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ORIGINAL ARTICLE

A Survey of Energy-Use Behaviour in Apartment Buildings in East and West Malaysia

*[1]Hirda Lailani Khalid and [2]Mastura Bujang

[1]School of Built Environment, University of Technology Sarawak, 96000 Sibu, Sarawak, Malaysia
[2]School of Engineering and Technology, University of Technology Sarawak, 96000 Sibu, Sarawak, Malaysia

ABSTRACT - Achieving thermal comfort is a common problem in Malaysia due to the hot and humid conditions throughout the year. Passive ventilation solely or with the aid of fan is no longer a practical solution, especially in an urban area. As a result, air-conditioning system (AC) has become a new necessity for residential buildings, proven by the increasing demands. This paper presents the study on the energy-use behaviour through the window opening and space cooling methods (AC and fan) in East and West Malaysia, particularly in apartment buildings. It was conducted through a survey of 160 apartment households in Klang Valley and several main Sarawak cities, Kuching, Sibu, and Bintulu. Data was obtained based on five categories in the questionnaire survey; socio-demographics, house characteristics, house occupancy, window opening, and space cooling methods. In analysing the behaviour, the energy-use patterns or profiles on window opening, AC and fan hourly usages during weekdays and weekends were developed from the Frequency Analysis. The data revealed that most urban households are a working society, reflecting the result of lower energy consumption during weekdays due to the non-occupancy during working hours. The occupants prefer to leave the windows open during the daytime for the fresh air, although their houses are unoccupied. However, the percentage is lesser during the nighttime concerning insects, rain and privacy. Few variables such as the total bedroom, the total number of non-working occupants and AC usage during weekdays and weekends are moderately correlated with monthly electricity bills as the indicator of household energy consumption. The results concluded that occupants' tendencies to fulfil their needs in achieving indoor thermal comfort contributed to high energy consumption even with the passive solutions applied. It supports the evidence that the AC system greatly influences building energy consumption. Therefore, it is suggested that improvements could be made in the future study to the appropriate apartment design and its regulations to accommodate occupants' needs and preferences, thus minimising the AC usage.

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Air-conditioning
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INTRODUCTION

In the tropical region, occupants used to rely on window opening to optimise passive ventilation, commonly coupled together with a simple active system such as a fan to achieve indoor thermal comfort. The hot and humid weather throughout the year, with an average of 28°C of low wind speed, and high humidity with abundant rainfall, make it desirable and a tremendous advantage for tropical building occupants.

However, this desirable condition is hardly achieved nowadays due to urbanisation resulting in increased density and the effect of climate change each day. This condition has forced the building occupants to resort to more sophisticated cooling aid such as air-conditioning systems (AC) to maintain

*Corresponding Author: Hilda Lailani Khalid. University of Technology Sarawak (UTS),
email: hirda.lailani@uts.edu.my

their preferred indoor conditions. Due to this situation, the demand for AC has been observed to be increasing [1] [2] [3] [4] and [5].

The evidence revealed that energy-use behaviour and energy-related behaviour is one of the crucial scopes to be focused on as it has a large influence on building energy demand [6] [7] [8] and [9] to minimise the excessive future energy demand and its negative impacts on the environment. Thus, this paper investigates the energy-use behaviour through the window opening and space cooling methods (AC and fan) in East and West Malaysia apartment buildings, in line with the issues in filing the gaps.

LITERATURE REVIEW

The issues of excessive future energy demand due to climate change have been acknowledged by many for decades [10]. Past works of literature have identified a number of parameters in this scope of the study. However, the discrepancies in output for precise prediction have been observed due to the unrealistic input based on the uncertainties of occupants' behaviour [11] [6] [7] [12] and [13]. Therefore, this gap is worth exploring, especially in the tropical Asian region, where people's lifestyles are much affected by their cultural beliefs and household income.

