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Survey of Resident Behaviour Related to Air Conditioner Operation in Low-Cost Apartments of Kuala Lumpur

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Predictions of air conditioner (AC) use can greatly facilitate efforts to increase energy efficiency in buildings and promote sustainability. In order to determine the statistical characteristics of occupant behaviour related to AC operation, a series of surveys were conducted between September 2013 and December 2015 in 63 dwellings within two apartments in Kuala Lumpur, Malaysia. Measurements were taken either in the bedroom or living room of each dwelling. The results indicate that occupants who use ACs more frequently tend to use them for longer periods. It was found that AC use in bedrooms is not affected by outdoor temperature but is controlled by the habitual behaviour of the occupant. AC usage in living rooms slightly increases with increases in outdoor temperature. AC usage predominantly occurs at night time, with a maximum of 50 % of occupants using ACs in bedrooms. The start time and duration of use vary for each dwelling. These findings on stochastic resident behaviour might be useful for various building energy simulations in predicting realistic AC loads, particularly in tropical climates.

1. Introduction

Occupant behaviour describes how people respond to their indoor environment by making use of the building controls, for example, by switching on the lights, opening windows, or turning on the air conditioners (AC). Several studies have investigated occupant behaviour regarding window opening (Rijal et al., 2007), lighting (Reinhart, 2004), adaptation of thermal comfort in office buildings in Malaysia, Singapore, Indonesia, and Japan (Damiati et al., 2016), in Japanese university building with free running and cooling mode offices (Mustapa et al., 2016), university classroom in Malaysia and Japan (Zaki et al., 2017a), and switching on/off AC (Tanimoto and Hagishima, 2005). These studies were conducted in different countries with varying climate conditions. They also involved different building types and climate. It is very important to conduct the studies on energy consumption-related occupant behaviour for developing stable energy grids. These studies are often then used to develop behavioural models based on statistical algorithms that predict the probability of user action. In order to know the reality of energy use of AC, there are several factors. First is human factor such as when and how long people want to use AC, thermal environment that occupants satisfy or accept in reality (Hwang et al., 2009), and AC setpoint of temperature. Second is AC performance and building insulation. The amount of thermal energy which AC remove from the room air and AC electricity consumption can be estimated using building energy consumption (Tanimoto and Hagishima, 2010). Accurate estimations of the stochastic natures of energy demand for AC use, which are affected by the diverse occupant behaviour, are needed, for the design and operation of residential cogeneration systems and distributed generation systems coupled with renewable energy sources and supply-demand management technologies. Past studies have mainly focused on developed countries and knowledge of tropical regions, including many emerging countries with large populations, remains limited. For example, Zaki et al. (2017b) developed a simple algorithm to synthesise stochastic time patterns of AC operation schedules based on field measurement of usage behaviour of AC in low cost apartment in Malaysia. Ranjbar et al. (2017a) carried out the measurement of total and AC electricity consumption for middle-income family in Kuala Lumpur, Malaysia. They found that

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1-min resolution is more accurately measured electricity energy consumption of household. Ranjbar et al. (2017b) had extended the investigation of similar study and noticed the pattern of electricity energy consumption is based on the occupancy schedule of each dwelling, and AC is the main contribution of electricity consumption. The main purpose of this research is to identify the factors that influence occupant decisions regarding AC usage in order to construct a model of AC temporal patterns in tropical regions. Field measurements of occupants' AC usage behaviour were conducted in 63 dwellings from two low-cost apartments in Kuala Lumpur, Malaysia.

2. Methods

2.1 Surveys

63 dwellings within two low-cost apartments were selected for a series of field measurements in the period from September 2013 to May 2015, summarised in Table 1.

