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USAGE OF AIR-CONDITIONERS AND WINDOWS IN RESIDENTIAL AREAS IN JOHOR BAHRU CITY: PLANNING METHODS OF COASTAL RESIDENTIAL AREAS IN CONSIDERATION OF WIND FLOW

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ABSTRACT

This study discusses planning methods of residential areas in coastal cities, focusing on the effect of wind flow. This aims to determine strategies that reduce energy consumption in residential areas, targeting especially a reduction in the use of air-conditioners. As a part of the above study, this paper presents the findings of a questionnaire survey on usage of windows and air-conditioners among selected households in apartment houses in Johor Bahru City, Malaysia and compares the results with those in terraced houses surveyed previously.

Keywords: Adaptive behavior, Wind flow, Energy-saving, Energy consumption, Coastal areas

1. Introduction

The world crude oil price has been continuing rise and it has been badly affecting Southeast Asian economies. Moreover, the threat of global climate change requires all countries to take immediate actions for tackling global warming. Many cities in Southeast Asian countries are located in coastal areas. Since coastal areas receive relatively much natural wind such as land and sea breeze, it is important to consider planning methods to utilize such natural wind in order to help achieve energy-saving objectives and reduce emissions of green house gases.

The main purpose of this study is to discuss planning methods of residential areas in coastal cities, focusing on the effect of wind flow. This aims to determine strategies that reduce energy consumption in residential areas, targeting especially a reduction in the use of air-conditioners. As a part of the above study, this paper presents the findings of questionnaire surveys on usage of windows and air-conditioners among selected households in residential areas in Johor Bahru City, Malaysia.

The surveys on residential energy use have been carried out by many researchers in various countries for a long time. There have been similar studies regarding energy usage in residential buildings (e.g. Unander et al., 2004; Tso et al., 2003). The above papers are an excellent source of information for understanding the structure of residential energy use in respective cities. However, it was suggested that although ownership and energy consumption data of appliances easily can be seen in the literatures, usage patterns of household appliances have received less attention (Mansouri et al., 1996). There are also several similar studies on residential energy use in Southeast Asian countries (e.g. Pongsapich et al., 1994; Bensel et al., 1995). The above studies, however, do not particularly deal with the usage patterns of household appliances.

Open windows is defined as one of occupants' adaptive behaviors for thermal comfort in buildings. There is an argument that such adaptive behaviors would strongly affect their thermal sensations especially in naturally ventilated buildings (e.g. Baker et al., 1996; Brager et al., 1998). Several researchers attempted to clarify the above argument (e.g. Feriadi et al., 2004; de Dear et al., 2002). In the above studies, the usage of windows was investigated, but they did not focus especially on it.

The present survey focuses especially on the usage of both air-conditioners and windows in residential areas. This aims to examine the effects of both usages on the increase/decrease of household electricity consumption. The author also carried out a similar questionnaire survey among selected households in terraced houses in Johor Bahru City (Kubota et al., 2005, 2006). This paper presents the results of a questionnaire survey in selected apartment houses and compares the results with those in terraced houses surveyed previously.

2. Methods

2.1. Outline of case study areas

Johor Bahru City is located in the southernmost part of Peninsular Malaysia. It is the second largest city after Kuala Lumpur. Its population size including the conurbations was about one million in 2000. According to the property market report (Malaysia, 2002), terraced houses accounted for about 57% of the total Malaysian housing stock in 2002, followed by apartment houses (25%) and detached houses (11%). Since the majority of housing types in Malaysia was considered to be terraced houses, the previous survey focused especially on them. As the second step, the present survey focuses on apartment houses in particular and compares the results with those in terraced houses.

The previous survey revealed that the "household income" is one of the significant factors affecting "household electricity consumption" (Kubota et al., 2005, 2006). Therefore, the selection of case study areas was taken into account of the average household income. In order to cover respondents with a wide range of household income, five housing estates were selected from Johor Bahru City for the following questionnaire survey (Table 1).

