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*Research Article*

# Energy Efficiency and Feasibility Analysis of Solar Power Generation Using Hybrid System of an Educational Institution in Malaysia

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Energy is one of the basic inputs and driving forces for economic and social development modernization. Sustainable energy supply is one of the major challenges in the modern world. Sustainable energy supply can be obtained through alternative energy sources, and efficient energy use is a high priority to optimize the environmental impact. This paper investigates the potential for energy savings involving five end-load equipment in academic institutions. The saving potential is obtained through energy efficiency analysis and feasibility analysis of the solar power generation systems. An energy audit is conducted on end-use consuming equipment (i.e., fans, lights, air conditioning, ICT equipment, etc.) in these five end-load sectors to find out the major energy-consuming equipment, energy consumption, and potential energy savings. The analysis of energy consumption per equipment helps determine the appropriate type of equipment to be upgraded and replaced for energy saving. The feasibility of rooftop solar power generation has been also analysed to integrate into the energy end load. The research findings confirm that laboratory equipment, lighting, and air conditioning are vital to energy consumption in academic buildings. The energy savings, bill savings, and carbon emissions reductions have been estimated based on integrating rooftop solar power generation. The feasibility analysis of onsite energy generation using a hybrid solar system found that the total energy-saving potential and bill savings within five years are 311,131 kWh and RM 113,563, respectively. This value refers to comprehensive energy-saving and bill for all academic buildings involved in this research.

## 1. Introduction

Global warming is a real challenge and is accepted as a worldwide issue. Active action to handle this challenge must be taken. Malaysia set a target in the year 2030 to achieve reducing greenhouse gases (GHGs) emission intensity of gross domestic product (GDP) by up to 45% compared to the 2005 level [1]. There are three types of methods that can be implemented to reduce carbon emissions in the energy sector. This method improves energy conservation, maintains and enhances energy efficiency, and promotes renewable energy application [2]. Encouraging the use of renewable energy source can reduce greenhouse gas emissions. The gases is a significant contributor to global warming [3]. All the previous research work by [4–7] conclude implementing an energy audit is the best strategy to gather data about high-energy-consuming equipment inside the educational building. Assessing energy-saving potential is key to predicting future sustainable use patterns of energy. A study conducted by [5, 8–10] reveals that focusing on energy consumption per equipment of certain types is more effective in achieving the energy-saving target. Most researchers set the target equipment, such as lighting, cooling, water heating, and motors. This paper audits some equipment types stated in the previous research work but adds laboratory equipment as a new highlight in an academic institution's energy audit process.

The concept of the energy efficiency gap was first introduced at the end of the 1970s and subsequently developed and reached a stage of maturity around the early 1990s [11]. The United States has begun to reflect on its first energy efficiency policy assessments based on demand-side management (DSM) in response to the oil crisis of the 1970s. The first evaluation from an economic perspective of the DSM program was carried out by [12]. They show a negawatt-hour cost that represents the cost of saving one unit of energy. In the 1990s, many studies focused on understanding the potential of specialized energy technologies in the power and fuel cell sectors [13, 14]. The study discusses the experience of implementing energy efficiency programs in many countries such as Russia, the United States, and Mexico [15–18]. In the early 2000s, when the issue of global warming became increasingly alarming [19] and was linked to carbon dioxide emissions, it led to the focus of research towards reducing the energy efficiency gap through an international commitment to make it happen. Energy efficiency gap estimates that refer to the difference between current energy consumption and energy consumption if the most efficient technology is used have proven useful to guide research and development (R&D) and policy design. Most engineering studies are beginning to pay attention to energy efficiency as it is identified as the most effective way to reduce the cost of carbon dioxide emissions [20]. Measures to improve energy efficiency by reducing fossil fuels will help reduce the effects of climate change from greenhouse gases [21–23].

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 [24]. Research by [24, 25] presents the feasibility analysis of photovoltaic power installation with an off-grid system. However, relying only on standalone solar energy systems cannot meet electricity demand effectively because they are inefficient and variable. Solar power system depends on the weather and requires backed up by traditional fossil fuel energy [25]. Installing a hybrid solar system is one of the practical solutions for standalone power generation systems. Research by [26] explores the feasibility analysis to calculate the potential of renewable energy resources in Sarawak, Malaysia. Using HOMER software, the feasibility analysis of solar PV, battery, and fuel cells is investigated for a load at a village longhouse in Kapit, Sarawak. Besides, the other research by [27] also used HOMER software to investigate the techno-economic analysis of the hybrid systems in Peru. This paper does not follow the methodology of using simulation software like HOMER to make the analysis but uses estimation calculation [28, 29]. Nowadays, electricity consumption in educational institutions is high, mainly because of the extensive use of conventional air-conditioning system. This situation contributes to the environmental effect due to the increasing level of $CO_2$ emission. Using a solar air-conditioning system to drive the cooling cycles can minimize the number of fossil fuel energy use, and it is environmentally friendly [30]. The ability of the solar air-conditioning system is explored by [31–33] using an off-grid system only. Extending the research focusing on the impact of solar air conditioning powered by another source from an on-grid system will give added information from the economic perspective. This research analyzed the energy-saving potential of five end load groups, including laboratory equipment which was the main highlight. The analysis of energy consumption per equipment indicates the types of equipment that should be targeted for energy saving.

The main aim of the paper is to conduct a detailed energy audit to confirm whether laboratory equipment has full significance as a major contributor to high energy consumption in academic buildings or not, and to evaluate the feasibility of installing a rooftop solar power generation in Politeknik Sultan Azlan Shah (PSAS). This research presents a feasibility analysis using a hybrid solar power generation system. For the feasibility analysis, average irradiation and daylight time have been considered to estimate the power generation [28]. This paper refers to General Circular No. 2 of 2014 [34], Malaysian Polytechnic POLYGreen Blueprint 2015 [2]. All government buildings need to reduce or save their utility cost minimum by 5% per year. The results support the mission of Malaysian Polytechnic to reduce the number of carbon emissions as stated in SmartGreen Polytechnic Community College 2021-2026 [35].

## 2. Methodology

*2.1. Research Approach.* This research investigated energy consumption for academic buildings in PSAS through the energy audit method to collect the data. The methodology proposed always refers to the Malaysian Standard MS 1525 : 2007, Code of Practice on Energy Efficiency and Use of Renewable Energy for Nonresidential Buildings. The documentation of manual equipment and building layout was also evaluated during the energy audit process. The interview session is conducted with the person in charge to understand the equipment function and usage.