AC usage from the building sector solely has contributed to the high energy consumption associated with CO_2 emissions [2] [14], which caught the attention of industry players, researchers and policymakers. According to [15] and [16], space cooling, including AC, takes up almost 20% of the total energy consumption of the building. However, there is a lack of emphasis on AC usage in the residential buildings, especially on the regulations [3] [5] and [17] in this building sector compared with commercial, industrial, and office buildings. [5] highlighted the need of investigating occupants' behaviour from the AC usage to come out with energy-saving measures. Unlike in public buildings, the occupants of residential buildings have more freedom of control based on their preferred conditions, making it noticeable to increase energy consumption [18].

The apartment buildings were chosen for the survey as the worst-case scenario of residential buildings, considering the high-density and compact design characteristics. Besides that, apartment buildings have become a trend and lifestyle in Malaysia [19] due to affordability, appropriate size, facilities, and strategic location. Therefore, important key parameters as the input as investigated by [19] [3] [14] and [13], such as building characteristics, indoor environment, home appliances ownership and usage, and micro-climate, are required to develop the energy-use patterns or profiles [21] [22] and [23]. This information will be accessed from the questionnaire survey adopted by previous studies [3].

Based on these reviews, this study has been structured onto a quantitative method to assess the occupants' energy-use behaviour that focuses on window opening and space cooling methods in apartment buildings, identified as the research gap.

METHODOLOGY

Data Collection

The survey was done randomly, majorly in Klang Valley (West Malaysia) and several cities in Sarawak (East Malaysia), such as Kuching, Sibu and Bintulu, to represent the data of the whole of Malaysia. As shown in Figure 1, East and West Malaysia are separated by the South China Sea. These two regions differ in the context of culture and development, which need to be considered in generalising the results.

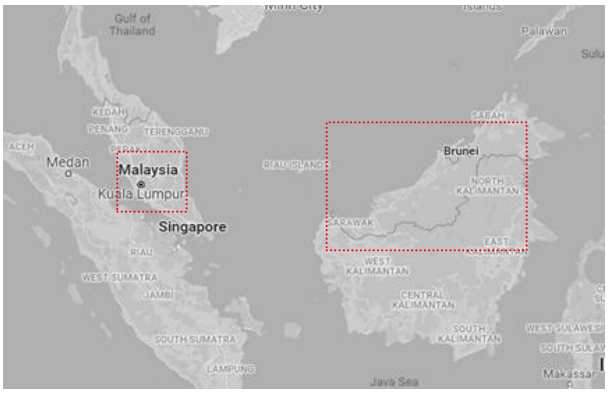

Figure 1. The locations of surveys done in East and West Malaysia [24]

A-priori sample size calculator was used to determine the required minimum total sample size [25]. A total of 128 total samples is required for a two-tailed hypothesis with a 0.05 probability level. Based on the online survey with a targeted approach to apartment occupants in urban areas, a total of 160 respondents have been obtained from both regions. The questionnaire survey is divided into five parts based on the key parameters identified from the past studies, as shown in Table 1:

Table 1. Categories, parameters and variables in the questionnaire survey

Part	Parameters	Variables
I	Demographics	Monthly electricity bill, household income, total occupants, total working and non-working occupants
II	House characteristics	Total bedroom, ownership
III	House occupancy	Occupancy during weekdays and weekends
IV	Window opening	Opening during weekdays and weekends, reasons to open/close
V	AC and fan usage	Usage during weekdays and weekends

Data analysis

There are three stages of data analysis in this study. Firstly, all variables were analysed using Frequency Analysis. Secondly, the energy-use patterns based on hourly profiles on house occupancy, window opening, and AC and fan usage were developed to further analyse the occupants' behaviour. Then, the relationships between monthly electricity bills and other variables were tested using Pearson Correlation (for continuous data) and Kendall's Tau-b Correlation (for ordinal data), which is important to determine the best input in the behavioural study of similar conditions.

RESULT AND DISCUSSION

Demographic

Out of 160 respondents, the data indicate that most apartment units consumed relatively low energy based on their average monthly electricity bills, where 46.25% at the lowest range of RM50-RM100, followed by 26.6% at RM101-150, 10.15% at RM151-200, and gradually decreasing for the other ranges (Figure 2). However, comparing the data on average monthly electricity bills and average monthly household income contradicts several studies [26] and [27]. Figure 3 shows that the majority of 47.5% is from the highest income group above RM5501, and less than 10% are from the lowest income groups below RM1000 to the range of RM3001-RM3500.