2.2. Data collection

The present questionnaire survey was carried out in five selected housing estates (Case1-Case5) from 29 April to 26 June 2006. Basically, the survey was based on interviews using the questionnaire sheet. Firstly, the letters of requesting cooperation to the survey were distributed to households in selected housing estates at random. Then, on the following weekends, surveyors visited selected households in the housing estates and interviews were made using the questionnaire sheet. However, in Case 4 and 5, since the surveyors were not allowed to enter the housing estates for security reasons, the questionnaire sheets were distributed to the households' postboxes by one of the officer in housing estates at random. In this case, the answers were collected by the officer, one or two weeks after the distribution. The response rates in respective estates are indicated in Table 1. The overall response rate was 22%.

Table 1. Outline of questionnaire survey

Case	Category	Story level	No. of blocks	No. of households	Survey period	No. of visited households	No. of responses	Response rate (%)	Mean household income (RM)
1	Flats	5	9	496	6–7 May	496	103	21	1,711
2	Flats	5	5	220	14 May	220	63	29	2,194
3	Apartment	5	19	630	29–30 April	270	73	27	3,838
4	Condominium	17	2	550	15 May–1 June	300	39	13	3,314
5	Condominium	20	2	170	5 Jun–26 June	125	28	22	6,007
Total		–		2,066	–	1,411	306	22	2,835

The questionnaire consisted of 32 questions and requirements. The main questions are summarized as follows:

(1) Profile of respondents.
(2) Frequency and duration of operating air-conditioners.
(3) Frequency and duration of opening windows.
(4) Frequency and duration of operating ceiling fans.
(5) Monthly household electricity consumption.

Electricity consumption data were gathered by investigating respondents' electricity bills through the interview. Although monthly electricity data over the past 12 months were required, not many respondents have kept the required electricity bills. In this case, the surveyors questioned the respondents on the mean monthly electricity fee based on their remembrance. After that, the mean monthly electricity consumption was predicted by the above reported electricity fee using the electricity tariff.

3. Results and discussion

3.1. Profile of respondents

Malaysians mainly consist of three ethnic groups, namely Malay, Chinese and Indian. The proportion of these ethnic groups in this survey was similar with the national approximate average; 65% of respondents were Malays, 24% were Chinese and 9% were Indians, respectively. The average household size of respondents was 4.6. The average age of householder among respondents was 41 years old. They had an average of 1.7 workers and 1.7 children in household. The percentage of households with older person (above 60 years old) was only 9.9%. Around 60% of respondents owned their houses, while 38% were living in rented houses. The percentage of the above house ownership is relatively lower by 18% than that in terraced houses surveyed previously.

3.2. Usage of air-conditioners

The present survey shows that approximately 36% of the respondents owned at least one air-conditioner (Fig.1). This air-conditioner ownership is much lower than that in terraced houses (62%) surveyed previously. The previous survey showed that there was a clear relationship between the household income and the air-conditioner ownership. Similarly, the present survey also showed that there is a clear relationship between the two variables (Fig.1). It indicates that the more monthly income they earn, the more air-

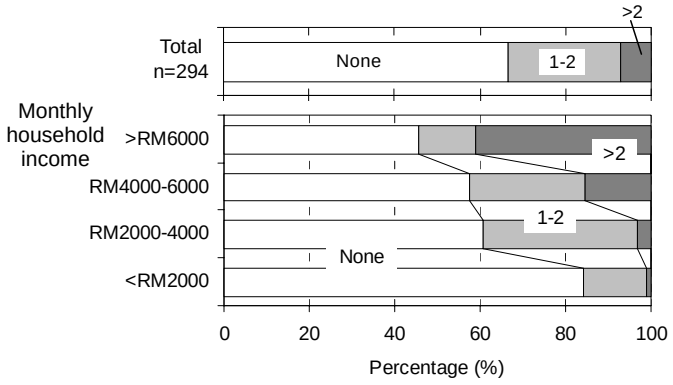
conditioners they have. Therefore, the air-conditioner ownership in Malaysian apartment houses is also expected to further rise according to the economic growth in the near future.

