POTENTIAL DESIGN PARAMETERS FOR ENHANCING THERMAL COMFORT IN TROPICAL TERRACE HOUSE: A CASE STUDY IN KUALA LUMPUR

Nasibeh Sadafi, Elias Salleh, Lim Chin Haw and Mohd. Fakri Zaky Jaafar
Department of Architecture, Faculty of Design and Architecture,
Universiti Putra Malaysia, Malaysia

ABSTRACT

Thermal comfort conditions in residential buildings vary according to the designs, modifications of the house and adaptation of the occupants. While air-conditioning is the most popular form of adaptation, natural ventilation is still relied upon for some parts. This study investigates thermal comfort performance of terrace housing in Kuala Lumpur, Malaysia, using Fanger's predicted mean vote (PMV) thermal comfort index. A case study of a terrace house was carried out in a housing scheme in Kuala Lumpur where field measurement was conducted during a three-day recording in naturally-ventilated space of the house. The study showed that the house was thermally comfortable for almost fifteen hours during day and night. Comfort conditions mostly occurred during night hours while around noon hours could be considered as critical times. To improve the thermal conditions, ceiling fans were used to increase the indoor air velocity. However, it was observed that this measure did not improve the thermal comfort condition when the air temperature had reached its maximum level. On the other hand, reducing the solar heat gain could improve the thermal comfort condition of the house.

Keywords: Thermal Comfort, Terrace House, Predicted Mean Vote

1. INTRODUCTION

The concerns over global warming and the need for reduction of high emission of greenhouse gases demand the utilization of strategies for indoor climate modification in promoting comfortable indoor environment (Givoni, 1994). In warm humid tropics, overheated building interior is common due to solar penetration through the building envelope and windows and lack of ventilation (Rajapaksha et.al., 2003). Terrace houses, as one of the most common typologies of residential buildings in Malaysia, are also faced with these problems. Due to the high density of the building blocks and crowded dwellings, a large number of buildings do not fulfill the requirements for thermally comfortable environment. Several studies have been undertaken by researchers in Malaysia in relation to thermal comfort in residential buildings (Abdulshukor, 1993; Zainal, 1996; Ahmad, 2002, Zainudin et.al., 2006). The main scope of these studies was to find the neutral temperature according to the country's tropical climate. Findings revealed a higher comfort temperature in comparison with those recommended by international standards where in naturally-ventilated buildings the upper range of comfort could be stretched with the aid of higher natural air movement. The main concern was the variations of air temperature and its effects on the occupant's thermal sensation. The study finds a dearth of comprehensive studies on the thermal performance of terrace houses in Malaysia.

This study has two main objectives:

1) To measure the thermal comfort conditions in a case study terrace house located in Kuala Lumpur, Malaysia.
2) To model the comfort conditions of the case study terrace house by investigating the thermal variations in the building.

According to climatic evaluations for Malaysia, April is considered as one of the hottest months during the year (MMR, 2007). So the monitoring of thermal behavior for this case study building was conducted on site between 10^{th}-13^{th} April 2007. This paper discusses the results of the building's thermal performance by calculating the predicted mean vote (PMV) as well as utilizing computer simulation which help to assess the improvement of the thermal condition based on the suggested alterations.

2. THERMAL COMFORT

The first major issue about climate is the comfort level (Salleh, 2004). This thermal sensation is affected by environmental factors: air temperature, mean radiant temperature, air movement, humidity as well as the clothing worn and the activity being performed. There have been several attempts by researchers to produce a unified mean of assessing thermal comfort by taking into account some or all of these factors into a single index.

An elaborate prediction of thermal comfort at steady-state conditions had been carried out by Fanger (1970). Even though his experiments were conducted in temperate climate, Fanger proposed that PMV can be used for the tropics by applying the method based on the findings of Ellis (1953). In his work, Ellis investigated European and Asian subjects in Singapore and the established thermal neutrality was found to be similar to the value proposed by PMV.

