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Investigation of Indoor Thermal Environments in a Two-Story Corner Terrace House in Malaysia

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Abstract

An effective passive cooling strategy is essential for reducing energy consumption in a residential building without ignoring thermal comfort. Therefore, a field measurement on the thermal performance of a corner terrace house in Kuala Lumpur was conducted to reveal the effectiveness of free running (FR) with four different approaches – no ventilation, full ventilation, day ventilation, and night ventilation. The measurement was done for all bedrooms and family area on the first floor. Also, mixed mode (MM) consisting of natural ventilation, mechanical ventilation with ceiling fan, and cooling with an air-conditioner that represents the actual condition of this house was also measured at living and dining area on the ground floor for comparison. The results reveal that FR from all approaches recorded a mean indoor air temperature of approximately 31 °C. The actual thermal condition of the house with MM on the ground floor was recorded at 30 °C, 1 °C lower than FR approach on the first floor. When compared with relevant international standards on predicting indoor comfort temperature based on outdoor temperature, FR was approximately 5 °C higher than predicted temperature based on American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 55 (2017), 3.4 °C higher than European Standard EN15251 and 1.5 °C higher than adaptive thermal comfort equation (ACE) for hot-humid climate. In comparison, MM performed better and was closer to relevant international standards, especially ACE for the hot-humid climate. As a conclusion, FR is not suitable for a hot-humid climate such as Malaysia to achieve a comfortable indoor thermal environment without any assisted ventilation use in MM.

Keywords: free running ventilation, mixed mode ventilation, thermal comfort, corner terrace house

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1. Introduction

In 2016, residential sector in Malaysia was the main consumer of electricity, and it contributed 21.6% of total electricity consumption, out of which 11% of the total electricity consumed in the residential sector are for space cooling purposes [1]. One of the reasons for high electricity consumption in the residential area is because of cooling demand due to high indoor air temperature. Research by Zaki et al. [2] found that indoor air temperatures in Malaysia dwellings are approximately 22 – 31 °C. The maximum temperature is much higher compared to the average comfort room temperature in Malaysia at 24 °C to 26 °C [3]. Due to the high air temperature in the house, occupants in Malaysia use 7.6 hours of air-conditioners per day to release excessive heat in the house to achieve the required thermal comfort level, especially during night time [4]. Also, Zaki et al. [2] also reported that air-conditioner was used up to 7 to 9 hours for heavy users during night time. Therefore, it is an urgent task to improve the thermal environment in residential buildings to avoid excessive usage of electricity for space cooling purpose.

According to Kubota et al. [5], most of the newly developed urban houses in this region are constructed using brick and concrete, which seem to be very different from the original nature of vernacular houses. In Malaysia, for example, brick houses account for approximately 91% of the total existing urban houses in which landed terraced houses are the most common housing type. Brick houses with a high thermal mass usually affect stabilizing the indoor thermal environment [5], but it is still unknown whether high thermal mass buildings are suitable for the hot-humid climates in Southeast Asia.

With regards to the studies above, corner unit terrace house with different building parameters and more exposure to outdoor climate compared to standard units are limited in climatic research and required further study. Therefore, the objective of this research is to reveal the indoor thermal environment with different ventilation strategies of free running mode (FR) for corner unit terrace house in Malaysia. At the same time, the actual living environment of mixed mode (MM) was also recorded for comparison. The results from FR and MM were compared with relevant international standards on predicting indoor comfort temperature based on the outdoor temperature.

2. Methodology

2.1. Investigated house

Field measurement was conducted on a two-story corner terrace house (Figure 1) located in Taman Melati, Kuala Lumpur, Malaysia (3°13'10.3"N 101°43'33.9"E) from 15th February until 11th March 2018. The total built-up area of the house is 177.7 m^2. The apartment consists of a living area, dining area, kitchen and study room on the ground floor, together with three bedrooms and a family area on the first floor. The height of the ground and first floors are 3.0 m and 3.2 m, respectively.

The construction of the house was completed in 2004 with brick walls on the reinforced concrete frame structure. The floor slabs on both floors are reinforced concrete slab. The first floor was covered with cement board ceiling and concrete roof tiles on the roof level. No heat insulation was installed in the roof attic and wall. Table 1 shows the detail information on orientation, floor area, ratios of wall and window area over room volume and specification on materials of the investigated house.

Figure 1: The investigated house: a) Location plan from Google map, b) Front view, c) Side view.

Table 1: Details information on the investigated house.

