A Field Experiment on the Cooling Effect of Night Ventilation in Malaysian Terraced Houses

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Abstract
Night ventilation is recognized as one of the effective and low-energy means to reduce daytime temperature, thus cooling load, in buildings under various climates. This study aims to examine the cooling effect of night ventilation in the most common residential type in Malaysia, i.e. terraced houses. A field experiment was conducted in June and July in two adjacent typical terraced houses under various open window conditions in order to evaluate night ventilation effect against no ventilation, daytime ventilation and full-day ventilation respectively. In this paper, the cooling effect of night ventilation was compared with the other ventilation conditions based on indoor air temperature at 1.5m height. Besides, vertical distribution of air temperature from floor to ceiling in each room was analyzed. The potential of indoor air temperature reduction by applying night ventilation and insulation is discussed.

Keywords: Night ventilation; passive cooling; hot-humid climate; terraced house

1. Introduction

Increased energy consumption due to rapid urbanization is a major concern in most developing countries. In Malaysia, the final energy demand in 2000 is almost a fivefold increase from year 1980 [1]. Furthermore, the Malaysia Energy Centre estimates that CO_2 emissions per capita from the energy sector increased 45% from 1994 to 2005 [2]. A recent study finds that household electricity consumption and air-conditioner usage is highly correlated [3]. Thus, it is important to find passive cooling means that can reduce the need for air-conditioning in this hot-humid climate. This study aims to examine the cooling effect of night ventilation as a passive cooling method in the most common residential type in Malaysia, i.e. terraced houses.

Night ventilation is well-noted as an effective and low-energy means to reduce daytime temperature, thus cooling load, in buildings under various climates. Recent studies have provided extensive information on night ventilation in commercial [4, 5] and residential [6, 7] buildings in different regions. All these researches support the cooling potential of night ventilation through experiments conducted in various parameters. However, there is uncertainty on the usefulness of night ventilation in cooling and maintaining comfort temperature throughout the day and night in hot-humid climate. Major obstacles to applying night ventilation effectively in the tropics include high solar radiation and low prevailing wind speed. Moreover, high humidity level may require all-time ventilation to reduce dampness [8].

This paper presents the results of a field experiment which compare the temperature cooling effect of night ventilation with no ventilation, daytime ventilation and full-day ventilation respectively. Besides, an analysis on the vertical distribution of air temperature from floor to ceiling in the ground and first floors is shown. These findings lead to a discussion on the potential of indoor air temperature reduction by applying night ventilation and insulation.

2. Methods

2.1 Outline of case study houses

This study focuses on terraced housing. Terraced housing in Malaysia has grown to cover more than 2 million units or 54.4% of the existing residential stock [9]. A previous study by Kubota et al. [3] gives evidence that present households in terraced housing tend to use air-conditioners and close windows especially to cool their master bedrooms at night.

Two adjacent typical terraced houses were selected for the field experiment. They were double-storey terraced houses located in a major housing estate in the suburb of Johor Bahru City. Both were selected as the most typical terraced house in terms of its room layout with average house size (GFA=155 m^2) among 93 samples from more than 20 housing estates in Johor Bahru.

The design of the two houses is symmetrical but same (Figs. 1 and 2). The building structure is reinforced concrete with 140mm thick plastered brick walls or 240mm thick for party walls. The concrete tiled roof is laid with a very thin layer of double-sided aluminium foil underneath. The ceiling for the ground floor is the first floor concrete slab while the ceiling for the first floor is asbestos-free cement board without insulation. All windows are either casement or sliding type and glazed with 5mm thick clear glass (single glazing). There is a clerestory window of fixed louvered glass above the family area on the first floor. Such construction represents common practice in terraced housing in Malaysia.

