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Energy Consumption, Energy Analysis, and Solar Energy Integration for Commercial Building Restaurants

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Abstract: In the domain of energy consumption in restaurant-type commercial buildings, traditional energy audits tend to concentrate mainly on electrical loads, often neglecting the specifics of the restaurant sector, especially regarding liquified petroleum gas fuel consumption. This research employs a comprehensive energy audit framework specifically designed for the commercial building restaurant sector. Using energy data from 130 restaurants, we computed the building energy index that ranged in between 650 and 1000 kWh/m^2/year. Using linear regression, we assessed the relationship between building energy index and restaurant area, uncovering a low R^2 value, suggesting the unsuitability of the building energy index as an exclusive measure for restaurants. Concurrently, our detailed comparative study showed that liquified petroleum gas-fueled equipment uses about 38% more energy than electric fueled equipment but is 0.5% cheaper and significantly less polluting. Investigating renewable energy potentials, we found solar PV application as a viable option for restaurants. The results showed that solar PV installation could produce approximately 11,064,898 kWh, translating to utility savings of RM 7,381,929 and reductions of 7,108,327 kgCO_2, 68,959 kgSO_2, and 31,823 kgCO emissions. Conclusively, our findings underline the need for a diversified energy assessment in restaurants and the tangible benefits of renewable energy integration.

Keywords: energy audit; energy analysis; solar energy; restaurants; commercial building; building energy index

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1. Introduction

The rapid urbanization of the 21st century has brought with it a surge in commercial infrastructure [1]. Among these, restaurants, with their extended operating hours and specific energy needs, stand out as significant consumers of energy [2]. However, despite their substantial footprint, energy consumption in restaurants often goes unchecked or under-optimized. An energy audit is a systematic evaluation of a building, facility, or system's energy consumption and efficiency [3]. Its main objectives are to pinpoint areas of energy wastage, recommend strategies to enhance energy efficiency, decrease energy costs, and reduce the environmental ramifications of energy utilization [4,5]. Energy audits for buildings are classified into three distinct levels:

- Level 1: This basic type of energy audit, often called a walk-through audit, involves a visual inspection of the building or system to pinpoint evident inefficiencies and areas where energy consumption can be optimized. The process typically includes a review of energy bills, utility rates, and past energy consumption data to establish a baseline for energy usage [4].

- Level 2: Going beyond a walk-through, this audit delves deeper into energy consumption patterns. It includes a detailed inspection of the building's envelope, lighting systems, HVAC systems, water heating systems, and other energy-intensive equipment [4,6,7]. Its key components are:
    - Thorough data analysis, including energy usage patterns and potential demand-reduction strategies.
    - Evaluation of energy and cost savings for specific ECMs, such as lighting upgrades or insulation improvements.
    - Preliminary financial analysis of the proposed ECMs, including estimates of the payback period and return on investment.
    - A detailed report summarizing findings, proposed ECMs, anticipated energy and cost savings, and an implementation plan [8].
- Level 3: This is the most extensive type of energy audit. It comprises detailed engineering calculations, energy simulation models, and a tailored energy management plan [9–11]. Key components include:
    - Comprehensive data collection and analysis, encompassing interval meter data, weather-normalized energy consumption, and benchmarking against comparable buildings.
    - In-depth financial analysis of the suggested ECMs, with evaluations such as life-cycle cost analysis, net present value, and internal rate of return to assess the long-term fiscal advantages [5].

Table 1 presents the literature review of researchers using the above established energy audit methodology to evaluate a building's energy consumption, efficiency, and the relevant potential ECMs.

Table 1. Review of the methodology used for an energy audit.

Method of Analysis	Reference
Energy and emission analysis for industrial motors in Malaysia were analyzed. The number of motors used in 5% of the surveyed industry was audited. The savings obtained by replacing the existing motors with VSD, HEM, payback period, and emission reduction were mathematically analyzed.	[12]
Energy consumption, energy savings, and emission analysis in Malaysian office buildings are examined. The energy-saving calculation is performed by application of CFL, temperature adjustment on air conditioning, advanced glazing, and housekeeping. Estimations of energy savings by using HEM and VSD were performed. Emission reduction and payback estimation by using the energy savings were calculated.	[13]
End-use energy in a Malaysian public hospital was investigated. It was found that most of the energy consumption was by motors. Estimations of energy savings by using a mathematical approach for HEM, and VSD for motors, were performed. Emission reduction, bill savings, and payback period were also calculated.	[14]
Energy use, energy savings, and emission analysis in the Malaysian rubber producing industries were conducted. It was found that the highest percentage of energy usage is by motors. Estimations of energy savings by using a mathematical approach for high-efficiency motors and variable speed drives for motors were performed. Emission reduction, bill savings, and payback period were also calculated.	[15]
Chillers' energy consumption, energy savings, and emission analysis in an institutional building were studied. Estimations of energy savings using the calculation for variable speed drives used for pumps, motors, and chillers were performed. Bill savings and payback period are also calculated and reported.	[16]
Energy management strategies for a governmental building in Oman were investigated. The collected data were calibrated and re-simulated to match the real-time energy consumption. The calibrated data were then used to obtain and identify energy-saving opportunities on building envelope, lighting, and air conditioning temperature set point.	[11]
Studies on daylight factor and lighting zoning were conducted using a model structure. These studies were specifically to investigate the transitional space used for architecture and the impact on the daylight factor by using natural light. The overall energy savings obtained = 15.7%.	[17]
An in-depth energy assessment was carried out to examine the energy usage trends and identify possible energy-saving measures in the Research and Development (R&D) facility at Universiti Malaya. It was categorized into eight distinct equipment types for analysis, and the outcomes were cross-referenced with the building's utility statements. Switching to LED lighting led to substantial energy and cost reductions, with a return on investment in roughly one year.	[18]

Based on the reviews presented in Table 1, it is evident that specific research on commercial restaurant buildings has not been conducted. Moreover, most assessment applies the traditional energy audit methods that have typically been compartmentalized, focusing on individual elements like air conditioning systems, lighting, or other integral components that use electricity. While such methods provide valuable insights, they sometimes miss the broader picture, specifically the interplay and synergies between different energy-consuming components, especially within a restaurant's complex ecosystem.

In addition to that, as the global community pushes towards more sustainable practices, there is an urgent need for standardized metrics that can benchmark and monitor energy performance. The BEI, a promising metric that quantifies a building's energy efficiency, has been applied to various commercial sectors [18,19]. In recent years, Malaysia has seen a growing adoption of the BEI as the government aims to boost energy efficiency and curtail energy usage in structures. The BEI has become a popular tool, especially in the commercial and industrial domains, which are traditionally high energy consumers. With a vision to meet its energy and environmental targets, the government is actively advocating for the incorporation of BEI and other energy-conserving practices in building design and management [20,21]. While the MS1525:2007 guideline suggests that the BEI for buildings should not exceed 135 kWh/m^2/year, it seems to overlook the diverse building types present in Malaysia, casting doubts on the comprehensiveness of the data [18,22]. The aforementioned BEI value might be fitting for structures like offices, institutional buildings, governmental spaces, and hospitals [18,22,23]. However, it does not factor in buildings in Malaysia with uninterrupted operations, such as restaurants. Accordingly, its applicability and effectiveness in the unique context of restaurants commercial building remain underexplored.

Food, being fundamental to life, has led to a rising demand for restaurants, paralleling the growth of the global population [2]. The proliferation of easily accessible restaurants has become a noteworthy trend in recent times [24–26]. Nowadays, restaurants can be found in various commercial settings, including shopping malls, shopfronts, transport hubs, and gas station alliances, and as standalone entities. Due to the extensive use of thermal energy required for cooking and maintaining hygienic food preparation standards, these establishments have high energy consumption rates [2]. One promising solution to mitigate this consumption is the adoption of solar energy. While many studies have explored the potential of solar energy in different commercial buildings [27–31], there remains a gap in addressing the unique challenges associated with integrating solar energy specifically into diverse restaurant formats within commercial structures.

Recognizing these gaps, this research aims to introduce a holistic framework for energy audits, one that takes into account the comprehensive energy consumption landscapes of restaurants alongside delving into the BEI for such establishments, exploring its potential as a reliable and interpretable metric. In addition to that, the prospects of solar energy integration into various commercial buildings are presented in detail. Through this research, we aspire to provide restaurant owners, policymakers, and building designers with an integrated toolset for better energy management, aligning commercial success with environmental responsibility.

2. Methodology

2.1. Data Collection Procedure

A walk-through audit was conducted in 130 fast food restaurants across Malaysia, each with an average gross floor area of 4651 square feet. The audit adhered to the standard energy audit protocol, a methodology frequently employed by researchers, as summarized in Table 1.

Each building typically features a ground floor with a kitchen, an indoor air conditioned dining area, and an outdoor dining space with mechanical ventilation. The kitchen stands as the focal point of the restaurant, serving as the hub for live food production. For the purposes of this study, the primary emphasis is on the kitchen. Despite variations in kitchen layout depending on the building's architecture among the 130 audited restaurants, the types and quantities of kitchen equipment remained consistent across all establishments. Table 2 enumerates the specific equipment types and their corresponding quantities.

Table 2. The number of kitchen equipment, quantity, and energy type in restaurant.