	Master Bedroom	Bedroom 2	Bedroom 3	Family Area	Living Area	Dining Area	U-value (W/m^{2}K)
Level		First			Ground		
Orientation	West	East	East/South	South	West	South	
Floor Area (m^2)	15.2	9.6	9.6	16.3	15.2	15.7	
Window	Aluminum frame fixed single clear glass casement window						5.17
Door	Solid hardwood panel door						0.64
Ceiling	4 mm thick cement board			Concrete slab			0.30
Wall material	114 mm thick a brick wall with 18 mm thick cement plaster on both sides						2.15
Floor material	150 mm thick reinforced concrete slab with 6 mm thick hard wood parquet finish.			150 mm thick reinforced concrete slab with 15 mm thick broken marble finish.			0.20
Roof covering material	Concrete roof tile						0.70
Shading device to the window	Concrete roof tile canopy roof						

2.2. Case studies

Two ventilation modes, namely free running (FR) and mixed mode (MM) were applied in this study. FR was applied at unoccupied first floor with four ventilation approaches - no ventilation (NoV), full ventilation (FuV), day ventilation (DaV), and night ventilation (NiV). The window was used as a control of ventilation by closing or opening from 8 am to 8 pm in the daytime and 8 pm to 8 am in the night time, as recommended by Kubota et al. [4], while the door was kept closed. No ventilation fan or exhaust was installed in the house. Each approach was measured for three days in consecutive days. All bedrooms and family area were not occupied, and no cooling or ceiling fans were switched on during measurement period to record the actual thermal condition with FR on the first floor. At the same time, MM was applied concurrently on the ground floor without any control of ventilation. The owner together with his wife lived on the ground floor and to maintain thermal comfort during hot days while they were in the house, a mixture mode, consisting of full natural ventilation, natural ventilation with ceiling fan or cooling (CL) only were applied. The ground floor was measured at the living and dining area to make a comparison with the first floor. Table 2 displayed the details of investigation approaches taken.

Table 2: Details of ventilation modes and ventilation approaches.

Floor	Room	Ventilation Mode	Ventilation Approach	Date	Windows Operation	
					Day (8 am – 8 pm)	Night (8 pm – 8 am)
First	Master Bedroom, Bedroom 2, Bedroom 3, Family Area	FR	NoV	15 – 18/2/2018	close	close
			FuV	18 – 21/2/2018	open	open
			DaV	21 – 24/2/2018	open	close
			NiV	8 – 11/3/2018	close	open
Ground	Living Area, Dining Area	MM	FR or FR with a ceiling fan or CL with ceiling fan	15 – 24/2/2018, 8 – 11/3/2018	Open, only close when CL was switched on.	

Note: FR: free running, MM: mixed mode, NoV: no ventilation, FuV: full ventilation, DaV: day ventilation, and NiV: night ventilation, CL: cooling mode.

2.3. Measurement setup

The indoor air temperature (T_a), relative humidity (RH_a), globe temperature (T_g) and air velocity (V_a) were measured in the master bedroom, bedroom 2, bedroom 3, and family area on the first floor and a living area and dining area on the ground floor. T_a and RH_a were measured at three different heights at 0.5 m, 1.5 m, and 2.5 min the investigated areas. On the other hand, T_g and V_a were measured at 1.5 m height from the floor. In the roof attic, roof air temperature (T_{a_R}) was measured at 0.8 m and 1.6 m above the ceiling at the center of the roof attic. Surface temperature for roof tile (T_{s_R}) was measured at the bottom surface of roof tile facing east. At the same time, top surface temperature (T_{s_CT}) and bottom surface temperature (T_{s_CB}) for ceiling board and external surface temperature (T_{s_WE}) and internal surface temperature (T_{s_WI}) of the external wall were measured at the family area.

The outdoor air temperature (T_o), relative humidity (RH_o), and wind speed (V_o) were measured at the open space beside the house. The T_o and RH_o were measured at three levels at 1.5 m, 3.0 m, and 4.5 m from the ground. The external sensor was housed in a fan aspirated solar shield to avoid any effect of solar radiation. Simultaneously, solar radiation (*SR*) was measured at 5.0 m height from the ground. Meanwhile, V_o was measured at 1.7 m height. Penetration of heat between indoor and outdoor was studied through measurement of airtightness of each investigated room. It was measured based on the estimated air change rate per hour (*ACH*) using the gas traced method of CO_2 concentration.

The instruments used in this field measurements were listed in Table 3. Figure 2 shows the locations of the setup of the devices and the climatic parameters measured. All indoor and outdoor devices record at a minute interval, except for CO_2 concentration, which was at 15 seconds interval. All instruments were calibrated, and their consistency was verified before measurement.

