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Load and Household Profiles Analysis for Air-Conditioning and Total Electricity in Malaysia

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Abstract

Load profile of household air-conditioning (AC) and total electricity consumption is essential to increase the stability of the energy demand on the grid. Therefore, field measurements on time series data of total and AC electricity consumption from 20 households were conducted from March 2016 to August 2017. The questionnaire survey was carried out simultaneously to grasp the profile of each family. The average total daily and AC consumption were 14.5 kWh/day and 3.9 kWh/day, respectively. The average hourly electricity consumption for total was 0.6 kWh/hour, meanwhile for AC was 0.2 kWh/hour. About 20% of the total peak demand was contributed by the consumption of AC. The indoor air temperature was measured in the bedroom (BR) when AC was switched ON and OFF with an average of 27 °C and 29 °C, respectively. However, the indoor air temperature in the living room (LR) was 2°C and 1°C higher if compared to BR for both conditions. Based on the questionnaire survey, 92% of the occupants preferred a temperature setting below than the level recommended by the Malaysian standard i.e., 24 °C. These results might be beneficial to understand the occupant behavior of electricity demand in Malaysia for designing smart grid energy systems in the future.

Keywords: household electricity, air-conditioning operation, load profiles

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1. Introduction

Over the last few decades, a massive increase in energy consumption from Malaysia has shown that 19% of the total energy comes from the residential area [1]. The final energy consumption by electricity has been increased from 6313 ktoe in 2003 to 10,590 ktoe in 2013 [2]. Therefore, AC usage in the residential area gets a lot of notice as the consumption has made a drastic increase from 6.5 % in 1990 to 16.2% in 2000. It might contribute to pressing environmental issues such as global warming, climate change

and also air pollution. It also has been stated that more than 50% of total electrical energy is used for AC and refrigerator [3, 8]. The high power of AC consumption causes fluctuations in energy demand and has to be reduced to increase the stability of energy demand on the grid [4]. Therefore, a structure of detailed AC and total electricity consumption are essential for a reliable power system.

A few researchers have attempted to investigate the characteristic of residential energy consumption to have an accurate prediction of energy demand. For example, about 400 unit AC was observed for a full year in China to obtain the data on their cooling and heating usage [5]. Moreover, a particular Australian household dataset has been analyzed to build a household electricity consumption model by establishing a statistical linear regression model [6]. In 2015, the daily probability profile of AC exposure that included 43,000 Singaporean students has been concluded by using a Gaussian mixture model to measure data of temperature, humidity, and pressure [7]. The analysis of AC usage showed that a drastic increase occurred in the frequency of AC usage at night for high frequent users who consumed up to seven to nine hours per day [9]. Improving the thermal environment is important to avoid excessive energy usage in the residential area.

However, from all previous studies, it is still hard to find valid data that disclose the detailed profile of both AC and total household energy consumption, especially in Malaysia. These data were relevant as Malaysia is enhancing the technology of power grid to improve and maximize the grid's efficiency and reliability [10]. Thus a field measurement of each minute data of total and AC electricity consumption have been conducted in 20 households to investigate the load profiles of residential electricity consumption in Malaysia. Besides that, the questionnaire survey also has been done to grasp the visibility of each household by gathering information from respondents.

2. Research Method

2.1. Overview of field measurement

The field measurement was conducted in 19 households from a low-cost apartment in Desa Rejang, Kuala Lumpur (3.1900° N, 101.7304° E) and a two-storey terrace house that located in Kajang, Selangor (3.0082° N, 101.8084° E) from September 2016 to August 2017 for 52 to 386 days at most. Total electricity consumption of the households and their air-conditioner were measured include the indoor temperature of the measured

room. We only measured the room that equipped with frequently used AC such as the living room or bedroom as listed in Table 1.

Table 1: Household profile.

