Equipment (MTE): in the medical biochemistry laboratory, contributes to the increase in electricity consumption at the building. At PSAS, MED is the only department that offers degree programs other than diploma programs where the level of use of laboratory equipment increases while conducting experiments or practical work. Figure 4.7 illustrates the graph of annual energy consumption and the annual bill for five end-loads in MED. From the chart, the air-conditioning and laboratory equipment significantly impact energy consumption of almost 230,000 kWh and energy bills of more than RM 80,000 per year.

**Table 4.15: Summary of energy consumption, energy bill, and load apportionment for five end-load equipment in MED**

| No | End-load | Annual Energy Consumption (kWh) | Annual Energy Bill (RM) | Load Apportionment (%) |
|---|---|---|---|---|
| 1 | Laboratory Equipment | 103,223 | 37,676 | 32 |
| 2 | Fan | 7,059 | 2,576 | 2 |
| 3 | Lighting | 85,985 | 31,385 | 26 |
| 4 | Air-conditioning (ACSU+WCPU) | 124,838 | 45,566 | 38 |
| 5 | ICT Equipment | 4,785 | 1,746 | 1 |
| **TOTAL** | | **325,890** | **118,950** | **100** |

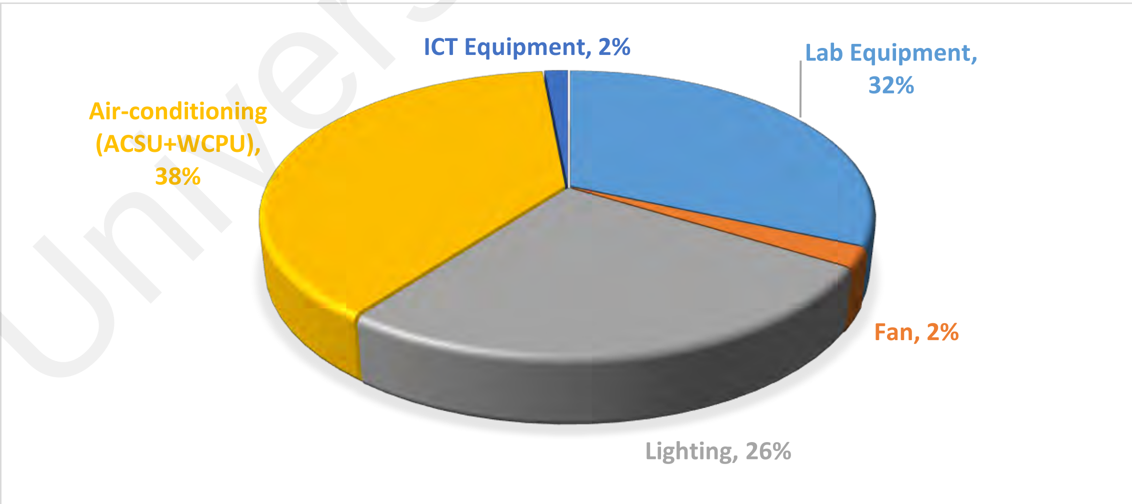



**Figure 4.6: Summary percentage of load apportionment for five end-loads in MED**

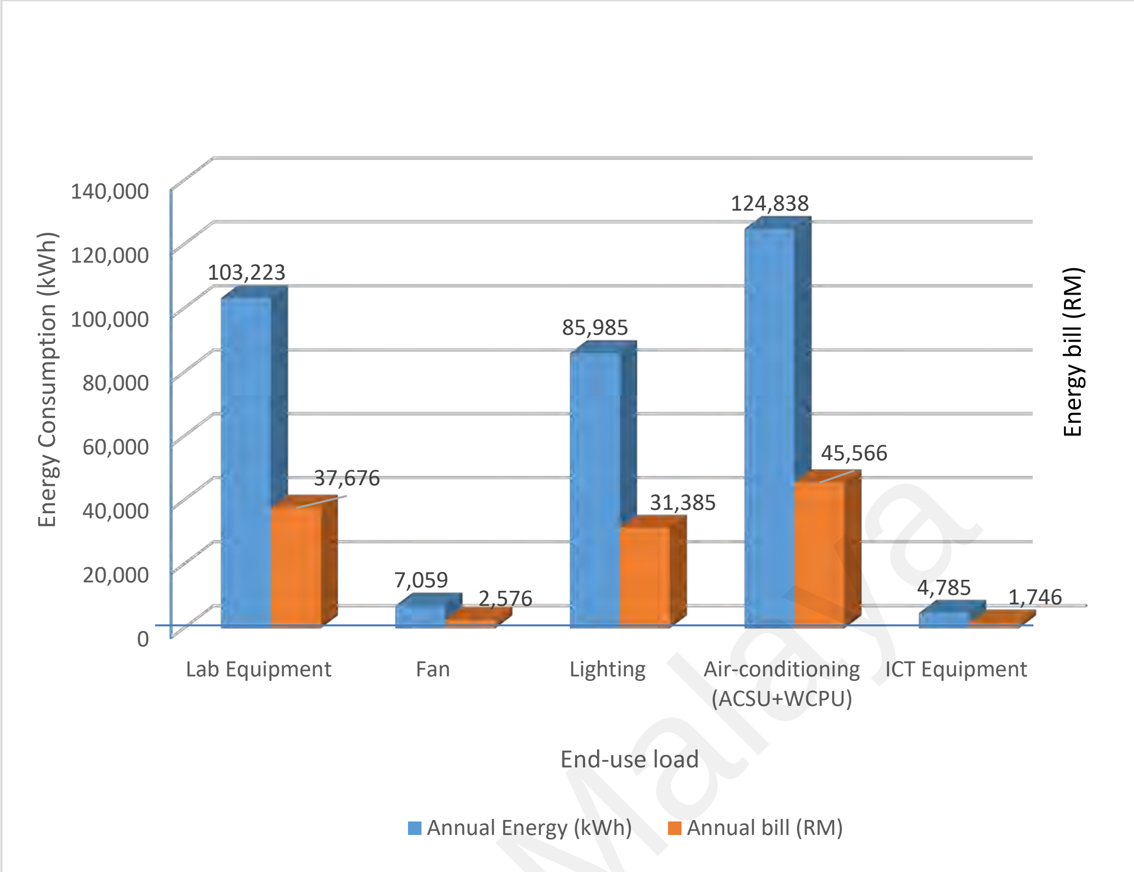



**Figure 4.7: Summary of annual energy consumption and annual bill for five end-loads in MED**

### 4.2.2 Identify and analyze the energy-consuming equipment at CED

Using data from Tables 3.17, 3.18, 3.19, 3.20, 3.21, 3.22 and calculated using Equation (3.1), then the detail of annual energy consumption and annual bill for each type of equipment listed under five end-loads in CED are shown in Tables 4.16, 4.17, 4.18, 4.19, 4.20, 4.21. The annual energy consumption (kWh) is multiplied by the charge rate of RM 0.365 to get the value of the annual energy bill (RM) at CED following the tariff rates 2018 issued by TNB.

**Table 4.16: Annual energy consumption and annual bill for laboratory equipment at CED**

| No | Types of Equipment | Annual Energy Consumption (kWh) | Annual bill (RM) |
|---|---|---|---|
| 1 | Universal Oven | 2,342 | 855 |
| 2 | Incubator | 420 | 153 |
| 3 | Lab Mixer | 621 | 227 |
| 4 | Lab Grinder Machine | 621 | 227 |
| 5 | Sieve Shaker | 464 | 169 |
| 6 | Balance / Scaler | 37 | 14 |
| 7 | Dissolved Oxygen Meter | 62 | 23 |
| 8 | Triaxial Test Apparatus | 186 | 68 |
| 9 | Motorized Casagrande Device | 25 | 9 |
| 10 | Multi-Purpose Teaching Flume / Flow Channel | 159 | 58 |
| 11 | Liquid limit Cone Penetrometer | 37 | 13 |
| 12 | Vacuum Pump | 366 | 134 |
| 13 | Drilling Machine | 1,098 | 401 |
| 14 | Air Compressor | 488 | 178 |
| 15 | Hot Air Gun | 976 | 356 |
| 16 | Lathe Wood Machine | 68 | 25 |
| 17 | Saw Machine | 8,845 | 3,228 |
| 18 | Dryer | 1,537 | 561 |
| 19 | Concrete Mixer | 732 | 267 |
| 20 | Dowel Boring Machine | 976 | 356 |
| 21 | Electric Hand Drill | 1,074 | 392 |
| 22 | Pneumatic Angle Polisher | 132 | 48 |
| 23 | Field Density Apparatus | 15 | 5 |
| 24 | Specific Gravity Apparatus | 11 | 4 |
| 25 | Unconfined Compression Apparatus | 35 | 13 |
| 26 | Air Hammer Drill | 122 | 45 |
| 27 | Brick Cutting Machine | 2,684 | 980 |
| 28 | Cone Penetration | 12 | 4 |
| 29 | Ring and Ball Apparatus | 171 | 62 |
| 30 | Automatic Marshall Compactor | 90 | 33 |
| 31 | Marshall Specimen Water Bath | 244 | 89 |
| 32 | Flow Channel | 119 | 43 |
| 33 | Hydraulic Bench | 55 | 20 |
| 34 | Spectrophotometer | 2 | 1 |
| 35 | JAR Test Apparatus | 10 | 4 |
| 36 | Hollow Chisel Mortising Machine | 537 | 196 |
| 37 | Radial Arm Saw | 1,592 | 581 |
| 38 | Jointer | 1,224 | 447 |
| 39 | Thicknessing Planer Machine | 1,830 | 668 |
| 40 | Universal Testing Machine | 185 | 68 |

| | | | |
|---|---|---|---|
| 41 | Time recorder machine | 19 | 7 |
| 42 | LCD Projector | 2,451 | 895 |
| 43 | Television | 1,739 | 635 |
| 44 | Portable PA System | 37 | 13 |
| 45 | Domestic Refrigerator | 6,138 | 2,240 |
| **TOTAL** | | **40,586** | **14,814** |

**Table 4.17: Annual energy consumption and annual bill for lighting at CED**

| No | Types of Lighting End-load | Annual Energy Consumption (kWh) | Annual Bill (RM) | Load Apportionment (%) |
|---|---|---|---|---|
| 1 | T8 36W | 10,297 | 3,758 | 22 |
| 2 | T8 18W | 663 | 242 | 1 |
| 3 | CFL 24W | 696 | 254 | 1 |
| 4 | MH 400W | 24,840 | 9,067 | 54 |
| 5 | Ttube 18W | 9,877 | 3,605 | 21 |
| **TOTAL** | | **46,372** | **16,926** | **100** |

**Table 4.18: Annual energy consumption and annual bill for a domestic fan at CED**

| No | Types of Fan | Annual Energy Consumption (kWh) | Annual Bill (RM) | Load Apportionment (%) |
|---|---|---|---|---|
| 1 | Ceiling | 4,938 | 1,802 | 80 |
| 2 | Wall Mounted | 1,133 | 413 | 18 |
| 3 | Stand | 136 | 50 | 2 |
| **TOTAL** | | **6,207** | **2,266** | **100** |

**Table 4.19: Annual energy consumption and annual bill for air-conditioning (ACSU) at CED**

| No | Capacity (Horse Power) | Annual Energy Consumption (kWh) | Annual Bill (RM) | Load Apportionment (%) |
|---|---|---|---|---|
| 1 | 1 hp | 3,303 | 1,206 | 12 |
| 2 | 1.5 hp | 14,865 | 5,426 | 53 |
| 3 | 2 hp | 9,903 | 3,615 | 35 |
| **Total** | | **28,071** | **10,246** | **100** |

**Table 4.20: Annual energy consumption and annual bill for air-conditioning (WCPU) under CT 2 for CED**

| No | Code | Annual Energy Consumption (kWh) | Annual bill (RM) |
|---|---|---|---|
| 1 | K-0-42 | 11,211.2 | 4,092.1 |
| 2 | K-1-43 | 9,643.2 | 3,519.8 |
| 3 | K-2-44 | 14,660.8 | 5,351.2 |
| **TOTAL** | | **35,515.2** | **12,963.0** |

**Table 4.21: Annual energy consumption and annual bill for ICT equipment at CED**

| No | Equipment | Annual Energy Consumption (kWh) | Annual Bill (RM) | Load Apportionment (%) |
|---|---|---|---|---|
| 1 | Desktop (assets) | 791 | 289 | 34.4 |
| 2 | Administration Computer | 875 | 319 | 38.0 |
| 3 | Notebook | 169 | 62 | 7.4 |
| 4 | Laser Printer | 368 | 134 | 16.0 |
| 5 | Bubble Jet Printer | 10 | 4 | 0.4 |
| 6 | Dot Matrix Printer | 18 | 6 | 0.8 |
| 7 | Plotter Printer | 35 | 13 | 1.5 |
| 8 | Scanner | 38 | 14 | 1.6 |
| **TOTAL** | | **2,303** | **841** | **100** |

Table 4.22 summarises energy consumption and energy bill for five end-loads in CED. According to Table 4.22 and Figure 4.8, the highest energy consumption and annual energy bills in CED are contributed by air-conditioning (ACSU and WCPU), about 40%. These results are similar to MED and support a study conducted by previous authors (Ali et al., 2021). Air conditioning systems are the leading equipment that recorded 34% of the total energy consumption in the Research and Development (R&D) building, Universiti Malaya. Based on Table 4.22, the second-highest energy consumption at CED is identified from lighting (29%). Table 4.17 shows the highest load apportionment percentage is Metal halide 400W, around 54%. This result coincides with educational buildings where workshops or laboratories typically have tall ceilings on the floor and

large spaces for performing practical work. The installed lighting Metal Halide (spotlight) must meet the minimum standards for lighting in the workshop according to standard MS1525: 2014 regarding the brightness of the space. Research at CED also focuses on laboratory equipment to see if it significantly affects the total energy consumption in the academic building studied. Table 4.22 and Figure 4.8 show that CED's laboratory equipment is the third-highest energy consumer, about 26%. It means that laboratory equipment is vital to CED's total energy consumption. Figure 4.9 illustrates the graph of annual energy consumption and the annual bill for five end-loads in CED. From the bar graph, air-conditioning and lighting significantly impact energy consumption of almost 100,000 kWh and energy bills of more than RM 40,000 per year.

**Table 4.22: Summary of energy consumption, energy bill, and load apportionment for five end-load equipment in CED**

| No | End-load | Annual Energy Consumption | Annual Bill | Load Apportionment |
|---|---|---|---|---|
| | | (kWh) | (RM) | (%) |
| 1 | Laboratory Equipment | 40,586 | 14,814 | 26 |
| 2 | Fan | 6,207 | 2,266 | 4 |
| 3 | Lighting | 46,372 | 16,926 | 29 |
| 4 | Air-conditioning (ACSU + WCPU) | 63,587 | 23,209 | 40 |
| 5 | ICT Equipment | 2,303 | 841 | 1 |
| **TOTAL** | | **163,494** | **159,055** | **58,055** |

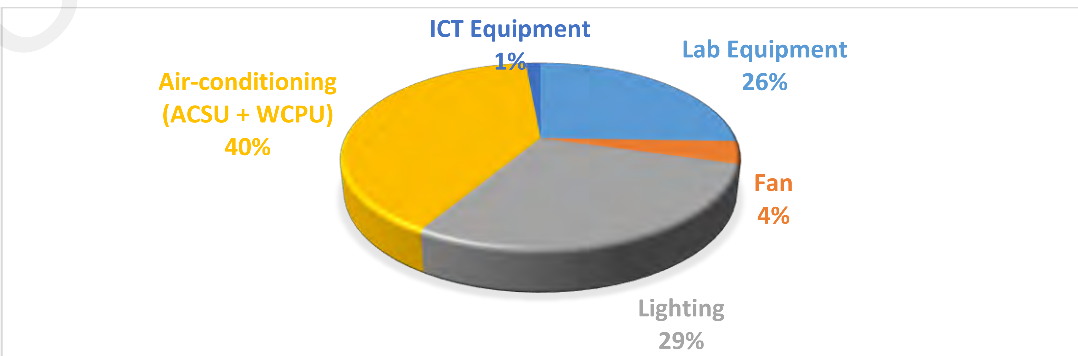



**Figure 4.8: Summary percentage of load apportionment for five end-loads in CED**

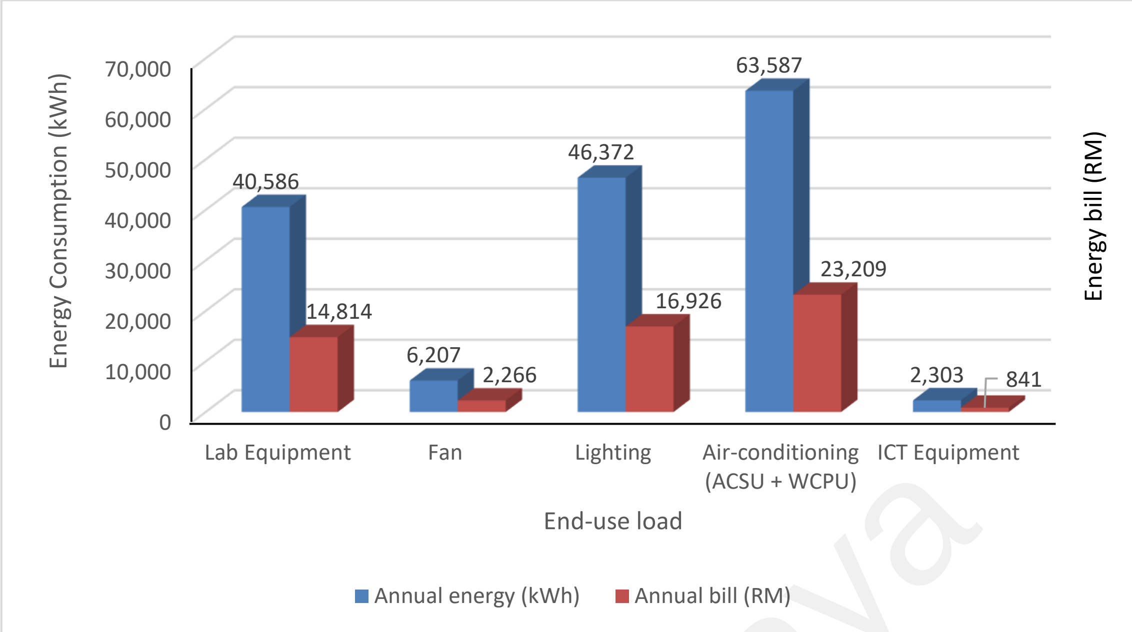



**Figure 4.9: Summary of annual energy consumption and annual bill for five end-loads in CED**

### 4.2.3 Identify and analyze the energy-consuming equipment at EED

Using data from Tables 3.24, 3.25, 3.26, 3.27, 3.28, 3.29 and calculated using Equation (3.1), then the detail of annual energy consumption and annual bill for each type of equipment listed under five end-loads in EED are shown in Tables 4.23, 4.24, 4.25, 4.26, 4.27, 4.28. The end-loads involve laboratory equipment, lighting, domestic fan, air-conditioning (ACSU and WCPU), and ICT equipment. The EED's annual energy bill (RM) follows the tariff rates 2018 issued by TNB.