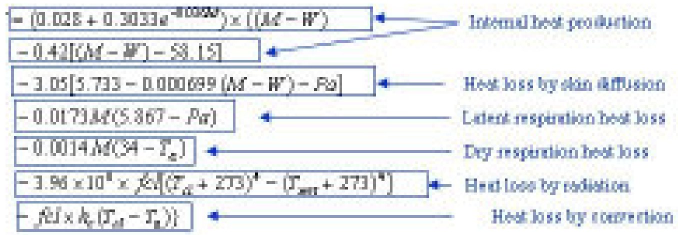
While several field studies using the Fanger's PMV-PPD (Predicted Mean Vote-Predicted Percentage of Dissatisfied) method seem to agree with the results obtained, a study by de Dear et al. (1998) has found discrepancies with it. It found that PMV can predict the comfort temperature for air-conditioned buildings more accurately as opposed to naturally-ventilated buildings where people are more acceptable to higher internal temperatures. These new trends produced an extension of the PMV model for naturally-ventilated buildings in warm climates (Fanger and Toftun, 2002). In the latter study, an expectancy factor is proposed for non-air-conditioned buildings which will be multiplied with PMV. Current study applies the expectancy factor of 0.9.

Table 1: Expectancy Factor for Non Air-conditioned Buildings in Warm Climate (Source: Fanger and Toftun, 2002)

Expectation	Classification of non-air-conditioned buildings		Expectancy factor, e
	Location	Warm periods	
High	In regions where air-conditioned buildings are common	Occurring briefly during the summer season	0.9-1.0
Moderate	In regions with some air-conditioned buildings	Summer season	0.7-0.9
Low	In regions with few air-conditioned buildings	All seasons	0.5-0.7

The basis of Fanger's (1970) comfort index was obtained from conducted experiments where the thermal sensation votes indicated the personally experienced deviation to the heat balance. The index is based on a seven point scale, from -3 [cold] to +3 [hot], 0 being neutral (optimum). Fanger's (1970) PMV formula is:

PMV=



Where M: metabolism (w/m2)
W: external work, equal to zero for most activity (w/m2)
M: metabolism (w/m2)
Icl: thermal resistance of clothing (clo)
fcl: ratio of body's surface area when fully clothed to body's surface area when nude
Pa: partial water vapor pressure (Pa)

3. TERRACE HOUSE

Commonly called link or terrace house, they are attached houses with similar façade treatment. Terrace houses are the ubiquitous form of housing in Malaysia in single or double stories. Each house unit occupies a rectangular lot with a land area between 130 and 170 square meters. The choicest unit, located on a corner lot, is usually twice as large as the intermediate lots. With such spatial constraints, the planning of these houses is usually predictable and mundane: deep living spaces, a smaller rear kitchen, and bedrooms with toilets. On the upper floors are the master bedroom (including toilet) and bedrooms. Nevertheless, this typology remains the mainstay of the country's mass housing strategy (Salleh, 1989). However, due to low benefits, developers have not put much effort into these sectors as compared to the medium and high-end sectors. Several studies in Malaysia have revealed that the modern terrace houses have not been built according to the country's climatic features (Takahashi, 1981; Mohamad Ali, 2003). Many of the houses have been built in unsuitable orientations without appropriate shading design. Furthermore, building materials tend to collect heat most of the time and the house design has limited front and back openings on the building. Due to these characteristics, we can claim that most terrace house designs have ignored the importance of thermal comfort zone in the interiors. Therefore, an investigation on climatic design considerations for fulfillment of thermal comfort in existing modern terrace houses seems necessary.

4. AMBIENT CLIMATE

The study area is located in Kuala Lumpur, which is situated at latitude 3° 7' N and longitude 101° 33' E. Being close to the Equator, the hot and humid conditions are emphasized with heavy rain fall and sunshine throughout the year.

It has a yearly mean temperature of about 27°C and relative humidity (RH) of 70% to 90% throughout the year (Sabarinah, 2007). The monthly mean of maximum temperature values ranges from 33.5°C in March and April to 31.9°C in December while the monthly mean of minimum temperature values ranges from 23.1°C in January to 24.3°C in May (MMR, 2007).

