

USAGE PATTERNS OF HOUSEHOLD APPLIANCES AND ENERGY-SAVING EFFECTS BY REDUCING AIR-CONDITIONING IN RESIDENTIAL BUILDINGS OF MALAYSIA

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1. Introduction

Most of the countries that continue to experience rapid urbanization and population growth today are seen in developing world. The energy consumption in these countries has shown tremendous increase over the last few decades. For instance, the nationwide final energy demand in Malaysia has increased fivefold over the last two decades¹⁾, while the total population has doubled in the past 30 years from 10.4 million in 1970 to 22.2 million in 2000²⁾. The household energy consumption has been studied intensively in many countries, especially in the developed world. Though investigations in the above subject can also be seen in the developing world, it is still hard to find reliable data that reveal the detailed profile of household energy consumption.

The majority of the towns in Southeast Asia experience hot-humid climate all the year round. In order to cope with this climatic condition, Malaysian vernacular houses for example, which are widely known as the Malay house, have employed lightweight materials such as wood and thatch for their building construction and utilize natural ventilation properly. However, the above traditional Malay houses are rarely seen in urban areas, though many of them still exist in its rural areas. A large amount of the modern houses in Malaysian urban areas is brick and concrete houses. According to the national census²⁾, about 85% of the existing housing stocks in urban areas are brick or brick and plank houses. These brick modern houses basically require air-conditioning to cope with the local tropical climate unlike the traditional wooden houses. In fact, the results of national census²⁾ showed that the total number of households with air-conditioning in Malaysia has dramatically increased from 13,000 in 1970 (0.8%) to 229,000 in 1990 (6.5%) and 775,000 in 2000 (16.2%). Thus, it is particularly important to understand the detailed energy consumption structure in such modern houses in the tropics, focusing especially on air-conditioning usage.

This study provides the detailed information on household energy consumption in residential buildings of Malaysia. This paper firstly attempts to analyze electricity consumption due to air-conditioning in typical Malaysian residential buildings. Secondly, the detailed usage patterns of air-conditioning are investigated in order to discuss the potential energy-saving means.

2. Outlines of Surveys

In this study, two surveys were conducted in the city of Johor Bahru, Malaysia in different years. The first survey (Survey 1) was carried out from September to October 2004, in order to understand the occupants' behavior about air-conditioning usages in typical Malaysian modern houses³⁾. The second survey (Survey 2) was carried out in October 2009 to reveal the household energy consumption structure in the same residential areas⁴⁾. Johor Bahru is the second biggest city in terms of population size after Kuala Lumpur. The city is located in the southernmost part of the Peninsular Malaysia with a population of about one million as of 2000²⁾. Most of the urban residential areas in Malaysia are composed of homogeneous large-scale housing estates and the terraced house is the most common housing type. It accounts for 44% of the total housing stocks in urban areas in 2000²⁾ (Fig. 1).

Both surveys were conducted in the same housing estates in Johor Bahru. Three typical housing estates,

*Keywords: Household energy consumption, Energy-saving, Air-conditioning, Tropics, Malaysia

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namely BBU, TD and TMR, were selected for the surveys by considering their locations and established years (Table 1). These surveys were based on face-to-face interview using questionnaire form. Survey 1 included about 800 households and a total of 366 responses were obtained with the average response rate of 45%, while 388 responses were interviewed with the average response rate of 34% in Survey 2. The households were selected to cover a wide range of income groups in both surveys. Data for the following questions were collected in Survey 1; (1) usage patterns of air-conditioning, (2) usage patterns of windows, and (3) usage patterns of ceiling fans, etc. Meanwhile, the following information were obtained through Survey 2; the ownership and usage time of household appliances, the electric capacity of appliances, and the household electricity and gas consumption, etc.

3. Results and Discussion

(1) Household Characteristics

In Survey 1, the respondents comprise 64% of Malays, 28% of Chinese and 7% of Indians, which nearly correspond to the nationwide average proportion. The average household size was 5.4 persons. The age of household head was 45 years old on average. The average number of workers in household was 2.1. The respondents had an average of 2.4 children per household. About 70% of the respondents answered that at least one of the household members stays at home even during the daytime on weekdays, while the corresponding frequency for the weekends is about 80%.