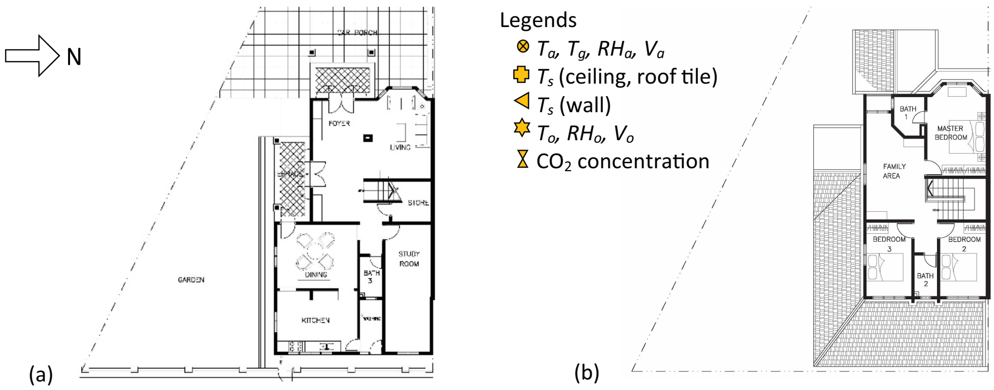

Figure 2: Schematic view on the location of measurements in the investigated building: a) Plan view of the ground floor, b) Plan view of the first floor.

3. Results and Discussions

TABLE 3: List of instruments used.

Instrument	Parameter	Manufacturer, Country	Sensor Type	Resolution	Accuracy and Range
Indoor					
Thermo recorder U12-013	T_a T_g RH_a	Onset, USA	External sensor tmc1-hd External sensor tmc1-hd + 40mm black sphere Internal sensor	0.03 °C 0.05% *RH*	±0.35 °C [0 to 50 °C] ±2.5% *RH* (10% to 90%)
Hot-wire anemometer	V_a	Kanomax, Japan	Needle probe 6542-2G	0.01 m/s	±2% of reading or ±0.015 m/s whichever is greater
TR-76Ui	CO_2 concentration	T&D, Japan	Internal sensor		±50ppm ±5% reading [0 to 9999 ppm]
Data logger GL820	T_a T_s	Graphtec, Japan	Thermocouple type K		±(0.05 % of reading +1.0 °C)
Outdoor					
Thermo recorder U12-013	T_o RH_o	Onset, USA	External sensor tmc1-hd Internal sensor	0.03 °C 0.05% *RH*	±0.35 °C [0 to 50 °C] ±2.5% *RH* (10% to 90%)
Ultrasonic anemometer HD52.3D	V_o	Deltaohm, Italy	Ultrasonic	0.01 m/s	±0.2 m/s or ±2% [0 to 35 m/s], ±2% [>35 m/s]
Multifunction data logger HD31	CO_2 concentration	Deltaohm, Italy	HD31.B3 CO_2 probe	1 ppm	±(50 ppm + 3% of measure) [0...5,000 ppm]

3.1. Variations of indoor and outdoor climatic parameters

Table 4 summarized the mean of indoor climatic parameters across four ventilation approaches for all investigated rooms. Mean T_a was approximately 31 °C with FR and 30 °C with MM. The range of T_a on the first floor with FR was 27 – 37 °C. It was wider than the findings by Zaki et al. [6] on the indoor temperature of 29 – 31 °C before AC was switched on for apartments in Kuala Lumpur.

On the other hand, on the ground floor with MM, the range of 27 – 33 °C is slightly wider and closer to Zaki et al.'s [6] findings. Figure 3a showed the sharp drop of T_a when CL was switched on during hot days at the living area with MM mode. The overall results are higher than the requirement on normal comfort room temperature in Malaysian Standard of 24 – 26 °C [3]. Meanwhile, the mean RH_a were 62 – 64% with FR, and 68 – 69% with MM. This is because ground floor with MM has higher relative humidity compared to the first floor due to better ventilation approach especially during NoV and DaV, where windows were closed at night for FR.

Figure 3c shows the overall T_g was approximately 27 – 38 °C on the first floor and 27 – 33 °C on the ground floor and was generally similar to the T_a on first and ground floor. The mean V_a below 0.1 m/s on the first floor is insignificant. However, on the ground floor, it was approximately 0.1 - 0.39 m/s. The higher V_a at ground floor, especially at the living area during NiV, was due to the use of ceiling fan by the owners. The mean V_o recorded at outdoor was 0.55 m/s with a maximum V_o of 2.92 m/s. The mean *SR* recorded during daytime was 0.45 kW/m^2 with a maximum of 1.19 kW/m^2.

In general, NiV recorded the widest range of T_a approximately 27 – 37 °C followed by FuV of 27 – 36 °C, DaV of 27 – 35 °C, and NoV of 28 – 36 °C. The minimum temperature is almost identical with only 1 °C difference for all FR approaches. Contrarily, for maximum temperature, the difference is 2 °C apart. The highest T_a of 37 °C was recorded in NiV.

Table 4: Mean indoor climatic parameters for all areas across four ventilation approaches.

