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A Study of Indoor Thermal Environment of Terrace Housing in Malaysia

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Abstract

The pervasive use of air-conditioning among households in Malaysia has expanded great energy consumption in order to achieve indoor cooling comfort. More often than not, the application of air conditioning in residential buildings widely applied, due to increase of urban population. Effective passive cooling strategies are very important to provide thermal comfort and good health of building occupants while minimising energy use. This study aims to determine indoor thermal environment condition of residential building in hot humid climate. Field measurement of indoor thermal environment for single storey terrace house in Melaka, southern peninsular Malaysia was carried out for 3 days. The indoor temperature, air velocity and relative humidity were measured with U-12- Hobo data logger air temperature, humidity and anemometer sensor. The findings of the study show that the mean of indoor air temperature was between 30.71^{0}C and mean of air velocity as 0.06 m/s throughout the period were not adequate to provide comfortable indoor thermal environment and beyond range of recommended in ASHRAE Standard 55 (The American Society of Heating, Refrigerating and Air Conditioning Engineers).

Keywords: Indoor thermal environment, Terrace house

Introduction

Since the early 1970s, Malaysia has experienced significant growth of economic and social development. Comparable other developing countries and through national policies, Malaysia continue to experience rapid urbanisation around the country and transforming into an urban society. Rapid socio-economic development especially in the urban centres has increased the rate of population growth leading to high demand for housing of all typologies at various levels of the society. Therefore, more lands at the periphery or within urban centres were transformed to housing development to meet the increasing demand. The number of residential units in Malaysia has increased over the years and terrace houses are the most common typology of housing stock approximately 42%.

Significant increase of energy consumption in Malaysia has been reported from 6313 ktoe in 2003 to 10,590 ktoe in 2013 (Energy Commission, 2015). Research by Al- Mofleh et al. reported 21.6% of total energy consumption in residential sector is due to air conditioning used for space cooling purpose. Most residential occupants in Malaysia use more than 7 hours of air conditioning daily, especially during night time to release excessive heat in the house and to achieve the required indoor thermal comfort level. The development of the residential buildings has seen rapid growth to meet consumer demands but without much concern on the improvement of indoor thermal comfort by building design. Common brick urban terrace houses have been built with high thermal mass without considering the importance of thermal comfort zone in the houses. In accordance with ASHRAE Standard 55, thermal comfort is defined as “condition of mind which express satisfaction with the thermal environment and is assessed by subjective evaluation”.

Indoor thermal environment for residential buildings should provide healthy, comfortable and safe condition as people spend more 90% of their lifetime indoors. Overheated and poor indoor thermal environment will affect occupant’s health, wellbeing and decrease occupant’s productivity.

Malaysian Climatic Condition

Fig. 1 Location of Malaysia.

Malaysia experiences a tropical climate, characterized as hot and humid climate. It is located near to the equatorial region within 2^0 30’ North latitude and 112^0 30’ East longitude (figure 1). The climatic elements classified as uniform diurnal pattern, high temperature and high relative humidity. The average daily maximum temperature is 34^0C and average daily minimum temperature is 23^0C. The annual mean temperature is 26.4^0C and the annual relative humidity ranges between 75% and 86%. The average rainfall distribution over the country is recorded from 2500 mm to 3500 mm.

Throughout the year, Malaysia receives high solar radiation approximately 400 MJ/m^2 to 600 MJ/m^2 every month. The combination of high solar radiation with inconsistent and low air speeds resulted in many houses getting overheated internally, especially from February to June. Heat, air velocity and humidity are the main parameters that need to be considered in order maintain thermally comfortable conditions and health of occupants living inside building.

Terraced houses

Housing is the most important need that its provision has globally become one of the main challenges of urbanisation. The raise of population in urban area due to urbanisation eventually leads to more demands for affordable housing. Therefore, terrace houses in Malaysia have been constructed ubiquitously since 1970’s, due to consistently large demand for housing. The terrace house is the most common housing typology in Malaysia and it represents 41.4% of the Malaysian existing housing stock in 2014 (NAPIC, 2014). It is also known as the ‘row house’ which is formed in rows. Generally, it is designed repetitively and monotonously with narrow frontage and deep plan on rectangular lots with clear boundaries.

