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Determinant Factors of Electricity Consumption for a Malaysian Household Based on a Field Survey

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Abstract: Electricity-saving strategies are an essential solution to overcoming increasing global CO_2 emission and electricity consumption problems; therefore, the determinant factors of electricity consumption in households need to be assessed. Most previous studies were conducted in developed countries of subtropical regions that had different household characteristic factors from those in developing countries of tropical regions. A field survey was conducted on electricity consumption for Malaysian households to investigate the factors affecting electricity consumption that focused on technology perspective (building and appliance characteristics) and socio-economic perspective (socio-demographics and occupant behaviour). To analyse the determinant factors of electricity consumption, direct and indirect questionnaire surveys were conducted from November 2017 to January 2018 among 214 university students. Direct questionnaire surveys were performed in order to obtain general information that is easily answered by respondents. On the other hand, some questions such as electricity consumption and detailed information of appliances must be confirmed by the respondents' parents or other household members through an indirect questionnaire survey. The results from multiple linear regression analyses of the survey responses showed that appliance characteristic factors were the main variables influencing electricity consumption and house characteristics were the least significant. Specifically, air conditioners, fluorescent lamps, and flat-screen TVs emerged as appliances with the most significant effect on electricity consumption. Occupant behaviour factors had a more significant influence than socio-demographic factors. The findings in this study can be used by policymakers to develop electricity-saving strategies in Malaysia.

Keywords: appliance characteristic; determinant factors; electricity consumption; house characteristic; occupant behaviour; socio-demographic

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1. Introduction

In recent years, energy consumption in Malaysia has seen a 20.7% contribution from the residential sector [1]. The average electricity consumption for residential was 345 kWh per month based on the survey of 348 samples in Malaysia [2]. The electricity consumption for residential in Malaysia is expected to rise due to increasing appliance ownership, economic improvement and changing lifestyle [3]. An electricity-saving strategy for the residential household is required to overcome these issues.

Developing an electricity-saving strategy for residential households is challenging due to different factors such as socio-demographic factors, house characteristics, appliance characteristics, and occupant behaviour. Those factors can be classified as monthly income, education level, family composition, total floor area, house type, appliance ownership, use of appliances and so on. Furthermore, the amount of electricity consumed may be affected by complex interactions between these factors [4].

Kim [5] examined determinant factors of households in Korea from 2250 samples and found that socio-demographic factors, appliance characteristics, and occupant behaviour had complex interactions with electricity consumption. Data confirmed that type of cooling had a strong correlation with age and education level of household head, monthly income, family composition, total floor area, and the number of people living in the household. Chen et al. [6] conducted a field survey about residential energy consumption in China from 642 households during winter and 838 households during the summer. They found that the number of rooms, family size, age, number of air conditioners, education level and air conditioning consumption showed intercorrelation with each other. Shahi et al. [7] studied energy use in rural, semi-urban, and urban areas of Nepal from 442 households. They identified intercorrelated energy use between income, occupation, family size, education level, and usage of LED lamps.

The assessment of the determinants of electricity consumption is needed in order to find out which factors are significant contributors to electricity consumption in residential households. These determinant factors can be divided into four general groups: socio-demographics [4,6,8], building characteristics [9–11], appliance characteristics [12–14], and occupant behaviour in terms of using appliances [15–19].

1.1. Socio-Demographic Factors

The effect of socio-demographic factors on household electricity consumption has been studied by many previous research studies. Jones and Lomas [20] studied determinants of high electrical energy demand for residential dwellings in the UK from a sample of 315. Higher annual income households showed more significant factors affecting high electricity consumption than lower annual income households. The oldest people in the home were responsible for less electricity consumption than younger people. Chen et al. [6] conducted a field survey regarding residential energy consumption in China from 642 households during winter and 838 households during summer; significant factors affecting residential energy consumption were income, age of respondents, and family composition. Similar findings were found by Hara et al. [8] who studied determinant factors of residential electricity consumption in Japan based on a large-scale questionnaire. In a nutshell, previous investigations in temperate or so-called subtropical, hot and humid regions confirmed that the socio-demographic factors emerged as factors unaffected by climate. Socio-demographic factors such as monthly income [4,8,15], the number of household occupants [2,16,21], family composition [4,6,14,15,22], age of household occupants [4,6,8], education level [18,23,24], and employment status [4] were determined as significant factors influencing electricity consumption.

1.2. Building Characteristic Factors

Building characteristic factors showed different effects on household electricity consumption. Tso and Yau [9] conducted a study of electricity consumption for residential dwellings in Hong Kong with 1500 respondents. Some house characteristic factors were found to be significant influencers of electricity consumption such as the type of house and total floor space. Karatasou et al. [11] conducted a study to investigate the determinants of high residential electricity consumption from 144 dwellings in Europe; they found that the number of bedrooms showed a strong correlation with electricity consumption. The total floor area and the age of the building were also significant influencers of electricity consumption. Esmaeilimoakher et al. [10], who studied determinants of electricity consumption for social housing in Western Australia from a sample of 17 households, obtained different results. They found that dwellings with larger floor areas tended to use less electricity than those with smaller floor areas.

Some studies in temperate regions consider additional retrofits such as glazing windows [25,26] and house insulation [11,25,26] as significant factors affecting electricity consumption, as these help with extreme temperature management in hot and cold seasons without consuming electricity. Other studies in hot and humid regions have confirmed that floor area [12,18] and the number of rooms [12] are significant factors affecting electricity consumption.

1.3. Appliances Characteristic Factors

According to previous studies, household appliances caused a significant impact on electricity consumption. Ndiaye and Gabriel [13] studied determinant factors of electricity consumption from 269 houses in Canada. The results showed that the type of air conditioning (AC) and the number of incandescent lamps emerged as significant factors affecting electricity consumption. Bedir et al. [14] and Bedir and Kara [27] reported on the determinant factors of electricity consumption from 323 dwellings in the Netherlands. Appliances such as entertainment appliances (televisions, computers, games consoles, etc.), cooking appliances (coffee machines, electric kettles, microwave ovens, etc.), and cleaning appliances (irons, vacuum cleaners, washing machines, etc.) were confirmed as significant factors affecting electricity consumption. Azlina et al. [12], who studied factors influencing the electricity consumption in Terengganu, Malaysia with a sample of 1561 respondents, obtained similar results. The number of air conditioning appliances, cooking appliances (refrigerators, electric kettles), televisions, heaters, and vacuum cleaners significantly contributed to electricity consumption.

Ownership of some appliances such as clothes dryers [9,14,21,23], heating systems [18,26,28], and air conditioners [13,14,29] appeared as significant factors of electricity consumption in temperate regions. These appliances are needed in regions with extreme conditions such as hot, rainy, and cold climates that need heaters and coolers to maintain the room temperature and clothes dryers to dry clothes. Fan ownership was not common in temperate regions and was not a significant factor affecting electricity consumption [9]. Nevertheless, fan ownership emerged as a substantial factor in influencing electricity consumption in hot and humid climates [12,18].

1.4. Occupant Behaviour Factors

Occupant behaviour showed various characteristics of household electricity consumption. Ashouri et al. [29] confirmed that occupant behaviour significantly affected energy consumption based on large datasets in Japan. Jones and Lomas [15] analysed determinant factors of high electricity consumption for 183 dwellings in the UK to examine occupant behaviour in the use of appliances. The duration of usage of some appliances such as desktop computers, laptops, telephones, electric hobs, dishwashers, washing machines, and electric showers emerged as significant factors affecting electricity consumption. Similar findings were also confirmed by Huebner et al. [16], who studied determinant factors of electricity consumption using a sample of 845 households in the UK. The duration of usage of household appliances such as televisions, ovens, electric grills, dishwashers, lighting, and dryers significantly affected the total electricity consumption. Wijaya and Tezuka [18] investigated electricity consumption and the factors driving it in residential homes using a sample of 200 households in Indonesia. Usage of cooling, cooking, and entertainment and information devices significantly affected electricity consumption.

Occupants in temperate regions showed different behaviour than those in hot and humid regions. Steemers et al. [17] performed a study in the United States based on 4882 housing units and reported that occupants tended to consider outdoor temperatures while using heating and air conditioning appliances. Pal et al. [30] also proved that the occupant behaviour in using heating appliances affected the energy consumption from an office in France. In contrast, Kubota et al. [19] conducted a survey with 338 respondents on terrace houses in Malaysia and found that occupants did not consider outdoor temperatures while using air conditioning appliances. This was because Malaysia has hot and humid weather conditions regularly and outdoor temperatures remain almost constant throughout the year. Ranjbar et al. [31], who investigated 10 dwellings of low-cost apartments in Malaysia, obtained similar results; they confirmed a weak correlation between outdoor air temperature and air conditioning usage.

Jaffar et al. [28] studied energy demand for residential buildings in Kuwait using 250 households and they found that most occupants set the temperature of air conditioning between 20 °C and 22 °C. In other studies, Kubota et al. [19] reported that occupants in Malaysia set the temperature between 20 °C and 21 °C based on a survey from 213 respondents. Hisham et al. [32] who performed field measurements on 19 dwellings consisting of low-cost apartments and one terraced house in Malaysia, found that the temperature setting of air conditioning ranged from 16 °C to 28 °C.

Kim [5] discovered that the average operating time for air conditioners was 0.32 h/day in 2250 households in Korea. In contrast, Kubota et al. [19] found that the average operating times for air conditioning appliances in Malaysia was 6 h/day. Zaki et al. [33] studied 38 dwellings in Kuala Lumpur and found that the average operating times of air conditioning appliances mostly ranged from 1 h/day to 6 h/day. Similarly, Aqilah et al. [34] reported that the average operating times of air conditioning appliances in Kuala Lumpur was almost 3 h/day.

1.5. Research Gaps and Objectives

Previous studies of determinant factors of electricity consumption have been mostly conducted in developed countries in subtropical regions. There are few similar studies on this topic in developing countries, especially in tropical regions where determinant factors of electricity consumption might differ from those in developed countries due to different socio-economic levels, cultures, and climatic conditions. Data on factors affecting electricity consumption are essential for tropical regions so that specific electricity-saving strategies can be established based on factors related to household characteristics.

For Malaysia, only Azlina et al. [12] examined a limited number of socio-demographic factors (marital status, monthly income, number of people living), house characteristics (total floor area, number of bathrooms), occupant behaviour (attitudes toward energy savings, environmental information), and appliance characteristics (air conditioners, refrigerators, freezers, heaters, vacuums, rice cookers, kettles, irons, and televisions). The current study improves knowledge and understanding by investigating comprehensively additional factors of household characteristics. This study also aims to determine a comprehensive set of determinant factors affecting electricity consumption in Malaysian households. Its specific objectives are to use multiple linear regression analysis to assess correlation significance amongst factors of household characteristics in terms of electricity consumption.