Room	**Mode**	**Variable**	**T_a (°C)**	**RH_a (%)**	**T_g (°C)**	**V_a (m/s)**
Master Bedroom	FR	Mean	31	64	31	0.03
		S.D.	1.7	5.5	1.8	0.02
Bedroom 2	FR	Mean	31	63	31	0.03
		S.D.	1.6	5.6	1.6	0.02
Bedroom 3	FR	Mean	31	62	31	0.03
		S.D.	2.3	7.3	2.3	0.01
Family Area	FR	Mean	31	64	31	0.06
		S.D.	1.5	6.1	1.4	0.03
Living Area	MM	Mean	30	68	30	0.39
		S.D.	0.7	4.7	0.7	0.12
Dining Area	MM	Mean	30	69	30	0.05
		S.D.	0.9	5.2	0.9	0.05

Note: FR: free running, MM: mixed mode, S.D.: standard deviation, T_a: air temperature, RH_A: relative humidity, T_g: globe temperature, V_a: air velocity.

Further study was carried out in the family area to investigate the influence of roof attic and the external wall on the indoor thermal environment by measuring the surface temperature of roof tile, ceiling board, and brick wall. Figure 3a and 3b show the variation in temperature for this measurement across the four ventilation approaches applied in the family area. Roof tile surface with direct exposure to solar radiation recorded a mean T_{s_R} of 34.3 °C, followed by T_{a_R} in the roof attic of 32.3 °C, ceiling top surface T_{s_CT} of

31.7 °C, ceiling bottom surface T_{s_CB} of 31.6 °C, external surface T_{s_WE} of external wall of 30.3 °C, internal surface T_{s_WI} of external wall of 30.5 °C. However, the recorded indoor T_a was approximately 31 °C, which was very close to the internal surface T_{s_WI} of the external wall. At the same time, the recorded outdoor mean T_o is approximately 28.6 °C.

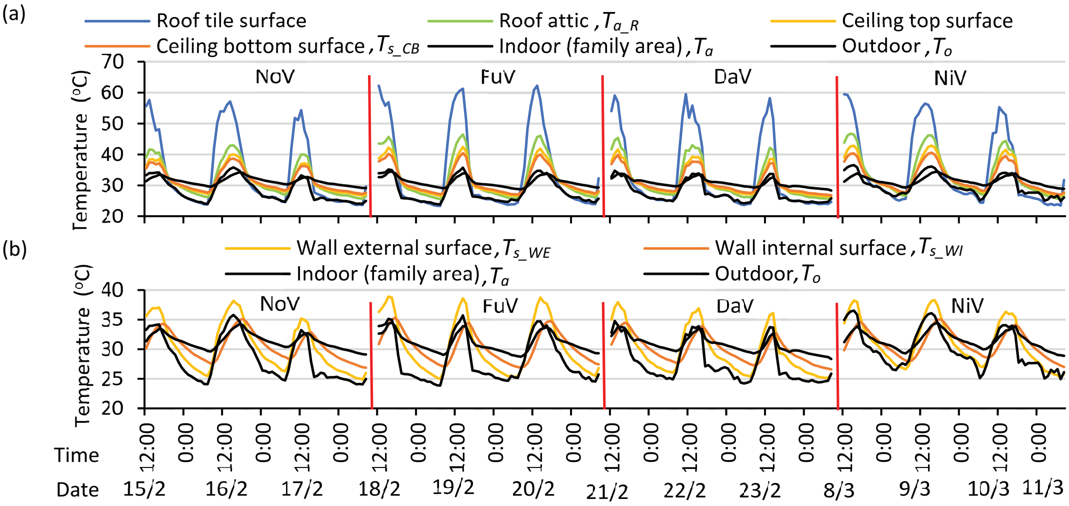

Figure 3: Comparison between T_s and T_a across four ventilation approaches on: a) T_s for top and the bottom surface of ceiling board and roof tile, and T_a for roof attic, b) T_s for the external and internal surface of external wall, and T_a for indoor and T_o for outdoor.

Figure 4 and Table 5 shows the regression analysis on the correlation between T_o and T_a across four ventilation approaches. All correlations were found to be statistically significant ($p < 0.05$) for all bedrooms. FuV and DaV recorded better correlation between T_o and T_a compared to NoV and NiV with a higher R^2 value. When comparing between bedrooms, T_a in bedroom 2 has a stronger relationship with T_o compared to bedroom 3 with the same floor area.

