Contents list available at CBIORE journal website

International Journal of Renewable Energy Development

Journal homepage: https://ijred.cbiore.id

Research Article

Quantification of household electricity consumption for supporting energy efficiency of urban metabolism: Material flow analysis

Sharif Shofirun Sharif Ali[1], Saraswathy Kasavan[2*], Muhammad Rizal Razman[3], Azahan Awang[4], Pedro J. Zarco-Periñán[5]

[1]*School of Government, College of Law, Government and International Studies (COLGIS), Universiti Utara Malaysia (UUM), 06010 UUM Sintok, Kedah, Malaysia.*

[2] *Faculty of Business Management and Professional Studies, Management and Science University, Off Persiaran Olahraga, Seksyen 13, 40100 Shah Alam, Selangor, Malaysia.*

[3] *Research Centre for Sustainability Science and Governance (SGK), Institute for Environment and Development (LESTARI), Universiti Kebangsaan Malaysia (UKM), 43600 UKM, Bangi, Malaysia.*

[4] *School of Social, Development and Environmental Studies, Faculty of Social Science and Humanities, Universiti Kebangsaan Malaysia (UKM), 43600 UKM, Bangi, Malaysia.*

[5]*Departamento de Ingenieria Electrica, Escuela Superior de Ingenieria, Universidad de Sevilla, Spain.*

Abstract. Despite growing public, academic, and government awareness of the energy consumption issue, there is still little research on the scales and patterns of Household Electricity Consumption (HEC), particularly in developing countries such as Malaysia. Therefore, the present study examines the status of HEC using electricity consumption breakdowns, key performance indicators (KPIs) for electricity consumption and Material Flow Analysis (MFA) by showing potential electricity savings, cost savings, and emission reductions using 5-star energy efficiency appliances. This study used a face-to-face survey of 400 participants in Seremban, the capital city of Negeri Sembilan. The study found that the majority of respondents (49%) consumed about 300-600 kWh/month of electricity with an estimated cost of MYR231.80 per month. Additionally, the study found that households in flats recorded lower average electricity consumption (460.16 kWh/unit) than bungalow households (885.92 kWh/unit) due to respondents' socio-economic status, the physical size of the houses and the number of appliances owned. The study also revealed that the average energy consumption was higher for refrigerators (9.6 kWh/day) and air conditioners (4.5 kWh/day) due to the use of large amounts of energy to maintain a steady temperature. The material flow analysis shows that energy savings were approximately 22.53%, potential cost savings were MYR12,676.15 per month, and the potential reduction emissions were about 100,759.92 kgCO2e for one month with using EEA compared to non-EEA. The present study empirically discussed the significance of HEC quantification and the opportunity for energy efficiency is critical as a solution for sustainable urban metabolism in a developing country.

Keywords: Electricity Consumption Breakdowns, Key Performance Indicators (KPIs), Potential Electricity Saving, Cost Saving, Emissions Reduction, 5-Star Energy Efficiency

Received: 22nd April 2024; Revised: 8th Juli 2024; Accepted: 3th August 2024; Available online: 14th August 2024

1. Introduction

Energy wastage poses a sustainability issue, including unsustainable energy production and consumption, resource exhaustion, and increasing greenhouse gas emissions, leading to global warming. Global energy consumption has increased significantly, with the Asian Pacific region being the most significant energy consumer with a total consumption of about 71,544 terawatt-hours (TWh), followed by North America (32,384 TWh), Europe (23,282 TWh), the Middle East (10,771 TWh), South & Central America (7,947 TWh), and Africa (5,520 TWh) (Ritchie & Roser, 2020). Urban spaces have become the epicentre of globalisation and information exchange in a global scenario, whereby people and their activities have placed pressure on the natural environment. In particular, urban areas use 75% of global final energy consumption (Roy Chowdhury *et al.*, 2020). Increasing energy consumption has led to several environmental degradation issues. Fossil fuel combustion to generate electricity produces significant levels of greenhouse gases such as CO_2, SO_2, and NO_X, which contribute to climate change, environmental pollution, urban heat islands, and degradation (Cheah *et al.*, 2018; Hisham Bin Jaaffar *et al.*, 2023) For example, the use of coal for electricity generation has contributed to CO_2 emissions of around 14,502 MT, followed by oil and natural gas (IEA, 2019). Currently, cities are devastated by high greenhouse gas emissions due to increased energy consumption rates, affecting human well-being in urban areas. Given cities' significant role as energy consumers, it is crucial to understand their energy consumption patterns to reshape energy flows toward a more sustainable system.

Electricity is essential for a better quality of living in the modern world. Households are consumers who are directly

* Corresponding author
Email: Saraswathy_kasavan@msu.edu.my (S. Kasavan)

involved in the consumption stage. Ali *et al*., (2020) found that electricity consumption in the residential sector increased dramatically from 770 kilotons of equivalent (ktoe) in 1997 to 2610 ktoe in 2017 due to urban population growth and land use demand. A long-term strategy and mechanism for reducing Household Electricity Consumption (HEC) in metropolitan areas is imperative, including providing specific information on electricity consumption for decision-making and raising awareness among households. An understanding of the quantification of HEC may also help address issues relating to urban sustainability, energy security, and the tailoring of energy efficiency solutions. Furthermore, the quantification of HEC can also lead to economic benefits (e.g., controlling the use of energy systematically and cost saving), social benefits (e.g., enhancing energy efficiency and quality of life), and environmental benefits (e.g., reducing GHG emissions).

Improving the energy efficiency of buildings is a countless way to minimize greenhouse gas emissions while increasing thermal comfort (Streimikiene *et al*., 2024). Increasing energy efficiency via renewable energy generation and consumption is able to reduce the carbon emissions from fossil fuel burning. The crucial challenges facing in Malaysia's energy sector is the availability of renewable energy (RE) whereby not all type of RE can be generated in Malaysia. Besides, solar, biodiesel and hydro for electricity generation are the highest RE production compared to other type of RE. However, the level of renewable energy generation and consumption in Malaysia is still low due to high cost for installing, maintenance and insufficient commitment by the government. The primary energy supply from hydropower and biodiesel indicated significant increment in 2021 (2676 ktoe and 827 ktoe) respectively while solar, biomas and biogas supply remain low (Suruhanjaya Tenaga Malaysia, 2020). In the Eight Malaysia Plan (2001-2005), the Five-Fuel Diversification Policy incorporated renewable energy as a fifth source of energy, with the goal of contributing 5% of overall energy mix by 2010. Supporting to that, the government introduced feed-in tariff (FiT) mechanism which aim to address the deficiencies found in the Small Renewable Energy Power (SREP) Program from 2001 to 2010 (Wong *et al*., 2015).

Urban metabolism employs flows to identify how resources move through a city, which can help build sustainable urban areas and find intervention areas that promote sustainability. Energy metabolism studies at the household level can provide a close look at intervention points for reshaping household energy consumption and informing decision-makers regarding a more sustainable urban energy system. Understanding how housing type and appliance ownership shape energy flows is essential. In Malaysia, HEC per capita climbed quickly from 626 kWh/person in 2000 to 4549 kWh/person in 2016 (Energy Commission, 2021). Malaysia's electricity sector primarily relies on fossil fuel resources, such as diesel, coal, and natural gas, which account for 77.27% or 23,518.10 MW of total energy usage, and only 3.96 per cent (1205.20 MW) is derived from renewable energy sources, such as biomass and biogas solar. Previous studies have primarily concentrated on various factors for HEC, such as socio-economic profile, housing characteristics, and appliance ownership (Jaaffar *et al*., 2023; Permana *et al*., 2013; Yalcintas & Kaya, 2017). Despite growing public, academic, and government awareness of the energy consumption issue, there is still little research on the scales and patterns of HEC, particularly in developing countries such as Malaysia. Therefore, the present study examines the status of HEC, and total cost and potential savings in the rapidly growing city. The study also evaluates the electricity consumption breakdowns and key performance indicators (KPIs) for electricity consumption. Finally, the study presents the results of the Material Flow Analysis (MFA) by showing potential electricity, cost saving, and emissions reduction using 5-star energy efficiency.

2. Methods

2.1 Study area

Negeri Sembilan is one of the states in Peninsular Malaysia and is located at 20 43'N 1010 56'E. The study took place in Seremban, the capital city of Negeri Sembilan. Seremban is the largest city in Negeri Sembilan with a dense population and rapid urban expansion due to its location close to the Kuala

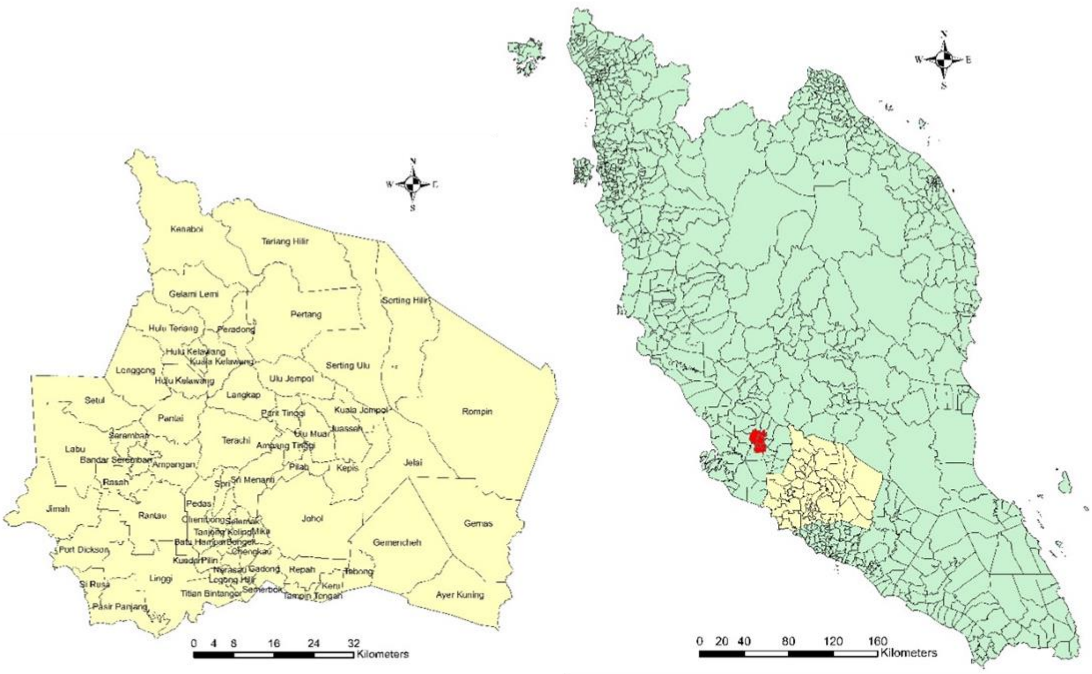

Fig. 1. Map of study area
(Sources: The map was generated by using GIS software)