ID	Floor Number	Number of households	Room Measured
1	6th	7	Living Room
2	17th	6	Bedroom 1 and 3
3	6th	3	Bedroom 1
4	18th	3	Bedroom 1 and 2
5	3th	5	Living Room
6	9th	4	Living Room
7	10th	8	Bedroom 1
8	3th	7	Bedrooms 1 and 3
9	8th	6	Living Room, Bedroom 1 and Bedroom 3
10	13th	9	Bedroom 3
11	7th	4	Bedroom 1
12	9th	3	Living Room, Bedroom 2 and Bedroom 3
13	10th	2	Bedroom 3
14	16th	6	Living Room and Bedroom 1
15	14th	6	Bedroom 1
16	9th	4	Bedroom 1
17	18th	2	Living Room and Bedroom 3
18	18th	4	Living room and Bedroom 2
19	8th	6	Bedroom 1
20	*	5	Bedroom 1

* Two-storey Terrace House

The floor areas for the household in the apartment and terrace house are about 60 $m^2$and 167 m^2respectively. Both household's physical structure was reinforced concrete. The range of household size is from 2 to 9. Figure 1 displays the schematic plan layout for both types of households.

2.2. Measurement items

The energy-monitoring devices (OWL) were installed at the circuit breaker (Figure 2a) and the AC unit of the house (Figure 2b) for measuring current within the one-minute interval. The power factor and voltage of the investigated house were assumed as unity and 240 V respectively. The typical supply voltage for residential and private premises is around 230 to 253 V (Suruhanjaya Tenaga 2008). Our measurement data

Figure 1: Schematic plan view for a layout of a) Apartment (ID1 – 19) and b) Terrace house (ID20). X and Y refer to the equipment for energy monitoring and air temperature respectively.

was verified with the monthly energy consumption from the energy meter, and it shows a strong correlation. Thermo recorder (T&D Corporation, TR-77Ui) was used to measure the indoor air temperature in each measured room within five minutes interval. It was installed at the center of the room as shown in Figure 3. Furthermore, all sensors were calibrated and verified before the measurement was done.

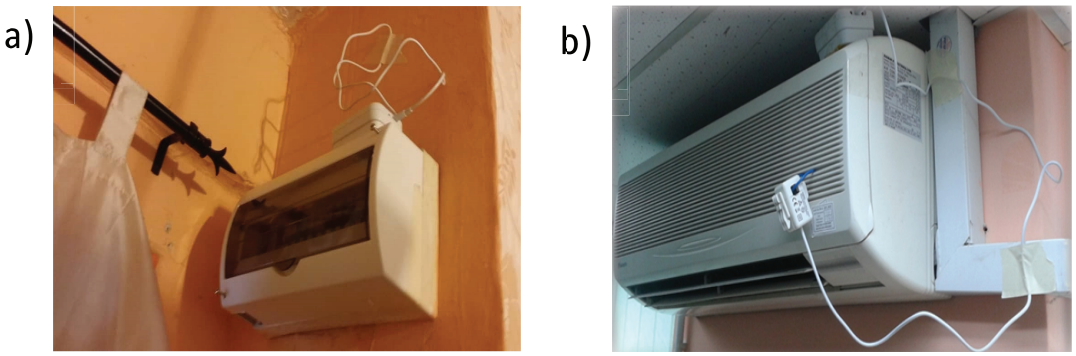

Figure 2: Installation of OWL at a) circuit breaker, b) air-conditioner.

Figure 3: Installation of thermo recorder.

2.3. Questionnaire survey

The questionnaires survey was conducted through an interview with 20 respondents of each household. It consists of household information (e.g: household size, household income, ownership status, years stay), significant appliances ownership, AC usage, utility bills and occupancy schedule (weekday and weekend). This questionnaire focuses on the characteristics of AC usage and electricity consumption besides the occupant's behavior (e.g.: hourly time for major appliances used and occupancy schedule).

3. Results and Analysis

3.1. Histogram of one-minute electricity consumption

The histogram of one-minute data of total and AC electricity consumption from each measured rooms in all 20 investigated households were displayed in Figure 4. The total AC refers to the summation of all electricity consumption of measured AC in each house. The average electricity consumption for complete electricity data was 0.0106 kWh/min with standard deviation (S.D) of 0.01 kWh/min. Besides, the consumed electricity by the residents ranged from 0 to 0.12kWh/min. It also can be seen that both one-minute data of AC and total electricity consumption mostly ranged from 0 to 0.01 kWh/min. The average for one-minute data of AC was 0.0026 kWh/min with S.D of 0.0065 kWh/min.