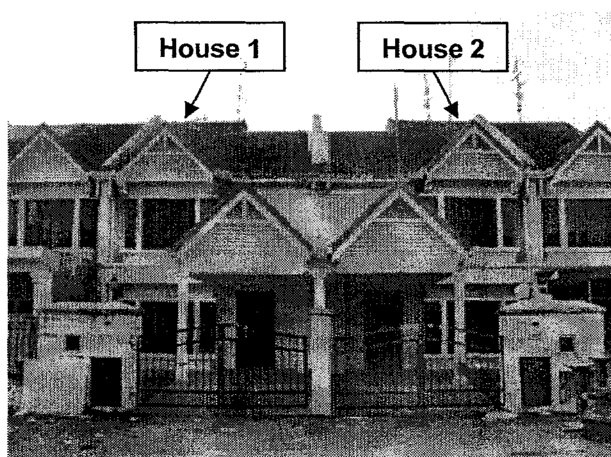
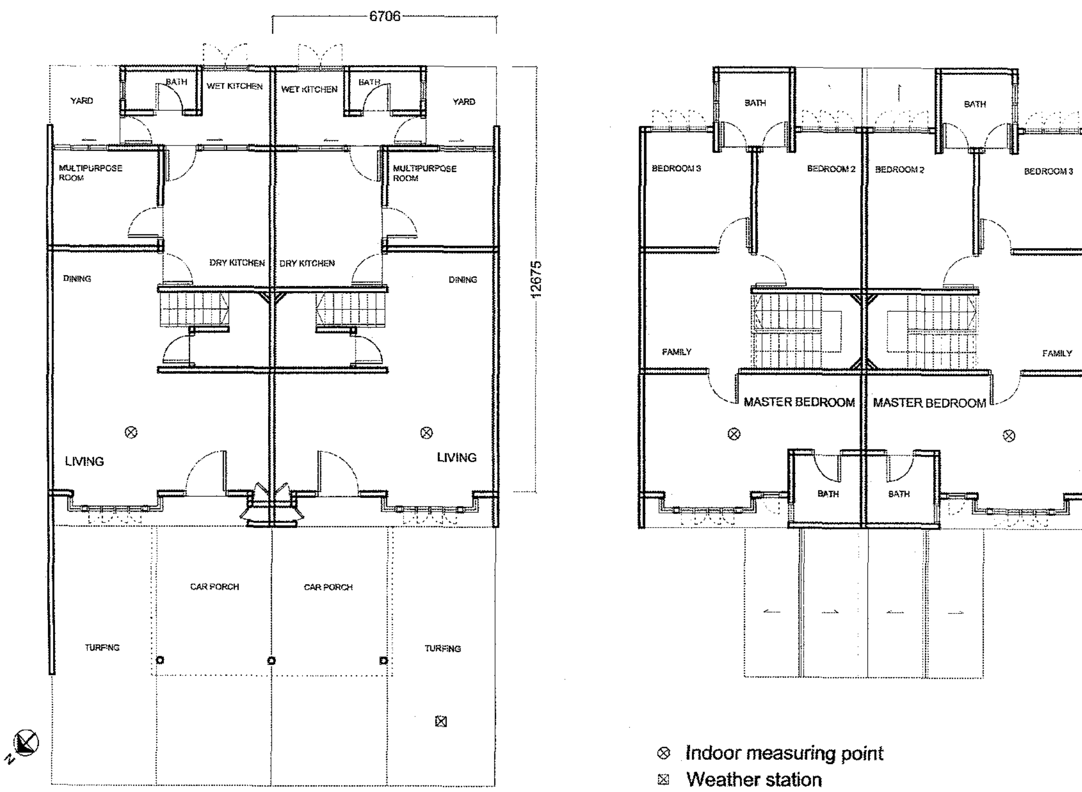


Fig. 1. View of the case study houses

House 1 House 2 House 1 House 2



(a) Ground floor plan (b) First floor plan

Fig. 2. Floor plans of the case study houses

2.2 Outline of field experiment

Table 1. Measured indoor parameters

Measuring point (Height from floor, mm)	Measured parameters	
	Living Rooms	Master Bedrooms
3000	Ceiling surface temp.	Ceiling surface temp.
2900	Not measured	Air temp.
2400	Air temp.	Air temp.
1500	Air temp., Relative humidity, Air velocity, Globe temp.	Air temp., Relative humidity, Air velocity, Globe temp.
600	Air temp.	Air temp.
0	Floor surface temp.	Floor surface temp.