The demographic profile of the respondents in Survey 2 shows the similar information with that in Survey 1. The respondents comprise Malays (67%), Chinese (24%) and Indians (8%). The average household size was 4.6 persons. The average staying duration of households was about 15.4 hours per day on weekdays, while it was 20.4 hours on weekends. The houses of the respondents comprise 51% of one-storey and 49% of two-storey buildings, with an average of 3.3 bedrooms. They were all terraced houses.

(2) Usage of Household Appliances and Their Electricity Consumption



Fig. 1. Terraced house area

Table 1. Summary of survey areas

	BBU	TD	TMR	Total
Established year	1980s	1990s	2000s	-
Distance from CBD	8 km	12 km	19 km	-
Survey 1 (2004)				
No. of responses	144	147	75	366
Response rate	44%	45%	47%	45%
Survey 2 (2009)				
No. of responses	136	103	99	388
Response rate	41%	24%	45%	34%

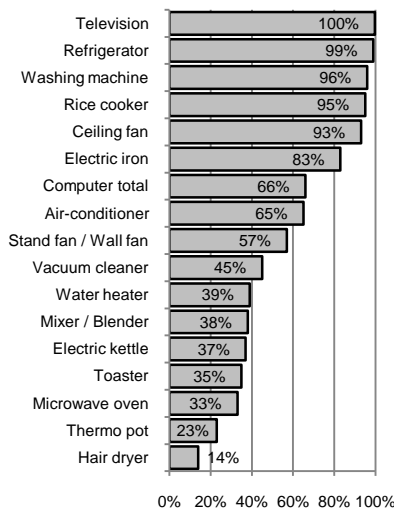


Fig. 2. Ownership level

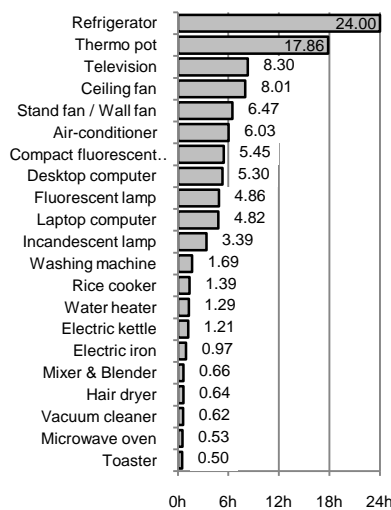


Fig. 3. Daily usage time

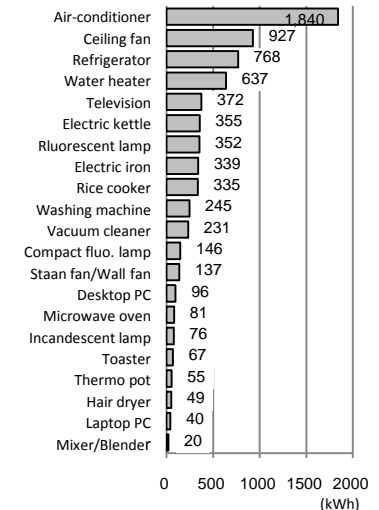


Fig. 4. Yearly electricity consumption

Fig. 2 indicates the ownership level of household appliances surveyed in 2009. As shown, almost all the respondents own at least one unit of the first 5 items; television (100%), refrigerator (99%), washing machine (96%), rice cooker (95%) and ceiling fan (93%). The air-conditioner ownership level was found to be 65%. As shown, about 57% of the respondents use stand or wall fans on the other hand. Fig. 3 shows the averaged daily usage time of respective appliances. The usage time for ceiling fan is about 8 hours, while the same for air-conditioning is about 6 hours per day. Incandescent lamps were found to be installed in the bathrooms and therefore the usage time for them is relatively shorter compared with the other lamps.

The averaged yearly electricity consumption was calculated for each appliance based on the number, usage time and electric capacity of the items (Fig. 4). As explained before, Malaysia experiences hot-humid climate all the year round and the monthly mean air temperature and humidity are almost constant in most of the towns. Thus, in this paper, the usage pattern of household appliances was assumed to be constant throughout the year. The results show that the air-conditioners are the biggest contributor, which record the averaged electricity consumption of 1,840 kWh.