*2.2. Active Equipment in Academic Buildings.* This study focuses on five active equipment types: laboratory equipment, fan, lighting, air conditioning, lighting, and information technology (ICT) equipment. Air conditioning consists of two 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.

*2.3. Baseline Data.* The baseline data refer to the information on energy consumption measured using a fixed digital power meter (DPM) installed in each academic building at PSAS. This reference value will be compared with the calculated energy consumption to minimize the error percentage between measured and calculated data. Baseline data refers to measured data for energy consumption (kWh) in 2019. Predicting energy consumption and saving in PSAS for future years has been estimated based on baseline data. The data collected refer to average energy consumption data (kWh) for 12 months from January 2019 to December 2019. The data was extracted via the online energy monitoring system (EMS) owned by PSAS. Table 1 shows the baseline data for energy consumption in the year 2019 imported from EMS involving three main academic buildings.

*2.4. Data Collection through the Online System and Audit Process.* The energy audit will focus only on four academic departments in this research stage. The academic buildings involved are the Mechanical Engineering Department (MED), Civil Engineering Department (CED), Electrical Engineering Department (EED), and Commerce Department (CD). This research uses 15 measured data from 55 DPM units installed on each subswitch board (SSB) on the PSAS campus. This meter measures the energy consumption in each related block. Calculated data has been taken from the audit process. The number of class day data held based on the PSAS academic calendar year was also collected. Data gathering follows the methodology [8, 28, 29], where energy audit has been conducted in 4 primary academic departments at PSAS. Most researchers [36–38] implement the energy audit methodology to identify which types of equipment consume the highest energy. In this research, types of 5 end loads that use the highest amount of energy in academic buildings have been identified. The walk-through energy audit collects information about types of equipment, quantity, power rated and operating hours. Table 2 summarises the type, quantity, rating power, and average operating hour per year for five end-load equipment at the MED, CED, EED, and CD.

Summary of data for air conditioning involves two different types of systems, namely ACSU and WCPU, where the air conditioning is connected to the cooling tower no. 1 or 2. However, the estimated operating hours per equipment have been calculated using equation (2). The active hour of equipment per day is acquired from lecturers, the head of program, or the head of department. The total number of days in 1 year of equipment operation (ON) is calculated based on 32 weeks of the lecture without including weekend days. The public holiday of PSAS during lecture week also needs to count, and for the year 2019, it only involves three days of a public holiday. The estimated operating hours for fans and lighting have been calculated by considering the the total active hour per day is 8 hours. The number of days involving fan operation and lighting (ON) in 1 year is calculated based on 32 weeks of lectures and four weeks for the final exam. However, the estimated operating hours are only half as not all fans will operate simultaneously.

Estimated operating hours for air conditioning in this study have been calculated based on the total number of working hours per day for 9 hours. The number of days for air conditioning (ON) in 1 year is calculated based on additional weeks (52, 42, and 32 weeks). This week's number refers to the air conditioning power capacity (horsepower) and user group type using this equipment. The number of public holidays for 52 and 42 weeks is 14 days. Most of the total estimation of operating hours for air conditioning is assumed to be half because not all the air conditioning will be on simultaneously. 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. The average operating hours show how much an active hour is for each equipment group on average.

*2.5. Mathematical Equation.* The estimated annual energy consumption for electrical equipment in the academic building in PSAS can be calculated using the equation (1) [8, 9, 28, 29].

$$\mathrm{AEC} = P_r \times H_a \times L_f. \quad (1)$$

AEC represents the estimation of annual energy consumption in kWh, $P_r$ is rated power of electrical equipment in kW, $H_a$ is the annual estimated operating hours, and $L_f$ is the loading factor of electrical equipment. Estimated operating hours, $H_a$ obtained from the following

$$H_a = H_d \times \left(O_n - O_f\right). \quad (2)$$

$H_d$ is the operating hour of equipment, $O_n$ is the number of days in 1 year that equipment already operates (on) and $O_f$ is the number of days in 1 year that equipment does not function (off) because of a public holiday. The number of days that electrical equipment is operating or not is based on the academic calendar for PSAS 2019. On weekends, the routine is considered no educational activity, and most electrical appliances do not work. All the electrical equipment loading factors will be ideal in this research and set to 1 [9]. The estimation of annual energy saving for lighting in the PSAS is calculated using the following equation (3) [8, 9, 28, 29].

$$\mathrm{AES} = P_r \times Hy \times L \times R_p, \quad (3)$$

where AES is an annual estimated energy saving of electrical equipment (kWh), $P_r$ is the rated power of electrical equipment, $Hy$ is an operating hour operation by year, $L$ is the loading factor of electrical equipment and is set to 1 for the worst case, and $R_p$ is a percentage of electrical equipment replacement. Energy saving for each type of energy efficiency equipment in this study have been calculated according to the different replacement quantity rates. Annual bill savings using energy-efficient equipment are calculated using the following equation in (4): [8, 9, 28, 29].

$$\mathrm{ABS} = \mathrm{AES} \times E_C. \quad (4)$$

AES is annual energy saving (RM), Ec is the average energy cost (RM/kWh), and ABS is annual bill savings (RM). The tariff rate for PSAS refers to tariff C1 for medium voltage general commercial tariff. In Malaysia, most power plant generation burned fossil fuels to produce electricity. The effect of burning fossil fuels produces emissions of greenhouse gases (GHG) such as $CO_2$, $SO_2$, and

Table 1: Baseline data for the year 2019 imported from EMS.

| Meter no. | Building | Energy consumption (kWh)/year 2019 |
|---|---|---|
| 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 |

CO [8]. However, based on energy-saving strategies implemented at an academic building in PSAS, the GHG reduction according to the percentages of electricity generation in Malaysia involves different fuel mix types. The estimated GHG emission calculation will include the electricity percentages generated by each fuel type, such as hydro, gas, coal, and diesel, plus emission factors in a power station refer to Malaysian condition [39]. Energy savings strategies are directly related to emission reductions and estimated value according to the fuel types, electricity generated percentage by the specific fuel, and the fuel emission factor for electricity production using the following mathematical equation (5) [9, 40, 41]. The emission factor per unit energy generation for four types of fuels has been taken from references [9, 40, 41] and shown in Table 3. The electricity generation mix in Malaysia has been taken from the Malaysia Energy Statistics Handbook 2017, where the reference source is from 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 others, respectively, for the year 2016 [39].

$$\mathrm{EM}y = \mathrm{EP}y\left(\mathrm{PE}y^1 \times \mathrm{Em}_p^1 + \mathrm{PE}y^2 \times \mathrm{E}m_p^2 + \mathrm{PE}y^3 \times \mathrm{Em}_p^3 + \cdots\cdots\cdots \mathrm{PE}y^n \times \mathrm{Em}_p^n\right), \quad (5)$$

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. $\mathrm{Em_p}^2$ is the emission factor per energy generation unit of fuel type $n$.