Table 1: Profiles of field surveys conducted in Kuala Lumpur

Apartment	A	B
Location	N 3° 11' 16", E 101° 43' 53"	N 3° 10' 7", E 101° 43' 25"
Number of samples	54 dwellings	9 dwellings
Characteristics of dwellings	19-storey building with a floor area of 60 m^2	13-storey and 4-storey buildings with floor areas of 55 m^2 and 74 m^2
Measurement period	15 to 58 days per dwelling, from September 2013 to December 2015	29 to 68 days per dwelling, from February 2015 to December 2015

The households are comprised of nuclear families (two adults plus children), single-parent families, and extended families (including grandparents). Figure 1 shows the number of occupants living in each house. The average household size is four with a standard deviation of 1.2. The maximum number of people living in the same house is eight.

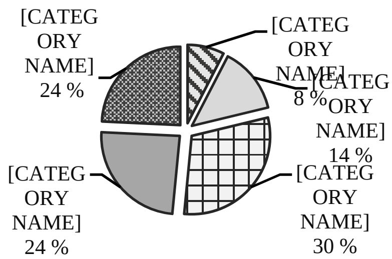

Figure 1: Number of occupants living in each house

2.2 Measurement set up

Figure 2 displays the annual variation in outdoor air temperature during the survey period. Malaysia is located on the equator and is categorised as a tropical zone, with a relatively constant outdoor air temperature throughout the year. In the figure, there are several short periods during which no data were recorded due to maintenance of the weather station. Although there were no field measurements conducted during these periods, it does not affect the results of this study.

A thermo recorder (resolution 0.1 °C, accuracy ± 0.25 °C: 0 °C to 50 °C) was installed at the air outlet of the AC unit. The room temperature was measured in the centre of the room using the same sensor. Data were collected in 15 min intervals. Measurements were performed in either the living room or bedroom, depending on the location of the AC unit. Some of the dwellings had more than one AC installed in different rooms. Due to the limited number of instruments available, it was not possible to place sensors inside all of these rooms. Occupants were interviewed on their AC usage preferences, and any AC's that were rarely used were omitted. There was an equal distribution of AC's, in that 50 % of sensors were installed in bedrooms and 50 % were installed in living rooms. The measured data was used to determine when the occupants switched on or off theirs AC's in each day. The criteria to decide that AC usage in each dwelling based on the difference temperature between AC outlet air and room air temperature. If the temperature difference was 1.5 °C, the occupant switched on the AC. The times period of occupants switched on and off the AC's was called as event. A weather station for recording outdoor air temperature was installed on the rooftop of the Malaysia-Japan International Institute of Technology (MJIIT) building, less than 2 km from both apartments. The detail setup of the station was described in the previous studies done by Swarno et al. (2017).

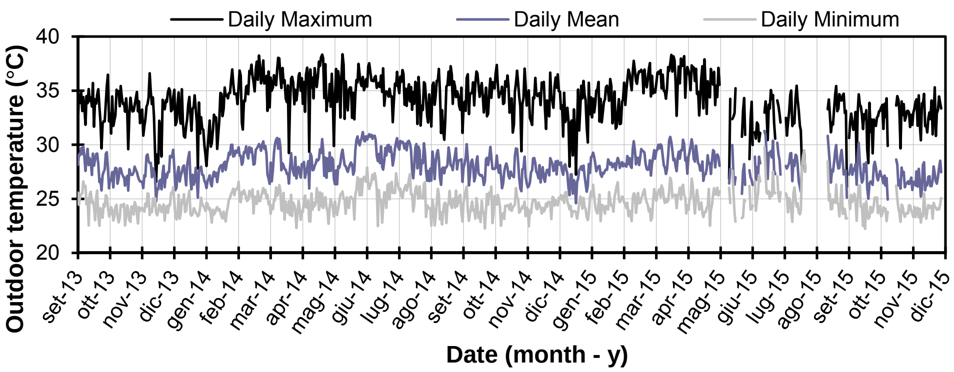

Figure 2: Outdoor air temperature profiles in Kuala Lumpur observed from the rooftop weather station of the MJIIT building

3. Results and Discussion

3.1 Outdoor temperature and air conditioner usage

The effects of outdoor temperature conditions on occupant decisions to use the air conditioner can be observed by studying the relationship between the daily hours of AC usage and daily statistics of outdoor air temperature, as shown in Figure 3. The size of the plots refers to the number of samples. In Figure 3a, AC usage in the living room slightly increases with outdoor temperature. Figure 3b shows that AC usage in the bedroom remains constant despite the increasing outdoor temperature. This may be a result of occupants' daily habits, in which the AC in the bedroom is always used at night, regardless of the outdoor temperature.