Table 1
Summary of the respondents' socio-economic profile and housing characteristics

Variables	Frequency	Percentage (%)
Ethnicity		
Malay	332	83
Chinese	36	9
Indian	24	6
Others	8	2
Household Income (RM)		
500-1000	17	4.3
1001-2000	49	12.3
2001-3000	83	20.8
3001-4000	87	21.8
4001-5000	59	14.8
> 5001	105	26.3
Household Size		
0-3 people	116	29
3-5 people	197	49.3
.> 6 people	87	21.8
Number of Rooms		
2 rooms	14	3.5
3 rooms	202	50.5
4 rooms	138	34.5
> 5 rooms	46	11.5

Lumpur Corridor (KLK), the most rapidly developing economic region in Malaysia. Due to the increasing population, most areas in Seremban were developed for residential use, with a total population of 633,100 in 2016 (Unit Perancang Ekonomi Negeri Sembilan, 2015). There are nine sub-districts under the jurisdiction of Seremban City Council (MBS), which are Seremban, Ampangan, Labu, Lenggeng, Pantai, Rasah, Rantau, Seremban town and Setul.

2.2. Description of the study material

In this study, the materials comprised data on HEC in Seremban. The researcher only selected the respondents living in Seremban to ensure only eligible respondents were selected and to get variability in terms of electricity consumption among urban households. The respondents were selected based on their willingness to participate in this research. After obtaining the approval of respondents, a set of questionnaire forms was given and recollected after respondents answered the questionnaire. Table 1 displays the summary of the respondent characteristics.

A household is generally defined as a group of related or unrelated persons who usually live together and make standard provisions for food, energy, and other living essentials. Therefore, only respondents residing in Seremban were prioritised in this study. Energy consumption is highly influenced by human activities in urban regions (Ali *et al.*, 2020b). The quantification of HEC is significant in seeking energy reduction and conservation potential, particularly in urban areas due to rising living costs. Therefore, crucial to define the type of electrical appliances ownership and total consumption among urban households. Meanwhile, housing types were determined based on the residential land use development classification stated in the Seremban development plan. The present study classified the housing types as flats, village/traditional houses, single-storey terraces, double-storey terraces, semi-detached, and bungalows.

This study used a face-to-face survey for data collection. Researchers went to one-by-one houses in the study area to distribute questionnaire forms. A questionnaire survey was distributed to 620 respondents in the entire study area for this study. However, only 400 completed questionnaires were returned, resulting in a response rate of 64.51%. The questionnaire form consisted of two main sections. The first, Section A, covered socio-economic background such as income level, occupation sector, and household size. Section B was related to housing characteristics such as type of house, number of rooms, appliance ownership, and duration of usage. The present study quantifies electricity consumption based on 11 electrical appliances, a refrigerator, a washing machine, a rice cooker, a ceiling fan, a television, a fluorescent lamp, an air conditioner, a standing fan, a vacuum cleaner, a light bulb, and a microwave. These selected items were based on households' most frequently used devices in the study area. The appliances were then categorised into three categories of appliances according to their purpose: cooling, lighting, and kitchen.

The quantification of HEC was implemented for one month, covering weekdays and weekends to ensure the total capacity of the electrical appliances was covered. This may influence the results as they may not necessarily represent the rest of the year. After that, information on HEC was manually calculated through direct measures, concentrating on total electricity consumption and cost, electricity consumption by housing types and appliances, key performance indicators (electricity consumption per capita, cost per capita, and emissions per capita), and material flows of electricity consumption. Lastly, all information was transferred into an Excel spreadsheet to record consumption flows. Fig. 2 shows the process of quantifying electricity consumption.

2.3. Data analysis

2.3.1. Direct measures of HEC and breakdowns

In the first analysis, data on HEC are presented and analysed to identify the electricity consumption pattern in each household. The quantification of electricity consumption refers to the whole electricity consumption from each appliance (Ali *et al.*, 2021). For this analysis, the HEC was determined according to the electrical appliances' possession (and usage), power rating, and duration of appliance usage (Olaniyan *et al.*, 2018). Generally, the total electricity consumption was measured using an electromechanical meter, Malaysia's most common electricity meter. Every month, the meter reader visits one house to another to read the meter. Smart electricity meters are currently

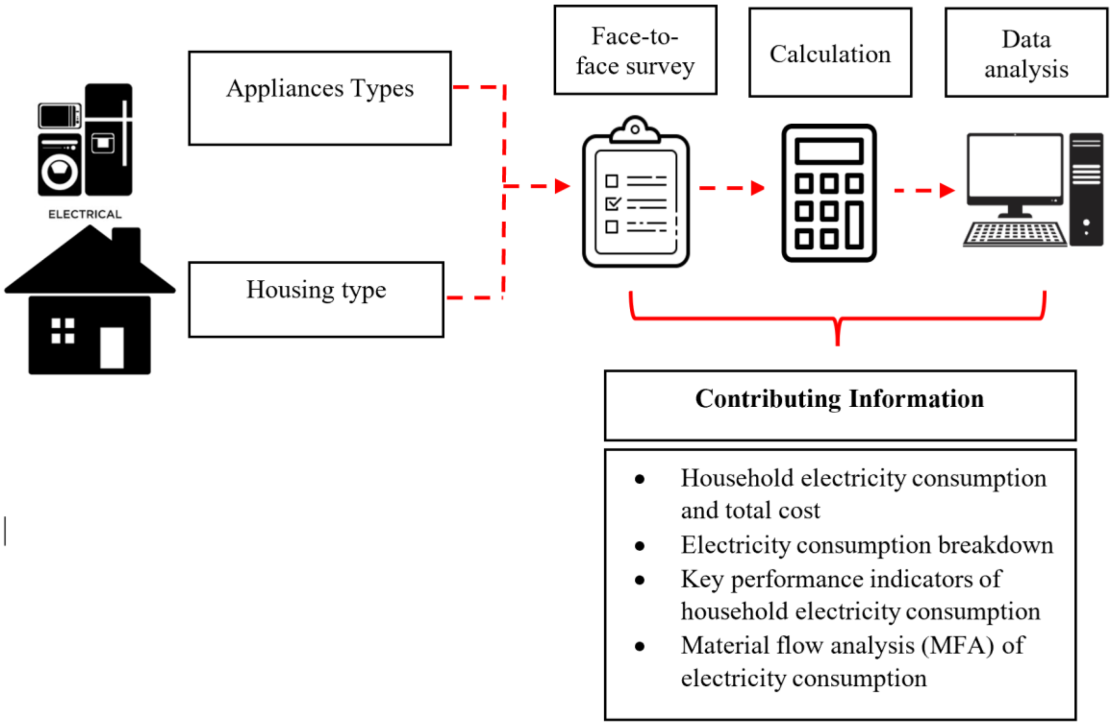

Fig. 2. Process of quantification of household electricity consumption (Source: Author's mapping)

not fully installed in Malaysia. Therefore, the total of HEC for one month is calculated using the equation below:

$$E_{ha} = \frac{\sum_{i-1}^{n}(Ri \times Hi \times Qi)}{1000} \times 30 \text{ days} \quad (1)$$

Where E_{ha} is the total electricity consumption by each household in kilowatts per hour (kWh/month), R_i is the power rating of each used appliance, H_i is the duration of each appliance's operation, and Q_i is the number of appliances. All the daily consumption data were converted to monthly usage (30 days), as commonly practised by Tenaga Nasional Berhad (TNB). TNB is the largest electricity utility in Malaysia, with about 9.2 million customers in Peninsular Malaysia, Sabah, and Labuan. The quantification of HEC is determined starting from the beginning that appliances are used until shut down daily. Therefore, the total electricity consumption for one day is calculated using the equation below:

$$E_{ha} \text{ for 1 day} = \frac{Total\ electricity\ consumption\ for\ 1\ month}{30\ days} \quad (2)$$

in the household sector used to investigate the electricity consumption per capita level by housing types in the study area. The KPIs quantification of HEC concentrated on electricity consumption per capita, electricity cost per capita, and emissions per capita. In this light, quantifying the electricity consumption baseline could provide more critical information regarding HEC and a solution for reducing electricity consumption in urban regions. A previous study by Kasavan *et al.*, (2021) highly influenced the quantification guidelines. The study made some adjustments to align with electricity consumption in urban areas. The modification was made to ensure the quantification is representative of each household. Electricity consumption per capita is the whole electricity consumption from each household in the study area. This measurement could provide additional information towards reducing electricity consumption among urban households. The quantification of electricity consumption per capita can be calculated using the equation below:

$$Electricity\ consumption\ per\ capita = \frac{\sum_{i=1}^{n} X_i\ (total\ electricity\ consumption\ for\ 1\ month)}{\sum_{i=1}^{n} Y_i\ (size\ of\ household)} \quad (3)$$

Xi refers to the total electricity consumption for one month, while *Yi* is the size of the household of Seremban. The electricity cost per capita can be defined as the total cost of electricity consumption from each household in the study area. This quantification could offer valuable data about electricity expenses for each household and strategies to reduce the cost of electricity. The quantification of electricity cost per capita can be calculated using the equation below:

$$Electricity\ Cost\ per\ capita = \frac{\sum_{i=1}^{n} M_i\ (total\ electricity\ cost\ for\ 1\ month)}{\sum_{i=1}^{n} Y_i\ (size\ of\ household)} \quad (4)$$

Mi refers to the total electricity cost per capita for one month, while *Yi* is household size. Meanwhile, emissions per capita refer to the total emissions generated from electricity consumption from each household in the study area. The calculation is significant for quantifying release emissions by each household via electricity consumption.

$$Emissions\ per\ capita = \frac{\sum_{i=1}^{n} K_i\ (total\ emissions\ for\ 1\ month)}{\sum_{i=1}^{n} Y_i\ (size\ of\ household)} \quad (5)$$

Therefore, overall electricity consumption per capita, electricity cost per capita and emissions per capita can be calculated by dividing the total of each indicator for one month (electricity, cost, and emissions) and household size.