It should be noted that the above electricity consumption caused by air-conditioning is averaged between air-conditioner owners (65%) and non-owners (35%). The above high electricity consumption for air-conditioning is, therefore, not necessarily due to its ownership level but due to their high electric capacity, which is 581W on average, and the long usage time (6 hours). The other important factor is probably its set-point temperature (Fig. 5). As shown, the average set-point temperature was found to be 20.8°C, while more than 15% of the respondents set the temperature to be 16-17°C, which is considered the lowest set-point.

(3) Household Energy Consumption

The averaged yearly household energy consumption including electricity and gas was estimated in joule (J). Gas consumption (LPG) was calculated based on the frequency of refilling cooking gas cylinder. None of the households used gas for water heating – some of them used electric water heater instead (see Fig. 2). The averaged yearly household energy consumption among the respondents was found to be 24.5 GJ with the standard deviation of 10.5 GJ (Fig. 6). As shown, the cooking gas (26%) is the largest contributor, followed by air-conditioners (17%), ceiling fans (10%) and refrigerator (9%), etc. The energy consumption for cooking accounts for 45% in total, while that for cooling is 29%.

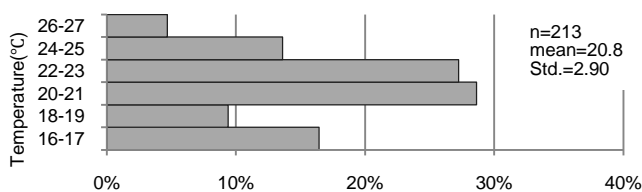


Fig. 5. Set-point temperature for air-conditioners

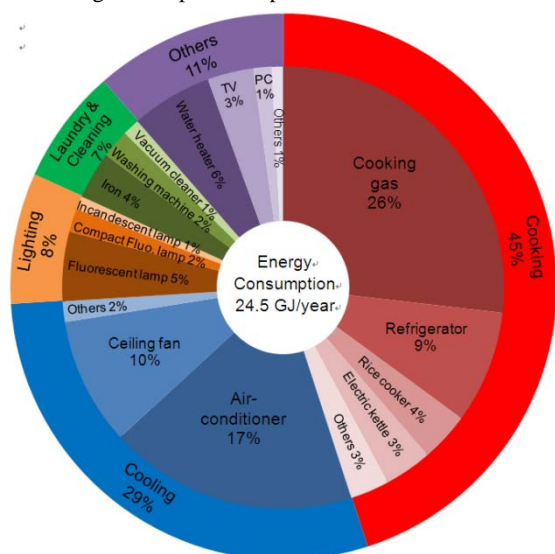


Fig. 6. Yearly household energy consumption

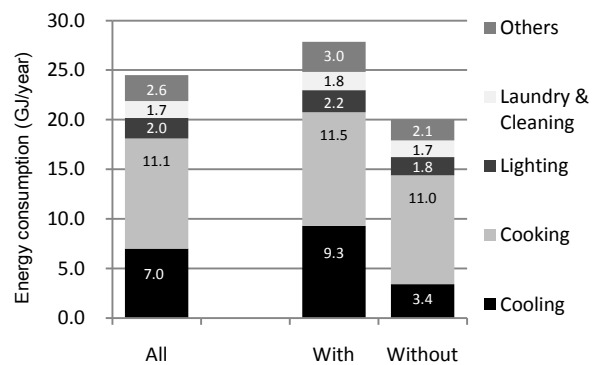


Fig. 7. Energy consumption with/without air-conditioner

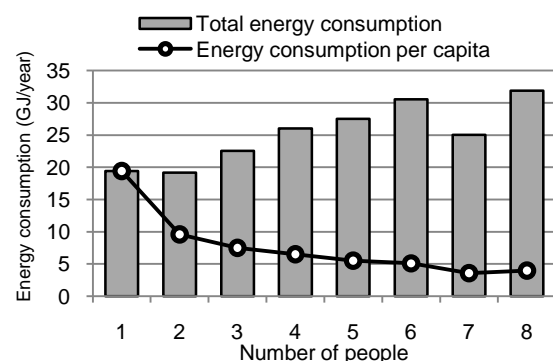


Fig. 8. Energy consumption by household size

Fig. 7 analyses the difference of yearly energy consumption between the households with air-conditioning and those without it. As expected, the averaged yearly household energy consumption for the respondents with air-conditioning is 1.4 times larger than that for non-owners in total. This clearly indicates that the reduction of air-conditioning usage would be one of the most effective means for achieving energy-saving objectives in modern Malaysian houses.