Equipment	Qty	Energy	Equipment	Qty	Energy
Grill (2 Platen)	2	Electric/LPG	Rice Cooker	3	Electric
Chicken Fryers	3	Electric/LPG	Portable Chiller	2	Electric
4 Split Vat Fryers	1	Electric/LPG	Portable Freezer	2	Electric
3 Full Vat Fryers	1	Electric/LPG	Meat Freezer	1	Electric
Holding Cabinet	2	Electric	Heat Treat Machine	2	Electric
Freezer	1	Electric	APD Machine	1	Electric
Cooler	1	Electric	Pie Counter	1	Electric
Water Heater	1	Electric	Coffee Machine	1	Electric
Beverage Station	1	Electric	Ice Cream Blender	1	Electric
Bagging Station	1	Electric	Juice dispenser	1	Electric
Ice Machine	2	Electric	Bun steamer	2	Electric
Soda Factory	1	Electric	Universal Holding Cabinet	2	Electric
Preparation Table	1	Electric			

From Table 2, it is evident that four specific pieces of equipment in the restaurant can operate on different energy sources: the Grill 2 Platen, Chicken Fryers, 4 Split Vat Fryers, and 3 Full Vat Fryers. This distinction indicates the presence of two kitchen types in fast food restaurants:

- Electric Kitchen: All equipment operates solely on electrical energy.
- Gas Kitchen: While most equipment runs on electricity, four pieces specifically (as mentioned above) can also operate using LPG.

Notably, the Grill 2 Platen displays a unique energy configuration. As illustrated in Figure 1b, the lower platen can be powered by either LPG or electricity. In contrast, the upper platen, often referred to as the clamshell, exclusively uses electrical energy. This dual-energy source for the Grill 2 Platen is pivotal, given that both forms of energy will be evaluated in the context of this equipment. Meanwhile, equipment such as the 3 Full Vat Fryers (Figure 1a), 4 Split Vat Fryers (Figure 1c), and Chicken Fryers (Figure 1d) primarily use LPG, though they require a minimal amount of electrical energy to operate their programmable boards. Given their central roles in cooking main dishes in these restaurants, the study will predominantly focus on analyzing the energy consumption and efficiency of these specific pieces of equipment.

2.2. Business Operating Hours

Conversations with the staff and managers of the surveyed restaurants revealed that they operated for a span of 20 h daily, starting from 6 am and closing at 2 am. Furthermore, according to their internal guidelines, an intensive 8 h cleaning and preventive maintenance session was mandated only twice a month. When calculated annually, this amounted to 1556 non-operational hours. Consequently, the establishment functioned for 7204 h each year, equivalent to 360.2 operational days annually.

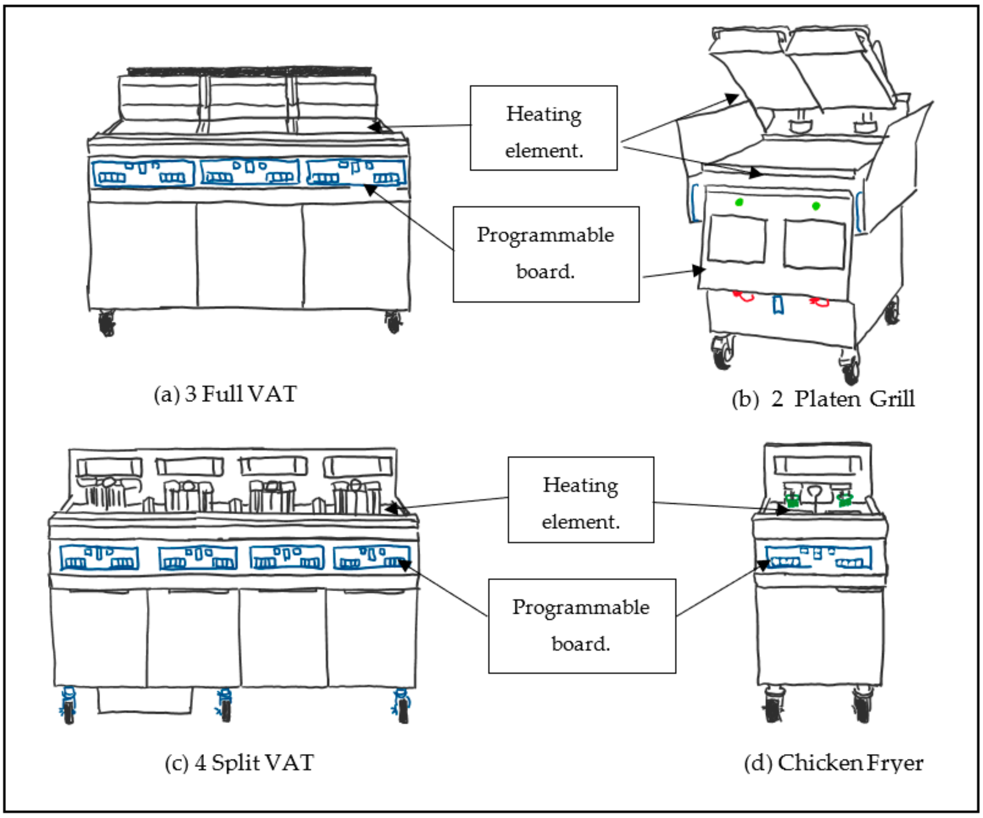


Figure 1. Sketch of the equipment.

2.3. Equipment Operation Hours

The operational hours of the equipment did not always align with the restaurant's business hours. This discrepancy was due to the specific roles and utilization frequencies of different equipment. For instance, lighting, fans, and air conditioning systems ran continuously during both business hours and maintenance activities to ensure that the crew had proper lighting and ventilation. Essential devices, including freezers, chillers, multiplexers, ice machines, heat treat machines, and water heaters, functioned both during business and non-business hours. Their operation was crucial to maintain certain standards, such as the temperature of raw ingredients, hot water storage tank temperatures, ice supply, and product quality preservation. For instance, the compressor in a walk-in cold room exhibited varied energy consumption. Its energy use fluctuated since the compressor cut off once the set-point temperature was reached. A comprehensive breakdown of the equipment's operational hours was elaborated upon in the subsequent sections.

2.4. Energy Audit Framework for Restaurants Commercial Building

Given the absence of a well-defined methodology for energy audits in commercial building restaurants, the proposed energy audit framework, which is tailored for such buildings, is illustrated in Figures 2 and 3, respectively.

From Figures 2 and 3, firstly, the building information needs to be gathered, such as building footprint, business operation hours, and precise zone functions. These are as described in Section 2.1 via a walk-through audit. Next, the equipment fuel type and equipment manufacturer's data sheet need to be studied accordingly. Following that, the relevant analysis is perform using mathematical formulation as presented in Section 2.7, respectively.

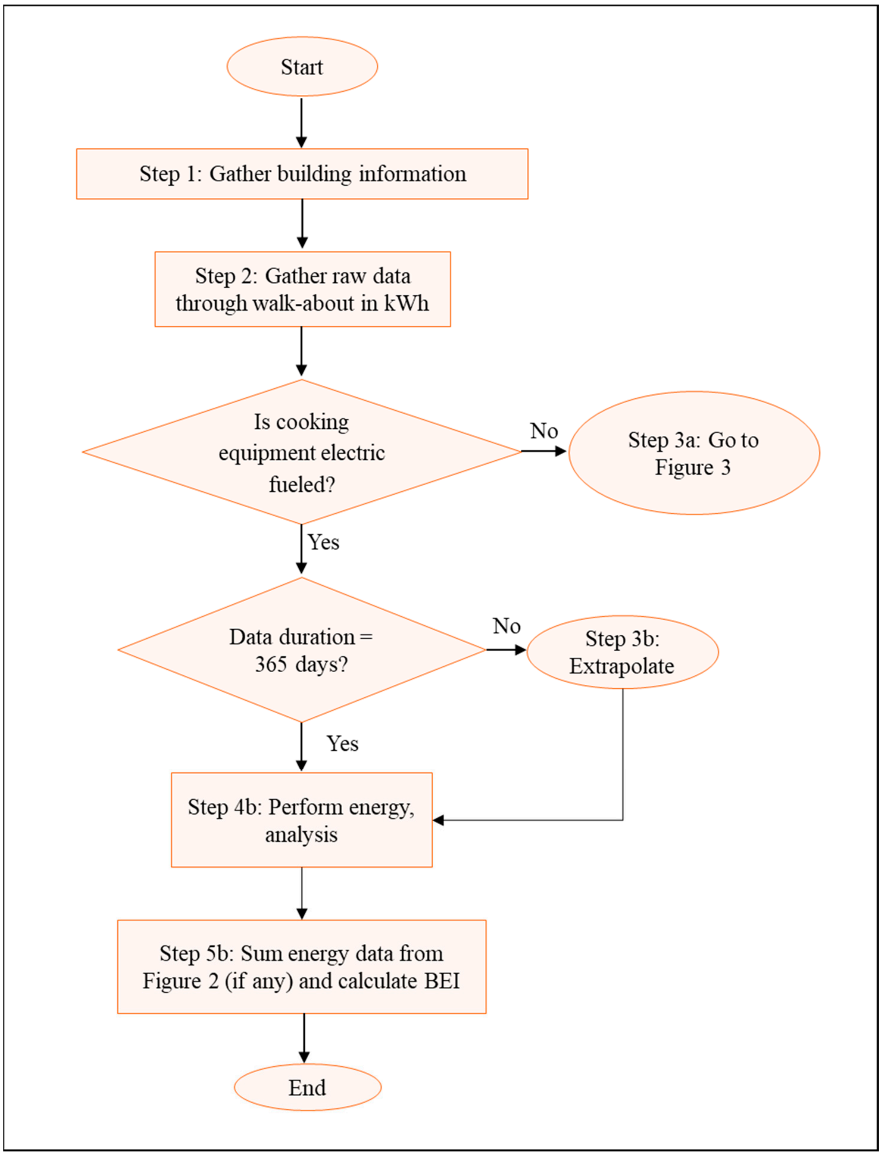


Figure 2. Proposed energy audit framework for restaurants.