3.2. Vertical variations of indoor and outdoor air temperatures

Figure 5 shows the vertical variations of mean T_a at three different heights for all investigated rooms and roof attic with different ventilation approaches. Also, the T_o was also plotted together with SR and prevailing winds. With FR on the first floor, the mean T_a was found lower near the floor level and gradually rose vertically to the ceiling level. It was recorded at 30.6 °C at 0.5 m levels, 31.2 °C at 1.5 m levels, and 31.7 °C at 2.5 m. At ground floor with MM, the mean T_a at 0.5 m level was 29.4 °C, 29.7 °C at 1.5 m levels, and 30.1 °C at 2.5 m levels. FR recorded much higher T_a compared to MM. Across four ventilations, NiV recorded the highest mean T_a with 30.9 °C at 0.5 m levels, 31.6 °C at 1.5 m level and 32.3 °C at 2.5 m level. At the same time, the vertical variations

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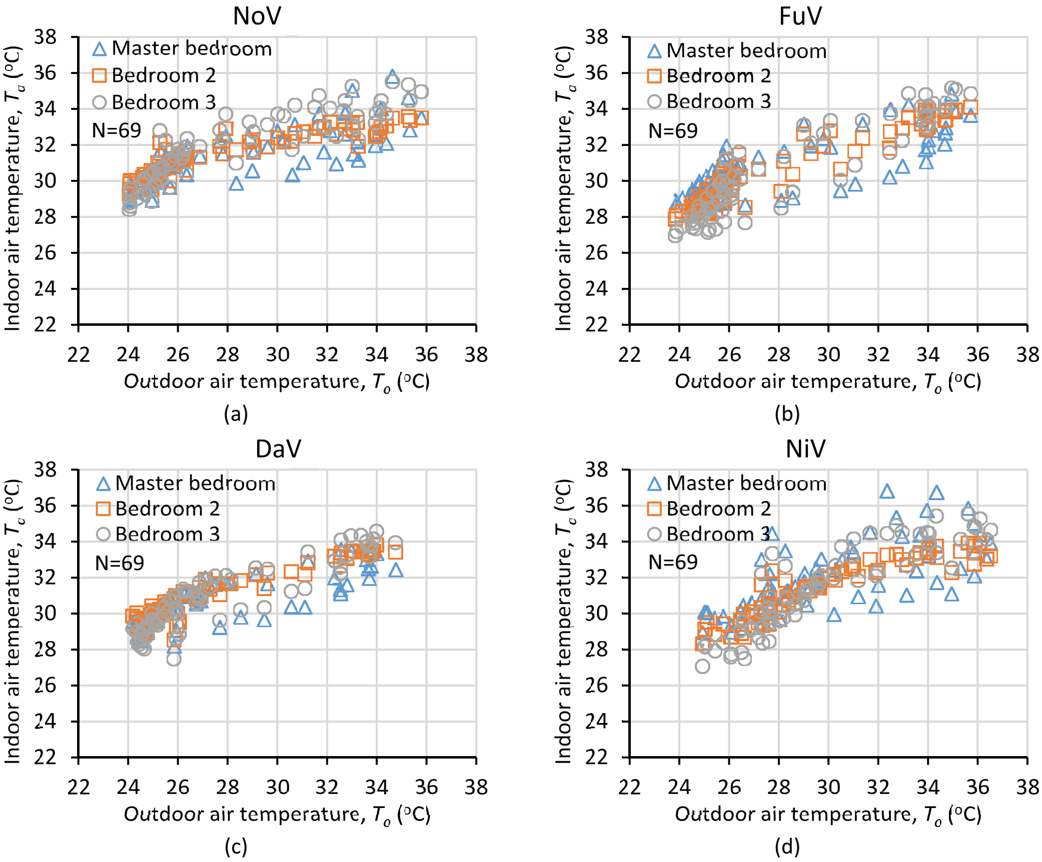

Figure 4: Correlation between T_o and T_a across four ventilation approaches: a) NoV, b) FuV, c) DaV, d) NiV. The dotted line shows the regression equations: blue – master bedroom, orange – bedroom 2, grey – bedroom 3.

of mean T_o at outdoor are very minimal with 28.8 ˚C at 1.5 m, 28.7 ˚C at 3.0 m and 28.6 ˚C at 4.5 m.

