Cross-cultural comparison of occupants’ behaviour towards cooling of residences between Japan and Malaysia

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Abstract
Field surveys of occupants’ behaviour toward cooling of dwellings in residential buildings were conducted in Malaysia and Japan. The results suggest that the behaviour of Malaysians is more habitual and less affected by the varying outdoor thermal condition.

Keywords – Occupants’ behaviour, Air-conditioning operation, Thermal adaptation

1. Introduction

Accurate forecast of the time-varying demands for electricity and hot water as well as the air-conditioning (A/C) load has become crucial for designing reliable smart grid systems coupled with renewable energy sources. In particular, the time-series demands in residences are highly diverse and heterogeneous across households, weather conditions, and building specifications, partly because of the diverse behaviour and preferences of the occupants, thus, prompting the development of proper estimation methodologies.

Various field observations on the characteristics of the occupants’ behaviour associated with the A/C load and energy usage for past decades have been made [1]. Many of them have suggested that the probabilities of occupants’ actions, such as switching-on an air conditioner and opening a window, are affected by not only the occupants’ schedule, such as entering/leaving a room and sleeping, but also the environmental factors. These environmental factors were widely expressed by logistic models as functions of environmental variables, such as indoor air temperature and external illuminance. However, most of these studies occurred in midlatitude
developed countries, and the research targeting both developing countries and tropical or subtropical climate zones is limited.

Because of this sparse coverage, the authors performed a series of field observations of occupants’ behaviour towards cooling of residences located in two areas with contrasting climate conditions, namely Fukuoka, Japan in the temperate zone and Kuala Lumpur, Malaysia in the tropical zone. The aim was to provide event-based data of occupants’ behaviour of A/C usage to develop stochastic models for building energy simulations and to deepen the understanding of cross-cultural differences in occupants’ behaviour caused by climate conditions.

2. Outline of Field Surveys

Table 1 summarizes the profiles of these surveys. The observations in Japan were conducted in 20 dwellings located in the southern outskirts of the city of Fukuoka over approximately 3 months during the summer of 2014. The measurements in Malaysia were conducted in 60 dwellings located in a public low-cost housing complex in Kuala Lumpur. The measurement period for each dwelling in Malaysia varied from approximately 10 days to 2 months during the period from 2013 to 2015.

Fig. 1 shows the annual variations of outdoor air temperature of the two regions during 2014, which is the period of measurement for the observations in Fukuoka, Japan. The outdoor air temperature of Kuala Lumpur, Malaysia, located on the equator, is relatively constant year-round; in contrast, Fukuoka, Japan experiences a distinct seasonal cycle. Despite the different climate zones of the two regions, the outdoor air temperatures in Japan during the measurement period from July to September were similar to those in Malaysia.
Considering the little seasonal change of tropical climate shown in Fig. 1, it is supposed to be acceptable that the measurement period of each dwelling in Malaysia did not coincided with each others.

Fig. 1 Annual variation of daily statistics of outdoor air temperature observed in the two cities during 2014. ‘JP’ refers to the data observed at the Dazaifu weather station, which is approximately 4 km away from the target dwellings in Fukuoka, Japan, and the nearest station within the Automated Meteorological Data Acquisition System (AMeDAS) network. ‘MY’ refers to the data observed on the rooftop of the Malaysia-Japan International Institute of Technology building at the Universiti Teknologi Malaysia Kuala Lumpur Campus, Malaysia.

Fig. 2 Proportions of number of people in target dwellings.

Fig. 2 shows the proportions of number of occupants of the target dwellings in the two cities, indicating highly diverse compositions especially in Kuala Lumpur, which varied from single occupant up to eight occupants.

The time-series variations of air temperature in a room (living or bedroom) and at the outlet of the room’s air conditioner were measured in each dwelling. In addition, an occupant of each home completed a detailed questionnaire survey to capture demographic information, usual behaviour schedules, perception of thermal comfort, and approach to A/C usage.

Based on the estimated schedule of A/C usage, the authors sampled A/C events defined as the period from when occupants turned on an air conditioner
until they turned it off. The data associated with start time, event duration, outdoor and room air temperature at the start time, and average temperature of both the outdoor air and the room air for the duration were analysed.

3. **Comparison of statistics of A/C events between two countries**

Fig. 3 shows the relationship between the total duration of A/C usage and total number of A/C events derived from the measurements in the two regions, in which each data point is an average over the measurement period for each dwelling. The graph clearly indicates that daily hours of A/C usage varied from 0 to over 14 hours among the dwellings. In addition, Fig. 3 shows a positive relationship, which suggests reasonably that a family that uses A/C more per day, tends to turn the A/C on and off more frequently compared to families that use the A/C for shorter periods per day. In terms of A/C usage in Malaysian living rooms versus bedrooms, the latter had slightly less A/C events than the former under similar daily hours of A/C usage, indicating that A/C events in bedrooms tend to be longer than those in living rooms.