According to Abdul Rahman et al. ‘…current housing developments in Malaysia are low quality due to unawareness and inadequate provisions regarding to build standards, layout arrangement, thermal comfort and quality materials as compared to other forms of domestic buildings’. As a result, these houses are overheated and uncomfortable to live in which leading the occupants to spend more money and consume large amount of electricity on air conditioning to cool their houses (Davis et al., 2005). Zaki et al. reported that air conditioning accounted for 44% of total monthly electricity consumption of an average urban household. Thus, occupants and house owners had to pay high monthly electricity bills rather to avoid suffering from overheating due to excessive solar radiation penetrations into their houses.

As occupants spend a significant portion of their time at home, the indoor thermal condition of these houses need to be more thermally comfortable and livable. The human body needs to be maintained at a thermally comfortable zone regardless of the prevailing ambient condition. ASHRAE has published a guideline for a standard thermal environmental conditions for human occupancy (ASHRAE Standard 55) which is determined by various factors including air temperatures, humidity, air velocity, metabolic rate and clothing. This study focuses on environmental factors which are air temperature, air velocity and relative humidity as parameter controls for the intermediate terrace house typology.

Research Methodology

The main research method used for this study was a field experiment which took place in Taman Muhibbah, Melaka. This field experiment was conducted at a selected single storey intermediate terrace house for three days (figure 2). The indoor temperature, relative humidity, air velocity and light intensity were measured using HOBO U12 data loggers and HOBO T-DCI-F900-L air velocity sensor. One HOBO data logger was fitted to the living area at to record the indoor temperature and relative humidity while another data logger was fitted with a HOBO air velocity sensor at the same location to record air velocity. The data loggers were set to record data every minute for three days. The case study house was built with a floor area of 105 m^2 with the lowest ceiling height of 3 meters. This house consists of four bedrooms, a living area, a dining area, a kitchen and two bathrooms as shown in Figure 3. This house is fully naturally ventilated. It was built with a reinforced concrete structure and 150 mm thick cement bricks infill panels throughout. The party walls are made of 200 mm thick cement bricks. The 200 mm thick floor slab was also made of reinforced concrete with ceramic tile finish. The roof was constructed with cement roof tiles on galvanized iron structure at 30^0 slope with 15 mm thick fibrous ceiling cement board panels (Table 1).

A questionnaire survey was also carried out in the same residential estate where the case study house for field experiment. The survey was conducted. to determine occupants' thermal comfort perception towards their houses. The selected residential building typology comprise of single storey terraced houses with an average of 3-4 bedrooms. Total number of respondents are 178 occupants and the survey was conducted during weekend and weekdays from 9 am to 6pm. This survey is based on ASHRAE thermal sensation seven-point scale to represent the occupants' comfort votes.

Fig. 2 Front elevation of case study house.

Fig. 3 Floor plan of case study house.

Table 1. Building construction specification for case study house.

Specification	Building Component
125mm brick wall with 25mm thick cement plaster on both side	Wall
200mm reinforced concrete slab with screed, 10mm ceramic tile and 5mm polyurethane membrane	Floor
20mm concrete roof tiles with 15mm ceiling board	Roof
6mm clear float single glazing glass	Window
50 mm plywood door	Door
10mm clear float single glazing sliding door	Sliding Door