2.5. Building Energy Index Data and Formulation

The audited building consists of various restaurant building types, such as transport hub, mall, shopfront, and standalone drive-through. Even though the electrical loads applied in the restaurants are identical, the quantity and utilization of the appliances vary according to restaurant building types. For example, restaurants in mall and transport hubs utilize the air conditioning system from the servicing building via the chill water system. In contrast, shopfronts and standalone building air conditioning systems are self-provided and use electricity. On the other hand, the quantity of lighting for all types of buildings accordingly vary based on the restaurant's size. The aim of this study is to identify the interpretability of BEI for restaurants in comparison to the established BEI for a commercial building, which is 135 kWh/m^2/y. Energy consumption for a total of 130 restaurants is being analyzed for BEI. Analyzed restaurant energy is present in various buildings. The breakdown of the number of restaurants data as per building type is:

- Transport hub = 7
- Mall = 35
- Shopfront = 25
- Standalone entity = 63

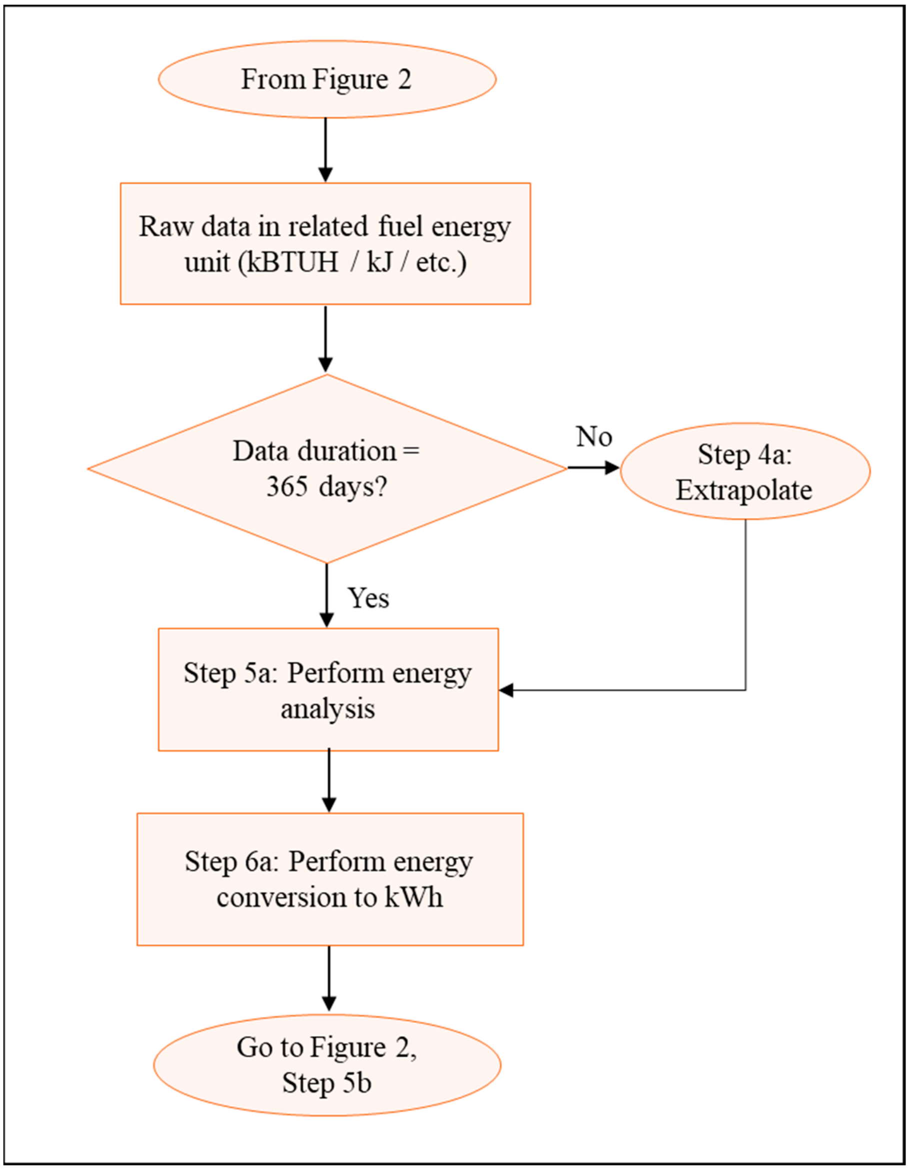


Figure 3. Energy audit framework other fuel energy.

As per the proposed energy audit framework, the LPG and electrical consumption of restaurants were being considered as a part of the building energy audit in this study. Thus, energy conversion (Figure 3—step 6a) from BTUH to kWH was performed using the following conversion coefficient:

- 1 kg LPG: 46,452 BTUH
- 1 kg LPG: 13.6 kWh
- 1 kWh: 0.074 kg LPG

These were categorized by building type for detailed and comprehensive results. The collected data were from year 2019 to 2021, as presented in Figures 4–7.

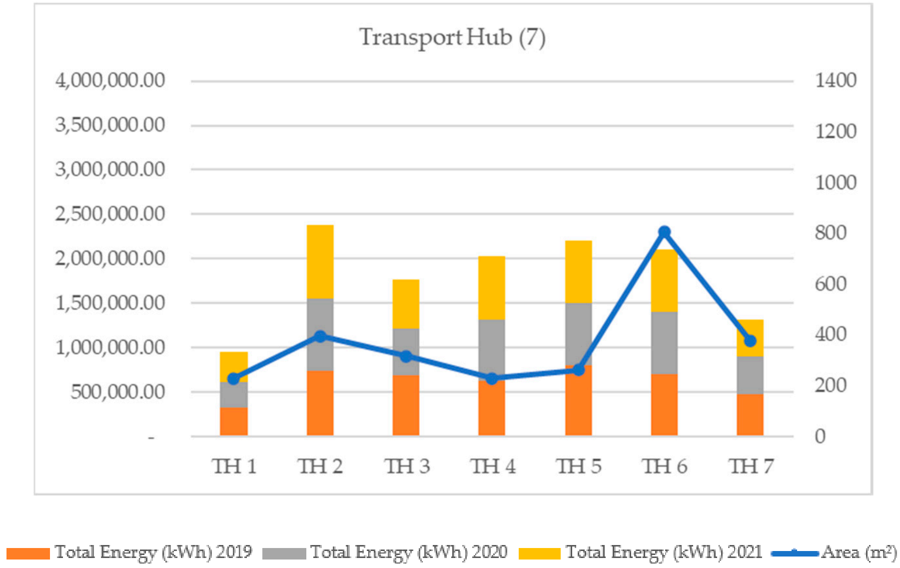


Figure 4. Transport hub restaurants energy data.

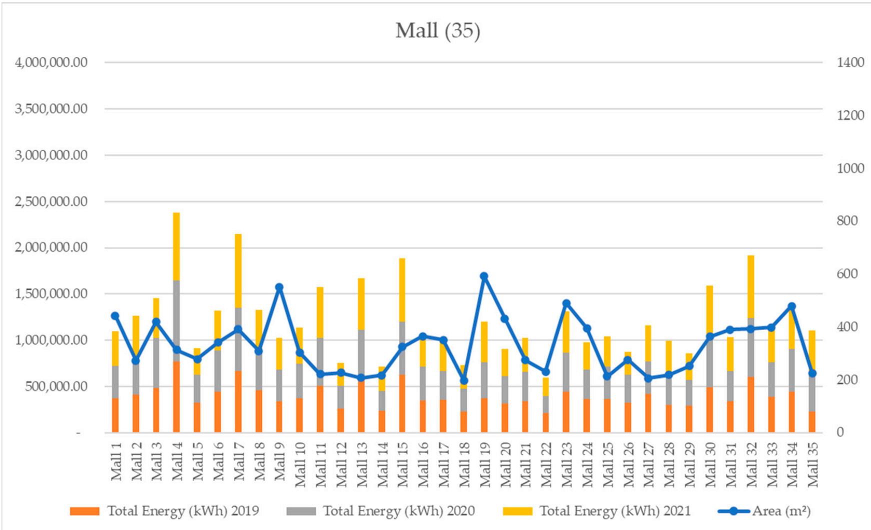


Figure 5. Mall restaurants energy data.