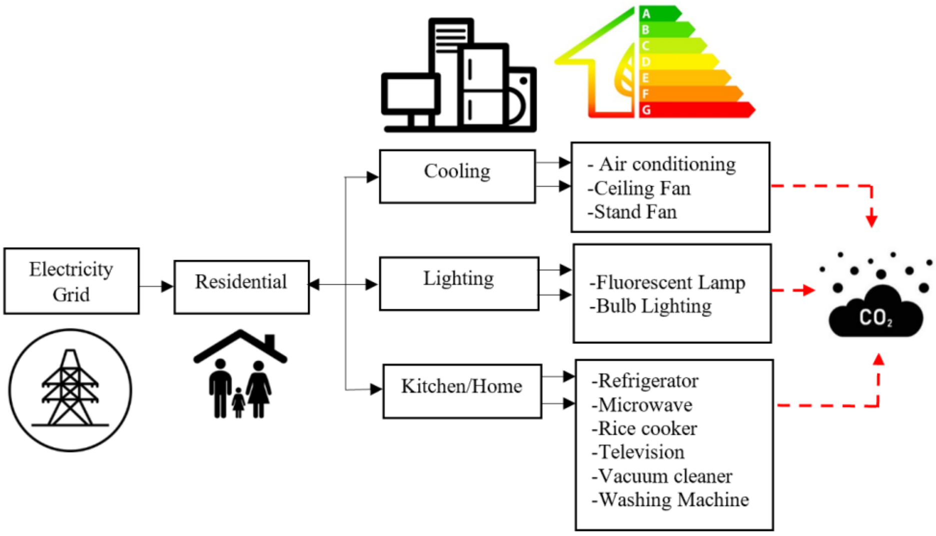

Fig. 3 Energy flow diagram in Seremban

2.3.2. Material Flow Analysis (MFA) of electricity consumption

MFA is a technique that can explain a system's resource consumption. MFA is a systematic tool used to measure and analyse material flow distribution in a specific time and space scale. MFA is also used to study the laws of material metabolism by exploring the relationship between material flow, resource consumption, and socio-economic development. MFA is the only technique connecting resources from the input to output generation (Turner *et al.*, 2016). MFA has been widely used in various fields to analyse the flow of energy and materials, such as the stock and flow of cement (D. Hu *et al.*, 2010), wood resources (Nissing & Von Blottnitz, 2007), stainless steel (Kolby *et al.*, 2017), wastewater pipeline network (Pauliuk *et al.*, 2014), biomass energy (Hanserud *et al.*, 2017), food waste (Kasavan, Ali, Ali, *et al.*, 2021) and many more. MFA application is significant for providing meaningful information and data on electricity consumption as this aspect is crucial for present and future urban planning. The MFA analysis has three essential components: systems, input, process, and flow. Systems can be defined as a group of elements, interactions, boundaries, and other elements in space and time; the process can be defined as the transformation, transport, or storage of the materials, while flows can be defined as the rate of mass flow (Kasavan, Ali, Ali, *et al.*, 2021). In the present study, the MFA section consists of two parts; the first part focuses on the results from Sankey diagrams on household electricity consumption without energy-efficiency appliances (WEEA) based on two indicators: the type of house and appliance ownership. The second part includes results of electricity consumption with energy-efficiency appliances (EEA) on evaluating Sankey diagrams for tracking potential electricity saving, cost saving and emissions reduction.

The production of energy diagram can be summarised as presented in Fig. 3. For this analysis, the HEC is considered an overall input of electrical power used by each appliance. After that, the flow of electricity consumption will be analysed and presented using a Sankey diagram to portray the overall consumption for each appliance and housing type. For this analysis, the total electricity consumption will be used to illustrate the flow of electricity consumption. Furthermore, the study also concentrated on the use of energy-efficiency products. The Malaysian government has categorised several appliances under a 5-star energy rating: refrigerator, microwave, rice cooker, television, fluorescent lamp, and air conditioning. Information regarding the flow of electricity consumption is crucial for energy reduction at the urban scale. Households can be more aware of their energy consumption, and they are ensuring energy saving and efficiency can be achieved.

3. Results

This section presents the main results of HEC to understand the scale and pattern of electricity consumption in Seremban. This study considers the quantification of HEC based on two indicators: the type of house and appliance ownership. The analysis assumes that the quantification of HEC, KPI and energy consumption breakdown was calculated using non-energy-efficiency appliances. Moreover, in the MFA section, we compared the quantification of electricity consumption without energy-efficient appliances and with 5-star efficiency appliances based on potential electricity saving, cost saving and emissions reduction. In this study, the power rating of each appliance was determined based on the standard power rating suggested by Tenaga Nasional Berhad (TNB), the primary electricity provider in Malaysia.

3.1. Household electricity consumption and total cost

This analysis cooperated direct measures of HEC based on the number of appliances owned and the duration of usage. According to survey data, the study revealed that the total household electricity consumption for one month in Seremban was 258,036.33 kWh, with an average consumption per house of 645.09 kWh/day. Based on the current electricity tariff (see Table 2), 49% of the households consumed about 300-600 kWh/month with an estimated cost of MYR231.80 per month, while 37.5% of the households utilised 601-900 kWh per month with an estimated cost of MYR395.60 per month. About 12.25% of households recorded the highest electricity consumption (above 901 kWh/month), with an average monthly cost of more than MYR396.00. The remaining respondents (1.25%) consumed about 1 to 200 kWh/month with an estimated cost of about MYR43.60 per month.

The study showed that electricity consumption in Seremban varies according to housing types due to the socio-economic background of the user. The study revealed that spacious houses such as bungalows utilised more electricity than other houses such as flats and traditional/village houses. As shown in Table 3, the lowest electricity consumption was

Table 2
Current electricity tariff

Respondent (%)	Tariff category	Current Rate (per kWh)	Estimated Cost (MYR/month)
1.25	For the first 200 kWh (1 - 200 kWh) per month	21.80	43.60
0	For the next 100 kWh (201 - 300 kWh) per month	33.40	77.00
49	For the next 300 kWh (301 - 600 kWh) per month	51.60	231.80
37.5	For the next 300 kWh (601 - 900 kWh) per month	54.60	395.60
12.25	For the next kWh (901 kWh onwards) per month	57.10	>396.00

Table 3
Total electricity consumption and cost for one month

Type of House	Units	Total consumption (kWh)	Average consumption per unit for 1 month (kWh)	Total cost for 1 month [a] (MYR)	Average cost per unit for 1 month [a] (MYR)
Flats*	15	6902.52	460.17	1504.75	100.32
Traditional/Village House	20	11,201.44	560.07	2441.91	122.09
Single Story Terrace	196	114,371.86	583.53	24,933.07	127.21
Double Story Terrace	91	62,848.69	690.64	13,701.01	150.55
Semi-Detached	38	27,274.9	717.76	5945.92	156.47
Bungalow	40	35,437.02	885.93	7725.27	193.13

*Including flat, condominium and apartment, [a] Based on the current electricity tariff, which is MYR 0.218 for the domestic sector, 1 month is equivalent to 30 days

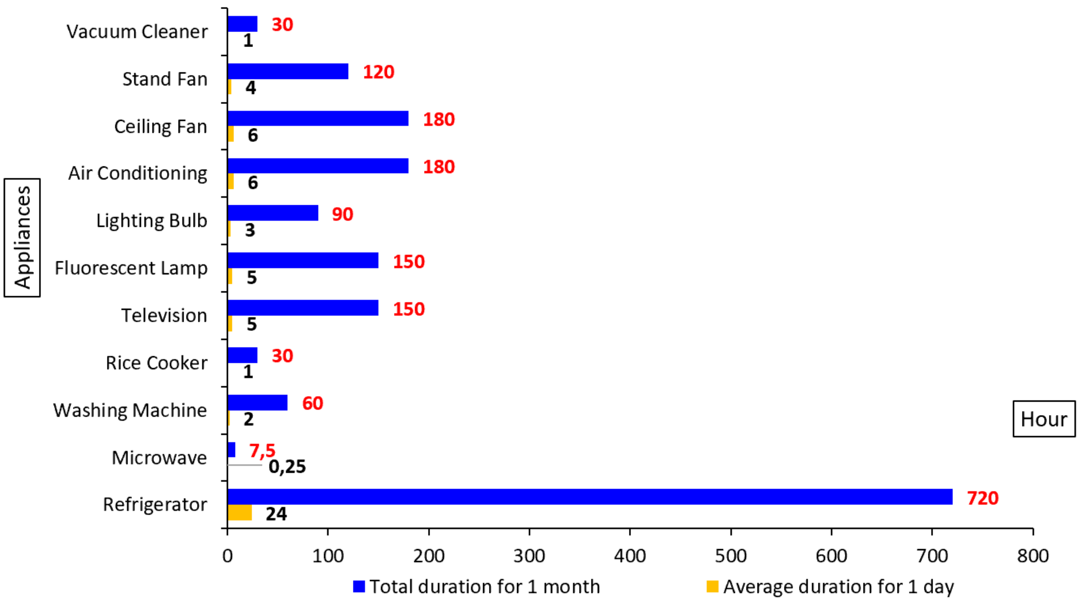

Fig 4. Total and average duration by type of appliances (hour)

from flats, with a total consumption of 6902.52 kWh for one month. The flats expensed the least cost for electricity bills, approximately MYR100.32 for one month based on the current tariff. Meanwhile, bungalows recorded high average electricity consumption (885.93 kWh/units), which is probably influenced by the respondents' socio-economic status, the physical size of the houses, and the number of appliances owned. A spacious house is believed to consume more electrical power, particularly for heating and cooling, as posited by Kubota and Ahmad, (2005) and Wijaya and Tezuka, (2013). Furthermore, bungalows expensed higher costs for electricity bills, approximately MYR 193.13 for one month, followed by a semi-detached house (MYR 156.47) and a double-storey terrace (MYR 150.55).