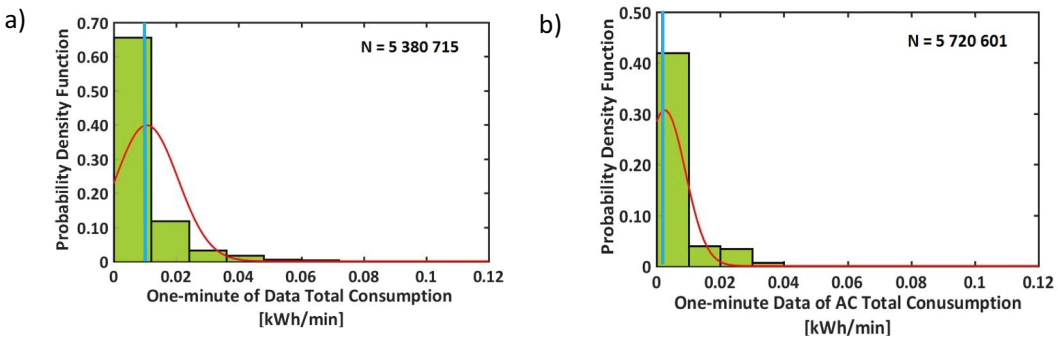

Figure 4: Histogram one-minute data of a) total and b) AC electricity consumption. N is the number of samples and the blue line indicate the average values of one-minute data for total and AC electricity consumption.

3.2. Histogram of daily electricity consumption

The average daily total and AC total electricity for each 20 investigated households were sorted based on lower to higher consumption as displayed in Figure 5 and 6 respectively. Note that the data for total electricity consumption from household ID5 was not recorded the measured data because of some problem of sensors. The average electricity consumption for household ID9 was the largest for both total (30.0 kWh/day) and AC total (14.1 kWh/day) electricity consumption. It could be due to three active unit of measured AC which was used by six members in the household.

The histogram of daily total and AC electricity consumption of all investigated households are shown in Figure 7a and 7b respectively. It can be seen that most of the electricity consumption is ranged from 10 to 15 kWh/day for total and 0 to 3 kWh/day for AC. The average for total and AC electricity consumption is 14.5 kWh/day and 3.9 kWh/day with a standard deviation of 6.5 kWh/day and 4.1 kWh/day respectively. The findings almost similar to the results of other research on the field measurement in Kuala Lumpur in which the authors determined an average monthly total electricity consumption for 50 households from the middle class with 404.64 kWh/month and 13.5 kWh/day [11]. In contrast, a similar measurement was observed in 66 households in Japan. It recorded an average of 16.3 kWh/day for daily total electricity usage during summer [12].

3.3. Histogram of hourly electricity consumption

Figure 8 shows the hourly histogram of total electricity consumption for total (Figure 8a) and AC (Figure 8b). The histogram clearly illustrates that the dominant peak hourly electricity consumption usually consumed between 0.3 to 0.5 kWh/hour (total) and 0

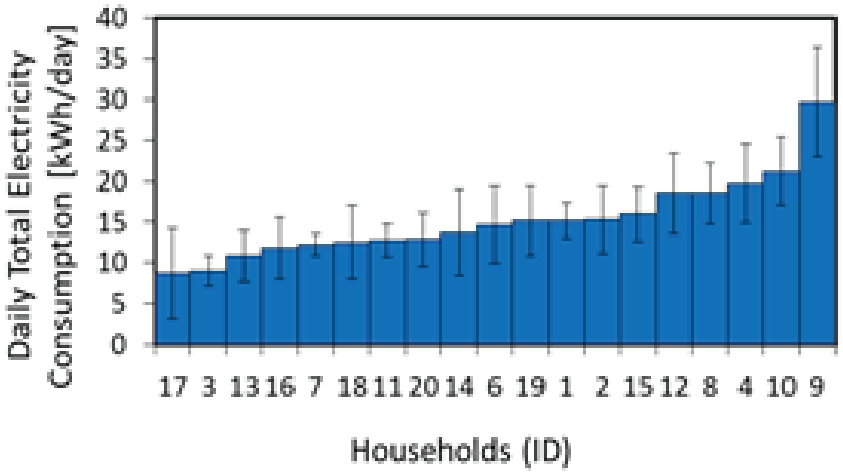

Figure 5: Average daily total electricity for each household. Error bar refers to standard deviation.