**Table 4.23: Annual energy consumption and annual bill for laboratory equipment at EED**

| No | Types of Equipment | Annual Energy Consumption (kWh) | Annual bill (RM) |
|---|---|---|---|
| 1 | Cleaning Machines | 515 | 188 |
| 2 | LCD Projector | 2,324 | 848 |
| 3 | Speaker | 5 | 2 |
| 4 | Portable PA System | 16 | 6 |
| 5 | Universal Oven | 166 | 61 |

| | | | |
|---|---|---|---|
| 6 | Plotter | 8 | 3 |
| 7 | Isolation Transformer | 12,660 | 4,621 |
| 8 | Solar Panel System | 144 | 53 |
| 9 | AC Power Supply | 7,159 | 2,613 |
| 10 | Generating Station Simulation Lab | 203 | 74 |
| 11 | Mobile Radio | 3 | 1 |
| 12 | Audio Splitter | 9 | 3 |
| 13 | Mixer | 34 | 12 |
| 14 | Test Pattern Generator | 5 | 2 |
| 15 | Air Compressor | 5,024 | 1,834 |
| 16 | Grinding Machine | 2,072 | 756 |
| 17 | Electrical Machine Trainer | 1,884 | 688 |
| 18 | Pillar Drilling Machine | 218 | 79 |
| 19 | Digital Frequency Counter | 1,382 | 504 |
| 20 | Signal Generator | 487 | 178 |
| 21 | Oscilloscope | 5,677 | 2,072 |
| 22 | Static Relay and Relay Protection | 414 | 151 |
| 23 | Motor Fault Simulator (MV 1046 3-Phase Squirrel Cage Motor) | 345 | 126 |
| 24 | UV Expose Units | 5,024 | 1,834 |
| 25 | Electric Machine | 3,297 | 1,203 |
| 26 | Electric Hand Drill | 30,395 | 11,094 |
| 27 | Programmable Logic Controller | 6,280 | 2,292 |
| 28 | Electro-Pneumatic Trainer + Portable Compressor | 3,391 | 1,238 |
| **TOTAL** | | **89,143** | **32,537** |

**Table 4.24: Annual energy consumption and annual bill for lighting at EED**

| No | Types of Lighting End-load | Annual Energy Consumption (kWh) | Annual Bill (RM) | Load Apportionment (%) |
|---|---|---|---|---|
| 1 | T8 36W | 37,558 | 13,709 | 57 |
| 2 | T8 18W | 1,720 | 628 | 3 |
| 3 | CFL 24W | 258 | 94 | 0 |
| 4 | MH 400W | 13,910 | 5,077 | 21 |
| 5 | Ttube 18W | 11,923 | 4,352 | 18 |
| **TOTAL** | | **65,370** | **23,860** | **100** |

**Table 4.25: Annual energy consumption and annual bill for a domestic fan at EED**

| No | Types of fan | Annual Energy Consumption (kWh) | Annual Bill (RM) | Load Apportionment (%) |
|---|---|---|---|---|
| 1 | Ceiling | 3,611 | 1,318 | 54 |
| 2 | Wall Mounted | 2,832 | 1,034 | 42 |
| 3 | Stand | 238 | 87 | 4 |
| **TOTAL** | | **6,681** | **2,438** | **100** |

**Table 4.26: Annual energy consumption and annual bill for air-conditioning (ACSU) at EED**

| No | Capacity (Horse Power) | Annual Energy Consumption (kWh) | Annual Bill (RM) | Load Apportionment (%) |
|---|---|---|---|---|
| 1 | 1 hp | 1,652 | 603 | 1 |
| 2 | 1.5 hp | 44,594 | 16,277 | 20 |
| 3 | 2 hp | 113,095 | 41,280 | 52 |
| 4 | 3 hp | 59,191 | 21,605 | 27 |
| **Total** | | **218,532** | **79,764** | **100** |

**Table 4.27: Annual energy consumption and annual bill for air-conditioning (WCPU) under CT 1 for EED**

| No | Code | Annual Energy Consumption (kWh) | Annual bill (RM) |
|---|---|---|---|
| 1 | M-0-16 | 6,570 | 2,398 |
| 2 | M-0-17 | 9,643 | 3,520 |
| 3 | M-2-18 | 10,270 | 3,749 |
| 4 | M-1-20 | 3,207 | 1,170 |
| 5 | M-2-21 | 6,507 | 2,375 |
| 6 | M-0-24A | 9,722 | 3,548 |
| 7 | M-0-24B | 13,955 | 5,094 |
| 8 | M-1-25B | 6,586 | 2,404 |
| 9 | M-1-25B | 6,586 | 2,404 |
| 10 | M-2-26A | 6,742 | 2,461 |
| 11 | M-2-26B | 3,214 | 1,173 |
| 12 | DK-28 | 3,097 | 1,130 |
| **TOTAL** | | **86,099** | **31,426** |

**Table 4.28: Annual energy consumption and annual bill for ICT equipment at EED**

| No | Equipment | Annual Energy Consumption (kWh) | Annual Bill (RM) | Load Apportionment (%) |
|---|---|---|---|---|
| 1 | Administration Computer | 1,185 | 433 | 73 |
| 2 | Lab Computer (rent) | 282 | 103 | 17 |
| 3 | Notebook | 38 | 14 | 2 |
| 4 | Laser Printer | 74 | 27 | 4 |
| 5 | Bubble Jet Printer | 10 | 4 | 1 |
| 6 | Plotter Printer | 35 | 13 | 2 |
| 7 | Scanner | 11 | 4 | 1 |
| **TOTAL** | | **1,634** | **597** | **97** |

Table 4.29 summarizes energy consumption and energy bills for the five types of end loads found in EED. Table 4.29 and Figure 4.10 show energy consumption and the highest annual energy bill in EED contributed by air-conditioning (ACSU and WCPU), about 65%. The result is similar to the research finding (Sarbu & Adam, 2016), where air conditioning systems significantly impact building energy consumption, contributing 60%. According to Figure 4.11, the graph shows EED's energy consumption pattern and bill quite different from MED's or CED's chart. The load apportionment percentage for air-conditioning was recorded at 65%, showing the dominant consumption comes from air-conditioning with a high score. There is a difference in the share of energy consumption load recorded by air conditioners at EED compared to the percentage at MED and CED. Although these three departments showed the highest rate of energy consumption was from air conditioning, the percentage values recorded showed quite significant differences as follows: EED (65%), MED (38%), and CED (40%). This difference is due to the high number of ACSU and WCPU-type air conditioners available in EED compared to the other two departments. It can be proved by referring to Tables 3.27 and 3.28, where there are 77 ACSU-type air conditioner units and 12 AHU units (WCPU) in EED, causing the total energy consumption in this academic department to

be high. Based on Table 4.29, the second-highest energy consumption at EED is identified from laboratory equipment, just 19%. This is because the total quantity of laboratory equipment is 633 units, including 28 types of laboratory equipment, as stated in Table 3.24, and partly under the small electrical and electronic equipment category. Based on the results, it is found that the percentage of load apportionment for laboratory equipment in EED is only 19%. This percentage means that laboratory equipment has a less significant effect on EED's total energy consumption than the results recorded at MED and CED. Figure 4.11 illustrates the graph of annual energy consumption and the annual bill for five end-loads in EED. From the bar graph, air-conditioning has a high impact on energy consumption of 304,631 kWh and energy bills of more than RM 111,190 per year.

**Table 4.29: Summary of energy consumption, energy bill, and load apportionment for five end-load equipment in EED**

| No | End-load | Annual Energy Consumption (kWh) | Annual Bill (RM) | Load Apportionment (%) |
|---|---|---|---|---|
| 1 | Laboratory Equipment | 89,143 | 32,537 | 19 |
| 2 | Fan | 6,681 | 2,438 | 1 |
| 3 | Lighting | 65,370 | 23,860 | 14 |
| 4 | Air-conditioning (ACSU+WCPU) | 304,631 | 111,190 | 65 |
| 5 | ICT Equipment | 1,634 | 597 | 0.3 |
| **TOTAL** | | **467,460** | **170,623** | **100** |

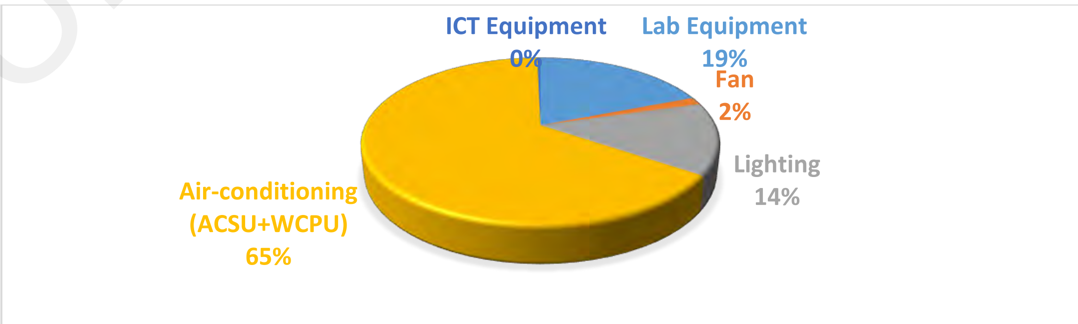



**Figure 4.10: Summary percentage of load apportionment for five end-loads in EED**

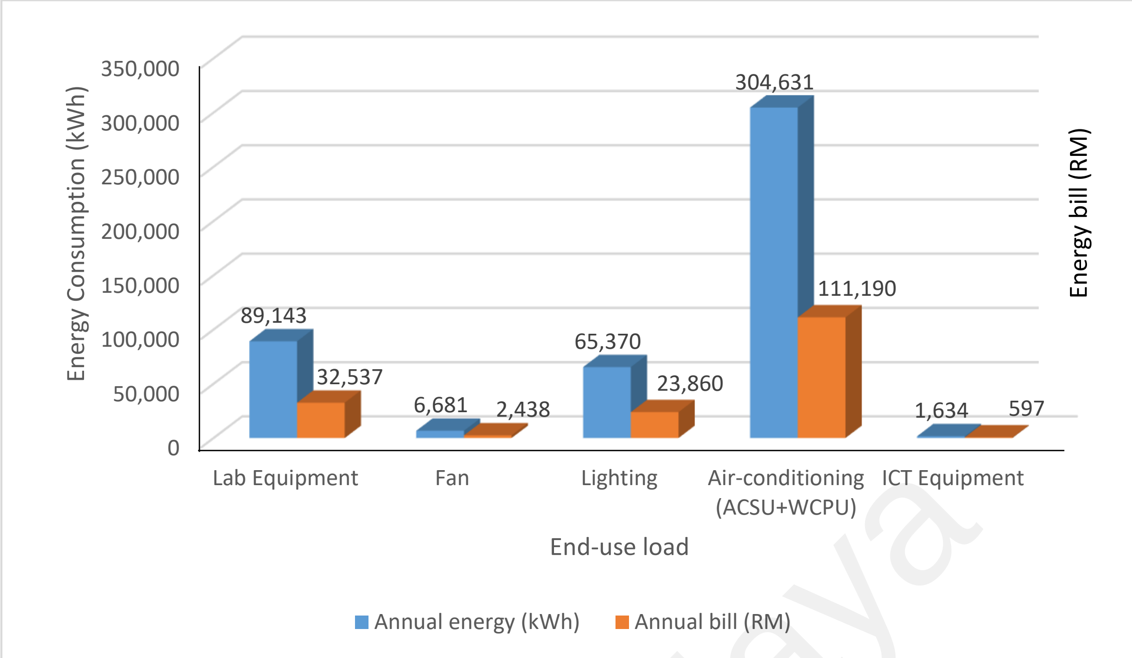



**Figure 4.11: Summary of annual energy consumption and annual bill for five end-loads in EED**

### 4.2.4 Identify and analyze the energy-consuming equipment at CD

Using data from Tables 3.31, 3.32, 3.33, 3.34, 3.35, 3.36 and calculated based on Equation (3.1), then the details of energy consumption and the annual bill for each type of equipment listed under five end-loads in CD are shown in Tables 4.30, 4.31, 4.32, 4.33, 4.34, 4.35. The end-loads involve laboratory equipment, lighting, domestic fan, air-conditioning (ACSU and WCPU), and ICT equipment. The annual energy bill (RM) at CD follows the tariff rates for 2018 issued by TNB.

**Table 4.30: Annual energy consumption and annual bill for laboratory equipment at CD**

| No | Types of Equipment | Annual Energy Consumption (kWh) | Annual bill (RM) |
|---|---|---|---|
| 1 | Cashier Machine | 33 | 12 |
| 2 | Garment Steamer | 1,408 | 514 |
| 3 | Audio Amplifier and Mixer | 6,624 | 2,418 |
| 4 | Projection Screen | 119 | 43 |

| | | | |
|---|---|---|---|
| 5 | PA System | 373 | 136 |
| 6 | Microwave | 994 | 363 |
| 7 | Bakery Refrigerator | 2,612 | 953 |
| 8 | Display Chiller Refrigerator 3 Door | 11,242 | 4,103 |
| 9 | LCD Projector | 306 | 112 |
| 10 | TV Box | 62 | 23 |
| 11 | Electric Stoves | 745 | 272 |
| 12 | Water Dispenser | 2,484 | 907 |
| 13 | Electronic White Board | 828 | 302 |
| 14 | Chocolate Warmer | 1,987 | 725 |
| 15 | Food Warmer | 1,242 | 453 |
| 16 | Hot Water Dispenser | 352 | 128 |
| 17 | Chocolate Warmer | 1,656 | 604 |
| 18 | Chiller and Freezer 2 Door | 7,665 | 2,798 |
| 19 | Retail Shop Billing Machine | 166 | 60 |
| 20 | Microphone System | 5,664 | 2,067 |
| 21 | Controller video conferencing | 960 | 351 |
| **TOTAL** | | **47,521** | **17,345** |

**Table 4.31: Annual energy consumption and annual bill for lighting at CD**

| No | Types of Lighting End-load | Annual Energy Consumption (kWh) | Annual Bill (RM) | Load Apportionment (%) |
|---|---|---|---|---|
| 1 | T8 36W | 31,835 | 11,620 | 67 |
| 2 | T8 18W | 1,490 | 544 | 3 |
| 3 | CFL 24W | 683 | 249 | 1 |
| 4 | Ttube 18W | 13,414 | 4,896 | 28 |
| **TOTAL** | | **47,422** | **17,309** | **100** |

**Table 4.32: Annual energy consumption and annual bill for a domestic fan at CD**

| No | Types of Fan | Annual Energy Consumption (kWh) | Annual Bill (RM) | Load Apportionment (%) |
|---|---|---|---|---|
| 1 | Ceiling | 3,478 | 1,269 | 59 |
| 2 | Wall Mounted | 2,124 | 775 | 36 |
| 3 | Stand | 338 | 123 | 6 |
| **TOTAL** | | **5,939** | **2,168** | **100** |

**Table 4.33: Annual energy consumption and annual bill for air-conditioning (ACSU) at CD**

| No | Capacity (Horse Power) | Annual Energy Consumption | Annual Bill | Load Apportionment |
|---|---|---|---|---|
| | | (kWh) | (RM) | (%) |
| 1 | 1 hp | 1,316 | 480 | 3 |
| 2 | 1.5 hp | 14,865 | 5,426 | 38 |
| 3 | 2 hp | 13,204 | 4,820 | 37 |
| 4 | 3 hp | 9,905 | 3,615 | 25 |
| **Total** | | **39,290** | **14,341** | **104** |

**Table 4.34: Annual energy consumption and annual bill for air-conditioning (WCPU) under CT 1 for CD**

| No | Code | Annual Energy Consumption | Annual Bill |
|---|---|---|---|
| | | (kWh) | (RM) |
| 1 | J-0-9 | 8,938 | 3,262.2 |
| 2 | J-1-10 | 10,898 | 3,977.6 |
| 3 | J-2-11 | 10,584 | 3,863.2 |
| 4 | J-0-12A | 6,076 | 2,217.7 |
| 5 | J-0-12B | 7,127 | 2,601.2 |
| 6 | J-1-13A | 4,453 | 1,625.4 |
| 7 | J-1-13B | 6,194 | 2,260.7 |
| 8 | DK-15 | 4,155 | 1,516.6 |
| **TOTAL** | | **103,476** | **58,424** |

**Table 4.35: Annual energy consumption and annual bill for ICT equipment at CD**

| No | Equipment | Annual Energy Consumption | Annual Bill | Load Apportionment |
|---|---|---|---|---|
| | | (kWh) | (RM) | (%) |
| 1 | Desktop (assets) | 45 | 16 | 4.5 |
| 2 | Administration Computer | 762 | 278 | 76.2 |
| 3 | Notebook | 38 | 14 | 3.8 |
| 4 | Laser Printer | 155 | 57 | 15.5 |
| **TOTAL** | | **1,000** | **365** | **100** |

Table 4.36 summarises energy consumption and energy bill for five end-loads in CD. According to Table 4.36 and Figure 4.12, the highest energy consumption and annual

energy bills in CD are contributed by air-conditioning (ACSU and WCPU), about 49%. The result is similar to the research finding at MED, CED, and EED, where air conditioning systems significantly impact building energy consumption. According to Figure 4.13, the graph shows that the energy consumption and energy bill for laboratory equipment and lighting are similar at CD. Besides that, the result confirms laboratory equipment has a significant energy consumption building,

**Table 4.36: Summary of energy consumption, energy bill, and load apportionment for five end-load equipment in CD**

| No | End-load | Annual Energy Consumption (kWh) | Annual Bill (RM) | Load Apportionment (%) |
|---|---|---|---|---|
| 1 | Laboratory Equipment | 47,521 | 17,345 | 24 |
| 2 | Fan | 5,939 | 2,168 | 3 |
| 3 | Lighting | 47,422 | 17,309 | 24 |
| 4 | Air-conditioning (ACSU+WCPU) | 98,050 | 35,788 | 49 |
| 5 | ICT Equipment | 1,000 | 365 | 0.5 |
| **TOTAL** | | **199,932** | **72,975** | **100** |

