Investigation on Indoor Thermal Satisfaction in the Humid Tropics of Malaysia

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***Abstract*— Reports on occupants' behaviors toward the indoor environment in Malaysia are limited in literature. Occupants are the key element in building thermal design with thermal comfort approach. In naturally ventilated buildings; occupants have some available use of controls to improve their thermal sensation toward the indoor environments, such as open windows, usage of fans, curtains, when necessary. However, many factors may affect occupants 'choices such habits, noise, air quality, acclimatization and others. We analyzed the data from a thermal comfort field study of residential buildings in Kota Kinabalu. Some observations on subject behavior were made. The results also provided insight on people behavior toward the indoor thermal environment in residential buildings.**

Keywords— ***thermal comfort; window; grill; insect screen; subjects; satisfaction; behavior***

I. Introduction

Thermal comfort in buildings affects the health, satisfaction and productivity of the dwellers [1]. It was argued that comfort and adaptation are complementary. Thus adaptation strategies cannot be ignored in thermal comfort studies and retrofitting strategies [2]. For instance, the available opportunities to open window, draw a blind, turn on fan likely helps in reducing thermal stress and widen the range of the indoor thermal requirements [3].

In residentially buildings, occupants have some available use of controls to improve their thermal sensation toward the indoor environments, such as open windows, usage of fans, curtains, and others. However, many factors may affect occupants 'choices such noise, air quality, acclimatization. Understanding the impact of some of these factors will certainly help in improving building design with thermal comfort approach. This is because people behave inside their houses not only for the purpose of feeling thermally comfortable. Among the challenges in the assessment or predicating the indoor thermal comfort of any building is whether to assume windows are closed or opened. More precisely which time of the day windows are usually closed and when are opened. Such information affects the whole building thermal design analysis. This is because cross ventilation affects the indoor temperature. This in turn will affect occupants' thermal comfort. Therefore, the objective of this investigation is to provide some observations on subjects' behaviors toward the indoor environment in residential buildings.

II. Methodology

A field study was carried out to investigate and assess occupants' preference in selecting various behavioral actions to enhance their thermal comfort. The survey was carried out in residential buildings in Kota Kinabalu. After data collection, the result from the questionnaire survey on people behavior inside their dwellings was analyzed. The questionnaire adopted in this part of the study is somehow partly replication from a conducted survey carried out in Johor Bahru city with some changes [4]. Hence comparison between the two findings was made.

III. Analysis of Occupants' Behaviour in Naturally Ventilated Houses

After data collection and preliminary data analyses, the data were plotted into graphs for better interpretation and discussion about the results. The first observation is about people behavior toward open or close window during daytime and night time. Fig 1 shows percentage frequency distribution of the usage and the duration of open windows at various times of the day.

Figure 1 (a) shows that about 90% of occupants in the present study reported open windows from 9 a.m. to 6 p.m., and the percentage reduced considerably at night to nearly 12% from 12 a.m. to 4 a.m. This observation is consistent with the conducted study in Johor Bahru city [4]; where it was observed that nearly 10% of respondents open windows during night-time and usually 80% during daytime.

Feriadi and Wong [5] also carried out their investigation in residential buildings located in Indonesia. They observed that only 8.6% of occupants open windows at night. The reduced percentage of open windows observed at night was attributed by the authors to the cooler condition and partially due to privacy and security reasons.