Fig. 8 shows the yearly household energy consumption by the household size. As indicated, the household energy consumption increases with the increase of household size, except for the households with 2 and 7 persons. In this figure, it is appealing to see that the energy consumption for single-person households is slightly higher than that for the households with 2 persons. This is probably because relatively large houses, which have more than two bedrooms, are provided even for the single-person households in Malaysia. This tendency is not seen in Japan, for example, in which much smaller houses (special units) are normally provided for the single-person households.

(4) Usage Patterns of Cooling Appliances

The air-conditioner ownership level surveyed in 2004 was found to be 62%, which is a little lower than the above newly conducted survey (Fig. 9). As shown, almost all the households with air-conditioning (99%) own ceiling fans at the same time. The results showed that there is a clear relationship between the monthly household income and air-conditioner ownership. The higher the income the more air-conditioners they have. These air-conditioners have been installed mainly in their bedrooms (Fig. 10). As shown, about 94% of the respondents installed air-conditioners in their master bedroom first, followed by other bedrooms (52%).

Fig. 11 indicates the hourly frequencies of operating air-conditioning during the day by the respondents. As indicated, only 10% of the owners operate air-conditioning during the daytime. However, its percentage increases from 7 p.m. and reaches 80% by 11 p.m. It should be noted that more than 50% of the owners continue to use air-conditioning throughout the night until 5 a.m. The average usage time for air-conditioning was found to be 7.6 hours per day, which shows slightly longer time than the newly conducted survey (6.0 hours). As described above, most of the owners have installed air-conditioners in bedrooms and operate them at night. Therefore, it is easily considered that most of them use air-conditioning during the sleep.