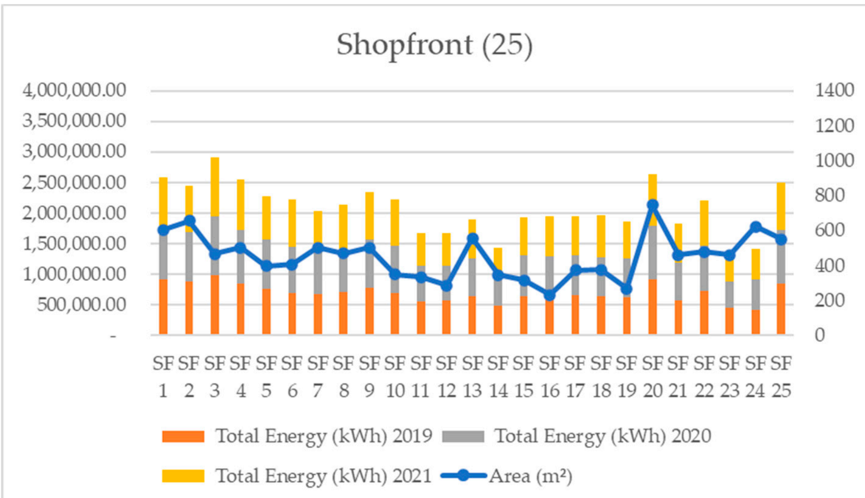
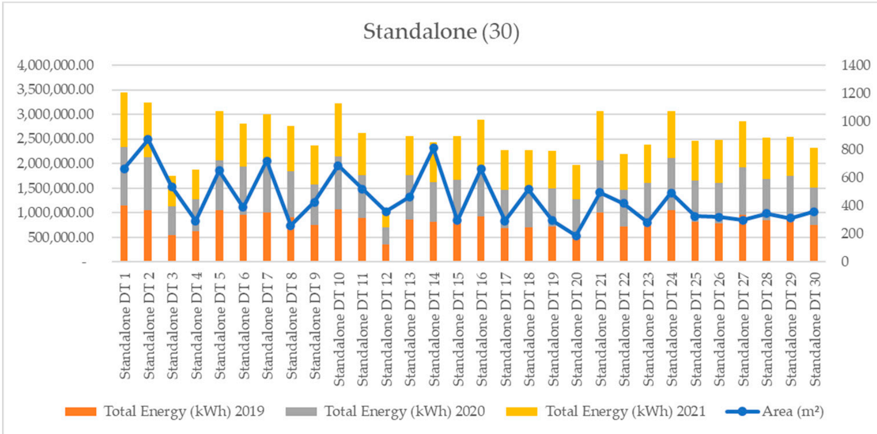
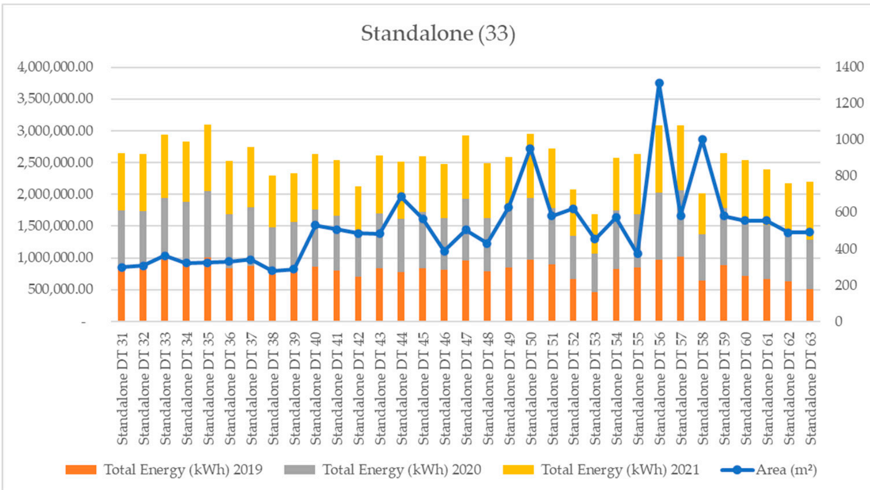


Figure 6. Shopfront restaurants energy data.



(**a**)



(**b**)

Figure 7. Part of standalone building restaurants energy data.

BEI is a common metric used to measure the energy efficiency of buildings. The BEI provides an indication of a building's annual energy use per unit area, usually expressed in kilowatt hours per square meter per year (kWh/m^2/year). Multiple BEI formulas have been established globally. The following established formula will be used to suit the needs of the analyzed building, based on the Malaysian scenario [2,19,32].

$$\text{BEI} = \frac{\text{Total Energy Consumption (kWh) per annum}}{\text{Net Floor Area (m}^2\text{)}} \quad (1)$$

In the context of analyzing the relationship between the BEI and the area of a building, linear regression was used, as it was a fundamental and versatile method employed to ascertain relationships between variables. The use of linear regression in this situation was to provide input on the below:

- Interpretability: Linear regression provided clear insights into how the area of a building might influence its BEI through easily interpretable coefficients.
- Efficiency: It was computationally efficient, making it suitable for large datasets.
- Inferential capability: Beyond mere prediction, it allowed for hypothesis testing to determine the statistical significance of the building's area in predicting its BEI.

In our analysis of the relationship between the BEI and the area of a building using linear regression, the R^2 value, or the coefficient of determination, played a pivotal role.

This metric indicated the proportion of variance in the BEI that was predictable from the building area.

2.6. Feasibility of Solar Energy Integration on Restaurant Building

The integration of solar energy for restaurants will contribute to lowering restaurants' energy consumption and energy dependability from the grid. This also directly reduces the GHG produced by the restaurant, as the energy taken from the grid is composed of various generation mixes, as shown in Figure 10. However, the integration of solar energy is not a straightforward exercise, as restaurant buildings are available in various formats. The prospects and challenges of integrating solar energy for restaurants in malls, transport hubs, shopfronts, gas station alliances, and standalone entities are described in detail below:

- Restaurants in malls:

Malls typically have large rooftop areas that can accommodate extensive solar arrays. If the restaurant is located inside the mall, they can either use the shared solar electricity produced for the entire mall or set up dedicated panels for their operations. However, shared rooftop space might mean that the allocation of energy and the costs may need to be distributed among different tenants. There might also be structural constraints or weight restrictions on some rooftops.

- Restaurants in transport hubs:

Transport hubs like train stations or airports usually have substantial roof space and a constant energy demand. Restaurants within these hubs can benefit from a consistent supply of solar power, and there can also be good public relation prospects by promoting green energy usage in such public spaces. Nevertheless, these hubs are typically under tight security, so installation and maintenance may require more coordination. Additionally, the architecture of some transport hubs may not always support easy solar installation.

- Restaurants in shopfronts:

A restaurant with a shopfront format often has limited space. Yet, with the advent of technology, solar energy can be incorporated into facades, windows (using transparent solar cells), or awnings, making it possible for even small spaces to generate solar energy. Even so, the energy generated might not be substantial due to the limited area, and it might not cater to the restaurant's entire energy needs. Also, the orientation of the shopfront might not always be optimal for solar energy capture.

- Restaurants with oil alliances:

Oil alliances are restaurants located within or near gas stations. There are two potential solutions for solar energy integration with this type of building. First is the installation of solar panels on the rooftops of the restaurants, and this can offset some of the restaurant's electricity dependability on the grid. Secondly, the pump island of a gas station is generally a large area and can cater for large number of solar panels. These island roof spaces, if utilized completely, could potentially offset or at least reduce energy consumption. Restaurants at these locations can also tap into this infrastructure, as gas stations usually consume less electricity compared to restaurants, as they coincide with operational needs. It is important to note the concern on safety as primary, so solar installations will need to be performed carefully to ensure no hazards.

- Standalone restaurants:

Standalone restaurants typically have the freedom to modify their structures, allowing them to incorporate solar panels on rooftops, parking areas, or even gardens. They have the potential to meet a significant portion of their energy needs through solar power. However, initial investment costs might be higher for a standalone entity without shared infrastructure. Moreover, they would need to handle all aspects of installation, maintenance, and energy storage independently.

From the above, the integration of solar energy for commercial building restaurants in a standalone entity is highly possible, as it is more agile compared to the other restaurant formats. A total number of 15 standalone restaurant buildings are analyzed for the installation of solar PV through the below stages:

- Identify the available roof space based on drone shot, as shown in Figure 8.
- Application of solar PV on rooftop of building, as shown in Figure 8.

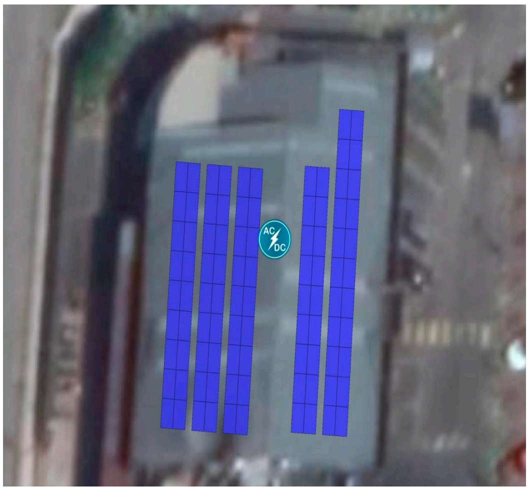


Figure 8. Example of drone shot from analyzed site.

The data collected from the above stages are presented in Table 3.

Table 3. Feasibility analysis of solar energy generation for selected sites.

Item.	Project Site	DC Capacity (kWp)
1	Subang	57.6
2	Kota Damansara	66
3	Taman Connaught	47
4	Bandar Baru Bangi	31.4
5	Bandar Seri Putra	31
6	Section 3 Shah Alam	27.5
7	Kajang Perdana	21
8	Giant Jalan Kebun	23
9	Puncak Alam	25
10	Klang Sentral	11
11	Puchong Gateway	22
12	Prima Saujana Kajang	20
13	Caltex Denai Alam	23
14	Kota Emerald	20
15	Persiaran Raja Muda Musa	28.5
Total		454

From the above data presented in Table 3, a comprehensive analysis on energy, economic, and environmental assessment was conducted to understand the potential impact. When comparing the capacity of each solar PV with the energy consumed by restaurants, a self-consumption solar PV system would be a better option, as power generated from solar will be first consumed by the restaurant load and the balance energy derived from grid. Figure 9 shows the connection diagram of solar PV to the main switch board of the restaurant.

