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Short-Term Measurements of Household Electricity Demand during Hot Weather in Kuala Lumpur

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ABSTRACT

The aim of this study was to conduct short-term measurements on household electricity demand under hot weather conditions in a residential area in Kuala Lumpur. The measurements included total and air conditioner (AC) electricity consumption of 10 households in an apartment building as well as outdoor air temperatures, which were collected from March to May 2016. Results indicated that the average AC electricity consumption contributed to a major portion of total household electricity consumption, which ranged from 19.4 to 52.3% during the measurement period. Additionally, 1-minute interval time series data indicated household energy consumption more accurately than 30- or 60-minute interval.

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1. INTRODUCTION

In recent years, global warming has become a pressing issue globally, which has urged the improvement of energy efficiency in the building sector and an increase in renewable energy sources [1],[2]. Global temperatures will continue to rise and with the presence of the El Niño phenomenon, and overall temperatures may be higher than expected. This brings about increases in overall electricity consumption in urban residential areas because of increased air conditioner (AC) usage under hot weather conditions. Over the past decades, many efforts have been made to monitor global energy consumption [3]-[5]. For example, researchers studied the impact of household characteristics on electricity consumption for 27 households in Ireland over 20 months [6]. Researchers discovered that daily routines and energy consumption patterns under particular weather conditions are key in recognising household electricity consumption-related behaviour. This method showed that family energy consumption data can be used to predict energy consumption from 15 households [7]. Additionally, household electricity consumption of different categories of appliances in 72 households in the United Kingdom was investigated to identify trends in electricity consumption [8].

Field measurement is necessary for electrical grid planning and developing renewable energy sources, especially since time-series data of electricity consumption in developing countries and tropical zones are limited. Therefore, short-term measurements to monitor electricity consumption in a residential area in Kuala Lumpur, Malaysia were conducted. The aim of this research was to contribute to knowledge regarding the monitoring of household electricity consumption to supplement the database of energy demand in Malaysia.

2. RESEARCH METHOD

The survey was conducted in 10 households in a nineteen-story low-cost public apartment building in an urban area of Kuala Lumpur. The size of each apartment was around 60 m^2, which included a living room, kitchen, and three bedrooms. The living room and/or bedrooms were equipped with ACs for cooling purposes. Measurements were taken over three months (March–May 2016) during the hot season. Table 1 provides a summary of each household for the measurement period, which varied from 53 to 87 days.

Table 1. Summary of households included in field measurements

Household no.	Floor number	Number of family members	Room measured	Measurement period (days)
H1	6th	7	Living room	87
H2	17th	6	Bedrooms 1 & 3	85
H3	6th	3	Bedroom 1	83
H4	18th	3	Bedrooms 1 & 2	79
H5	3th	5	Living room	77
H6	9th	4	Living room	81
H7	10th	8	Bedroom 1	53
H8	3th	7	Bedrooms 1 & 3	72
H9	8th	6	Living room & Bedroom 1	82
H10	13th	9	Bedroom 3	81

Power monitoring devices were installed at the miniature circuit breaker (MCB) and at all frequently used AC units in each household (Figure 1). The power monitoring device installed at the MCB was used to record the overall electricity consumption of the entire household, whereas that installed at the AC unit was used to monitor the electricity consumption when the AC was operated. Both instruments recorded in 1-minute intervals. Outdoor temperatures, recorded every 10 minutes, were obtained from a weather station installed at 2.5 m above ground level at the Universiti Teknologi Malaysia. This weather station was located approximately 3.6 km from the target households. In addition, an intensive survey via questionnaires was conducted to quantify the underlying factors of the energy demand, such as household size, number of working or school-going persons and ownership of various electrical appliances. This additional information helped to clarify the pattern of electricity consumption from the data obtained.