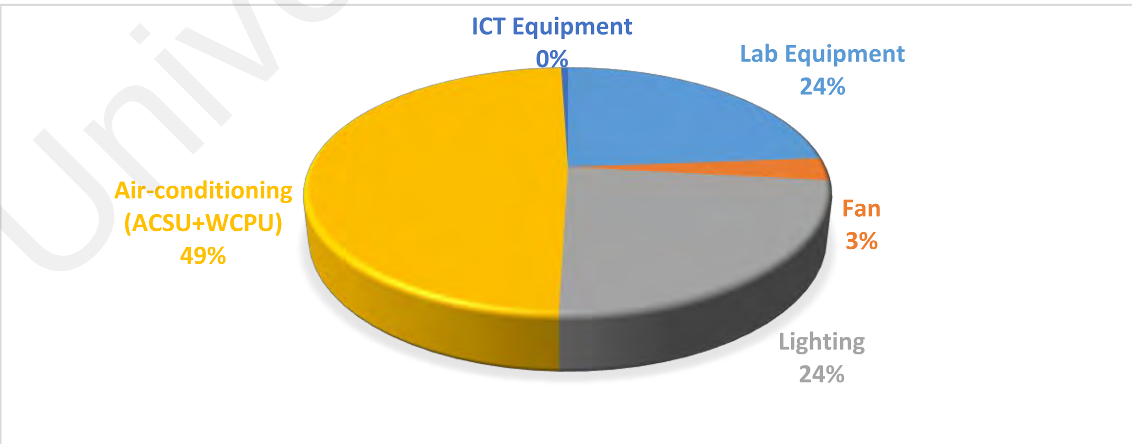



**Figure 4.12: Summary percentage of load apportionment for five end-loads in CD**

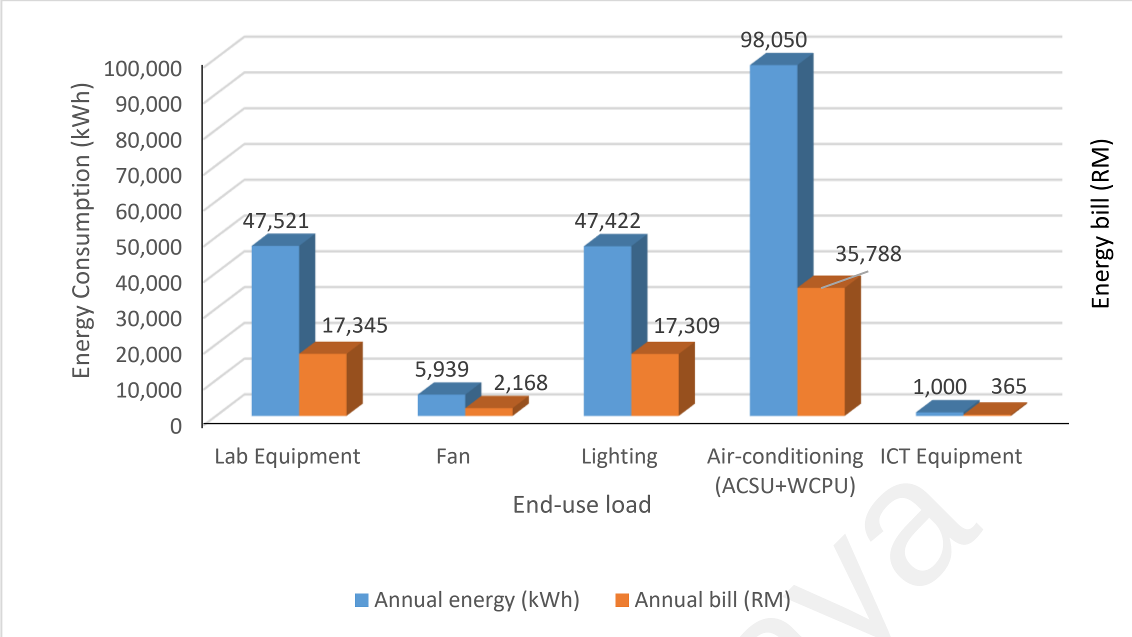



**Figure 4.13: Summary of annual energy consumption and annual bill for five end-loads in CD**

### 4.2.5 Energy usage optimization measures for an academic building

After completing the energy consumption analysis for the five designated active equipment, the detailed study of energy consumption and energy bills for the four academic buildings involved are summarized in Table 4.37. The line chart in Figure 4.14 illustrates the comparison pattern of energy consumption in the four departments. The design analyses the ranks for each piece of equipment, and the energy consumption can be determined more quickly. The analysis results confirmed that air conditioners were the highest energy-consuming equipment in all the academic departments studied. The pattern displayed through the line chart also demonstrates that laboratory equipment is the second highest energy consumer except for CED. Besides that, it confirms that laboratory equipment also provides a positive significance in increasing the overall energy consumption in the academic department. After the equipment that needs to be focused on for energy saving through energy efficiency improvement is identified, Energy Saving Measures (ESM) will be proposed. Although the equipment that used the highest power in each academic department studied was air conditioning, the proposed ESM also chose the equipment that recorded the second-highest value. Based on Table 4.37 and Figure 4.14, the targeted equipment for energy-saving measures for MED, CED, EED, and CD has been identified. Table 4.38 summarises the results from a measured meter, energy audit, error percentage, and ESM recommended for four involved departments. CED and EED findings are not different from the research carried out by (Rodrigues et al., 2016); lighting and air-conditioning are contributors to most power consumption in the office. From the results in Table 4.38, the error percentage between measured and calculated values for MED, EED, and CD is less than 1% but for CED is about 8.3%. The results show the error percentage is not more than 10% and is considered acceptable. Verification of the error percentage values obtained is vital to ensure that the error percentage values are good tolerance following ASHRAE Guidelines 14-2014, International Performance Measurement and Verification Protocol (IPMVP), and Federal Energy Management Program (FEMP) (Ruiz & Bandera, 2017).

**Table 4.37: Summary of annual energy consumption and energy bill for five end-loads in MED, CED, EED, and CD**

| No | End-load | Department | Quantity | Total Power (kW) | Annual Energy Consumption (kWh) | Annual Energy Bill (RM) |
|---|---|---|---|---|---|---|
| 1 | Laboratory Equipment | MED | 1022 | 45.17 | 103,223 | 37,676 |
| | | CED | 100 | 52.335 | 40,586 | 14,814 |
| | | EED | 633 | 14.649 | 89,143 | 32,537 |
| | | CD | 35 | 18.32 | 47,521 | 17,345 |
| 2 | Fan | MED | 113 | 0.299 | 7,059 | 2,576 |
| | | CED | 109 | 0.299 | 6,207 | 2,266 |
| | | EED | 102 | 0.299 | 6,681 | 2,438 |
| | | CD | 88 | 0.299 | 5,939 | 2,168 |
| 3 | Lighting | MED | 2241 | 0.496 | 85,985 | 31,385 |
| | | CED | 1341 | 0.496 | 46,372 | 16,926 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | EED | 2250 | 0.496 | 65,370 | 23,860 |
| | | CD | 1047 | 0.078 | 47,422 | 17,309 |
| 4 | Air-conditioning (ACSU + WCPU) | MED | 59 | 73.008 | 124,838 | 45,566 |
| | | CED | 14 | 48.656 | 63,587 | 23,209 |
| | | EED | 89 | 163.653 | 304,631 | 111,190 |
| | | CD | 18 | 80.113 | 98,050 | 35,788 |
| 5 | ICT Equipment | MED | 186 | 0.378 | 4,785 | 1,746 |
| | | CED | 85 | 0.591 | 2,303 | 841 |
| | | EED | 66 | 0.361 | 1,634 | 597 |
| | | CD | 32 | 0.346 | 1,000 | 365 |
| **TOTAL** | | MED | **3621** | **119.351** | **325,890** | **118,950** |
| | | CED | **1649** | **102.377** | **159,055** | **58,055** |
| | | EED | **3140** | **179.458** | **467,460** | **170,623** |
| | | CD | **1220** | **99.156** | **199,932** | **72,975** |

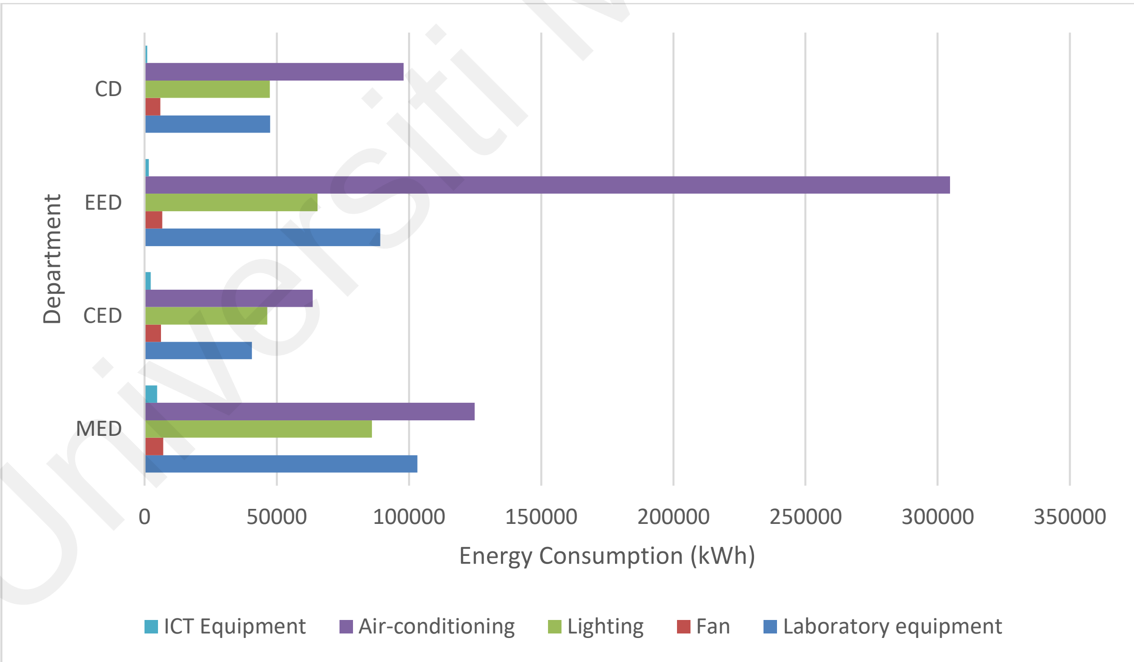



**Figure 4.14: Comparison of energy consumption pattern for five end-loads in the four academic departments involved in 2019.**

### 4.2.6 Energy-Saving Measures (ESM)

Based on Table 4.38, the proposed energy consumption optimization measures refer to ESMs involving air conditioning and lighting only through energy efficiency improvement methods. No ESM is recommended for MED because the laboratory equipment comprises 30 different equipment types with various specifications and capacities. MED can obtain energy-saving potential through the use of renewable energy power supplies. Table 4.38 shows that lighting is the target equipment identified to implement energy-saving measures in CED. The energy consumption for the lighting found in CED within a year is 46,372 kWh, while the energy bill is RM 16,926, as stated in Table 4.37. Based on Table 4.17, the lighting type known as metal halide (MH 400W) is recorded as the highest energy consumption percentage; about 54 needs to be focused on the ESM program. However, this type of lamp is not listed in the Malaysian Standard document MS 25798: 2014 under the minimum energy performance standard (MEPS) for lights. Nevertheless, MH 400W is still selected as targeted equipment for the energy-saving program even though it is not on the MEPS list related to lighting.

Most laboratories or workshops in CED are fitted with 400W Metal Halide type lamps. Table 4.39 shows the illuminance level by areas served at CED, where the data is collected using a lux meter in the involved area. The average status of lumens in a laboratory or workshop in CED compared to the MS 1525 standard meets the set standards. No problem with the illuminance produced by existing lighting at the laboratory or workshop at CED, but the capacity of lamp watts for MH 400W used in the CED is 400W. The target to reduce energy consumption in CEDs is reasonable through the MH 400W replacement program with 200W light-emitting diodes (LED) industrial high bay light. Replacing MH 400W with the new lighting system using LED high bay light can increase the life span of light and significantly reduce the total energy consumption and cost-saving (Luewarasirikul, 2015). The mean lumens for MH 400W and 200W LED are approximately 24000 lumens (Hylite, 2015) and 23000 lumens, respectively (Alibaba, 2021). The real difference in lumens between MH 400W and 200W LED is only around 1000 lumens, and it does not affect the lighting level of the existing location.

**Table 4.38: Summary of the results from a measured meter, energy audit, error percentage, and ESM recommended for four involved departments.**

| Academic Building | Total kWh/year for the whole academic building involves: [Measured value] (A) | Total kWh/year for the whole academic building involves: [Calculated value] (B) | Error percentage between measured and calculated value: (A-B)/A x 100 (%) | Targeted equipment for Energy Saving Measures (ESM) |
|---|---|---|---|---|
| MED | 327,324 | 325,890 | 0.4 | Laboratory equipment |
| CED | 173,468 | 159,055 | 8.3 | Lighting |
| EED | 470,589 | 467,460 | 0.7 | Air-conditioning |
| CD | 201,878 | 199,932 | 1.0 | Lighting |
| (MED + CED + EED + CD ) | **1,173,259** | **1,152,337** | | |

**Table 4.39: Summary of average illuminance level by areas served at CED**

| No | Type of use | Average Illuminance (Lux) | MS 1525 | Deviation | Tolerance ± 20% | Status |
|---|---|---|---|---|---|---|
| 1 | Office | 248 | 300 | -52 | -17.3 | Within |
| 2 | Toilet | 120 | 100 | 20 | 20 | Within |
| 3 | Laboratory/ Workshop | 266 | 300 | -34 | 11.3 | Within |

| | | | | | | |
|---|---|---|---|---|---|---|
| 4 | Classroom | 252 | 300 | -48 | 16 | Within |

The recommended ECM for EED is installing the High-Efficiency Split Unit Air Conditioner (ACSU) and Advanced Thermal Control System (WCPU Smart Controller). Referring to Table 4.12, the 2hp ACSU is the type of air conditioner with the highest total energy consumption. This 2hp air-conditioner is suggested to placing inside the lecturer room to separate the centralized WCPU with no class mode instead of using WCPU consumption for the individual user. The WCPU Controller unit's primary is similar to a digital thermostat by adding analog output based on temperature value to control the Variable Speed Frequency (VSF) that runs a compressor speed based on room temperature. The ESM proposed for this WCPU is common in energy saving for air conditioning systems using variable frequencies on the compressor drive for capacity control (Abdullah et al., 2020).

Table 4.38 shows the lighting was identified as targeted equipment for energy-saving purposes at CD. Table 4.31 shows the T8 36W lamp at CD records the highest energy consumption of about 67%. Therefore, a T8 36W lamp is recommended for the ESM program at CD by replacing T8 36W with the new lighting system using LED lights (Perdahci et al., 2018)

## 4.3 Analysis of energy audit data for Non-Academic Building

An analysis of energy audit data in three non-academic buildings at PSAS, namely the Islamic Center (IC), the Sports Center (SC), and the Multipurpose Hall (MH), was conducted. These buildings were chosen due to their operating hours during office hours, at night, and on weekends. Although this building is not considered an academic building, it is identified as one of the PSAS buildings that use high energy. Energy audits collect information such as equipment type, quantity, power, and operating hours. Estimating energy consumption per equipment can help identify which equipment uses high energy in this building. Energy audit analysis was performed on four groups of end loads: fans, lighting, air conditioners, and other equipment. Annual energy consumption and bills for all types of final loads listed were calculated using the same methodology used on academic buildings.

### 4.3.1 Identify and analyze the energy-consuming equipment through annual energy consumption, yearly bills, and load apportionment at IC

Using data from Tables 3.39, 3.40, 3.41, and 3.42 and calculated using Equation (3.1), the detail of annual energy consumption for each type of equipment listed under end-loads in IC is shown in Tables 4.40, 4.41, 4.42, 4.43. The estimation of annual energy bills (RM) is calculated by multiplying the annual energy consumption (kWh) with the charge rate of RM 0.365 (TNB, 2019b). In an IC building, the highest load apportionment for the fan has a 26" industrial wall fan of about 58%. IC uses a downlight because it effectively helps improve the light quality where this light is installed. They are recessed into the ceiling, directing the light down into a narrow beam. Installing the downlight at the top makes the room look bigger and more modern (Modern.Place, 2017). The 5hp air-conditioning is identified as the highest energy consumption, where the load apportionment is about 55%. According to Table 3.8, the gross floor area for IC is 1486 $m^2$. To cool the internal space of the IC with the rate of a site, the number of air conditioning units with a 5hp capacity used is more than other types of capacity. The results obtained from the analysis for the category of different types of equipment available in the IC show that the refrigerator recorded a high energy consumption of about 48%.

**Table 4.40: Annual energy consumption and annual bill for a fan at IC.**

| No | Types of Fan | Annual Energy Consumption (kWh) | Annual Bill (RM) | Load Apportionment (%) |
|---|---|---|---|---|
| 1 | 26" Industrial Stand Fan | 2,166 | 791 | 35 |
| 2 | 26" Industrial Wall Fan | 3,582 | 1,308 | 58 |
| 3 | 16" Wall Fan | 425 | 155 | 7 |
| **TOTAL** | | **6,174** | **2,253** | **100** |

**Table 4.41: Annual energy consumption and annual bill for lighting at IC**

| No | Types of Lighting | Annual Energy Consumption (kWh) | Annual Bill (RM) | Load Apportionment (%) |
|---|---|---|---|---|
| 1 | T8 36W | 208.66 | 76.16 | 2 |
| 2 | Downlight | 8,197.20 | 2991.98 | 98 |
| **TOTAL** | | **8,405.86** | **3068.14** | 100 |

**Table 4.42: Annual energy consumption and annual bill for air-conditioning (ACSU) at IC**

| No | Capacity (Horse Power) | Annual Energy Consumption (kWh) | Annual Bill (RM) | Load Apportionment (%) |
|---|---|---|---|---|
| 1 | 1 hp | 528.17 | 192.78 | 3 |
| 2 | 1.5 hp | 2,376.76 | 867.52 | 12 |
| 3 | 2 hp | 6,333.77 | 2311.83 | 31 |
| 4 | 5 | 11,086.57 | 4046.60 | 55 |
| **Total** | | **20,325.26** | **7418.72** | **100** |

**Table 4.43: Annual energy consumption and annual bill for other equipment at IC**

| No | Types of Equipment | Annual Energy Consumption (kWh) | Annual Bill (RM) | Load Apportionment (%) |
|---|---|---|---|---|
| 1 | Water dispenser | 4,180.00 | 1,526 | 33 |
| 2 | Refrigerator | 6,138.00 | 2,240 | 48 |
| 3 | Vending Machine | 1,628.00 | 594 | 13 |
| 4 | CCTV Camera | 132.00 | 48 | 1 |
| 5 | Freezer | 330.00 | 120 | 3 |
| 6 | Television 50" | 168.00 | 61 | 1 |
| 7 | PA System | 171.60 | 63 | 1 |
| **TOTAL** | | **12,747.60** | **4,652.87** | **100** |

Table 4.44 summarises energy consumption, energy bill, and load apportionment for four end-loads in IC. Figure 4.15 illustrates the summary percentage of load apportionment for four end-loads at IC. According to Table 4.44 and Figure 4.15, the highest energy consumption and annual energy bills per equipment in IC, known as Mosque, are contributed by air-conditioning (ACSU), about 43%. The results are similar to research findings on academic buildings, where air conditioning has been confirmed to significantly impact overall energy consumption in the buildings studied. According to the person in charge at IC, three routine programs are held: Maghrib lecture, Perdana lecture only on Mondays and Thursdays, and Friday prayers. Most of the air conditioners were operated almost entirely during the program. It causes air conditioning to be the highest energy consumer in IC. According to Figure 4.16, the combo graph illustrates the annual energy consumption and annual bills for the four types of end-loads in the IC. The analysis results on non-academic buildings show the second highest energy users represented by IC are from other equipment type categories at about 27%. The results show that the analysis results differ between academic and non-academic buildings, where the second-highest users are other types of equipment, not the lighting type.