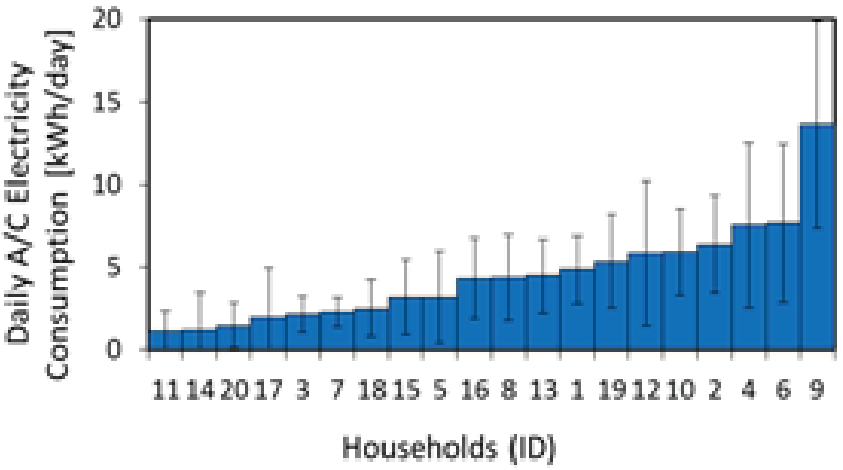

Figure 6: Average daily AC total electricity for each household. Error bar refer to standard deviation.

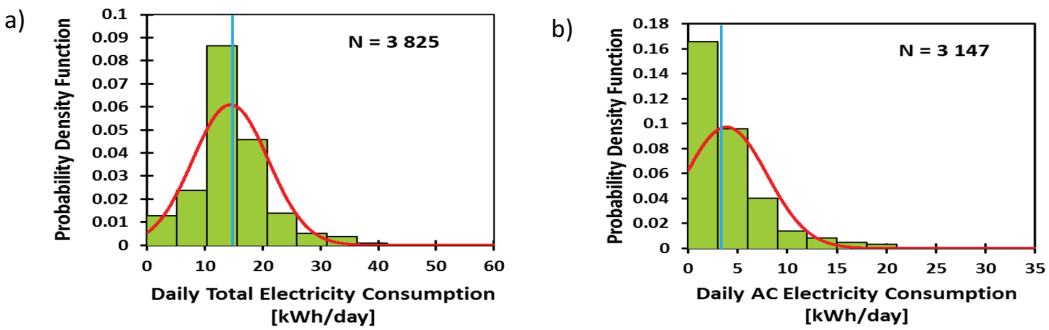

Figure 7: Histogram of a) daily total electricity consumption and b) daily AC electricity consumption. N is the number of samples, and the blue line indicates the average values for daily total and AC electricity consumption.

to 0.1 kWh/hour (AC). The average of hourly electricity consumption for total was 0.6 kWh/hour with S.D of 0.3 kWh/hour and 0.2 kWh/hour with S.D of 0.2 kWh/hour for

AC. It is consistent with the results of the estimated hourly profile in Fukushima, Japan which stated 0.1 to 0.2 kWh/hour of electricity usage for AC in summer [13].

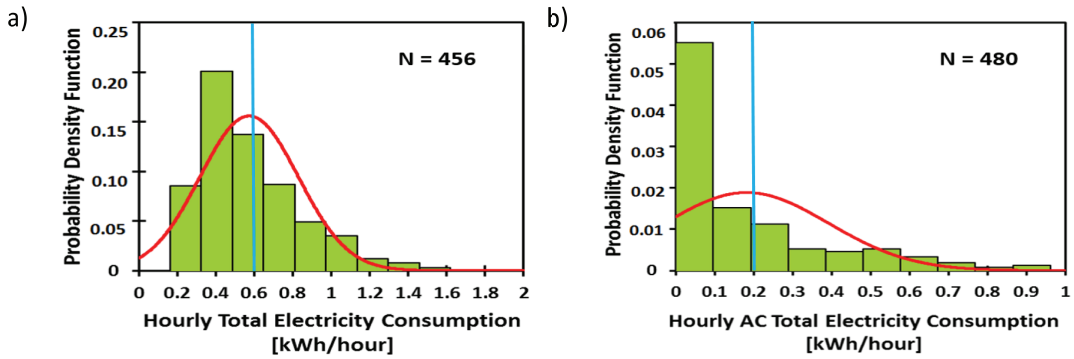

Figure 8: Histogram of a) hourly total electricity consumption and b) hourly AC electricity consumption. N is the number of samples, and the blue line indicate the average values for hourly total and AC electricity consumption.