Figure 1. Installation of power monitoring device at a miniature circuit breaker (left) and an air conditioner (right)

3. RESULTS AND ANALYSIS

3.1. Outdoor air temperature

The variation of outdoor air temperature during the measurement period is shown in Figure 2. The pattern was consistent over the measurement period. Variation of daily temperature was caused by high daytime temperatures and lower night-time temperatures and ranged between 23 and 40 °C. However, there were missing data from 9th to 11th April because of instrumental errors. This might have been due to high wind speeds during the measurement period. The high temperatures during the measurement period were likely due to the El Niño phenomenon that occurred during that time.

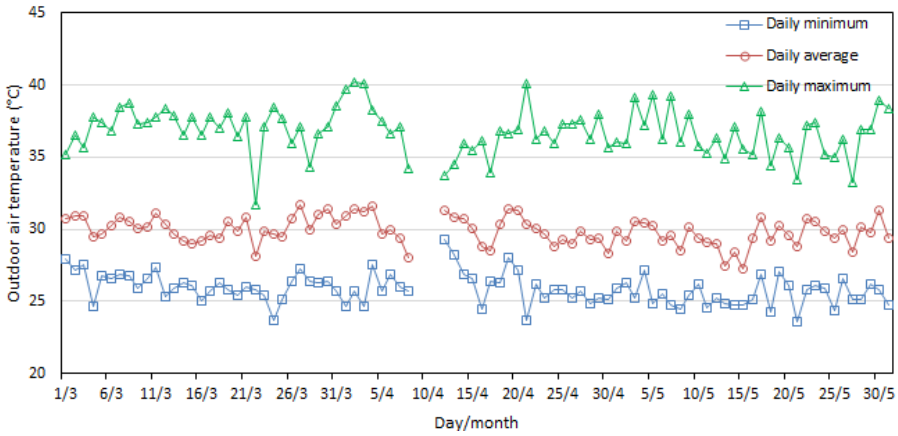


Figure 2. Variation of outdoor air temperature during the measurement period (March, April, and May, 2016)

3.2. Electricity consumption in relation to outdoor air temperature

The overall trend of average total electricity consumption for the 10 households in relation to outdoor air temperature during the measurement period is displayed in Figure 3. There was no correlation between total electricity consumption and outdoor air temperature. There was low total electricity consumption during the daytime from 8:00 to 18:00, when most occupants were at work or school and high demand occurred during sleeping time at night. On the other hand, outdoor air temperature increased from 9:00 to 15:00 and decreased after 15:00 until the end of the day.

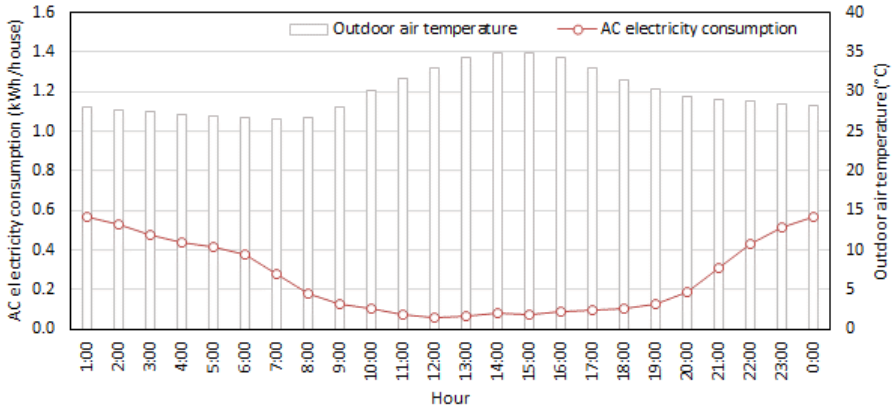


Figure 3. Comparison of the overall trend of average hourly total electricity consumption and outdoor air temperature of 10 households during the measurement period

3.3. Electricity consumption by household

The total and AC electricity consumption of the 10 households during the measurement period, with hot daytime temperatures, is shown in Figure 4. The H5 data-logger for total electricity consumption malfunctioned during the measuring period due to a connection problem between the sensor and MCB for total electricity. Thus, data from this household were omitted from further analysis. Total electricity consumption during the measurement period ranged from 9.2 kWh/day for H3 to 30.7 kWh/day for H9. AC electricity consumption ranged from 2.4 kWh/day for H7 to 14.1 kWh/day for H9. The use of AC in certain households contributed significantly to the total electricity consumption. The proportion of electricity consumption by ACs and other appliances is shown in Figure 5. The electricity consumption of ACs ranges from 20.0% for H7 to 57.3% for H6. AC usage during hot weather contributed to more than half of the total electricity consumption in certain households, namely H4 and H6. The rest of the total electricity

consumption came from other electrical appliances such as lights, refrigerators, water heaters, washing machines, etc.