## 3. Results and Discussion

An analysis of energy audit data for five end-loads has been conducted in 4 main academic buildings. The quantity of equipment, power rated (kW), operating hours, energy consumption, and energy bill is also recorded and calculated. The annual energy consumption and annual energy bill for all types of end load have been calculated using equation (1). Using the data from Table 2 and calculated using equation (1), the details of total energy consumption for five types of end-load in 4 academic buildings are shown in Table 4. The calculation estimation of energy bills refers to tariff rates 2018 issued by TNB. PSAS refers to tariff category C1, known as medium voltage general commercial tariffs for all kWh per month at a charge rate of RM0.365 [42].

*3.1. Equipment Proposed for Energy Efficiency Improvement.* The line chart in Figure 1 illustrates the comparison pattern of energy consumption in the four departments. The targeted equipment for energy-saving for MED, CED, EED, and CD has been identified from this graph. The analysis results confirmed that air conditioners were the highest energy-consuming equipment in all the academic departments studied. These results support the findings of a study conducted by previous authors [43–47] where air conditioning systems consume the highest electrical energy in the office or educational building. According to Tables 4 and 5 and Figure 1,

Table 2: Summary of types of end load, a total of quantity, rating power, and operating hours for routine activity at MED, CED, EED, and CD.

| No | End-load | Department | Quantity | Total power (kW) | Average operating hours (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 | 2,972 |
| | | CED | 1649 | 102.377 | 3,888 |
| | | EED | 3140 | 179.458 | 3,911 |
| | | CD | 1220 | 99.156 | 4,906 |

Table 3: Emission factor per unit of energy use for various types of fuels in Malaysia [8].

| 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 |

the second-highest annual energy consumption and annual energy bills in MED are contributed by laboratory equipment by 32%. It was found that the difference in the percentage of load distribution between the air conditioning and the laboratory equipment was only 6%. It means that laboratory equipment has a solid significance on the amount of energy consumed in MED. The result obtained is related to the condition at MED where this department most uses the heavy machine during their practical session or experiments. These findings align with what the researchers [48] mentioned: heavy-duty machine tool typically consumes much more power but receives less attention regarding energy saving.

From the graph, the air-conditioning and laboratory equipment at MED has a high impact on energy consumption of almost 230,000 kWh and energy bills of more than RM 80,000 per year. In CED, the results show lighting is identified as the second-highest energy consumption, at about 29%. The number of classrooms and laboratories equipped with lighting such as metal halide 400 W is large, and the location is not installed an air conditioning system. This result coincides with the condition in CED buildings where workshops or laboratories typically have high ceilings from the floor and large spaces for performing practical work. The installed metal halide lighting meets the minimum standards for lighting in the workshop according to standard MS1525: 2014 about the brightness of the space. However, the laboratory equipment in CED is the third-highest energy consumer, but the percentage of load apportionment is about 26%. It means that laboratory equipment has vital significance for CED's total energy consumption. From the result, the air conditioning and lighting have a high impact on energy consumption at CED, with almost 100,000 kWh and energy bills of more than RM40,000 per year.

According to Figure 1, the graph shows the energy consumption pattern and energy bill for EED quite differently from the chart for MED or CED. The load apportionment

Table 4: Summary of yearly 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 |

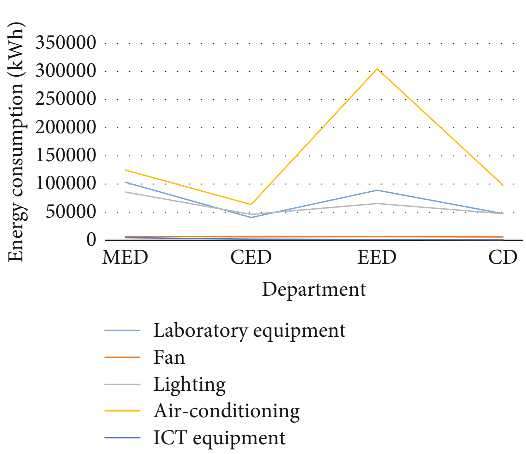


Figure 1: Comparison of energy consumption pattern for five end loads in the four academic departments involved.

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. This difference is due to the number of ACSU and WCPU-type air conditioners available in EED being high compared to the other two departments. The second-highest energy consumption at EED identified from laboratory equipment is only 19. Most of the electrical and electronic equipment in the EED falls under the category of small appliances that do not consume much power when operating. This percentage means that laboratory equipment has a less significant solid effect on total energy consumption in EED when compared to the results recorded at MED and CED. According to Figure 1, the graph shows that the energy consumption and energy bill for laboratory equipment and lighting are pretty similar at CD. The result also confirms that laboratory equipment has a significant on energy consumption at the CD building. Besides that, the pattern displayed through the line chart also demonstrates that laboratory equipment is in the second position as the highest energy consumer, except in CD. It also 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, an energy saving measure (ESM) will be proposed. Although the equipment that used the highest power in each academic

Table 5: Summary of error percentage values and recommended ESM.

| Academic building | Total kWh/year for whole academic building involve: (measured value) (A) | Total kWh/year for whole academic building involve: (calculated value) (B) | Error percentage between measured and calculated value: (A – B)/A × 100 (%) | Targeted equipment for energy saving measure (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 | Lighting |
| (MED+CED+EED+CD) | 1,173,259 | 1,152,337 | | |

department studied was air conditioning, the proposed ESM chose the equipment that recorded the second-highest value. Based on Table 4 and Figure 1, the targeted equipment for energy-saving measures for MED, CED, EED, and CD has been identified. Table 5 shows the summary of error percentage values and the recommended ESM. The summary shows the results from a measured meter, energy audit, error percentage, and ESM recommended for the four involved departments. CED and EED findings are not different from the research work carried out by [49] mentioned; lighting and air conditioning are contributors and account for most power consumption in the office.