The average number of air-conditioners among their owners was 1.9 units per household, which is lower by 0.4 units than that in terraced houses. The air-conditioner owners have installed their air-conditioners in respective rooms in the following order; master bedroom (92%), other bedrooms (40%), living room (32%) and dining room (7%). Since the owners have installed their air-conditioners mainly in their bedrooms, it is considered that they use air-conditioners as a cooling appliance especially for sleeping.

Fig.2 indicates the hourly frequency of air-conditioner owners who operate air-conditioners during the day. Since the purpose of this question was to examine general situation of operating air-conditioners in the whole dwellings, it did not specify particular rooms, e.g. living room, bedrooms etc. As indicated in Fig.2, only 10% of their owners operate air-conditioners during the daytime. However, its percentage rose during the evening from 7pm and reached 79% at 11pm. It should be noted that more than 50% of their owners continue to use air-conditioners during the whole nighttime until 5am. Fig.3 shows the time period of operating air-conditioners per day. The average time period is 7.1 hours, while the average value in terraced houses was 7.6 hours.

3.3. Usage of windows

Fig.4 indicates the hourly frequency of respondents who open their windows during the day. The result shows that nearly 80% of respondents usually open their windows during the daytime from 9am to 7pm. The frequency, however, gradually dropped from 8pm and reached around 30% from 1am to 5am. The frequency during the nighttime is higher by 20% than that in terraced houses, which was around 10%,



Note: chi-sq. = 66.1 with 6 DF, significant at 1% level

Fig.1. Number of air-conditioners by monthly household income

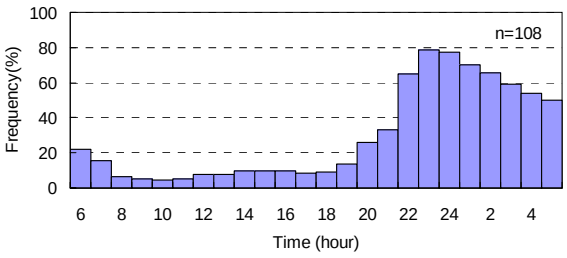


Fig.2. Frequency of operating air-conditioners during the day

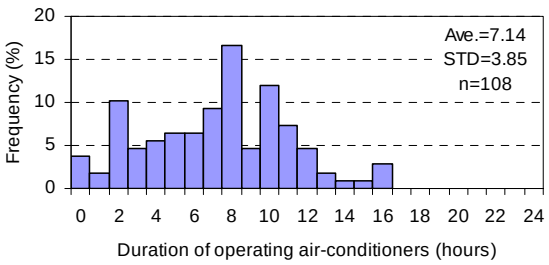


Fig.3. Duration of operating air-conditioners per day

surveyed previously. This indicates that more occupants in apartment houses tend to open their windows during the nighttime than those in terraced houses. Fig.5 shows the time period of opening windows per day. The average time period is 13.9 hours. This is longer by 2 hours than that in terraced houses surveyed previously. Compared to the answer obtained in terraced houses, although the peak of the graph is observed at the similar point of around 13 hours, in apartment houses, fewer respondents (2%) do not open their windows at all (0 hour) and more respondents (11%) do so during the whole day (24 hours).

In the previous survey in terraced houses, it was found that the air-conditioner ownership was not necessarily related to the occupants' behavior for opening the windows. This indicated that whether or not the households owned air-conditioners, they tended to open their windows during the daytime and close them during the nighttime. The similar tendency was found in the present survey in apartment houses according to the following analysis.