3.2. Electricity consumption breakdowns

Table 4 revealed electricity consumption breakdowns by appliances and type of house. Refrigerators, fluorescent lamps, air conditioning, and ceiling fans recorded high electricity consumption compared to other appliances such as microwaves, standing fans and vacuum cleaners. For instance, refrigerators consumed more than 50% of the total electricity consumption in Seremban due to its 24 hours operation, while microwaves and vacuum cleaners consumed less electricity in flats and single-storey terraces. Meanwhile, the refrigerator (38.1%) and air conditioning (26.6%) consumed the highest electrical power, while the stand fan (1.2%) and vacuum cleaner (1.36%) consumed the least electricity in the bungalow. The air conditioning also increased electricity consumption due to the high-power rating compared to other appliances (such as

Table 4
Percentage of electricity consumption by type of house and appliance

Appliances categories	Appliances	Flats (%)	Traditional/Village House (%)	Single Story Terrace (%)	Double Story Terrace (%)	Semi-Detached (%)	Bungalow (%)
Kitchen/Home Appliances	Refrigerator	**58.4**	**54**	**49.6**	**45.4**	**47.5**	**38.1**
	Microwave	0	1.22	0.78	1.24	1.21	1.47
	Washing Machine	2.21	2.94	2.7	2.13	2.23	2.57
	Rice Cooker	2.29	3.38	3.57	2.63	2.70	2.63
	Television	**4.90**	4.80	4.48	4.07	3.72	3.96
	Vacuum Cleaner	0.19	1.10	0.76	1.43	1.27	1.36
Lighting Appliances	Fluorescent Lamp	4.72	**7.10**	**4.80**	**5.14**	**5.19**	**7.51**
	Bulb Lighting	1.26	3.20	2.74	2.03	1.65	2.50
Cooling Appliances	Air Conditioning	**17.34**	**5.62**	**15.91**	**21.7**	**21.7**	**26.6**
	Ceiling Fan	**6.99**	**11.9**	**12.06**	**12.2**	**11.1**	**12.1**
	Stand Fan	1.70	4.74	2.60	2.03	1.73	1.20

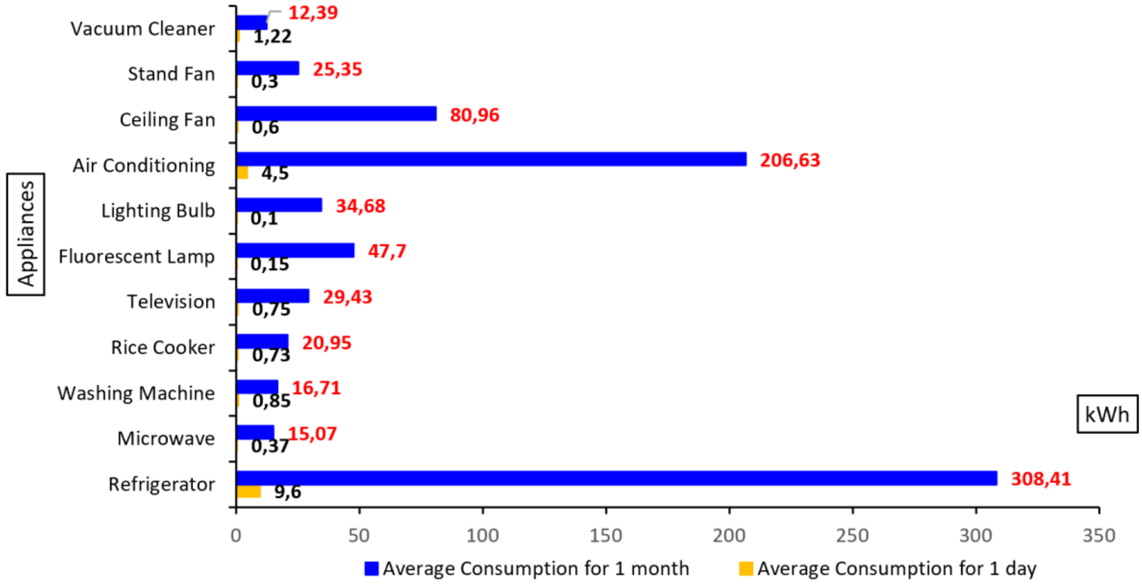

Fig 5. Total and average consumption by type of appliances (kWh)

vacuum cleaners and stand fans), which are used for a shorter time

Figure 4 also indicates that the duration of electrical usage influences the higher cost of electricity. The duration of use of each appliance was gathered from the survey. During the survey, information on the duration and number of appliances was provided by each household. For instance, refrigerators were operated 24 hours a day, air conditioners and ceiling fans were operated for about 6 hours per day, and fluorescent lamps and television were operated for about 5 hours per day (Fig. 4). The analysis also indicated that the appliance duration usage probably influences average electricity consumption (kWh/day). For instance, the average consumption for a refrigerator was about 9.6 kWh/day, followed by an air conditioner (4.5 kWh/day) and other appliances, as seen in Fig. 5. In this light, the average electricity consumption increases the duration of use of the home appliance and the power rating required for each appliance.

3.3. Key Performance Indicators (KPIs) for electricity consumption

This section presents the main result of key performance indicators for electricity consumption in Seremban, as shown in Table 5. The study revealed that a spacious house has a higher electricity consumption per capita. For instance, bungalows recorded the highest electricity usage per capita (407.32 kWh/month), followed by double-storey terraces (363.28 kWh/month) and semi-detached houses (328.61 kWh/month). Meanwhile, the minor electricity consumption per capita is traditional/village houses (266.70 kWh/capita). Regarding cost per capita, respondents from the bungalow spent about MYR 88.80 for one month, followed by a double-storey terrace (MYR 79.20 /month) and semi-detached (MYR 71.64/month).

Meanwhile, the result indicated a significant relationship between high carbon emissions and high electricity consumption in Seremban. Bungalows released about 276.97 kgoe/month of carbon emissions, followed by double-storey terraces (247.04 kgoe/ month) and semi-detached houses (223.46 kgoe/month). In contrast, minor carbon emissions were released from traditional/village houses (181.36 kgoe/month). Furthermore, respondents paid high electricity bills due to appliances' high-power ratings. A previous study indicated that heating and cooling appliances such as air conditioning released high greenhouse gas emissions compared to other appliances, such as vacuum cleaners, which are used for a short period (Ali

Table 5
Average of electricity consumption, cost and emissions output by type of house (per capita).

Housing type	Size of household	Total consumption for 1 month (kWh)	Total consumption per capita for 1 month (kWh)	Total cost for 1 month (MYR)	Cost per capita for 1 month [a] (MYR)	CO_2 emissions for 1 month (kg)	CO_2 emissions per capita for 1 month (kg) [b]
Flats*	22	6902.52	313.75	1504.75	68.40	4693.71	213.35
Traditional/Village	42	11,201.44	266.70	2441.91	58.14	7616.98	181.36
Single Story Terrace	364	114,371.86	314.21	24,933.07	68.50	77,772.86	213.66
Double Story Terrace	173	62,848.69	363.29	13,701.01	79.20	42,737.11	247.04
Semi-Detached	83	27,274.9	328.61	5945.93	71.64	18,546.93	223.46
Bungalow	87	35,437.02	407.32	7725.27	88.80	24,097.17	276.97

* Including flat, apartment, and condominium, [a] Based on the current electricity tariff, which is MYR 0.218 for the domestic sector, [b] 1 kWh is equivalent to 0.68 kg of CO_2

Table 6
Average of electricity consumption, cost and emissions output by appliances ownership

Appliances Types	Number of appliances	Power Rating without energy efficiency [a]	Total consumption for 1 month (kWh)	Average consumption per appliances for 1 month (kWh)	Average cost per appliances for 1 month (MYR) [b]	Average CO_2 emissions per appliances for 1 month [c] (kgoe)
Refrigerator	395	400	121,824.0	308.41	67.23	209.72
Microwave	177	1500	2668.78	15.08	3.29	10.25
Washing Machine	382	425	6384.49	16.71	3.64	11.36
Rice Cooker	380	730	7961.46	20.95	4.57	14.25
Television	372	150	10,948.01	29.43	6.42	20.01
Vacuum Cleaner	220	1220	2725.95	12.39	2.70	8.43
Fluorescent Lamp	292	30	13,930.32	47.71	10.40	32.44
Bulb Lighting	179	36	6207.98	34.68	7.56	23.58
Air Conditioning	237	750	48,973.39	206.64	45.05	140.52
Ceiling Fan	378	100	30,606.3	80.97	17.65	55.06
Stand Fan	229	75	5805.75	25.35	5.53	17.24

[a] Based on TNB classification (2021), [b] Based on current electricity tariff which is MYR 0.218 for domestic sector, [c] 1 kWh is equivalent to 0.68 kg of CO_2

et al., 2020b). As indicated in Table 6, each household spent around MYR 67.23 for one month with a refrigerator (used 24 hours) and MYR 45.04 for one month for air conditioning, while less than MYR 10.00 for one month was spent on other appliances (microwave, washing machine, rice cooker, television, light bulb, standing fan and vacuum cleaner). Regarding average emissions for one month, appliances such as refrigerators (209.72 kgoe), air conditioning (140.52 kgoe) and ceiling fans (55.06 kgoe) released high carbon emissions, while other appliances released minor carbon emissions

.

3.4. Material Flow Analysis

3.4.1. Electricity consumption without energy-efficiency appliances (WEEA)

As illustrated in Fig. 6, the electricity consumption flow without energy-efficiency appliances (WEEA) indicated that traditional/village houses had a total consumption of 11,201.44 kWh for one month, with a total consumption per capita for one month of 266.70kWh. Specifically, 67.44% of the total electricity consumption in a traditional/village house was allocated for kitchen/home appliances, such as refrigerators, microwaves, washing machines, rice cookers, televisions, and vacuum cleaners. Meanwhile, 22.26% of electricity in a traditional/village house was allocated for cooling appliances such as air conditioning, ceiling, and standing fans. In contrast, the remaining electricity (10.3%) was dedicated to lighting appliances such as fluorescent lamps and light bulbs.

The electricity consumption in single-storey terraced houses indicated similar results. A total of 114,371.86 kWh for one month was recorded for this type of house, with the total consumption per capita for one month being 314.21 kWh. The high electricity consumption from this type of house is probably due to the increased sample size, as this dwelling type is the most prevalent in Seremban. In a single-storey terrace house, refrigerators consumed nearly 49.6% of electricity, followed by air conditioning (15.91%), and ceiling fans took up 12.06%. Meanwhile, microwaves and vacuum cleaners remained the lowest electrical appliances in terms of consumption (1.54%). The study also found that the total electricity consumption in double-storey terraced houses was 62,848.69 kWh for one month, with the total consumption per capita for one month being 363.29 kWh. The MFA identified that refrigerators, air conditioning, and ceiling fans consumed nearly 79.3% of the electricity flow in double-storey terrace houses. The results revealed that the total electricity consumption in semi-detached houses was 27274.9 kWh for one month, with an average consumption of 328.61 kWh per capita. From the total, MFA results revealed that refrigerators, air conditioners, and ceiling fans consumed 80.3% of the total electricity consumption, while the lowest electricity consumption was by microwaves (1.21%), standing fans (1.73%), light bulbs (1.65%), and vacuum cleaners (1.27%).

