Analysis of Night Ventilation Potential for Residential Buildings in Hot-Humid Climate of Malaysia

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ABSTRACT: This paper discusses the potential of applying night ventilation as a passive cooling technique for Malaysian terraced houses based on the results of a full-scale field experiment. The results revealed that night ventilation provides better diurnal and nocturnal air temperature reductions than daytime ventilation, full-day ventilation and no ventilation. Night ventilation improves thermal comfort more than the other ventilation conditions based on operative temperature. However, further measure to lower indoor humidity such as by dehumidification or to increase indoor air velocity such as by fan may be required to improve the thermal condition in the night ventilated room in terms of SET, especially in the daytime. Ceiling insulation may increase the cooling potential of night ventilation in Malaysian terraced houses.*
Keywords: passive cooling, night ventilation, natural ventilation, thermal comfort, hot-humid climate

INTRODUCTION

Many developing nations have been facing increasing energy consumption due to rapid urbanization and economic growth in the recent decades. In Malaysia, its urban population rose from 27% in 1970 to 67% in 2005 [1] while the final energy demand in 2000 recorded a fivefold increase from 1980 level [2]. It is reported that residential and commercial buildings account for almost half of the total electricity use in the country as of 2002 [2]. Since Malaysia and many other developing nations experience year-round hot conditions, it can be projected that reducing air-conditioning in buildings would contribute largely towards lowering energy use, especially in urban areas.

Night ventilation is a notable passive cooling technique for well-insulated, high mass buildings [3]. This technique utilizes the nocturnal ambient air to cool the structural mass of a building via convection. The cooled structural mass may maintain lower indoor temperatures on the following day if the building is closed during the daytime [3]. To this effect, many researchers have noted that night ventilation effectively reduces daytime indoor air temperature in various types of buildings and climates. These studies extensively covered office buildings in moderate climate [4-7] and other test buildings in hot-arid climate [8]. The same studies [4, 7] noted that the efficiency of night ventilation highly depends on the building and climatic parameters as well as the ventilation rate at night. In comparison, night ventilation has received far less attention in the hot-humid tropics with relatively few studies which addressed this technique. Night ventilation is also rarely applied by present urban households in Malaysia, who mostly close windows at night and open them during the daytime, as revealed in a previous survey [9]. According to the survey, the majority of present households in Malaysian terraced houses apply daytime ventilation and night-time air-conditioning mainly in bedrooms [9]. As indicated above, the cooling efficiency of night ventilation technique differs in different buildings and climatic regions. Thus, despite the extensive developments of night ventilation techniques already established in moderate and hot-arid climates, the effectiveness and applicability of night ventilation for Malaysian residential buildings is yet to be determined, in both research and practice.

This paper discusses the potential of applying night ventilation as a passive cooling technique for Malaysian terraced houses based on the results of a full-scale field experiment. In Malaysia, the terraced house is the most common type of housing in urban areas – 44% of the urban housing units nationwide are terraced houses in 2000 [10]. Unlike the lightweight Malaysian traditional houses, modern urban houses in Malaysia are mainly constructed of heavyweight materials such as concrete and brick. As such, night ventilation may be a suitable technique for these houses. This paper firstly compares the effects of night ventilation with daytime ventilation, full-day ventilation and no ventilation on indoor thermal environment in the master bedrooms of the case study houses. Secondly, this paper examines the effect of heat from the ceiling in Malaysian terraced houses based on the vertical temperature distribution analysis.

METHODS

A field experiment was conducted in two adjacent and identical two-storey terraced houses (Figs. 1 and 2) in the city of Johor Bahru from June to August 2007 to compare the indoor thermal conditions under different natural ventilation strategies. Johor Bahru is the second largest city in Malaysia based on population count [10]. Its monthly mean air temperature and humidity are generally uniform throughout the year, which is typical of most Malaysian towns.