On the average, Malaysia receives about 6 hours of sunshine per day with most places recording solar radiation ranging from 14 to 16 MJm^{-2} per day. Rainfall distribution pattern over the country is recorded from 2500 mm to 3500 mm which is the result of seasonal wind flow patterns coupled with the local topographic features. In fact, Malaysia experiences uniform high temperature and high humidity throughout the year accompanied by heavy rain falls and weak wind velocity. Heat and humidity are the main issues that need to be considered in order to achieve comfort in this climate.

5. METHODOLOGY

There are different investigative techniques in thermal comfort studies. Steady-state models are developed by climate chamber studies while adaptive models rely on findings from field studies. The main advantage of the field studies is the inclusion of dynamics of real life conditions of an occupied space under investigation which is deemed more valid for specific situations. However, the drawback of this method is the uncertainty factor due to lack of control of the parameters. Computer modeling with both 'climatic chamber studies' and 'field surveys' is one of the common methods used to analyse the results as well as to verify the validity of the findings. It can be used in these areas of researches as it helps to consider various conditions for buildings (Tablada, 2002; Muhaisen, 2006). In this study, field measurement is conducted for monitoring the thermal behavior of the case study building. Based on the results and evaluations of the field measurements, thermal condition is simulated using ECOTECT software in order to improve the thermal sensation.

5.1 The Investigated Building

A double storey terrace house with a built-up area of 219 m^2 was selected for the case study. The ground floor consists of family areas (kitchen, living area, dining area and utility) and the first floor consists of bedrooms and bathrooms.

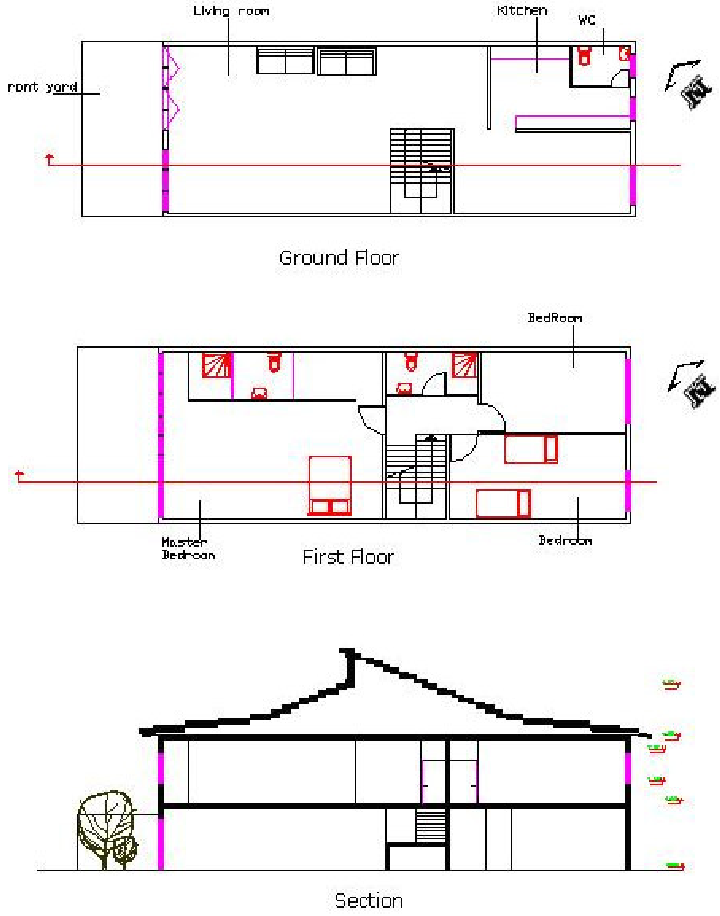


Figure 1: Floors plans and longitudinal section of the case study terrace house.