Journal of Multidisciplinary Engineering Science and Technology (JMEST)
ISSN: 3159-0040
Vol. 2 Issue 11, November - 2015

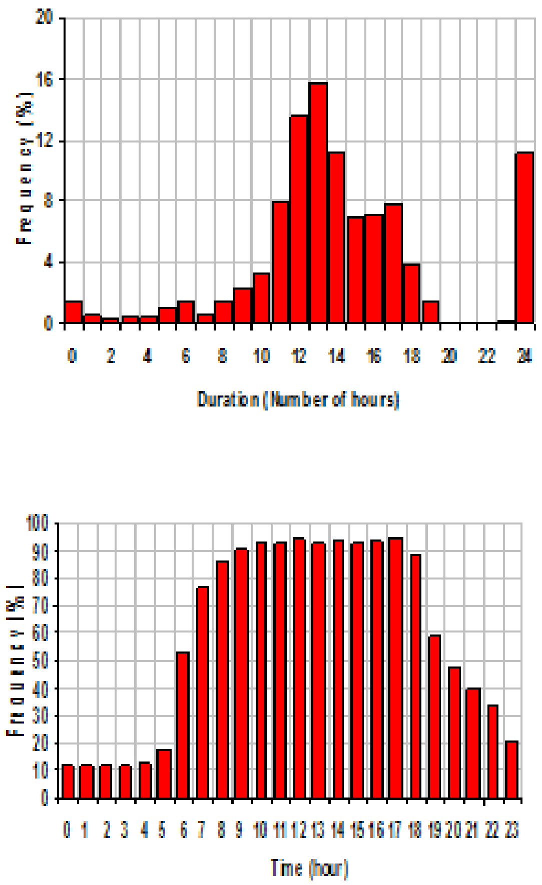


Fig. 1. *Frequency of open Windoewa*
Number of Houses=702

Kubota and Ahmad [4] mentioned that it was argued night ventilation is effective in reducing the effect of thermal conditions in the Malaysian terraced houses. The results of a case study conducted by Harimi, et al. [6] to assess the impact of open and close windows on indoor air temperature in a typical low-cost apartment in Kota Kinabalu, the authors observed that the indoor air temperature increased during daytime when windows and doors were opened compared to the opposite case. They also found a slight decrease in indoor air temperatures at night when windows were closed or opened. However, the decrease in the indoor air temperatures was more pronounced in their case study with doors and windows opened at night. Generally, indoor air temperature follows closely outdoor air temperature when cross ventilation is ensured.

These results contradict the argument of Fanger and Toftum [7] in their statement that in warm climates, the normal strategy in naturally ventilated buildings is to cool the building during night and then close the windows some time during morning when the outdoor temperature exceeds the indoor temperature. This statement could be attributed to the authors own observations of some countries subjected to different climate during summer seasons where people have a tendency to open windows at night. This is not the case of some tropical countries such Malaysia, Indonesia, even though few occupants do close windows because of the increase in air temperature. Finally, it must be emphasized that for housing thermal design in naturally ventilated building with thermal comfort approach, designers and researchers may take the observation of close windows at night and open windows during daytime into consideration.

From Figure 1(b), it was observed that the highest relative frequency of open windows was 16% for 13 hours duration and the minimal relative frequency of close windows was 2% of. Nearly 14 hours is the average duration per day of open windows (N=702, STD=4.9, Confidence Interval=13.8-14.5).

In Kubota and Ahmad [4] field study, the authors found that 12 hours was the average duration of open windows per day and nearly 8% of respondents reported close windows. A close observation at the published figure in their paper, it was apparent that 13 hours were also the highest relative frequency of open windows of 14%. Another important observation in the present investigation is related to the sudden increase of the relative frequency of open windows of 24 hours duration. This can be explained by the fact that during night or specifically sleeping time, occupants either close or open windows till the next day. This is different from daytime were many factors affect occupants choices.

Apart from asking directly occupants about the frequency of open windows when they are in their dwellings, observation of open windows were taken in each house from the space where the survey was conducted. The results are plotted in Fig. 2. The highest discrepancy in the observed values was recorded around 6 p.m. It must be highlighted that windows might have been opened in other rooms. This may explain some of the differences between the observed and the reported values.