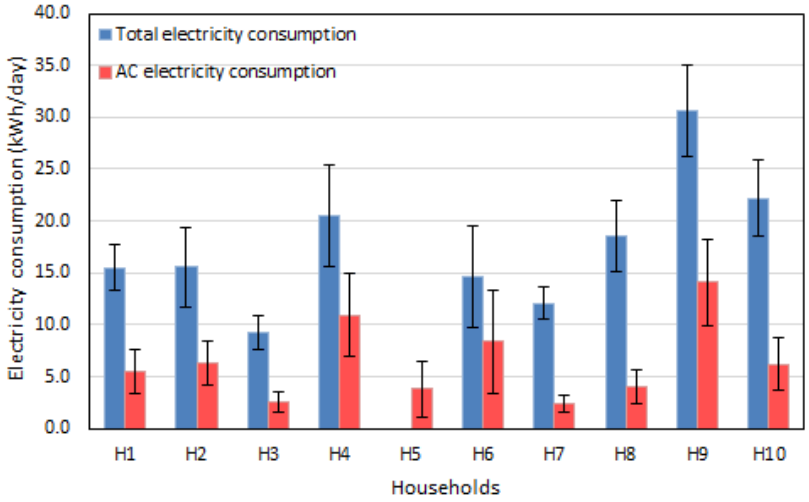


Figure 4. Total and air conditioner (AC) electricity consumption of 10 households during the measurement period (March–May 2016); error bars indicate standard deviation. (Total electricity consumption of H5 could not be measured due to a faulty miniature circuit breaker)

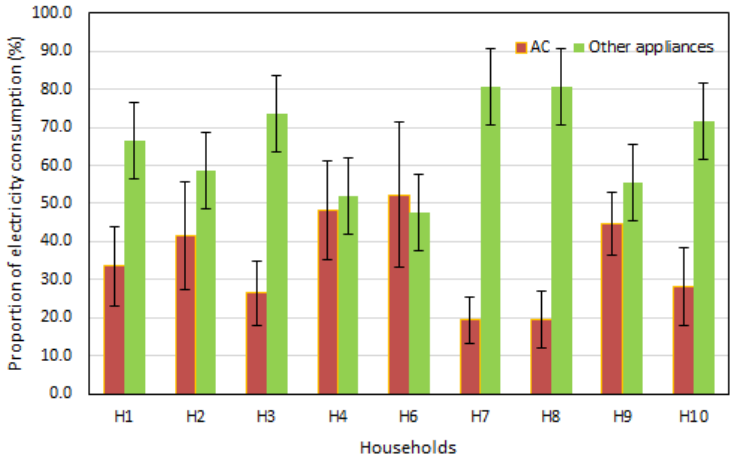


Figure 5. The proportion of electricity consumption by air conditioners (ACs) and other appliances in nine households during the measurement period (March–May 2016). (Total electricity consumption of H5 could not be measured due to a faulty miniature circuit breaker)

3.4. Effect of time on electricity consumption

H9, which had the highest electricity consumption of the 10 households, was selected for a detailed investigation into the effect of time on household electricity consumption. High-resolution time-series data were collected at 1-minute intervals. A comparison of 1-, 30-, and 60-minute average time intervals of total electricity consumption for H9 on 11 March 2016 is shown in Figure 6. The current graph shows that the two averaged plots lag behind the 1-min data. The daily peak exhibits differ according to the average time. For example, the 1-minute average time showed a peak at 20:00, while the 30- and 60- minute plots recorded the same peak at 24:00. This indicates that the high-resolution time series is more accurate in representing the variation of daily schedules in households rather than 30- or 60- minute intervals. Demand was highest from approximately 22:00 to 04:00, which could be explained by AC usage during sleeping time. This might be due to usage of high-power appliances such as kettles and shower heaters within a short time span. Table 2 shows the average electricity consumption and different standard deviations for these three times interval.