2. Materials and Methods

2.1. Field Survey

Field questionnaire surveys were conducted on 214 volunteer students at the Malaysia-Japan International Institute of Technology (MJIIT), Universiti Teknologi Malaysia (UTM), Kuala Lumpur from November 2017 to January 2018. The students answered the survey questions referring to their family or parent's house since most of them were staying in the university dormitory at the time the survey was conducted. The sample consisted of 113 males (52.8%) and 101 females (47.2%). The average age was 22 years old, with a standard deviation of 6 years. Family or parent houses of students were in various states as shown in Figure 2. The total number of students who answered about their house location was 179 (83.6%). Most of the surveyed houses were in Selangor (24.3%), Kuala Lumpur (14.5%), and Johor (11.2%). The number of buildings per state based on the collected data is shown in Table 1.

Table 1. Number of buildings per state.

States	Building Numbers
Selangor	52
Kuala Lumpur	31
Johor	24
Pahang	14
Sarawak	11
Perak	10
Kelantan	9
Negeri Sembilan	8
Kedah	7
Penang	6
Melaka	3
Sabah	2
Terengganu	2

Figure 1 shows the daily average, maximum, and minimum outdoor temperatures during the field survey. This information was obtained from the weather station in Sultan Abdul Aziz Shah Airport, Selangor, Malaysia [35]. The outdoor temperature might be a little different for other locations. However, Malaysia experiences a hot and humid climate throughout the year therefore the monthly outdoor temperature means is almost constant in most of the towns [19]. December 2017 had the highest average outdoor temperature (28.4 °C) and January 2018 had the lowest average outdoor temperature (27.2 °C). The average outdoor temperature for all days was 27.8 °C with a standard deviation of 1.2 °C.

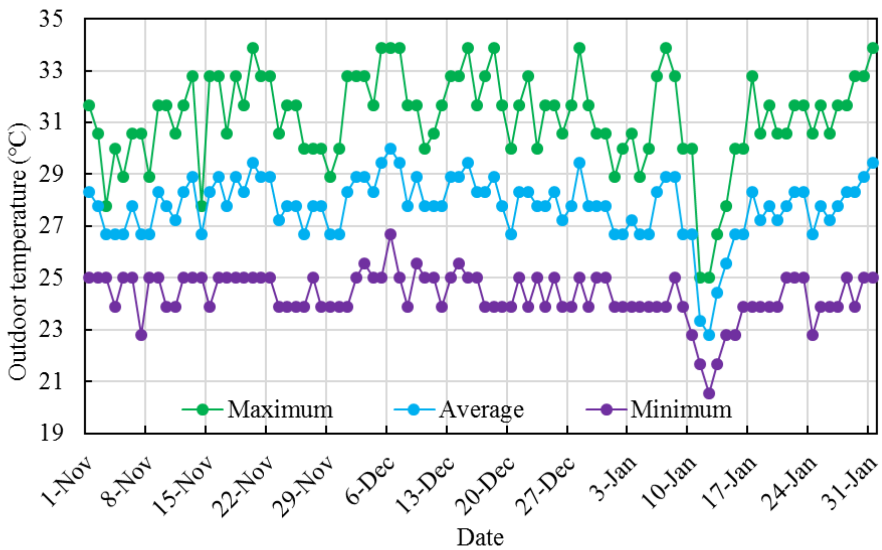


Figure 1. Outdoor daily temperature from November 2017 to January 2018 [35].

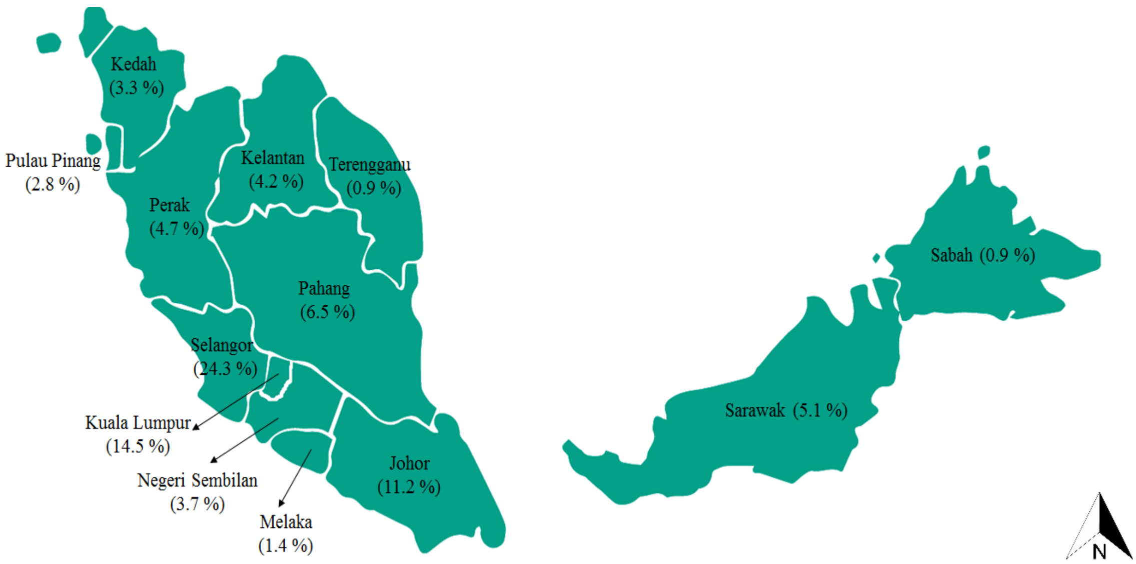


Figure 2. Location and percentage of surveyed houses in Malaysia. Image from [36].

2.2. *Questionnaire Survey*

The questionnaire survey was based on one developed by the Jyukanko Research Institute (JRI) [37] and modified by the lead author to meet the objectives of this research. The questionnaire was in English with a Malay translation. The questionnaire surveys were divided into two stages such as direct and indirect. The direct questionnaire surveys were conducted based on the appointed schedule between the lead author and respondents. The surveys were performed by disseminating the questionnaire then all respondents would fill up the questionnaire based on guidance from the lead author. The lead author explained each question and used pictures in some difficult questions to ease the respondents in their answers. After finishing the direct questionnaire survey, the lead author would check the answer. The lead author would conduct an indirect questionnaire survey in order to investigate some illogical questions or answers by confirming to the respondent's parents or other household members. The lead author used social media apps so that the respondents could confirm unanswered questions and uncleared answers with the person who knows best for the answer. After the family member informed the required information, the respondent would give it to the lead author using social media apps. If the lead author still found an invalid and incomplete answer on the questionnaire, the author would contact the respondent using social media apps through an indirect questionnaire survey and otherwise. Figure 3 shows the flowchart of a direct and indirect questionnaire survey.

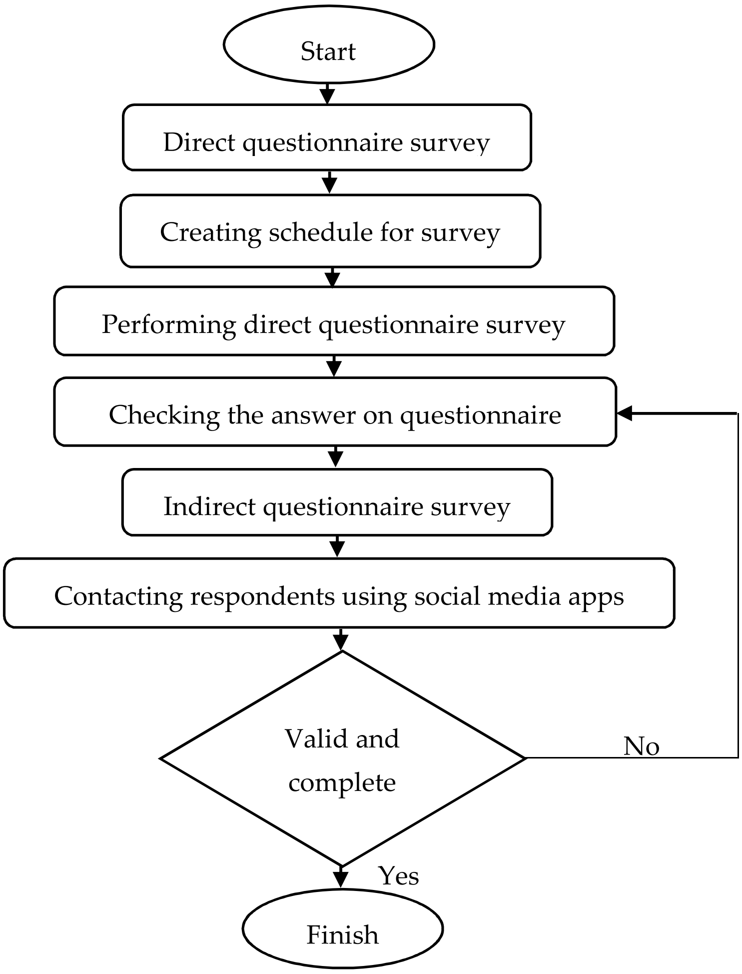


Figure 3. Flowchart of a direct and indirect questionnaire survey.

Electricity consumption values were obtained by collecting monthly electricity bills from the respondents. The data of monthly electricity consumption were collected between July 2017 and January 2018. Table 2 shows four categories in the questionnaire with general descriptions for each factor. The number of energy stars for the appliances refers to the standard of the United States Environmental Protection Agency and Department of Energy (US EPA and DOE) rating system [38]. Tenure type means the house was private ownership, rented house, or third-party ownership. Education level was interpreted as the education level for the household head, mother, or another person. Some important questions and detailed descriptions for each factor are provided in Appendix A, Appendix B, Appendix C.

Table 2. Four categories in the questionnaire.

Categories	General Descriptions
Socio-demographic	Monthly income, number of people living in the house, family composition, number of working people in the household, education level of the household head and mother or another person
House characteristics	Type of house, materials used for the walls and roof, number of storeys, age of the house, tenure type, total floor space or housing area, number of rooms, shading devices, glazing of windows and glazing ratio, house orientation and type of rooms
Appliance characteristics	Total number of appliances, characteristics of each appliance (e.g., set temperature for the air conditioners, age of the appliance, power rating), and number of energy stars for the appliances (US EPA and DOE ENERGY STAR Rating system)
Usage behaviour of appliances	Occupancy schedule at home, the operation time of household appliances and method of climate control of the home during day and night.

2.3. Statistical Methods

Two statistical methods were used: Pearson correlation and multiple linear regression analysis. The Pearson correlation method was used to investigate the degree of standardized covariance with respect to the relationship between two variables and cross-correlation analysis amongst variables.