**Table 4.44: Summary of energy consumption, energy bill, and load apportionment for four end-load equipment in IC**

| No | End-load | Annual Energy Consumption | Annual Bill | Load Apportionment |
|---|---|---|---|---|
| | | (kWh) | (RM) | (%) |
| 1 | Fan | 6,173.76 | 2,253 | 13 |
| 2 | Lighting | 8,405.86 | 3,068 | 18 |
| 3 | Air-conditioning (ACSU) | 20,325.26 | 7,419 | 43 |
| 4 | Other equipment | 12,747.60 | 4,653 | 27 |
| **TOTAL** | | **47,652.48** | **17,393** | **100** |

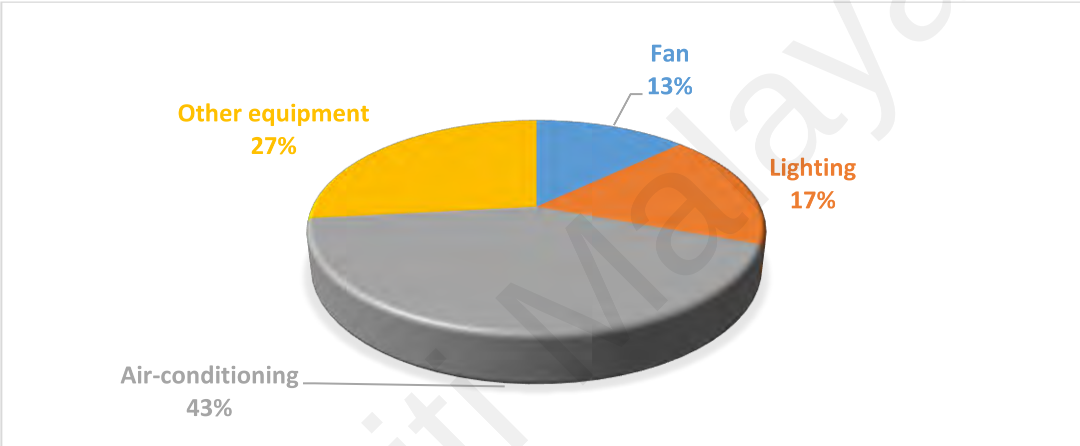



**Figure 4.15: Summary percentage of load apportionment for four end-loads in IC**

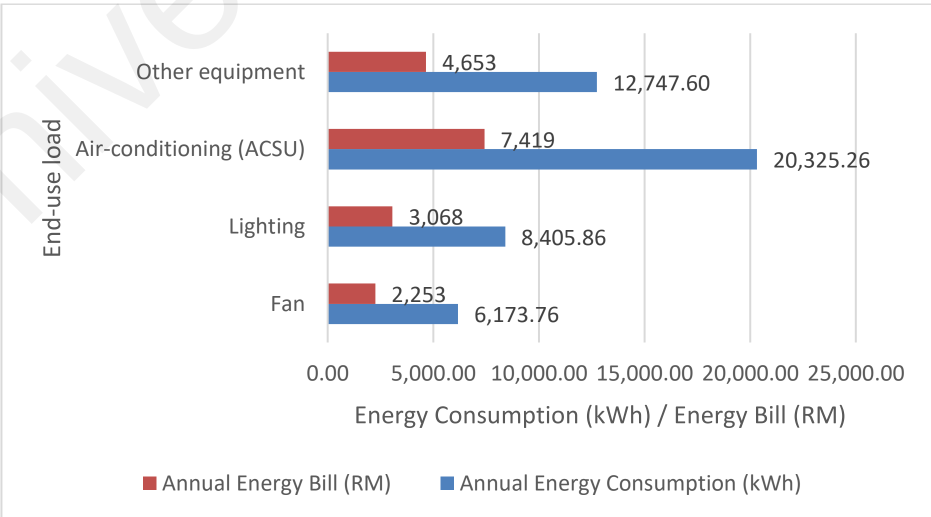



**Figure 4.16: Summary of annual energy consumption and annual bill for four end-loads in IC**

### 4.3.2 Identify and analyze the energy-consuming equipment at MH

Using data from Tables 3.44, 3.45, and 3.46 calculated using Equation (3.1), the details of annual energy consumption for each type of equipment listed under final load in MH are shown in Tables 4.45, 4.46, 4.47. The estimated yearly energy bill (RM) is calculated using the same tariff rate as the IC buildings. The building is only equipped with a fan of the wall fan type without involving other fans. As for lighting, Metal Halide 400W was identified as the highest energy consumer in MH at about 54%. The light produced by Metal Halide is 3-5 times more efficient and has high-quality light (Binay, 2022), and it can illuminate the interior space of MH even if the ceiling height is high. In PSAS, only MH has air conditioning with a capacity of 10hp. The results in this 10hp air conditioner produce the highest energy consumption of about 71%. However, this MH building differs from other non-academic buildings because it does not have equipment from the "other equipment" category.

**Table 4.45: Annual energy consumption and annual bill for a fan at MH**

| No | Types of Fan | Annual Energy Consumption (kWh) | Annual Bill (RM) | Load Apportionment (%) |
|---|---|---|---|---|
| 1 | Wall Mounted Fan | 2973.6 | 1,085 | 100 |
| **TOTAL** | | **2973.6** | **1,085** | **100** |

**Table 4.46: Annual energy consumption and annual bill for lighting at MH**

| No | Types of Lighting | Annual Energy Consumption (kWh) | Annual Bill (RM) | Load Apportionment (%) |
|---|---|---|---|---|
| 1 | T8 36W | 1967.328 | 718.07 | 17 |
| 2 | T8 18W | 119.232 | 43.52 | 1 |
| 3 | CFL 24W | 953.856 | 348.16 | 8 |
| 4 | MH 400W | 6624 | 2417.76 | 57 |
| 5 | Ttube 18W | 1863 | 680.00 | 16 |
| **TOTAL** | | **11527.42** | **4207.51** | **100** |

**Table 4.47: Annual energy consumption and annual bill for air-conditioning (ACSU) at MH**

| No | Capacity (Horse Power) (ACSU) | Annual Energy Consumption (kWh) | Annual Bill (RM) | Load Apportionment (%) |
|---|---|---|---|---|
| 1 | 1 hp | 1054.84 | 385.02 | 2 |
| 2 | 2 hp | 1054.14 | 384.76 | 2 |
| 3 | 2.5 hp | 11070.91 | 4040.88 | 25 |
| 4 | 10 hp | 31673.60 | 11560.86 | 71 |
| **Total** | | **44853.49** | **16372** | **100** |

Table 4.48 summarises energy consumption results, energy bills, and load apportionment for the three end-load types in MH. The energy audit in this building only involves three kinds of end loads without involving other equipment, as in the Islamic Center. Figure 4.17 summarises the percentage load distribution for the three end loads in MH. According to Table 4.48 and Figure 4.17, the highest energy consumption and annual energy bill per equipment in MH are contributed by air conditioners (ACSU), about 76%. The result analysis confirms air-conditioning systems have a high impact on the energy consumption of buildings and result in the same result obtained in academic buildings. According to Figure 4.18, the combo graph summarises annual energy consumption and bills for three end-loads in MH. The chart shows the vast differential in total energy consumption between air-conditioning and lighting, about 33,326 kWh or 57%.

**Table 4.48: Summary of energy consumption, energy bill, and load apportionment for four end-load equipment in MH.**

| No | End-load | Annual Energy Consumption (kWh) | Annual Bill (RM) | Load Apportionment (%) |
|---|---|---|---|---|
| 1 | Fan | 2,973.60 | 1,085 | 5 |
| 2 | Lighting | 11,527.42 | 4,208 | 19 |
| 3 | Air-conditioning (ACSU) | 44,853.49 | 16,372 | 76 |
| **TOTAL** | | **59,354.51** | **21,664** | **100** |

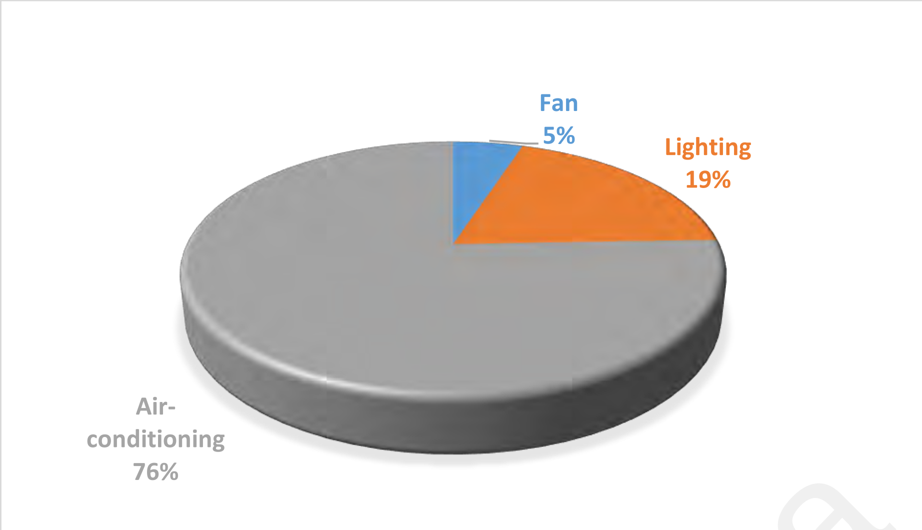



**Figure 4.17: Summary percentage of load apportionment for 3 end-loads in MH**

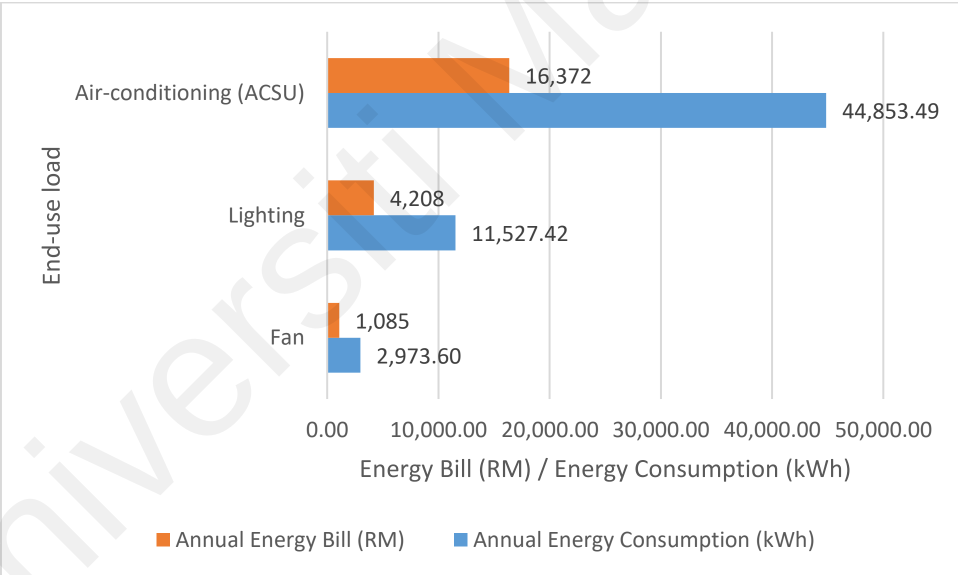



**Figure 4.18: Summary of annual energy consumption and annual bill for four end-loads in MH**

### 4.3.3 Identify and analyze the energy-consuming equipment at SC

Using data from Tables 3.48, 3.49, 3.50, and 3.51 calculated using Equation (3.1), the detail of annual energy consumption for each type of equipment listed under end-loads in SC is shown in Tables 4.49, 4.50, 4.51, and 4.52. The estimated yearly energy bill (RM) is calculated by multiplying the annual energy consumption (kWh) by RM 0.365. The highest load apportionment percentage for fans in SC buildings is from the exhaust fan type, about 44%. Exhaust fans are used to improve ventilation performance in a sports hall. Hall temperature and air velocity are usually related to the number of exhaust fans installed in the sports facility (Ismail & Jamil, 2020). Most educational facilities are built using a skeletal framework known as a bay. High bay lights record the highest percentage of about 52% of energy consumption for lighting. A hanging device suspends the lighting fixture in the SC. Since no rigid rules set standard height values, ceiling heights for sports facilities such as sports halls or indoor sports courts typically have high ceilings (Fried & Kastel, 2020). It usually exceeds 6.1 meters or 20 feet, which refers to the IES illumination criteria for Class IV play (Mohammed et al., 2018; Sielachowska & Zajkowski, 2020). 5hp air conditioners are identified as the highest swim users based on the percentage of load distribution, about 48% of which are installed in sports offices. According to Table 3.8, the gross floor area of the Sports and Co-Curriculum Unit building is 1,548 $m^2$. Due to the office's relatively large rough floor area and having to do with space, using 5hp air conditioners in large quantities will help cool ample office space. The results show that water dispensers recorded a high percentage of energy consumption for other equipment available in SC, about 45% because the power rating is high. The operating time of the equipment is 2200 hours regarding Table 3.51.

**Table 4.49: Annual energy consumption and annual bill for a fan at SC**

| No | Types of Fan | Annual Energy Consumption | Annual Bill | Load Apportionment |
|---|---|---|---|---|
| | | (kWh) | (RM) | (%) |
| 1 | Ceiling fan | 106 | 39 | 5 |
| 2 | Exhaust fan | 1,020 | 372 | 44 |
| 3 | 16" Wall Fan | 1,204 | 439 | 52 |
| **TOTAL** | | **2330** | **850** | **100** |

Table 4.50: Annual energy consumption and annual bill for lighting at SC

| No | Types of Lighting | Annual Energy Consumption (kWh) | Annual Bill (RM) | Load Apportionment (%) |
|---|---|---|---|---|
| 1 | T8 36W | 2,701.73 | 986.13 | 37 |
| 2 | T8 18W | 50.98 | 18.61 | 1 |
| 3 | High Bay light | 3,823.20 | 1395.47 | 52 |
| 4 | Spotlight | 708.00 | 258.42 | 10 |
| **TOTAL** | | **7,283.90** | **2658.62** | **100** |

Table 4.51: Annual energy consumption and annual bill for air-conditioning (ACSU) at SC

| No | Capacity (Horse Power) (ACSU) | Annual Energy Consumption (kWh) | Annual Bill (RM) | Load Apportionment (%) |
|---|---|---|---|---|
| 1 | 1 hp | 3,186.00 | 1162.89 | 19 |
| 2 | 1.5 hp | 2,378.88 | 868.29 | 14 |
| 3 | 2 hp | 3,164.76 | 1155.14 | 19 |
| 4 | 5 hp | 7,929.60 | 2894.30 | 48 |
| **Total** | | **16,659.24** | **6081** | **100** |

Table 4.52: Annual energy consumption and annual bill for other equipment at SC

| No | Types of Equipment | Annual Energy Consumption (kWh) | Annual Bill (RM) | Load Apportionment (%) |
|---|---|---|---|---|
| 1 | Water dispenser | 4,180.00 | 1,526 | 45 |
| 2 | Amplifier | 78.00 | 28 | 1 |
| 3 | Keyboard | 5.20 | 2 | 0 |
| 4 | PA System | 726.00 | 265 | 8 |
| 5 | Guitar Electric | 93.60 | 34 | 1 |
| 6 | Equalizer | 520.00 | 190 | 6 |
| 7 | Server Internet | 770.00 | 281 | 8 |
| 8 | Track Mill (Brad) | 676.00 | 247 | 7 |
| 9 | Track Mill BH Fitness | 780.00 | 285 | 8 |
| 10 | Indoor Exercise Bike | 1,092.00 | 399 | 12 |
| 11 | Computer | 432.00 | 158 | 5 |
| **TOTAL** | | **9,352.80** | **3,414** | **100** |

**Table 4.53: Summary of energy consumption, energy bill, and load apportionment for four end-load equipment in SC**

| No | End-load | Annual Energy Consumption (kWh) | Annual Bill (RM) | Load Apportionment (%) |
|---|---|---|---|---|
| 1 | Fan | 2,329.32 | 850 | 7 |
| 2 | Lighting | 7,283.90 | 2,659 | 20 |
| 3 | Air-conditioning (ACSU) | 16,659.24 | 6,081 | 47 |
| 4 | Other equipment | 9,352.80 | 3,414 | 26 |
| **TOTAL** | | **35,625.26** | **13,003** | **100** |

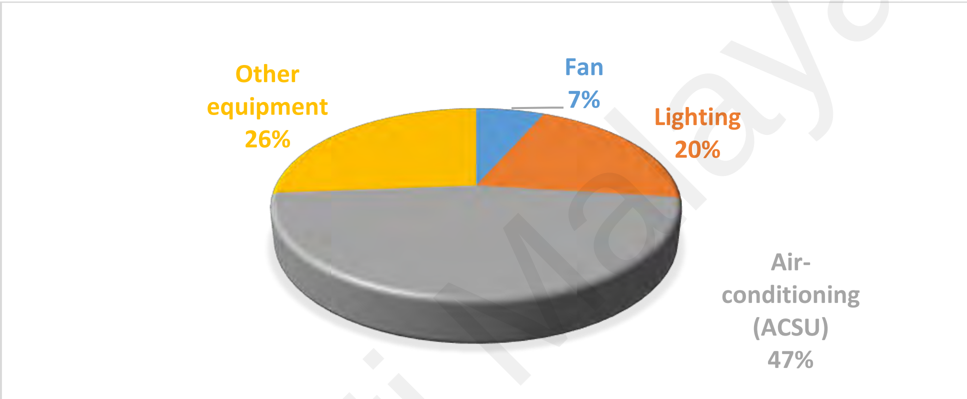



**Figure 4.19: Summary percentage of load apportionment for four end-loads in SC**

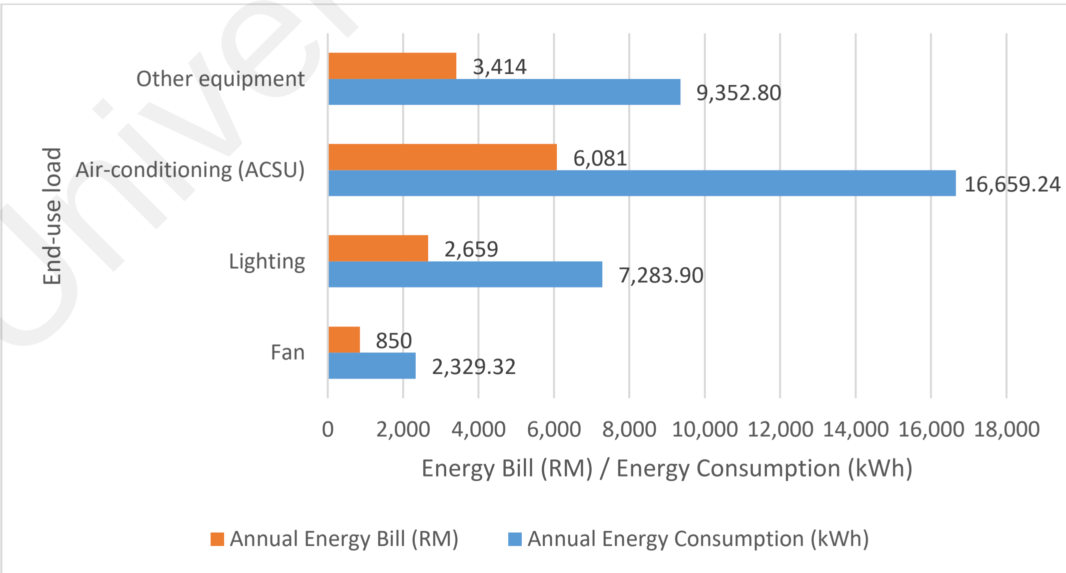



**Figure 4.20: Summary of annual energy consumption and annual bill for four end-loads in SC**

### 4.3.4 Highest energy consumer in non-academic building

Based on the analysis conducted on three non-academic buildings, the final load's total estimated annual energy consumption is approximately 142,632 kWh, as shown in Table 4.54. The energy bill is about RM 52,060. This analysis also helps to identify the equipment that uses the highest energy in the building. The energy consumption analysis of each piece of equipment found that air conditioning is the highest energy user among the three non-academic buildings audited. The total energy consumption for air conditioning is approximately 81,837.99 kWh. It is about 57% of the energy consumption in the three buildings.

**Table 4.54: Summary of annual energy consumption and energy bill for three non-academic buildings (IC, MH & SC)**

| No | Department | Total Power | Annual Energy Consumption | Annual Bill |
|---|---|---|---|---|
| | | (kW) | (kWh) | (RM) |
| 1 | Islamic Centre | 9.97 | 47,652.48 | 17,393 |
| 2 | Multipurpose Hall | 27.57 | 59,354.51 | 21,664 |
| 3 | Sport Centre | 13.77 | 35,625.26 | 13,003 |
| **TOTAL** | | **51.31** | **142,632.25** | **52,060** |

## 4.4 Mixed Energy Audit Data Analysis by Zone

Energy Monitoring System (EMS) will help monitor energy consumption on the 55 of load. Each load's energy consumption can be measured in real-time through 55 units of Fixed Digital Power Meter (DPM) already installed at PSAS. PSAS is divided into six main zones, where five zones are divided according to the number of Main Switchboards (MSBs), while one more zone is separated from the five zones because it involves individual meters. A Fixed Digital Power Meter (DPM) has been installed in these five zones to record energy consumption in real-time. The monthly energy consumption data recorded by the EMS system for the five related zones are shown in Table 3.6. It was found that Zone 5 recorded the highest total annual energy consumption compared to the other four zones.