On average, Malaysia's total number of households was 4.31 per dwelling in 2010 [28], which aligned with the data obtained. The highest percentage of 23.3% is from four-person per dwelling, followed by three-person and two-person with 21.4% and 20.8%, respectively (Figure 4). From these figures, the majority of occupants are working households with a ratio of 7:3 compared with non-working households (Figure 5). Thus, it reveals the fact that most houses are not occupied for most hours during weekdays.

Furthermore, 49% of the total working households consist of two persons per unit, followed by one person and three persons with 26.5% and 14.2%, respectively (Figure 6). Figure 7 shows that 45.7% of the respondents are solely working households without having any other non-working households staying in the same house. The house's occupancy factor generally explains why the total electricity consumption observed from the electricity bill is relatively low in this study.

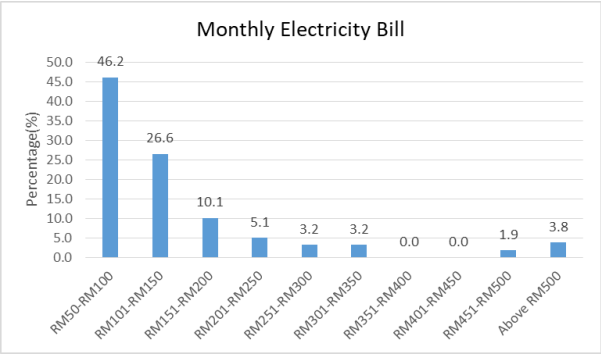

Figure 2. Average monthly electricity bill

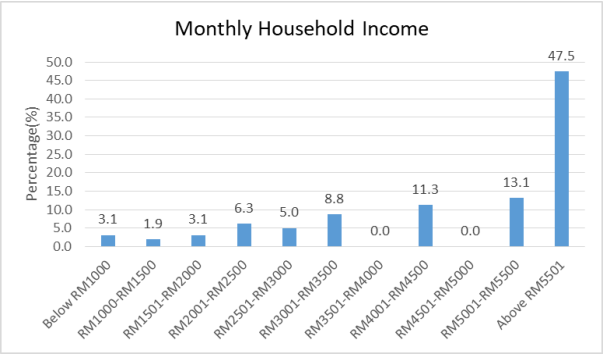

Figure 3. Average monthly household income

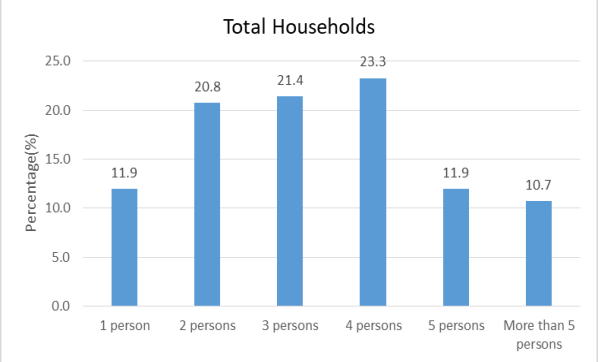

Figure 4. Total households per house

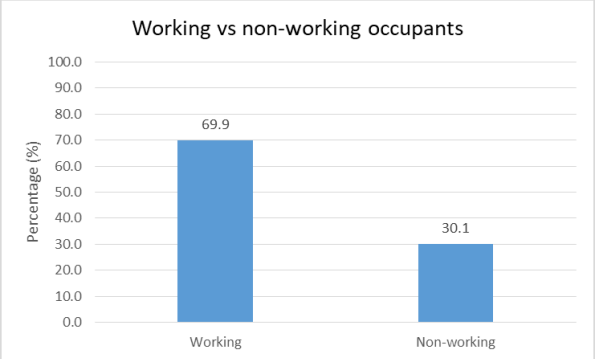

Figure 5. Ratio of working and non-working households

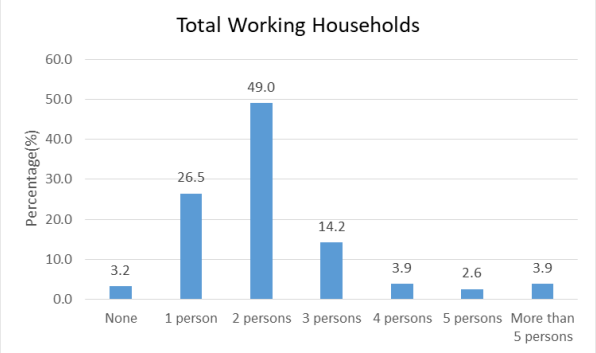

Figure 6. Total working households

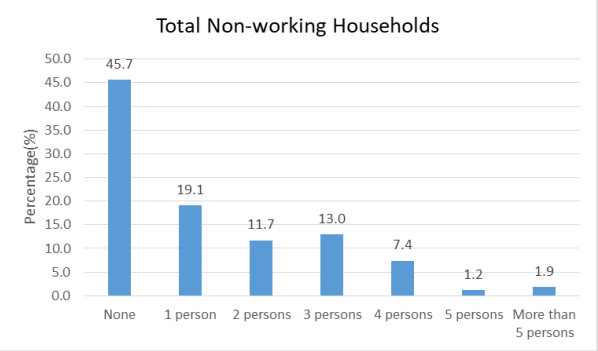

Figure 7. Total non-working households

House Characteristics and Occupancy