Results and Discussion

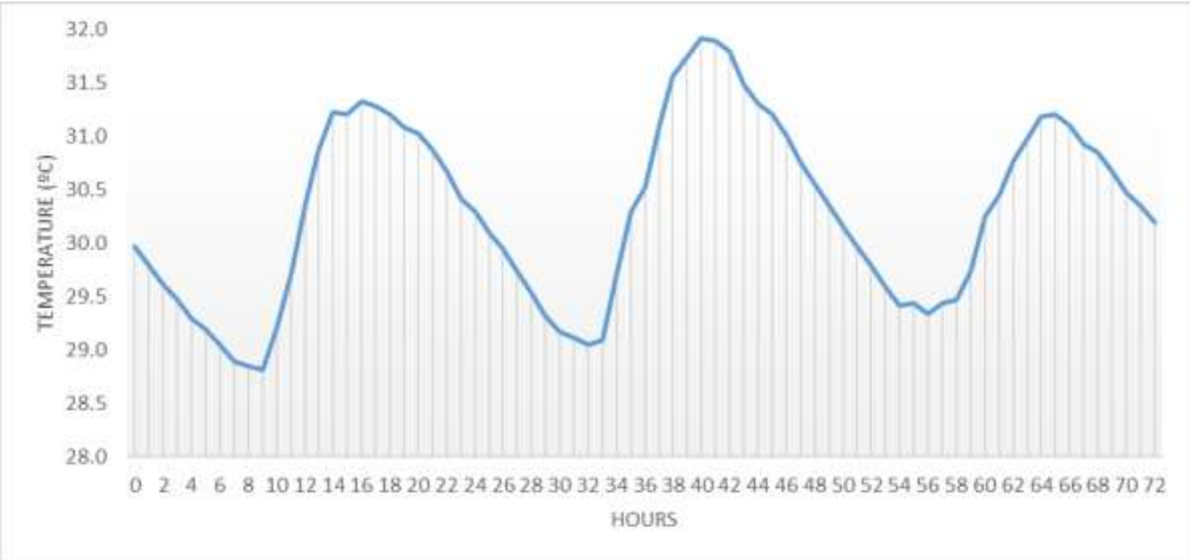

Fig. 4 Indoor temperature.

Figure 4 illustrates three days of internal temperature measurement at the house. During this 72 hours of monitoring, the highest indoor temperature recorded is 31.91^{0}C. Within every 24- hour cycle, the indoor temperature of the house rises steadily after 10 am and reaches peak temperatures between 3 pm and 4 pm in the afternoon. On the contrary, the lowest indoor temperatures of this house were recorded from 8 am to 9 am with respective readings of 28.81^{0}C, 29.05^{0}C and 29.3^{0}C in each 24-hour cycle. However, most of the indoor temperatures recorded were above the ASHRAE Standard 55 comfort range. This poor condition was observed mostly in the afternoons until late evenings when this house experienced overheating. This is due to the fact that the building fabric has high thermal mass capacity which stores heat gained during the day which was then re-radiated into the internal rooms until late evening. Therefore, thermally comfortable temperatures were not observed at this house.