The building openings are oriented in NorthWest-SouthEast direction where the front façade (NW) has large windows to enhance cross ventilation as well as to admit natural lighting in the building (refer to Figure 2)

Figure 2: Front facade of the case study building.

5.2 Data Collection

The building was monitored for three days from 10th to 13th April 2007. Under each boundary configuration namely, "air temperature, relative humidity, air velocity and globe temperature", the building was monitored using "Inova Thermal Data Logger equipment" which was programmed to record the readings at every ten-minute interval. Globe temperature is the nearest value to Mean Radiant Temperature (MRT). The measurement system was placed at the central part of the family area (in the middle of the living and dining area on the ground floor) at '1.1m' above floor level. The data was downloaded by 7701 Demo software and the output file was then exported to Microsoft Excel 2003 spreadsheet for analysis.

5.3 Assessment Tool

The assessment of measurements is mainly concerned with the variation of PMV during day and night. To calculate PMV, a program was developed by VB (Visual Basic) as macro in Excel.

5.4 Assumptions of the Study

In order to relate to normal daily living, different values of "Clothing Insulation and Metabolic Rate" factors were assigned according to the "time of the day" and "occupants conditions". These assumptions are shown in Table 2.

Table 2: Assumptions in PMV Calculation

Factor	Assumptions	
	Time	Value
Clothing Insulation (Clo)	7:30 a.m. – 7:30 p.m.	0.6 (Trousers, cotton and open-neck shirt)
	7:30 p.m. – 7:30 a.m.	0.4 (under wear + normal trousers + T-shirt)
Metabolic Rate (Met)	8:00 a.m. – 9:30 p.m.	1.2 (Standing relax)
	9:30 p.m.-11:00 p.m.	1.0 (Seated Relax)
	11:00 p.m. – 6:30 a.m.	0.8 (Reclining)

6. RESULTS AND DISCUSSION

As different individuals, although living under the same conditions, the evaluation of thermal environments in any given condition will give a range of responses (Al Obaidi, 2003). Thus, using PMV as a seven-point scale, it is possible to find out the proportions of respondents who fall into each of the categories at a particular environmental condition. Then the needed amendments to improve the uncomfortable conditions are recommended. This section will discuss the results in terms of PMV variations and the effects of air velocity, mean radiant temperature and shading.

6.1 PMV Variations

Overall, the PMV ranges from -1.4 to +2.7 with the minimum value of -1.4 at 3.30 a.m. and the maximum value of +2.7 at 3.30 p.m. (Figure 3). This range can be divided into three different comfort conditions as follows:

i) Comfortable condition (PMV -1.4 to 1.5)
ii) Acceptable condition (PMV +1.5)
iii) Uncomfortable condition (PMV +1.7 to +2.7)

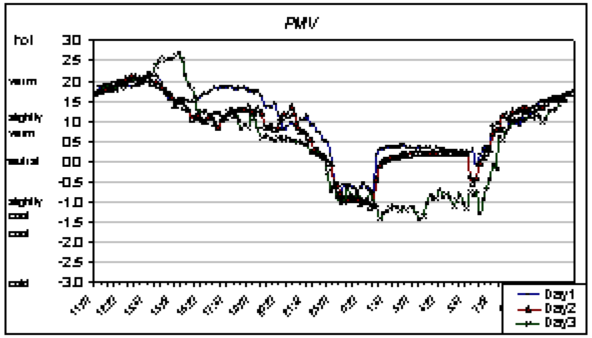


Figure 3: Variation of PMV at the ground floor family area during three days field measurement.

<u>Comfortable Condition</u>
This condition of PMV between -1.4 to +1.5 occurred during the following hours:

i) Between 7.00 a.m. to 9.00 a.m.
ii) Between 8.30 p.m. to 11.30 p.m., and
iii) Between 11.30 p.m. until 6.30 a.m.

The comfortable condition existed because of the following factors:

Air temperature. During these hours the air temperature ranged from 26.0°C to 28.5°C, which was near to the comfort range of 26.0°C - 29.5°C for Kuala Lumpur (Sabarinah, 2007). Coupled with reduced or complete absence of solar radiation, this range helped the occupants to feel reasonably comfortable.