Table 2. Opening window schedule

	House 1			House 2		
	Condition	8 a.m.-8 p.m.	8 p.m.-8 a.m.	Condition	8 a.m.-8 p.m.	8 p.m.-8 a.m.
Case 1	No ventilation	Close	Close	Night ventilation	Close	Open
Case 2	Full-day ventilation	Open	Open	Night ventilation	Close	Open
Case 3	Daytime ventilation	Open	Close	Night ventilation	Close	Open

Measurements of indoor thermal environment were taken in the living room (ground floor) and master bedroom (first floor) of both houses (see Fig. 2). The measuring points and measured parameters at each point are summarized in Table 1. Room floor-to-ceiling height is 3m. 10-minute logging interval was used for all units. The temperature accuracy ranged from 0.2°C to 0.55°C. All air temperature sensors were protected from radiation effect using shading devices. Outdoor climate data was measured with a weather station placed in the immediate outdoor of one of the houses (see Fig. 2). The climatic parameters recorded include ambient air temperature and humidity, solar radiation, wind speed, wind direction and rainfall.

The main purpose of this experiment is to compare the cooling effect between night ventilation and other ventilation conditions. For this purpose, the field experiment was carried out in three cases of different opening window conditions (Table 2). Each case was run for 6 continuous days in order to ascertain longer-term cooling effect as well as to obtain various outdoor climate conditions including typical hot day in equatorial climate. The experiment period was between 28 June and 19 July 2007.

In this study, natural ventilation was applied by opening all windows of the entire house manually according to the time period specified (Table 2). No forced or mechanical ventilation was used to aid night ventilation, daytime and full-day ventilation. Throughout the experiments, both houses were unoccupied and empty except for the field measurement equipments in the experiment rooms. Therefore, internal heat gain from occupants and appliances was not taken into account.

3. Results and discussion

3.1 Cooling effect assessment at 1.5m

Fig. 3 illustrates the measured air temperature at 1.5m height in the master bedrooms (first floor) and living rooms (ground floor) for all three cases. Both outdoor and indoor patterns for the two experiment houses are shown. Fig. 4 shows the air temperature difference between House 2 (night-ventilation) and House 1 (other ventilation conditions) at 1.5m height in the master bedrooms and living rooms. Positive figures indicate that night ventilation gave lower temperature than the compared ventilation effect. Weather conditions during the experiment are indicated briefly in the lower part of the respective figures.

In Case 1, night ventilation (House 2) was examined against no ventilation condition (House 1). Although windows were closed during daytime in both houses, the night-ventilated house had lower daytime temperature (Fig. 4). The peak indoor temperatures in the night-ventilated master bedroom were about 3°C to 5°C lower than the outdoor maximum temperature (Fig. 3(a)) while in the night-ventilated living room, the temperatures were about 4°C to 7°C lower (Fig. 3(b)). On the other hand, the master bedroom without ventilation was 2°C to 4°C lower than outdoor peak (Fig. 3(a)) while the non-ventilated living room was 3°C to 6°C lower (Fig. 3(b)). Night ventilation was able to reduce indoor maximum temperature by about 1°C lower than no ventilation condition during the day (Fig. 4). At night, the night-ventilated rooms followed the night ambient air more closely and were 2-3°C cooler than no ventilation rooms throughout the experiment. The cooling effect can be seen clearly by comparing the temperature pattern on the pre-experiment night (8 p.m.-8 a.m. before day 1) with the experiment nights (Fig. 3).

In Case 2, night ventilation effect was compared with full-day ventilation effect. As indicated in Fig. 4, daytime cooling effect of night ventilation is relatively heightened in this case. When windows were opened on sunny days for the full-day ventilated house, indoor temperatures for first and ground floors were only 1°C to 3°C lower than the maximum ambient air temperature (Fig. 3). Comparatively, the night-ventilated house achieved 3°C to 6°C lower maximum temperature during the outdoor hottest period. Even in cloudy condition (afternoon of day 9 and day 12), the daytime