Firstly, the answer for "frequency of open windows (Fig.4)", which consists of 303 responses, were divided into the following two groups: air-conditioner owners (n=107) and its non-owners (n=196). After that, the answers of two groups were compared and analyzed. As a result, the significant difference was not found between the two groups of answer. This indicates that the usage patterns of windows are almost same between air-conditioner owners and its non-owners. Secondly, the simple regression analysis was attempted between the "duration of operating air-conditioners" and the "duration of open windows (Fig.5)". As a result, a clear relationship between the two

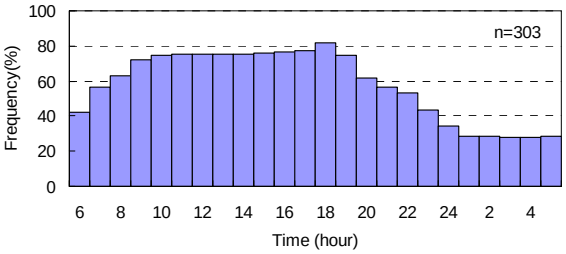


Fig.4. Frequency of open windows during the day

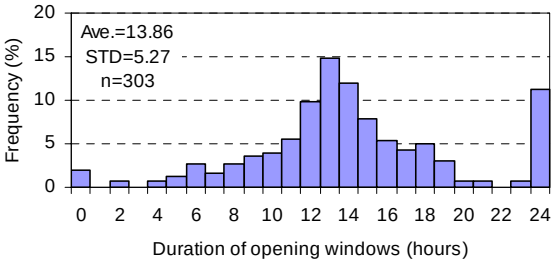


Fig.5. Duration of open windows per day

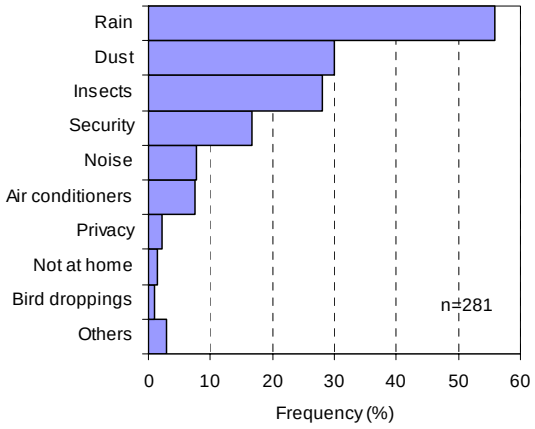


Fig.6. Reasons for not opening windows

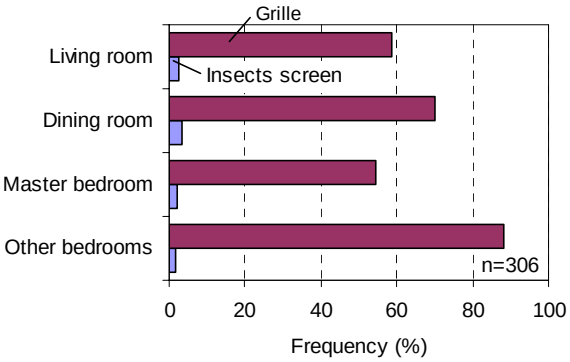


Fig.7. Window devises in each room

variables was not found in this survey (r=0.12). Therefore, in the present survey, it also can be concluded that the air-conditioner ownership is not necessarily related to the occupants' behavior for opening the windows.

Fig.6 illustrates the main reasons for not opening windows. Approximately 56% of the respondents answered "rain" as the main reason, followed by "dust (30%)", "insects (28%)" and "security (17%)" etc. These answers show different tendency compared to the previous survey conducted in terraced houses. The answer surveyed in terraced houses was as follows; insects (38%), scurity (35%), rain (22%), dust (18%) and air-conditioners (13%) etc. As indicated above, the percentage of "insects" and "security" in apartment houses obtained lower values than those in terraced houses. By contrast, the percentage of "rain" and "dust" recorded higher values than those in terraced houses.

Fig.7 indicates the frequency of respondents who have installed window devises. Although more than 80% of the respondents have installed window grilles on their windows in "other bedrooms", the frequency in other rooms, i.e. living room, dining room and master bedroom, are not so high as indicated in Fig.7. In terraced houses, its percentage was nearly 90% in all the rooms.

3.4. Usage of ceiling fans

In Malaysia, most houses are equipped with ceiling fans from its construction phase. In this survey, 92% of the respondents owned at least one ceiling fan. The average number of ceiling fans among their owners was 2.8 units, while the average number in terraced houses was 3.9 units surveyed previously. They have installed ceiling fans in respective rooms in the following order; living room (97%), master bedroom (66%), other bedrooms (49%) and dining room (36%). Although most respondents installed their air-conditioners in their bedrooms for sleeping as described in the section 3.2, ceiling fans tend to be installed in their living room.