The method uses two parameters which are Pearson correlation coefficient (r value) and p-value. The r-value is between −1 for negative correlation and +1 for positive correlation. The higher coefficient of Pearson correlation or r-value, the higher correlation among observed variables. The measures of variability in one variable that is accounted for by other variables or so-called p-values range from 0 to 1. The higher p-value, the lower significance of independent variable to the dependent variable and otherwise, the lower p-value (usually below 0.05 or 0.01), the more significance of independent variable to a dependent variable [39]. The factors that had a significance ($p \leq 0.05$) and a strong correlation with electricity consumption were then used as the inputs in the multiple linear regression analysis.

Multiple linear regression (MLR) was performed to assess the strength of the relationship among datasets of independent variables or so-called explanatory variables and single output datasets of dependent variables. The method was used to investigate determinant factors affecting electricity consumption because the variance of the dependent variable, which was electricity consumption, can be explained by a set of independent variables which were household characteristic factors as confirmed by [18,22]. Equation (1) shows the general multiple linear regression model.

$$y = a_1x_1 + a_2x_2 + \ldots + a_nx_n + b \quad (1)$$

where x_1 to x_n are explanatory variables which consist of household characteristic factors such as socio-demographic, house characteristics, appliance characteristics, and occupant behaviour. a_i to a_n are regression coefficients, b is a constant regression coefficient, and y is the electricity consumption. Similar to MLR, weighted regression is also performed to investigate the relationship among variables by considering the amount of data in each bin. There are four main parameters in the regression that are considered to interpret the results such as regression coefficient (C), beta (β), p-value and coefficient determination (R^2). The regression coefficient is used to measure how much the impact of explanatory variables on the increase or decrease in electricity consumption. The higher coefficient, the greater the number of electricity consumption or otherwise. Beta measures the influence of the variables on the variance of electricity consumption. p-value explains the significance of the variables to the overall model. Coefficient determination (R^2) measures the variability of the output variable accounted for by the explanatory variables. Beta, p-value and R^2 have a similar range from 0 to 1 which means that the higher those parameters to 1, the stronger the influence, significance and variance of those parameters to the model, respectively.

IBM SPSS version 23 was used as statistical software to analyze the dataset which offered four methods of developing multiple linear regression: enter, forward, backward, and stepwise. The stepwise method was selected as the preferred method because this method generated multiple linear regression without a multicollinearity problem [39].

3. Results and Discussion

3.1. Overview of a Questionnaire Survey

Figure 4 shows the number of people living with a percentage of households. The majority of households had people living in the house between three persons (25.2%) and four people (22.4%). Only 1.8% of the household which had one person living in the house. Figure 5 shows the year of house construction with the percentage of households. Most of the surveyed houses were constructed from 2000 to 2004 (27.6%) and the 1990s (20.6%). The minority of the house was built in 1980 or earlier (3.3%) and only 8.4% of the house were established in 2010 or after.

Figure 4. Number of people living.

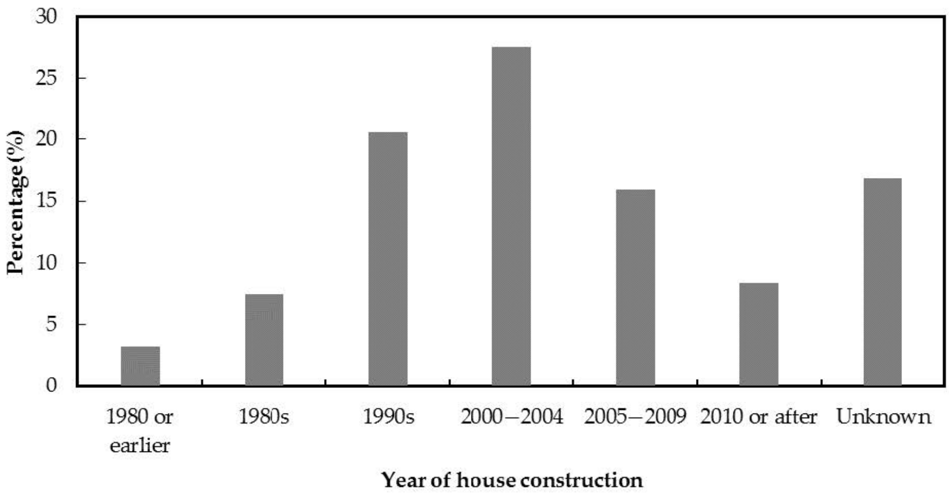


Figure 5. Year of house construction.

Figure 6 shows the ownership of the appliance type for the household involved in the questionnaire survey. Most households used fluorescent lamps (89.7%) while only 32.7% of households used LED lamps in the house. Flat-screen TVs were used by 89.3% of households with the ownership of energy star TVs at 53.3%. Only 20.6% of households used CRT TV in their house. On the other side, wall-mounted ACs were owned by 68.7% of households, and 45.3% of households utilized star ACs.

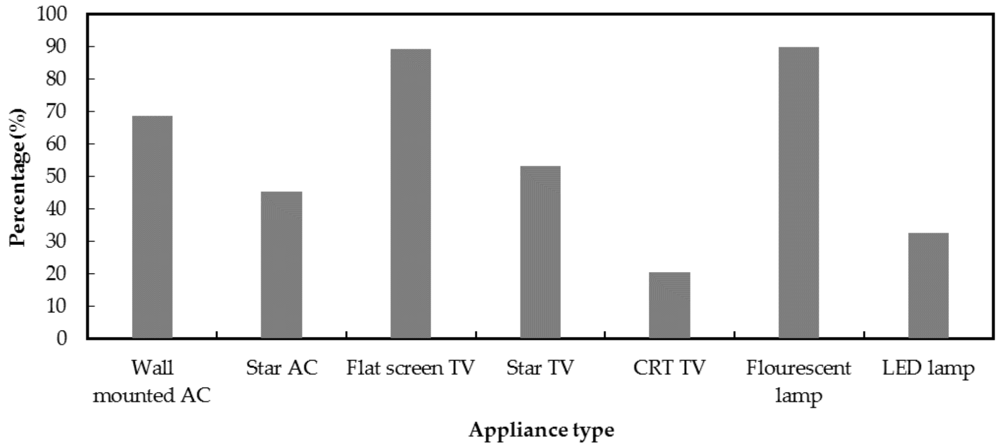


Figure 6. Ownership of appliance type.

3.2. *Relationship between Household Characteristic Factors and Electricity Consumption*

Table 3 shows only those household characteristic factors with significant and strong correlations with electricity consumption according to the Pearson correlation analyses. Monthly income, education level of the household head, and the number of household members had a moderately significant correlation with electricity consumption. These results were similar to those reported by Kim [5] and Chen et al. [6] except that family composition was not found to be statistically significant in the current results, while Kim [5] found that it was statistically significant.

Table 3. Pearson correlation between household characteristic factors and electricity consumption.

Household Characteristic Factors	*N*	*r*	*p*
Monthly income	214	0.36	<0.001
Number of people in the household	214	0.22	0.001
Number of working people in the household	214	0.18	0.005
Education level of the household head	214	0.30	<0.001
Education level of the mother or other persons	214	0.14	0.022
Number of storeys	214	0.16	0.009
Total floor area	214	0.14	0.023
Number of rooms	214	0.31	<0.001
Number of windows	214	0.18	0.004
Number of fluorescent lamps	192	0.31	<0.001
Number of LED lamps	70	0.12	0.036
Number of lamps (all)	214	0.40	<0.001
Glazing ratio of north-facing window(s)	214	0.16	0.010
Number of TV energy stars	114	0.20	0.002
Number of AC energy stars	97	0.26	<0.001
Number of kitchen hooks	99	0.13	0.030
Number of microwave ovens	150	0.16	0.009
Number of game consoles	65	0.19	0.004
Number of satellite TVs	157	0.23	0.001
Age of AC	147	0.32	<0.001
Power rating of AC	147	0.27	<0.001
Number of chargers—tablet	97	0.30	<0.001

Table 3. *Cont.*

Household Characteristic Factors	*N*	*r*	*p*
Number of routers	133	0.29	<0.001
Number of hair dryers	86	0.24	0.001
Number of chargers—smartphone	213	0.27	<0.001
Number of water pumps	30	0.18	0.004
Age of refrigerator	214	0.20	0.002
Cubic capacity of refrigerator	214	0.19	0.003
Number of vacuum cleaners	168	0.30	<0.001
Number of washing machines	210	0.12	0.039
Number of chargers—laptop	196	0.20	0.002
Number of flat screen TVs	191	0.36	<0.001
Number of CRT TVs	44	−0.13	0.031
Number of miscellaneous appliances	212	0.32	<0.001
Number of stand fans	167	−0.16	0.012
Number of ceiling fans	203	0.26	<0.001
Age of stand fan	167	−0.22	0.001
Number of standalone freezers	22	0.17	0.006
Number of water heaters	105	0.18	0.003
Number of wall-mounted ACs	147	0.54	<0.001
Usage of AC on weekdays	138	0.23	0.001
Usage of AC on weekends	141	0.24	0.001
Set temperature of AC	148	0.27	<0.001
Speed setting of stand fan	168	−0.19	0.005
Usage of entertainment appliance on weekends	212	0.15	0.033
Usage of entertainment appliance on weekdays	211	0.19	0.005
Usage of miscellaneous appliance on weekdays	212	0.18	0.008
Usage of water dispenser on weekdays	76	0.18	0.010
Usage of charger—laptop on weekdays	152	0.2	0.004
Usage of router on weekdays	116	0.26	<0.001
Usage of hair dryer on weekdays	61	0.15	0.025
Usage of electric water heater on weekdays	93	0.18	0.008
Usage of hair dryer on weekends	60	0.15	0.030
Usage of electric water heater on weekends	94	0.15	0.032

Note: *N*: number of samples, *r*: Correlation coefficient, *p*: Significant value of regression coefficient.

The number of rooms had a moderately significant correlation which was similar to findings from Jaffar et al. [28], while Chen et al. [6] found that the number of rooms was not significantly correlated. Although Kim [5] found that the age of the building and house type were significantly correlated, such factors did not show a significant correlation in our study. The number of air conditioning units and the total number of lamps had a significant correlation which was similar to findings from Chen et al. [6] and Bedir and Kara [27].

Some appliances such as CD/DVD players, washing machines, vacuum cleaners, incandescent lamps, freezers, irons, and hair dryers were not significantly correlated, which differ from what Genjo et al. [40], Azlina et al. [12], and Bedir and Kara [27] found. Usage of some appliances on weekdays and weekends such as entertainment, cooking, and miscellaneous appliances were not significantly correlated with electricity consumption. Bedir and Kara [27] also found that usage of entertainment and miscellaneous appliances was not significantly correlated, however, they also found that usage of cooking appliances was significantly correlated with electricity consumption.