From the results in Table 5, the error percentage between measured and calculated value for MED, EED, and CD is less than 1%, but for CED, it 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 Guideline 14-2014, the International Performance Measurement and Verification Protocol (IPMVP), and Federal Energy Management Program (FEMP) [50].

*3.2. Feasibility Analysis of the Hybrid Solar Power Generation System.* The potential value of energy savings obtained by the PSAS academic building is calculated using a feasibility analysis on applying rooftop solar photovoltaic (PV) power generation standalone systems. Assuming the power generated by solar PV is connected to an ongrid system where the electricity generated is for its use first [49] before using the electricity from the ongrid system. Energy-saving (kWh) and bill saving (RM) per year for the academic buildings have been calculated. The annual energy savings, annual bill saving, and reduction of carbon emissions have been calculated as following the equations (3), (4), and (5) with focusing on three equipment that is laboratory equipment, lighting, and air conditioning. 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 [51]. 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 each academic building involved. The projection has been calculated for five years based on the energy supplied by solar PV starting 2020 to 2024 years. 2020 was when the COVID pandemic hit Malaysia, and the Movement Control Order (MCO) was enforced where all educational institutions were ordered to close. It causes the actual electricity consumption in PSAS to decrease quite significantly. Nevertheless, the energy-saving forecast for the next five years is calculated based on the 2019 baseline without considering the implementation of this MCO in 2020. Based on PSAS's geographical conditions, where it is located in hilly terrain and receives the sun's energy without obstacle, the most suitable renewable energy source to be utilized is solar PV. A feasibility analysis of solar power generation using a rooftop solar photovoltaic (PV) system known as a battery-equipped hybrid solar system has been carried out. Energy supply comes from solar, secondly, from a battery, and the last comes from a utility company (TNB). This research evaluates the feasibility analysis on a system that uses standard-size solar panels for industrial use with 430 $W/50\,V$. The PV solar panels used are of the monocrystalline solar module type. According to [52, 53], Malaysia's average peak sun hours are between 4.0 and 5.4 hours, depending on the location. Considering the rapid cloud movement and hot and humid conditions throughout the year in Malaysia, the average peak hours of sunlight peak hours in this research are calculated for 4 hours only. There are three main elements of the solar system analyzed: solar capacity, solar charger controller, and energy storage. Referring to Table 6, the total annual energy consumption for calculation value in MED is 325,860 kWh, which means the annual energy bill is RM118,950. The solar capacity to meet the required energy demand at MED is 226 kW per day when the solar irradiation hours is 4 hours. The solar energy panel performance cannot produce an energy supply of 100% efficiency in the actual implementation. Recent studies stated that panel solar PV efficiency achieves a maximum range of 80% [54, 55]. The maximum energy produced by solar panels to cover the energy demand in MED is 260,712 kWh if the efficiency is 80%. However, the efficiency of solar panels decreases from year to year and involves a certain period rather than occurring in a short period. Most solar panel PV module manufacturers guarantee a power drop in the module of not more than 20% within the warranty period [56]. Worldwide, most solar PV module manufacturers establish a warranty contract to their customers either 25

Table 6: Calculation of the number of solar PV panels to install in academic buildings based on a total load of each building.

| Department | Total load (kWh/year) | Total load (kWh/month) | Total load (kWh/day) | Solar capacity (kW) | Maximum total energy produced by solar panel efficiency 80% (kWh) | No. of a panel (100% run by solar) (pcs) | Total energy produced by solar panel: cover 25% of the whole load (kWh) | No. of a panel (25% run by solar) (pcs) |
|---|---|---|---|---|---|---|---|---|
| MED | 325890 | 27158 | 905.25 | 226 | 260712 | 526 | 81473 | 132 |
| CED | 159055 | 13255 | 441.82 | 110 | 127244 | 257 | 39764 | 64 |
| EED | 467460 | 38955 | 1298.5 | 325 | 373968 | 755 | 116865 | 189 |
| CD | 199932 | 16661 | 555.37 | 139 | 159946 | 323 | 49983 | 81 |

Table 7: Calculation for solar charger controller (inverter) and energy storage (battery) for solar system covers 25% of the total load.

| Department | Total energy produced by solar panel: cover 25% from total load (kWh/year) | Total load (kWh/month) | Total load (kWh/day) | Solar capacity (kWp) | Load inverter (kWp) | No. of battery (using for night only) (units) | Battery capacity (Ah) | No. of panel solar (units) | No. of inverter (units) |
|---|---|---|---|---|---|---|---|---|---|
| MED | 81473 | 6789 | 226.31 | 57 | 30 | 75 | 18859 | 36 | 2 |
| CED | 39764 | 3314 | 110.45 | 28 | 26 | 37 | 9205 | 17 | 1 |
| EED | 116865 | 9739 | 324.63 | 81 | 45 | 108 | 27052 | 51 | 3 |
| CD | 49983 | 4165 | 138.84 | 35 | 25 | 46 | 11570 | 22 | 1 |

years or 30 years [57]. Recent studies have reported that annual degradation rates are in the percentage range of 0.6%-0.7% [56, 58]. 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 only 2% degradation occurred for five years. Based on the calculation results shown in Table 6, the solar panel units are enormous if the solar energy supply needs to cover 100% of energy consumption. For example, MED requires 526 units of solar panels to be installed to cover the total energy consumption in this department. The MED rooftop does not have enough space to accommodate this amount of installation. Therefore, the goal of reducing energy consumption and energy bills by 25% can only be achieved by PSAS if the solar energy supplied to the academic building is 27% of the maximum capacity. This value is obtained after considering the factor of degradation in energy production for five years, which involves only 2%. The percentage represents the power supplied by solar PV (5%, 10.5%, 16%, 21.5%, and 27%) will gain for each year starting from 2020 to 2024. Table 6 shows that the calculation is based on 25% of the energy supply supplied by the solar PV system.