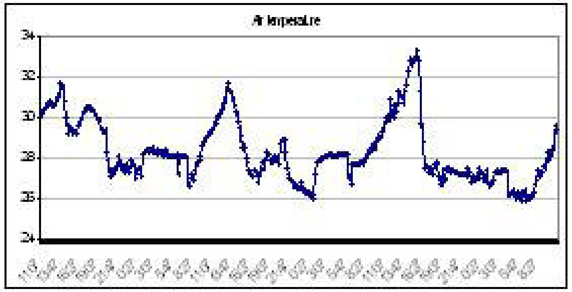


Figure 4: Temperature variations during three days field measurement.

Radiant temperature. After sun set and in the first hour of sunrise, almost no solar radiation would pass through the environment such that terrestrial surfaces did not get heated up. Nevertheless, absorbed heat did get released to the cooler surroundings in the early hours of the night depending on the thermal design of building elements. In this case the globe temperatures were noticeably lower than air temperatures.

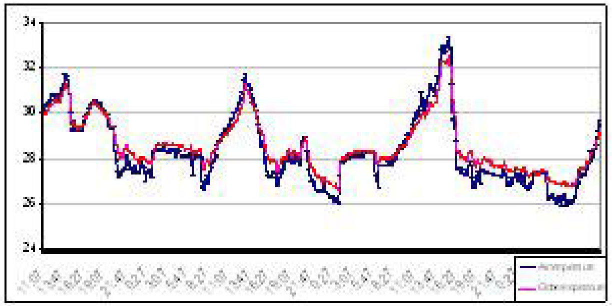


Figure 5: Globe temperature and air temperature variations during three days field measurement.

Decrease in Metabolic Rates. Normally muscular activity would decrease during night hours where the occupants would produce less heat (energy) by metabolism and feel more comfortable. The amount of metabolic (Met) value would decrease from 1.2 to 0.8 during these hours. This decline contributed to the comfortable condition.

<u>Acceptable Condition</u>

This condition of PMV around +1.5 occurred during the following hours:

i) Between 9.30 a.m. to 11.00 a.m. and

ii) Between 6.30 p.m. to 8.00 p.m.

The reason for this condition could be attributed to the air temperature and globe temperature. During these hours the air temperature had a range of 28.5°C to 29.5°C where it was very close to the upper limit of acceptable range for comfort (26.0°C to 29.5°C). Due to the absorbed heat through the terrestrial surfaces during the day, the globe temperature had higher values in comparison with the air temperature.

<u>Uncomfortable Condition</u>

This condition of PMV between +1.7 to +2.7 occurred between 11.00 a.m. to 8.00 p.m.

This is the worst condition in terms of thermal comfort in the terrace house during the field measurement period. This is due to the following factors:

Air Temperature. The air temperature ranged from 29.5°c to 33.3°C during this period which was well above the comfort range for Kuala Lumpur (26°C - 29.5°C).

Globe Temperature. During the day time, the surface of the building would receive more heat from the sun. The stored heat through the materials would be radiated into the interior of the house and consequently increase the mean radiant temperature.

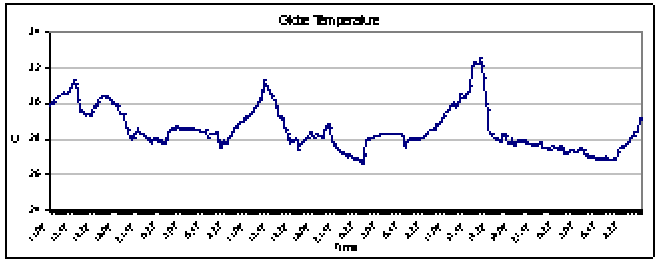


Figure 6: Temperature variations during three days field measurement.

Metabolic Rate. Ordinary muscular activities increased during day hours and the occupants would produce more heat by metabolism and feel more uncomfortable. The amount of Met value would increase from 1.0 to 1.2 during these hours. This aspect contributed to more uncomfortable condition.