Both case study houses are considered to represent the typical Malaysian terraced houses. The selected houses are high thermal mass buildings. The building structure is reinforced concrete with plastered brick walls of 240mm thickness for party walls and 140mm thickness for other walls. The thermal mass of the master bedrooms was estimated to be 1100kg/m². The concrete roof tiles are laid with a thin layer of double-sided aluminium foil underneath as radiant barrier. The ceiling for the first floor is 4mm thick cement boards without insulation. The floors are reinforced concrete slab, and finished with ceramic tiles on the ground floor and timber strips on the first floor. All windows are either casement or sliding type and constructed of 5mm thick single-glazed clear glass. A clerestory window of fixed glass louvers is available above the family area on the first floor. During the experiment, the houses were empty of furniture and unoccupied.

In the present experiment, three cases are included as outlined in Table 1. Cases 1-3 compare night ventilation with daytime ventilation, no ventilation and full-day ventilation respectively. Daytime ventilation was obtained by opening all windows from 8 a.m.-8 p.m. and closing them from 8 p.m.-8 a.m., to emulate the current window opening behaviour [9]. In contrast, all windows were closed from 8 a.m.-8 p.m. and opened from 8 p.m.-8 a.m. for night ventilation. On the day before each case, all windows in both houses were opened equally from 8 a.m.-8 a.m. (24h) so that their indoor thermal conditions would be similar at the start of respective cases.

Measurements of indoor thermal environment were taken in the master bedrooms (first floor) and living rooms (ground floor) of the two houses (Fig. 2). The floor-to-ceiling height of the rooms is 3.0m. The measured parameters at 1.5m height above floor in the master bedrooms are air temperature, relative humidity, air velocity and globe temperature, for the analysis of thermal environment. The data loggers used are Delta Ohm (DO9847) and Innova AirTech Instruments A/S

Figure 1: View of the case study houses.

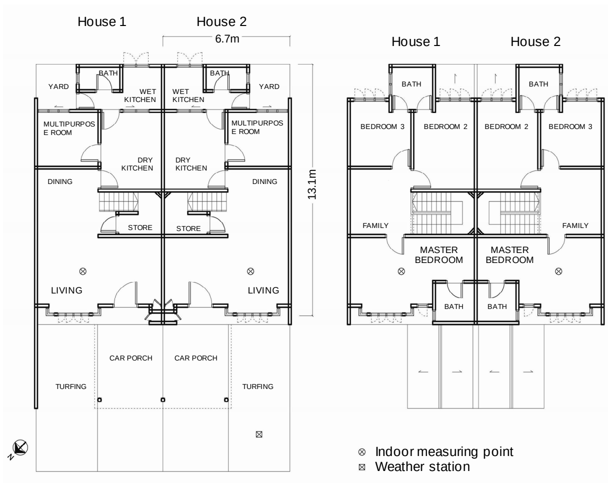


Figure 2: Floor plans of the case study houses.

Table 1: Ventilation conditions for Cases 1-3.

Case	House 1	House 2
1	Daytime ventilation	Night ventilation
2	No ventilation	Night ventilation
3	Full-day ventilation	Night ventilation

(Type 1221). In addition, air temperature measurements were taken at 0.6m, 2.4m and 2.9m in the master bedrooms and 0.6m, 1.5m and 2.4m in the living rooms for vertical temperature distribution analysis. Floor and ceiling surface temperatures were also recorded on both floors. All indoor measurements were logged automatically at 10-minute intervals. A weather station (EASIDATA Mark 4, Environdata) was placed in the immediate outdoor of House 2 (Fig. 2) to record the ambient air temperature, relative humidity, wind speed and direction, global horizontal solar radiation, rainfall and barometric pressure throughout the experiment.