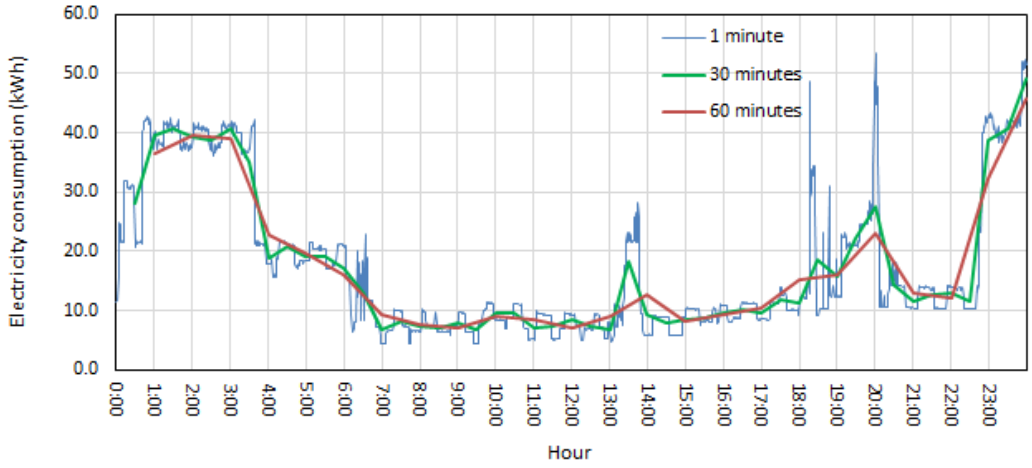


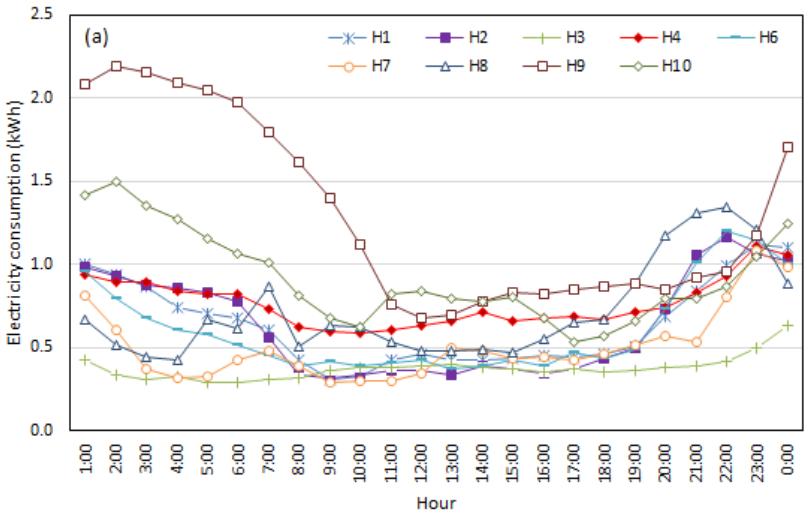
Figure 6. Time series data for 1-, 30- and 60- minute time intervals of total electricity consumption for Household 9 (H9) on 11 March 2016

Table 2. Average electricity consumption for 1-, 30- and 60-minute intervals for Household 9 (H9) on 11 March 2016

Electricity consumption	1 minute	30 minutes	60 minutes
Average (kW)	17.46	17.46	17.46
Standard deviation	12.19	11.28	11.41

3.5. Hourly electricity consumption

To understand the characteristics of hourly electricity consumption for each household during the measuring period, we calculated the average hourly total and AC electricity consumption as shown in Figure 7(a). In general, there was significant variation in total hourly electricity consumption of the 10 households, except for H3, which had an almost consistent load. The peak demand occurred during the night between 22:00 and 7:00 because of AC usage during sleep (Figure 7(b)). In contrast, the minimum demand during the daytime was between 8:00 until 18:00, except for H9.