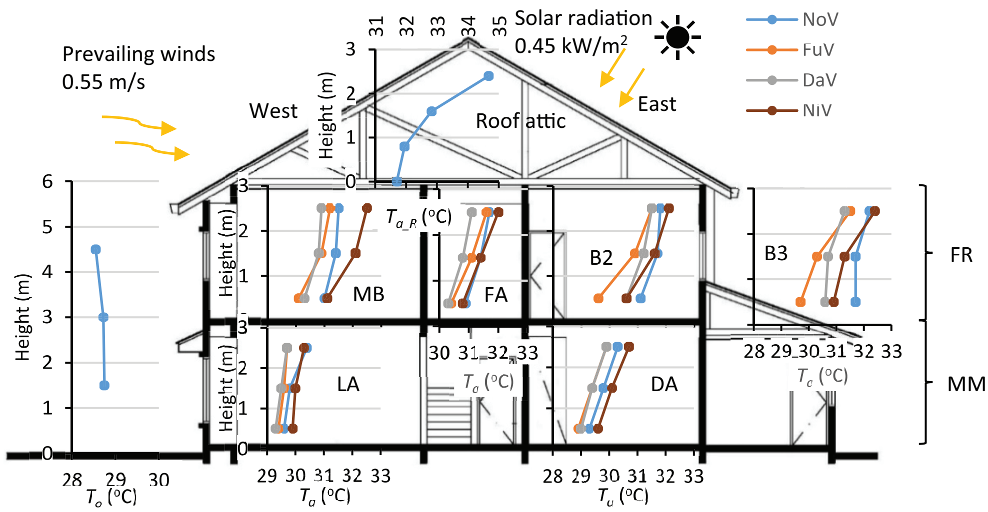

Figure 5: Vertical profile of average indoor T_a and outdoor T_o at three different heights across four ventilation approaches.

TABLE 5: Mean indoor climatic parameters for all areas across four ventilation approaches.

Room	Master bedroom	Bedroom 2	Bedroom 3
No ventilation (NoV)			
Equation	$T_a = 0.348T_o + 21.0$	$T_a = 0.417T_o + 19.5$	$T_a = 0.508T_o + 16.8$
R^2	0.67	0.89	0.81
p	$p < 0.001$	$p < 0.001$	$p < 0.001$
Full ventilation (FuV)			
Equation	$T_a = 0.355T_o + 20.7$	$T_a = 0.491T_o + 16.8$	$T_a = 0.622T_o + 12.9$
R^2	0.63	0.89	0.85
p	$p < 0.001$	$p < 0.001$	$p < 0.001$
Day ventilation (DaV)			
Equation	$T_a = 0.348T_o + 21.0$	$T_a = 0.417T_o + 19.5$	$T_a = 0.508T_o + 16.8$
R^2	0.67	0.89	0.81
p	$p < 0.001$	$p < 0.001$	$p < 0.001$
Night ventilation (NiV)			
Equation	$T_a = 0.404T_o + 19.8$	$T_a = 0.435T_o + 18.4$	$T_a = 0.642T_o + 12.2$
R^2	0.49	0.84	0.80
p	$p < 0.001$	$p < 0.001$	$p < 0.001$

Note T_a: indoor air temperature, T_o outdoor air temperature, R^2: coefficient of determination, p: significance level of the regression coefficient.

3.3. Comparison between indoor and outdoor air temperatures

Figure 6 shows the variations on the differences between indoor T_a and outdoor T_o across four ventilation approaches for all the investigated areas. The conditions of T_o are quite identical for NoV, NiV and DaV with mean T_o at approximately 28 °C, except NiV with a higher T_o at 30 °C. The mean difference between T_a and T_o was lower during NiV across all investigated areas with NoV of 3.2 – 3.6 °C, FuV of 2.4 – 3.6 °C, DaV of 3.1 – 3.5 °C, and NiV of 1.9 – 2.8 °C especially B2 and B3 with 1.9 °C and 2.2 °C, respectively.

Figure 8a,b analyzed further the differences between four ventilation approaches for a whole day and during nighttime for all areas. For whole day measurements, rooms at first floor with FR recorded a difference of 1.9 – 3.7 °C, a wider range compared to the ground floor with MM of 2.6 – 3.6 °C. During the nighttime, the difference was much higher between indoor and outdoor when compared to a whole day. The first floor was recorded approximately 2.2 – 4.9 °C while the ground floor was 2.3 – 4.0 °C.

International Energy Conservation Code (IECC) 2012 [7] recommended an air leakage rate of less than or same as 5 *ACH* for residential energy efficiency design in a tropical climate. The measured *ACH* for investigated rooms with FR under NoV approach are 0.58 *ACH* for master bedroom, 0.45 *ACH* for bedroom 3, and 0.36 *ACH* for bedroom two which are much lower than the standard. The low *ACH* reflected proper airtightness of the rooms and minimum heat gain through gaps within the building envelope.

Meanwhile, NoV has the highest difference between T_a and T_o compared to other FR ventilation approaches, with master bedroom and bedroom 2 recording a temperature of 3.6 °C, and 3.7 °C for bedroom 3 (Figure 8a). The difference in temperature and *ACH* between three different rooms did not show any significant relationship.