3.3. Correlation Analysis for Set Temperature of AC and Electricity Consumption

Figure 7 shows the set temperature of air conditioners variation with the percentage of households. The majority of households set the temperature somewhere between 19.1 °C and 25 °C (68.4%). These findings were similar to those found by Jaffar et al. [28] and Kubota et al. [19].

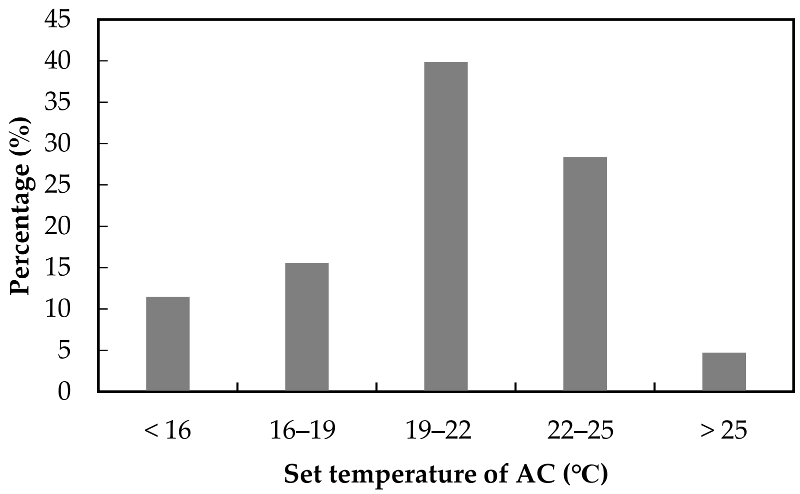
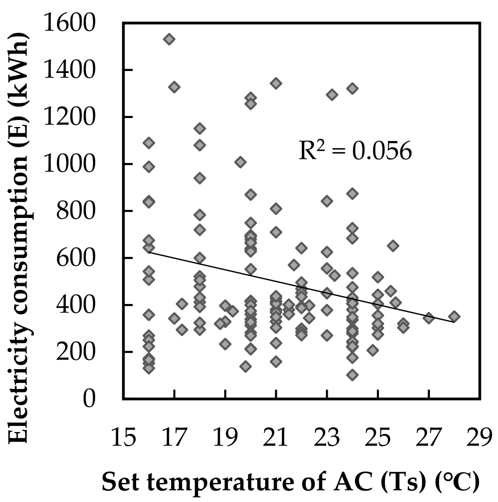
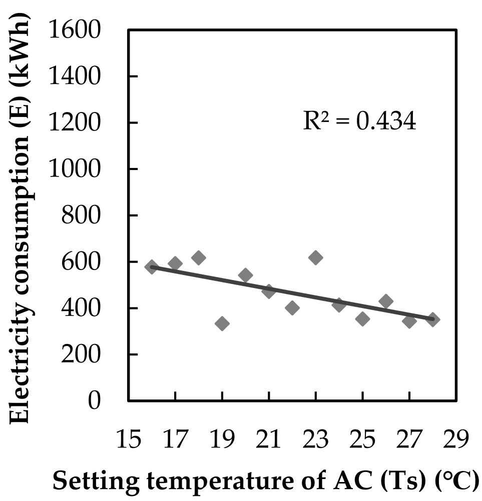


Figure 7. Set temperature of air conditioning unit.

Figure 8 shows the correlation between the set temperature of air conditioners and electricity consumption for raw data and binned data at 1 °C intervals. Raw data refer to the observed data which were obtained in field survey and binned data proceed the observed data into some group number of bins. Many researchers such as de Dear et al. [41] and Gautam et al. [42] used the binned data to increase the reliability of the regression model (R^2) but the regression coefficient would be similar for both data.



(**a**) Raw data



(**b**) Binned data

Figure 8. Correlation of set temperature of air conditioning (AC) with respect to electricity consumption.

The binned data were analyzed using weighted regression analysis in order to investigate the trends in scattered plots of raw data. The coefficient of determination of binned data was much higher compared to raw data as shown in Equations (2) and (3) for the set temperature of air conditioners as an explanatory variable (*Ts*), the number of samples (*n*), coefficient of determination (R^2), standard error of regression coefficient (*S.E*), statistically significant value for regression coefficient (*p*), and electricity consumption as dependent variable (*E*), respectively. The slope and constant of raw data and binned data were similar and thus either of the equations can be used to estimate the average electricity use. However, the raw data could be used to show the actual set temperature of air conditioners in daily life.

Raw data:

$$E = -24.8\ Ts + 1021.4\ \left(n = 148,\ R^2 = 0.056,\ S.E = 299.1,\ p = 0.004\right) \quad (2)$$

Binned data:

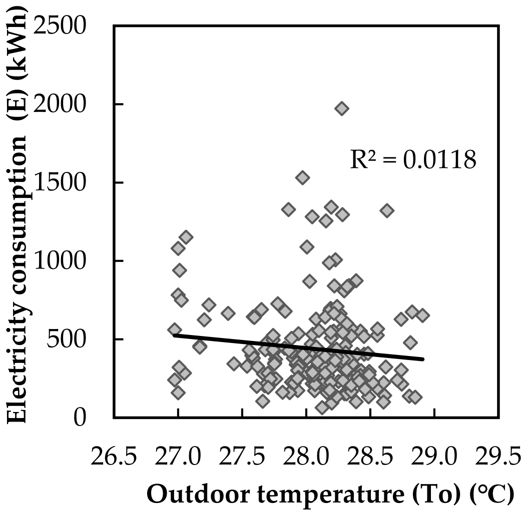
$$E = -18.7\ Ts + 876.5\ \left(n = 13,\ R^2 = 0.434,\ S.E = 86.9,\ p = 0.014\right) \quad (3)$$

Setting the air conditioners temperature showed a significantly moderate correlation with electricity consumption by binning the data. This result was similar to Santin et al. [26] and Jaffar et al. [28]; the latter also found that setting temperatures for heater appliances were significantly correlated.

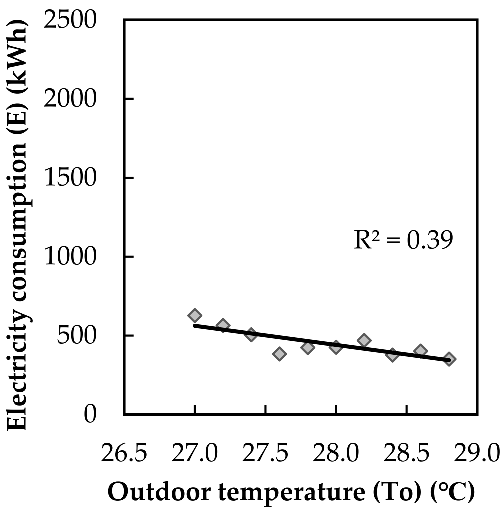
3.4. Correlation Analysis for Outdoor Temperature and Electricity Consumption

Many factors might affect electricity consumption as explained in the previous sections. Outdoor temperature is one such factor that can affect people using household appliances as reported by Steemers et al. [17]. Regression analyses were performed to understand the relationship between outdoor temperature and electricity consumption. Information on outdoor temperature was obtained from the weather station at Sultan Abdul Aziz Shah Airport, Selangor, Malaysia [35].

Figure 9 shows the variation in electricity consumption with outdoor temperature based on raw data and binned data. The regression model of binned data at 0.2 °C intervals shows a much higher coefficient of determination than that of raw data as shown in (4) and (5) for the outdoor temperature as an explanatory variable (*To*), number of the sample (n), coefficient of determination (R^2), standard error of regression coefficient ($S.E$), statistically significant value for regression coefficient (p), and electricity consumption as dependent variable (E), respectively. The slope and constant of binned data were slightly higher than the raw data. This might be due to the small range of outdoor temperature which needs to consider in further studies.



(**a**) Raw data



(**b**) Binned data

Figure 9. Correlation between outdoor temperature vs. electricity consumption.

Raw data:

$$E = -78.7\ To + 2648\ \left(n = 214,\ R^2 = 0.01,\ S.E. = 49.5,\ p = 0.113\right) \quad (4)$$

Binned data:

$$E = -94.6\ To + 3092.8\ \left(n = 10,\ R^2 = 0.39,\ S.E. = 42.1,\ p = 0.05\right) \quad (5)$$

Outdoor temperature showed a low correlation. This finding was contradicted to that of Galvin et al. [43] who established that outdoor temperature affects electricity consumption in Germany in temperate regions.

3.5. Cross-Correlation Analysis for Household Characteristic Factors

Cross-correlation analyses for household characteristic factors were performed in order to investigate the correlation among them as provided in Appendix D, Appendix E, Appendix F, Appendix G. Monthly income had a significantly moderate correlation with some factors such as education level of the household head, the number of people living, the number of rooms and the number of air conditioning appliances as shown in Table 4. The wealthier people moderately tend to have better education, larger house and consume more electricity since they have more appliances. These results were similar to Chen et al. [6] who found a correlation between monthly income and some factors such as number of rooms, number of people living in the household, and number of air conditioning appliances, and Kim [5] who confirmed a correlation between monthly income and education level of the household head.

Table 4. Cross-correlation analysis for household characteristic factors with respect to monthly income.

	N	Monthly Income	*p*
Number of people living	214	0.14	0.045
Education level of household head	214	0.27	<0.001
Number of rooms	214	0.32	<0.001
Number of wall mounted air conditioning	147	0.32	<0.001
Number of lamps	214	0.34	<0.001
Number of charger laptop	152	0.29	<0.001
Usage of router on weekdays	116	0.31	<0.001
Usage of router on weekends	116	0.33	<0.001

The number of air conditioning appliances had a strong correlation with the age of the air conditioning, the power rating of air conditioning, set temperature of air conditioning, the number of energy star air conditioning, usage of air conditioning on weekdays and weekends. Whilst number of air conditioning appliances had a moderate correlation with the number of ceiling fans, number of lamps, number of energy star TVs, and usage of the router on weekdays as shown in Table 5. The more ownership of air conditioning appliances, the usage of air conditioning appliances was also higher, as confirmed by Chen et al. [6].

Table 5. Cross-correlation analysis for household characteristic factors with respect to number of wall-mounted air conditioning units (AC).