The targeted approach of the survey was characterised by the apartment type located in the urban context. Klang Valley is considered the most populated area with high density and fast-paced development in terms of location. On the other hand, most areas in Sarawak are less populated and have a slow-paced development. Therefore, the micro-climates of these two regions are much affected by the Urban Heat Island (UHI) that corresponds to the physical contexts of its climatic conditions.

All apartments are almost similar in general characteristics. Most units consist of three bedrooms, typical for apartment housing in Malaysia (Figure 8). The layouts are generally similar and repeated from floor to floor without considering the best orientation to reduce the impact of solar radiation. In Figure 9, it shows that most respondents owned their houses, followed by rent with non-family and rent with family, with 43.8%, 31.3% and 25%, respectively. The correlation of Kendall's Tau-b reveals that this variable has a negative and weak relationship (-0.176 at 0.05 level) with the monthly electricity bill.

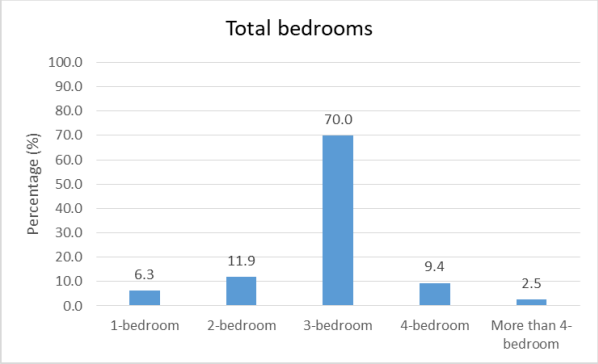

Figure 8. Total bedrooms

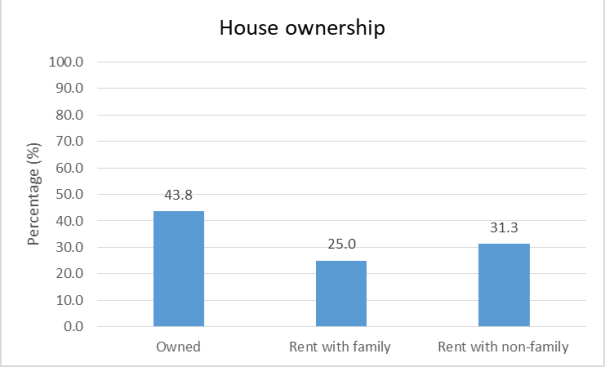

Figure 9. House ownership

The occupancy during weekdays is significantly lower by 15.6% than at weekends (Figure 10), where the difference could be observed during office hours between 7.00 am to 7.00 pm. This is due to several factors discussed under the demographic section, such as total working and non-working households. However, during weekends, the percentage indicates a slight reduction of non-occupancy, determining they did not entirely spend their time at home.