Fig.8 illustrates hourly frequency of respondents who operate ceiling fans during the day. As indicated in Fig.8, higher frequency of around 80% was recorded during the evening from 7pm to 10pm. The frequency is relatively high during the whole day compared to that of operating air-conditioners (Fig.2). Even during the nighttime, its frequency recorded around 40%.

Fig.9 indicates the time period of operating ceiling fans per day. As indicated in this figure, approximately 11% of the respondents operate their ceiling fans during the whole day (24 hours). The average time period is 14.0 hours, which is nearly two times longer than that of air-conditioners (Fig.3).

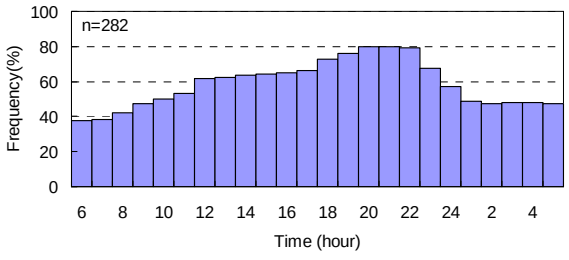


Fig.8. Frequency of operating ceiling fans during the day

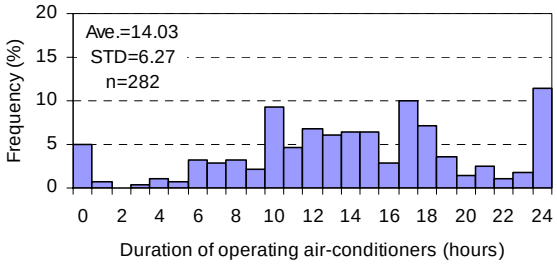


Fig.9. Duration of operating ceiling fans per day

Table 2. Correlation coefficients between selected variables and mean monthly household electricity consumption

Variables	r-value	Sig.
Number of air-conditioners	0.52	**
Duration of operating air-conditioners	0.50	**
Household income	0.41	**
Number of bedrooms	0.31	**
Number of water heaters	0.23	**
Number of ceiling fans	0.21	**
Duration of staying home	0.21	**
Household size	0.19	**
Floor level	0.19	**
Year of stay	0.05	
Duration of opening windows	0.03	
Duration of operating ceiling fans	0.02	

*=significant at 5% level; **=significant at 1% level

Table 3. Coefficients of variables included in regression equation

Independent variables	Unstandardized coefficient	Standardized coefficient	Significant
x_1: Number of air-conditioners	32.62	0.20	**
x_2: Duration of air-conditioners	14.09	0.30	**
x_3: Household income	0.018	0.20	**
x_4: Number of bedrooms	44.47	0.12	*
Constant	54.67		
Coefficient of determination (R^2)	0.38		

*=significant at 5% level; **=significant at 1% level

3.5. Electricity consumption among households

The mean monthly household electricity consumption among respondents is 282kWh. This is much lower than that in terraced houses surveyed previously, which was 455kWh. In order to examine the determinants of the above mean monthly household electricity consumption, a multiple regression analysis was attempted as shown below.

Table 2 indicates results of correlation analysis between selected variables and mean monthly household electricity consumption. The highest r-value of 0.52 was obtained between the “number of air-conditioners” and the “household electricity consumption”, followed by “duration of operating air-conditioners (0.50)”, “household income (0.41)”, “number of bedrooms (0.31)” etc. Secondly, several significant variables with relatively higher r-value were selected from Table 2 and multiple regression analysis was made by using the above selected variables. Table 3 indicates the coefficients of all variables included in the regression equation.