Moreover, 84.31% of electricity in bungalows was consumed by refrigerators, fluorescent lamps, air conditioners, and ceiling fans compared to other appliances such as microwaves, standing fans, and vacuum cleaners. The high electricity consumption in bungalow houses is probably for cooling and lighting as these houses are more spacious than other types of houses. Meanwhile, the total electricity consumption in flats was 6902.52 kWh for one month, with an average consumption of 313.75 kWh per capita for one month. Appliances such as refrigerators, air conditioning, ceiling fans and fluorescent lamps dominated electricity consumption in bungalows, while other appliances consumed less electricity.

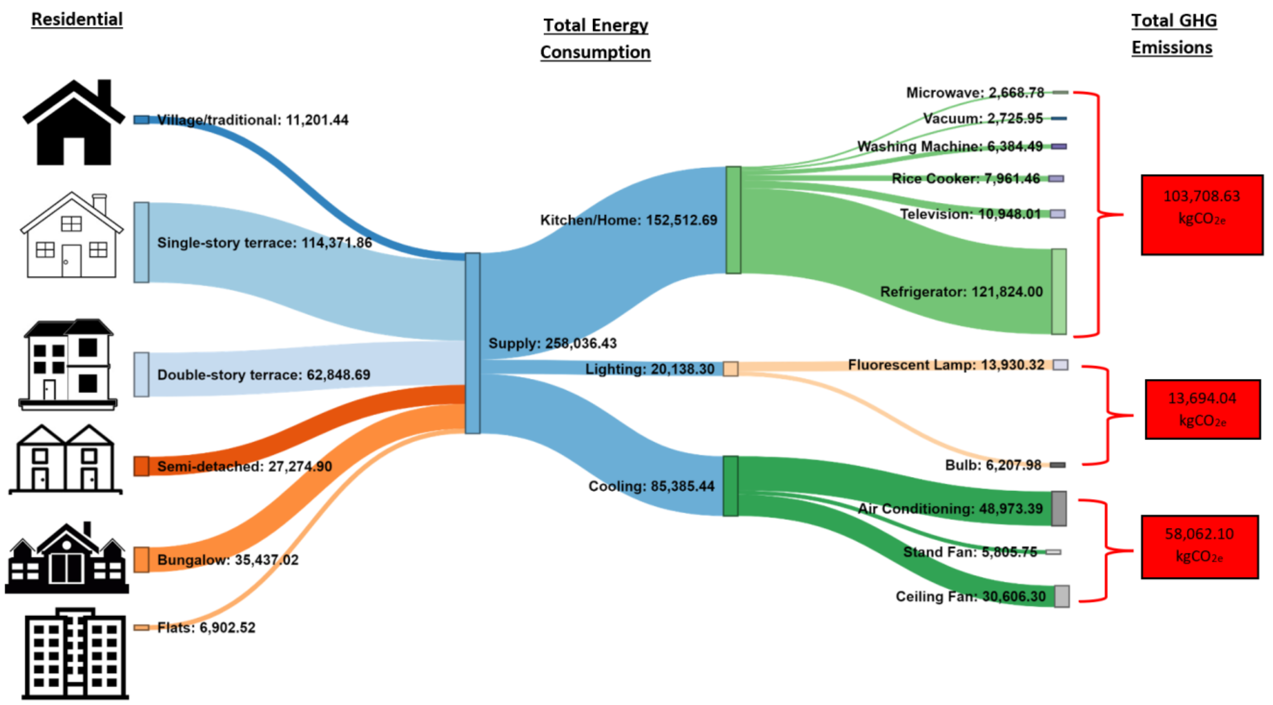

Fig 6. Sankey diagram of energy consumption among households without energy saving (5-star efficiency) (kWh/month) (Source: Author's mapping by using Sankeymatic.com)

Similarly, electricity consumption in flats was dominated by refrigerators, air conditioners, and ceiling fans. The analysis also revealed that bulbs, standing fans, vacuum cleaners, and microwaves consumed less of the electricity used by appliances in flats. The MFA also indicated an approximate total of 103,708.62 kg CO_{2e} for one month, or 59.1% of the carbon emissions, were released from home/kitchen appliances, 33.09% (58,062.10 $kgCO_{2e}$ for one month) emitted by cooling appliances, and 7.81% (13,694.04 $kgCO_{2e}$ for one month) of the carbon emissions were released by lighting appliances in Seremban.

3.4.2. *Electricity consumption with energy-efficiency appliances (EEA)*

The Ministry of Energy, Green Technology and Water (NEEAP, 2015) introduced the National Energy Efficiency Action Plan, which focused on promoting minimum energy performance standards (MEPS) to ensure productive energy use and minimise waste. Under this action plan, several appliances were considered energy efficient, such as refrigerators, microwaves, rice cookers, televisions, fluorescent lamps and air conditioning. For example, a refrigerator and fluorescent lamp with 5-star energy efficiency can save energy consumption by 25% compared to other appliances without 5-star efficiency, followed by microwave (65%) and television (70%). The highest electricity saving with 5-star energy efficiency was for a rice cooker (89%), while the lowest electricity saving with 5-star energy efficiency was for air conditioning (15%).

Figure 7 demonstrates electricity consumption flow using energy-efficiency appliances (EEA). The material flow analysis depicted that electricity consumption reduction has more significance to achieved through EEA. As indicated in Table 7, the highest electricity saving was identified from a single-storey terrace, whereby EEA's total electricity consumption was 41,749.82 kWh for one month and an average consumption of about 199.51 kWh per capita for one month. The result depicted that a potential electricity saving for a single-storey terrace of around 114.69 kWh per capita for one month or MYR 303.38 can be saved through EEA. The result also shows a significant potential emissions reduction with about 77.99 $kgCO_2e$ per capita for one month.

The total electricity consumption with EEA in traditional/village houses was about 7924.07 kWh for one month, with an average consumption of 188.67 kWh per capita. It was anticipated that a potential electricity saving of around 78.03 kWh per capita for one month or MYR17.01 could be saved per person through EEA in traditional/village houses. Based on Figure 6, the results revealed the potential reduction in emissions was about 675.95 $kgCO_{2e}$ per capita for one month. According to Kasavan *et al.* (2021), household energy consumption varies from region to region due to weather conditions and social customs. Jones and Lomas, (2016) found a similar result, which stated that adopting energy-efficient appliances contributed to savings on monthly bills and minimising carbon emissions.

Total electricity consumption using EEA in the double-storey terraces was about 37,236.73 kWh for one month, averaging 215.24 kWh per capita. Using EEA, the potential of energy saving in a double-storey terrace can be up to 40.75%, with a significant reduction in energy consumption via the use of 5-star energy-efficiency appliances such as refrigerators, microwaves, rice cookers, televisions, fluorescent lamps and air conditioning. Similarly, the total electricity consumption using EEA in semi-detached houses was 15,874.92 kWh for one month, with an average of about 191.26 kWh per capita per month. The potential energy saving from semi-detached houses is expected to be up to 41.80% using EEA. The potential cost saving of around MYR 29.94 per capita for one month, and the potential reduction in emissions was about 93.40 kgCO2e per capita for one month.

Meanwhile, total electricity consumption using EEA in bungalow houses was 19,118.34 kWh for one month, with an average consumption of about 219.75 kWh per day. The potential energy savings in bungalow houses can be up to 46.05%, mainly from kitchen/home and cooling appliances

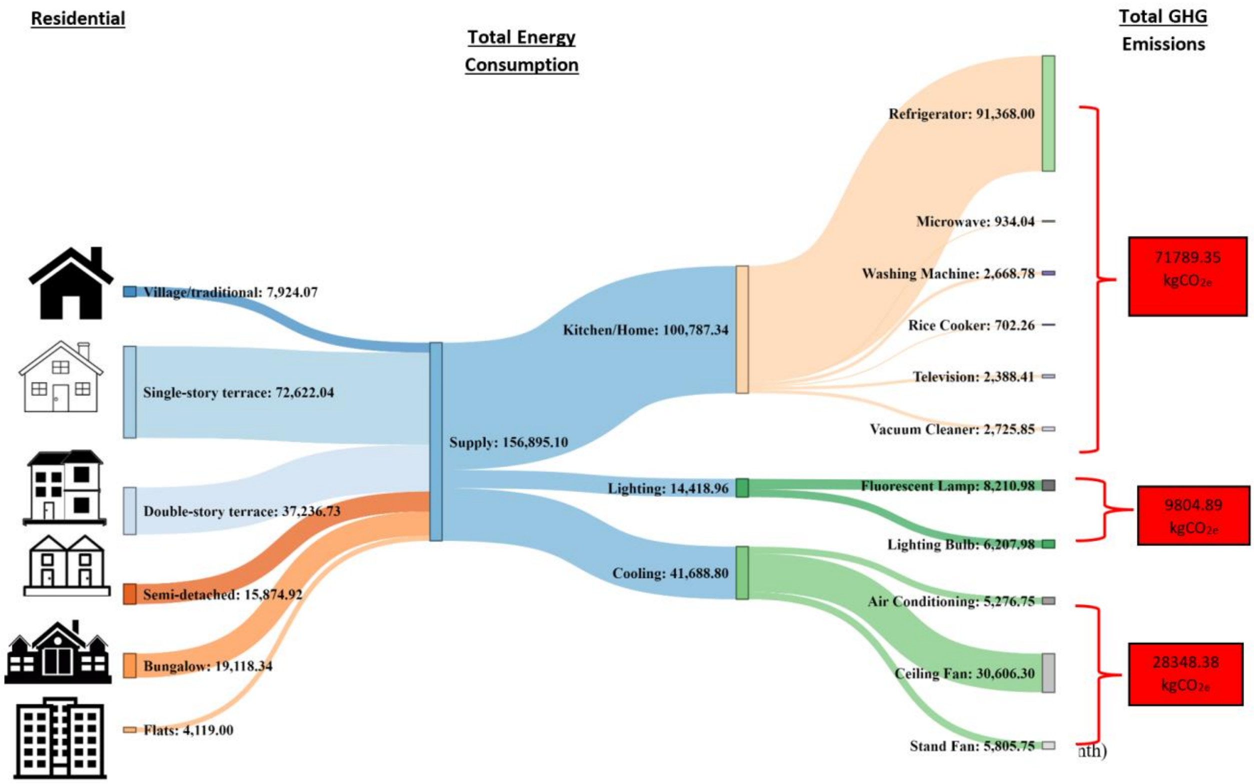

Fig 7. Sankey diagram of energy consumption among households with energy saving (5-star efficiency) (kWh/month) (Source: Author's mapping by using Sankeymatic.com)

such as refrigerators and air conditioning. Potential cost savings of around MYR 40.89 per capita for one month, and potential reductions in emissions of about 127.54 kgCO2e per capita for one month were found. In flats, total energy consumption using EEA was about 4119 kWh for one month, with an average was about 187.23 kWh per capita for one month. Most electricity in flats was allocated for kitchen/home and cooling appliances. Using EEA, the energy that could be saved was roughly 40.33% compared to non-EEA. Therefore, this study's findings revealed that a massive amount of energy could be saved through EEA as each housing type indicated potential energy savings ranging from 29 to 46% for one month.