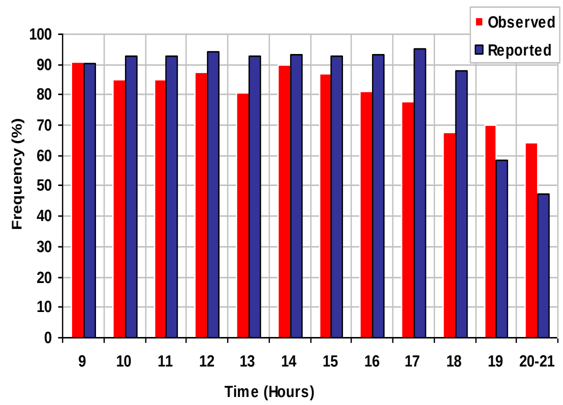


Fig. 2. *Observed and reported frequencies of opening window*

Further analysis was carried out to understand the reasons behind close windows. The obtained results from the questionnaire were plotted in Fig. 3. The occupants were given a choice to select more than one reason when it applies. It can be readily seen from Fig. 3 that 'dust' is a major contributing factor for close windows, followed by 'security', 'rain', 'insects', and 'smell'. Only 20% of the occupants close windows because of 'privacy'.

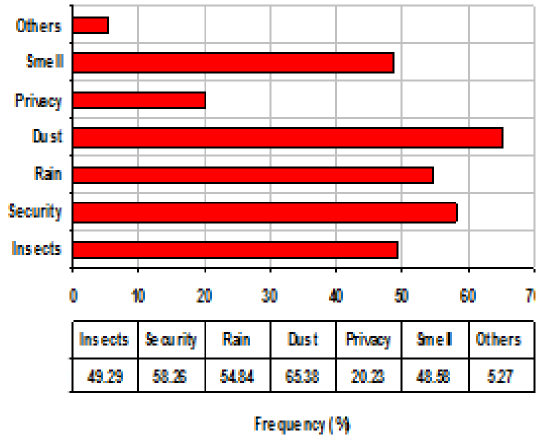


Fig. 3: Reason for closing windows

Thus, among reasons for closing windows at night could be attributed to 'security' and 'insects'. This is because 'dust' and 'rain' might not be really linked to a specific time of the day. As a matter of fact, dust accumulation could be more pronounced during day time. Air movement also can increase the accumulation of dust inside buildings. The analysed results from the conducted study in Johor Baru showed that 'insects' (38%) was the main reason for closing windows followed by 'rain' (22%) and then 'dust' (18%). The difference in the order and the percentages between the two studies could be accounted to the difference of buildings design and site locations of the buildings under investigations. However, there is an agreement between the two studies that 'dust', 'security', 'rain' and 'insects' are the main reasons for close windows. Other reasons given by the occupants for close windows in their observations are 'noise', 'smokes', 'health (Asthma)', 'strong wind', 'protection of young children', 'sudden jump of cats inside their dwellings', 'air is hot'.

The proportion of windows open at respective indoor air temperature of 28^{0}C to 34^{0}C recorded during the conducted survey is shown in Fig. 4. The proportion of windows open increased slightly with the increase of the indoor air temperature.

In naturally ventilated buildings, air movement plays a significant role in enhancing indoor thermal comfort [8]. Fig. 5 shows that 75% of the occupants found the indoor air movement acceptable; whereas less than 10% reported that the wind inside their dwellings was strong. A Comparison with the Johor Bahru study cannot be made because air flow is more related to site location, surrounding microclimate of the buildings under investigations, and buildings design. Further the word 'moderate' was replaced in this study by 'acceptable' and different scales were used.