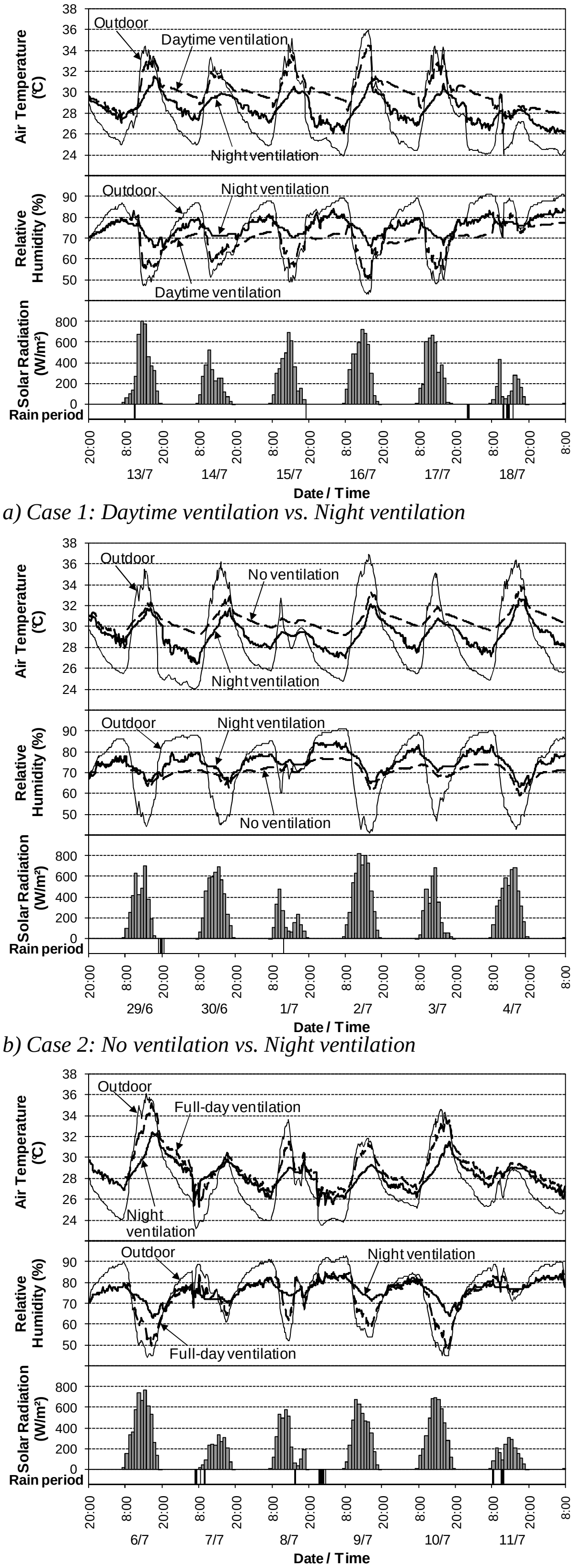
RESULTS AND DISCUSSION

THERMAL ENVIRONMENT ANALYSIS

This section focuses on measurement results at 1.5m height above floor in the master bedrooms (see Fig. 2). Fig. 3 shows the measured air temperature and relative humidity with the corresponding outdoor conditions during Cases 1-3. As shown in the figure, the occurrence of rain before noon affects the outdoor air temperature patterns, in particular the peak temperatures considerably. It can be seen that the measured air temperature in night ventilation condition was generally lower than those of daytime ventilation, no ventilation and full-day ventilation conditions during the six-day measurement for each case (Fig. 3). In order to further evaluate the cooling potential of night ventilation compared to the other ventilation conditions, the following analysis employed only data of fair weather days, which recorded relatively high outdoor air temperature.

Fig. 4 shows the hourly mean air temperature on the fair weather days of respective cases. Maximum outdoor air temperature averaged 34-35°C while its minimum averaged 24-25°C (Fig. 4). In all, it was observed that night ventilation lowered the peak indoor air temperature by 2.5°C, compared to both daytime ventilation and full-day ventilation conditions (Fig. 4ac). Night ventilation also lowered nocturnal indoor air temperature by 2.0°C more than the daytime ventilation and no ventilation conditions on average (Fig. 4ab).

When the daytime ventilation was applied in Case 1, the maximum indoor air temperature reached 33.0°C, which is only about 1.0°C lower than that of the outdoors (Fig. 4a). In contrast, maximum air temperature in the night ventilated room was reduced to 30.5°C (Fig. 4a). It can be deduced from the above results that diurnal air temperature in the daytime ventilated room was close to the outdoors mainly due to its opened window condition which allowed outdoor hot air into the house. Furthermore, the heat from outdoor air was stored in the building structures and radiated to the indoor spaces at night. As windows were closed during night-time, the heat was confined in the house and nocturnal indoor air temperature in the daytime ventilated room maintained high at 30.0°C on average (Fig. 4a). In comparison, opened window condition at night allowed the natural flow of cooler ambient air into the house, which reduced nocturnal indoor air temperature in the night ventilated room to 28.0°C on average (Fig. 4a). When no ventilation was applied in Case 2, the nocturnal indoor air temperature was also maintained high at 30.5°C on average (Fig. 4b), which is similar to the daytime ventilation condition. It was found that without night cooling, the maximum air temperature in unventilated room is 1.0°C higher than the night ventilated one although windows were closed during the daytime (Fig.