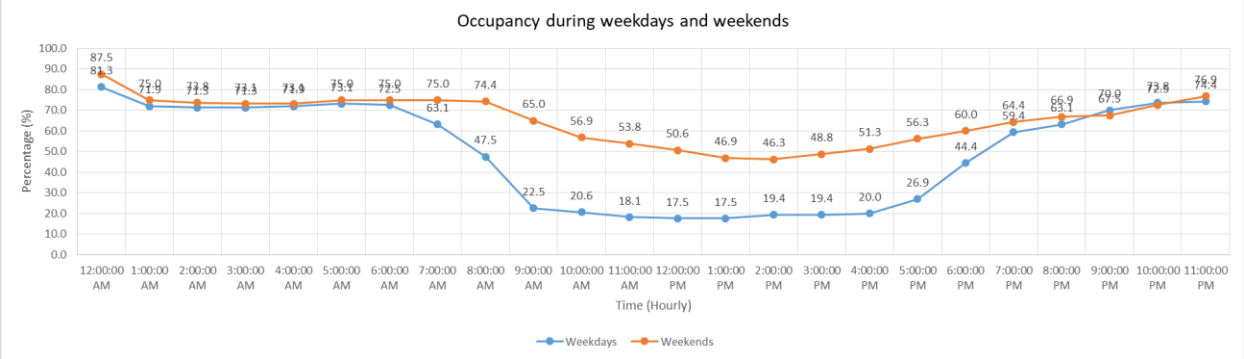

Figure 10. Occupancy during weekdays and weekends

Window Opening

The overlapping occupancy and window opening profiles indicate the occupants' preference to open the window throughout the daytime, although they were unoccupied during working hours and reduced throughout the nighttime (Figure 11). The main reasons to open the window are due to mainly 'to provide fresh air into the house' (86.3%), 'followed by to remove bad odour' and 'to provide cooling temperature' (both are 55.6%), and 'to remove humid air' (53.1%). On the other hand, the main reasons to close the window are due to insects (56.3%), rain (53.1%), privacy (51.9%), and AC usage (41.9%), as shown in

Figure 12(b). These data are relatable to Malaysia's geographical and cultural context that affects their lifestyles and behaviour.