3.4. Histogram of daily peak consumption

The daily peak electricity demand is defined as the maximum power consumed in a day that observed from 1-min data and varies from time to time. Figure 9a and 9b show the histogram of daily peak electricity demand for total and AC electricity consumption respectively. On average, the peak demand in a day is around 3.1 kW for total and 1.0 kW for AC. It can be concluded that the peak demand is ranging from 0 to 7 kW for total and 0 to 6 kW for AC throughout the measurement period. It is very nearly to the study in Sydney, Australia that discovered the total peak demand of 12 sampled households which ranging from 0 to 10 kW in summer [14].

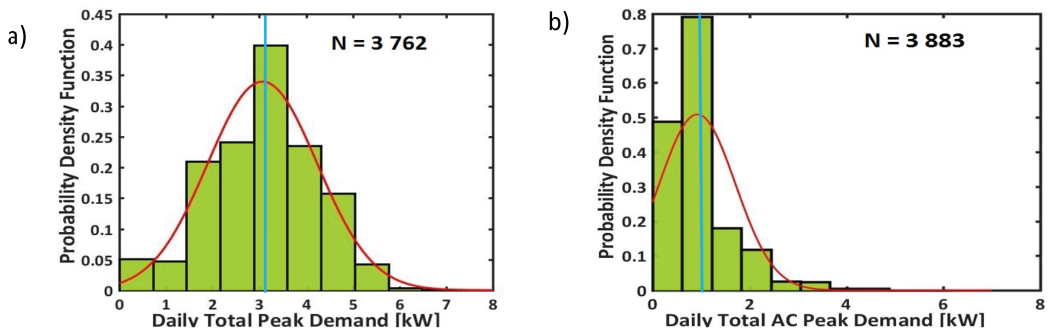

Figure 9: Histogram of a) daily total peak demand and b) daily total AC peak electricity demand. N is the number of samples, and the blue line indicates the average values of the daily peak for total and AC electricity consumption.

3.5. Histogram of indoor temperature

The histogram of statistics indoor air temperature when AC was switched ON and OFF for bedroom (BR) and living room (LR) of all investigated households are shown in Figure 10 and 11 respectively. BR refers to all measured rooms. It can be seen that the average indoor temperature in BR when AC was switched ON is 27.3 °C and 29.6 °C when AC was switched OFF. This can be supported by [15] that stated the highest indoor temperature in Kuala Lumpur for the bedroom is 32.6 °C. For indoor temperature in LR, the average when AC was switched ON and OFF are 29.5 °C and 30.1 °C correspondingly. It was significantly higher than in BR as space for LR is more open and will consume extra work to maintain the temperature.

Figure 12 shows the correlation between indoor temperatures and AC electricity consumption under switched ON condition. It can be seen that AC consumes an average of 12.4 Wh/min when was switched ON in BR. Meanwhile, in LR, the average electricity consumption was 15.4 Wh/min. In order to avoid the excessive heat and suitable thermal comfort level in the house, the occupants in Malaysia use seven to nine hours of AC per day at most, therefore leads to a lower indoor temperature [9].

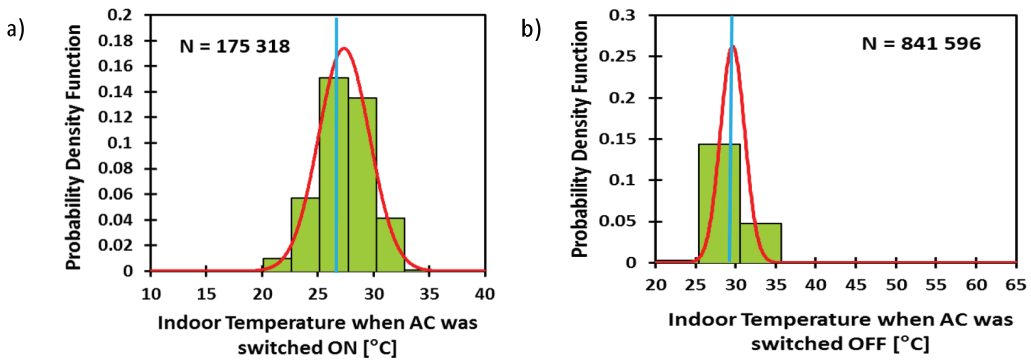

Figure 10: Histogram daily indoor temperature for BR a) AC was switched ON b) AC was switched OFF. N is the number of samples, and the blue line indicates the average values for the daily indoor temperature of BR when was switched ON and OFF.