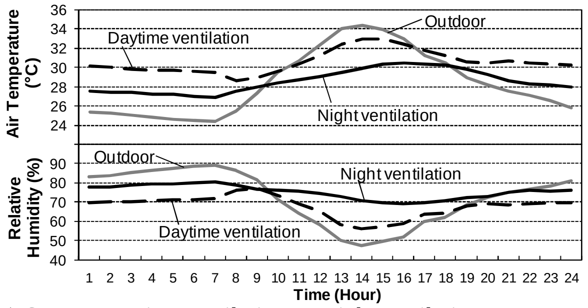


a) Case 1: Daytime ventilation vs. Night ventilation

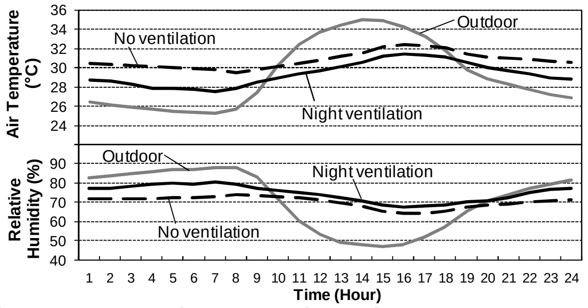
b) Case 2: No ventilation vs. Night ventilation

c) Case 3: Full-day ventilation vs. Night ventilation

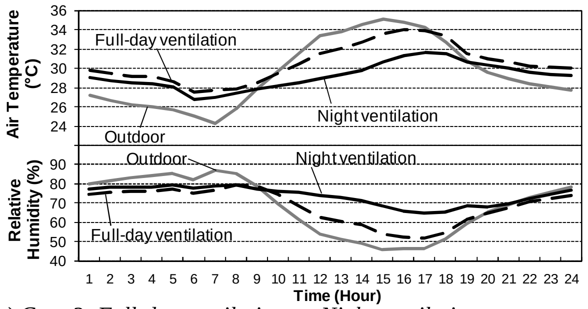
Figure 3: Measurement results at 1.5m in the master bedrooms for Cases 1-3.



a) Case 1: Daytime ventilation vs. Night ventilation

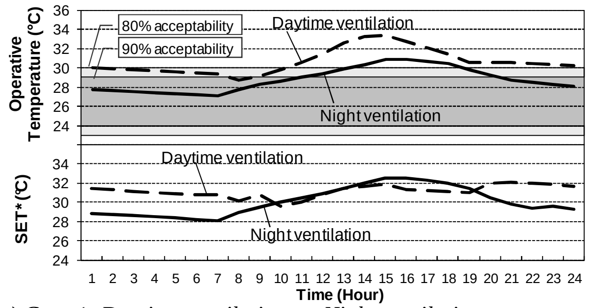


b) Case 2: No ventilation vs. Night ventilation

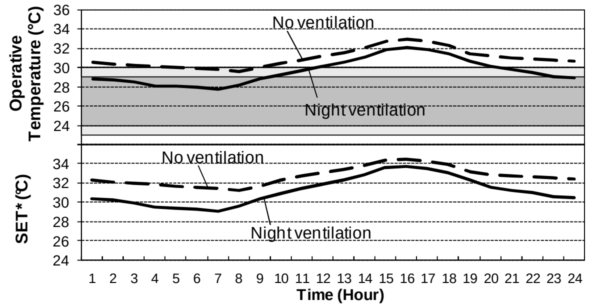


c) Case 3: Full-day ventilation vs. Night ventilation

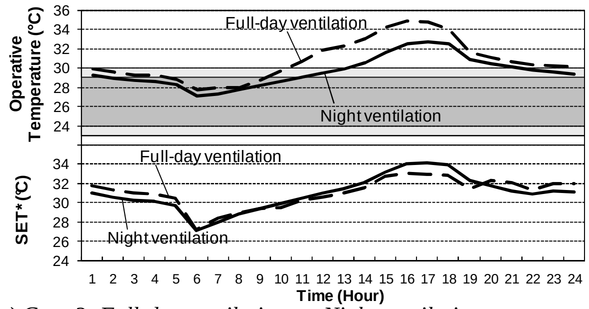
Figure 4: Hourly mean air temperature and relative humidity for Cases 1-3.



