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# Time series data measurement on electricity consumption for selected domestic appliances in typical terrace house of Malaysia

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**ABSTRACT**

This paper describes the pattern of electricity consumption from total and selected domestic appliances at a typical terrace house in Malaysia. The measured appliances can be classified into four groups on the basis of pattern of use which are ‘standby’ (TV), ‘active’ (massage chair, charger of hand phone, laptop and power bank, washing machine, air-conditioners, iron, standing fan, shower heaters, rice cooker, toaster, microwave), ‘cold’ (refrigerator) and ‘cold and hot’ (water dispenser). The major contribution of monthly electricity consumption comes from ‘cold’ appliances that consume 118.8 kWh/month followed by ‘active’ appliances that consume 87.8 kWh/month and ‘cold and hot’ appliance with 52.5 kWh/month. ‘Standby’ appliances shown a small contribution to the total electricity with 0.9 kWh/month. The amount of energy consumed depends on time-of-use, power characteristics of particular appliances as well as occupancy period.



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## 1. INTRODUCTION

Energy demand in Malaysia continues to surge due to rapid infrastructure development and economic growth. The energy consumption was recorded increase to 7.5% in 2012 and was foreseen to rise for the upcoming years [1]. It indicates that the power sector alone has come up with 54.8% of the total CO2 emissions in 2013 [2]. As the electricity consumption in the residential sector accounts for about one-third of the total electricity consumption in the world, the electricity consumption characteristics in the residential sector should be focused [3]. Apparently, in Malaysia, residential buildings are responsible for 21% of total electricity consumption [4]. Hence, there is a need to reduce the residential electricity consumption by understanding the determinants of electricity consumption. On the basis of these findings, comparative study in [5] concluded that electricity consumption without space and water heating will have an impact on the appliances ownership and socio-demographics. Meanwhile, the authors from [6] in their study stated that specific appliances as one of the determinants that significantly impact the usage with higher consumption.

It is necessary to understand the time series data of household energy consumed from the domestic appliances in order to reduce future energy and CO2 emissions [7]. Many researchers have carried out field measurement and survey in terms of total power consumption and domestic appliances load. For example, a time series data has been investigated to determine the occupant’s total electricity consumption and the air-conditioner usage behaviour in Malaysia [8, 9]. Demand response has been provided with a high resolution of power consumption and load profiles of major household appliances to develop realistic load models [10]. Furthermore, the estimation of energy consumption, energy saving and reduction of emissions of greenhouse gases are focused on the use of household appliances in Malaysia [11]. So far, there have been many studies on analyzing residential electricity consumption at all kinds of countries and climate zone using various methods. Load profiles and power consumption of home appliances were investigated intensively. They utilized and obtained the power consumption data of all basic home appliances of the two-person family in Turkey with high resolution in one-second intervals [12]. In Taiwan, the factors that affect residential electricity consumption through a socioeconomic and direct use perspective has been examined [3]. In China, the authors adopted the decomposition method to explore the effect of urbanization on the changes in residential electricity consumption and analyze the factors that affect residential electricity consumption [13]. Aside from that, a study that aims to review and classify three most prevalent methods used before comparing the two methods and make a suggestion on how previous datasets can inform estimates of device-level energy consumption in US has been conducted [14]. However, from all previous research, there are still limited studies on the characteristic of domestic appliances usage in the hot-humid region. Therefore, the aim of this study is to investigate the time series data of total and selected domestic appliances electricity consumption of middle income family household in typical a terrace house in Malaysia.

## 2. RESEARCH METHOD

The field measurement was conducted in a two-storey terrace house from middle-income of five family members that located in Selangor, Malaysia from September 2016 to August 2017 for 365 days. The family members consist of working male, housewife, and three children. The floor area of this house is 167.22 $m^2$. The power monitoring devices (OWL) were installed at home energy meter as shown in Figure 1 and several major appliances to measure the current within a minute interval. The measured appliances are two units of AC's (AC1, AC2), two units of shower heaters (SH1, SH2), television (TV), rice cooker (R), toaster (T), microwave (M), washing machine, standing fan, water dispenser, refrigerator, iron, massage chair, charger of hand phone, laptop, and charger of power bank.