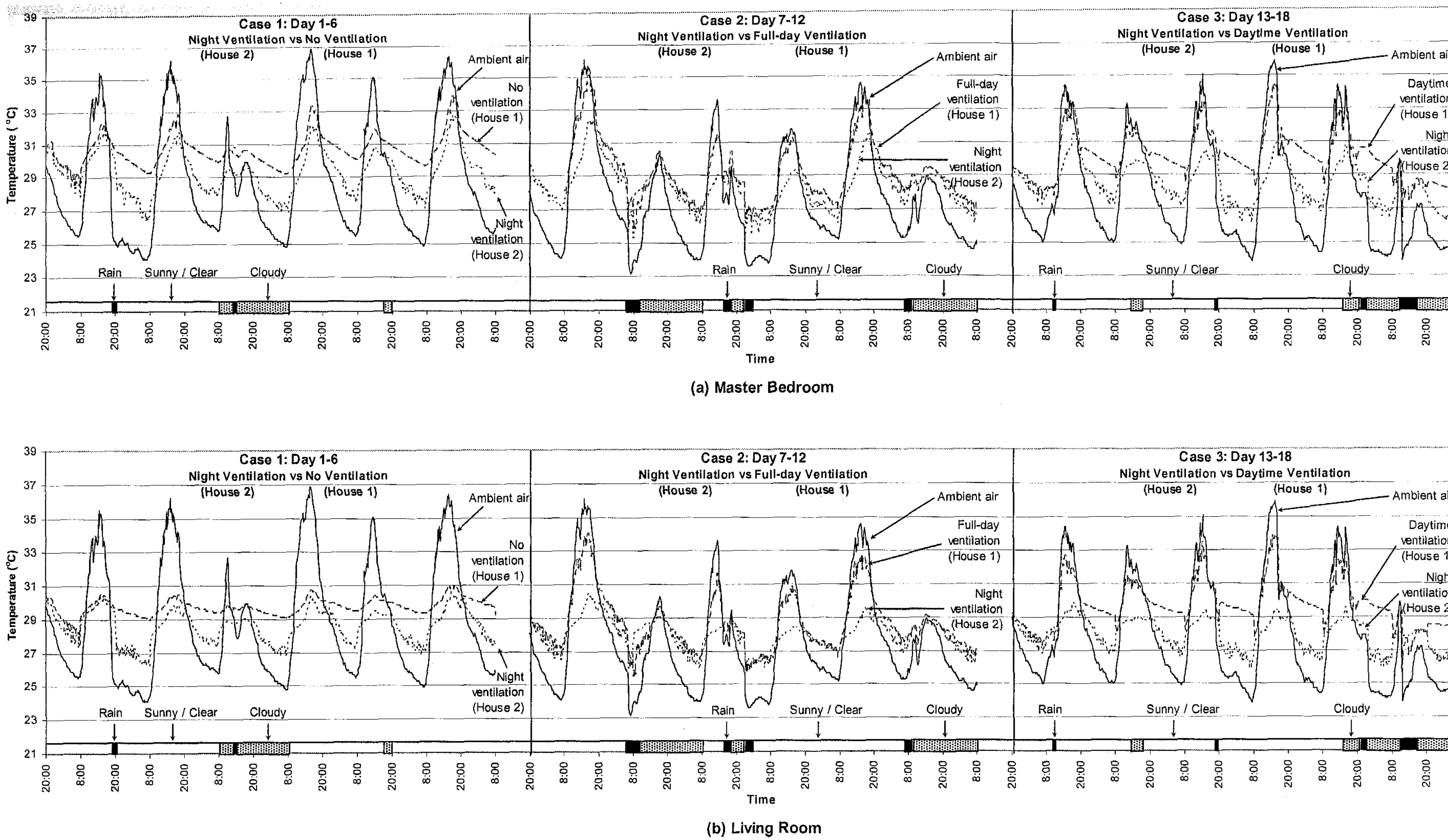
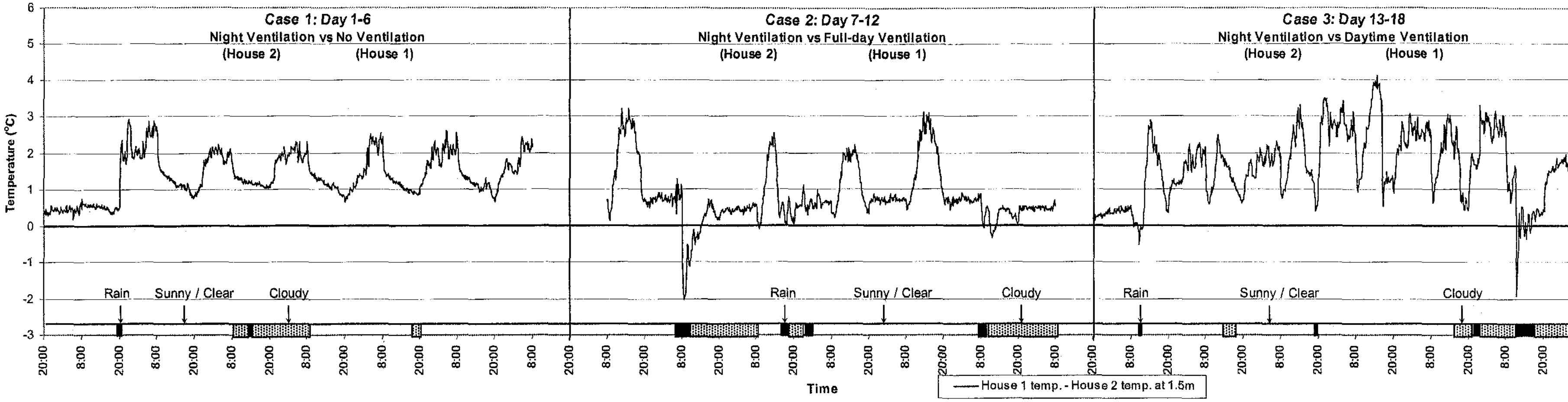