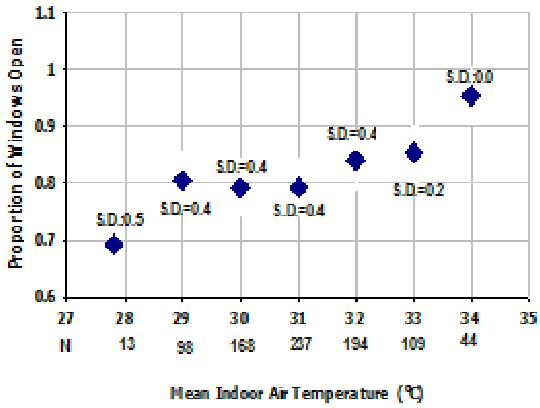


Fig. 4. Proportion of windows
S.D.: standard deviation; N: number of respondents

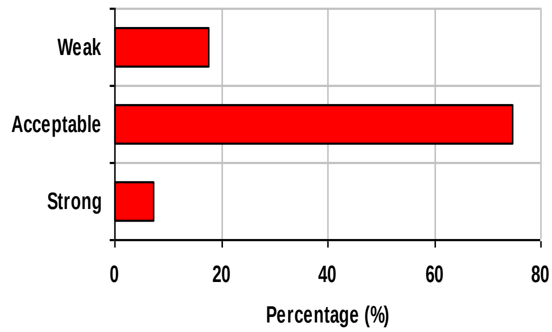
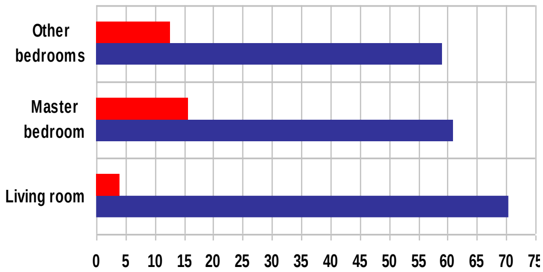


Fig. 5. Occupants evaluation of air speed in their dwellings

Further investigation related to the installation of window insect screens and window grills in different spaces was considered. Opening windows specifically during night may depend on the availability of grill and insect screen. Such analysis helps in understanding occupant thermal behavior toward indoor environment during night. This is because it is not known about occupants thermal comfort requirements during night in the humid tropics. For instance, if occupants close windows during night despite the availability of insect screens and grills, then it is more likely that occupants were feeling cooler during night-time compared to what they were feeling during day-time. In this study, living rooms as shown in Fig. 6 recorded the highest relative frequency of about 70% in grills installation. This was followed by master bedroom and bedrooms having almost similar percentage.



	Living room	Master bedroom	Other bedrooms
Insect Screen	4	16	13
Grills	70	61	59

Frequency (%)

Fig. 6: Rooms with grill and insect screen

For insect screen, master bedroom recorded slightly higher percentage than other bedrooms, whereas the lowest percentage in the installation of insect screen was noted in living room. These results matched with Kubota and Ahmad [4] observations in Johor Baru study but having different percentages. The results showed that the installation of grills surpassed considerably the installation of insect screen. This was despite that many occupants indicated that insects were among the major reasons for close windows. To encourage people to open windows especially during the night-time, Kubota and Ahmad [4] suggested the installation of the insects' screens at the construction phase of the dwellings which is also recommended in the present study. Further, it can be inferred from the results that occupants were not motivated for the installation of insect screen. Fans were a substitution to improve their thermal requirements. From the foregoing analysis, it may be said that many occupants were not fully satisfied with the indoor thermal environment at night.

For the purpose of understanding further the reasons behind not being always satisfied with the indoor environment at least occasionally, occupants were asked to select reasons for not being satisfied with the indoor thermal environment. 'Air temperature is hot', 'air movement is 'low' and 'the sun can penetrate in the rooms' were the major reasons of not being satisfied. The results are summarized in Fig. 7. The occupants were given a choice to select more than one reason when it applies.

Despite the highest percentage of the occupants reported that air movement in their dwellings was acceptable rather than weak, 'air movement is low' was selected as a second reason for not being satisfied with the indoor environment by many occupants as depicted in Fig. 7

This could be attributed to that, although air movement was overall considered acceptable, occupants whenever were not satisfied with the indoor air temperature in their houses wanted higher air movements to offset the warmer temperatures.