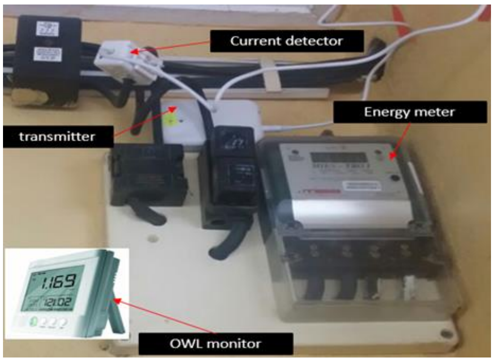



Figure 1. Photo of OWL installation at energy meter (TNB meter)

In this house, the owner used the same socket plug for a rice cooker, toaster and microwave since it was used at different time. Therefore, the same OWL was used for these appliances and it was classified as RTM. In a similar way, the same socket was used for massage chair, charger of hand phone, laptop, and charger of power bank. These appliances were called as 'socket' since it used the same source of a plug socket. All measured appliances can be seen in Figure 2 that shows the schematic plan view for the location of each appliance in the house. Table 1 shows the details information of each measured appliances. Four categories of household appliances have been discovered based on their trend when in use. 'Cold' appliances have a continuous use but not hold a constant load power. 'Cold and hot' basically the same as 'cold' appliance but with an addition of heating load. 'Standby' appliances refer to low power consumption when the switch was off because they can still consume the power except being disconnected from the power supply. 'Active' appliances have no standby mode and are clearly either actively switched on or off. The power factor and voltage of the investigated house were assumed as unity and 240 V respectively. The typical supply voltage for residential and private premises is around 230 to 253 V [15]. However, the reliability of the measured data was confirmed through comparison with monthly electricity consumption from the energy meter of electricity supply in Malaysia known as Tenaga National Berhad (TNB). In addition, all equipments were calibrated and verified before the measurement was done.

Table 1. List of details information of each measured appliances

| Room | Appliances | Rated Power [W] | Appliance Category |
|---|---|---|---|
| Kitchen | Water dispenser | Hot : 630 ~ 770<br>Cold : 90 ~ 110 | Cold and Hot |
| | Refrigerator | 206 | Cold |
| | Rice cooker (R) ** | 400 | Active |
| | Toaster (T) ** | 1300 | Active |
| | Microwave (M) ** | 1200 | Active |
| Laundry | Washing machine | 350 | Active |
| Living room | Air conditioner 2 (AC2) | 6720 | Active |
| | Air conditioner 1 (AC1) | 2640 | Active |
| Room 1 | Massage chair * | 110 | Active |
| | Charger of hand phone * | 35~84 | Active |
| | Laptop * | 360 | Active |
| | Charger of power bank * | 10 | Active |
| Room 2 | Iron | 1000 | Active |
| Room 3 | Standing fan | 50 | Active |
| Bathroom 1 | Shower heater 1 (SH1) | 3600 | Active |
| Bathroom 2 | Shower heater 2 (SH2) | 3600 | Active |
| Family room | TV | 192 | Standby |

* Use the same OWL installed in Room 1 and known as Socket
**Use the same OWL installed in kitchen area and known as RTM