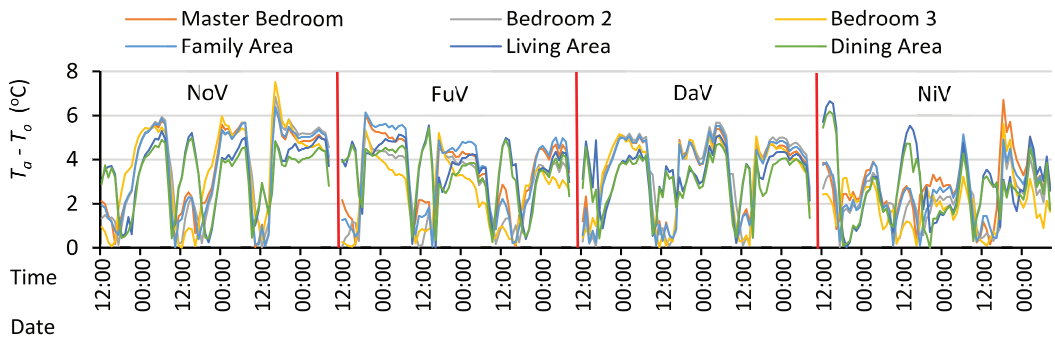

Figure 6: Variation of air temperature difference between indoor and outdoor across four ventilation approaches.

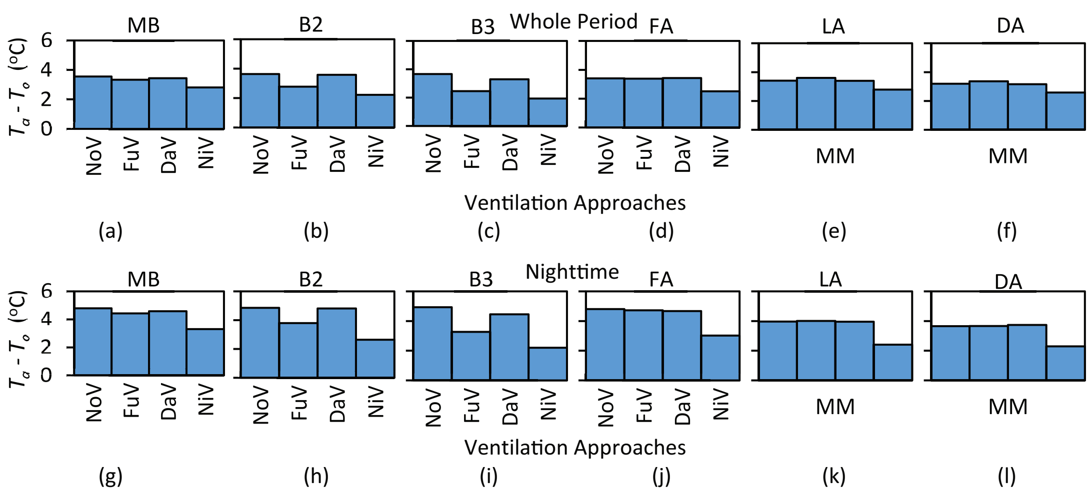

Figure 7: Variation of the mean air temperature difference between indoor and outdoor across four ventilation approaches for the whole period (a) – (f) and nighttime (g) – (l).

3.4. Evaluation of indoor comfort temperature using adaptive comfort standards

The calculated operative temperature (T_{op}) under each ventilation strategy can be compared with the predicted indoor comfort temperature using adaptive comfort standards [4]. According to various adaptive comfort standards, the pleasant indoor comfort temperature based on T_{op} for a natural ventilated space can be predicted using outdoor T_o. Different standards adopted slightly different equations on predicting the comfort temperature. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 55 (2017), section 5.4 [8] defines the acceptable thermal environment for occupant-controlled naturally conditioned spaces is based on 80% acceptability limits of T_{op} in the space. The equation for the calculation of indoor

$$T_{op} is : T_{comfop} = 0.31T_{outmm} + 17.8 \quad (1)$$

Where T_{comfop} is indoor neutral T_{op} (°C), and T_{outmm} is daily mean outdoor air temperature (°C). However, European Standard EN15251 [9] adopted a different equation in the calculation of acceptable indoor temperatures for the design of buildings without mechanical heating and cooling systems. The equation under Annex A2, EN15251 is:

$$T_{comfop} = 0.33T_{outmm} + 18.8 \quad (2)$$

Further to that, Toe et al. [10] developed an adaptive thermal comfort equation for naturally ventilated buildings in hot-humid climates using ASHRAE RP-884 database. The equation is:

$$T_{comfop} = 0.57T_{outmm} + 13.8 \quad (3)$$

Indoor T_{op} can be calculated based on measured data. Table 6 summarises the average values for the calculated mean radiant temperature (T_{mrt}), T_{op} and absolute humidity (*AH*) climatic parameters in all rooms with different ventilation modes and approaches. The calculated T_{op} was consistently at approximately 31 °C on the first floor with FR and about 30 °C at ground floor with MM. In Figure 8, the calculated T_{op} for all rooms across two ventilation modes (FR and MM) and four ventilation approaches of FR are plotted against 80% of three comfortable temperatures predicted from adaptive thermal comfort equation (ACE). The predicted comfortable temperature ranges from 25.4 – 26.6 °C for ASHRAE Standard 55, 27.0 – 28.2 °C for EN15251, and 28.4 – 30.6 °C for ASHRAE RP-884 database of the hot-humid climates. The results show that the first floor with FR mode of natural ventilation across four ventilation approaches do not comply with the predicted comfortable indoor T_a under all three standards. However, ground floor with MM mode of ventilation complied with the equation developed for the hot-humid climate. FR or MM mode, as well as NoV, FuV, DaV and NiV, which were closer to the mark, were unable to meet the requirements of ASHRAE 55 and EN15251.