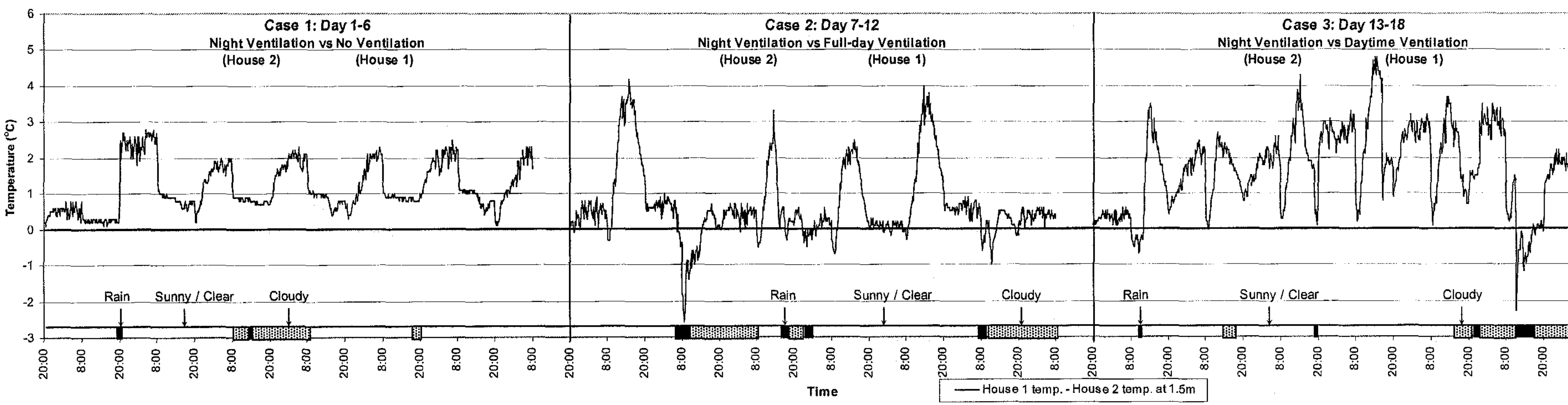