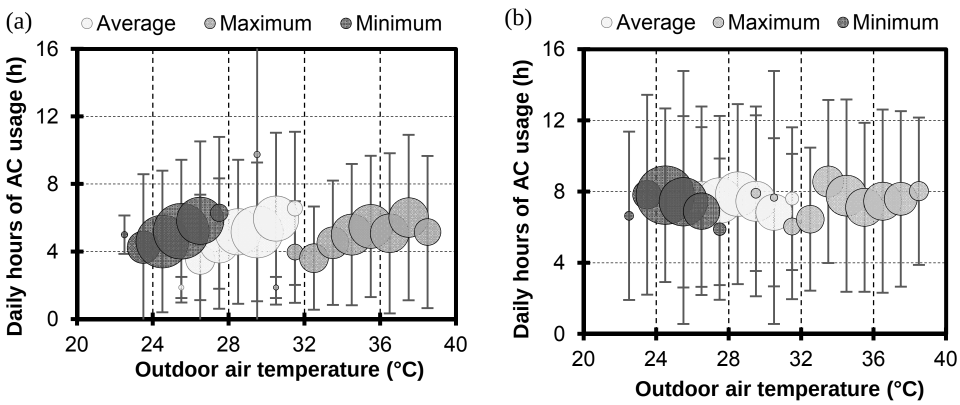

Figure 3: Relationship between daily hours of AC usage and daily outdoor air temperature: (a) living rooms and (b) bedrooms

3.2 Statistics of AC events

To observe how daily habits or schedules affect decisions regarding air conditioner usage, the joint probability distributions of events in terms of event start time and duration are displayed in Figure 4. The horizontal axis shows the time when occupants turn on the AC in a 24-h clock system. The vertical axis shows the duration of AC use in hours. Figure 4a also shows peaks at 11 pm and midnight, but with shorter durations of 0 to 2 hours. This result is consistent with the questionnaire survey done by Kubota et al. (2011), which AC is mainly used during sleeping time in Malaysia. Figure 4b also shows two peaks: at 11 pm and midnight, with a duration of 6 to 8 h. This indicates that air conditioner use in the bedroom is determined by the occupants' sleep schedule.

Figure 5 shows that there are peak times in which occupants are more likely to switch on their AC. It also shows the proportion of AC units that are switched on at different times of the day. In the living room, the peak time is around 11 pm to 1 am, with approximately 30 % of occupants using the AC during this time. It is evident that air conditioners in the bedroom are used for sleeping, with a maximum 50 % of occupants using their AC between 11 pm and 6 am. The proportion of occupants using the AC in the bedroom decreases significantly between 8 am and 7 pm. In general, occupants use the AC more during the night.

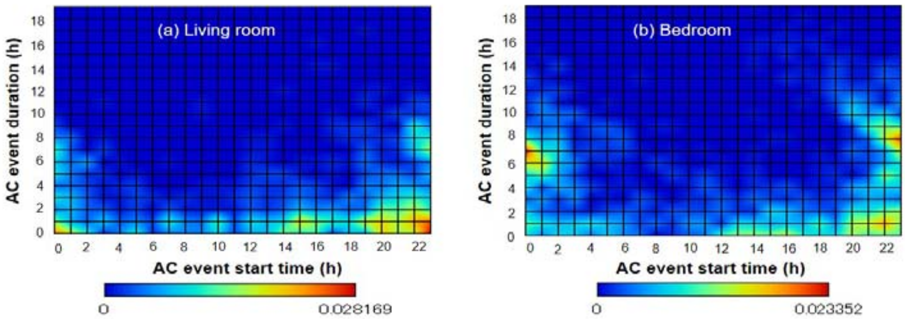

Figure 4: Joint probability distributions of AC event duration and event start time. Colours refer to the probability density of AC event duration and event start time