### 4.4.1 Identify and analyze the energy-consuming equipment at Zone 5

A walk-through energy audit involves identifying which equipment consumes the most energy at academic and non-academic buildings. In this part of the analysis, the energy audit will focus on zone 5 because of the highest energy consumption recorded. Zone 5 (MSB 5) consists of academic buildings such as Electrical Engineering Department (EED) and Commerce Department (CD), while non-academic buildings such as Training & Continuing Education Unit (TCEU), Canteen (C), and Multipurpose Hall (MH). The academic building will collect the data according to 5 categories: lab equipment, fan, lighting, air-conditioning (ACSU), and ICT equipment. Non-academic buildings will collect data for fan, lighting, and air-conditioning (ACSU). The other categories will access based on the function of each building involved. Summary data collection for TCEU and C shows in Tables 3.53 and 3.54. The other summary table for zone 5 needs to refer to Table 3.30 for EED, Table 3.37 for CD, and Table 3.47 for MH. The audit results on the TCEU building confirmed that the building consists of several types of fans, such as ceiling fans, wall-mounted fans, and standing fans. The type of lamp consists of T8 36W, T8 18W, and Compact Fluorescent Lamp (CFL) 24W. In addition, at TCEU, there are two types of air conditioners: ACSU and WCPU. ACSU consists of 2 classes with 1hp and 2hp capacity, while there are two units for Air Handling Unit (AHU) -WCPU. The audit results revealed 18 other types of equipment available at TCEU, such as shredders, vacuums, water heater showers, domestic refrigerators, water dispensers, laundry machines, clothes dryers, irons, etc. Referring to the list of other appliances available at TCEU, half are household appliances. In TCEU, there is Hotel Tanjung Inn, where interested outsiders can rent rooms, especially those who attend face-to-face courses organized by PSAS.

The energy audit of the canteen building only involved three types of end load without affecting equipment under the category of ICT equipment as well as other equipment available at TCEU. This building has only a ceiling fan and two lamps: T8 36W and T8 18W. This building only has one type of air-conditioning (ACSU) with a capacity of 2hp. Using data from Tables 3.53 and 3.54, then calculated using Equation (3.1), the detail of annual energy consumption for each type of equipment listed under the TCEU and C buildings is shown in Tables 4.55 and 4.56. The summary data of energy consumption, energy bill, and load apportionment for end-load equipment in EED, CD, and MH can be referred to in Tables 4.29, 4.36, and 4.48. Based on the analysis shown in Table 4.55, about 71% of energy consumption comes from the end-load category named "other equipment". This high percentage explains the use of electrical equipment in hotel rooms, such as water heater showers and refrigerators in TCEU, being the main contributor to the high energy consumption in this building, as shown in Table 4.57. The percentage of other equipment has already surpassed the total energy consumption by air conditioners, which is usually dominant as the highest consumer for a building as found through analysis of a previous academic or non-academic building. In addition, it is also closely related to the ACSU air conditioners used in TCEU, where there is only 1hp (12 units) and 2hp (14 units) capacity. There are only 2 AHU-WCPU units in the building. The total quantity of air-conditioning ACSU and WCPU is 28 units, as shown in Table 3.53.

**Table 4.55: Summary of energy consumption, energy bill, and load apportionment for end-load equipment in TCEU**

| No | End-load | Annual Energy (kWh) | Annual Bill (RM) | Percentage (%) |
|---|---|---|---|---|
| 1 | Others Equipment | 216,367 | 78,974 | 71.0 |
| 2 | Fan | 3,705 | 1,352 | 1.2 |
| 3 | Lighting | 26,349 | 9,617 | 8.6 |
| 4 | Air-conditioning (ACSU+WCPU) | 57,001 | 20,805 | 18.7 |
| 5 | ICT Equipment | 1,202 | 439 | 0.4 |
| **TOTAL** | | **304,624** | **111,188** | **100** |

**Table 4.56: Summary of energy consumption, energy bill, and load apportionment for end-load equipment in C**

| No | End-load | Annual Energy (kWh) | Annual Bill (RM) | Percentage (%) |
|---|---|---|---|---|
| 1 | Fan | 2,549 | 930 | 9.0 |
| 2 | Lighting | 21,478 | 7,839 | 76.1 |
| 3 | Air-conditioning (ACSU) | 4,214 | 1,538 | 14.9 |
| **TOTAL** | | **28,240** | **10,308** | **100** |

**Table 4.57: Detail types, quantity, power, operating hours, annual energy, and energy bill for other equipment at TCEU.**

| No | Types of Equipment | Quantity | Power (kW) | Average Operating Hours (h/year) | Annual Energy (kWh) | Annual Bill (kWh) |
|---|---|---|---|---|---|---|
| 1 | Shredder | 1 | 0.146 | 78 | 11 | 4 |
| 2 | Vacuum | 1 | 0.542 | 600 | 325 | 119 |
| 3 | LCD Projector | 5 | 0.37 | 1200 | 2,220 | 810 |
| 4 | Video Visualizer | 1 | 0.37 | 1200 | 444 | 162 |
| 5 | Microphone | 1 | 0.135 | 64 | 9 | 3 |
| 6 | Television | 22 | 0.3 | 1680 | 11,088 | 4,047 |
| 7 | PA System | 1 | 0.33 | 1200 | 396 | 145 |
| 8 | Sealer Machine | 2 | 0.3 | 78 | 47 | 17 |
| 9 | Water Heater Shower | 18 | 4.3 | 1900 | 147,060 | 53,677 |
| 10 | Domestic Refrigerator | 21 | 0.93 | 2200 | 42,966 | 15,683 |
| 11 | Toaster | 1 | 2.24 | 210 | 470 | 172 |
| 12 | Kettle | 18 | 1.2 | 210 | 4,536 | 1,656 |
| 13 | Water Dispenser | 1 | 1.9 | 2200 | 4,180 | 1,526 |
| 14 | Laundry Machine | 1 | 1.6 | 300 | 480 | 175 |
| 15 | Clothes Dryer | 1 | 3 | 300 | 900 | 329 |
| 16 | Iron | 18 | 0.6 | 90 | 972 | 355 |
| 17 | Water Pump | 2 | 0.725 | 90 | 131 | 48 |
| 18 | CCTV Camera | 1 | 0.06 | 2200 | 132 | 48 |
| **TOTAL** | | **116** | **19.048** | | **216,367** | **78,974** |

Table 4.56 shows that about 76.1% of energy consumption comes from the lighting end-load category. The canteen building has a large number of lighting, 320 units, while

other end load equipment such as ceiling fans are only 48 units and 2hp air conditioners are only four units. Although the research results for the highest energy consumption in TCEU and canteen buildings showed different results than those of other buildings, this study was conducted based on buildings. However, the findings do not reflect the same analysis results when analyzed by zone. Therefore, analysis by zone should be made by summing the energy consumption of the five buildings involved jointly in a table according to the type of end-load equipment category.

**Table 4.58: Summary of annual energy consumption for Zone 5**

| No | Building | Annual Energy Consumption (kWh) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Lab Equipment | Other Equipment | Fan | Lighting | Air-conditioning | ICT Equipment | Total |
| 1 | EED | 89,143 | - | 6,681 | 65,370 | 304,631 | 1,634 | 467,460 |
| 2 | CD | 47,521 | - | 5,939 | 47,422 | 98,050 | 1,000 | 199,932 |
| 3 | TCEU | - | 216,367 | 3,705 | 26,349 | 57,001 | 1,202 | 304,624 |
| 4 | C | - | - | 2,549 | 21,478 | 4,214 | - | 28,240 |
| 5 | MH | - | - | 2,974 | 11,527 | 44,853 | - | 59,355 |
| **Total** | | **136,664** | **216,367** | **21,848** | **172,147** | **508,749** | **3,836** | **1,059,610** |
| **Percentage (%)** | | **12.9** | **20.4** | **2.1** | **16.2** | **48.0** | **0.4** | **100.00** |

**Table 4.59: Summary of energy consumption for all zone in PSAS**

| Zone | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 5 | Zone 6 |
|---|---|---|---|---|---|---|
| Average Energy Consumption Monthly (kWh/month) | 90,414 | 77,018 | 46,650 | 2,934 | 91,152 | 33,172 |
| Total Average Energy Consumption Yearly (kWh/year) | 1,084,965 | 924,213 | 559,800 | 35,213 | 1,103,829 | 398,065 |

According to the summary of the estimated annual energy consumption obtained from the energy audit, as shown in Table 4.58, air-conditioning is identified as the highest energy consumer in Zone 5, at about 48%. The findings from this analysis are similar to the results obtained by other researchers. Air conditioners are the major appliances that consume a large portion of the total energy consumption in the buildings studied (Ali et al., 2021; Khorram et al., 2020; Sarbu & Adam, 2016). Figure 4.21 illustrates the level of energy consumption for each final load involved, where the air conditioner shows the highest level of consumption in Zone 5, concerning the five main buildings. However, the focus should also be on other equipment, which recorded the second-highest total energy consumption of 20.4%. This other equipment is used by TCEU, which is closely related to the hardware commonly found in a hotel. This information is helpful to the management of educational institutions with hotel accommodation facilities to plan appropriate energy-saving measures because the energy consumption pattern in the TCEU building differs from other office buildings studied.

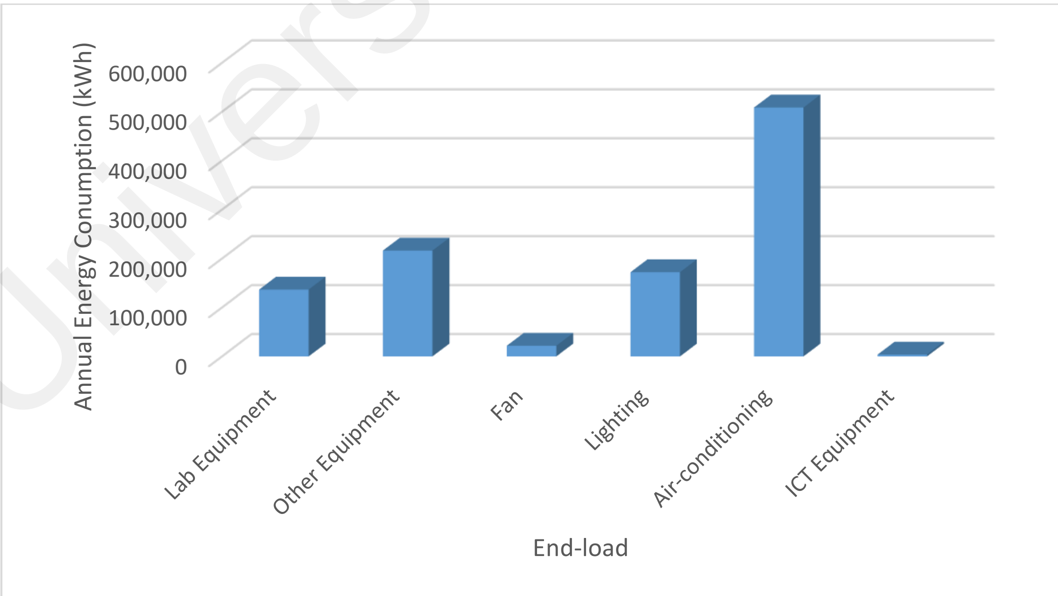



**Figure 4.21: Graph of annual energy consumption for the six types of end-loads found in zone 5**

### 4.4.2 PSAS Historical Energy analysis

Coronavirus Disease 2019 (COVID-19) was officially announced by the World Health Organization on January 12, 2020, and was detected to originate from Wuhan before becoming an epidemic that spread worldwide (Shah et al., 2020). In January 2020, the first three cases of COVID-19 in Malaysia, categorized as import cases, were detected and confirmed by the Ministry of Health Malaysia. The first wave of the COVID-19 epidemic in Malaysia involved 22 cases. The second outbreak wave started on February 27; the number of cases reached 129 on March 10 (Hashim et al., 2021). On 16th March 2020, the accumulated cases surpassed the 500 cases where the first death was recorded on 17 March 2020 (Aziz et al., 2020). Following the sudden increase in the number of positive cases of COVID-19 and the difficulty in tracing close contact with infected individuals, the Malaysian Government enforced Movement Control Order (MCO) on 18th March 2020 (Hashim et al., 2021; Shah et al., 2020; Tang, 2020). All educational institutions are instructed to close their premises when the MCO is enforced (Tunku Mansur et al., 2022).

All modes of learning and teaching sessions involving face-to-face meetings are prohibited and changed to online learning modes. Implementing work-from-home instructions 100% involves academic and non-academic staff. All staff is not permitted to be in the office except to perform essential services with special permission. Implementing work-from-home instruction and online learning were key factors influencing an institution's load profile change (Edomah & Ndulue, 2020). This situation has led to a significant downward trend in energy consumption on campus (Jiang et al., 2021). Figure 4.22 shows the results of the analysis of the energy history of PSAS for five years from 2016 to 2020, as shown in Table 3.5. This analysis illustrates the energy consumption pattern and energy demand for five years. Overall, total energy consumption and demand for each year assessed have decreased and increased. These fluctuations in total energy consumption are related to changes in the current number of PSAS occupants consisting of staff and students. Usually, the number of staff is almost the same every year, but the number of students varies. The number of student admissions that changes each year affects the pattern of the formed graph. The amount of intake causes the energy graph readings to increases and decreases. However, from March 2020, there was a drastic decline in energy consumption, where total energy demand plunged to the lowest level in its five-year history. This situation follows the implementation of the Movement Control Order by the National Security Council to curb the spread of the COVID-19 epidemic. The results of this energy analysis during the MCO align with the research findings obtained by other researchers worldwide (Tan et al., 2021; Tunku Mansur et al., 2022)

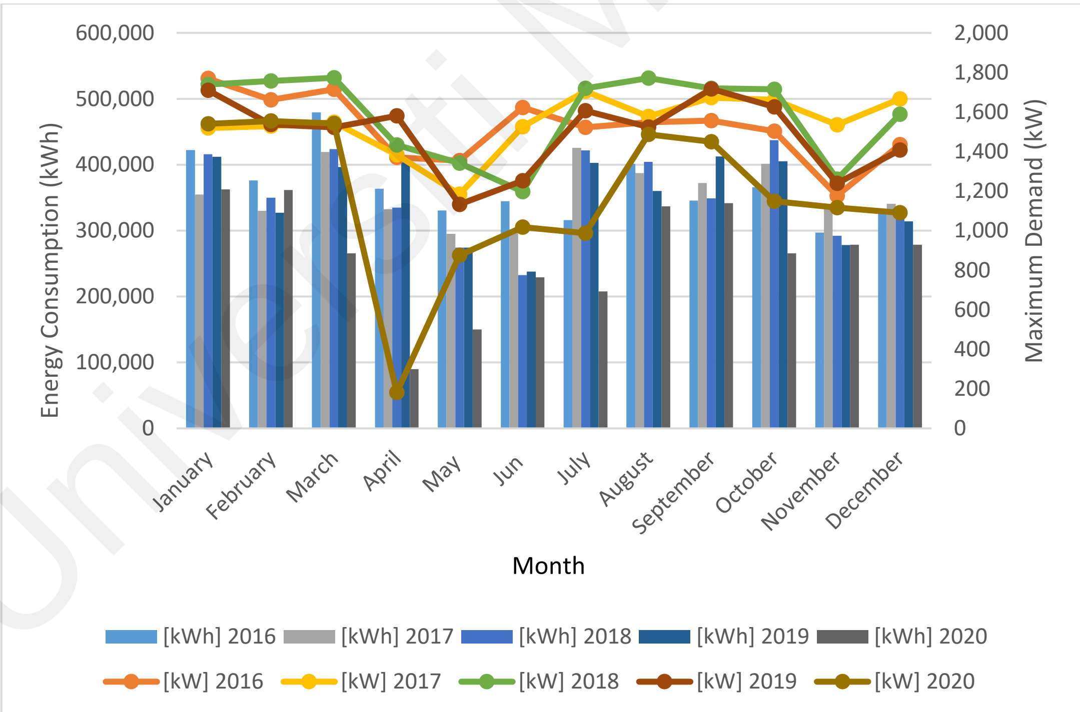



**Figure 4.22: PSAS historical energy analysis**

### 4.4.3 Energy analysis of annual energy consumption at all zone at PSAS

The annual energy consumption data for zone 1 until 5 are obtained from EMS recorded by power meter and shown in Table 3.6. While the yearly energy consumption for zone 6 is obtained from Table 3.2 and multiplied by 12 months. Zone 6 is a residential area where energy consumption data are recorded by an individual meter by TNB. A survey was conducted on the occupants of PSAS quarters to obtain utility bill data in Zone 6. The summary of energy consumption for all PSAS zones is shown in Table 4.59. Figure 4.23 illustrate the graph of annual energy consumption versus zone in PSAS. The chart shows the highest energy consumption among all zone is zone 5. The lowest energy consumption is zone 4 because this building consists workshop or laboratory building for MED and CED, as stated in Table 3.7. Most of these workshops do not have air conditioning. Each workshop has ample space to conduct lab sessions such as automotive work and requires minimum electrical power during the lab session or workshop.

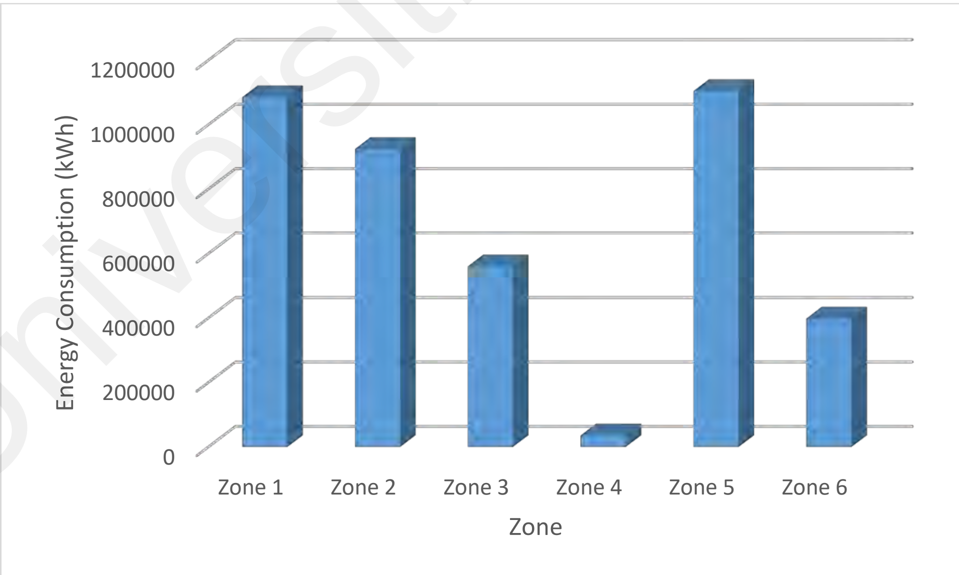



**Figure 4.23: Graph of annual energy consumption versus zone in PSAS**

In this part of the analysis, the measured data were obtained from two meters, either a power meter from EMS or a meter by TNB (utility bill). The utility bill will give information about overall energy consumption at PSAS and become the primary reference. At the same time, the data from EMS provide information about energy consumption in a single building. Table 4.60 shows the monthly energy consumption data for all main MSB taken by EMS and compared with a utility bill to get the error percentage. The utility bill is an average energy consumption value for five years, from 2016 until 2020, and can be referred to in Table 3.5. The total energy consumption for all MSB is obtained from Table 3.6, where this data becomes baseline data and is imported from EMS for 2019. The error percentage is vital to verify the imported data from EMS is acceptable and does not exceed the utility bill as the primary reference. In Table 4.60, the error percentage data for July and December is more than 20%, revealing inaccuracies but still acceptable. The digital meter that records data for a particular month suffers a technical malfunction and records an error reading value. However, the comparison between measured data annually by EMS and TNB meter is 14% and considered acceptable based on International Performance Measurement & Verification Protocol. Figure 4.24 compares two measured data named EMS and utility bill. From the graph, the TNB meter data (utility bill) is always more than the digital power meter (EMS) value. It means the measured data from EMS is acceptable to use for analysis. The graph pattern is not the same for every month, especially for May and Jun, which is recorded among the lowest value of energy consumption. Both months are semester breaks for students based on Academic Calendar 2018/2019 for Politeknik Malaysia. A minimal number of activities involve the student this month at the campus. Even though the energy demand will decrease for both months, the staff is still working, explaining why the energy is still more than 290,000 kWh.