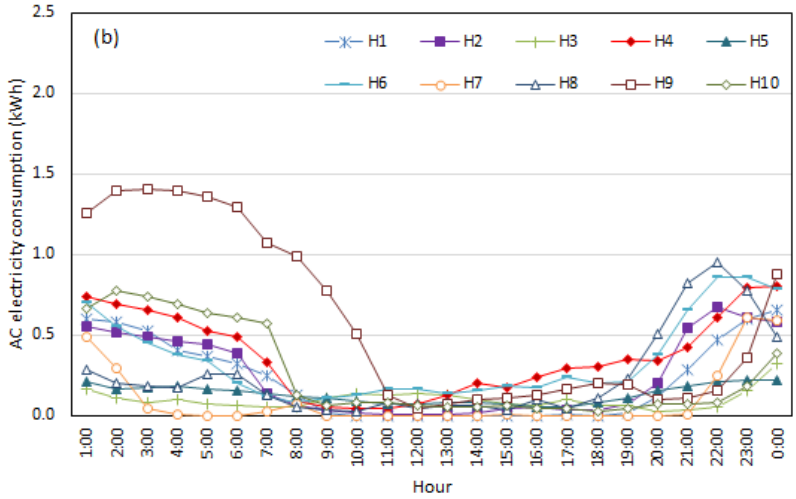


Figure 7. Average hourly (a) total and (b) air conditioner (AC) electricity consumption of 10 households during the measurement period (March–May 2016)

3.6. Daily electricity consumption by household size

The average daily electricity consumption per person by household size is shown in Figure 8. The minimum and maximum household sizes corresponded to three and nine occupants, respectively, with the average daily electricity consumption per person being 5.0 and 2.5 kWh, respectively. There was no household with five members in the sample since H5 was omitted from data analysis because of a faulty data-logger. In general, average daily electricity consumption per person decreased as the number of occupants increased, except for households with six and nine occupants. The number of occupants for H9 was six people, which had the highest electricity consumption.

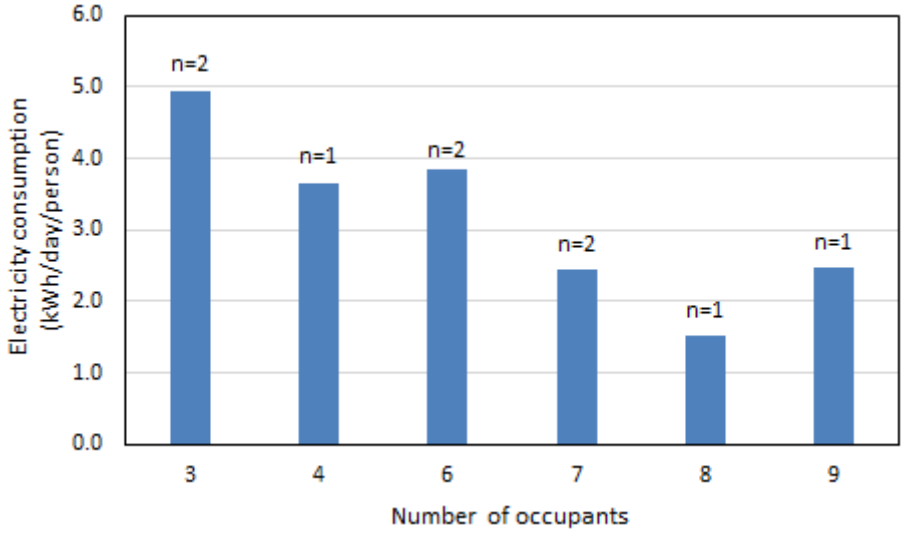


Figure 8. Average daily electricity consumption per person by household size during the measurement period (n: number of samples)

3.7. Monthly electricity consumption

The total monthly and AC electricity consumption of the 10 households is shown in Figure 9. There was no significant monthly change in either total or AC electricity consumption over the measuring period. The total monthly electricity consumption ranged from 17.4 to 18.7 kWh/day and the monthly AC electricity consumption ranged from 5.7 to 7.2 kWh/day.