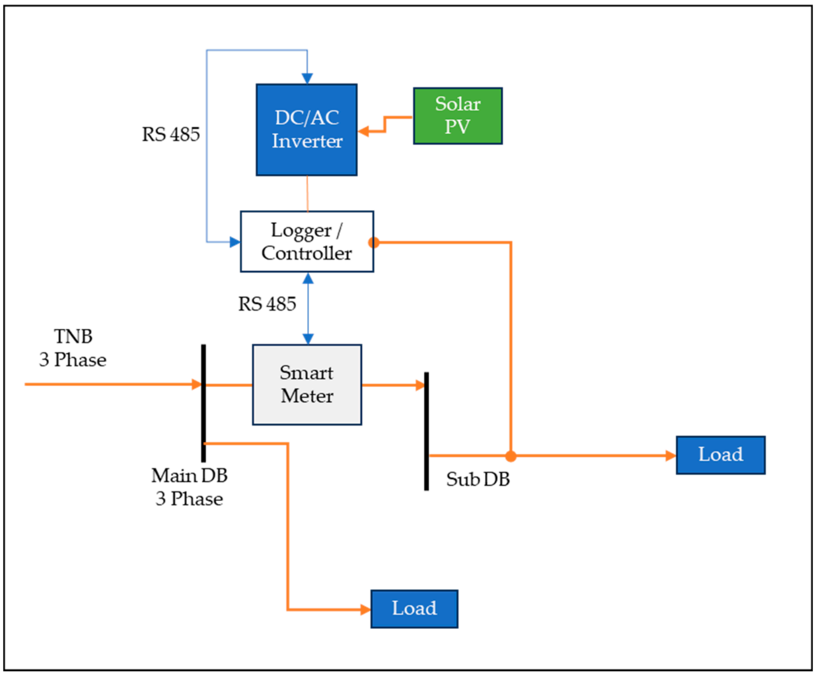


Figure 9. Connection diagram of solar PV for self-consumption.

2.7. Mathematical Formulation

2.7.1. Energy Analysis

Table 4 provides a summary of the types of equipment, along with the operating hours for kitchen equipment in the restaurants. Meanwhile, Table 5 presents their corresponding energy consumption data. To compute the electrical energy consumed by the kitchen equipment, Equation (2) was applied and formulated using energy assessment data derived from the energy consumption patterns observed in the audited fast food restaurants [18,33]:

$$AEC^a = UH^y \times C^a \times LF \times 0.001 \quad (2)$$

Table 4. Equipment operating hours of equipment per annum.

Equipment	Quantity	Operating Hours (h/y)
Grill (2 Platen)	2	7151
Chicken Fryers	3	7151
4 Split Vat Fryers	1	7151
3 Full Vat Fryers	1	7151

Table 5. Energy consumption for types of equipment.

Equipment	Quantity	LPG		Electric Energy
		BTU	kW	kW
Grill (2 Platen)	2	80,000	9.8	22.0
Chicken Fryers	3	300,000	0.4	51
4 Split Vat Fryers	1	300,000	0.4	56
3 Full Vat Fryers	1	225,000	0.4	42

For equipment powered by LPG, the energy consumption can be determined utilizing Equation (3) as follows, based on the methodology described in Figures 2 and 3.

$$AGC^{a} = UH^{y} \times X^{a} \times LF \times 0.001 \quad (3)$$

For the purposes of calculations, the load factor was assumed to be one (1), implying that the equipment operated consistently at its maximum capacity.

Equation (4) was used to calculate the estimated amount of energy output from solar PV installed on the rooftop of a respective restaurant building:

$$\text{Solar PV kWh output} = \text{DC Capacity (kWp)} \times \text{peak hours} \times 365 \text{ days} \times 20 \text{ years} \times \text{DF} \quad (4)$$

The peak hour was taken into consideration after reviewing the results by other researchers. The research in [34] highlighted that peak sunlight hours typically lasted for 6 h. However, other studies suggested a range of 4 to 6 h [35]. According to [36], Malaysia experienced average peak sun hours ranging from 4.0 to 5.4 h, varying by geographic location. Given Malaysia's frequent cloud cover and consistently hot, humid climate, the observed average peak sunlight duration in this investigation was limited to 3.5 h. This 3.5 h timeframe was consistent with many studies that identified it as the minimum value. Adopting this 3.5 h standard could aid in preventing design scenarios where the power generation does not match theoretical estimates. For the degradation factor (*DF*), the first year was considered as 1 due to the solar panels being newly installed and performing at their optimal levels. For the second and subsequent year, an annual degradation factor of 0.5% was applied.

2.7.2. Economic Analysis

The electricity pricing in Malaysia was based on the most recent findings from the Energy Commission [37], and it was measured in Ringgit Malaysia (RM). Fast food establishments of this kind fell under the low voltage commercial rate. For the initial 200 kWh, the cost was RM 0.435 per kWh, and any consumption above 200 kWh cost RM 0.509 per kWh. These rates were consistent from 2019 through 2021. Additionally, the government sets the LPG price for household use [38], but rates for commercial and industrial gas remain uncontrolled. Tank size determines whether the gas is categorized as domestic or commercial. The limits for homes are 12 kg and 14 kg, whereas businesses can use up to a 50 kg cylinder. A detailed survey revealed that gas prices varied and were reassessed biannually. Yet, information from pertinent managerial sources indicated that the mean price for a 50 kg LPG tank stayed at RM 210 for the years 2019 to 2021.

2.7.3. Environment Analysis

For the environmental assessment, the emission factors, as illustrated in Table 6, were utilized.

Table 6. Emission factor per unit energy use for various fuels [33,39–41].

Type of Fuels	Emission Factors (kg/kWh)		
	CO_2	SO_2	CO
Coal	1.18	0.0139	0.002
Petroleum	0.85	0.0164	0.002
Natural gas	0.53	0.0005	0.005
Hydro	0	0	0
RE	0	0	0

The resulting emissions could be determined through Equation (5) by translating the overall BTUH to kWh for LPG-powered devices and directly considering kWh for electric devices [33,39–41].

$$EM_i = EP_i\left(PE_i^1 \times Em_p^1 + PE_i^2 \times Em_p^2 + PE_i^3 \times Em_p^3 + \ldots + PE_i^n \times Em_p^n\right) \quad (5)$$

Electricity generation was derived from various fuels, including coal, petroleum, and natural gas, along with alternative sources, such as solar farms, biogas, and biomass plants [42]. Figure 10 depicts Malaysia's electricity generation distribution. There is a notable emphasis on coal, as its prevalence in power generation continues to be substantial, leading to the release of greenhouse gases.

The increasing reliance on coal-powered plants is alarming due to its environmental implications. Forecasts for Malaysia's energy infrastructure indicate a sustained dependence on coal for a significant portion of its power generation. However, the energy supply correlates with demand, underscoring the importance of promoting energy efficiency on the consumption side. As a result, curbing emissions becomes a paramount challenge for Malaysia's ecological sustainability.

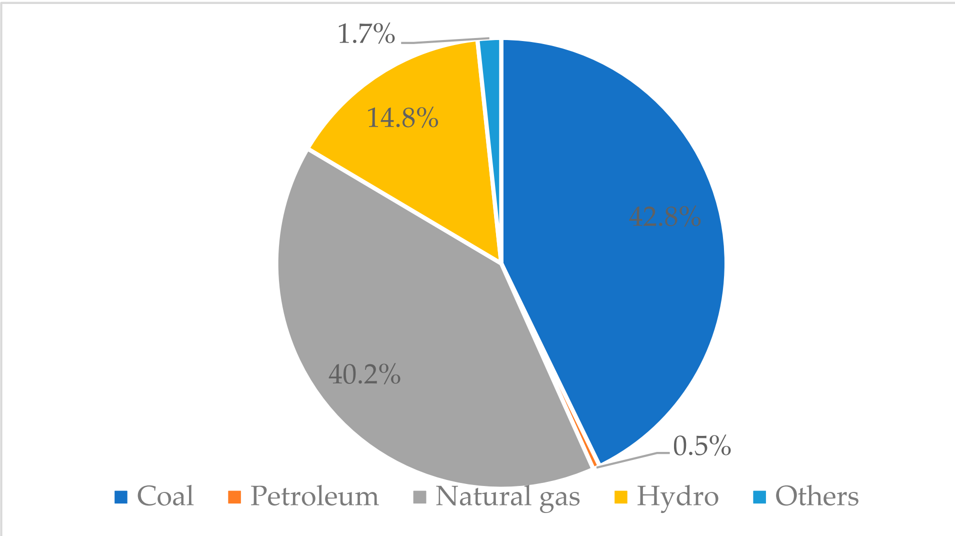


Figure 10. Percentage of electricity generation mix as of 2019 [43].

3. Results and Discussion

3.1. BEI Analysis

From presented data in Figures 4, 5, 6 and 7b, the BEI of the restaurants based on building types are calculated using Equation (1). Table 7 presents the result of the average BEI of respective building types.

Table 7. Average BEI of restaurants.

Building Types	BEI (kWh/m^2/Year)
Transport hub	1865.14
Mall	1308.36
Shopfront	1628.14
Standalone	1972.74

From the results shown in Table 7, it can be clearly seen that the BEI for commercial building restaurants can be in between 1300 to 2000 kWh/m^2/year. In order to compare this against the established Malaysia BEI for commercial buildings, which is 135 kWh/m^2/year, there is a need to include a normalization factor. The reason being is that the established BEI for commercial buildings is based on 10 h operation. Elsewhere, this research is focusing on restaurants that have continuous operation of approximately 20 h a day, as mentioned in Section 2.2. Table 8 presents the result of the normalized BEI based on the operation hours of the restaurant.

Table 8. Normalized BEI for restaurants.

Building Types	Normalized BEI (kWh/m^2/Year)
Transport hub	932.57
Mall	654.18
Shopfront	814.07
Standalone	986.37

However, the value of the BEI was not comparable to the established Malaysia BEI for commercial buildings, which was 135 kWh/m^2/year. Most of the analyzed buildings for Malaysia consist of institutions, government facilities, hotels, and hospitals, which are usually present in large spaces [11,14,15,18,33,44]. Hence, even if energy consumption is high, the BEI can be comparatively low. However, in the cases of commercial building restaurants, which usually present in smaller footprints compared to the above buildings, the BEI was much higher. One of the main reason is due to the equipment usage in the restaurants, which utilize heating and refrigeration elements, as presented in [2]. Hence, it is a need to benchmark an index for restaurants for future perusals. To conclude such benchmarking indexes, the relationship between BEI and areas of buildings were analyzed through the linear regression method. In analysing the relationship between the BEI and the area of a building, linear regression, the R^2 value, or coefficient of determination, plays a pivotal role. This metric indicated the proportion of variance in the BEI that was predictable from the building area. The results for the R^2 of restaurant areas and the BEI based on building types are presented in Figures 11–14 below.