The analysis of the energy generated by the solar panels is calculated based on the objective to cover only 25% of a total load of each academic department involved. Solar capacity is calculated by dividing the whole load per day by 4 hours. The solar charger controller system used in this standalone solar power generation system is an inverter with maximum power point tracking (MPPT) controller type. The capacity of the hybrid inverter is 8 kW [59], where the inverter maximum power point (MPP) have two-channel MPPT where each channel can receive 5000 W with a maximum PV input voltage is 500 V (5000 W/500 V). One channel can support the output of 10 solar PV panels where each panel input is 50 V ($50\,V \times 10$ panels = 500 V). To ensure that the inverter specifications are matched to receive the power generated by the solar panel, a calculation of the number of inverters needs to be made. Each academic department's number of solar panels will be divided by 20 solar panels (2 MPPT channels).

Energy storage for this system uses lithium batteries (LifePO4), where the standard battery rating is 250 Ah at 12 V. The battery's power for 100% usage is 3 kWh, but in this analysis consume, 50% of the battery power is 1.5 k Wh. To calculate the number of batteries needed in this system, divide the total load per day by 1.5 kWh and divide by two cause batteries used for a night only. The battery capacity is calculated by multiplying the number of batteries by 250 Ah. The summary of calculation for solar charger controller (inverter) and energy storage (battery) for solar system covers 25% of the total load is shown in Table 7. Table 8 shows the value of actual energy consumption and target energy consumption reduction for five years from 2020 until 2024. It shows the expected value of energy consumption savings and energy bills earned for the next five years if the targeted savings are 5% each year. Within five years, the total reduction in energy consumption is 87,990 kWh, and the energy bill is RM32,116. The summary of annual energy saving and energy bill proportional to the percentage energy supplied by solar at MED, CED, EED, and CD is presented in Table 9. The results show that incrementing the total power provided by a solar will decrease energy consumption supplied by TNB and proportionally increase the amount of bill saving. The forecast for energy saving and bill saving has been calculated based on an increment of the percentage of solar PV energy supplied to academic buildings to ensure the reduction achieves the

Table 8: Value of actual energy consumption and targeted energy consumption reduction for five years from 2020 until 2024.

| Department | Actual energy consumption [2019] | | Targeted 5% reduction energy consumption (2020) | | Targeted 10% reduction energy consumption (2021) | | Targeted 15% reduction energy consumption (2022) | | Targeted 20% reduction energy consumption (2023) | | Targeted 25% reduction energy consumption (2024) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Annual energy consumption (kWh) | Annual energy bill (RM) | Annual energy consumption (kWh) | Annual energy bill (RM) | Annual energy consumption (kWh) | Annual energy bill (RM) | Annual energy consumption (kWh) | Annual energy bill (RM) | Annual energy consumption (kWh) | Annual energy bill (RM) | Annual energy consumption (kWh) | Annual energy bill (RM) |
| MED | 325,890 | 118,950 | 309,596 | 113,002 | 291,672 | 106,460 | 273,748 | 99,918 | 255,824 | 93,376 | 237,900 | 86,833 |
| CED | 159,055 | 58,055 | 151,102 | 55,152 | 142,354 | 51,959 | 133,606 | 48,766 | 124,858 | 45,573 | 116,110 | 42,380 |
| EED | 467,460 | 170,623 | 444,087 | 162,092 | 418,377 | 152,707 | 392,666 | 143,323 | 366,956 | 133,939 | 341,246 | 124,555 |
| CD | 199,932 | 72,975 | 189,935 | 69,326 | 178,939 | 65,313 | 167,943 | 61,299 | 156,947 | 57,286 | 145,950 | 53,272 |

Table 9: Summary of annual energy saving and energy bill proportional with percentage energy supplied by solar at MED, CED, EED, and CD.

| Department | Year | Percentage energy supplied by solar | Annual energy saving (kWh) | Annual bill saving (RM) |
|---|---|---|---|---|
| MED | 1 | 5.00% | 16,295 | 5,947 |
| | 2 | 10.50% | 34,218 | 12,490 |
| | 3 | 16.00% | 52,142 | 19,032 |
| | 4 | 21.50% | 70,066 | 25,574 |
| | 5 | 27.00% | 87,990 | 32,116 |
| CED | 1 | 5.00% | 7,953 | 2,903 |
| | 2 | 10.50% | 16,701 | 6,096 |
| | 3 | 16.00% | 25,449 | 9,289 |
| | 4 | 21.50% | 34,197 | 12,482 |
| | 5 | 27.00% | 42,945 | 15,675 |
| EED | 1 | 5.00% | 23,373 | 8,531 |
| | 2 | 10.50% | 49,083 | 17,915 |
| | 3 | 16.00% | 74,794 | 27,300 |
| | 4 | 21.50% | 100,504 | 36,684 |
| | 5 | 27.00% | 126,214 | 46,068 |
| CD | 1 | 5.00% | 9,997 | 3,649 |
| | 2 | 10.50% | 20,993 | 7,662 |
| | 3 | 16.00% | 31,989 | 11,676 |
| | 4 | 21.50% | 42,985 | 15,690 |
| | 5 | 27.00% | 53,982 | 19,703 |

Table 10: Emission reduction at a certain percentage of energy supplied by solar to MED, CED, EED, and CD using an off-grid system.

| Department | Percentage energy supplied by solar | Annual energy saving (kWh) | Emission reduction (kg) | | |
|---|---|---|---|---|---|
| | | | $CO_2$ | $SO_2$ | CO |
| MED | 5.00% | 16,295 | 11,984 | 101 | 49 |
| | 10.50% | 34,218 | 25,166 | 212 | 104 |
| | 16.00% | 52,142 | 38,348 | 323 | 158 |
| | 21.50% | 70,066 | 51,530 | 434 | 213 |
| | 27.00% | 87,990 | 64,712 | 545 | 267 |
| CED | 5.00% | 7,953 | 5,849 | 49 | 24 |
| | 10.50% | 16,701 | 12,283 | 103 | 51 |
| | 16.00% | 25,449 | 18,716 | 158 | 77 |
| | 21.50% | 34,197 | 25,150 | 212 | 104 |
| | 27.00% | 42,945 | 31,584 | 266 | 130 |
| EED | 5.00% | 23,373 | 17,190 | 145 | 71 |
| | 10.50% | 49,083 | 36,098 | 304 | 149 |
| | 16.00% | 74,794 | 55,007 | 463 | 227 |
| | 21.50% | 100,504 | 73,916 | 622 | 305 |
| | 27.00% | 126,214 | 92,824 | 781 | 383 |
| CD | 5.00% | 9,997 | 7,352 | 62 | 30 |
| | 10.50% | 20,993 | 15,439 | 130 | 64 |
| | 16.00% | 31,989 | 23,526 | 198 | 97 |
| | 21.50% | 42,985 | 31,613 | 266 | 130 |
| | 27.00% | 53,982 | 39,701 | 334 | 164 |

minimum value by 5%. This value is related to the Malaysian Polytechnic POLYGreen Blueprint [2]. All the polytechnic institutions need to reduce their utility costs by at least 5% per year.