Cross Correlation	*N*	Number of Wall Mounted AC	*p*
Age of AC	147	0.63	<0.001
power rating AC	147	0.58	<0.001
Set temperature of AC	147	0.65	<0.001
Number of energy star AC	147	0.37	<0.001
Number of ceiling fans	203	0.39	<0.001
Number of lamps	214	0.37	<0.001
Number of energy star TV	114	0.17	0.02
Usage of AC on weekdays	147	0.60	<0.001
Usage of AC on weekends	147	0.59	<0.001
Usage of router on weekdays	116	0.32	<0.001

Usage of air conditioners on weekdays had a moderate correlation with ownership of miscellaneous appliances, usage of miscellaneous appliances on weekdays and usage of entertainment appliances on weekdays and weekends, number of lamps (all), and usage of electric water heater on weekends as shown in Table 6. Miscellaneous appliances consist of the washing machine, hairdryer, lighting, water pump, vacuum cleaner, and electric water heater. Entertainment appliances consist of televisions, game consoles, satellite TVs, routers, chargers of smartphones, laptops, and tablets. These results were similar to Kim [5] who found that usage of air conditioners had a correlation with the number of household appliances, usage of television, and usage of the washing machine.

Table 6. Cross-correlation analysis for household characteristic factors with respect to usage of air conditioning (AC) on weekdays.

Cross Correlation	*N*	Usage of AC on Weekdays	*p*
Usage of AC on weekend	147	0.95	<0.001
Number of miscellaneous appliances	212	0.16	0.02
Usage of entertainment on weekdays	212	0.16	0.02
Usage of entertainment on weekends	211	0.15	0.02
Usage of miscellaneous appliances on weekdays	212	0.25	<0.001
Usage of electric heater on weekends	93	0.4	<0.001
Number of lamps	214	0.33	<0.001
Number of rooms	214	0.26	<0.001
Number of wall mounted AC	147	0.60	<0.001

Number of rooms had a moderate correlation with total floor space, number of people living, number of lamps (all), number of air conditioning appliances and monthly income, as shown in Table 7. Similarly, Chen et al. [6] also reported that the number of rooms had a correlation with the total floor area, number of people living, number of air conditioning appliances, and monthly income. The number of people living in the household had an insignificant correlation with the total floor area ($r = -0.05$, $p = 0.948$) and number of air conditioning appliances ($r = -0.004$, $p = 0.56$) which contradicted Chen et al. [6]. However, the number of people living in the household showed a significant correlation with the number of rooms ($r = 0.26$, $p < 0.001$) and an insignificant correlation with the usage of air conditioning appliances on a weekday ($r = -0.004$, $p = 0.953$) and the usage of air conditioning appliances on weekends ($r = 0.02$, $p = 0.97$) which was similar to Chen et al. [6].

Table 7. Cross-correlation analysis for household characteristic factors with respect to number of rooms.

Cross Correlation	*N*	Number of Rooms	*p*
Total floor space	147	0.30	<0.001
Number of people living	212	0.26	<0.001
Number of lamps	211	0.31	<0.001
Number of wall mounted air conditioning	147	0.30	<0.001
Monthly income	214	0.32	<0.001

Kim [5] found that the type of cooling such as fan and air conditioners had a significant correlation with the education level of household head, monthly income, number of people living, and total floor area. The current study found that the correlation between the number of stand fans is insignificant for the education level of the household head, and the number of people living, as shown in Table 8. Number of stand fans also found a negative correlation with monthly income, which means that the more ownership of the stand fan, the less monthly income. On the other side, the number of stand fans had a significant correlation with the total floor area, which was similar to Kim [5]. Interestingly, the current study confirmed that the number of ceiling fans had similar characteristics as established by Kim [5] except for the number of people living, which had an insignificant correlation.

Table 8. Cross-correlation analysis for household characteristic factors with respect to number of stand fans.

Cross Correlation	*N*	Stand Fan	*p*
Ceiling fan	203	−0.38	<0.001
Education of head household	214	−0.08	0.29
Number of people living	214	0.07	0.32
Income	214	−0.17	0.02
Total floor space	214	0.15	0.03

Kitchen appliances showed an indirect effect on other household characteristic factors. Monthly income correlated with energy star fans, electric pots, hand mixer and microwave oven. Kitchen hook correlated with glazing ratio north (r = 0.22, p = 0.001) and dishwasher also correlated with water dispenser (r = 0.38, p < 0.001). Table 9 shows the cross-correlation analysis for household characteristic factors with respect to monthly income.

Table 9. Cross-correlation analysis for household characteristic factors with respect to monthly income.

Cross Correlation	*N*	Monthly Income	*p*
Energy star fans	192	0.15	0.03
Electric pots	114	0.22	0.001
Hand mixer	97	0.18	0.009
Microwave oven	150	0.16	0.02

Number of people living shows correlation with usage of entertainment on weekdays (r = 0.18, p = 0.008), usage of entertainment on weekends (r = 0.14, p = 0.04). The findings were similar to Domínguez-Amarillo et al. [44] who found that the more people living in the house, the more people use television and entertainment appliances. Silva et al. [45] confirm that the correlation between building types with respect to occupant behaviour. While Dziedzic et al. [46] found that profile of occupancy strongly correlated with the usage of household appliances. Similar findings were also found in current study, type of room shows correlation with respect to occupancy schedule in weekdays (r = 0.17, p = 0.01) and occupancy schedule in weekend (r = 0.19, p = 0.006). Furthermore, glazing windows correlated with usage of air conditioning on weekdays (r = 0.16, p = 0.02) and usage of air conditioning on weekends (r = 0.15, p = 0.03).

3.6. Multiple Linear Regression Model Based on Household Characteristic Factors

Five multiple linear regression models were constructed in single, double combined and triple combined models as shown in Figure 10. The single model consisted of appliance characteristic factors. The double combined models consisted of socio-demographic and appliance characteristic factors, and occupant behaviour and appliance characteristic factors. The triple combined model consisted of socio-demographic, appliance characteristic factors, and occupant behaviour in one model, and socio-demographic, house characteristic factors, and occupant behaviour in a second model. The single model was developed based on appliance characteristic factors. The double and triple combined model was built by combining the factors from each category on household characteristic factors. The factors were selected based on two parameters such as p (statistically significant value) and variance inflation factor (*VIF*). The factors which had a p-value of more than 0.05 and a *VIF* value of more than 3.3 were removed from the models.

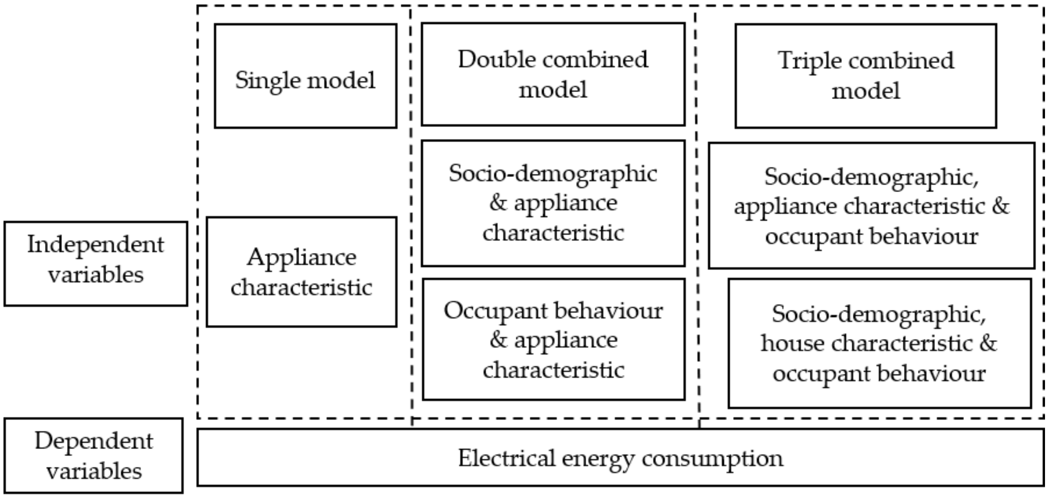


Figure 10. A framework of determinant factors of electricity consumption.

3.6.1. First Model: Appliance Characteristic Factors

The first model showed that the regression of appliance characteristic factors explained 42.3% of the variance in electricity consumption. Table 10 shows the determinant factors of electricity consumption for appliance characteristic factors. The number of air conditioning appliances exerts the greatest influence on the variance of electricity consumption. The number of fluorescent lamps showed a stronger influence than the number of smartphones charger, the number of flat-screen TVs, and the number of stand-alone freezers. Interestingly, the number of energy star air conditioners showed a negative contribution which means that the ownership of energy star air conditioners would reduce electricity consumption.

Table 10. Determinant factors of electricity consumption for appliance characteristic factors.

Variable	Descriptive Statistics			Regression Analysis		
	M	***D***	***C***	β	ε	***p***
x_1	1.9	1.8	86.9	0.54	12.19	<0.001
x_2	4.2	1.5	28.5	0.15	10.9	0.009
x_3	1.2	1.6	−37.8	−0.21	12.7	0.003
x_4	0.1	0.3	113.9	0.14	43.7	0.010
x_5	13.0	11.2	5.4	0.22	1.4	<0.001
x_6	1.3	0.8	57.9	0.16	22.1	0.009
b	-	-	45.2	-	49.9	0.365

Note: x_1: Number of wall-mounted ACs; x_2: Number of chargers–smartphone; x_3: Number of air conditioner energy stars, x_4: Number of standalone freezers; x_5: Number of fluorescent lamps; x_6: Number of flat-screen TVs; b: constant, M: mean; D: standard deviation, C: coefficient, β: beta, ε: standard error, p: p-value; standard error and p values are for the coefficient.

Equation (6) shows the multiple linear regression model. Here, the independent variables (x_n) denote the appliance characteristic factors and electricity consumption are the dependent variables (y).

$$y = 86.9\,x_1 + 28.5\,x_2 - 37.8\,x_3 + 113.9x_4 + 5.4x_5 + 57.9x_6 + 45.2 \quad (6)$$

Table 10 shows that for each wall-mounted air conditioner and TV, electricity consumption increased by 86.9 kWh and 57.9 kWh, respectively when other variables were constant. Standalone freezers accounted for 113.9 kWh each while each air conditioner energy star reduced consumption by 37.8 kWh. Equation (6) can be used to estimate electricity consumption for given variables. The estimated electricity saving with the implementation energy star AC was 11.2%.

3.6.2. Second Model: Socio-Demographic and Appliance Characteristic Factors

The second model showed that the regression of socio-demographic and appliance characteristic factors explained 44.5% of the variance in electricity consumption. Table 11 shows the determinant factors of electricity consumption for socio-demographic and appliance characteristic factors.

Table 11. Determinant factors of electricity consumption for socio-demographic and appliance characteristic factors.