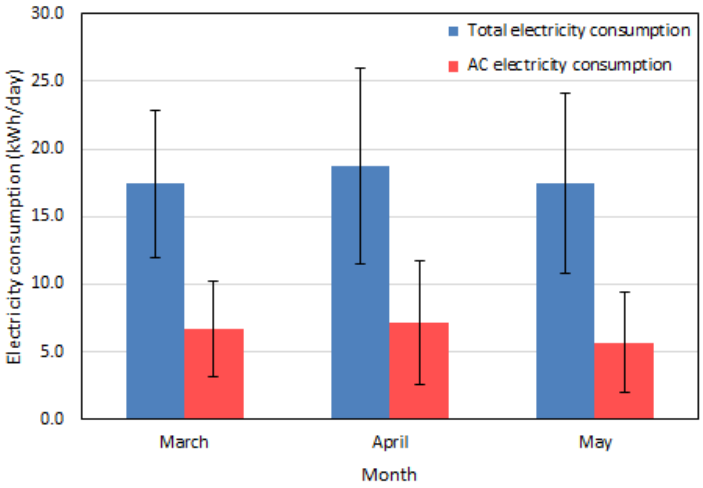


Figure 9. Monthly total and air conditioner (AC) electricity consumption of 10 households from March to May 2016; error bars indicate standard deviation

4. CONCLUSION

In conclusion, the total and AC electricity consumption of 10 households in a low-cost public apartment building in Kuala Lumpur were collected in March, April and May 2016. Results indicated that the outdoor air temperature was consistent over these months in the hot season due to the El Niño phenomenon. The highest total electricity consumption over the measuring period was measured in H9, which was 30.7 kWh/day, and the lowest was measured in H3, which was 9.2 kWh/day. The average AC electricity consumption contributed to a major portion of total electricity consumption, which ranged from 19.4% to 52.3% during the measurement period. High-resolution time series data of 1-minute intervals showed a variation of electricity consumption in more detail when compared to 30- and 60-minute intervals. In addition, there was no correlation between electricity consumption and outdoor air temperature in most households. This was because of the occupancy level during the daytime, when most occupants were at work or school. Accurate estimations of time series data are important to develop simple methods of forecasting total daily household and AC electricity consumption. Therefore, further investigation with longer measurement periods is needed for developing this model.

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REFERENCES

[1] D. J. Arent, *et al.*, "The status and prospects of renewable energy for combating global warming," *Energy Economics*, vol. 33, pp. 584-593, 2011.
[2] D. H. Li, *et al.*, "Impact of climate change on energy use in the built environment in different climate zones–a review," *Energy*, vol. 42, pp. 103-112, 2012.
[3] H. Najmeddine, *et al.*, "State of art on load monitoring methods," in *Power and Energy Conference, 2008. PECon 2008. IEEE 2nd International*, pp. 1256-1258, 2008.
[4] T. Ueno, *et al.*, "Effectiveness of an energy-consumption information system for residential buildings," *Applied Energy*, vol. 83, pp. 868-883, 2006.
[5] A. Zoha, *et al.*, "Non-intrusive load monitoring approaches for disaggregated energy sensing: A survey," *Sensors*, vol. 12, pp. 16838-16866, 2012.
[6] Yohanis Y. G., *et al.*, "Real-life energy use in the UK: How occupancy and dwelling characteristics affect domestic electricity use," *Energy and Buildings*, vol/issue: 40(6), pp. 1053-9, 2008.
[7] J. M. Abreu, *et al.*, "Using pattern recognition to identify habitual behavior in residential electricity consumption," *Energy and Buildings*, vol. 49, pp. 479-487, 2012.
[8] Firth S., *et al.*, "Identifying trends in the use of domestic appliances from household electricity consumption measurements," *Energy and Buildings*, vol/issue: 40(5), pp. 926-36, 2008.

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