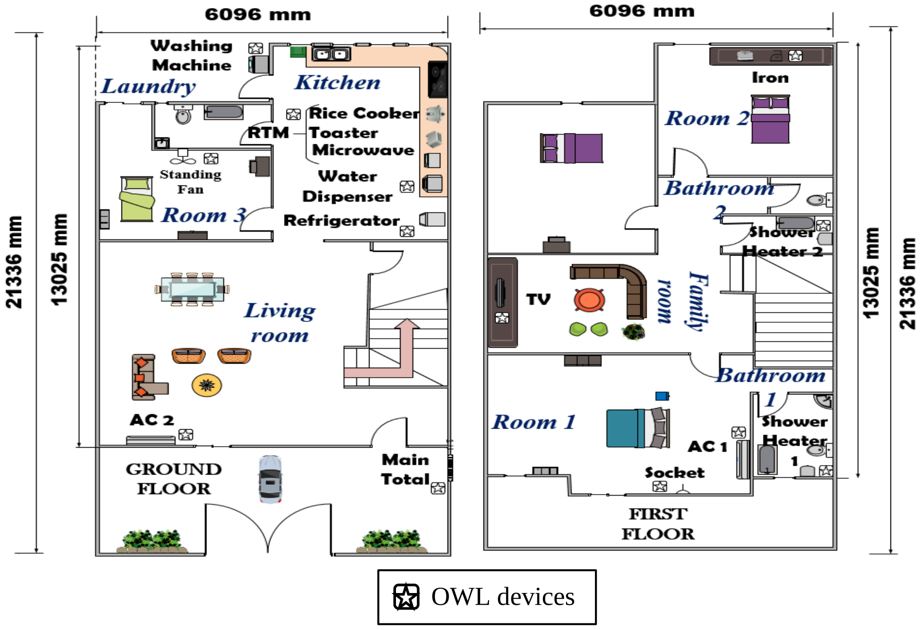



Figure 2. A schematic plan view for the location of each appliances in the house

## 3. RESULTS AND ANALYSIS

### 3.1. Verification of measurement data

The measurement data of total electricity consumption was verified based on two approaches. The first approach was a comparison of mean daily electricity consumption from home energy meter (TNB meter) with the measured data during the period of measurement as shown in Figure 3 except for data in November 2016 due to the unoccupied condition. It shows a strong correlation between measured data and TNB meter with a coefficient of determination, $R^2$ of 0.97. The second approach basically similar to the previous approach, except including the effect of maximum and minimum of voltage since we assumed that the voltage is 240 V as aforementioned in our measurement. We estimated the energy coefficient as follows:

$$\Delta P = \pm \left(\frac{V_{max} - V_{min}}{240}\right) \times P_m \quad (1)$$

Where $V_{max}$ is the maximum voltage from TNB ($V_{max}$=253), $V_{min}$ is the minimum voltage from TNB ($V_{min}$=230) and $P_m$ is the measured energy. Figure 4 displays the scatter plots of daily electricity consumption from measuring data for 335 days. The mean daily electricity consumption from measured and TNB meter also included in this graph for comparison. The energy coefficient showed the variation ranging from 0.61 to 2.73. The pattern was consistent for both mean measured and TNB meter with (S.E) was ranged from 0.27 to 0.66. These two approaches indicate that we can rely on the measured data for further investigation and analysis.

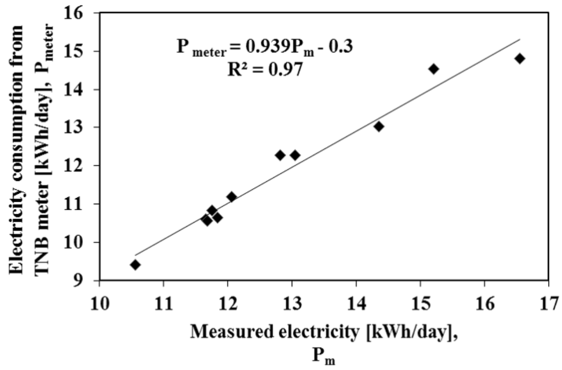



Figure 3. Comparison between TNB meter and measured data

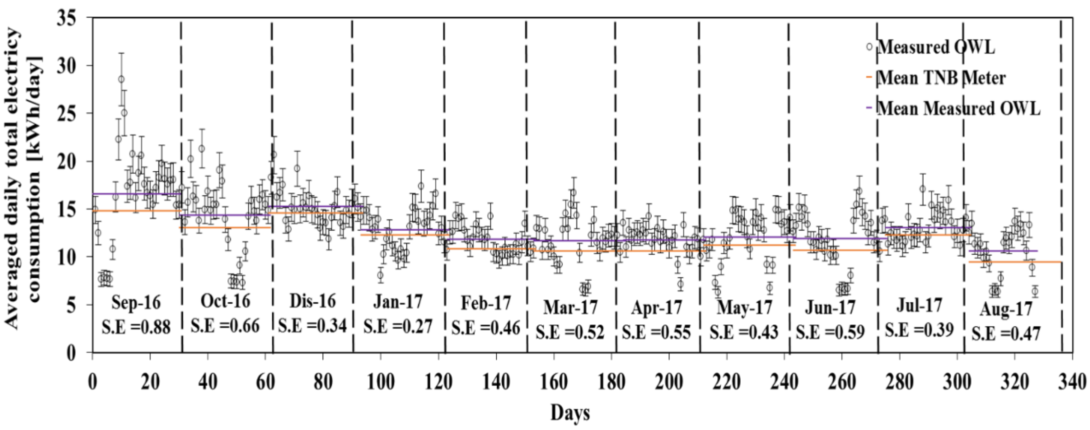



Figure 4. Scatter plot of daily electricity consumption with a comparison between daily mean measured and TNB meter for 335 days (Error bar indicate the standard error)