**Table 4.60: Comparison of energy consumption data between EMS and TNB meter.**

| Month | Total Energy All MSB (A) EMS-DPM (kWh) | Utility Bill (B) TNB (kWh) | Error (B - A) | % Error |
|---|---|---|---|---|
| January | 375,457 | 397,634 | 22,177 | 6 |
| February | 321,441 | 352,134 | 30,693 | 9 |
| March | 388,411 | 440,761 | 52,350 | 12 |
| April | 289,215 | 341,448 | 52,233 | 15 |
| May | 274,669 | 300,082 | 25,413 | 8 |
| Jun | 282,007 | 292,208 | 10,201 | 3 |
| July | 276,190 | 387,820 | 111,630 | 29 |
| August | 358,560 | 396,804 | 38,244 | 10 |
| September | 308,905 | 373,936 | 65,031 | 17 |
| October | 322,854 | 401,602 | 78,748 | 20 |
| November | 255,574 | 309,049 | 53,475 | 17 |
| December | 254,737 | 334,112 | 79,375 | 24 |
| **TOTAL** | **3,708,020** | **4,327,590** | **619,570** | **14** |

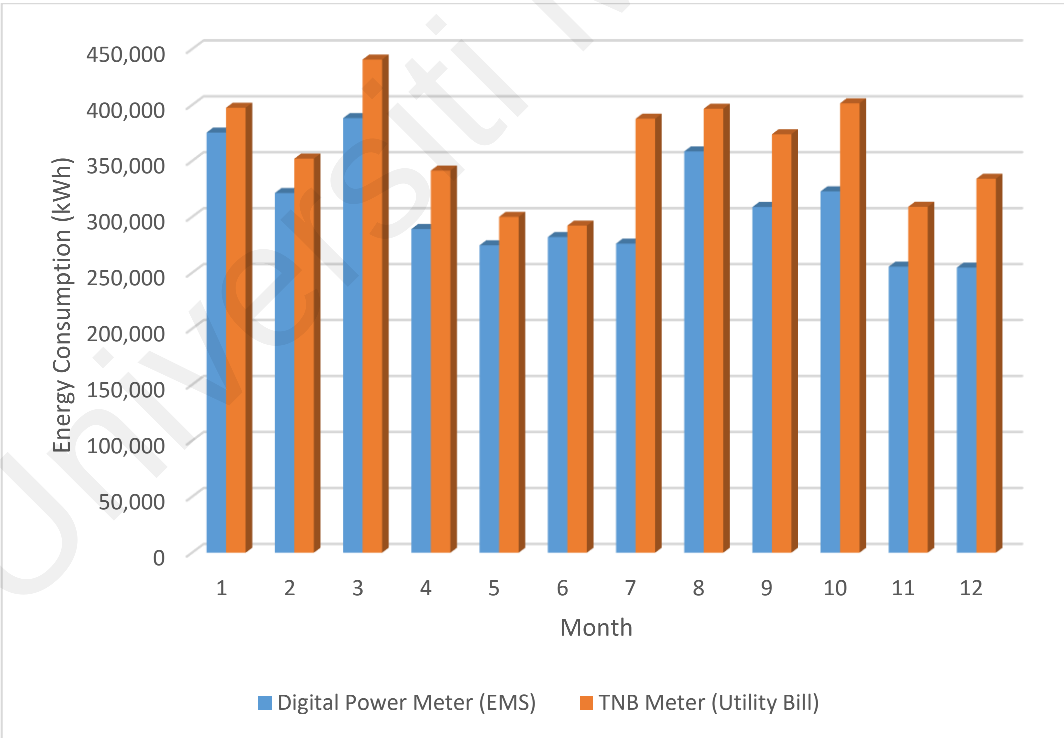



**Figure 4.24: Comparison between two measured data (EMS vs Utility bill)**

### 4.5 Feasibility of on-site energy generation in PSAS

PSAS receives an electricity supply of 11kV from the national grid and steps down to 415V via five MSB (Zone 1 until 5) to separate buildings. In the analysis in this section, residential quarters (zone 6) are not included in the assessment because they are billed separately based on TNB's individual meters. Figure 4.25 illustrates the PSAS electricity distribution from the TNB incoming power supply and the power distribution to the MSB involved. PSAS is currently equipped with a single TNB power meter where the electricity charge rate is based on the C1 tariff value. This C1 charge is a flat rate charge of RM 0.365/kWh, while the maximum demand charge (MD) is RM 30.3/kW (TNB, 2022).

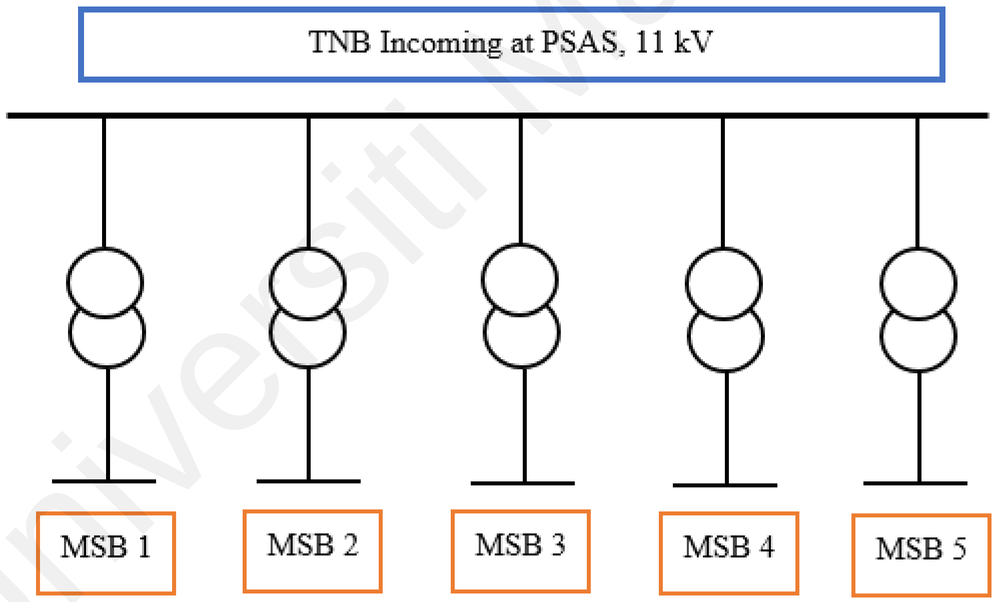



**Figure 4.25: PSAS electricity distribution**

Understanding the power distribution system in PSAS can help the system modification process towards reducing energy consumption while saving electricity bill costs. The current distribution system in PSAS uses a ring connection that allows the power transfer from one or more paths, also known as parallel lines (Deyhimi et al., 2021), between the distribution substation and the load. The ring system results in better utilization and improves the voltage stability in the distribution system (Patel et al., 2019). Figure 4.26 show the current ring distribution system at PSAS. The power from MSBs distributes to other buildings, as stated in Table 3.7. The feasibility analysis will show that this modified system is practical and helps achieve energy-saving objectives. The analysis results must also support the policy stated in the Malaysian Polytechnic Action Plan 2015-2020 and the SmartGreen Polytechnic Community College (PolyCC) Action Plan 2021-2026 related to implementing green technology known as an innovative campus.

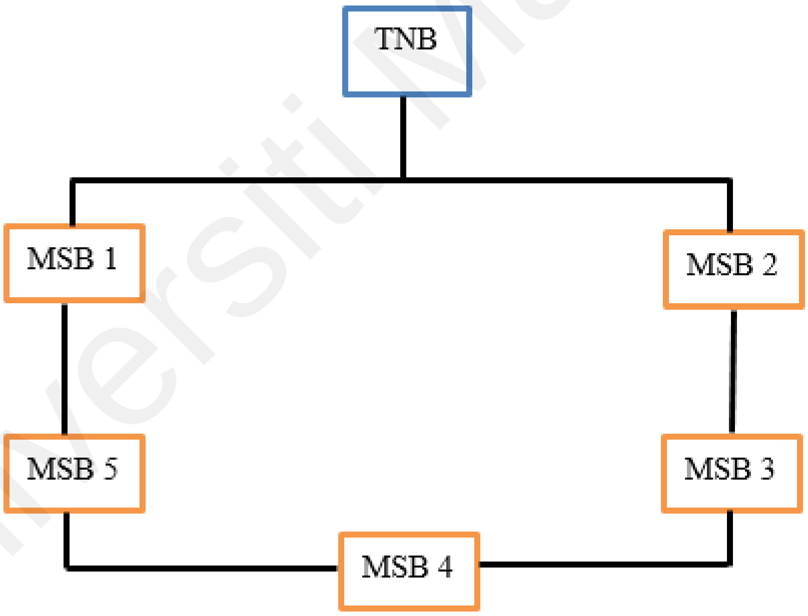



**Figure 4.26: Current ring distribution system at PSAS**

The research investigates the feasibility of on-site energy generation in PSAS using rooftop photovoltaic (PV) solar power generation systems. The potential value of energy savings obtained by the PSAS is calculated using a feasibility analysis of renewable energy power generation systems. Solar energy was chosen as the most suitable electricity power generation energy because PSAS's geographical location in Behrang Perak receives average solar irradiation of 1,650 kWh/m$^2$. Besides that, the rain effect in Malaysia is ideal for installing solar PV systems due to frequent auto cleaning, cooling down solar panels, and still producing power in rain showers. The feasibility analysis of this research is done using rooftop solar power generation and refers to the Net Energy Metering (NEM 3.0) mechanism known as NEM GoMEn.

### 4.5.1 Analysis of energy demand at PSAS

The feasibility analysis starts by identifying the highest monthly energy consumption in 1 year as an input to design a solar PV system that meets the established energy management objectives. This research's primary reference for energy-saving purposes is General Circular No. 2 of 2014: Guidelines on Energy Saving Method at Government offices and Malaysian Polytechnic POLYGreen Blueprint 2015 (JPPKK, 2015; Peter et al., 2018). Both documents state that all government buildings need to reduce or save their utility cost minimum by 5% per year. This calculation predicts energy consumption savings and annual energy bills of at least 5% of the baseline data for PSAS. This analysis refers to energy consumption and maximum demand for the year 2019. 2020 was the year the covid epidemic hit Malaysia, and the Movement Control Order (MCO) was enforced where all educational institutions were ordered to close. As a result, the total electricity consumption in PSAS decreased significantly, and the energy consumption pattern was abnormal. Likewise, in 2021 the MCO is still in effect, causing abnormal energy consumption patterns. Therefore, energy savings forecasts are calculated based on the 2019 baseline to forecast energy consumption in 2023 and the following years.

Table 3.5 shows the energy consumption value in 2019, where September recorded the highest reading, while the lowest value occurred in June—the month of September recorded a value of 412,774 kWh, while June 238,018 kWh. The difference in the amount of energy recorded is because the education system at the Polytechnic has two modes of activity, namely lecture sessions and semester breaks, either in the middle or at the end of the semester. The analysis in this section involves two different times, namely normal time (lecture session) and holiday time (semester break). In addition, the average maximum demand (MD) recorded for 2019 is 1,488 kW. Approximately 4 hours of maximum energy yield is used in the calculation. The justification for why the value of 4 hours is used is discussed in more detail in Section 4.5.2

**Normal time:**

$$Energy\ consumption\ per\ day = \frac{412{,}774\ \text{kWh}}{30\ days} = 13{,}760\ kWh/day$$

$$5\%\ of\ daily\ energy\ consumption\ is\ supplied\ by\ solar = 688\ kWh/day$$

$$PV\ system = \frac{688\ \text{kWh}}{4\ hours} = 172\ kW$$

**On-leave time:**

$$Energy\ consumption\ per\ day = \frac{238{,}018\ \text{kWh}}{30\ days} = 7{,}934\ kWh/day$$

$$5\%\ of\ daily\ energy\ consumption\ is\ supplied\ by\ solar = 397\ kWh/day$$

$$PV\ system = \frac{397\ \text{kWh}}{4\ hours} = 100\ kW$$

From the calculation above, the total monthly energy consumption is reduced by approximately 42% during the semester break. Therefore, PV systems are designed for total energy consumption at normal times. The surplus energy produced during this semester break will be transferred to the grid system through the NEM meter. Referring to the value in Table 3.5, the total annual energy consumption for PSAS in 2019 is 4,231,412 kWh. It means the total cost of energy in 2019 is RM 1,544,465. This value is obtained when the kWh consumption is multiplied by the value of the current tariff rate for PSAS, which is RM 0.365. This value did not represent the current charge in the PSAS utility bill 2019 because it does not include the maximum demand (kW) calculation.

### 4.5.2 Design of PV system

This research makes a feasibility analysis evaluation on a system that uses standard-size solar panels for industrial use with a capacity of 500W/50V. The PV solar panels used are of the monocrystalline solar module type. Based on the solar irradiation curve (Rajendran & Smith, 2016) and located in a tropical region in Peninsular Malaysia, the average hours of full or clear sunlight in normal conditions range from 4 to 6 hours per day. The research by (Shavalipour et al., 2013) mentioned the peak sun hour is 6 hours, and other authors stated 4-6 hours (Pitech, 2020). According to (TNBX, 2020), Malaysia's average peak sun hours are between 4.0 to 5.4 hours, depending on the location. Considering the rapid cloud movement and hot and humid conditions throughout the year in Malaysia, the average Sunlight Peak hours in this research are calculated for only 4 hours. The justification of these 4 hours is taken because most studies stated that 4 hours is the lowest value. In addition, 4 hours was in line with practical value in the industry and helped avoid system designs that could not meet the power generation requirements as calculated due to using 6 hours and becoming under design. The proposed solar PV system using the NEM scheme only involves solar PV and an inverter without a battery, as shown in Figure 4.27. The efficiency of solar panels decreases yearly and involves a specific period rather than occurring in a short period. Most solar panel PV module manufacturers guarantee a power drop in the module is not more than 20% within the warranty period (Virtuani et al., 2019). Worldwide, most solar PV module manufacturers establish a warranty contract with their customers for 25 or 30 years. (Tsanakas et al., 2016). Recent studies have reported that annual degradation rates are in the percentage range of 0.6%-0.7% (da Fonseca et al., 2020; Virtuani et al., 2019). Based on some of the findings mentioned above, assume the annual degradation of solar panel energy production in this energy analysis is 0.5% per year, which means for five years, only 2% degradation occurred. The solar energy panel performance cannot produce an energy supply of 100% efficiency in the actual implementation. Recent studies stated panel solar PV efficiency achieves a maximum range of 80% (Kamanzi & Sibanda, 2017; Muslim et al., 2020).

Solar capacity is calculated by dividing the total daily load by 4 hours. The inverter used in this solar power generation system is an inverter with maximum power point tracking (MPPT) controller type. The capacity of the hybrid inverter is 8kW (de Brito et al., 2019), where the inverter maximum power point (MPP) has a two-channel MPPT where each channel can receive 5000W with a maximum PV input voltage is 500V (5000W/500V). One channel can support the output of 10 solar PV panels where each input is 50V (50V x 10 panels = 500V). The number of inverters needs to be made to ensure that the inverter specifications are matched to receive the power generated by the solar panel. The number of solar panels required to generate a solar power supply of 5% of PSAS's total daily energy consumption is calculated by multiplying the value of 5% of the value of solar capacity and dividing by the power for one solar panel, 500W. The number of inverters the PSAS building requires is divided into 20 solar panels (2 MPPT channels). Assume that parameter for solar panel refers to standard testing condition (STC) where air mass atmosphere 1.5, 1000 watt per meter square ($W/m^2$) solar irradiance 25°C cell temperature (Ya'acob et al., 2014)

#### 4.5.2.1 Case Study 1: Feasibility Analysis of Rooftop Solar Photovoltaics (Option 1)

The solar capacity for a PV system to meet the required energy demand of at least 5% at PSAS is 172 kW per day. Based on the calculation results in Table 4.61, solar panel units are enormous if the solar energy supply needs to cover 100% of energy consumption. The research in this section focuses on the case study, Option 1, where PSAS installed a solar system on the roof involving eight three-story buildings and above, as listed in Table 3.8. Solar PV installation is not recommended for buildings with one floor because of the shading effect factor. 11 out of 41 buildings represent 27% of the buildings that can be installed solar. Six blocks of quarters are not included in the list of facilities that will be installed with solar PV even though the blocks have five floors, as in Table 3.8. It is due to quarters using individual meters. An overview of the roof area of the 11 listed buildings can be referred to in Figure 3.2 on the PSAS Site Plan. Figure 4.27 shows a list of three-story buildings in the electricity distribution system in PSAS that are connected from MSB 1 to MSB 5.