As indicated in Table 8 (refer at appendix), the analysis revealed that total potential electricity saving is projected to reach about 57786.61 kWh/ per month with a total cost saving for one month of about MYR 12,597.48 using energy-efficiency appliances. The highest electricity saving was contributed to by refrigerators (30,456 kWh/month), televisions (7663.61 kWh/month) and air conditioning (7364.01 kWh/month). The result also depicted that refrigerator contributed the highest cost saving, with a total estimated saving of about MYR6639.41 per month or MYR221.31 per day. The refrigerators are also expected to contribute the highest potential emission reductions with a total of 20710.08 kgoe/month or 690.336 kgoe/day due to the total ownership of the refrigerator being the highest among other appliances.

The awareness and knowledge of the user contributed to the considerable potential for energy and cost savings and; they were promoting reducing carbon emissions, particularly in urban regions. The material flow analysis showed potential energy savings are approximately 22.39% using EEA compared to non-EEA, with a significant percentage of electricity consumption allocated for refrigerators (35.41%), followed by air conditioning (12.74%) and other appliances. Potential cost savings from kitchen appliances were MYR 10,233.93 for one month, followed by cooling appliances (air conditioning) of MYR 1605.35 for one month and lighting appliances (fluorescent lamp) of MYR 759.20 for one month. The potential reductions in emissions from kitchen appliances was 31,918.85 kgCO2e for one month, followed by cooling appliances (air conditioning) of 5007.53 kgCO2e for one month and lighting appliances (fluorescent lamp) of 2368.15 kgCO2e for one month.

4. Discussion

Even though the unsustainability of HEC seems a common problem in developed and developing countries, finding a sustainable solution for the Energy Efficiency of Urban Metabolism is challenging, particularly in a growing city such as Seremban. Tenaga Nasional Berhad (TNB) is the primary electricity provider in Malaysia, and the electricity tariff classification by TNB is based on business activity and supply voltage level. For example, the pricing for domestic, commercial, industrial, mining, specific agriculture, and street lighting electricity consumption are all calculated separately in the electricity tariff system. For residential use, a progressive rate structure is implemented according to electricity consumption volume to save energy and protect low-income groups from rising energy prices. Besides that, the Sustainable Energy Development Authority of Malaysia (SEDA) introduced the Feed-in Tariff (FiT) in 2011. Under this tariff, 1% of the electricity tariff from consumers (except for low-income consumers with an average monthly electricity consumption of <200 kWh) is utilised to assist the growth of renewable energy and reduce CO_2. The study found that the majority of respondents (49%) consumed about 300-600 kWh/month of electricity with an estimated cost of MYR231.80 per month. According to Energy.Gov, (2022), low-income households face an energy burden three times higher than other households. The

Table 7
Potential electricity and cost saving and emissions reduction with using 5-star energy efficiency-based housing type

Type of house	Total consumption without using 5-star energy efficiency for 1 month (kWh)	Average consumption without using 5-star energy efficiency for 1 day (kWh) *(30 days)	Total consumption with using 5-star energy efficiency for 1 month (kWh)	Average consumption with using 5-star energy efficiency for 1 day (kWh) *(30 days)	Potential Electricity Saving for 1 month (kWh)	Potential Electricity saving for 1 day a (kWh) *(30 days)	Cost saving [a] (MYR/month)	Cost saving (MYR/day) *(30 days)	Potential emissions reduction [b] (kgoe/month)	Potential emissions reduction (kgoe/day) *(30 days)
Flats*	6902.52	230.08	4119.00	137.3	2783.52	92.78	606.81	20.23	1892.79	63.09
Traditional/Village	11,201.44	373.38	7924.07	264.14	3277.37	109.25	714.46	23.82	2228.61	74.28
Single Story Terrace	114,371.86	3812.40	72,622.04	2420.73	41,749.82	1391.66	9101.46	303.38	28,389.88	946.33
Double Story Terrace	62,848.69	2094.95	37,236.73	1241.22	25,611.96	853.73	5583.41	186.11	17,416.13	580.54
Semi-Detached	27,274.9	909.2	15,874.92	529.16	11,399.98	380.00	2485.20	82.84	7751.99	258.40
Bungalow	35,437.02	1181.23	19,118.34	637.28	16,318.68	543.96	3557.47	118.58	11,096.70	369.89

* Including flat, apartment, and condominium, [a] Based on current electricity tariff which is MYR 0.218 for domestic sector, [b] 1 kWh is equivalent to 0.68 kg of CO_2

findings are consistent with Velody *et al.*, (2003) low-income households spend the most each month on energy costs after food expenses.

Besides that, the study found that respondents' socio-economic status, the physical size of the houses, and the number of appliances owned also influence energy consumption. For example, households in flats (460.16 kWh/units) recorded less average electricity consumption than bungalow households (885.93 kWh/units). Therefore, the size of house played a significant role in electricity consumption in Seremban, as bigger houses required more electricity consumption, especially for cooling and lighting. A study by Huang, (2015) and Hu *et al.*, (2020) indicated that the size and design of a house are very significant in determining the electricity consumption for heating and cooling, which is the most crucial component of residential building energy consumption. Specifically, Hu, (2017) found that a bigger house size (floor-to-ceiling height) will lead to higher electricity consumption for cooling and lighting, although the floor area of the house is equal. Conversely, Wyatt, (2013) reported that bungalow houses in England recorded low electricity consumption as they are usually inhabited by the elderly.

The study also revealed that HEC is highly influenced by electrical appliance ownership, particularly refrigerators and air conditioning, compared to other appliances such as microwaves, standing fans and vacuum cleaners. For instance, refrigerators and air conditioning also increase electricity consumption due to the large amounts of energy used to maintain a steady temperature. This result is consistent with the study by Kubota *et al.*, (2011), which found that large electricity-consuming appliances were refrigerators and air conditioners. Similarly, Zhou and Teng, (2013) mentioned that households with refrigerators would use high amounts of electricity compared to households without refrigerators. These findings imply that the rebound effect was significant for air conditioners and refrigerators due to energy efficiency providing smaller energy consumption reductions than other appliances.

In addition, this study found that appliance duration usage probably influences average electricity consumption (kWh/day). For instance, the average energy consumption for refrigerators was about 9.6 kWh/day due to operating 24 hours, and the air conditioner was about 4.5 kWh/day due to operating 6 hours. Malaysia has hot and humid weather (with average daily temperatures ranging from 21 °C to 32 °C) all year, so air conditioning is becoming a common cooling appliance. Air conditioning consumes 53% of the electricity consumption in Malaysian buildings, both commercial and residential, to ensure the thermal comfort of the occupants (Shaikh *et al.*, 2017). Ahmad and Othman, (2014) also indicated a similar result, mentioning that air conditioning presented high electricity consumption, comprising 76% of the average electricity cost in Brunei. Aldossary *et al.*, (2015) also stated that 73% of households in Saudi Arabia use air conditioning for about 10 to 24 hours per day because natural ventilation fails to provide cooling in an arid country like Saudi Arabia. Therefore, cooling appliances are highly utilised in tropical and desert countries due to the hot climate compared to western or European countries.

This study also revealed that the rate of greenhouse gas emissions and the total cost are parallel with the total electricity consumption in Seremban. This finding can also be found in the study by Begum *et al.*, (2017), suggesting that the more electricity consumed, the more carbon emission emitted. Cooling appliances used higher amounts of electricity and contributed to increased greenhouse gas emissions in Seremban. Hertwich and Roux, (2011) also presented that cooling appliances consumed high electricity (1000 kWh/year) and contributed to about 90 to 1000 $kgCO_2e$ greenhouse gases e mission in Norway. These facts supported other findings that residential and commercial buildings produce 7.9% of greenhouse gas emissions, and 60-70% of that comes from urban areas (Satterthwaite, 2008). Therefore, investigating factors that influence electricity consumption is crucial in moving towards more sustainable electricity consumption while simultaneously minimising greenhouse gas emission effects in urban areas.

To date, there has been little agreement on the actual impact of energy-efficient appliances on residents' electricity consumption. The present study was designed to compare the quantification of electricity consumption without energy-efficient appliances and with 5-star energy-efficiency appliances via MFA. This study considers the MFA analysis based on two indicators: the type of house and appliance ownership. The information from the MFA helps users understand the potential electricity saving, cost saving and emissions reduction with and without 5-star-rated energy-efficiency appliances in growing cities. The material flow analysis shows that energy savings are approximately 22.39% with EEA compared to non-EEA. This study found that potential cost savings were MYR 12,597.48 for one month, and the potential reduction emission was about 39,294.53 kgCO2e for one month using EEA compared to non-EEA. The results imply that EEA significantly impacts energy consumption, total costs and emissions compared to non-EEA.