6.2 Effect of Air Velocity

Ventilation provides comfortable indoor thermal condition by preventing the body from feeling hot and wet. In order to cool the body the air movement must have a sufficient speed to be felt at body level. If the air movement is not felt, it is not providing the effective convective cooling (Evans, 1980). According to the data from the field measurement, the interior air speed especially during uncomfortable hours was very low (less than 0.3 m/s). In order to improve the thermal condition, an attempt was made to evaluate the effects of using ceiling fan to increase the air velocity in internal areas.

In a high air temperature condition (31ºC), different settings for the fan had been tested to verify the influence of air velocity in an area underneath the ceiling fan at "1.1m" above the floor level. As shown in Table 3, changing the fan speeds to 1m/s would affect the air velocity and change the PMV values. The significance of these changes was that although the air velocities were changed up to 4.3m/s (by using the fan) the variation of PMV under conditions with higher air temperature would not change considerably. For example in Table 3, at 1.47 p.m. which had the air temperature around 31.7°C, increasing the air velocity from 1m/s to 2m/s (or even 3m/s) would not change the PMV value.

Table 3: PMV Variation According to Changes in Air Velocity at 1.47 p.m.

Fan Setting	Air Velocity	PMV
0	0.1 m/s	2.2
1	1 m/s	2.0
2	2 m/s	2.0
3	3 m/s	2.0
4	4.3 m/s	1.9

This may indicate that at high air temperatures (i.e., 31.7°C) the influence of high air velocity on PMV will decrease. As Fanger (1970) discusses in his studies, variations of air temperature have greater influence on comfort condition in comparison with higher air velocity. Unlike the air temperature, the relationship between the air velocity and the PMV is non-linear. The rate of convective heat exchange is a function of square root of air velocity. In fact, increasing the velocity produces smaller changes in the thermal comfort level.

6.3 Mean Radiant Temperature

In order to retain the PMV around its acceptable range, further investigation was carried out to evaluate the effects of mean radiant temperature (MRT) variations on PMV. The aims were to find out when the air temperature and humidity would reach the maximum level and how heat gains through radiation would affect the amount of PMV as well as the thermal condition of the house. Table 4 shows the effect on PMV according to the variation of mean radiant temperature.

Table 4: PMV Variations According to Changes in Mean Radiant Temperature

Humidity (Measured)	Temperature (Measured)	Air velocity (Measured)	Mean radiant T (Assumption)	PMV
61	31°C	0.1 m/s	30.0	1.8
61	31°C	0.1 m/s	29.5	1.7
61	31°C	0.1 m/s	29.0	1.6
61	31°C	0.1 m/s	28.5	1.6
61	31°C	0.1 m/s	28.0	1.5
61	31°C	0.1 m/s	27.5	1.4
84.4	29°C	0.1 m/s	29.5	1.6
79	29°C	0.1 m/s	29.5	1.5

It is clear that decreasing the amount of heat absorption through radiation have considerably strong influence on PMV variations. So one of the best ways to have a thermally comfortable condition in a house is to decrease the radiant heat in the house by preventing the penetration of sun's heat. This can be done by using suitable shading device and/or proper insulation (especially the roof in tropical climates) to prevent increase in internal surface temperature.

6.4 Effect of Shading

Computer software Ecotect has been used for simulating the penetration of the sun inside the house for three different months of the year (March, Jun and December) and different times of the day (9 a.m., 12 p.m. and 3 p.m.). See Ecotect model in Figure 5. Table 5 summarises the results from the sun penetration investigations. It was clear that the most penetrations of the sun normally happened in the morning and afternoon hours according to the low angle of the sun's beams. From the analysis of the living area which faced NW and had big windows, it was found that the penetration of the sun was normally critical in the afternoon whereas in the kitchen and utility area which faced SE, the critical penetration of the sun was in the morning.