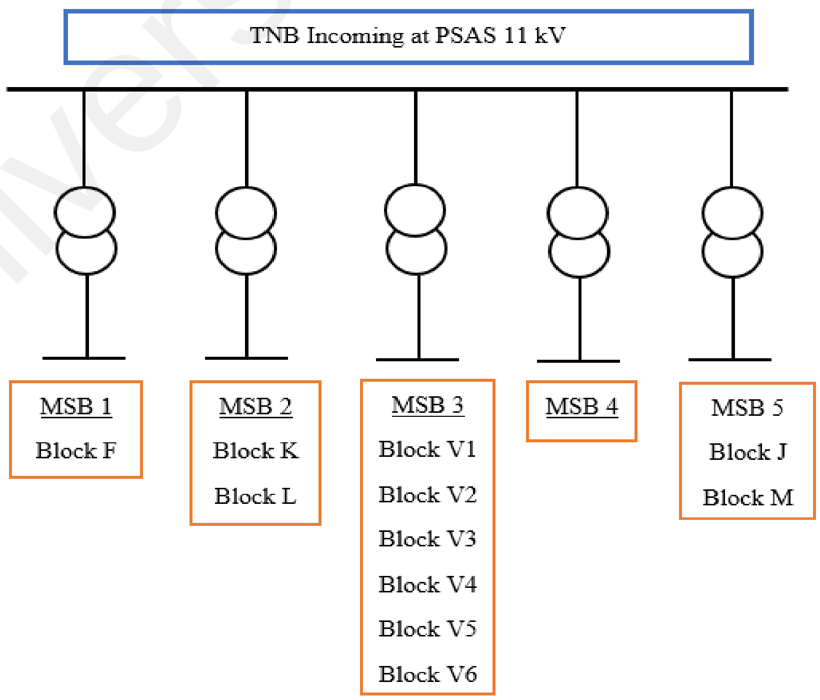
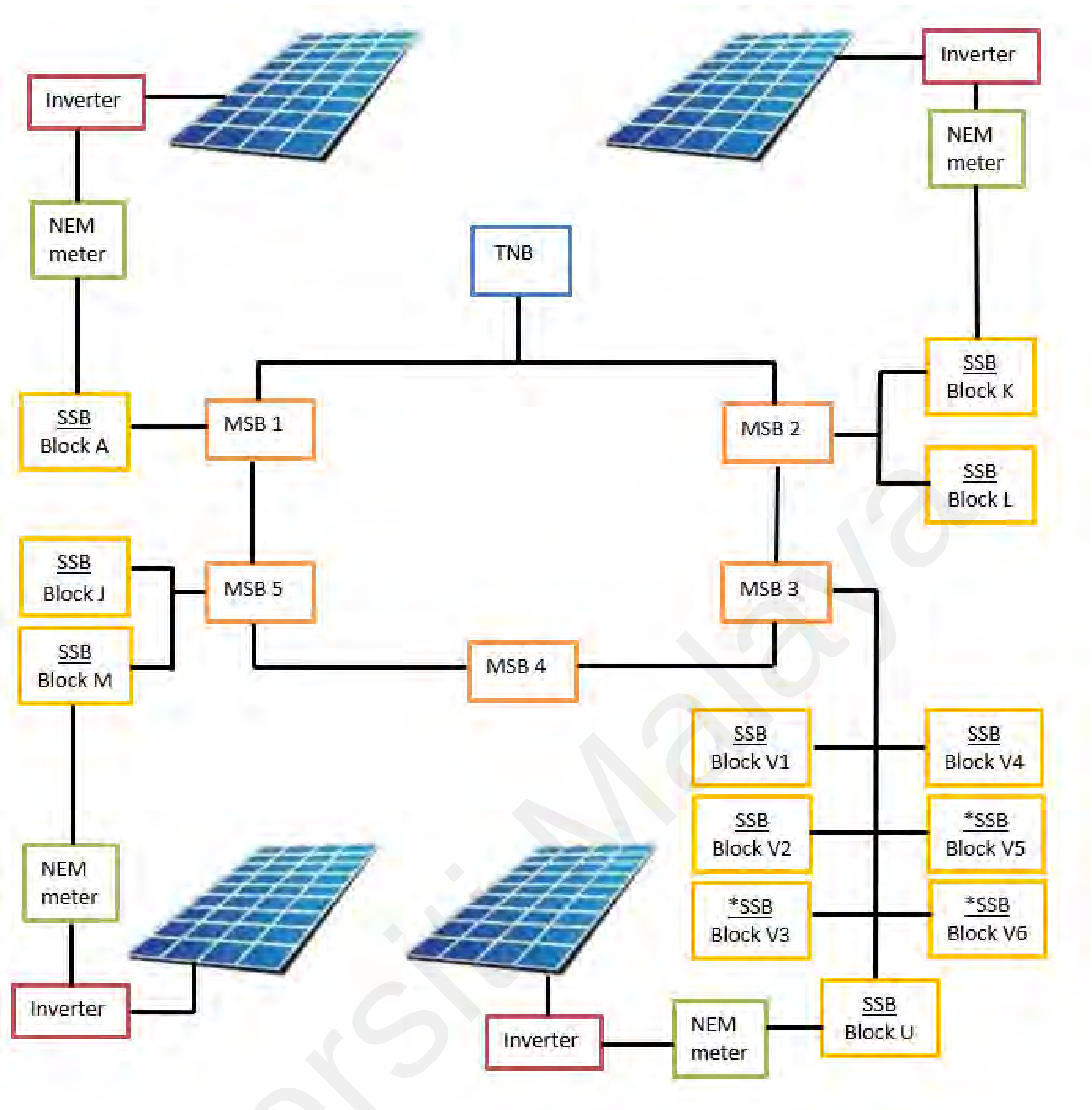



**Figure 4.27: List of three-story buildings in the electricity distribution system at PSAS.**

Setting a value of 20% of the total power supply in PSAS generated by solar is practical, assuming only eight over eleven buildings are involved in the generation. The remaining building is considered a reserve in case there are listed buildings with roof damage. The PV system design is calculated to cover only 20% of the total load based on the 2019 reference value. There are two categories of routine and non-routine activities in PSAS. Typical activities include lectures and practicals at workshops or laboratories and co-curriculum activities. Non-routine activities contribute to increased energy consumption in PSAS and need to be considered in PV system design. Examples of non-routine activities include Convocation ceremonies, Higher Education Institution Sports (SUKIPT), external programs that use premises at PSAS, and programs directed by the JPPKK Headquarters. This research's solar PV system generation ratio is based on a 20:80 ratio, where 20 refers to the power supply generated by solar PV while 80 refers to the power supply supplied by TNB. Considering these non-routine activities is vital to successfully achieving the year's energy reduction objectives. If these non-routine activities consume more than 20% of energy in a given month, TNB will supply power for the remaining 80%. In simple language, non-routine activities can be held at any time in PSAS without worrying about the energy-saving objectives not being successfully achieved. Therefore, the goal of reducing energy consumption and energy bills by 20% can only be achieved by PSAS if the solar energy supplied to the PSAS building is 21.5% of the maximum capacity. This value is obtained after considering the factor of degradation in energy production for four years, which involves only 1.5%. Figure 4.28 is a proposed modification based on the current distribution layout on PSAS shown in Figure 4.26. New design layout plus rooftop solar photovoltaic connected with NEM meter. Next, the meter is connected to the Sub-switch Board (SSB), which is interconnected with certain buildings, as shown in Figure 4.27. Details related to buildings that receive power supply from MSB 1 to 5 can be referred to in Table 3.7.




* Reserve block to install rooftop solar PV.



**Figure 4.28: Proposed the rooftop solar photovoltaic diagram using a NEM meter connected to SSB**

**Table 4.61: Main components capacity in rooftop solar PV systems**

| Percentage reduction of total daily energy consumption | Solar capacity [kW] | A load of the inverter [kW] | No. of panel solar [units] | No. of the inverter [units] |
|---|---|---|---|---|
| 5% | 172 | 86 | 17 | 1 |
| 10% | 344 | 172 | 72 | 4 |
| 15% | 516 | 258 | 165 | 8 |
| 20% | 688 | 343 | 296 | 15 |

Table 4.61 shows calculations for the main components' capacity in rooftop solar PV systems based on energy reduction objectives from 5% to 20% of PSAS's total daily energy consumption. The percentage of daily energy consumption reduction in PSAS (5%, 10%, 15% & 20%), as shown in Table 4.61, refers to the highest monthly energy consumption value in 2019. The highest monthly value referred to is only used to design solar PV systems. Nevertheless, the annual energy reduction objective of at least 5% of the PSAS utility bill refers to the total yearly energy consumption in 2019 involving the summation of 12 months of energy. The solar capacity size of 172 kW is obtained by multiplying the value of daily energy consumption of 13760 kWh (normal time) by 5% and dividing by 4 hours. The inverter load is calculated based on the highest monthly maximum demand value for 2019, as stated in Table 3.5, which is 1717 kW. 5% of 1717 kW is equivalent to 86 kW. The number of solar panels required to generate a solar power supply of 5% of PSAS's total daily energy consumption is multiplied by 172 kW by 5% and divided by the power for one solar panel, 500W. The forecast for annual energy savings and bills proportional to the percentage of energy supplied by solar at PSAS is presented in Table 4.62. The percentage rate of energy supply by solar must be multiplied by an additional percentage value of 0.5% each year (10.5%, 16%, 21.5%) due to the degradation rate in the production of solar energy by PV panels. This additional 0.5% each year can ensure sufficient solar energy and lead to a 5% reduction.

Predictions related to energy savings and bill savings are calculated according to the increase in the total percentage of solar PV energy generated by related PSAS buildings to ensure the reduction achieves the minimum value of 5% per year. Annual energy savings starting at 5% are obtained by multiplying the set percentage by the yearly energy consumption value of 4,231,412 kWh. The annual bill saving is calculated by multiplying the yearly energy saving by RM 0.365. In four years, assuming that every year there is an energy saving of at least 5%, it is predicted that the minimum energy savings that PSAS will obtain are 2,242,649 kWh, while the annual bill savings is RM 818,566. Option 1 involves considerable financial implications because it involves various types of costs. The feasibility analysis for option 1 requires upfront costs for buying a PV solar system, installation, testing and commissioning, online system monitoring, NEM application, assessment and metering, operation and maintenance fee, etc. In addition, PSAS needs to apply for new financial allocations from the Ministry of Higher Education to install solar PV systems and NEM meters. There is no guarantee that the requested financial budget will be approved.

**Table 4.62: Forecast for annual energy and bill savings through Option 1**

| Percentage of energy supplied by solar | Yearly energy saving (kWh) | Annual bill saving (RM) |
|---|---|---|
| 5.0% | 211,571 | 77,223 |
| 10.5% | 444,298 | 162,169 |
| 16.0% | 677,026 | 247,114 |
| 21.5% | 909,754 | 332,060 |
| **Total** | 2,242,648 | 818,567 |

#### 4.5.2.2 Case Study 2: Feasibility Analysis of Rooftop Solar Photovoltaics Car Park (Option 2)

The PSAS's electrical power supply distribution system uses a ring system, as shown in Figure 4.26. Besides installing solar PV systems on the roofs of existing buildings at PSAS, there are other methods of generating electricity. A practical approach to be implemented by PSAS is to create a car parking lot with solar PV installed on the roof. PSAS currently has two main areas for parking. However, the area only provides parking without a roof. Based on the red circle in Figure 4.29 shows that two open spaces are currently parking lots. The proposed parking area will be upgraded to a covered parking area equipped with solar PV. Figure 4.30 show the Google Earth image for the proposed site 1 for the car parking upgrade. According to google earth calculations, the perimeter of the proposed area is 287.62 m, while the area is 4,007.21 $m^2$. Figure 4.31 shows the actual view at the proposed site 1. The realistic picture shows that the parking area is extensive.


**Figure 4.29: Overview PSAS image was taken from Google Earth**


**Figure 4.30: Google Earth image shows proposed site 1 for parking upgrade**

**Figure 4.31: The actual view of the proposed site 1**


**Figure 4.32: Google Earth image shows proposed site 2 for parking upgrade**

**Figure 4.33: The actual view at the proposed site 2**



Figure 4.32 show the Google Earth image for the proposed site 2 for the car parking upgrade. According to google earth calculations, the perimeter of the proposed area is 284.07 m, while the area is 4,816.66 $m^2$. The justification for why these two areas are proposed to be upgraded to a rooftop solar PV car park is closely related to the location of the MSB 1 position. The position of MSB 1 is close to the proposed site area facilitating the installation of the NEM meter, as shown in Figure 4.32. In addition, the area ($m^2$) of the two locations mentioned is enough for installing rooftop solar PV capable of generating electricity up to 1 MW which is the installation capacity limit. The NEM 3.0 scheme, known NEM GoMEn initiative, has set an installation capacity limit of 1 MW per account opened (KeTSA, 2020). Figure 4.33 shows the actual view at the proposed site-2, where the location is currently used as a car park without a roof. Figure 4.34 shows the proposed rooftop solar photovoltaic car park diagram using a NEM meter installed at the ring distribution system at PSAS. The proposed layout modifies the original PSAS electricity distribution system, as shown in Figure 4.26. The proposed modification integrates solar PV, inverters, and NEM meters into the existing PSAS electricity distribution system, as shown in Figure 4.34. A bi-directional meter (TNB-NEM, 2022) will be installed on the ring connection in the distribution power system at PSAS. The ring system allows solar energy generation by any building connected to a rooftop PV solar system that is also connected to the PSAS distribution system. The solar energy produced will be distributed to all MSBs, and if there is excess power, then the energy will be exported to TNB's national grid system through NEM meters.

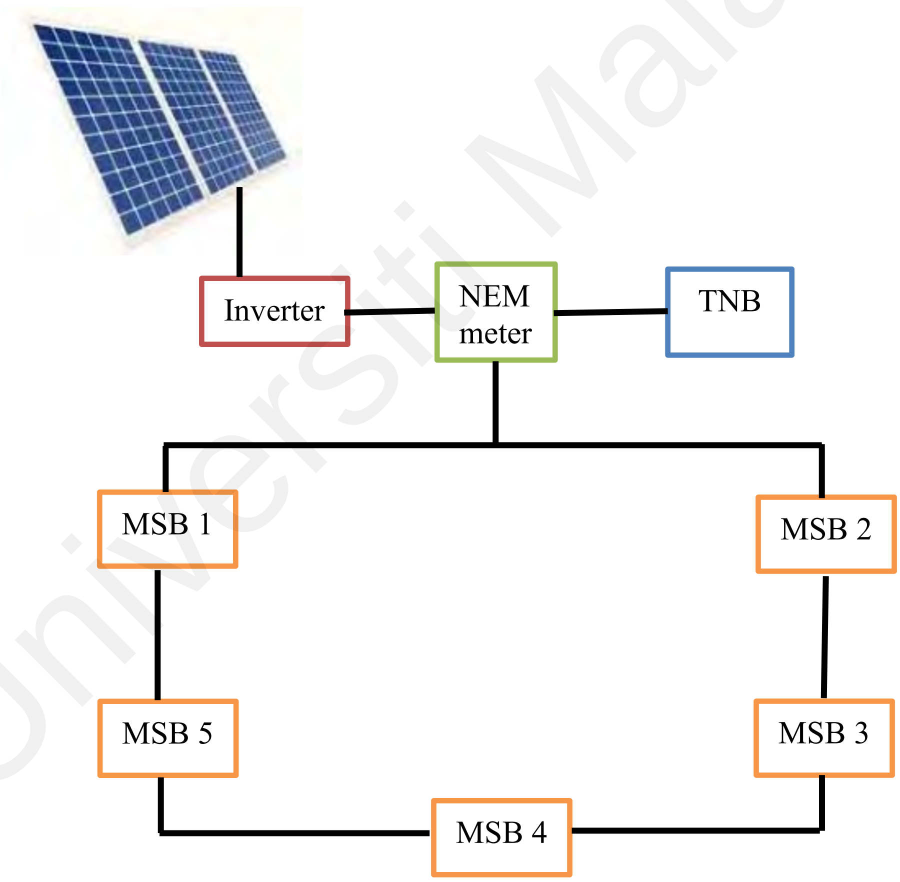



**Figure 4.34: Proposed the rooftop solar photovoltaic car park diagram using a NEM meter and installed at the ring distribution system at PSAS**

At this stage of the analysis, it is determined that feasibility analysis is made using Option 2 because of the zero upfront cost factor, but it provides multiple benefits to PSAS. The calculation assumes that PSAS has signed a Tripartite Supply Agreement with Renewable Energy (SARE) with TNB, represented by its subsidiary GSPARX Sdn Bhd. The analysis focuses on Zero Capital Expenditure (Capex) savings through a 20-years contract (GSPARX, 2022). Through this agreement, PSAS does not have to incur any expenses, including upfront capital, to install the rooftop photovoltaic system, known as zero upfront cost. In addition, PSAS is only charged a fixed solar tariff rate of RM 0.31 for the energy generated by the PV system (MESTECC, 2022) compared to the current charge of RM 0.365. The energy generated by PSAS will be used first, reducing the amount of energy imported from TNB. Under this NEM 3.0, any excess power generated will be exported to the utility grid and paid for on a "one-to-one" offset basis (SEDA, 2022b). It means that every 1 kWh exported to the grid system will be offset by 1 kWh imported from the grid (Vaka et al., 2020). As an educational institution, PSAS usually does not operate on weekends or public holidays. Therefore, a situation of excess energy generated will occur. This surplus energy is ideal for export to the grid.

However, PSAS's priority is to first use the energy generated by this solar system for its domestic needs. Credit from TNB allowed for maximum roll-over for 12 months according to NEM 1: 1 ratio (SEDA, 2022b). The estimated savings that PSAS will obtain during the 20 years of the contract in force are calculated based on the assumption that the size of the installed solar system is the same as the setting in Option 1. The capacity value of the solar PV system Option 2 is also designed to generate a solar PV system that covers the electricity supply of 20% of the total value of the energy supply used by PSAS. This proposed Option 2 solar PV system also follows the 20:80 ratio explained in the Option 1 analysis. The maximum value of solar PV capacity allowed by the Energy Commission for solar PV connected to grid systems for commercial buildings such as

PSAS is 75% of the maximum demand (MD) according to annual utility bills (SEDA, 2022b) in 2019. Calculations are made by referring to the value shown in Table 3.5. This analysis relates to the average value of MD in 2019, which recorded a value of 1488 kW. The 75% of maximum demand from annual utility bills as per Energy Commission Guidelines for Grid Connected Solar PV for the commercial customer is equivalent to 1,607,040 kWh (1488 kW x 4 hours x 30 days x 12 months x 0.75). However, this feasibility analysis does not use the maximum value of 75% of this MD because another condition in the NEM GoMEn sets the installed capacity limit for government buildings to 1MWac. In other words, accounts opened in the name of PSAS are only allowed to install solar PV systems that generate a maximum power of 1MWac. However, the proposed solar PV system can produce maximum annual energy consumption of 990,720 kWh (688 kW x 4h x 30 days x 12 months).

Nevertheless, the target of 20% of the total PSAS electricity supplied by the solar system is equivalent to 846,282 kWh (20% x 4,231,412 kWh). This 20% value does not exceed the solar installation capacity limit set for government buildings which is 1 MW. The goal of reducing energy consumption by 5% can be easily achieved if the solar energy supply that is generated is always following the ratio of 20:80.

### 4.5.3 Cost-benefit and environmental impact of renewable energy

Installing a rooftop solar PV system on either the buildings or car park rooftop confirms saving total energy consumption in a PSAS. This installation significantly impacts the environment by preserving greenhouse gas emissions such as $CO_2$, $SO_2$, and CO and supporting the green environmental vision. The cost-benefit analysis on the rooftop solar PV generation system involves case studies Option 1 & 2.

#### 4.5.3.1 Cost-benefit and environmental impact for Option 1

Option 1 involves upfront capital costs and various other costs. The system's total cost is calculated using the price of Tier 1 solar panels, where the equipment is of high quality and recognized worldwide. The total cost of this system refers to all the costs involved in developing the system. The price to buy a solar panel and inverter and pay for installation, testing and commissioning, online system monitoring, NEM application, assessment and metering, and operation and maintenance must be considered. The number of solar panels is obtained from Table 4.61. Table 4.63 shows the estimated cost of installing a rooftop solar PV system. The calculation uses the Q sells solar panel brand with a capacity of 500W, where the price in USD is $ 384.33 per unit (SolarStore, 2022b). Therefore, 1 USD ($), when converted to MYR (RM), is equivalent to RM 4.48 based on the currency on 31 August 2022. The total price for 296 units of solar panels is equivalent to RM 509 652. The unit price for the inverter is $ 4730.70 (SolarStore, 2022a), where the component specification for the input voltage is 600V, and the output power is 5000W. NEM application refers to the NEM assessment study where the fee is RM 8000 (SEDA, 2022a) if the installed capacity is more than 425 kW and not more than 1 MW. PSAS needs to appoint a registered PV service provider who manages the application to SEDA to obtain NEM quota approval. The actual price may be lower than the estimated price if the purchase is made as a set and not as a single component purchase. This analysis does not consider the government's tax incentives because PSAS is not an institution based on profit and not operating as a business company.