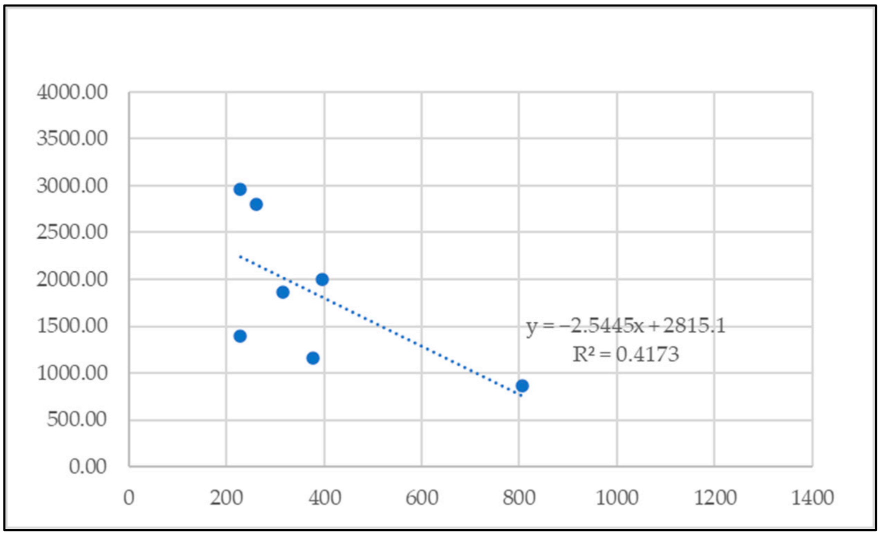


Figure 11. R^2 analysis for transport hub restaurants.

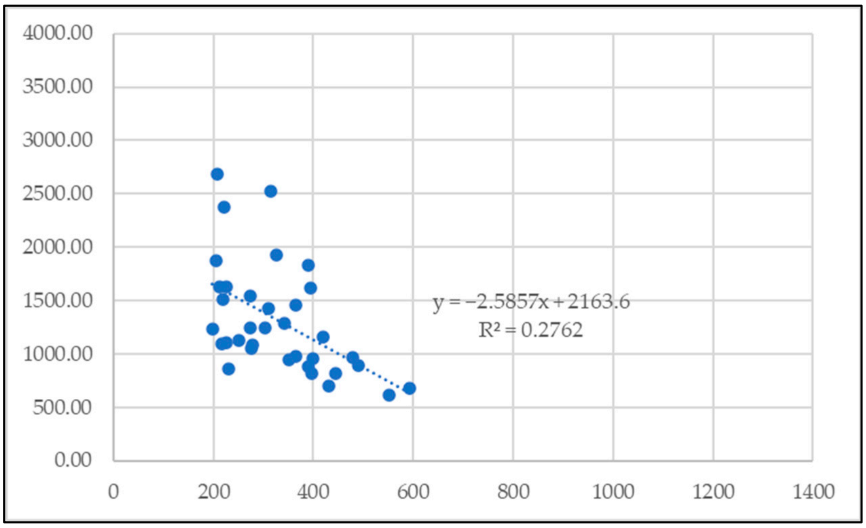


Figure 12. R^2 analysis for mall restaurants.

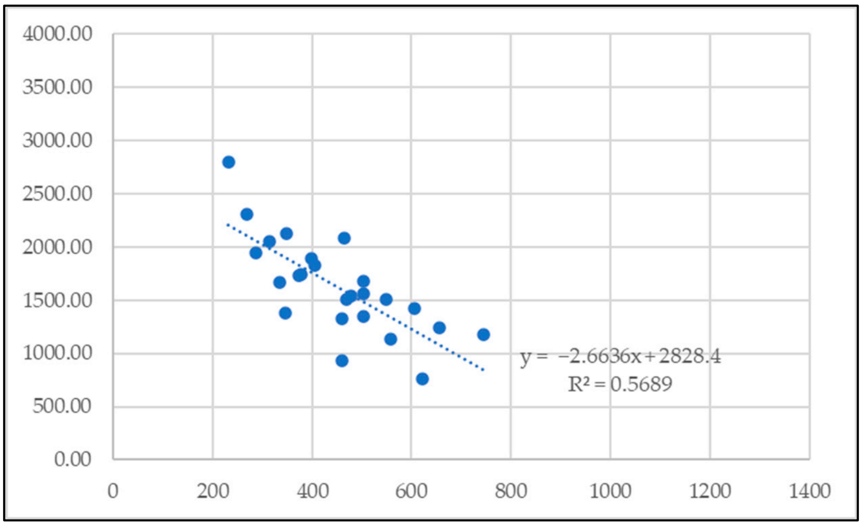


Figure 13. R^2 analysis for shopfront restaurants.

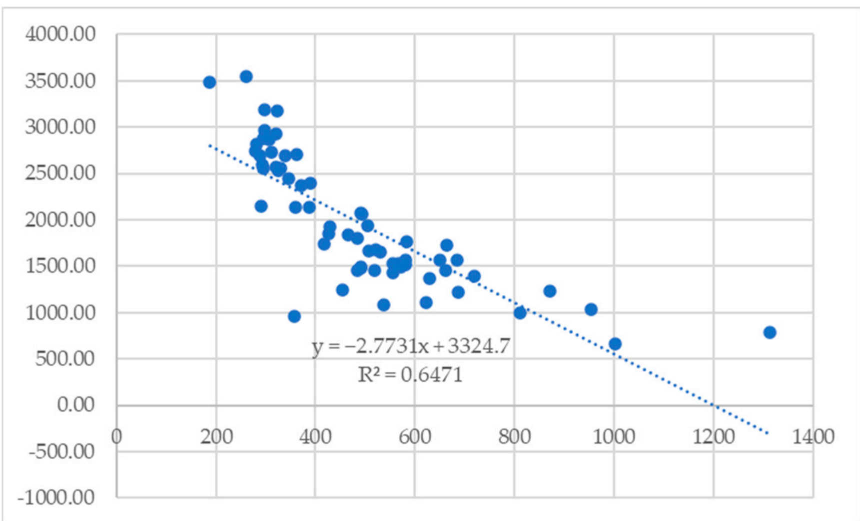


Figure 14. R^2 analysis for standalone building restaurants.

Figures 11–14 show a group of results consolidating with a breakdown of restaurants building types in transport hubs, malls, shopfronts, and standalone buildings, as the baseline BEI of 130 restaurants is in between 1300 and 2000 kWh/m^2/y. The results presented above indicate an interesting outcome on the right sizing of the building to be considered in order to optimize the energy consumption in a type of building in which a restaurant should be constructed. For transport hubs, the majority of the data are within 200 to 400 sqm. However, this result was inconclusive, as the sample data were too small. Even the R^2 value, set at 0.4173, did not indicate as true, as the sample size is low. On the other hand, shopfront restaurants, which were in the range of 200 to 800 sqm, showed optimal energy usage within the baseline BEI. In addition to that, the mall-type restaurants indicated that the right-sized area should be in between 200 and 400 sqm, and the standalone building size should be in the range of 400 to 700 sqm. The R^2 values for malls, shopfronts, and standalone buildings were 0.2762, 0.5689, and 0.6471, respectively. Only shopfronts and standalone building restaurants showed higher values of R^2.

Essentially, a higher R^2 suggested that our model closely fit the actual data points. For instance, an R^2 value of 0.8 implied that 80% of the variance in BEI was accounted for by the building's area. Based on the R^2 results obtained in Figures 11–14, the BEI indicator for commercial building restaurants, in this case, was inconclusive. The variations in energy data from restaurants may have arisen from their unique business operations and corresponding sales figures. While the 130 surveyed restaurants housed similar equipment, the energy they consumed was directly influenced by product demand. Consequently, a restaurant's sales played a pivotal role in its energy consumption, influencing the R^2 value. For instance, restaurants located in malls and transport hubs served diverse customer groups because they were situated within enclosed structures. The locations of these malls and hubs significantly impacted the restaurant's energy usage. On the other hand, shopfronts catered to a different customer base, determined by their locations and visitor frequencies. In contrast, standalone restaurants offered the broadest customer accessibility due to multiple service channels like takeaways, dine-ins, and drive-thrus. This accessibility range, in turn, influenced energy consumption, BEI, and the R^2 value. Therefore, BEI cannot be a true indicator for a commercial building restaurant type.

In order to further strengthen the R^2 value, the application of multi-regression would be a potential method. With the addition of more variables, the R^2 value can increase. One of the most prominent values in considering the BEI in restaurants would be the sales. The sales of a restaurant are directly proportional to the operational hours of its equipment. Hence, a product-based BEI would be relevant to further analyze the correct range of BEIs for restaurants. Another value that could add to the robustness of the data is the product mix, which indicates the amount of product sold. With the availability of these data, a multi-regression method can be performed to understand the relevancy of the BEI accordingly. In the absence of this data, the BEI indicator for commercial building restaurants is not completely true at this point, and more data are required to conclude these. Thus, the BEI is not an accurate indicator for quantifying energy intensity for restaurants. Yet, it could be used as a reference to determine optimal building size and its energy usage for restaurants.