Table 6: Average values for climatic parameters in all rooms and ventilation modes.

Room	Mode	Variable	T_{mrt} (°C)	T_{op} (°C)	AH (g/kg$_{DA}$)
Master bedroom	FR	Mean	31.3	31.3	18.2
		S.D.	1.8	1.8	1.0
Bedroom 2	FR	Mean	31.1	31.2	18.0
		S.D.	1.6	1.6	1.0
Bedroom 3	FR	Mean	31.3	31.2	17.6
		S.D.	2.4	2.3	1.0
Family area	FR	Mean	31.1	31.1	18.2
		S.D.	1.4	1.4	1.0
Living area	MM	Mean	30.3	30.0	18.0
		S.D.	0.7	0.7	1.2
Dining area	MM	Mean	29.6	29.7	18.2
		S.D.	0.9	0.9	1.1

Note FR: free running, MM: mixed mode, S.D.: standard deviation, T_{mrt}: mean radiant temperature, T_{op}: operative temperature, *AH*: absolute humidity.

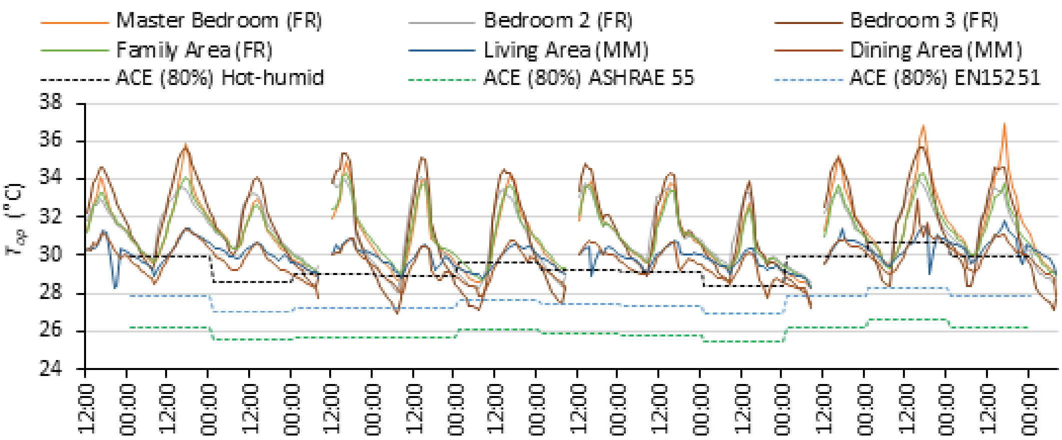

Figure 8: Comparison of the variation of operative temperature for all rooms across four ventilation approaches against related international standards.

4. Conclusions

The objective of this research to reveal the indoor thermal environment of FR ventilation with different approaches and compare with actual thermal conditions with MM ventilation for corner unit terrace house was achieved with some significant findings as follows:

1. The mean T_a on the first floor with FR ventilation was approximately 31 °C and 30 °C on the ground floor with MM ventilation.

2. The mean T_a was found lower near to floor level and gradually rose vertically to the ceiling level. It was recorded at 30.6 °C at 0.5 m levels, 31.2 °C at 1.5 m levels, and 31.7 °C at 2.5 m. During the nighttime, the difference was much higher between indoor and outdoor when compared to a whole day. The first floor was recorded approximately 2.2 – 4.9 °C and ground floor was 2.3 – 4.0 °C.

3. The calculated T_{op} at first floor was 31 °C, and it was approximately 5 °C higher than acceptable predicted comfort temperature by ASHRAE Standard 55, 3.4 °C higher than EN15251 and 1.5 °C higher than ACE hot-humid. At the ground floor, the calculated T_{op} was 30 °C. FR ventilation cannot achieve the predicted indoor thermal comfort temperature under the ASHRAE 55, EN15251 and ACE hot-humid. However, MM ventilation performed better with 1 °C lower than FR.

In conclusion, FR ventilation is not suitable for a hot-humid climate such as Malaysia to achieve a comfortable indoor thermal environment without any assisted ventilation use in MM ventilation.

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