Fig. 3. Measured air temperature at 1.5m in the 4 experiment rooms and outdoor temperature for Cases 1-3



(a) Master Bedroom



(b) Living Room

Fig. 4. Air temperature reduction effect in night-ventilated rooms (House 2) compared to other ventilation conditions (House 1

temperature of full-day ventilation house was similar to that of night-ventilated house at best. It is found from this case that continued ventilation after 8 a.m. may only be beneficial under certain outdoor condition, e.g. very low ambient temperature on the morning of day 8 which was below 27°C (Figs. 3 and 4). This means that night ventilation hour may be extended in such situation. The temperature reduced was up to 2°C (Fig. 4). However, continuing natural ventilation for the whole day did not lower the indoor temperature further as outdoor temperature increased after a while.

Case 3 is an experiment between night ventilation and daytime ventilation, which is the common behavior of present households [3]. The measured result shows that the day and night cooling effect of night ventilation is the most obvious when compared to daytime ventilation effect (Fig. 4). The difference between outdoor maximum and indoor maximum temperatures from day 13 – 16 (sunny condition) increased gradually from 3°C to 5°C in the night-ventilated master bedroom (Fig. 3(a)) and 5°C to 7°C in the living room of the same house (Fig. 3(b)). In this case, daytime ventilation on sunny days brought the maximum indoor temperature as close as 1°C to the outdoor peak temperature. For night hours, the night-ventilated house was at most 3°C higher than minimum ambient air temperature, whereas the day-ventilated house was up to 5°C higher for minimum night temperature (Fig. 3). Even on a cloudy day, daytime ventilation did not perform any better unless when the ambient air temperature dropped drastically as occurred on the final day of the experiment (Fig. 4) (cf. day 8 of case 2).

3.2 Vertical distribution of temperature in rooms

The vertical distribution of temperature was evaluated from measured data of all measuring heights in the living room and master bedroom of Houses 1 and 2. The temperature distribution patterns were analyzed in four periods, i.e. 8 a.m.-12 p.m., 12 p.m.-8 p.m., 8 p.m.-12 a.m. and 12 a.m.-8 a.m., by considering the ventilation period. Fig. 5 shows the averaged values in each analysis period on typical sunny days for all three cases. Averaged outdoor air temperature during each period is also marked in the figures.

All windows were closed in the night-ventilated house (House 2) from 8 a.m. During the first analysis period (8 a.m.-12 p.m.), the indoor of the night-ventilated house was cooler than the ambient air on average for all three cases, whereas the other ventilation conditions caused higher temperatures in House 1 (Fig. 5). In Case 1, all