3.2. Energy Analysis

3.2.1. Equipment

An energy analysis was conducted to emphasize energy consumption patterns and provide comparative insights. The cumulative energy consumption was calculated using both Equations (2) and (3), with the results summarized in Table 9.

Table 9. LPG and electrical equipment energy consumption per annum.

Equipment	Quantity	Gas Equipment: LPG and Electric Consumption Per Annum		Electrical Equipment Energy Consumption Per Annum
		kBTUH/y	kWh/y	kWh/y
Grill (2 Platen)	2	572,080	70,079.8	157,322
Chicken Fryers	3	2,145,300	2860.4	364,701
4 Split Vat Fryers	1	2,145,300	2860.4	400,456
3 Full Vat Fryers	1	1,608,975	2860.4	300,342
Total Energy Consumption		6,471,655	78,661	1,222,821

Gas Equipment LPG Consumption:

- The 4 Split Vat Fryer and Chicken Fryer were the largest energy consumers, registering at 2,145,300 kBTUH/y.
- The 3 Full Vat Fryers consumed 1,608,975 kBTUH/y.
- The grill had a consumption of 572,080 kBTUH/y.

The specific capacities of these equipment items explain their distinct fuel requirements. For instance, fryers, which use oil, inherently consume more energy compared to a grill that employs direct heating. Moreover, the grill stands out in terms of electrical energy consumption amongst gas equipment, using up to 70,079.80 kWh/y. This is attributed to its upper platen's direct electrical heating. In contrast, other gas equipment registered minimal annual electricity usage, amounting to 2860.4 kWh/y, primarily for their program boards.

Electrical Equipment Energy Consumption:

- The 4 Split Vat Fryer topped the list with 400,560 kWh/y.
- The Chicken Fryer followed closely at 364,701 kWh/y.
- The 3 Full Vat was next at 300,342 kWh/y.
- The Grill, comparatively, consumed the least, at 157,322 kWh/y.

To provide a balanced comparison between energy consumption metrics, we applied the conversion coefficient outlined in Section 2.5, facilitating the conversion from kBTUH to kWh. The results of this conversion are further detailed in Table 10.

Table 10. Energy conversion and comparison.

Equipment	Qty	Gas Equipment: LPG and Electric Consumption		Total Energy Consumed by Gas Equipment	Electrical Equipment Energy Consumption
		kBTUH/y to kWh/y	kWh/y	kWh/y	kWh/y
Grill (2 Platen)	2	167,491	70,079.8	237,570.7	157,322
Chicken Fryers	3	628,091	2860.4	630,951.3	364,701
4 Split Vat Fryers	1	628,091	2860.4	630,951.3	400,456
3 Full Vat Fryers	1	471,068	2860.4	473,928.6	300,342
The total energy in kWh		1,894,741	78,661	1,973,402	1,222,821

Table 10 reveals that the LPG-powered equipment consistently consumed more energy than their electrically powered counterparts. From the analysis, the following was derived for each equipment accordingly:

- Grill: An LPG grill consumed 34% more energy than its electrical counterpart.
- Chicken Fryer: The disparity was most prominent here, with the LPG chicken fryer consuming 42% more energy than the electrical variant.
- The 3 Full Vat Fryers and 4 Split Vat Fryers: These LPG fryers consumed 37% more energy than the electric versions.

On average, gas-powered equipment used 38% more energy than the electrical equipment. This observation aligned with the findings reported in [45,46], where gas-powered equipment was shown to consume 30.8% and 18.6% more energy than electric equipment in the respective studies.

3.2.2. Solar PV Integration

Using the data presented in Table 2 and Equation (4), the energy generated from solar PV was calculated for a period of 20 years in consideration of the solar panel warranty period. In addition to that, the solar PV degradation factor was included as 0.5% per annum, which was applicable from year 2 onwards. The energy generated using solar PV for the 15 sites are presented in Table 11.

Table 11. Solar energy generation for 20 years.

Year	Solar Generation (kWh Per Annum)	Year	Solar Generation (kWh Per Annum)
1	579,985	11	551,630
2	577,085	12	548,871
3	574,200	13	546,127
4	571,329	14	543,396
5	568,472	15	540,679
6	565,630	16	537,976
7	562,801	17	535,286
8	559,987	18	532,610
9	557,188	19	529,947
10	554,402	20	527,297

After considering the degradation factor of 0.5% per year, solar PV generation for the period of 20 years was summed to be 11,064,898 kWh.

3.3. Economic Analysis

3.3.1. Equipment

The computation of energy expenses over three successive years was based on the information found in Table 10, with the outcomes presented in Figure 15 and Table 12. When considering energy expenses, LPG-driven devices tended to be marginally more affordable than their electric counterparts. Between 2019 and 2021, gas device energy expenditures were, on average, 0.5% lesser than those of electrical devices.

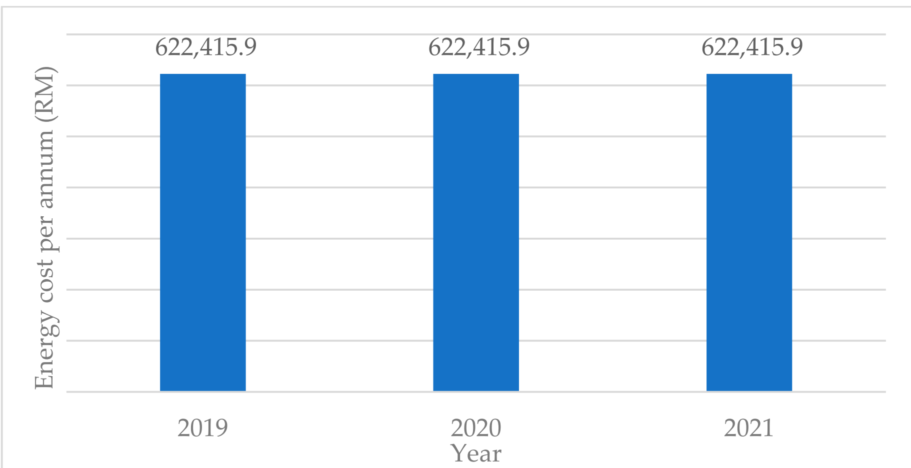


Figure 15. Year-on-year electrical equipment energy cost.

Table 12. LPG equipment energy cost.

Year	Gas Equipment: LPG and Electric Consumption Per Annum		Gas Equipment: LPG and Electric Energy Cost Per Annum		Total Cost
	kBTUH/y (a)	kWh/y (b)	RM (a × Gas Tariff)	RM (b × Electric Tariff)	RM
2019	6,471,655	78,661	613,030.8	40,038.4	653,069.3
2020	6,471,655	78,661	557,300.8	40,038.4	597,339.2
2021	6,471,655	78,661	585,165.8	40,038.4	625,204.2

Conversely, the findings differed from those shared by Anozie, Bakare [46] and George and Augustine [45]. Anozie, Bakare [34] noted that LPG-driven household devices had average energy expenses 74.2% greater than electrical devices over the years compared. Meanwhile, George and Augustine [33] highlighted an 8.13% greater energy cost for LPG than electricity. The primary discrepancy in energy expenses between this research and the referenced studies could have been attributed to the varying gas tariffs specific to each case.

3.3.2. Solar PV Integration

The utility tariff for commercial building restaurants in Malaysia was a low voltage commercial tariff. where the first 200 kWh was charged at RM 0.435 per kWh, and 201 kWh onwards was charged at RM 0.509 per kWh accordingly. On top of that, the utility bill in Malaysia consisted of factors such as imbalance cost pass through (ICPT) of total energy consumption and RE Fund charges at 1.6% of a total utilities bill. After including these aspects, the average savings in energy cost using solar PV were calculated based on RM 0.517 per kWh, with TNB tariff increments of 9% every three years [37]. These represented the real cases, as the approaches in analysis were applied by the authors of [47]. The results of the calculated energy cost savings are presented in Table 13.

Table 13. Energy cost savings using solar PV.

Year	Solar Generation (kWh/Year)	TNB Tariff	Energy Cost Saved (RM)	Year	Solar Generation (kWh/Year)	TNB Tariff	Energy Cost Saved (RM)
1	579,985	0.517	579,985	11	551,630	0.670	369,435
2	577,085	0.517	577,085	12	548,871	0.670	367,588
3	574,200	0.517	574,200	13	546,127	0.730	398,668
4	571,329	0.564	571,329	14	543,396	0.730	396,675
5	568,472	0.564	568,472	15	540,679	0.730	394,691
6	565,630	0.564	565,630	16	537,976	0.796	428,062
7	562,801	0.614	562,801	17	535,286	0.796	425,922
8	559,987	0.614	559,987	18	532,610	0.796	423,792
9	557,188	0.614	557,188	19	529,947	0.867	459,624
10	554,402	0.670	554,402	20	527,297	0.867	457,326

From the above Table 13, the total potential cost savings by implementing solar PV on 15 analyzed restaurants building for a period of 20 years was RM 7,381,929.

3.4. Environmental Assessment

3.4.1. Equipment

While LPG proves to be more cost-effective yet consumes more energy, it is essential to assess the emissions to determine the environmental impact when transitioning LPG equipment to electric. Figure 16 illustrates the shift from LPG to electricity regarding pollutant emissions.