**Table 4.63: Estimated cost of installing a rooftop solar PV system**

| No. | Description | Quantity [unit] | Price/unit [*$] | Price/unit [RM] | Total price [RM] |
|---|---|---|---|---|---|
| 1 | No. of solar panel | 296 | 384.33 | 1,722 | 509,652 |
| 2 | No. of inverter | 15 | 4730.7 | 21,194 | 317,903 |

| | | | | | |
|---|---|---|---|---|---|
| 3 | Installation, testing, and commissioning | 8 | | 4,000 | 32,000 |
| 4 | Online System Monitoring | 1 | | 3,000 | 3,000 |
| 5 | Operation & Maintenance | 8 | | 4,000 | 32,000 |
| 6 | NEM application, assessment, and metering | 1 | | 8,000 | 8,000 |
| 7 | Others | 1 | | 5,000 | 5,000 |
| **TOTAL** | | | | | **907,555** |

The estimated total cost or investment cost for installing solar PV using Option 1 is RM 907,555. PSAS needs to know whether the total cost to be invested in installing this solar PV system is worth it. The way to tell if this investment is worth it depends on the payback period's value. The payback period is synonymous with the amount of time it takes the owner of the solar system to recover the capital invested. According to the NEM scheme in force, the financial savings obtained by PSAS in the case of installing this solar PV system will be credited to PSAS's utility bill leading to a reduction in the total bill payment. The simple payback period is calculated using the formula below:

$$\text{Simple Payback Period} = \frac{\text{Total system cost of a solar PV system (RM)}}{\text{Annual bill saving (RM)}}$$

The total system cost of a solar PV system is obtained from Table 4.63. The value of the annual electricity bill is taken from the current charges shown on the monthly electricity bill in PSAS for 12 months in 2019. The electricity bill from the TNB statement displays the total amount of payments that have been added, covering the value of kWh consumption, maximum kW demand, Imbalance Cost Pass-Through (ICPT), TNB discount, and Renewable Energy Fund (KWTBB). Table 4.64 shows the monthly electricity bill for PSAS 2019 issued by TNB.

$$\text{Simple Payback Period} = \frac{\text{RM 907 555}}{\text{172 kW x 4 hours x 365 days x RM 0.365}}$$

$$\text{Simple Payback Period} = \frac{\text{RM 907 555}}{\text{RM 91658.8}}$$

$$\text{Simple Payback Period} = \text{9.9 years}$$

The payback period for installing rooftop solar PV using Option 1 is 9.9 years. The payback period is almost ten years because the price of solar panels and inverters is high due to the purchase from foreign countries. The cost of buying locally produced solar equipment will be lower, and the payback period can be less than nine years.

**Table 4.64: The monthly electricity bill for PSAS in 2019 issued by TNB**

| Month | Current charge in electricity bill (RM) |
|---|---|
| January | 189,928.78 |
| February | 155,797.23 |
| March | 183,684.88 |
| April | 189,808.09 |
| May | 129,243.93 |
| Jun | 119,618.46 |
| July | 188,158.26 |
| August | 170,763.44 |
| September | 194,810.72 |
| October | 189,662.65 |
| November | 133,563.27 |
| December | 151,124.28 |
| **TOTAL** | **1,996,163.99** |

Installing a rooftop solar PV system connected to a NEM meter confirms that the savings in total energy consumption in PSAS buildings are relevant and worthwhile. This installation significantly impacts the environment by preserving greenhouse gas emissions such as $CO_2$, $SO_2$, and CO and supporting the green environmental vision. The $CO_2$, $SO_2$, and CO emission reduction analysis results show how installing solar PV systems impacts the environment. The energy produced by solar PV equals the energy-saving obtained by PSAS. The carbon emission reduction for PSAS has been calculated using equation (3.6) and annual energy savings data from Table 4.62. Table 4.65 shows the carbon emission reduction after installing rooftop solar PV. Assuming that the reduction of carbon emissions each year in PSAS is represented by 5%, for the first year, PSAS can reduce as much as 155,600 kg of $CO_2$. Referring to Table 4.65, taking the example of gas emission reduction when the energy supplied by solar is 5%, then the result of $CO_2$ emission reduction is 155,600 kg. The value calculation is based on Equation (3.6) and the value of the emission factor, as shown in Table 3.55. Shown is an example of a calculation when the energy supplied by solar is 5% of the total energy consumption of PSAS in 2019 which is 4,231,412 kWh and is entered into Equation (3.6). By referring to the value of each percentage of electricity generation fuel mix for Malaysia in 2016, which is 13.0%, 42.5%, 0.4%, 43.5%, and 0.6% from hydro, coal, petroleum, natural gas, and other sources, then the value is multiplied by each $CO_2$ emission factor value.

Next, the product of the four types of fuels is added and multiplied by the annual energy saving of 5%, which is 211,571 kWh. Emission reduction: 155,600 kg $CO_2$ = 211,571 kWh x ((0.13x0)+(0.425x1.18)+(0.004x0.85)+(0.435x0.53)). The saving of 155,600 kg of $CO_2$ is also equivalent to 155.6 tons of $CO_2$ (ClimateChangeConnection, 2022), equivalent to 3,890 mature trees saved from being cut down. This calculation is based on the value of 1 ton of unabsorbed $CO_2$, equal to a total of 25 mature trees felled. These mature trees refer to twenty-five (25) trees per hectare of commercial species with a diameter of 45 cm or more that help restore the forest that has been cultivated (JPNK, 2022). The percentage of energy supplied by solar, which is 21.5%, leads to reduced emissions of 669,078 kg of $CO_2$, equivalent to 16,727 mature trees that were not cut down. Assuming that there is an energy saving of at least 5% every year, it is predicted that the minimum emission reduction that PSAS will obtain is 1,649,356 kg $CO_2$, equivalent to 41,234 mature trees that were saved being cut down. PSAS 'efforts align with the Government's initiative to reduce the country's $CO_2$ emissions by 2030.

**Table 4.65: Carbon emission reduction for PSAS after installing a solar PV system**

| Percentage of energy supplied by solar | Annual energy saving (kWh) | Emission reduction (kg) | | |
|---|---|---|---|---|
| | | $CO_2$ | $SO_2$ | CO |
| 5.0% | 211,571 | 155,600 | 1,310 | 642 |
| 10.5% | 444,298 | 326,759 | 2,750 | 1,348 |
| 16.0% | 677,026 | 497,919 | 4,191 | 2,053 |
| 21.5% | 909,754 | 669,078 | 5,632 | 2,759 |

#### 4.5.3.2 Cost-benefit and environmental impact for Option 2

The cost-benefits are calculated based on the assumption that PSAS cooperates with TNB GSparx through a 20-year contract. Table 4.66 shows the detailed results of the feasibility analysis of Zero Capital Expenditure Savings for SARE between PSAS and TNB GSPARX. The table shows the number of years calculated for the cost-benefits of the project is 21 years, where 20 years is the calculation during the contract in force and the 21st year is the calculation after the contract ends. For the first year, the electricity generated by solar energy was 990,720 kWh. This value is obtained from 20% of the daily energy consumption supplied by solar at normal times, which is 688 kW, multiplied by 4 hours x 30 days x 12 months. For the 2nd year and subsequent years, the annual degradation of solar PV panel energy production decreased by 0.5% per year. Energy cost is calculated based on TNB and solar tariffs. TNB's current tariff is RM 0.365/kWh because under category C1 buildings. The value of energy cost is also calculated by assuming that the annual degradation of solar PV panel energy production is 0.5% per year with a TNB tariff increase of 9% every three years (ST, 2018a). The year four energy cost using TNB tariff becomes RM 0.398 and additions to RM 0.434 in year 7. However, the solar tariff rate is a fixed tariff that will be used throughout the 20-year contract in force is RM 0.31. After the 20-year contract expires, the cost of energy using solar tariffs becomes zero. The cost of energy using TNB or solar tariffs is obtained by multiplying the annual value of solar generation with the relevant tariff value. While this agreement is in effect, PSAS does not have to pay operation and maintenance (O&M) costs, as TNB GSPARX covers everything related.

After the contract ends, PSAS will start paying O&M costs estimated at around RM 55,000 per year. Based on the analysis results, the estimated accumulated net savings for PSAS over the 20 years of the effective contract is RM 3,534,250. The environmental impact when implementing Option 2 is the same as choosing Option 1 because both designs use the same setting and reference values in the analysis. No analysis of Option 2 is shown in this section. This Zero Capex Solution program under Option 2 offers PSAS immediate added value to enjoy immediate monthly electricity bill savings upon agreeing to TNB GSparx using PSAS roof for solar PV system installation. In addition, Option 2 hedges against rising tariffs and offers free parking. In addition, Option 2 also offers other advantages that include aspects of development such as power system study, project management, insurance, PV system design & certification, online system monitoring, training staff and authorized personnel on operations, maintenance, and troubleshooting.

Table 4.66: Feasibility Analysis of Zero Capital Expenditure Saving for SARE between PSAS and TNB GSparx

| Year | Solar Generation (kWh/year) | TNB tariff (RM/kWh) | Solar Tariff (RM/kWh) | Energy Cost using TNB Tariff (RM) | Energy Cost using Solar Tariff Including Operation & Maintenance Cost (RM) | Operation & Maintenance Cost (RM) | Net Saving per Year (RM) | Accumulated Net Saving (RM) |
|---|---|---|---|---|---|---|---|---|
| 1 | 990,720 | 0.365 | 0.31 | 361,613 | 307,123 | 0 | 54,490 | 54,490 |
| 2 | 985,766 | 0.365 | 0.31 | 359,805 | 305,588 | 0 | 54,217 | 108,707 |
| 3 | 980,838 | 0.365 | 0.31 | 358,006 | 304,060 | 0 | 53,946 | 162,653 |
| 4 | 975,933 | 0.398 | 0.31 | 388,275 | 302,539 | 0 | 85,736 | 248,389 |
| 5 | 971,054 | 0.398 | 0.31 | 386,334 | 301,027 | 0 | 85,307 | 333,696 |
| 6 | 966,198 | 0.398 | 0.31 | 384,402 | 299,522 | 0 | 84,881 | 418,576 |
| 7 | 961,367 | 0.434 | 0.31 | 416,903 | 298,024 | 0 | 118,879 | 537,456 |
| 8 | 956,561 | 0.434 | 0.31 | 414,819 | 296,534 | 0 | 118,285 | 655,740 |
| 9 | 951,778 | 0.434 | 0.31 | 412,745 | 295,051 | 0 | 117,694 | 773,434 |
| 10 | 947,019 | 0.473 | 0.31 | 447,642 | 293,576 | 0 | 154,066 | 927,500 |
| 11 | 942,284 | 0.473 | 0.31 | 445,404 | 292,108 | 0 | 153,296 | 1,080,796 |
| 12 | 937,572 | 0.473 | 0.31 | 443,177 | 290,647 | 0 | 152,530 | 1,233,326 |
| 13 | 932,885 | 0.515 | 0.31 | 480,648 | 289,194 | 0 | 191,453 | 1,424,779 |
| 14 | 928,220 | 0.515 | 0.31 | 478,244 | 287,748 | 0 | 190,496 | 1,615,275 |
| 15 | 923,579 | 0.515 | 0.31 | 475,853 | 286,309 | 0 | 189,544 | 1,804,819 |
| 16 | 918,961 | 0.562 | 0.31 | 516,086 | 284,878 | 0 | 231,209 | 2,036,027 |
| 17 | 914,366 | 0.562 | 0.31 | 513,506 | 283,454 | 0 | 230,053 | 2,266,080 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 18 | 909,794 | 0.562 | 0.31 | 510,939 | 282,036 | 0 | 228,902 | 2,494,982 |
| 19 | 905,246 | 0.612 | 0.31 | 554,138 | 280,626 | 0 | 273,512 | 2,768,494 |
| 20 | 900,719 | 0.612 | 0.31 | 551,368 | 279,223 | 0 | 272,145 | 3,040,639 |
| 21 | 896,216 | 0.612 | 0.00 | 548,611 | 0 | 55,000 | 493,611 | 3,534,250 |
| **Total** | **19,797,077** | | | **9,448,517** | **5,859,267** | | **3,534,250** | |

### 4.5.4 Comparison of solar PV system characteristics between Options 1 and 2

Table 4.67 compares solar PV system characteristics between Options 1 and 2. Both types of options have their advantages and disadvantages. Five main elements have been reached, and a summary of these characteristics is shown in table form. The characteristics compared are the type of solar PV, solar PV connection, upfront cost, system ownership, and operation and maintenance cost.

**Table 4.67: Comparison of solar PV system characteristics between Options 1 and 2**

| No | Characteristic | Option 1 | Option 2 |
|---|---|---|---|
| 1 | Type of solar PV | Install at the **rooftop** of the **building**. | Install at the **rooftop** of the **car park**. |
| 2 | Solar PV connection | Solar PV connected to NEM meter and **Sub-switch Board (SSB)** | Solar PV connected to NEM meter and **Main Switch Board (MSB)** |
| 3 | Upfront cost | **Have** upfront cost | **Zero** upfront cost |
| 4 | System Ownership | This system is wholly owned by PSAS starting the **first day** the solar system is installed. | After **20 years** of the contract end, then the system is wholly owned by PSAS |
| 5 | Operation & Maintenance cost | Funded by **PSAS** | Funded by **TNB GSparx** |

## 4.6 Conclusion

The final objective of this research focuses on estimating the cost benefits and environmental impact when a renewable energy system is installed in a PSAS. The research analysis in this chapter is divided into three main sections: residential buildings, academic buildings, and non-academic buildings. The analysis results have helped identify the types of equipment that use the highest energy in staff quarters, academic buildings, non-academic buildings, and a combination of academic and non-academic buildings. The analysis shows proposed measures to optimize energy consumption by electrical appliances in the residential staff and academic and non-academic buildings to improve energy efficiency. The feasibility analysis has calculated the value of potential energy savings and related costs based on Option 1 or 2. Both options use a design adapted to NEM 3.0 called NEM GoMEn.

# CHAPTER 5: CONCLUSION AND RECOMMENDATION

This section elaborates on the conclusion and recommendation part for future research. This conclusion section highlights the main findings based on the four research objectives that have been set. The recommendation for future work has been stated in the subsequent sections.

## 5.1 Conclusion

This final chapter summarizes the main findings that align with the research objectives. In particular, this research focuses exclusively on designing and analyzing sustainable clean energy integration in a Malaysian higher educational institution. Conclusions are made based on the results obtained from the analysis. The results show that each objective of the study has been successfully achieved.

The main findings are summarised, and this study's significant results have been highlighted. The first objective of this research was to identify and analyze energy-consuming equipment in PSAS. Types of equipment that use high electrical energy need to be identified. The second objective of this research is to propose energy usage optimization measures and savings in PSAS. An effective strategy can be implemented in PSAS to optimize energy consumption while saving energy. To ensure that these two objectives are achieved, research needs to investigate energy consumption in three categories of buildings. The residential buildings use a survey questionnaire form and semi-structured interviews to gather the data. Non-residential buildings are academic and non-academic buildings where data collection uses energy audit methods. Analyzing energy consumption per piece of equipment helps to identify the equipment needs to be focused on optimizing energy usage and energy savings. The obtained result revealed that the ceiling fans recorded the highest energy consumption at PSAS residential, about 17.5%, followed by lighting at 15.5% and water heater at 15.5%. The effective energy-saving strategy focuses on replacing a new ceiling fan, LED 18W, and mini solar water heater. The analysis found that replacing 100% of an old ceiling fan with the latest version is insufficient to achieve the 5% reduced energy consumption target and bill-saving reduction for the following year. Other equipment should also be replaced to ensure that the PSAS residence's 5% energy reduction target can be achieved.

Based on the analysis of academic buildings, the total estimated annual energy consumption in the four main academic buildings at PSAS is approximately 1,152,337 kWh. In contrast, the annual bill is RM 420,603. The energy consumption analysis per equipment in MED, CED, EED, and CD recorded the different energy-consuming patterns. The research found that air conditioning was the highest energy consumer for MED, CED, EED, and CD, where systems significantly impact building energy consumption. This study confirms that laboratory equipment has a vital significance as among the highest energy users. It is evident when it recorded the result as the second highest energy consumer in 3 out of 4 academic buildings in PSAS except for CED. The estimated energy consumption per year is about 325,890 kWh, 159,055 kWh, 467,460, and 199,932 kWh, while the energy bill per year is about RM 118,950, RM 58,055, RM 170,623, and 72,975.

In this research, the total energy consumption estimation of end-load in 3 non-academic buildings is about 142,632 kWh. The energy bill per year is about RM 52,060. The energy consumption analysis per equipment identified air conditioning as the highest energy consumer among all end-loads audited in the three non-academic buildings. The total energy consumption for air conditioning is approximately 81,837.99 kWh. It equals about 57% of the energy consumption in the three buildings involved. Among the significant results of the energy consumption analysis for each piece of equipment is providing certainty and the right direction to implement a saving strategy. A strategy aimed at the right equipment significantly reduces energy consumption while providing energy savings as desired.

The third objective of this research is to investigate the feasibility of on-site energy generation based on the energy source available in PSAS. The result confirms that solar PV is a suitable energy source to install at PSAS due to its location. A feasibility analysis of sustainable clean power generation using solar PV for PSAS referred to the NEM 3.0 mechanism called NEM GoMEn. The PV system design is calculated to cover only 20% of the total load based on the 2019 reference value. This research uses a ratio of 20:80, where 20 refers to the power supply generated by solar PV while 80 refers to the power supply supplied by TNB. The proposed solar PV design is divided into Option 1 and Option 2. Option 1 proposed modifications based on the current distribution electricity layout at PSAS. The proposed Option 1 design involves a rooftop solar photovoltaic installation connected to a NEM meter and Sub-switch Board (SSB) already available and related to certain buildings. In four years, assuming that there is an energy saving of at least 5% every year, it is predicted that the minimum energy savings that PSAS will obtain are 2,242,649 kWh, while the annual bill savings is RM 818,566. Option 2 proposed a rooftop solar photovoltaic car park diagram using a NEM meter installed at the ring distribution system at PSAS. The proposed solar PV system can produce a maximum annual energy consumption of 990,720 kWh using the highest monthly energy consumption data in 2019. Nevertheless, the target of 20% of the total PSAS electricity supplied by the solar system is equivalent to 846,282 kWh based on total energy consumption 2019.

Finally, the last objective is to estimate renewable energy's cost-benefit and environmental impact based on the final analysis of the whole energy consumption at PSAS. The payback period for replacing a new ceiling fan in residential buildings is less than three years. Replacing 80% of old lamps with LED 18W is sufficient to reduce energy consumption and bill saving by at least 5%. The payback period is less than half of the year. The replacement of 40% of an old water heater with a mini solar water heater is sufficient and exceeds the target of reducing 5% of energy consumption. The payback period is less, which is between 7.83 to 9.11 years. However, the analysis of the whole buildings, excluding residential buildings, found that the estimated value of accumulated net savings for PSAS during the 20 years of the contract under NEM GoMEn is almost RM 3.54 million. This feasibility analysis reveals that educational institutions will reap significant benefits when installing rooftop solar PV on their premises, especially cost savings.

Replacing with efficient ceiling fans, LED lights, and solar water heaters in residential buildings can save many greenhouse gas emissions such as $CO_2$, $SO_2$, and CO. The analysis proves that $CO_2$ reduction is enormously significant with installing a rooftop solar PV system. Assuming that every year there is an energy saving of at least 5%, it is predicted that the minimum emission reduction that PSAS will obtain is 1,649,356 kg $CO_2$, equivalent to 41,234 mature trees that were saved from being cut down either choose Option 1 or 2. The environmental impact when implementing Option 2 is the same as choosing Option 1 because both designs use the same setting and reference values in the analysis. The analysis proves that $CO_2$ reduction is vital in installing sustainable clean energy generation through the solar system at PSAS.

## 5.2 Recommendation

Currently, only 55 digital meters have been installed at PSAS, and certain loads that are not installed and measured, locations where meters are not currently installed, will be installed in the future. In this research, all the estimated calculations for energy consumption for electrical equipment consider the worst case and are set to 1. Although the estimated value is within a reasonable range, for higher accuracy, it can be regarded as using the actual load factor value according to each electrical equipment instead of calculating based on the ideal value. In addition, the feasibility analysis for future research can consider a technical analysis that focuses on the stability of the proposed design if installed, considering the readiness of the existing system to be modified. In addition, it is suggested to make multiple case studies involving more than one polytechnic and then compare the energy consumption patterns of those institutions. The findings will be input to the upper management of the Department of Polytechnic Studies and Community Colleges (JPPKK) to improve the existing green policy. In the future, the generated energy consumption estimate template will be shared with other energy managers in educational institutions in Malaysia through the polytechnic management headquarters, which is JPPKK. The findings of this study will be forwarded to the JPPKK then this department will present a proposal to the Ministry of Higher Education (MoHE) related to the function of this template and obtain approval from the Ministry to distribute and implement energy-saving programs in other higher education institutions under the supervision of the MoHE.

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