*3.3. Emission Reduction.* Installing rooftop solar PV can save total energy consumption in an academic building in 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 reduction of carbon emission for MED, CED, EED, and CD has been calculated using equation (5) and annual energy savings data from Table 8, shown in Table 9. The energy produced by solar PV is equal to energy-saving obtained by departments. Table 10 summarizes the reduced emissions when solar energy is used to power off-grid systems for MED, CED, EED, and CD. Based on Table 10, within five years, 191,740 kg of $CO_2$, 93,582 kg of $CO_2$, 275,035 kg of $CO_2$, and 117,632 kg of $CO_2$, respectively, representing MED, CED, EED, and CD, were successfully reduced from being released into the air. In other words, within five years, the use of hybrid solar systems that supply 25% of the total electricity to the four departments studied was 677,989 kg of CO or 677.989 tonnes of $CO_2$ [60]. The 677.989 tonnes of $CO_2$ is equivalent to 16,950 mature trees saved from felling. This calculation is based on the value of 1 ton of unabsorbed $CO_2$ equivalent to 25 mature trees felled.

## 4. Conclusion

Based on the analysis, it is found that the total estimation of annual energy consumption in the four main academic buildings in PSAS is about 1,152,337 kWh, and the annual bill is RM420,603. The analysis of energy consumption per equipment gives the certainty and right direction to implement effective strategies for reducing energy usage while creating energy savings through data from an energy audit. The energy consumption analysis per equipment conducted in MED, CED, EED, and CD recorded the different energy-consuming patterns. The research found that the air conditioning was the highest energy consumer for MED, CED, EED, and CD, where systems significantly impact building energy consumption. The study confirmed that the laboratory equipment is the second-highest energy consumer in 3 of 4 academic buildings at PSAS except for CD. The estimation of energy consumption per year is about 325,890 kWh, 159,055 kWh, 467,460, and 199,932 kWh while energy bill per year is about RM118,950, RM58,055, RM170,623, and 72,975. The feasibility analysis found that for the next five years, from 2020 until 2024, the total reduction in energy consumption at four academic buildings is 311,131 kWh, and the energy bill is RM113,563.

Installed buildings with rooftop solar PV can save many greenhouse gas emissions. Within five years, 191,740 kg of $CO_2$, 93,582 kg of $CO_2$, 275,035 kg of $CO_2$, and 117,632 kg of $CO_2$, respectively, representing MED, CED, EED, and CD, were successfully reduced from being released into the air. In other words, within five years, the use of hybrid solar systems that supply 25% of the total electricity to the four departments studied was 677,989 kg of CO or 677.989 tonnes of $CO_2$. The 677.989 tonnes of $CO_2$ are equivalent to 16,950 mature trees saved from felling. This calculation is based on the value of 1 ton of unabsorbed $CO_2$ equivalent to 25 mature trees felled. The analysis proves that $CO_2$ reduction is strongly associated with installing clean energy generation through the hybrid solar system at PSAS. For future work, the feasibility analysis using hybrid solar PV for PSAS will refer to a Net Energy Metering (NEM 3.0) mechanism known as NEM GoMEn. NEM 3.0 is the latest initiative offered by the Malaysian government to increase the percentage of renewable energy consumption on government premises.

## Nomenclature

ACSU: Air-cooled split unit
$CO_2$: Carbon dioxide
SO: Carbon monoxide
WCPU: Centralized water-cooled package unit
CED: Civil Engineering Department
CT: Cooling tower
CD: Commerce Department
DSM: Demand-side management
EED: Electrical Engineering Department
EMS: Energy monitoring system
ESM: Energy saving measure
FEMP: Federal Energy Management Program
DPM: Fixed digital power meter
GHGs: Greenhouse gases
GDP: Gross domestic product
hp: Horsepower
HOMER: Hybrid optimization model for multiple energy resources
ICT: Information, communication technology
IPMVP: International Performance Measurement and Verification Protocol
kW: Kilowatt
kWh: Kilowatt-hour
$LifePO_4$: Lithium batteries
MPP: Maximum power point
MPPT: Maximum power point tracker
MS: Malaysian standard
MED: Mechanical Engineering Department
MH: Metal halide
MEPS: Minimum energy performance standards
MCO: Movement control order
PV: Photovoltaic
PSAS: Politeknik Sultan Azlan Shah
R&D: Research and development
SSB: Subswitch board
$SO_2$: Sulfur dioxide
TNB: Tenaga Nasional Berhad.

## Data Availability

Data are included in the main text as summarised form.

## Conflicts of Interest

The authors declare that there are no conflicts of interest in the manuscript.

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## References

[1] *National Energy Balance 2015*, Suruhanjaya Tenaga (Energy Commission), Putrajaya, Malaysia, 2015.

[2] "BluePrint POLYGreen politeknik Malaysia," 2015, https://www.mypolycc.edu.my/index.php.

[3] M. Shaaban, W.-S. Tan, and M. P. Abdullah, "A hybrid renewable energy system for a longhouse," *ELEKTRIKA-Journal of Electrical Engineering*, vol. 16, no. 3, pp. 23–29, 2017.

[4] A. Alajmi, "Energy audit of an educational building in a hot summer climate," *Energy and Buildings*, vol. 47, pp. 122–130, 2012.

[5] A. Escobedo, S. Briceño, H. Juárez, D. Castillo, M. Imaz, and C. Sheinbaum, "Energy consumption and GHG emission scenarios of a university campus in Mexico," *Energy for Sustainable Development*, vol. 18, pp. 49–57, 2014.

[6] M. F. M. Zublie, M. Hasanuzzaman, and N. A. Rahim, "Energy saving potential through energy conservation of office equipment in Malaysia polytechnic," in *5th IET International Conference on Clean Energy and Technology (CEAT2018)*, pp. 1–5, Kuala Lumpur, 2018.