Variable	Descriptive Statistics			Regression Analysis		
	M	***D***	***C***	**β**	**ε**	***p***
x_1	1.9	1.8	82.2	0.51	12.1	<0.001
x_2	4.0	1.6	27.4	0.15	9.8	0.005
x_3	1.3	0.8	62.3	0.17	21.4	0.004
x_4	13.0	11.2	5.1	0.20	1.4	<0.001
x_5	1.2	1.6	−32.6	−0.18	12.5	0.010
x_6	0.1	0.3	116.1	0.14	43.4	0.008
x_7	2.1	1.0	36.7	0.13	15.9	0.022
b	-	-	−16.7	-	52.8	0.752

Note: x_1: Number of wall-mounted air conditioner units; x_2: Number of people in household; x_3: Number of flat-screen TVs, x_4: Number of fluorescent lamps; x_5: Number of air conditioner energy stars; x_6: Number of standalone freezers; x_7: Education level of household head; b: constant, M: mean; D: standard deviation, C: coefficient, β: beta, ε: standard error, p: p-value; standard error and p values are for the coefficient.

Almost all factors from the first model appeared in the second model except the number of smartphones charger. The number of air conditioning appliances still emerged as the strongest factor affecting electricity consumption although the significance was decreased compared to the first model. Two socio-demographic factors such as the number of people in the household and the education level of the household head showed lower significance than those of appliance factors in the second model.

Equation (7) shows the multiple linear regression model for socio-demographic and appliance characteristic factors as explanatory variables (x_n) and electricity consumption as the predicted variable (y).

$$y = 82.2x_1 + 27.4x_2 + 62.3x_3 + 5.1x_4 - 32.6x_5 + 116.1x_6 + 36.7x_7 - 16.7 \quad (7)$$

Each wall-mounted air conditioner accounted for 82.2 kWh of consumption, and each additional person was linked to an additional 27.4 kWh, while other variables remained constant. Households, where the head had a high level of education, were estimated to increase consumption by 36.7 kWh, and each additional air conditioner energy star decreased consumption by 32.6 kWh while other factors remained unchanged. Equation (7) can be used to estimate electricity consumption for given variables. The estimated electricity saving with the implementation of energy star air conditioner was 10.4%.

3.6.3. Third Model: Appliance Characteristic and Occupant Baviour Factors

The third model showed that the regression of appliance characteristic factors and occupant behaviour explained 42% of the variance in electricity consumption. Table 12 shows the determinant factors of electricity consumption for appliance characteristics and occupant behaviour factors. Compared to the first and second models, the number of air conditioning appliances showed the strongest contribution to the variance of electricity consumption in the third model. The total number of lamps had a stronger influence than the number of smartphone chargers and cubic capacity of the refrigerator. The usage of air conditioners on weekdays and the number of air conditioner energy stars showed a negative influence which means that those factors tend to reduce electricity consumption. The usage of air conditioners on weekdays might reduce electricity consumption because the type of air conditioner was an energy saver.

Table 12. Determinant factors of electricity consumption for appliance characteristics and occupant behaviour.

Variable	Descriptive Statistics			Regression Analysis		
	M	***D***	***C***	β	ε	***p***
x_1	1.9	1.8	108	0.67	13.5	<0.001
x_2	18.3	12.4	4.9	0.22	1.4	<0.001
x_3	7.5	7.7	−7.7	−0.21	2.5	0.002
x_4	4.2	1.5	29.2	0.15	10.9	0.008
x_5	443.6	240.2	0.16	0.14	0.1	0.012
x_6	1.2	1.6	−32.3	−0.18	12.8	0.012
b	-	-	45.3	-	53.9	0.402

Note: x_1: Number of wall-mounted ACs; x_2: Number of chargers–smartphone; x_3: Number of air conditioner energy stars, x_4: Number of standalone freezers; x_5: Number of fluorescent lamps; x_6: Number of flat-screen TVs; b: constant, M: mean; D: standard deviation, C: coefficient, β: beta, ε: standard error, p: p-value; standard error and p values are for the coefficient.

Equation (8) gives the multiple linear regression model for appliance characteristic factors and occupant behaviour as independent variables (x_n) and electricity consumption as the dependent variable (y).

$$y = 108\ x_1 + 4.9\ x_2 - 7.7\ x_3 + 29.2x_4 + 0.16x_5 - 32.3x_6 + 45.3 \quad (8)$$

Electricity consumption increased by 108 kWh for every wall-mounted air conditioner but decreased by 7.7 kWh for every additional hour of air conditioner use on weekdays and by 32.3 kWh for each additional air conditioner energy star when other factors were constant. Equation (8) can be used to estimate electricity consumption for given variables. The estimated electricity saving with the implementation of an energy star air conditioner and flat-screen TV from the equation was 21.3%.

3.6.4. Fourth Model: Socio-Demographic, Appliance Characteristic, and Occupant Behaviour Factors

The fourth model showed that the regression of socio-demographic, appliance characteristics, and occupant behaviour explained 46% of the variance in electricity consumption. Table 13 shows the determinant factors of electricity consumption for these factors. Almost all factors from the previous model emerged in this model, except for the number of charger smartphones, stand-alone freezers, and the total number of lamps.

Number of air conditioning appliances showed the most significant effect on electricity consumption. The number of fluorescent lamps had a stronger influence than the number of people in the household. However, the number of people in the household had a stronger contribution compared to the cubic capacity of refrigerators and education of the household head.

Equation (9) shows the regression model for socio-demographic, appliance characteristics, and occupant behaviour factors as explanatory variables (x_n) and electricity consumption as the dependent variable (y).

$$y = 99.6\ x_1 + 27.9\ x_2 - 7\ x_3 + 0.2x_4 + 63x_5 - 32x_6 + 5\ x_7 + 35.7\ x_8 - 60.6 \quad (9)$$

Each wall-mounted air conditioner increased electricity consumption by 99.6 kWh if all other factors remained constant. Similarly, if all other factors were constant, the electricity consumption would increase as follows: 27.9 kWh for an additional one person in the household, 0.2 kWh with an in the cubic capacity of the refrigerator, 63 kWh for each additional flat-screen TV, 5 kWh for one fluorescent lamp, and 35.7 kWh with an increase in education level. With a similar assumption, the electricity consumption would decrease as follows: 7 kWh for the usage of air conditioner on weekdays and 32 kWh for each additional air conditioner energy star. Equation (9) can be used to estimate electricity consumption for given variables. The estimated electricity saving with the implementation of usage of air conditioner on weekdays and energy star air conditioner from the equation was 20.6%.

Table 13. Determinant factors of electricity consumption for socio-demographic, appliance characteristic and occupant behaviour factors.

Variable	Descriptive Statistics		Regression Analysis			
	M	***D***	***C***	***β***	***E***	***p***
x_1	1.9	1.8	99.6	0.62	13.5	<0.001
x_2	4.0	1.6	27.9	0.15	9.6	0.004
x_3	7.5	7.7	−7	−0.19	2.4	0.004
x_4	443.6	240.2	0.2	0.14	0.1	0.007
x_5	1.3	0.8	63	0.17	21.2	0.003
x_6	1.2	1.6	−32	−0.18	12.4	0.011
x_7	13.0	11.3	5	0.20	1.4	<0.001
x_8	2.1	1.0	35.7	0.12	15.8	0.025
b	-	-	−60.6	-	58.0	0.297

Note: x_1: Number of wall-mounted air conditioner units; x_2: Number of people in household; x_3: Usage of air conditioner on weekdays; x_4: Cubic capacity of refrigerators; x_5: Number of flat-screen TVs; x_6: Number of air conditioner energy stars; x_7: Number of fluorescent lamps; x_8: Education of household head; b: constant, M: mean; D: standard deviation, C: coefficient, β: beta, ε: standard error, p: p-value; standard error and p values are for the coefficient.

3.6.5. Fifth Model: Socio-Demographic, House Characteristic and Occupant Behaviour Factors

The fifth model showed that regression of socio-demographic, house characteristic, and occupant behaviour factors explained 26.7% of the variance in electricity consumption. Table 14 shows the determinant factors of electricity consumption for socio-demographic, house characteristics, and occupant behaviour factors. In the fifth model, monthly income emerged as the strongest factor affecting electricity consumption. The number of rooms showed a stronger influence than the education level of household head, usage of charger-laptop on weekdays, and set the temperature of the air conditioner. Setting rotation of stand fans had a negative influence on the variance of electricity consumption which means that the stronger rotation of stand fans would reduce electricity consumption.

Table 14. Determinant factors of electricity consumption for socio-demographic, house characteristic and occupant behaviour factors.

Variable	Descriptive Statistics		Regression Analysis			
	M	***D***	***C***	***β***	***E***	***p***
x_1	6955.7	5770.2	0.01	0.20	0.003	0.002
x_2	2.1	1.0	43.9	0.15	18.4	0.018
x_3	4.8	5.6	6.6	0.13	3.1	0.035
x_4	1.9	1.1	−42.2	−0.17	15.9	0.008
x_5	10.5	4.1	12.6	0.18	4.6	0.007
x_6	14.7	10.0	3.9	0.14	1.8	0.034
b	-	-	137.5	-	62.7	0.029

Note: x_1: Monthly income (RM); x_2: Education level of household head; x_3: Usage of charger–laptop on weekdays; x_4: Set rotation of stand fan (weak/medium/strong); x_5: Number of rooms; x_6: Set temperature of air conditioner (Celsius); b: constant, M: mean; D: standard deviation, C: coefficient, β: beta, ε: standard error, p: p-value; standard error and p values are for the coefficient.

Equation (10) shows the multiple linear regression model for socio-demographic, house characteristic, and occupant behaviour factors as explanatory variables (x_n) and electricity consumption as predicted value (y).

$$y = 0.01\ x_1 + 43.9\ x_2 + 6.6\ x_3 - 42.2x_4 + 12.6x_5 + 3.9x_6 + 137.5 \quad (10)$$

Electricity consumption was estimated to increase by 0.01 kWh for each Ringgit Malaysia (RM) of monthly income, while each hour of usage of a laptop charger on weekdays resulted in an increase in consumption of 6.6 kWh and 43.9 kWh when the education of the household head increased by one level. Each increase in the set temperature of the air conditioner increased consumption by 3.9 kWh while it decreased by 42.2 kWh when the rotation speed of fans was increased by one level. Equation (10) can be used to estimate electricity consumption for given variables. The estimated electricity saving with the implementation of a set rotation of stand fan from the equation was 20.6%.

4. Discussion

Some factors of household characteristic factors emerged as the most significantly correlated to electricity consumption ($p < 0.001$) such as monthly income ($r = 0.36$), number of lamps (all) ($r = 0.40$), number of air conditioning appliances ($r = 0.54$), and number of miscellaneous appliances ($r = 0.32$). Air conditioning appliances emerged as the most important factor which affected consumption because of all aspects of air conditioners such as the age of air conditioner ($r = 0.32$), the power rating of air conditioners ($r = 0.27$), and setting the temperature of the air conditioner ($r = 0.27$) also significantly correlated with electricity consumption.