![Fig. 3 Comparison between number of events of air conditioner usage [times in a day] and total duration of air conditioner usage per day [hours in a day].](image)

Based on the data shown in Fig. 3, all the dwellings were classified into three groups according to the A/C usage frequency in a living room. ‘Group A’, referring to high-frequency A/C users, had an average number of A/C events of over 0.5 times per day and total duration of over 6 hours per day; ‘Group C’ used A/C sparingly and had a total number of A/C events below 0.5 times per day; and the remaining dwellings were classified into ‘Group B’, having moderate use. The ratios of these three groups to the total samples are shown in Fig. 4, and are surprisingly very similar between the two regions.
To grasp the actual air-conditioned temperature, at which the occupants intended to keep a room, other than by the values of a thermostat that the occupants set, the average room air temperature during each A/C event was calculated. To exclude the effect of a transient temperature drop immediately after the A/C was turned on, only events with a duration longer than 30 minutes and data of the period from 30 minutes after the event initiation were used for the analysis. Fig. 5 shows the frequency of air-conditioned room air temperature in dwellings in the two regions. The data of Group C is not included due to its small sample numbers. The data from Japan varied from 26 °C to 28 °C, and the distribution of Group A (high-frequency users) slightly shifted toward lower temperatures compared to Group B (moderate users); in other words, frequent A/C users prefer cooler rooms compared to moderate A/C users.

The temperatures in Malaysian living rooms had a wider deviation, from approximately 22 °C to 31 °C, including much lower and higher temperatures, than those in Japanese dwellings for both Groups A and B. One possible reason for the high temperatures included in the data, which apparently exceed the criteria of thermal comfort of indoor environments, is
that the capacity of the air conditioners in the target dwellings with poor insulation performance was not sufficient to achieve the thermal condition the occupants required. Another reason may be that occupants were willing, or were forced, to be uncomfortable to reduce their electricity bill. With regard to the bedrooms in Malaysia, there was no obviously remarkable bias toward lower temperatures compared to the other categories. This tendency is consistent with Malaysian preference toward indoor thermal environment observed by a former questionnaire survey [2], which pointed out that Malaysian people prefer a cool room environment controlled by air conditioners during night-time sleep, whereas they usually open windows during the daytime to enhance evaporative cooling by utilizing natural ventilation and fans.

Fig. 6 shows the diurnal variations in ratios of dwellings where A/C was used. Comparing the data observed in living rooms of Group A (frequent users) between the two regions, there is an obvious difference in time patterns despite the fact that the daily hours of A/C usage in the two regions, as shown in Fig. 3, are similar. In general, Malaysians used A/C more during the night and less during the day compared to the Japanese. This may be due to the specific style of A/C usage in Malaysia. According to the supplementary interview with the Malaysian occupants, air conditioners installed in living rooms were frequently operated frequently at night, even though there was no occupant in the room, to cool connected bedrooms that lacked air conditioners. The high night-time usage ratio in Malaysian bedrooms is consistent with the survey by Kubota et al. [2].

![Diurnal variations in ratio of dwellings where A/C was used.](image)

Fig. 6 Diurnal variations in ratio of dwellings where A/C was used. ‘L’ and ‘B’ refer to the data observed in a living room and bedroom in Malaysia. Error bars refer to the standard deviation among all the dwellings.

The joint probability distributions of A/C events in terms of event duration, start time, and finish time shown in Fig. 7 illustrate more clearly how the occupants’ behaviour toward environment cooling differs between Japan and Malaysia. The data for Malaysian bedrooms exhibit a positive peak for a finish time between 6 am and 7 am and duration from 6 hours to 9 hours (Fig.
7(f)), and this peak is correlated with the diagonal stroke toward the lower right at night shown in Fig. 7(e). This indicates that A/C operation in a bedroom was determined by the occupants’ behaviour schedule for sleep. The data for living rooms in Malaysia also show a weak positive peak caused by events starting at midnight. Compared to these data, peaks of joint probability distributions for Japan generally appear at shorter event durations.

Fig. 7 Joint probability distributions of A/C events between event duration and event start and finish times.
Fig. 8 shows the relationships between the daily hours of A/C usage and the daily statistics of outdoor air temperature, which suggests how the occupants’ behaviour for environment cooling is correlated with the outdoor thermal environment. The plots of Japanese dwellings show clear positive relationships, indicating people use A/C more frequently under hotter outdoor conditions. In contrast, Figs. 8(b) and 8(c) suggest that the outdoor thermal condition has much smaller influence on the frequency of A/C usage in Malaysia, and this tendency is more remarkable in bedrooms, although the deviation of the daily statistics of outdoor air temperature in Malaysia is much smaller than that in Japan.

![Fig. 8 Relationships between daily hours of A/C usage and daily statistics of outdoor air temperature. Data for (a) living rooms of Fukuoka, Japan, (b) living rooms of Kuala Lumpur, Malaysia, and (c) bedrooms of Kuala Lumpur, Malaysia. The size of the circles corresponds to the number of samples.](image)

**4. Conclusions**

A field survey of occupants’ behaviour of A/C usage was conducted in residential buildings located in Fukuoka, Japan and Kuala Lumpur, Malaysia. The measurement data were translated into the collections of A/C events, and the various statistical data relating to the frequency and duration of A/C events were compared between the two regions. The results suggest that the
behaviour of the occupants in Malaysia, which is located in the tropical zone with little seasonal variation in climate, is more habitual and less affected by the outdoor thermal conditions compared to that of occupants in the temperate city in Japan.

When considering the future application for building energy simulation coupled with stochastic modelling of the occupants’ behaviour targeting tropical regions, the findings of this survey pose a new approach that differs from the widely adopted approach that uses state transition probabilities for the on/off switching action defined by the environmental variables in line with the concept of thermal adaptation behaviour.

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References