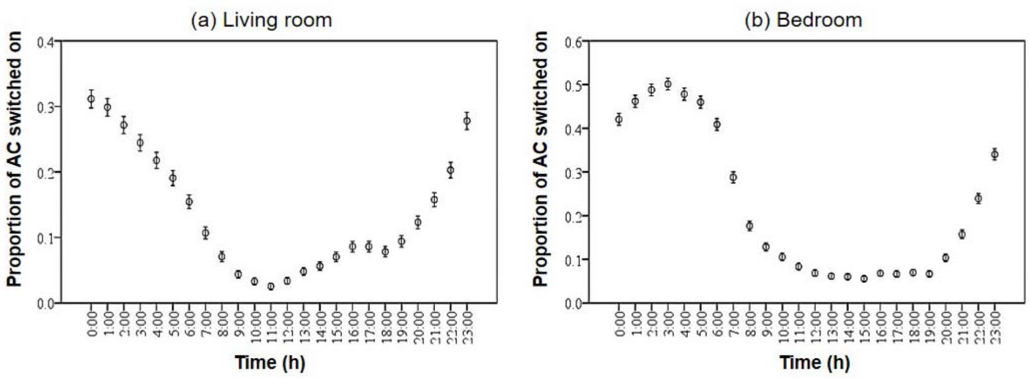

Figure 5: Proportion of AC that are switched on at different times (with a 95 % confidence interval)

Figure 6 shows the relationship between the total number of events and the total duration of AC usage. Generally, the total duration in a day varies from 0 to 13.7 h. The figure shows a positive relationship, indicating that occupants who use the AC more frequently are more likely to use the AC for longer periods. In terms of AC usage between the living room and the bedroom, the former had more AC events than the latter for a similar daily amount of AC usage. This indicates that AC events in bedrooms tend to be of a longer duration than those in living rooms.

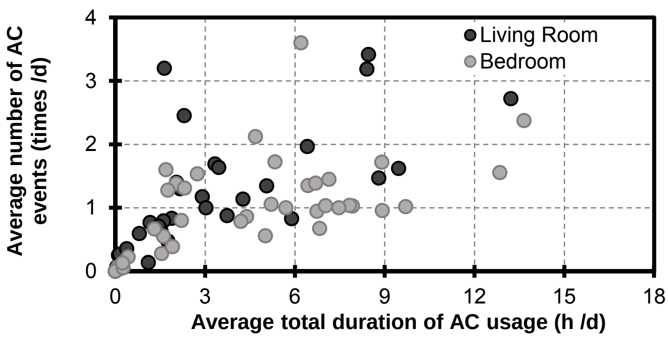

Figure 6: Comparison between number of AC usage events per day and total duration of AC usage per day for 63 dwellings

Figure 7 displays the relationship between the total number of events and the total duration, classified by working days and holidays for bedrooms and living rooms. One could hypothesise that occupants spend more time at home during holidays and are more likely to use the air conditioner when they are present in the room. Both figures show negligible differences between holidays and working days. This can be explained by the fact that occupants predominantly use the AC at night time, discussed in the following section.