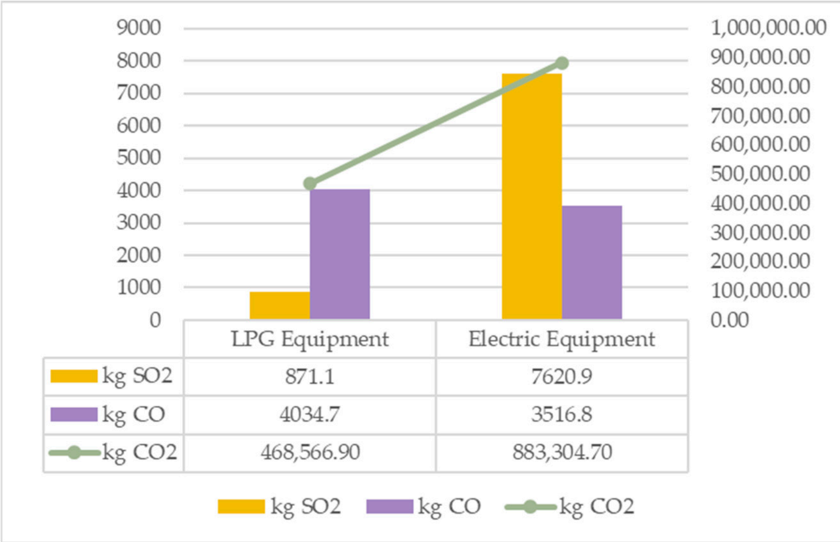


Figure 16. Emission of pollutants based on the year 2021 capacity mix in Malaysia.

Even with LPG's increased energy consumption, its pollution footprint is considerably smaller when comparing the emissions of devices powered by both fuels. Specifically, LPG equipment emits 47% less CO_2 and 89% less SO_2 than electric equipment, even though CO emissions from LPG are 15% greater. Hui, Xianneng [35] also found similar results, indicating that electric-powered devices emitted substantially more pollutants than LPG devices, including higher levels of PM2.5, SO_2, NOx, and CO_2.

LPG emissions primarily stem from the percentages of natural gas and petroleum in a generation mix. In contrast, electricity is generated from a diverse set of fuels, as detailed in Figure 10. A broader observation revealed that devices powered by electricity emitted more pollutants on average than those powered by LPG. This emission difference was mainly due to the significant reliance on coal, accounting for 42.8%, as depicted in Figure 10. Given the substantial role coal plays in Malaysia's anticipated energy infrastructure, this number might rise, leading to even greater emissions.

3.4.2. Solar PV Integration

The implementation of solar PV on commercial building restaurants will not only save energy but also contribute towards reductions in pollutants from the building. The impacts of reductions in the analyzed three parameters, which were CO_2, SO_2, and CO, were calculated using Equation (5), and the results are presented in Table 14.

Table 14. Emission reduction from solar PV integration.

Year	kg CO_2	kg SO_2	kg CO	Year	kg CO_2	kg SO_2	kg CO
1	418,952	3615	1668	11	351,940	3438	1586
2	368,180	3597	1660	12	350,180	3421	1579
3	366,339	3579	1651	13	348,429	3404	1571
4	364,508	3561	1643	14	346,687	3387	1563
5	362,685	3543	1635	15	344,954	3370	1555
6	360,872	3525	1627	16	343,229	3353	1547
7	359,067	3507	1619	17	341,513	3336	1539
8	357,272	3490	1611	18	339,805	3319	1532
9	355,486	3473	1602	19	338,106	3303	1524
10	353,708	3455	1594	20	336,415	3286	1517

Table 14 presents the emission reduction amount per annum for the integration of solar PV systems for the analyzed 15 restaurant buildings. The installation of solar energy will substitute the usage of fossil fuel-generated power, and the capacity is variable based on space availability. For the studied site, totals of 7,108,327 kg of CO_2, 68,959 kg of SO_2, and 31,823 kg of CO pollutants could be omitted by applying solar PV on the restaurant building.

3.5. Solar Energy as Cooking Fuel

Numerous studies have explored the feasibility of solar energy as a cooking fuel [48–56]. Utilizing solar energy for cooking presents several advantages, such as environmental sustainability, cost savings, health benefits, and conservation of non-renewable resources. This eco-friendly approach minimizes dependence on fossil fuels, emits no pollutants, and thereby supports the broader goal of combating climate change. However, solar cooking is not without its challenges. For instance, the efficiency of solar cookers is compromised on overcast days or in regions with limited sunlight. Fluctuating temperatures mean extended cooking durations, and some specialized cooking techniques might not be compatible with all solar cooker designs. Parabolic solar cookers, for instance, necessitate regular adjustments to keep aligned with the sun and ensure consistent cooking conditions [48,51,52,54,56]. While solar energy offers a green alternative to traditional cooking fuels, its applicability varies. Specifically, in the context of restaurants, solar cooking may not yet be a practical solution, given the current limitations.

3.6. Potential Research Extension

This research article emphasizes the need for thorough analysis in the realm of energy consumption for commercial building restaurants. Nevertheless, there are several avenues to enhance this study further:

1. Innovations in Energy Efficiency for Restaurants:

Expanding on the insights related to LPG and electric-powered equipment, there's scope to investigate the creation and assessment of cutting-edge energy-saving technologies designed especially for the restaurant industry. This could encompass advancements in cooking appliances, refrigeration, HVAC units, and energy-saving lighting, ensuring both energy savings and adherence to performance requirements. Integration of these technologies would directly lower the BEI for restaurants and result in a new benchmark for commercial building restaurant BEIs.

2. Enhancing Renewable Energy Use in Restaurants:

While solar PV is identified as a promising renewable energy option for eateries, a deeper analysis is warranted to determine the potential of incorporating diverse renewable energy sources. An exhaustive evaluation of energy sources, including solar, wind, and perhaps even geothermal or biomass, could be considered. However, this should factor in location-specific potentials, system compatibilities, and financial feasibilities.

3. Understanding Human and Operational Energy Consumption Influences:

To capture a complete picture of energy use in restaurants, it is essential to explore both behavioral and operational factors of the restaurant workforce, focusing on training methods, effective strategies for energy conservation, and even how customer behaviors affect energy use. The outcomes could pave the way for specialized training and interventions, leading to even greater energy savings.

These research areas could offer a more in-depth comprehension of energy usage in restaurant-based commercial structures. This would also aid in formulating strategies for enhancing energy efficiency and adopting renewable energy, a pivotal step toward sustainable and cost-efficient energy practices in the restaurant industry.

4. Conclusions

This paper introduced an enhanced energy audit framework tailored for restaurant-type commercial buildings. Traditional energy audits predominantly focused on electrical loads, overlooking the nuances specific to the restaurant sector. When LPG fuel consumption is not taken into account, these buildings will appear to have lower energy consumption, as traditional energy audits primarily focus on electrical loads alone. The BEI was analyzed using 130 restaurant energy data, and the normalized BEI for a restaurant was calculated to a range between 650 and 1000 kWh/m^2/year. To evaluate the interpretability of BEI, a linear regression method was performed between the BEI and area of restaurant, based on the various building-type restaurants. From the analysis, it was found that the R^2 value was low. Hence, the measure of BEI for restaurants was not true. These findings emphasized the need for a more holistic approach in energy audits for such buildings, underlining the efficacy of our proposed method. To analyze this further, future works could include data related to sales and product mixes of restaurants for the application of multi-regression analysis.

On the other hand, comparative analysis for energy, economic and environment was performed to identify the potential between electric and LPG -fueled equipment. Through a detailed comparative analysis, our study revealed that LPG-fueled equipment consumed approximately 38% more energy than its electric counterparts. However, from an economic perspective, the LPG was at a 0.5% lower cost compared to electrically fueled equipment. The environment assessment revealed that LPG-based equipment emitted substantially less pollutants than electrically fueled equipment.

While looking into the potential of solar energy integration in a restaurant building, solar PV applications in restaurants seem to be a applicable solution. From the studied sites, a total of 11,064,898 kWh could be generated with the installation of solar PV on restaurant buildings. This amounted to a cost saving of RM 7,381,929 in utility billing and totals of 7,108,327 kgCO_2, 68,959 kgSO_2, and 31,823 kgCO pollutant omissions.

Author Contributions: Conceptualization, M.K.G., M.H., C.T. and A.H.A.B.; methodology, M.K.G. and M.H.; validation, M.H. and V.P.; formal analysis, M.K.G.; investigation, M.K.G.; data curation, M.K.G.; resources, M.K.G. and V.P.; writing—original draft preparation, M.K.G.; writing—review and editing, M.H. and V.P.; visualization, M.K.G. and M.H.; supervision, M.H., C.T. and A.H.A.B.; project administration, M.H. and C.T.; funding acquisition, A.H.A.B. All authors have read and agreed to the published version of the manuscript.

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Nomenclature

AEC	Annual energy consumption (kWh) of equipment *a* in MWh
AGC	Annual LPG consumption of equipment *a* in kBTUH
BEI	Building energy index
BTU	British Thermal Unit
BTUH	British Thermal Unit per hour
C^a	Capacity of equipment *a* in kW
CFL	Compact fluorescent
DF	Degradation factor
ECM	Energy conservation measure
EM_i	Total emission for the unit of electricity generation (ton)
EP_i	The electricity production in the year *I* (kWh)
Em_p^n	The fossil fuel emission for a unit of electricity generation of fuel type

GHG	Greenhouse gas
HEM	High efficiency motor
kg	Kilogram
kgCO	Kilogram of carbon monoxide equivalent
$kgCO_2$	Kilogram of carbon dioxide equivalent
$kgSO_2$	Kilogram of sulfur dioxide equivalent
kW	Kilo Watt
kWh	Kilo Watt hour
LED	Light emitting diode
LF	Load factor = 1
LPG	Liquified petroleum gas
PE_i^n	Percentage of electricity generation in the year I of fuel type n
PV	Photovoltaic
Qty	Quantity
RE	Renewable energy
RM	Ringgit Malaysia
UH^y	Yearly usage hours of equipment a
VSD	Variable speed drive
X^a	Capacity of equipment a in kBTUH

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