3.6. Household characteristics

Table 2 displayed the detailed information of household characteristics such as household size, household income of the residents, monthly electricity consumption, and home ownership status, with average daily total electricity. Household size was spread across or range of two until nine, with approximately 25% of household size falling into six. About 35% of the respondent had an income of over RM 5000. With regards to the

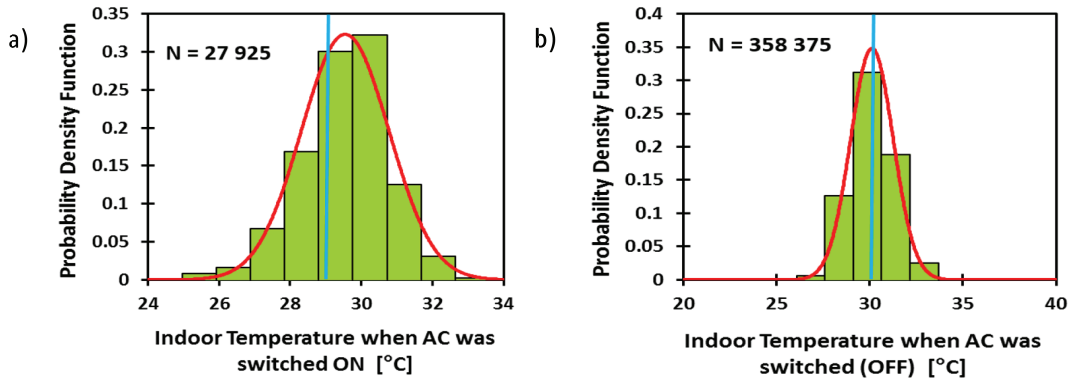

Figure 11: Histogram daily indoor temperature for LR a) AC was switched ON b) AC was switched OFF. N is the number of samples, and the blue line indicate the average values for a daily indoor temperature of LR when was switched ON and OFF.

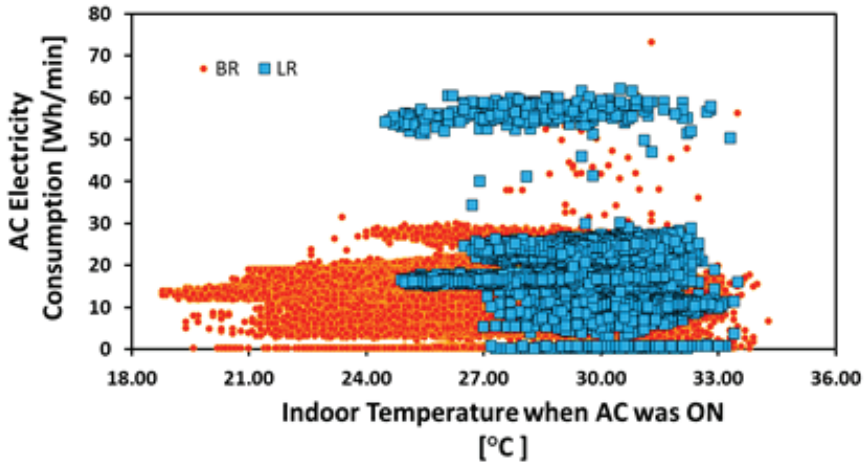

Figure 12: Scatter plot between daily AC electricity consumption and daily indoor temperature under switched ON condition.

average monthly electricity, the majority of household consumed between 401 to 500 kWh/month. In terms of home ownership status, 75% of the family owning their house. A Chi-square test was performed to reveal the influence of household characteristics on total electricity. From all variables, only household size was found to be statistically significant. Research that aimed to determine the determinants of use on electricity consumption through a questionnaire survey in Dutch dwellings has also found out that household size as one of the significant determinants [16].

3.7. Profiles of AC

The percentages for profiles of AC are shown in Figure 13 which include AC with energy star, number of AC, room AC's installed, set time for AC, set point temperature, cooling mode, and age of AC. It has been determined from the survey that 30% from the

Table 2: Household characteristics.