According to the regression equation, the coefficient of determination (R^2) was 0.38. Thus, more than 38% of the spatial variation of mean monthly household electricity consumption to the case study areas can be explained by the model. As indicated in Table 3, the standardized coefficient is the highest in “duration of operating air-conditioners (0.30)” at 1% significant level, followed by “number of air-conditioners (0.20)”, “household income (0.20)” and “number of bedrooms (0.12)”. This indicates that the reduction of both numbers and use of air-conditioners would be one of the most effective means for achieving electricity saving among households in apartment houses.

3.6. Comparison between results of apartment houses and terraced houses

The main results of the questionnaire survey in both terraced houses and apartment houses are summarized in Table 4. As indicated in Table 4, in terraced houses, the air-conditioner ownership was almost 1.7 times higher than that in apartment houses. As explained in the section 3.2, there is a clear relationship between the household income and the air-conditioner ownership (Fig.1). Thus, the difference of air-conditioner ownership between them is mainly because the average household income in terraced houses was 1.6 times higher than that in apartment houses. However, as indicated in

Table 4. Comparison between results of terraced houses and apartment houses

	Terraced houses	Apartment houses
Survey period	4 Sep – 9 Oct 2004	29 Apr – 26 June 2006
No. of responses	366	306
Response rate (%)	45	22
Household size (persons)	5.4	4.6
No. of bedrooms	3.5	2.7
Age of householder (years old)	45	41
No. of workers (persons)	2.1	1.7
Household income (RM)	4,613	2,835
Duration of staying home (hours)	Weekdays: 19 Weekends: 21	Weekdays: 15 Weekends: 20
Air-conditioner ownership (%)	62	36
Frequency of operating air-conditioners	7am-7pm: <20% 10pm-5am: >50%	7am-7pm: <20% 10pm-5am: >50%
Duration of operating air-conditioners (hours)	7.6	7.1
Frequency of open windows	9am-6pm: 80% 1am-5am: 10%	9am-7pm: 80% 1am-5am: 30%
Duration of open windows (hours)	11.8	13.9
Reasons for not opening windows	1. Insects (38%) 2. Security (35%) 3. Rain (22%) 4. Dust (18%)	1. Rain (56%) 2. Dust (30%) 3. Insects (28%) 4. Security (17%)
Ceiling fan ownership (%)	98	92
Frequency of operating ceiling fans	12am-12pm: >60% 1am-7am: 40%	12am-11pm: >60% 1am-7am: 40%
Duration of operating ceiling fans (hours)	14.5	14.0
Monthly electricity consumption (kWh)	455	282
Determinants of monthly electricity consumption	1. Duration of operating AC 2. No. of AC 3. Household income 4. Site area	1. Duration of operating AC 2. No. of AC 3. Household income 4. No. of bedrooms

Table 4, although the air-conditioner ownership differs between terraced houses and apartment houses, the frequency and duration of operating air-conditioners as well as ceiling fans correspond between them.

The frequency and duration of open windows slightly differ in between terraced houses and apartment houses. It should be noted that the frequency of respondents who open their windows during the nighttime in apartment houses is higher by 20% than in terraced houses. Most respondents in apartment houses live on the upper floor than the ground floor (89%). Thus, the above difference between apartment houses and terraced houses is likely due to the variation of occupants' consciousness towards security based on the difference of floor level. Although the "insects" and "security" were selected with high percentage as main reasons for not opening windows by the respondents in terraced houses, those percentages in apartment houses, especially "security", are much lower than in terraced houses.

The mean monthly electricity consumption among respondents in apartment houses is lower by 173kWh than that in terraced houses. In multiple regression analysis, the significant factors affecting household electricity consumption are almost same in between terraced houses and apartment houses; 1) duration of operating air-conditioners, 2) number of air-conditioners, 3) household income and 4) site area/number of bedrooms. This indicates that the increase of the average electricity consumption by 173kWh in terraced houses was mainly attributed to the changes of the above four factors between them.

4. Conclusions

This paper presented the findings of a questionnaire survey on usage of windows and air-conditioners among selected households in apartment houses in Johor Bahru City, Malaysia and compared the results with those in terraced houses surveyed previously. The main findings are summarized as follows:

(1) In apartment houses, approximately 36% of the respondents owned at least one air-conditioner, which was lower by 26% than that in terraced houses surveyed previously. There was a clear relationship between the household income and the air-conditioner ownership. Thus, the difference of air-conditioner ownership between them was mainly because the average household income in terraced houses was 1.6 times higher than that in apartment houses.