a) Case 1: Daytime ventilation vs. Night ventilation



b) Case 2: No ventilation vs. Night ventilation



c) Case 3: Full-day ventilation vs. Night ventilation

Figure 5: Hourly mean operative temperature and standard effective temperature (SET) for Cases 1-3.*

4b). When the full-day ventilation was applied in Case 3, diurnal indoor air temperature was similar to the pattern of the daytime ventilated one while nocturnal indoor air temperature was still 0.5°C higher than that of the night ventilated room (Fig. 4c). As before, the building structure was heated more when windows were opened during the daytime. As the mean outdoor wind speed dropped from 0.6m/s during the day to 0.1m/s at night, the night-time ventilation rate might be insufficient to cool the heated structure of the full-day ventilated house properly at night due to its high thermal capacity. On account of the thermal mass of the room, the night ventilation technique was effective in lowering the peak indoor air temperature by 3.5-4.0°C and delaying it by 2 hours from the outdoors on fair weather days (Fig. 4). However, it should be noted that nocturnal air temperature in the night ventilated room was still 2.0°C higher than the outdoors (Fig. 4), probably due to the same reasons of low ventilation rate at night and high thermal capacity.

On the other hand, the measurement results reveal that the air temperature reductions obtained by the night ventilation were accompanied by the increase in relative humidity (Fig. 3). The indoor relative humidity reached 65-80% when the night ventilation was applied on fair weather days (Fig. 4). In this aspect, full-day ventilation and daytime ventilation were able to control diurnal humidity level to about 15% RH lower than night ventilation (Fig. 4ac), but at the expense of the aforementioned cooling effects.

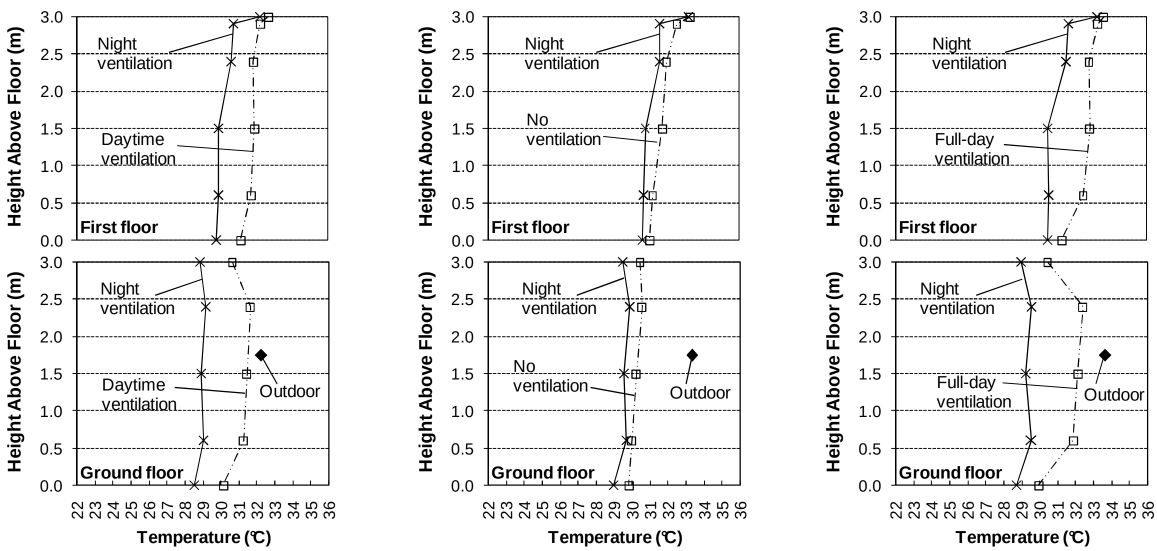
To examine whether the night ventilation is able to provide thermal comfort, the measurement results were transformed into two thermal indices, i.e. operative temperature and standard effective temperature (SET*). The Adaptive Comfort Standard (ACS) prescribed recently by ASHRAE [11] is considered one of the appropriate methods for determining acceptable thermal conditions in naturally ventilated spaces. Since the comfort criteria is based on operative temperature, SET* is also used in this analysis to take evaporative heat exchange between the occupant and the environment into account, in consideration of the high humidity conditions. In SET* calculation, the metabolic rate of 1.0 met and clothing insulation of 0.5 clo were applied.