Only a few previous studies investigated the cross-correlation analyses among household characteristic factors as performed by Chen et al. [6] and Kim [5]. Monthly income, air conditioning appliances and ownership of miscellaneous appliances emerged as the centre of cross-correlation analyses which almost had a significant correlation with all household characteristic factors and electricity consumption. These findings proved that wealthier people tend to have more appliances and consumed more electricity consumption.

Multicollinearity is an important issue for multiple linear regression analysis which occurs when one or more predictors have a linear relationship with other factors. The variance inflation factor (*VIF*) was used as a parameter to check for the multicollinearity problem in regression. The standard values for *VIF* were different in some previous studies with a VIF of less than 10 [18,24] and less than 3.3 [16,22]. In this paper, a *VIF* value of less than 3.3 was selected as a standard value. The highest *VIF* obtained from the regression analysis was 2.6 which means that no multicollinearity was found among variables.

In the first regression model, 43.4% of the variance was explained by the following:

- the number of wall-mounted air conditioner
- the number of smartphone chargers
- the number of air conditioner energy stars
- the number of standalone freezers
- the number of fluorescent lamps
- the number of flat-screen TVs.

In the second regression model, 44.5% of the variance was explained primarily from the following:

- Number of wall-mounted air conditioner
- Number of flat-screen TVs
- Number of fluorescent lamps
- Number of air conditioner energy stars
- Number of standalone freezers
- Number of people living in the household
- Education level of the household head.

While the number of smartphone chargers disappeared completely. In the third regression model 42% of the variance was explained by the:

- Number of wall-mounted air conditioner
- Total number of lamps
- Usage of air conditioner on weekdays
- Number of smartphone chargers

- Cubic capacity of refrigerators
- Number of air conditioner energy stars.

The combination of socio-demographic, appliance characteristics and occupant behaviour in the fourth model accounted for 46% of the variance of electricity consumption. Similar factors to the second and third models emerged except for the number of smartphone chargers that disappeared in the third model. The appearance of air conditioning appliances (Beta = 0.62) in this model was the reason why this model had the highest variance of electricity consumption among other models. All factors contributed to the increasing in electricity consumption except that the factors of air conditioning appliance such as the number of air conditioning appliances, the number of energy star air conditioner and usage of air conditioner on weekdays showed a reduction in energy use. This anomaly may be caused by the occupancy schedule in Malaysia that only used air conditioning appliances at night and on the weekend as confirmed by [19,29,30].

The fifth model, which combined socio-demographic, house characteristics, and occupant behaviour, explained 26.7% of the variance of electricity consumption. Similar factors from previous models also appeared in the fifth model; however, it also showed the following as being significant:

- monthly income
- usage of laptop chargers on weekdays
- rotation speed setting of stand fans
- set temperature of air conditioners

These results showed that the combination of factors in the last (fifth) model had less effect on the variance of electricity consumption than the combination of factors in other models. It might be caused by the appearance of usage of charger-laptop on weekdays (Beta = 0.13) and the set temperature of air conditioners (Beta = 0.14) which had less contribution to the variance of electricity consumption in the model. This finding confirmed that the last model was not suitable to represent electricity consumption for Malaysian households.

Some previous studies have developed similar regression models. A comparison between previous regression models and the current model is provided in Table 15. The current multiple linear regression model of appliance characteristics and occupant behaviour showed better correlation than previous models because three factors such as the number of wall-mounted air conditioners (Beta = 0.67), total number lamps (Beta = 0.22) and usage of air conditioners on weekdays (Beta = −0.21) had a strong contribution to the variance of electricity consumption in the current model. A similar model from Kim [5], Huebner et al. [16], and Santin [26] had less variance of electricity consumption than the current model because the previous model had some statistically insignificant factors.

Table 15. Comparison between current and previous multiple regression models.

Model	Current Model (R^2)	Reference	Previous Model (R^2)
Appliance characteristic and occupant behaviour	0.42	Huebner et al. [16], Kim [5]	0.34 0.10
Socio-demographic, house characteristic and occupant behaviour	0.28	Santin et al. [26]	0.04

Different findings of multiple linear regression models for Malaysian households were established by Azlina et al. [12], who explained 38.4% of the variance of electricity consumption. The previous model had less variance of electricity consumption than the current model, as some statistically insignificant factors were included in the model. However, the findings from the current and the previous models could improve the understanding of determinant factors of electrical energy consumption for Malaysian households.

The number of air conditioning appliances appeared in five multiple linear regressions making air conditioning appliances the most important factor concerning electricity consumption. The number of air conditioner energy stars, the number of flat-screen TVs, and the number of fluorescent lamps also appeared in four multiple linear regression making these factors significant contributors as well. The findings of determinant factors of electricity consumption in Malaysian households could become strong recommendations for policy-makers, engineers, and energy companies to design specific policies to manage energy conservation in residential households.

Some factors in this research were confirmed as new factors because previous studies did not consider them, for example, usage of laptop chargers, the number of working people in the household, and the setting of the rotation speed of stand fans as strong and significant factors in terms of electricity consumption. Previous studies did not specifically ascertain the type of appliance as significant factors; for example, Tso and Yau [9] only considered general types of fans and Bedir et al. [14] only examined general battery-charged types.

Current results were compared with national statistics of household characteristic factors performed by Khazanah Research Institute in 2018 [47]. The average number of people in the household was 4.0 persons with a standard deviation of 1.6 and the average monthly income was RM 6955.70 with a standard deviation of RM 5770.20. Those results were similar to national statistics in 2016 which established that the average number of people in the household was 4.1 person and the average monthly income was RM 6958.00.

Limitation and Future Research

This study has a limitation on the size of the sample. The total valid questionnaires for analysis in this paper were 214; therefore, the result of this research cannot be represented by the whole of Malaysia. Our current study only covered a population sample of students in Universiti Teknologi Malaysia for 21,997 students with a confidence level of 95% and margin of error of 7% based on sample calculation from Cochran [39]. Furthermore, five regression models in this research explain 27.5%, 42%, 44.5%, 43.4% and 46% variance of electricity consumption. These results confirmed that the overall trend of the regression model is quite good. It is recommended to consider a greater sample and also a non-linear model in order to develop the best model in predicting the electricity consumption in residential households.

The present study also had a limitation on the source of information. Here, only families with an academic background were surveyed. In the future, we will include families with other backgrounds also. Proportionate, but random sampling is a good recommendation for a future study where the society is stratified based on certain parameter levels such as income, occupation, or educational background.

While there were limitations to this research as already mentioned, the findings are useful for improving the understanding as to what factors affect electricity consumption in Malaysian households. Malaysia only had one previous study in this field which was conducted by Azlina et al. [12]. The current study investigated four groups of factors that consisted of socio-demographic, house characteristic factors, appliance characteristic factors, and occupant behaviour, which were more comprehensive than in the previous study.

5. Conclusions

The research was intended to assess comprehensive determinant factors of electricity consumption in Malaysian households. The data were collected from direct and indirect questionnaire survey from 214 volunteer students. Three types of regression models, such as single, double combined, and triple combined, were developed. Monthly income, number of air conditioning appliances and ownership of miscellaneous appliances emerged as factors that had a significant cross-correlation with many household characteristic factors. These results showed that households with higher income would have more appliances and used more electricity.

In the single model, appliance characteristics explained 43.4% of the variance in electricity consumption. In the double combined models, appliance characteristics explained 44.5% of the variance when combined with socio-demographic and 42% when combined with occupant behaviour. Socio-demographic factors showed a better contribution to the variance of electricity consumption than occupant behaviour factors. The number of air conditioners and the number of fluorescent lamps emerged as strong and significant factors for single and double combined models. The number of people living in the household had a stronger effect on the variability of electricity consumption than the education level of the household head. The usage of air conditioners on weekdays significantly affected the variance of electricity consumption in the double combined models. In the triple combined models, socio-demographic, appliance characteristic and occupant behaviour explained 46% of the variance in electricity consumption. The number of air conditioners emerged as the strongest and the most significant contributor. In contrast, socio-demographic, house characteristics and occupant behaviour factors explained 26.7% of the variance in electricity consumption. Monthly income had a stronger effect on the variance of electricity consumption than setting the rotation speed of stand fans, the set temperature of air conditioner, the number of flat-screen TVs and the cubic capacity of refrigerators. In these models, appliance characteristics showed a stronger effect on the variance of electricity consumption than house characteristics. The estimated electricity-saving based on the multiple linear regression model was from 10.4% to 21.3%.

Air conditioners, fluorescent lamps and flat-screen TVs emerged as strong and significant factors. Energy-saving air conditioners also arose as a factor that affected the variability of electricity consumption. These findings suggest that Malaysia has achieved a good implementation of the electricity-saving policy by producing an energy-saving program, that is, the energy star appliances.

Two types of light sources, (i) fluorescent and (ii) LED lamps, emerged as substantial factors in the partial correlation analysis. However, fluorescent lamps emerged as a factor affecting the variance of electricity consumption in the multiple linear regression models instead of energy-saving lamps. These findings confirm that the penetration level of LED lamp ownership is still less in Malaysia. Usage of air conditioner on weekdays and setting rotation of stand fan also emerged as significant factors that affect the variance of electricity consumption in the model. Recommending policies such as affordable LED lamp cost, scheduling usage of air conditioners and usage of fans in the house, schools, companies or government institutions may improve the awareness of the energy saving in the house.

The current study improves the understanding of the direct impact of comprehensive household characteristic factors on electricity consumption. Cross-correlation analysis was developed so that the indirect effect of household electricity consumption can be revealed. The study also escalates the insight about determinant factors affecting electricity consumption in the tropical country, therefore, the collaborative research or policy might be established with other country regions in order to accomplish the increasing of energy consumption in the future.

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Appendix A

Table A1. Socio-demographic factors in questionnaire.

Variables	Questions	Descriptions
Monthly income	Please fill your monthly household income from each member	Ringgit Malaysia
Number of people living in the household	Please indicate the number of people living in your home. Please indicate the number of those who lives at home at least five days a week.	Person
Family composition	Please indicate the members living in your home.	(1) Single person (2) Husband and wife (3) Couple and children (4) Couple, children, and grandparents (5) Couple and grandparents (6) Other relatives (7) Non-relatives (8) Others
Number of working people	Please indicate the number of members in your household who have job	Person
Education level	Please indicate the education level of the head of your household or the person who take responsibility for your family	(1) Secondary education (SPM) (2) Pre-university (Matriculation) (3) University

Appendix B

Table A2. Usage behaviour and appliance characteristic factors in questionnaire.