### 3.2. Time series data of total and selected domestic appliances electricity consumption

Figure 5 displays the hourly average of total and selected domestic appliances electricity consumption during the period of measurement. The peak power consumption of total electricity have occurred twice a day from 18:30 to 23:00 and from 06:00 to 07:00. It might be related to the high occupancy level during this time with high activity such as dinner, watching television, AC usage during sleeping, shower heater usage in the morning and other appliances (lighting and ceiling fans). Refrigerator and water dispenser using for 24 hours a day have been contributed to the high electricity consumption at approximately 10405 W and 5267 W respectively. Two times peak consumption for both shower heaters were observed at approximately 06:30 and 19:00. However, the power consumption started to remain constant from 07:30 to 17:30.

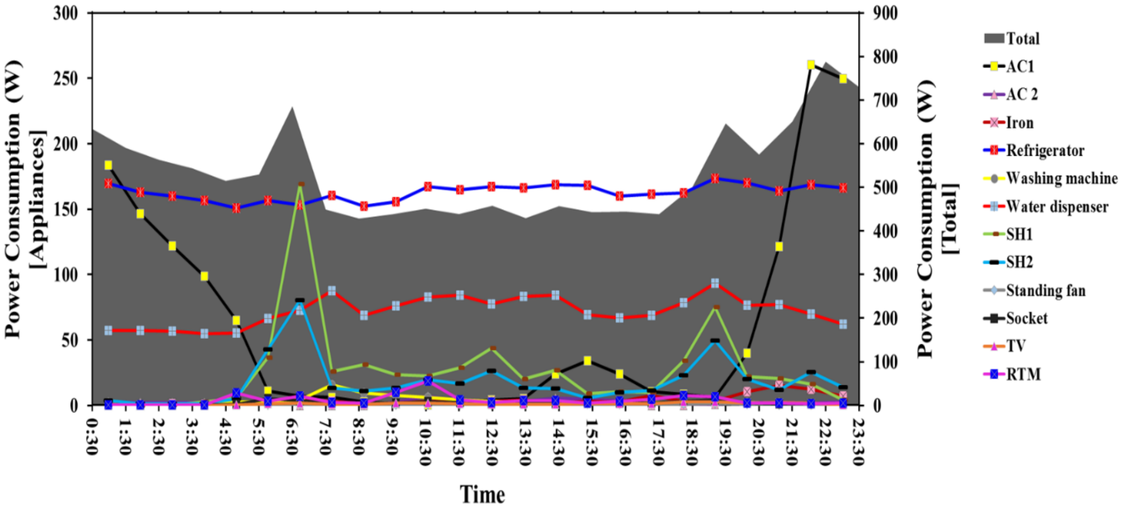
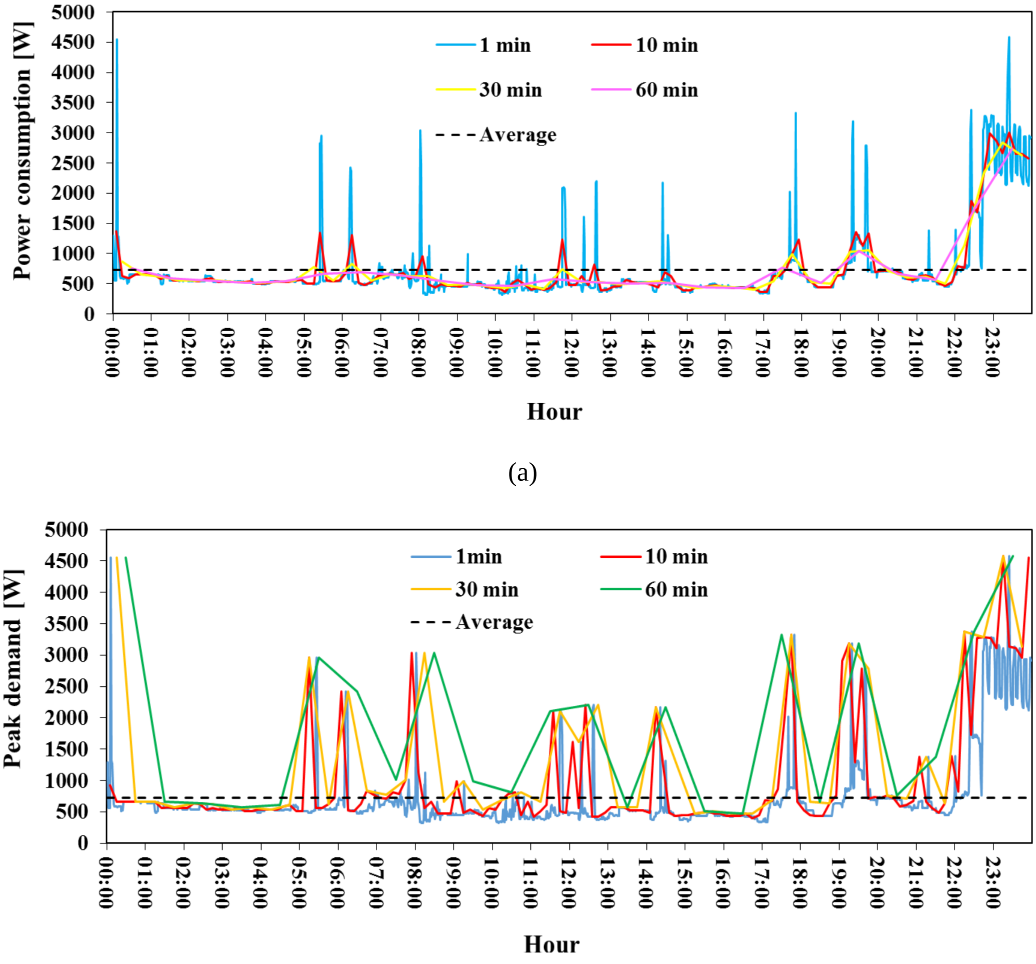