Fig. 5 presents the hourly mean operative temperature and SET* for respective cases. According to the ACS [11], the acceptable operative temperature limits for 80% and 90% acceptability were found to be 23-30°C and 24-29°C respectively, based on the mean monthly outdoor air temperature during the experiment period. As indicated in Fig. 5, the night ventilation technique was found to provide more acceptable operative temperature than the other ventilation conditions for the whole day. In all cases, operative temperature in the night ventilated room is well within the acceptable limits, mainly during the night hours from 9 p.m.-12 noon (Fig. 5). In comparison, operative temperature in other ventilation conditions did not meet the 80% acceptability limits until past midnight (Fig. 5). Thus, it can be seen that there is a huge potential for reducing the night-time air-conditioning in Malaysian terraced houses if occupants adapt to the night ventilation technique from their current behaviour of daytime ventilation. Still, operative temperature in the night ventilated room exceeded the 80% upper limit in the afternoon by up to 2.5°C (Fig. 5). In fact, maximum operative temperature in each room was 0.5-1.0°C higher than the respective maximum air temperature (cf. Figs. 4 and 5), signifying the occurrence of excessive radiant heat gain during the peak period.

Furthermore, in terms of SET*, the nocturnal cooling effect of the night ventilation technique is still seen in all cases (Fig. 5). However, the night ventilation does not provide better diurnal thermal conditions compared to daytime ventilation and full-day ventilation when the evaporative heat loss is considered in SET*. Maximum SET* in the night ventilated room is 0.5°C and about 1.0°C higher than the daytime ventilated and full-day ventilated ones respectively (Fig. 5ac), most likely due to the increase in diurnal humidity level when windows were closed. Besides, when windows were opened during the daytime, indoor air velocity reached about 0.3m/s on average whereas still air condition occurred in the night ventilated room. Thus, in order to improve the diurnal thermal condition in the night ventilated room in terms of SET*, further measure to lower indoor humidity such as by dehumidification or to increase indoor air velocity such as by fan may be required. Otherwise, full-day ventilation may be the better option even though the night-time thermal condition would be slightly warmer than the night ventilation condition.

VERTICAL TEMPERATURE DISTRIBUTION ANALYSIS

This section examines the effect of heat from the ceiling based on the vertical temperature distribution in the case study houses. Fig. 6 presents the average air and surface temperatures between 12 noon and 8 p.m. at respective measurement heights for Cases 1-3. The windows in the night ventilated house were closed during this period. As shown in Fig. 6, the ceiling surface temperature on the first floor in the night ventilated house was similar to the outdoor air temperature, even though the temperatures at all other measurement points in the house were much lower. It was 2-3°C higher than the floor surface and air temperatures of the same room (Fig. 6). In fact, the first floor ceiling surface temperature was almost same in both houses under the different ventilation conditions (Fig. 6).



a) Case 1 *b) Case 2* *c) Case 3*

Figure 6: Vertical distribution of average air and surface temperatures between 12 noon and 8 p.m. for Cases 1-3.