Variables	Questions	Units
Occupancy schedule at home	Please indicate for your hourly occupancy schedule in house for weekday and weekend	Hours
Availability person in weekdays	Is anybody in your household stays home during the day on normal weekdays? (e.g., Maid, housewife, grandmother, grandfather, etc.)	(1) Almost every weekday (2) 3–4 days a week (3) 1–2 days a week (4) Almost never days a week
Total number of appliances	Please indicate how many appliance in your house	Units
Set temperature of AC	Please indicate how you set temperature of AC appliance	Celsius
Age of appliance	Please indicate for the age of appliance in your house	(1) 1990 or earlier (2) 1991–1995 (3)1996–2000 (4) 2001–2005 (5) 2006–2010 (6) 2011 or later (7) Unknown
Power rating of AC	Please indicate for the power rating of AC in your house	(1) <2.2 kW (2) 2.2–2.4 kW (1 HP) (3) 2.5–2.7 kW (4) 3.6–3.9 kW (1.5 HP) (5) 4.5–5.1 kW (2 HP) (6) >5.2 kW (7) Unknown
Number of energy stars	Please indicate the owned energy star for selected appliances (refrigerator, fans, televisions, and air conditioners)	Units
Setting rotation speed of fan	Please indicate how you adjust rotation for speed of fan	(1) Weak (2) Medium (3) Strong

Table A3. Usage behaviour and appliance characteristic factors in questionnaire.

Variables	Questions	Units
Operating time of appliance	Please write down the usage profile of air conditioning in your house in weekday and weekend	Minutes
Method of climate control during the day and the night	Please indicate the way you use most to keep your home cool during the day and the night	(1) Open window (2) Turn on AC (3) Turn on fan (4) Turn on fans with window open (5) Turn on AC and fans (6) Others
Cubic capacity of refrigerator	Write down the cubic capacity in litres	Litres
Screen size of television	Write down the screen size of television	Inches
Rated power of television	Write down the rated power of television	(1) <40 W (2) 40–59 W (3) 60–79 W (4) 80–99 W (5) 100–119 W (6) 120–139 W

Appendix C

Table A4. Building characteristic factors in questionnaire.

Variables	Questions	Descriptions
Number of rooms	Please indicate the number of rooms for each type of room	Room
Type of room	Please indicate what type of room in your house	(1) Room containing living space, dining space, and kitchen (2) Room containing living and dining spaces (3) Room containing dining space and kitchen (4) Living room (5) Individual bedroom (6) Dining room (7) Kitchen (8) Bathing room (9) Toilet (10) Others
Number of storeys	Please indicate the number of stories used for residential use in your home	Floor
Construction year	Please indicate the year in which your home was built	(1) 1970s or earlier (2) 1980s (3) 1990s (4) 2000–2004 (5) 2005–2009 (6) 2010 or after (7) Unknown
Tenure type	Please indicate whether the house you live in is owned or rent	(1) Own (2) Rent (3) Other
Total floor space	Please give approximate total floor space of your home	(1) Less than 500 m^2 (2) 50–99 m^2 (3) 100–149 m^2 (4) 150–199 m^2 (5) 200 m^2 or more (6) unknown

Table A5. Building characteristic factors in questionnaire.

Variables	Questions	Description
Type of house	Please indicate the type of house you are living in.	(1) Detached/terraced house (2) Apartment/flat/condominium (3) Town house (4) Shop house
Wall material	What material is the roof of your house made of?	(1) Woods (2) Bricks (3) Concrete (4) Others
Roof material	What material are your walls made of?	(1) Concrete (2) Tile (3) Tin (4) Others
Glazing ratio	Please describe the glazing ratio based on four facades of building from your house	(1) 20% (2) 40% (3) 60% (4) 80% (5) 90% (6) 100%

Table A5. *Cont.*

Variables	Questions	Description
Shading device	Please describe the type of shading device for window in house for all room	(1) Curtain (2) Internal blinds (3) Awning (4) Louvre
Glazing type of window	Please describe the type of glazing for window in house for all room	(1) Single glazing (2) Double glazing (3) Triple glazing (4) Unknown
House orientation	Please describe the house orientation to the sun.	(1) North [N] (2) East [E] (3) South [S] (4) West [W] (5) SE (6) NE (7) SW (8) NW (9) NS (10) EW

Appendix D

Table A6. Cross correlation analysis for household characteristic factors with respect to monthly income.

	a	b	c	d	e	f	g	h	i	j	k
a	1										
b	0.14 *	1									
c	0.27 **	0.13 *	1								
d	0.32 **	0.26 **	0.29 **	1							
e	0.32 **	0.04	0.22 **	0.30 **	1						
f	0.33 **	0.07	0.24 **	0.31 **	0.37 **	1					
g	0.37 **	0.13 *	0.30 **	0.56 **	0.37 **	0.42 **	1				
h	0.40 **	0.21 **	0.29 **	0.32 **	0.20 **	0.35 **	0.30 **	1			
i	0.31 **	0.08	0.26 **	0.26 **	0.24 **	0.68 **	0.34 **	0.27 **	1		
j	0.31 **	−0.03	0.13 *	0.14 *	0.32 **	0.27 **	0.21 **	0.23 **	0.18 **	1	
k	0.33 **	−0.06	0.13 *	0.14 *	0.31 **	0.23 **	0.21 **	0.24 **	0.16 *	0.94 **	1

Note: * Correlation is significant at the 0.05 level, ** correlation is significant at the 0.01 level, a: monthly income, b: number of people living, c: education level of household head, d: number of rooms, e: number of wall mounted air conditioner, f: number of miscellaneous appliances, g: number of lamps (all), h: number of charger laptop, i: number of vacuum cleaners, j: usage of the router on weekdays, k: usage of router on weekends.

Appendix E

Table A7. Cross correlation analysis for household characteristic factors with respect to number of air conditioning.

	a	**b**	**c**	**d**	**e**	**F**	**g**	**h**	**i**	**j**	**k**	**l**
a	1											
b	0.63 **	1										
c	0.58 **	0.73 **	1									
d	0.65 **	0.86 **	0.70 **	1								
e	0.66 **	0.42 **	0.40 **	0.45 **	1							
f	0.39 **	0.32 **	0.29 **	0.23 **	0.24 **	1						
g	0.39 **	0.22 **	0.22 **	0.21 **	0.23 **	0.25 **	1					
h	0.37 **	0.24 **	0.27 **	0.23 **	0.20 **	0.33 **	0.28 **	1				
i	0.31 **	0.18 **	0.15 *	0.17 **	0.56 **	0.19 **	0.42 **	0.1	1			
j	0.60 **	0.57 **	0.47 **	0.59 **	0.40 **	0.23 **	0.24 **	0.34 **	0.17 **	1		
k	0.59 **	0.57 **	0.47 **	0.59 **	0.39 **	0.23 **	0.21 **	0.36 **	0.17 **	0.95 **	1	
l	0.32 **	0.19 **	0.16 **	0.19 **	0.21 **	0.27 **	0.26 **	0.21 **	0.21 **	0.07	0.08	1

Note: * Correlation is significant at the 0.05 level, ** correlation is significant at the 0.01 level, a: number of air conditioner, b: age of air conditioner, c: power rating air conditioner, d: set temperature of air conditioner, e: number of energy star air conditioner, f: number of ceiling fans, g: number of flat-screen TV, h: number of lamps (all), i: number of energy star TV, j: usage of air conditioner on weekdays, k: usage of air conditioner on weekends, l: usage of the router on weekdays.

Appendix F

Table A8. Cross correlation analysis for household characteristic factors with respect to usage of air conditioning.

	A	**b**	**c**	**d**	**e**	**f**	**g**	**H**	**i**	**j**	**k**	**l**	**m**	**n**	**o**
A	1														
B	0.95 **	1													
C	0.33 **	0.34 **	1												
D	0.16 *	0.13 *	0.27 **	1											
E	0.15 *	0.14 *	0.25 **	0.84 **	1										
F	0.25 **	0.23 **	0.43 **	0.43 **	0.39 **	1									
G	0.4 **	0.40 **	0.47 **	0.22 **	0.21 **	0.57 **	1								
H	0.13 *	0.16 **	0.25 **	0.13 *	0.19 **	0.14 *	0.12 *	1							
I	0.34 **	0.36 **	0.42 **	0.24 **	0.25 **	0.32 **	0.21 **	0.27 **	1						
J	0.26 **	0.28 **	0.31 **	0.25 **	0.24 **	0.20 **	0.18 **	0.30 **	0.56 **	1					
K	−0.004	0.002	0.07	0.18 **	0.14 *	0.16 **	0.12	−0.01	0.13 *	0.26 **	1				
L	0.27 **	0.32 **	0.22 **	0.18 **	0.17 **	0.13 *	0.09	0.21 **	0.52 **	0.44 **	0.07	1			
M	0.16 **	0.16 **	0.35 **	0.23 **	0.26 **	0.15 *	0.09	0.28 **	0.3 **	0.32 **	0.21 **	0.25 **	1		
N	0.60 **	0.59 **	0.37 **	0.19 **	0.14 *	0.21 **	0.32 **	0.21 **	0.37 **	0.3 **	0.04	0.2 **	0.2 **	1	
o	0.2 **	0.19 **	0.26 **	0.2 **	0.24 **	0.27 **	0.14 *	0.09	0.49 **	0.3 **	0.09	0.31 **	0.24 **	0.17 **	1

Note: * Correlation is significant at the 0.05 level, ** correlation is significant at the 0.01 level, a: usage of air conditioner on weekdays, b: usage of air conditioner on weekends, c: number of miscellaneous appliances, d: usage of entertainment on weekdays, e: usage of entertainment on weekends, f: usage of miscellaneous appliances on weekdays, g: usage of electric heater on weekends, h: total floor space, i: number of lamps (all), j: number of rooms, k: number of people living, l: number of windows, m: number of charger laptops, n: number of air conditioner, o: number of LED lamps.

Appendix G

Table A9. Cross correlation analysis for household characteristic factors with respect to number of stand fan.

	a	**b**	**C**	**d**	**e**	**f**
A	1					
B	−0.38 **	1				
C	−0.08	0.25 **	1			
D	0.07	0.08	0.13 *	1		
E	−0.17 **	0.26 **	0.27 **	0.32 **	1	
F	0.15 *	0.16 **	0.15 *	0.16 **	0.19 **	1

Note: * Correlation is significant at the 0.05 level, ** correlation is significant at the 0.01 level, a: number of stand fans, b: number of ceiling fans, c: education level of household head, d: number of people living, e: monthly income, f: total floor area.

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