Figure 5. Hourly average of total and appliances power consumption (September 2016-August 2017)

### 3.3. Effect of averaging time on power consumption and peak demand

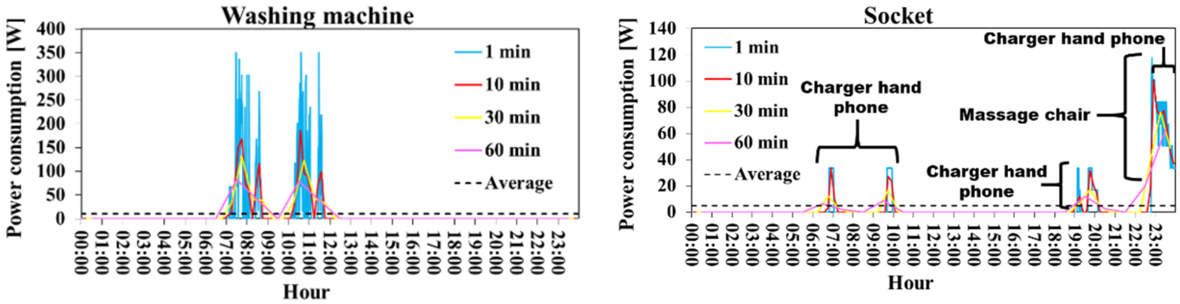
The effect of averaging time on power consumption and peak demand for total at 1-, 10-, 30- and 60-minutes on 3rd September 2016 are displayed in Figure 6. The 1-minute plot exhibits large and brief power consumption spikes compared to 10-, 30- and 60-minutes with low and smoother trends that also can affect the time when daily peak happens. Peak means a group of higher power or sudden spikes being consumed during the day. For example, 60-min resolution recorded the peak to happen at 23:00 however, with 1-min resolution the time when peak happen was captured at 23:24 to 23:25 as shown in Figure 6(a). It indicates that only the variation of 1-minute smoothing time can capture the rapid variations and the time for peak to happen is more accurate. This also can be supported with a study from [16] that proposed an enhanced approach for load forecasting at the residential level. They also recorded the data on electricity consumption at 1-min intervals using 21 sub-meters for two years.