(2) The frequency and duration of operating air-conditioners corresponded in between apartment houses and terraced houses. Only 10% of their owners operated air-conditioners during the daytime. However, its percentage rose during the evening from 7pm and reached 79% at 11pm. More than 50% of their owners continued to use air-conditioners during the whole nighttime until 5am.

(3) The frequency and duration of open windows slightly differed in between terraced houses and apartment houses. It should be noted that the frequency of respondents who open their windows during the nighttime in apartment houses was higher by 20% than that in terraced houses.

(4) In multiple regression analysis, the significant factors affecting household electricity consumption were almost same in between terraced houses and apartment houses; 1) duration of operating air-conditioners, 2) number of air-conditioners, 3) household income and 4) site area/number of bedrooms. The results showed that the reduction of both numbers and use of air-conditioners would be one of the most effective means for achieving electricity saving among households in both terraced houses and apartment houses. The mean monthly electricity consumption among respondents in apartment houses was lower by 173kWh than that in terraced houses. This indicated that the increase of the average electricity consumption by 173kWh in terraced houses was mainly attributed to the changes of the above four factors between terraced houses and apartment houses.

(5) A clear relationship between the “duration of open windows” and the “duration of operating air-conditioners” was not found in both surveys in terraced houses and apartment houses. This indicated that the air-conditioner ownership was not necessarily related to the occupants’ behavior for opening the windows in these surveys. Thus,

although more occupants opened their windows during the nighttime in apartment houses than those in terraced houses, it did not directly contribute to reduce the use of air-conditioners in apartment houses. Therefore, it is especially important to find out the means to reduce both numbers and use of air-conditioners, which have been installed mainly in their bedrooms, directly in order to help achieve energy-saving objectives in Malaysian residential areas.

5. Acknowledgements

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6. References

[1] Baker, N., Standeven, M. (1996) Thermal comfort for free-running buildings, Energy and Buildings 23, 175-182.
[2] Bensel, T.G., Remedio, E.M. (1995) Residential energy use patterns in Cebu city, Philippines, Energy 20(3), 173-187.
[3] Brager, G.S., de Dear, R. (1998) Thermal adaptation in the built environment: a literature review, Energy and Buildings 27, 83-96.
[4] de Dear, R., Brager, G.S. (2002) Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55, Energy and Buildings 34, 549-561.
[5] Feriadi, H., Wong, N.H. (2004) Thermal comfort for naturally ventilated houses in Indonesia, Energy and Buildings 36, 614-626.
[6] Kubota, T., Ahmad, S. (2005) Energy efficient city in Malaysia: wind flow in neighborhood areas, Proceedings of 6th International Seminar on Sustainable Environment and Architecture (SENVER), Institut Teknologi Bangung, Indonesia.
[7] Kubota, T., Ahmad, S. (2006) A field survey on usage of air-conditioners and windows in terraced house areas in Johor Bahru City, Journal of Environmental Engineering (Transactions of AIJ), No.608, pp.81-87 (in Japanese).
[8] Malaysia (2002) Property market report 2002, Ministry of Finance Malaysia.
[9] Mansouri, I., Newborough, M., Probert, D. (1996) Energy consumption in UK households: impact of domestic electrical appliances, Applied Energy 54(3), 211-285.
[10] Pongsapich, A., Wongsekiarttirat, W. (1994) Urban household energy consumption in Thailand, Energy 19, 509-516.
[11] Tso, G.K.F., Yau, K.K.W. (2003) A study of domestic energy usage patterns in Hong Kong, Energy 28, 1671-1682.
[12] Unander, F., Ettestøl, I., Ting, M., Schipper, L. (2004) Residential energy use: an international perspective on long-term trends in Denmark, Norway and Sweden, Energy Policy 32, 1395-1404.