The study indicated that RES can play a significant role in decarbonizing and reducing carbon emissions in urban regions. The ability of energy communities to integrate distributed energy resources, particularly within local energy systems, is crucial in assisting people worldwide in the shift to renewable energy sources and sustainable development (RES) (Kyriakopoulos, 2022). According to the International Energy Agency (IEA), renewable energy accounted for nearly 30% of global electricity generation in 2020, significantly contributing to carbon emissions reduction. For instance, solar photovoltaic (PV) systems produce electricity with negligible greenhouse gas emissions compared to coal-fired power plants, which emit approximately 820 grams of CO2 per kilowatt-hour (gCO2/kWh). The knowledge and perception on RES and technology also play a vital role in order to diversify the energy sources in various sector. For instance, study conducted by Drosos *et al*. 2021 revealed that increase environmental education programs in schools about renewable energy sources (RES) will increase environmental awareness among teachers and students, leading to greater active participation in efforts to "greenify" schools. Therefore, school administrators have a crucial role in implementing energy-saving measures in school buildings, thus it's important to educate and enlighten them about renewable energy technologies and possibilities (Ntanos *et al*., 2022).

5. Implications of the Study Findings

Based on the results, the highest electricity consumption was for kitchen/home appliances, followed by cooling and lighting appliances. According to the survey findings, energy-saving appliances are not being utilised to their full potential. Therefore, detailed information on housing type and appliance ownership are significant in understanding electricity consumption. In addition, there are only a few energy-efficient appliances on the market. The energy efficiency rating established by the Malaysian Energy Commission can only be met by five household appliances: refrigerators, televisions, microwave ovens, air conditioners, and washing machines (Malaysian Standard, 2017). Therefore, the findings suggest that the government must collaborate with various stakeholders to improve the Minimum Energy Performance Standard (MEPS) appliances by introducing additional 5-star ratings to the market for other appliances. Besides that, the study has the potential to stimulate economic activity in the green technology industry by encouraging investments in energy-efficient equipment and house retrofitting. Conventional products currently available on the market have been replaced with more energy-efficient products at a reasonable price. Policymakers can utilise the finding from the study to create more useful energy efficiency guidelines. Understanding the patterns and quantities of residential electricity usage allows policymakers to target regions with the greatest inefficiency. The government should also motivate customers by developing incentive programmes like sustainability Achieved via Energy Efficiency Programme (SAVE) for buying energy-efficient products with cash rebates via an e-commerce platform. Furthermore, promoting energy conservation guides via advertisements, smartphone apps, and social media was one way to encourage and gain knowledge of energy conservation among households. Therefore, government action is vital in promoting the use of energy efficiency appliances by introducing specific program and scheme in reducing tariff (Alberini & Umapathi, 2024). Besides that, identifying high-consumption patterns among households can lead to targeted initiatives to reduce electricity costs, resulting in significant long-term cost savings and mitigate the carbon emissions. The results offer a better understanding of energy flows within cities, which is essential for creating sustainable urban systems and boost the idea of urban metabolism.

6. Conclusion and future works

In the context of electric power, the residential sector continues to be one of the primary electricity consumers and is growing significantly, alongside the industrial and commercial sectors. Usually, people spend many hours daily in the house with their family and consume more electricity using various types of appliances. This paper presents a case study to help understand the current electricity consumption status among the 400 households in Negeri Sembilan, Malaysia. It indicates the necessity of conducting a comprehensive quantification of electricity consumption in various types of houses and by different appliances. The current research offers valuable insights for improving sustainable energy consumption and energy efficiency. These insights provide the platform for developing guidelines and strategies to improve household energy consumption and provide significant implications for Malaysia's electricity consumption policies. This study also helps researchers recognise electricity consumption hotspots in various household types with different appliances based on the mass flow analysis (MFA). In other words, this study visualises energy flow at the household level by creating Sankey diagrams to better understand potential electricity mitigation, cost saving and emissions reduction between EEA and non-EEA. However, this study has some limitations.

The results indicated that consumers need to use more energy-efficient electrical appliances based on the energy star rating to conserve energy in their homes. Future research may concentrate on developing energy-efficient electrical appliances to reduce energy consumption and environmental impacts and save money. Therefore, households, decision-makers, and the government may implement comprehensive and practical energy reduction measures by examining the key drivers of electricity consumption. A limit of the study is that we consider electricity consumption to be consistent daily, but in the real world, consumption could be different. The current study has conducted research in Seremban as a case study focusing on quantifying energy consumption. Therefore, this study does not provide generalisable information valid for all countries and cultures universally. Besides that, this study only considers the quantification of HEC based on two indicators: the type of house and appliance ownership. Moreover, this study used MFA analysis to compare the quantification of electricity consumption, total cost and carbon emissions between non-EEA and 5-star efficiency appliances. Therefore, the study suggests that future scholars must explore other factors, including the effect of human behaviour, legislative pressure, and policy on electricity consumption. In earlier studies, consumer behaviour was considered a significant determinant of residential electricity consumption because this is related not only to the characteristics of the building but also to the activities that people carry out within the building. Besides that, the current study quantifies energy consumption via survey data based on electrical appliances' possession (and usage), power rating, and the duration of appliance usage. Future researchers may use software tools linked to real-time meter readings based on annual, monthly, and hourly data. A building-scale analysis is also needed in future research, including better model calibration for boosting building performance to estimate unmeasured energy flows.

Acknowledgments

The authors greatly acknowledged the support from Management and Science University (MSU) under the grant MPCG-010-022023-FBMP. We would also like to express our gratitude to Ministry of Higher Education (MoHE) of Malaysia through The Fundamental Research Grant Scheme (FRGS/1/2022/SS07/UUM/02/6).,

References

Ahmad, A., & Othman, H. M. (2014). Electricity consumption in Brunei Darussalam: Challenges in energy conservation. *International Energy Journal*, 14, 155–166.

Alberini, A., & Umapathi, N. (2024). What Are the Benefits of Government Assistance with Household Energy Bills? Evidence from Ukraine. *The Energy Journal,* 45(3), 223–250. https://doi.org/10.5547/01956574.45.3.aalb

Aldossary, N. A., Rezgui, Y., & Kwan, A. (2015). An investigation into factors influencing domestic energy consumption in an energy subsidized developing economy. *Habitat International*, 47, 41–51. https://doi.org/10.1016/j.habitatint.2015.01.002

Ali, S. S. S., Razman, M. R., & Awang, A. (2020a). The estimation and relationship of domestic electricity consumption and appliances ownership in Malaysia's intermediate city. *International Journal of Energy Economics and Policy,* 10(6), 116–122. https://doi.org/10.32479/ijeep.8358

Ali, S. S. S., Razman, M. R., & Awang, A. (2020b). The nexus of population, gross domestic product growth, electricity generation, electricity consumption and carbon emissions output in Malaysia. *International Journal of Energy Economics and Policy*, 10(3), 84–89. https://doi.org/10.32479/ijeep.8987

Ali, S. S. S., Razman, M. R., Awang, A., Asyraf, M. R. M., Ishak, M. R., Ilyas, R. A., & Lawrence, R. J. (2021). Critical Determinants of Household Electricity Consumption in a Rapidly Growing City. *Sustainability (Switzerland)*I, 13(8), 4441.

Begum, R. A., Abdullah, S. M. S., & Sujahangir Kabir Sarkar, M. D. (2017). Time Series Patterns and Relationship of Energy Consumption and CO2Emissions in Malaysia. *Asian Journal of Water, Environment and Pollution,* 14(2), 41–49. https://doi.org/10.3233/AJW-170014

Cheah, S. K. A., Yeow, P. H. P., Nair, S. R., & Tan, F. B. (2018). Behavioural modification framework to address wastage in household electricity consumption. *Ergonomics,* 61(5), 627–643. https://doi.org/10.1080/00140139.2017.1397200

Drosos, D., Kyriakopoulos, G. L., Ntanos, S., & Parissi, A. (2021). School managers perceptions towards energy efficiency and renewable energy sources. *International Journal of Renewable Energy Development,* 10(3), 573–584. https://doi.org/10.14710/ijred.2021.36704

Energy.Gov. (2022). Low-Income Community Energy Solutions. *Energy Efficiency and Renewable Energy*. https://www.energy.gov/eere/slsc/low-income-community-energy-solutions

Energy Commission. (2021). Malaysia Energy Information Hub. Economic Data Analysis: Energy Indicator—Energy Intensity per Capita. *Suruhanjaya Tenaga*. https://meih.st.gov.my/statistics

Hanserud, O. S., Brod, E., Øgaard, A. F., Müller, D. B., & Brattebø, H. (2017). Erratum to: A multi-regional soil phosphorus balance for exploring secondary fertilizer potential: the case of Norway. *Nutr Cycl Agroecosyst*, (2016), 104, (307–320), 10.1007/s10705-015-9721-6). In Nutrient Cycling in Agroecosystems. https://doi.org/10.1007/s10705-017-9874-6

Hertwich, E. G., & Roux, C. (2011). Greenhouse gas emissions from the consumption of electric and electronic equipment by Norwegian households. *Environmental Science and Technology*, 45(19), 8190–8196. https://doi.org/10.1021/es201459c

Hisham Bin Jaaffar, A., Kasavan, S., Indati Mustapaa, S., Munirah Zawawi, N., & Fara Fadila Abdul Razak, S. (2023). Understanding green investment risks of renewable energy projects. In *Green Finance and Renewable Energy in ASEAN and East Asia* (pp. 36–56). https://doi.org/10.4324/9781003397670-3

Hu, D., You, F., Zhao, Y., Yuan, Y., Liu, T., Cao, A., Wang, Z., & Zhang, J. (2010). Input, stocks and output flows of urban residential building system in Beijing city, China from 1949 to 2008. *Resources, Conservation and Recycling,* 54(12), 1177–1188. https://doi.org/10.1016/j.resconrec.2010.03.011

Hu, S., Yan, D., Guo, S., Cui, Y., & Dong, B. (2020). A survey on energy consumption and energy usage behavior of households and residential building in urban China. *Energy & Buildings*, 148(2017), 366–378. https://doi.org/10.1016/j.enbuild.2017.03.064

Hu, Y. C. (2017). Electricity consumption prediction using a neural-network-based grey forecasting approach. *Journal of the Operational Research Society,* 68, 1259–1264. https://doi.org/10.1057/s41274-016-0150-y

Huang, W. H. (2015). The determinants of household electricity consumption in Taiwan: Evidence from quantile regression. *Energy,* 87(C), 120-133. https://doi.org/10.1016/j.energy.2015.04.101

IEA. (2019). WORLD ENERGY BALANCES: OVERVIEW. INTERNATIONAL ENERGY AGENCY. https://doi.org/10.1017/CBO9781107415324.004

Jaaffar, A. H., Kasavan, S., Mustapa, S. I., & Al-Amin, A. Q. (2023). The effect of the COVID-19 pandemic on Malaysian residential customers' energy-saving appliance purchasing behaviour. *International Journal of Energy Sector Management*. https://doi.org/10.1108/IJESM-02-2023-0006

Jones, R. V., & Lomas, K. J. (2016). Determinants of high electrical energy demand in UK homes: Appliance ownership and use. *Energy and Buildings,* 101(2015), 24–34. https://doi.org/10.1016/j.enbuild.2016.02.020

Kasavan, S., Ali, N. I. B. M., Ali, S. S. B. S., Masarudin, N. A. B., & Yusoff, S. B. (2021). Quantification of food waste in school canteens: A mass flow analysis. *Resources, Conservation and Recycling*, 164(August 2020), 105176. https://doi.org/10.1016/j.resconrec.2020.105176

Kasavan, S., Ali, S. S. B. S., & Siron, R. (2021). THE BEHAVIOUR OF HOUSEHOLDS TOWARDS ELECTRICITY CONSUMPTION_ A CASE STUDY AT SEREMBAN.pdf. Planning Malaysia, 19(4), 219–230.