Peak demand decreased with the increasing of time averaging can be seen in Figure 6(b). For example, 10-min resolution captured more peak demand at 05:00 to 06:00 with 2957 W and 2419 W meanwhile 60-min resolutions only have one peak demand at the same time which is 2957 W. Figure 7 displayed the same graph but for the selected appliances. The resolutions are based on the average of 1-minute of raw data. However, standing fan, iron and AC 2 were not used on that day. This household was not frequently used these appliances. From Figure 6, a constantly brief spike occurred from 22:00 to 06:00 and it can be confirmed from Figure 7(b), 7(c), 7(e), 7(f), and 7(h) that socket, AC, shower heater 1, and water dispenser (24 hours on) were used during that hour. This also includes the ‘cold’ and ‘standby’ appliances such as refrigerator and other appliances. In addition, the peak at higher resolution varies at a certain period of time that can be observed on the degree of fluctuation depending on what type of appliance being used.

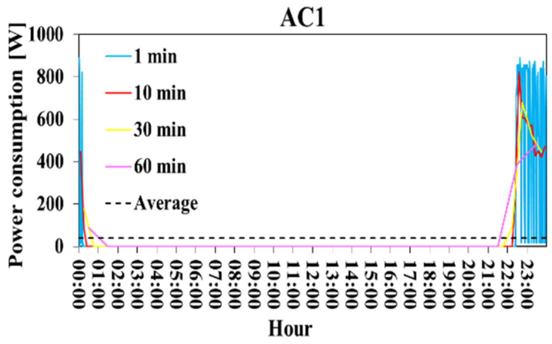



(b)

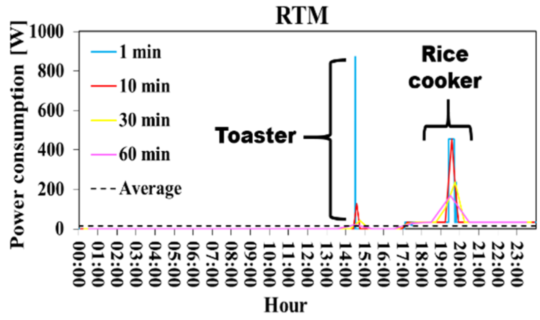
Figure 6. (a) Total power consumption, (b) Peak demand at 1-, 10-, 30- and 60-minutes on 3rd September 2016




(a) (b)




(c)

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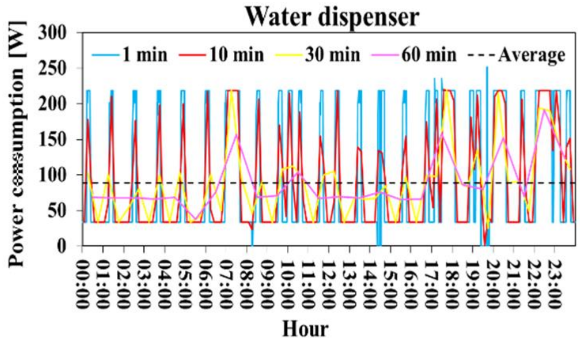


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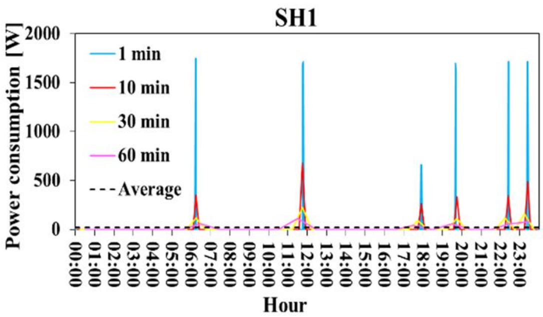