[7] M. W. Akram, M. Hasannuzaman, E. Cuce, and P. M. Cuce, "Global technological advancement and challenges of glazed window, facade system and vertical greenery-based energy savings in buildings: a comprehensive review," *Energy and Built Environment*, vol. 4, no. 2, pp. 206–226, 2023.

[8] M. A. Habib, M. Hasanuzzaman, M. Hosenuzzaman, A. Salman, and M. R. Mehadi, "Energy consumption, energy saving and emission reduction of a garment industrial building in Bangladesh," *Energy*, vol. 112, pp. 91–100, 2016.

[9] A. Roslizar, M. Alghoul, B. Bakhtyar, N. Asim, and K. Sopian, "Annual energy usage reduction and cost savings of a school: End-use energy analysis," *The Scientific World Journal*, vol. 2014, Article ID 310539, 8 pages, 2014.

[10] D. Kaya and H. Alidrisi, "Energy savings potential in air conditioners and chiller systems," *Turkish Journal of Electrical Engineering & Computer Sciences*, vol. 24, no. 3, pp. 935–945, 2016.

[11] L.-G. Giraudet and A. Missemer, *The Economics of Energy Efficiency, a Historical Perspective*, Working Papers halshs-02301636, HAL, 2019.

[12] P. L. Joskow and D. B. Marron, "What does a negawatt really cost? Evidence from utility conservation programs," *The Energy Journal*, vol. 13, no. 4, 1992.

[13] S. Srinivasan, R. Mosdale, P. Stevens, and C. Yang, "FUEL-CELLS: reaching the era of clean and efficient power

generation in the twenty-first century," *Annual Review of Energy and the Environment*, vol. 24, no. 1, pp. 281–328, 1999.

[14] J. G. Koomey, H. Scott Matthews, and E. Williams, "Smart everything: will intelligent systems reduce resource use?," *Annual Review of Environment and Resources*, vol. 38, no. 1, pp. 311–343, 2013.

[15] Y. D. Kononov, "Impact of economic restructuring on energy efficiency in the USSR," *Annual Review of Energy*, vol. 15, no. 1, pp. 505–512, 1990.

[16] R. Friedmann and C. Sheinbaum, "Mexican electric end-use efficiency: experiences to date," *Annual Review of Energy and the Environment*, vol. 23, no. 1, pp. 225–252, 1998.

[17] L. Schipper, R. B. Howarth, and H. Geller, "United States energy use from 1973 to 1987: the impacts of improved efficiency," *Annual Review of Energy*, vol. 15, no. 1, pp. 455–504, 1990.

[18] M. A. Islam, M. Hasanuzzaman, N. A. Rahim, A. Nahar, and M. Hosenuzzaman, "Global renewable energy-based electricity generation and smart grid system for energy security," *The Scientific World Journal*, vol. 2014, Article ID 197136, 13 pages, 2014.

[19] W. F. Lamb, T. Wiedmann, J. Pongratz et al., "A review of trends and drivers of greenhouse gas emissions by sector from 1990 to 2018," *Environmental Research Letters*, vol. 16, no. 7, 2021.

[20] H. C. Granade, J. Creyts, A. Derkach, P. Farese, S. Nyquist, and K. Ostrowski, *Unlocking Energy Efficiency in the US Economy*, McKinsey & Company, 2009.

[21] I. M. Azevedo, "Consumer end-use energy efficiency and rebound effects," *Annual Review of Environment and Resources*, vol. 39, no. 1, pp. 393–418, 2014.

[22] B. A. Thomas and I. L. Azevedo, "Estimating direct and indirect rebound effects for U.S. households with input- output analysis part 1: theoretical framework," *Ecological Economics*, vol. 86, pp. 199–210, 2013.

[23] B. A. Thomas and I. L. Azevedo, "Should policy-makers allocate funding to vehicle electrification or end-use energy efficiency as a strategy for climate change mitigation and energy reductions? Rethinking electric utilities efficiency programs," *Energy Policy*, vol. 67, pp. 28–36, 2014.

[24] Malaysia Energy Commission, "Peninsular Malaysia electricity supply industry outlook," Tech. Rep., Malaysia Energy Commission, 2013.

[25] J. Lofthouse, R. T. Simmons, and R. M. Yonk, *Reliability of Renewable Energy: Solar*, Institute of Political Economy, Utah-State University, 2015.

[26] H. S. Das, C. W. Tan, A. Yatim, and K. Y. Lau, "Feasibility analysis of hybrid photovoltaic/battery/fuel cell energy system for an indigenous residence in East Malaysia," *Renewable and Sustainable Energy Reviews*, vol. 76, pp. 1332–1347, 2017.

[27] F. Rinaldi, F. Moghaddampoor, B. Najafi, and R. Marchesi, "Economic feasibility analysis and optimization of hybrid renewable energy systems for rural electrification in Peru," *Clean Technologies and Environmental Policy*, vol. 23, no. 3, pp. 731–748, 2021.

[28] M. Zublie, M. Hasanuzzaman, and N. Rahim, "Feasibility analysis of rooftop solar photovoltaic for non-academic building in an educational institution in Malaysia," *IOP Conference Series: Earth and Environmental Science*, vol. 673, no. 1, article 012005, 2021.

[29] M. F. M. Zublie, M. Hasanuzzaman, and N. A. Rahim, "Feasibility analysis of solar power generation system for office building in academic institution," *IOP Conference Series: Materials Science and Engineering*, vol. 1127, no. 1, article 012039, 2021.

[30] R. Gugulothu, N. S. Somanchi, H. B. Banoth, and K. Banothu, "A review on solar powered air conditioning system," *Procedia Earth and Planetary Science*, vol. 11, pp. 361–367, 2015.

[31] A. Al-Ugla, M. El-Shaarawi, S. Said, and A. Al-Qutub, "Techno-economic analysis of solar-assisted air-conditioning systems for commercial buildings in Saudi Arabia," *Renewable and Sustainable Energy Reviews*, vol. 54, pp. 1301–1310, 2016.

[32] M. Goldsworthy, "Building thermal design for solar photovoltaic air-conditioning in Australian climates," *Energy and Buildings*, vol. 135, pp. 176–186, 2017.