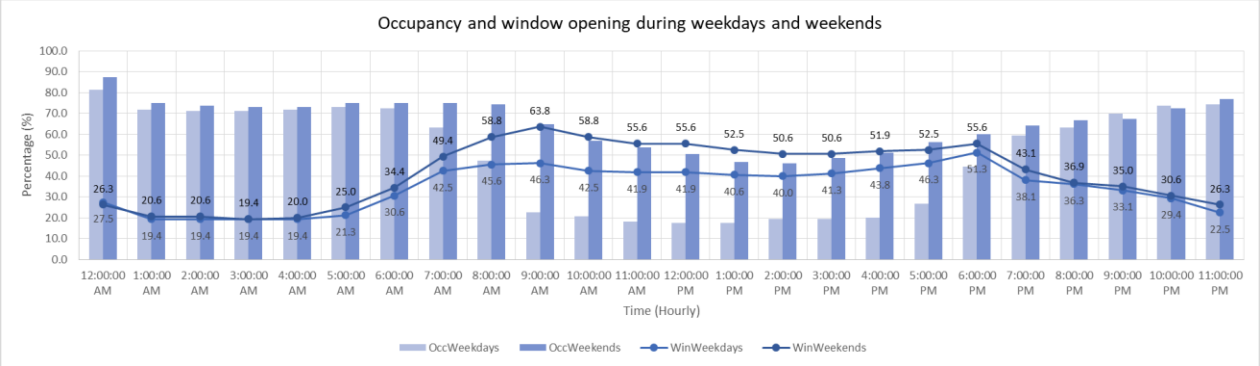

Figure 11. Occupancy and window opening pattern during weekdays and weekends

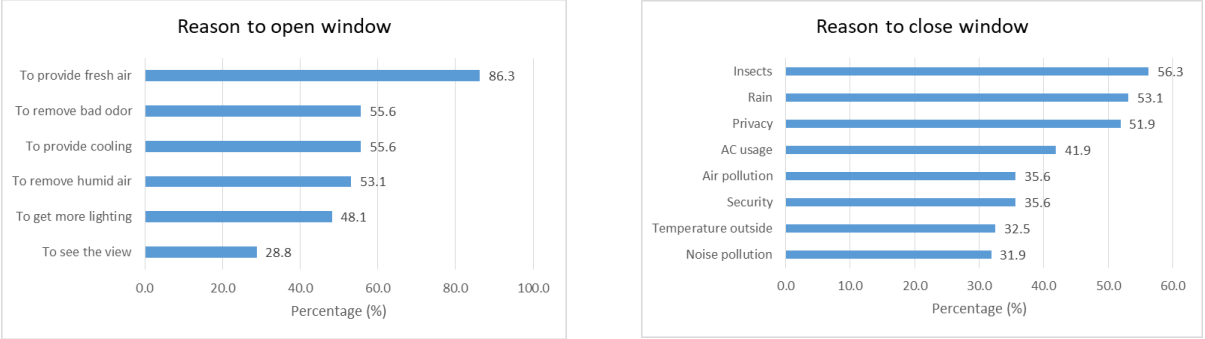

Figure 12. (a) Reasons to open window **(b)** reasons to close window

Fan and Air-Conditioning Usage

Fan usages during weekdays are lower than at weekends by 12.7%, where it is significantly reduced during office hours between 7.00 am and 7.00 pm on weekdays (Figure 13). However, the usages during weekends are quite constant, with an average of 55.3%, which determines the existence of households during this duration. Whilst, the AC usages during weekdays and weekends are similar in pattern or profiles (Figure 14). The usages are quite high at night with 32.4%, compared with daytime with only 9.5%. The lowest usages are from morning until late afternoon, before increasing gradually from 7.00 pm until midnight. This data supports [29] and [30] findings that AC usages in Malaysia are significantly higher during nighttime. In conclusion, fan usages are higher than AC usage, with an average of 48.9% and 21.75%, respectively, to indicate that simple mechanical cooling aid is still a priority or preference for the occupants.