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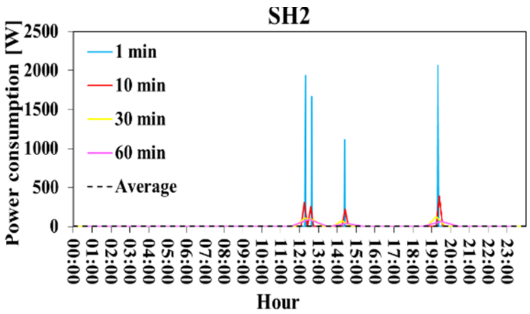
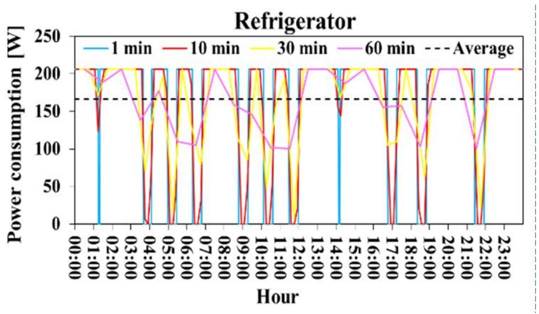
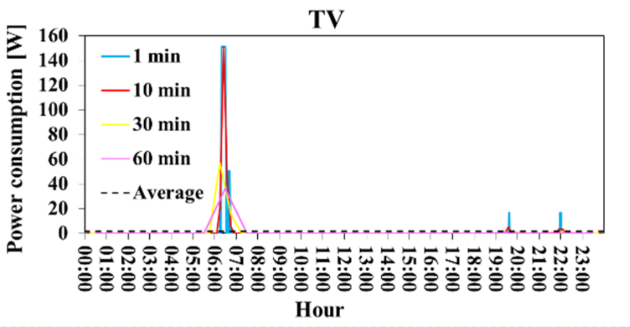



(g)




(h)




(i)

Figure 7. Power consumption of, (a) Washing machine (b) Socket, (c) AC 1, and (d) RTM, (e) Water dispenser, (f) Shower heater 1, (g) Shower heater 2, (h) Refrigerator, and (i) TV at 1-, 10-, 30, and 60-minutes resolution on 3rd September 2016

### 3.4. A portion of electricity consumption based on each appliance

The monthly average electricity consumption and the percentage of appliances usage were shown in Table 2. The measured average monthly electricity consumption showed 390.0 kWh/month with standard deviation (S.D) of 49.63 kWh/month. The highest electricity usage was refrigerator with 30.5%, followed by water dispenser (13.5%) and total AC (11.6%). In contrast, TV, washing machine, standing fan, socket, iron, and RTM were recorded less than 1% for electricity usage. Basically AC is the highest electricity consumption and has a significant effect on the total electricity consumption compare to other appliances [17-25], but it is contradicted with this household. It might be due to the use of AC as shown in Figure 7 only during the sleeping time for around four hours since the owner also used the ceiling fan at the same time. The AC temperature setting that applied in this household also 28°C.

Table 2. Monthly average electricity consumption of appliances

| Appliance | Electricity consumption [kWh/month] | Percentage (%) |
|---|---|---|
| TV | 0.9 | 0.2 |
| Refrigerator | 118.8 | 30.5 |
| Washing machine | 2.3 | 0.6 |
| Total AC ** | 45.2 | 11.6 |
| Total shower heater * | 32.6 | 8.4 |
| Socket | 1.3 | 0.3 |
| Standing fan | 0.4 | 0.1 |
| Water dispenser | 52.5 | 13.5 |
| Iron | 3.0 | 0.8 |
| RTM | 3.0 | 0.8 |
| Others (router, modem, internet box, ceiling fans, lighting devices, etc.) | 130.0 | 33.4 |
| Total | 390.0 | |

* Refer to sum up of SH1 and SH2
**Refer to sum up of AC1 and AC2

## 4. CONCLUSION

The aim of this study was to evaluate total electricity and selected domestic appliances of middle income family household. The findings can be summarized as follows: (a) The peak power consumption of total electricity was observed twice a day within 18:30 to 23:00 and from 06:00 to 07:00. It is because of the high occupancy level during this time with more activities such as dinner, watching television, AC usage during sleeping, shower heater usage in the morning and other appliances (lighting and ceiling fans). (b) The highest electricity usage from this experiment was the refrigerator with 118.8 kWh/month (30.5%), followed by water dispenser and total AC with 52.5 kWh/month (13.5%) and 45.2 kWh/month (11.6%) respectively. In contrast, TV, washing machine, standing fan, socket, iron, and RTM were recorded less than 1% for electricity usage. We might need more samples for further analysis in the future study for load shifting to off-peak times of selected appliances.

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