Household Characteristics	Group	Sample size (%)
	2	10
	3	15
Household size	4	20
	5	10
	6	25
	7	10
	8	5
	9	5
Income (RM)	1000- 1999	10
	2000- 2999	20
	3000- 3999	25
	4000- 4999	10
	Above 5000	35
Monthly Electricity	201-300	21
Consumption	301-400	11
(kWh/month)	401-500	42
	Over 500	26
Home Ownership	Own	75
	Rent	25

households have AC with energy star; meanwhile, 70% from them do not have. From all investigated households, 60% household has one AC unit followed by 30% that had two units of AC, and only 10% has three units of AC in their house. All investigated AC usually were installed in the bedrooms rather than in the living room, and 50% of them did not set the timer for their AC. Furthermore, about 92% of them more prefer below than 24 °C as their set point temperature. The range of set point temperature was recorded from 16 to 28 °C. Most of the household prefers to use AC with a fan instead of only used AC. The age of AC between seven and nine years was recorded as 51%. The efficiency of AC might be dropped and will contribute to the high use of AC as less efficiency AC used more energy consumption.

4. Conclusion

The results from conducted experiments at 20 chosen households in Malaysia from March 2016 until August 2017 discovered the structure of total and AC total electricity consumption. The findings can be concluded as follows:

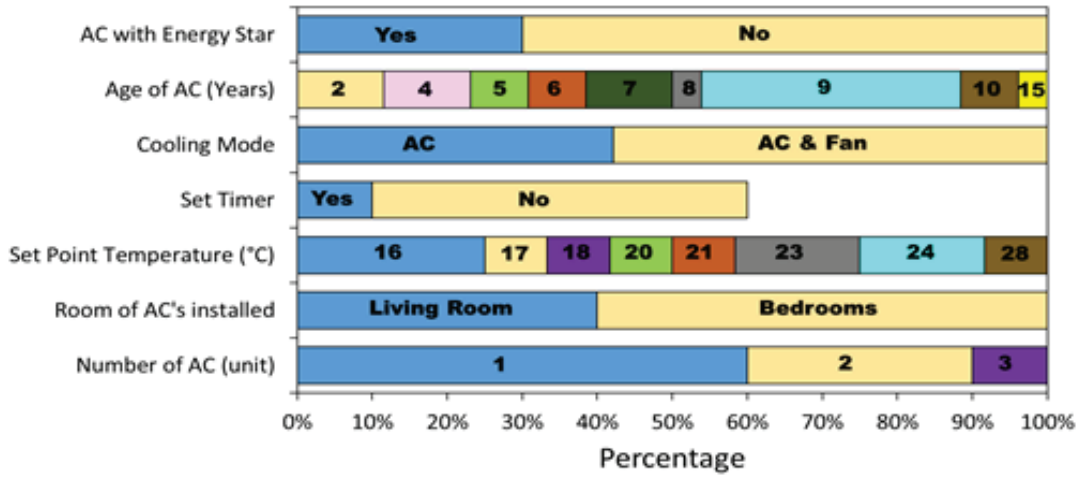

Figure 13: Percentages of AC in term of AC with energy star, number of AC, Room AC's installed, Set timer for AC, Set-point temperature, Cooling mode and Age of AC.

(a) The 1-min data from total electricity consumption among the residents was found to be majorly consumed at 0.01 kWh/min.

(b) The average total daily consumption was 14.5 kWh/day and 3.9 kWh/day for total AC consumption. Almost 30 % of the total electricity consumption was consumed by AC which also can be up to 50% at most.

(c) The average hourly electricity consumption for AC was 0.2 kWh/hour, slightly lower than for total which was 0.6 kWh/hour. This also clearly indicates that AC consumption influenced total consumption at about 33 %.

(d) 20 % from 0.1 kWh/day of total peak demand was contributed by the use of AC peak demand which recorded as 0.02 kWh/day.

(e) The average indoor temperature in LR was higher than in BR as space for LR is more open and will consume extra work to maintain the temperature. In BR, the average indoor temperature when AC was switched ON and OFF are 27.3 °C and 29.6 °C while in LR, it was recorded at 29.5 °C and 30.1 °C respectively.

(f) The relationship between household characteristics and electricity consumption shows that household size and monthly electricity consumption has a significant effect on electricity consumption.

(g) From the questionnaire survey, about 92% of them preferred the temperature setting below 24 °C.

By revealing the characteristic of total and AC electricity consumption, these results might be useful to understand the occupant behavior of electricity demand in Malaysia for future designing of smart grid energy systems.

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