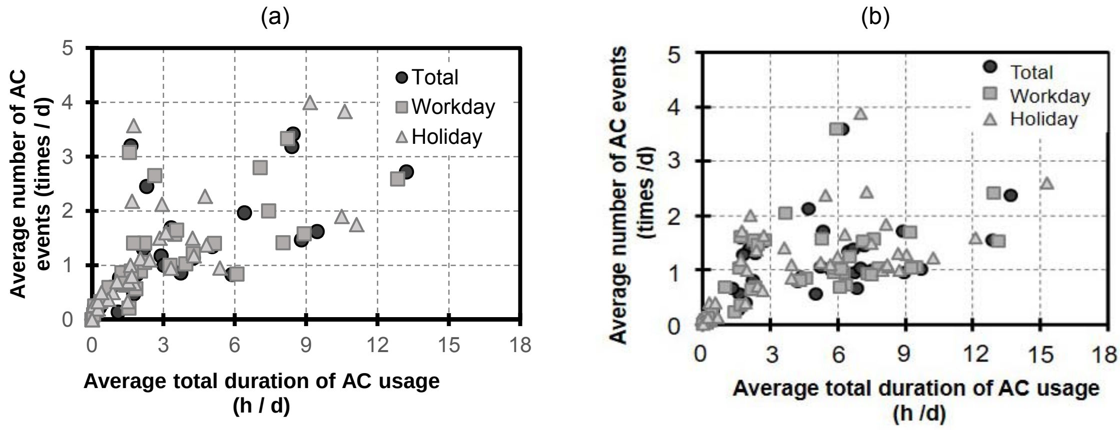

Figure 7: Comparison between number of AC usage events per day and total duration of AC usage in a day classified by working days and holidays for (a) 33 living rooms and (b) 42 bedrooms

The probability density of indoor air temperature before and during the occupants switch on and the AC operation in dwellings is shown in Figure 8. The mean indoor temperature in the both living and bedrooms before AC on varied from 29 °C to 31 °C. This indicates the upper limit of the acceptable thermal comfort of users that seem more tolerant of heat. They are more likely to withstand higher temperatures before making the decision to turn on the air conditioner. The mean indoor air temperatures for living room during event had deviated from 28 °C to 30 °C. In contrast, data from bedroom had a wider deviation from approximately 24 °C to 29 °C. The reason that exceeded the criteria of thermal comfort of indoor environment might due to the poor insulation performance and a tendency of owner to reduce the electricity bills.

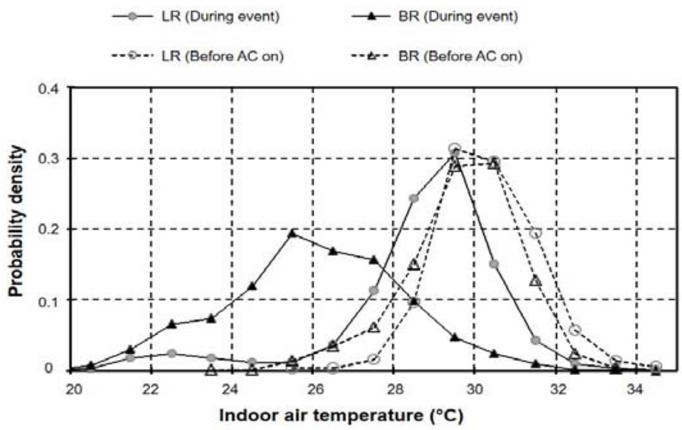

Figure 8: Room indoor air temperature before occupants switch on and during the AC operation

4. Conclusions

A series of measurements were conducted to determine air conditioner usage patterns among occupants of apartments in Kuala Lumpur, Malaysia. The recorded data was used to determine the factors that affect occupant decisions to turn on the air conditioner. The 63 target houses were examined according to the frequency, start and end time of AC usage. The findings of this study can be concluded as follows:

a. Air conditioner usage is not significantly affected by the outdoor temperature but is affected by occupants' habitual behaviour.

b. Malaysian residents tend to use the air conditioner during sleeping hours, but the start time and duration of use varies. AC events rarely occur during the daytime.

c. AC usage events in living rooms are more numerous than those in bedrooms for a similar daily amount of AC usage.

d. AC events in bedrooms tend to be longer than those in living rooms.

e. The indoor air temperature for living room before and during events are approximately 27 °C to 31 °C. The similar condition also observed from bedroom before AC on, but it had a wider deviation during AC event approximately 22 °C to 30 °C. The exceeded criteria of indoor thermal comfort might contribute from poor condition of existing insulation.

The findings of this survey could be used to generate an artificial AC operation schedule, with a specific emphasis on tropical regions.

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