Kolby, P., Pedersen, C., Sindrup, J. H., Gaub, J., Arendrup, M., & Gerstoft, J. (2017). Assessing global resource use: A systems approach to resource efficiency and pollution reduction. In *Danish medical bulletin*. https://www.resourcepanel.org/sites/default/files/documents/document/media/assessing_global_resource_use_amended_130318.pdf

Kubota, T., & Ahmad, S. (2005). Questionnaire Survey on Behavior for Natural Ventilation and Electricity Consumption in Terraced Houses: A case study of Johor Bahru City. *Asian Planning Schools Association (APSA) Conference* 2005, 11–14. https://core.ac.uk/download/pdf/11778318.pdf

Kubota, T., Jeong, S., Toe, D., & Ossen, D. (2011). Energy Consumption and Air-Conditioning Usage in Residential Buildings of Malaysia. Journal of International Development and Cooperation, 17(3), 61–69. https://doi.org/10.15027/32444

Kyriakopoulos, G. L. (2022). Energy Communities Overview: Managerial Policies, Economic Aspects, Technologies, and Models. *Journal of Risk and Financial Management*, 15(11), 521. https://doi.org/10.3390/jrfm15110521

Malaysian Standard. (2017). Energy efficiency and use of renewable energy for residential buildings - Code of practice. https://policy.asiapacificenergy.org/sites/default/files/Code_of_Practice_on_Energy_Efficiency_and_Use_of_Renewable_Energy_for_Residential_Buildings.pdf

NEEAP. (2015). National Energy Efficiency Action Plan. In National Energy Efficiency. https://www.pmo.gov.my/wp-content/uploads/2019/07/National-Energy-Efficiency-Action-Plan.pdf

Nissing, C., & Von Blottnitz, H. (2007). A material flow analysis of wood and paper in Cape Town: Is there potential to redirect flows in formal and informal sectors to foster use as a renewable resource? *International Journal of Environment and Sustainable Development*, 6(2). https://doi.org/10.1504/IJESD.2007.014199

Ntanos, S., Kyriakopoulos, G. L., Anagnostopoulos, T., Xanthopoulos, T., Kytagias, C., & Drosos, D. (2022). Investigating the Environmental and the Energy Saving Behavior among School Principals through Classification Algorithms. *International Journal of Renewable Energy Development,* 11(2), 449–461. https://doi.org/10.14710/ijred.2022.43007

Olaniyan, K., McLellan, B. C., Ogata, S., & Tezuka, T. (2018). Estimating residential electricity consumption in Nigeria to support energy transitions. *Sustainability* (Switzerland), 10(5), 1440. https://doi.org/10.3390/su10051440

Pauliuk, S., Venkatesh, G., Brattebo, H., & Müller, D. B. (2014). Exploring urban mines: Pipe length and material stocks in urban water and wastewater networks: Research Article. *Urban Water Journal*, 11(4), 274–283. https://doi.org/10.1080/1573062X.2013.795234

Permana, A. S., Aziz, N. A., & Jaffar, A. R. (2013). Potential urban development parameters that reduce energy consumption in residential area. *Planning Malaysia*, 11(2), !01-118. https://doi.org/DOI:10.21837/pmjournal.v11.i2.118

Ritchie, H., & Roser, M. (2020). CO_2 and Greenhouse Gas Emissions. Our World in Data. https://ourworldindata.org/co2-and-greenhouse-gas-emissions

Roy Chowdhury, P. K., Weaver, J. E., Weber, E. M., Lunga, D., LeDoux, S. T. M., Rose, A. N., & Bhaduri, B. L. (2020). Electricity consumption patterns within cities: application of a data-driven settlement characterization method. *International Journal of Digital Earth*. https://doi.org/10.1080/17538947.2018.1556355

Satterthwaite, D. (2008). Cities' contribution to global warming: Notes on the allocation of greenhouse gas emissions. *Environment and Urbanization,* 20(2), 539–550. https://doi.org/10.1177/0956247808096127

Shaikh, P. H., Nor, N. B. M., Sahito, A. A., Nallagownden, P., Elamvazuthi, I., & Shaikh, M. S. (2017). Building energy for sustainable development in Malaysia: A review. *Renewable and Sustainable Energy Reviews,* 75(May 2015), 1392–1403. https://doi.org/10.1016/j.rser.2016.11.128

Streimikiene, D., Kyriakopoulos, G. L., Ślusarczyk, B., & Stankuniene, G. (2024). Policies and measures for energy efficiency improvement at households: A bibliometric analysis. *International Journal of Renewable Energy Development,* 13(1), 31–51. https://doi.org/10.14710/ijred.2024.57769

Suruhanjaya Tenaga Malaysia. (2020). Malaysia Energy Statistics Handbook. In *Suruhanjaya Tenaga Malaysia*. https://meih.st.gov.my/documents/10620/23817e60-6b26-4dab-9b82-2c106a661aeb

Turner, D. A., Williams, I. D., & Kemp, S. (2016). Combined material flow analysis and life cycle assessment as a support tool for solid waste management decision making. *Journal of Cleaner Production,* 129, 234–248. https://doi.org/10.1016/j.jclepro.2016.04.077

Unit Perancang Ekonomi Negeri Sembilan. (2015). Data sosioekonomi Negeri Sembilan. https://www.ns.gov.my/capaian/penerbitan

Velody, M., Cain, M. J. G., Safety, S., Specialist, N., Philips, M., & Specialist, E. (2003). A Regional Review of Social Safety Net Approaches In *Support of Energy Sector Reform* (Issue October). https://pdf.usaid.gov/pdf_docs/PNACX443.pdf

Wijaya, M. E., & Tezuka, T. (2013). A comparative study of households' electricity consumption characteristics in Indonesia: A techno-socioeconomic analysis. *Energy for Sustainable Development*, 17(6), 596–604. https://doi.org/10.1016/j.esd.2013.09.004

Wong, S. L., Ngadi, N., Abdullah, T. A. T., & Inuwa, I. M. (2015). Recent advances of feed-in tariff in Malaysia. *Renewable and Sustainable Energy Reviews,* 41, 42–52. https://doi.org/10.1016/j.rser.2014.08.006

Wyatt, P. (2013). A dwelling-level investigation into the physical and socio-economic drivers of domestic energy consumption in England. *Energy Policy*, 60, 540–549. https://doi.org/10.1016/j.enpol.2013.05.037

Yalcintas, M., & Kaya, A. (2017). Roles of income, price and household size on residential electricity consumption: Comparison of Hawaii with similar climate zone states. *Energy Reports,* 3, 109–118. https://doi.org/10.1016/j.egyr.2017.07.002

Zhou, S., & Teng, F. (2013). Estimation of urban residential electricity demand in China using household survey data. *Energy Policy,* 61, 394–402. https://doi.org/10.1016/j.enpol.2013.06.092

Appendix

Table 8
Potential electricity and cost saving and emissions reduction with using 5-star energy efficiency based on appliances

Appliances	Total consumption without using 5-star energy efficiency for 1 month (kWh)	Average consumption without using 5-star energy efficiency for 1 day (kWh) *(30 days)	5-Star energy efficiency*	Total consumption with using 5-star energy efficiency for 1 month (kWh)	Average consumption with using 5-star energy efficiency for 1 day (kWh) *(30 days)	Potential Electricity Saving for 1 month (kWh)	Potential Electricity saving for 1 day [a] (kWh) *(30 days)	Cost saving [a] (MYR/month)	Cost saving (MYR/day) *(30 days)	Potential emissions reduction [b] (kgoe/month)	Potential emissions reduction (kgoe/day) *(30 days)
Refrigerator	121,824.0	4060.8	-25%	91,368	3045.6	30,456	1015.2	6639.41	221.31	20710.08	690.336
Microwave	2668.78	88.95	-65%	934.07	31.14	1734.71	57.82	378.17	12.61	1179.24	39.31
Washing Machine	6384.49	212.82	-	6384.49	212.82	-	-	-	-	-	-
Rice Cooker	7961.46	265.38	-89%	875.76	29.19	7085.70	236.19	1544.68	51.49	4818.28	160.61
Television	10,948.01	364.93	-70%	3284.40	109.48	7663.61	255.45	1670.67	55.69	5211.25	173.71
Vacuum Cleaner	2725.95	90.87	-	2725.85	90.87	-	-	-	-	-	-
Fluorescent Lamp	13,930.32	464.34	-25%	10447.74	348.26	3482.58	116.09	759.20	25.31	2368.15	78.94
Bulb Lighting	6207.98	206.93	-	6207.98	206.93	-	-	-	-	-	-
Air Conditioning	48,973.39	1632.45	-15%	41,627.38	1387.58	7364.01	245.47	1605.35	53.51	5007.53	166.92
Ceiling Fan	30,606.3	1020.21	-	30,606.3	1020.21	-	-	-	-	-	-
Stand Fan	5805.75	193.53	-	5805.75	193.53	-	-	-	-	-	-

* Appliances that has been categorised under 5-star energy rating (Energy Commissions 2021), [a] Based on current electricity tariff which is MYR 0.218 for domestic sector, [b] 1 kWh is equivalent to 0.68 kg of CO