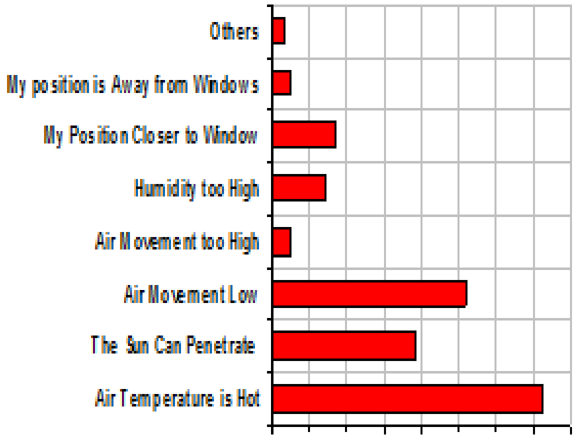


Fig. 7. Source of dissatisfaction with the indoor thermal environment

Humidity was not an important source of not being satisfied with the indoor environment for the majority of the occupants as illustrated in Figure 7. Apart from asking occupants to fill in the questionnaire, some observations were made during the field survey. Fig. 8 shows the frequency of switching light from 9am to 19 am, These observations were made during the time of the survey.

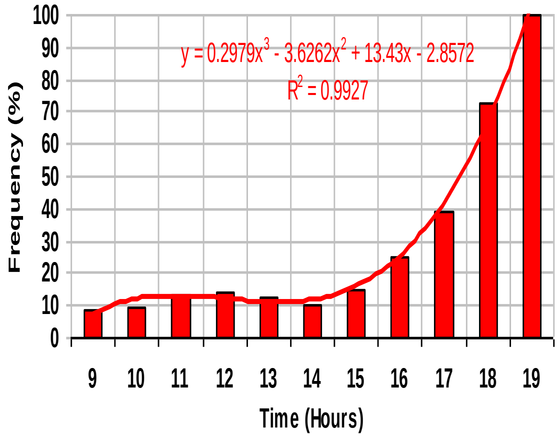


Fig. 8. Frequency of swithing the light on

The figure revealed that the percentage of occupants switching the light on was gradual but quite considerable around 5 p.m. (39%). This was despite the abundance of solar radiation in Kota Kinabalu during that time. This could be considered an architecture design issue which can first be solved by taking into account the outdoor daylighting of the location and by following some illumination rules of thumb [9]. The heating effect of daylight is about 1/2 to 1/10 of typical artificial lighting alternatives [10]. This also may reduce the generation of pollution [11]. It is also important for the well-being of occupants, health, and comfort. One of the reasons of switching on light around that time could be attributed to the construction of lengthy overhang for the porch in some terrace houses. This was observed in some of the visited residences.

IV. Conclusions

There are many issues to consider when designing field investigation on subjects satisfaction toward the indoor environment. Although some aspects were considered in the present investigation, it was not possible for every issue to be addressed. Observations were made on occupants' satisfaction toward the indoor thermal environment in residential buildings. It was found that occupants open their window mostly during day-time and close window at nights. 'Air temperature is hot', 'air movement is low' and 'the sun can penetrate in the rooms' are the major reasons reported by occupants of not being satisfied with the indoor environment at least occasionally. Microclimate of the building location should be the primary objective to improve the indoor thermal conditions. Air movement should be the second factor to be investigated in building thermal design. This is followed by preventing the penetration of solar radiation in the rooms. Other observations related to grill; daylighting and other factors were also investigated.

It might be important to mention that solar radiation has a drastic effect on thermal comfort of occupants. Generally, in field studies, occupants will select the least exposed space to solar radiation and the most convenient pleasant space for the completion of the questionnaire. In the hot humid tropics solar radiation is unlikely to be desired by occupants. Therefore, the assessment of the indoor space with thermal comfort approach should not only consider the addressed factors but also the space affected by solar radiation.

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