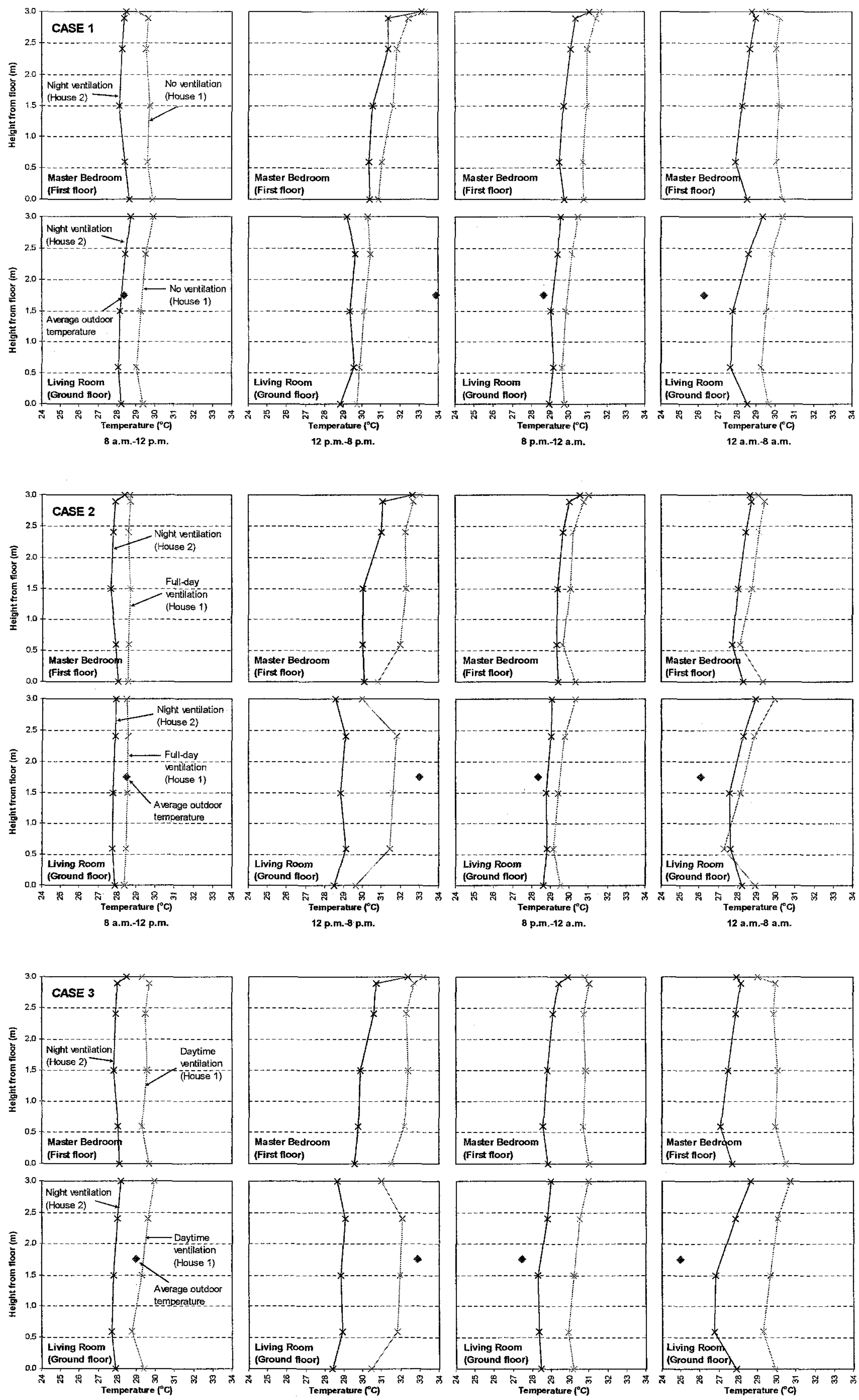


Fig. 5. Vertical distributions of average temperature on typical sunny days

points in the night-ventilated house were about 1-2°C lower than no ventilation condition. In Case 2, temperature distribution among measuring points and between floors was quite even for both houses, except for the ceiling surface temperature on the first floor of House 2. Night ventilation gave lower temperature (about 1°C) than full-day ventilation during this period. This means that night ventilation was able to maintain lower air temperature and surface temperature in the first four hour period after closing windows. As for Case 3, ventilation in this period brought House 1 temperatures up by about 2°C compared to House 2 (night ventilation). The ceiling board surface temperature was slightly higher than the air close to it at 2.9m of House 2 for Cases 2 and 3.

Between 12 p.m. and 8 p.m., the windows were still closed in House 2 (night ventilation). During this period, the vertical distribution patterns changed from the first analysis period as shown in Fig. 5. In Case 1, first floor temperatures were 1-2°C higher than ground floor temperatures for both houses. Temperatures in the night-ventilated house were about 1°C lower than the house with no ventilation. In Case 2, full-day ventilation brought in hot air and increased the indoor air temperatures in House 1 compared to House 2. The air temperatures of the two houses were further apart (2-3°C) than surface temperatures (1°C or less) due to the hot outdoor air which entered House 1. In Case 3, daytime ventilation without night cooling caused 3°C higher air temperatures on the ground floor and 2-3°C higher air temperatures on the first floor than night-ventilated house. Floor surface temperatures and ground floor ceiling in House 2 were 2°C lower than House 1. Night ventilation lowered not only the air temperature, but also provided structural cooling that was maintained cooler until 8 p.m.

For all cases in the 12 p.m.-8 p.m. period, the first floor ceiling surface temperature in both houses rose dramatically compared to other measuring points. As shown in Fig. 5, first floor ceiling temperature was almost same for both houses and very close to average outdoor temperature. In sunny afternoon, the ceiling board was heated up by intense solar radiation received from the roof. In turn, the heated ceiling, due to its high heat transmittance, passed the heat to the air on the first floor. It can be seen that the ground floor was cooler than the first floor especially when windows were closed, i.e. House 2 for all cases as well as House 1 in Case 1 (Fig. 5). The average temperature difference between ground and first floor at 1.5m height was 1°C in House 2 for all cases and 2°C for House 1 in Case 1. As mentioned earlier, proper roof or ceiling insulation has not been applied in both houses. This clearly indicates that indoor temperature especially in master bedrooms (first floor) can be reduced dramatically in the afternoon by applying insulation. It can be predicted from the above results that proper insulation can reduce up to 2°C on average on the first floor at 1.5m height.