[33] K. S. Al Qdah, "Performance of solar-powered air conditioning system under AlMadinah AlMunawwarah climatic conditions," *Smart Grid and Renewable Energy*, vol. 6, no. 7, pp. 209–219, 2015.

[34] *General Circular No. 2 of 2014: Guidelines on Energy Saving Methods at Government Offices and Premises*, General of Public Service Malaysia, 2014.

[35] "SmartGreen polytechnic community college 2021-2026," https://smartgreen.mypolycc.edu.my/v1/.

[36] M. Paucar, P. Amancha, E. Viera, T. San Antonio, and D. Salazar, "Implementation of a methodology to perform an energy audit with academic purpose," *International Journal of Applied Engineering Research*, vol. 12, no. 24, pp. 14908–14913, 2017.

[37] A. Kumar, S. Ranjan, M. B. K. Singh, P. Kumari, and L. Ramesh, "Electrical energy audit in residential house," *Procedia Technology*, vol. 21, pp. 625–630, 2015.

[38] R. Saidur, N. Rahim, H. H. Masjuki, S. Mekhilef, H. Ping, and M. Jamaluddin, "End-use energy analysis in the Malaysian industrial sector," *Energy*, vol. 34, no. 2, pp. 153–158, 2009.

[39] Energy Commission, *Malaysia Energy Statistics Handbook*, Suruhanjaya Tenaga (Energy Commission), Putrajaya, Malaysia, 2017.

[40] R. Saidur, M. Hasanuzzaman, S. Yogeswaran, H. Mohammed, and M. Hossain, "An end-use energy analysis in a Malaysian public hospital," *Energy*, vol. 35, no. 12, pp. 4780–4785, 2010.

[41] R. Saidur, "Energy consumption, energy savings, and emission analysis in Malaysian office buildings," *Energy Policy*, vol. 37, no. 10, pp. 4104–4113, 2009.

[42] T. N. Berhad and TNB, "Electricity pricing and tariffs rates," 2017, https://www.tnb.com.my/commercial-industrial/pricing-tariffs1/#commercial-tariffs.

[43] M. Balbis-Morejón, J. J. Cabello-Eras, J. M. Rey-Hernández, and F. J. Rey-Martínez, "Energy evaluation and energy savings analysis with the 2 selection of AC Systems in an educational building," *Sustainability*, vol. 13, no. 14, p. 7527, 2021.

[44] A. Almogbel, F. Alkasmoul, Z. Aldawsari, J. Alsulami, and A. Alsuwailem, "Comparison of energy consumption between non-inverter and inverter-type air conditioner in Saudi Arabia," *Energy Transitions*, vol. 4, no. 2, pp. 191–197, 2020.

[45] S. B. M. Ali, M. Hasanuzzaman, N. Rahim, M. Mamun, and U. Obaidellah, "Analysis of energy consumption and potential energy savings of an institutional building in Malaysia," *Alexandria Engineering Journal*, vol. 60, no. 1, pp. 805–820, 2021.

[46] I. Sarbu and M. Adam, "Investigation of the energy efficiency of conventional air-conditioning systems in office buildings," *Advances in Energy Research*, vol. 23, pp. 161–196, 2016.

[47] M. W. Akram, M. F. Mohd Zublie, M. Hasanuzzaman, and N. A. Rahim, "Global prospects, advance technologies and policies of energy-saving and sustainable building Systems: A Review," *Sustainability*, vol. 14, no. 3, p. 1316, 2022.

[48] Z. Shang, D. Gao, Z. Jiang, and Y. Lu, "Towards less energy intensive heavy-duty machine tools: power consumption characteristics and energy-saving strategies," *Energy*, vol. 178, pp. 263–276, 2019.

[49] S. Rodrigues, R. Torabikalaki, F. Faria et al., "Economic feasibility analysis of small scale PV systems in different countries," *Solar Energy*, vol. 131, pp. 81–95, 2016.

[50] G. R. Ruiz and C. F. Bandera, "Validation of calibrated energy models: common errors," *Energies*, vol. 10, no. 10, p. 1587, 2017.

[51] W. H. Libunao and C. J. Peter, "Education for sustainable development practices among polytechnics in Malaysia," in *Proceeding of the International Conference on Social Science Research, ICSSR 2013*, Penang, Malaysia, 2013.

[52] "(PITECH), P.I.T. 4 types of solar system in Malaysia that actually work," 2020, https://pitech.com.my/types-of-solar-system-in-malaysia/.

[53] TNBX, "3 easy steps to estimate solar size," 2020, https://www.tnbx.com.my/post/3-easy-steps-to-estimate-solar-size.

[54] J. Kamanzi and M. Sibanda, "Study and modelling of factors drivingthe performance of solar modules," *Engineering*, vol. 7, no. 3, pp. 333–360, 2017.

[55] N. H. Muslim, S. A. Ghadhban, and K. H. Hilal, "Enhancement of solar photovoltaic module performance by using a water-cooling chamber for climatic conditions of Iraq," *International Journal of Renewable Energy Research (IJRER)*, vol. 10, no. 3, pp. 1103–1110, 2020.

[56] A. Virtuani, M. Caccivio, E. Annigoni et al., "35 years of photovoltaics: analysis of the TISO-10-kW solar plant, lessons learnt in safety and performance—part 1," *Progress in Photovoltaics: Research and Applications*, vol. 27, no. 4, pp. 328–339, 2019.

[57] J. A. Tsanakas, L. Ha, and C. Buerhop, "Faults and infrared thermographic diagnosis in operating c-Si photovoltaic modules: a review of research and future challenges," *Renewable and Sustainable Energy Reviews*, vol. 62, pp. 695–709, 2016.

[58] J. E. F. da Fonseca, F. S. de Oliveira, C. W. M. Prieb, and A. Krenzinger, "Degradation analysis of a photovoltaic generator after operating for 15 years in southern Brazil," *Solar Energy*, vol. 196, pp. 196–206, 2020.

[59] M. A. G. de Brito, M. G. Alves, and C. A. Canesin, "Hybrid MPPT solution for double-stage photovoltaic inverter," *Journal of Control, Automation and Electrical Systems*, vol. 30, no. 2, pp. 253–265, 2019.

[60] "Climate change connection. CO2 equivalents," 2022, https://climatechangeconnection.org/emissions/co2-equivalents/.