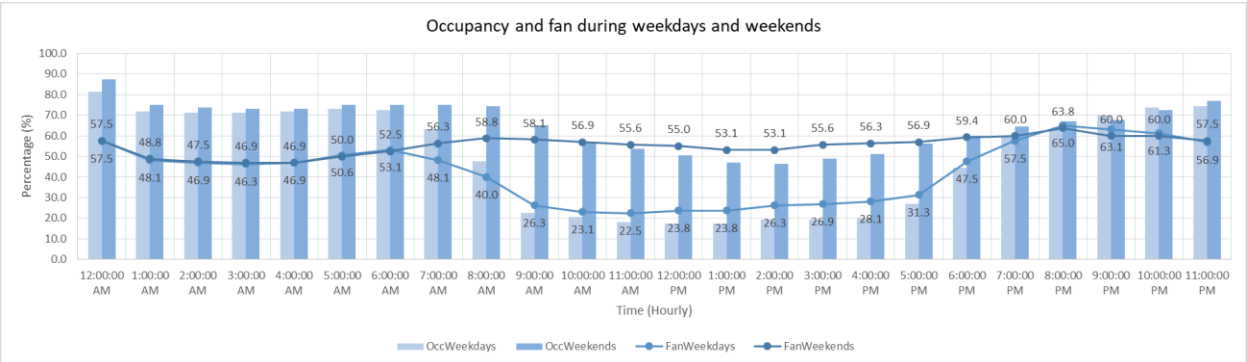

Figure 13. Fan usage during weekdays and weekends

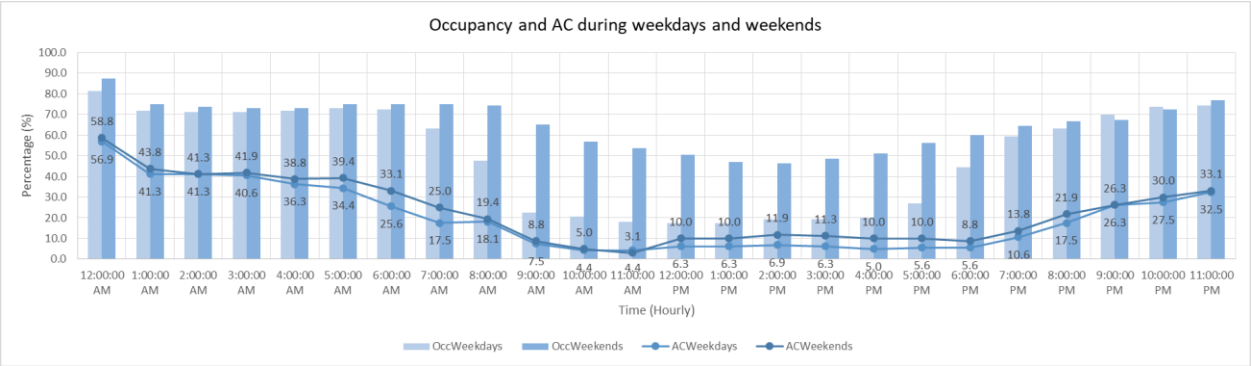

Figure 14. Air-conditioning usage during weekdays and weekends

Statistical Analysis

Table 2 summarises the relationships of variables from Pearson Correlation. From eleven variables, based on the relationship indicator levels [31], it reveals that the total bedroom, the total number of non-working occupants and AC usage during weekdays and weekends are moderately correlated with monthly electricity bills. On the other hand, the total number of occupants and occupancy during weekdays have weak relationships with the monthly electricity bills. Furthermore, there are no relationships or negligible for other variables. From this analysis, it could be concluded that the occupied houses depending on the number of bedrooms with non-working occupants, tend to use more AC. for space cooling, thus increasing household energy consumption.

Table 2. Relationship of variables from Pearson Correlation

Variables (n:160)	Monthly electricity bill			
	Pearson Correlation	Sig. (2-tailed)	Significant	Relationship
Total Bedroom	.387**	0.000	/	Moderate
Household Income	.177*	0.025	X	Negligible
Total Occupants	.262**	0.001	/	Weak
Working Occupants	-.158*	0.046	X	Negligible
Non-working Occupants	.437**	0.000	/	Moderate
Occupancy Weekdays	.232**	0.003	/	Weak
Occupancy Weekends	0.043	0.590	X	No
AC Weekdays	.536**	0.000	/	Moderate
AC Weekends	.451**	0.000	/	Moderate
Fan Weekdays	0.110	0.166	X	No
Fan Weekends	-0.007	0.932	X	No
**. Correlation is significant at the 0.01 level (2-tailed).				
*. Correlation is significant at the 0.05 level (2-tailed).				

CONCLUSION

From the study of occupants' energy-use behaviour in apartment buildings in Malaysia, there are several key findings identified as follows:

- Energy consumption in apartment buildings is relatively low and was not affected by the total household incomes.
- The household size is within the average size, where most of them are working occupants and left the house unoccupied mostly during working hours of the weekdays to justify the reason why the average energy consumption is low.
- The total number of bedrooms is moderately correlated with energy consumption, while the house's ownership status has a weak and negative correlation with the total consumption.
- Most occupants preferred to leave the window open throughout the daytime for the fresh air, remove the bad odour and cool the indoor temperature, even the house was unoccupied while they were working. However, they prefer to close the window during the night due to insects, rain, privacy, and AC usage.
- The fan is the major preference for the occupants as a cooling aid and is mainly used throughout the day and night. In contrast, AC. is preferred during the night, especially before or during sleeping hours.
- From many key variables tested, only the total number of bedrooms, total non-working occupants, and AC usage are identified to have moderate relationships with total energy consumption.

The key findings conclude occupants' tendencies to fulfil their needs in achieving indoor thermal comfort contributed to high energy consumption even with the passive solutions applied. This information is important for the architects, the policymakers and the key people in the building industry to utilise as the input for more appropriate design solutions or strategies in consideration of occupants' behaviour, especially in new apartment buildings. As a gap, it is recommended for future research to focus on the more in-depth study of occupants' behaviour in urban residential buildings in East Malaysia, not only in Sarawak but also in Sabah, to represent the entire Malaysia.

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