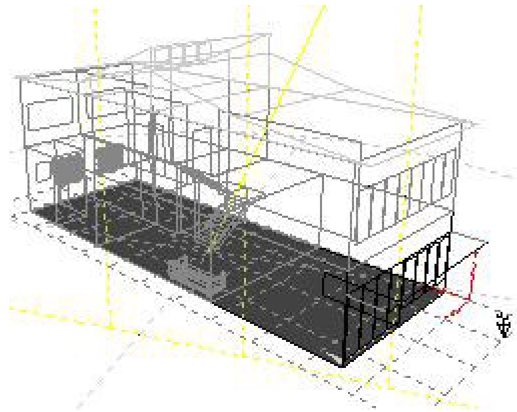


Figure 7: Designed shading device for the windows of living area.

Table 5: Sun Penetration on the Ground Floor

Month	Time	Window Orientation	Horizontal Shadow angle (HSA)	Vertical Shadow Angle (VSA)	Length of Sun Penetration
March	9am	SE	60.7 °	42.3 °	4m
	12pm	SE	49.7 °	75.9 °	1m
	3pm	NW	78°	73.8 °	1m
Jun	9am	SE	89.4 °	88.7 °	0.2m
	12pm	SE	115 °	78 °	0.1m
	3pm	NW	24.6°	60 °	1.5m
December	9am	SE	37.8 °	29 °	4.5m
	12pm	SE	6.5 °	58.93 °	1m
	3pm	NW	110.6°	74.8 °	0.6m

Considering the critical times as well as VSA and HSA, shading devices were designed for windows. Another simulation was run. The Ecotect thermal analysis showed that there were some effects of shading device on thermal comfort condition in the family area. Figure 8 displays the temperature differences of the living area before and after using the shading device. As observed, the temperature of the living area had decreased during the afternoon hours after introducing the shading device. PMV variations showed improvements in thermal condition inside the house. These variations of PMV are shown in Table 6.

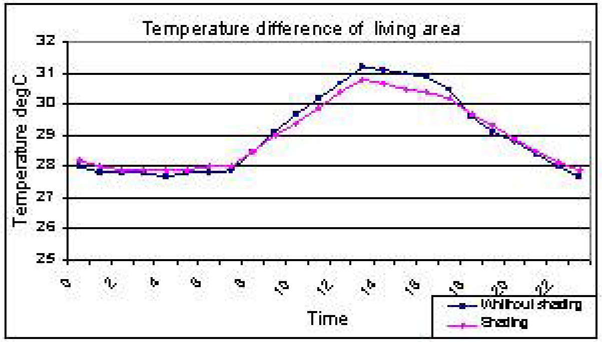


Figure 8: Temperature difference of living area before and after using shading device.

Table 6: PMV before and after Using the Shading Devices

Time	PMV Without shading	PMV With shading
12pm	1.9	1.8
1pm	1.9	1.8
2pm	2.0	1.9
3pm	1.8	1.7
4pm	1.7	1.6

7. CONCLUSION

The results obtained from thermal investigation show that the case study house is thermally comfortable for about fifteen hours during the day (6.30 p.m. to 10.30 a.m.). Fortunately it occurs during the times that the occupants are at home before going to work and after coming back. On the other hand, uncomfortable times normally occur during the day when the solar radiation and the air temperature have their maximum magnitude. Additionally, the manipulation of the indoor air velocity by occupants is found to have a positive influence on the thermal perception of the indoor climate by the occupants. It has been found that using fan can enhance the house condition during the critical hours by increasing the air velocity. Yet, when the air temperature has reached its maximum above the comfort range, the utilisation of the fans seems to have fewer effects. On the other hand, reducing the absorption of radiant heat by means of suitable shading devices help alleviate the comfort condition in the house. In fact, small changes in air temperature and humidity within a space are tolerable as long as the air movement and radiant environment can be suitably controlled. However, the investigation of this study was limited to only one case study terrace house. In order to have more accurate evaluation further studies on various cases in Malaysia are recommended. Further studies on the thermal effects of building envelope insulation and internal comfort sensations in tropical climates are also recommended.

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