Windows were opened in House 2 (night ventilation) from 8 p.m. From 8 p.m. to 12 a.m., the temperatures in each house were less varied among different heights than the previous period (Fig. 5). Throughout this period, indoor temperatures at all points were higher than average outdoor temperature in both houses for all three cases. In Case 1, the night-ventilated master bedroom was 1-2°C higher than ambient air temperature while the ground floor was less than 1°C higher. House 1 was 2-3°C higher than outdoor temperature on the first floor and 1-2°C higher on the ground floor. In Case 2, the vertical distribution was quite similar to that of Case 1 but with less temperature difference between the two houses since both were ventilated during this period. In Case 3, daytime ventilation caused the temperatures in House 1 to be 3-4°C higher than average outdoor temperature. It was also about 2°C higher than House 2 temperatures at each respective height. In this period except for House 1 in Case 3, the afternoon heat effect was still visible in the higher ceiling surface temperature in both master bedrooms.

The windows of House 2 (night ventilation) were kept open from 12 a.m. to 8 a.m. In this final analysis period, both houses maintained higher temperatures than outdoor average temperature in all cases, whether they were in open or closed window conditions (Fig. 5). In Cases 1 and 2, the average ambient air temperature was 26°C. Average temperatures in the night-ventilated house ranged between 28°C to 29°C in both cases. Temperatures in House 1 averaged 30°C with no ventilation (Case 1) and 27°C to 29°C when ventilated full-day (Case 2). In Case 3, the average outdoor temperature was lower at 25°C. House 2 temperatures were below 28°C on the first floor and below 29°C on the ground floor while House 1 temperatures were above 29°C on both floors.

As indicated in Fig. 5 (12 a.m.-8 a.m. period), even when windows were opened at night, i.e. House 2 in all cases and House 1 in Case 2, indoor temperatures of all measuring points indicated higher values (1-4°C higher) than the ambient air temperatures. This is partly due to the low air change rate caused by the extremely low night wind speed of less than 0.4m/s on average.

4. Conclusions

This study can be concluded on the following key points:

(1) Night ventilation provided better cooling effect than no ventilation, daytime ventilation and full-day ventilation based on both temperature analysis at 1.5m height and vertical thermal distribution. Night ventilation lowered not only the air temperature, but also provided structural cooling that was maintained cooler until 8 p.m. This means that present households can reduce indoor temperature considerably by opening their windows at night and closing it during daytime unless the day is cool.

(2) First floor ceiling temperature was almost same for both houses and very close to average outdoor temperature in sunny afternoons. When windows were closed in daytime, average temperature difference between ground and first floor at 1.5m height was 1°C in House 2 for all cases and 2°C for House 1 in Case 1. As mentioned earlier, proper roof or ceiling insulation has not been applied in both houses. This clearly indicates that indoor temperature especially in master bedrooms (first floor) can be reduced dramatically in the afternoon by applying insulation. It can be predicted from the above results that proper insulation can reduce up to 2°C on average on the first floor at 1.5m height.

(3) Even when windows were opened at night, i.e. House 2 in all cases and House 1 in Case 2, indoor temperatures of all measuring points indicated higher values (1-4°C higher) than the ambient air temperature. This is partly due to the low air change rate caused by the extremely low night wind speed of less than 0.4m/s on average. The cooling effect of night ventilation may be further improved by increasing air change rate, e.g. using ceiling fan which is common in Malaysian terraced houses.

(4) This study analyzed the cooling effect of night ventilation based on one thermal parameter only, i.e. air temperature. It is suggested that other thermal parameters (humidity, air velocity and globe temperature) be included in future analysis to evaluate overall thermal comfort. In hot-humid climate as in Malaysia, the effect of high humidity level may need particular attention in thermal comfort evaluation.

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