The above results imply that the ceiling was considerably heated, probably by the heat from solar radiation received at the roof during the daytime. Consequently, the heated ceiling passed the heat to the air on the first floor via convection. The heated ceiling also probably radiated heat into the room and thus increased the operative temperature further. This process might contribute to create the diurnal thermal discomfort in the night ventilated master bedroom. As presented in the previous section, according to the ACS, warm discomfort condition was seen in the night ventilated master bedroom in the afternoons: 2 p.m.-6 p.m. in Case 1, 12 noon-8 p.m. in Case 2, and 2 p.m.-9 p.m. in Case 3 (see Fig. 5). In comparison, in addition to the heated ceiling, ventilation with outdoor hot air further increased the air temperature in the daytime ventilated and full-day ventilated master bedroom, compared to the night ventilated one (Fig. 6ac).

It can be seen that the ground floor was cooler than the first floor especially when windows were closed, i.e. in the night ventilation and no ventilation conditions (Fig. 6). The air temperature at 1.5m on the ground floor was 1°C lower than that of the first floor when the night ventilation was applied (Fig. 6). This air temperature difference between floors is probably due to the heat from the ceiling on the first floor as discussed above. Considering that the ceiling was not insulated, applying thermal insulation to the ceiling may reduce the air temperature on the first floor to that of the ground floor, which would increase the cooling effect of the night ventilation technique by 1°C on average in the afternoon period.

CONCLUSIONS

(1) Night ventilation was found to be better than daytime ventilation, full-day ventilation and no ventilation in terms of air temperature reductions during the daytime and night-time. It was observed that night ventilation lowered the peak indoor air temperature by 2.5°C, compared to daytime ventilation and full-day ventilation conditions. Night ventilation also lowered nocturnal indoor air temperature by 2.0°C more than the daytime ventilation and no ventilation conditions on average.

(2) Night ventilation provides more acceptable operative temperature than the other ventilation conditions for the whole day. According to the Adaptive Comfort Standard, night ventilation would provide thermal comfort well, mainly during the night hours from 9 p.m.-12 noon.

(3) However, further measure to lower indoor humidity such as by dehumidification or to increase indoor air velocity such as by fan may be required to improve the diurnal thermal condition in the night ventilated room in terms of SET*. Otherwise, full-day ventilation may be the better option even though the night-time thermal condition would be slightly warmer than the night ventilation condition.

(4) It was found that the heat from the ceiling probably caused the air temperature on the first floor to be higher than that of the ground floor by 1°C on average in the afternoon period when the night ventilation was applied. Applying thermal insulation to the ceiling may increase the cooling potential of the night ventilation technique in Malaysian terraced houses.

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REFERENCES

1. Malaysia, (1966-2005). *Malaysia Plans 1st – 8th*. Economic Planning Unit.
2. Malaysia, (2002). *National Energy Balance Malaysia 2002*. Ministry of Energy, Communications and Multimedia Malaysia.
3. Givoni, B., (1994). *Passive and low energy cooling of buildings*. New York: Van Nostrand Reinhold.
4. Blondeau, P., Spérandio, M., and Allard, F., (1997). Night ventilation for building cooling in summer. *Solar Energy*, 61(5): p. 327-335.
5. Breesch, H., Bossaer, A., and Janssens, A., (2005). Passive cooling in a low-energy office building. *Solar Energy*, 79: p. 682-696.
6. Geros, V., Santamouris, M., Tsangrasoulis, A., and Guarracino, G., (1999). Experimental evaluation of night ventilation phenomena. *Energy and Buildings*, 29: p. 141-154.
7. Pfafferott, J., Herkel, S., and Jäschke, M., (2003). Design of passive cooling by night ventilation: Evaluation of a parametric model and building simulation with measurements. *Energy and Buildings*, 35: p. 1129-1143.
8. Givoni, B., (1991). Performance and applicability of passive and low-energy cooling systems. *Energy and Buildings*, 17: p. 177-199.
9. Kubota, T., and Ahmad, S., (2005). Questionnaire survey on behavior for natural ventilation and electricity consumption in terraced houses: A case study of Johor Bahru City. In *Proceedings of the 8th International Conference of the Asian Planning Schools Association*. Penang, Malaysia, September 11-14.
10. Malaysia, (2005). *General report of the population and housing census*. Department of Statistics Malaysia.
11. ASHRAE, (2004). *ASHRAE Standard 55-2004, Thermal Environmental Conditions for Human Occupancy*. Atlanta: ASHRAE.