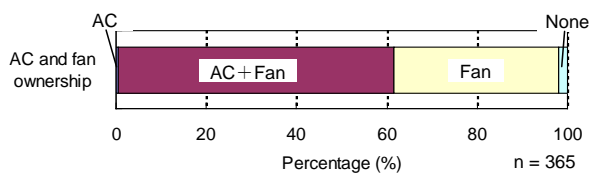


Fig. 9. Air-conditioner and ceiling fan ownership

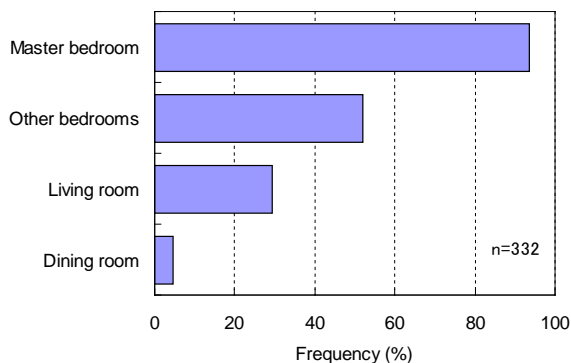


Fig. 10. Rooms in which air-conditioners are installed

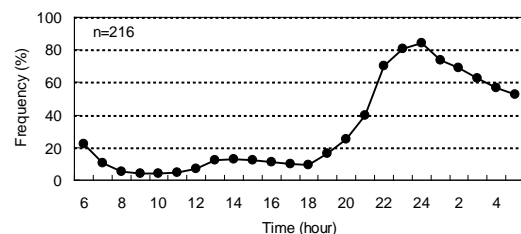


Fig. 11. Usage pattern of air-conditioning

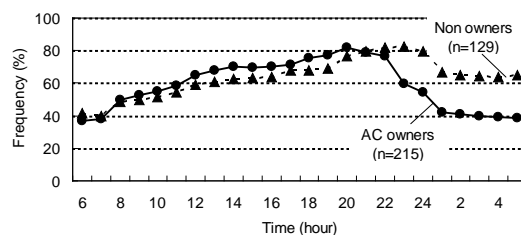


Fig. 12. Usage pattern of ceiling fans

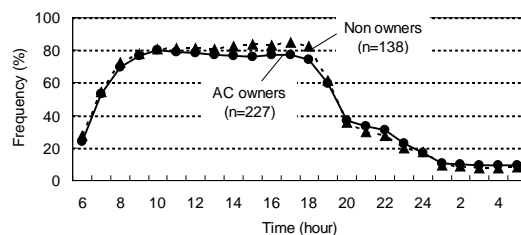


Fig. 13. Window opening pattern

In this survey, the ceiling fan ownership level was found to be 98% (see Fig. 9), which was 93% in the newly conducted survey (see Fig. 2). They have installed fans accordingly in the living room (96%), master bedroom (73%), other bedrooms (58%) and dining room (39%). Fig. 12 illustrates the hourly frequencies of operating ceiling fans during the day. As shown, there is a difference in the usage patterns between air-conditioner owners and its non-owners. More than 60% of non-owners continue to operate ceiling fans throughout the night until 5 a.m., while only 40% of the owners practice it. The average usage time for ceiling fans was found to be 14 hours for air-conditioner owners, while that for the non-owners was 15 hours.

(5) Window Opening Pattern

Fig. 13 shows the results of hourly frequencies of opening windows during the day for air-conditioner owners and its non-owners. Interestingly, an evident difference is not seen in the usage patterns of windows between the two groups. As shown, about 80% of the respondents usually open windows from 10 a.m. to 6 p.m. The frequency, however, gradually declines from 7 p.m. and drops to about 10% from 1 a.m. to 5 a.m. It is found that most of the occupants tend to open windows during the daytime and close them during the night-time regardless of the air-conditioner ownership. Further results showed that the main reasons for not opening windows were the entry of insects (38%), followed by security (35%), rain (22%) and dust (18%), etc. Although “insects” was recorded as the most significant reason, it was found that insect screens have been installed by only 1% of the respondents.

4. Conclusions

- (1) The results of the newly conducted survey revealed the household energy consumption structure in typical modern Malaysian houses. In this survey, the air-conditioner ownership level was 65% and its usage time was 6 hours on average. Even when non-owners of air-conditioners were included in the analysis, the yearly electricity consumption caused by air-conditioning recorded the largest amount, which was 1,840 kWh/year. It was found that the above high electricity consumption for air-conditioning is not necessarily due to its ownership level but due to their high electric capacity and the long usage time. In addition, very low set-point temperatures for air-conditioning practiced by the Malaysian residents were considered one of the important factors that increase the electricity consumption.
- (2) The averaged yearly household energy consumption among the respondents was found to be 24.5 GJ. In this survey, the cooking gas (26%) was conceived as the largest contributor, followed by air-conditioners (17%), ceiling fans (10%) and refrigerator (9%), etc. The energy consumption for cooking accounted for 45% in total, while that for cooling was 29%.
- (3) It was seen that the averaged household energy consumption for the respondents with air-conditioning was 1.4 times larger than that for non-owners. This clearly indicates that the reduction of air-conditioning usage would be one of the most effective means for achieving energy-saving objectives in modern Malaysian houses.
- (4) The detailed daily usage patterns of cooling appliances were revealed in another survey. The results showed that most of the air-conditioner owners have installed them in bedrooms and operate them at night during the sleep. The results also showed that they tend to open windows during the daytime but close them at night whether they have air-conditioners or not.

The authors investigated the thermal conditions in modern Malaysian houses under closed window conditions at night and revealed that the indoor air temperature would reach 30°C on average, which was about 4°C higher than the outdoors⁵. This is mainly due to the high thermal capacity of the building structure and the lack of natural ventilation. These are attributed to the unsuitable design of modern Malaysian houses, which are brick terraced houses. In order to reduce the nocturnal indoor air temperature and therefore discourage air-conditioning usage, passive cooling techniques should be applied to the Malaysian modern houses.

Acknowledgements

This research was supported by grants from the Sumitomo Foundation 2006 and 2009. We would like to express our sincere thanks to Prof. Supian, Prof. Hamdan and Ms. Halimah of *Universiti Teknologi Malaysia* for their generous supports. Last but not least, we sincerely pay a tribute to Mr. Fujita who shared the great experience in Malaysia.

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