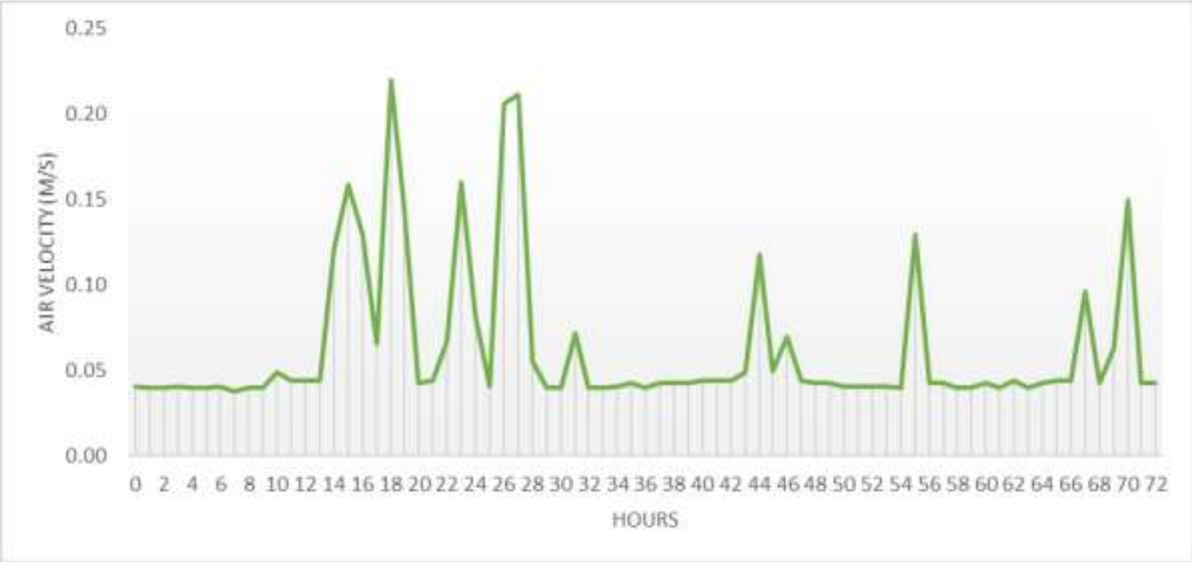

Fig. 5 Indoor air velocity.

Figure 5 shows the indoor air velocity of the house which ranges between 0.05 m/s to 0.22 m/s and reached its maximum speed after midday in each 24-hour cycle. The indoor air velocity tends to be lower as compared to the outdoors. The average air speed in this house is 0.06 m/s which is below the range of recommended air speed as specified by ASHRAE Standard 55. In this case, the poor indoor air speed is due to the long deep plan design of this house, obstructions by internal walls and inadequate fenestrations that restricts cross ventilation for air movement and air change rate. This condition caused the house to overheat during daytime due to poor ventilation and negligible indoor air movement.

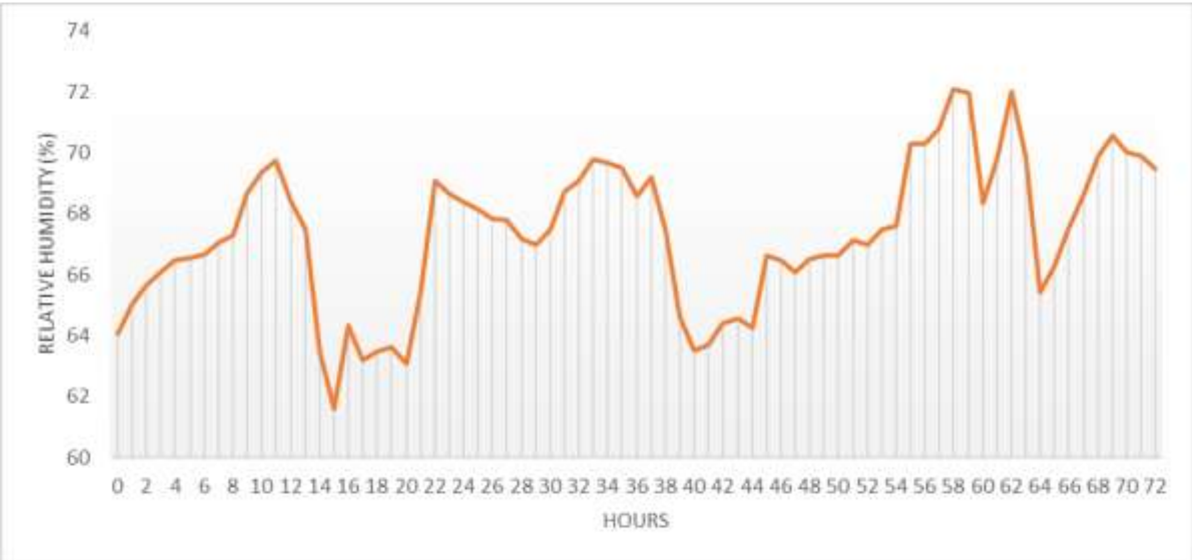

Fig. 6 Indoor relative humidity.

Figure 6 indicates the relative humidity distribution in the house over the 72 hours monitoring period. The graph shows that the relative humidity fluctuates within the range from 65.5% to 81.8%. The highest relative humidity for this house is 81.8%, which occurred between 7 am and 8 am. It clearly shows that the relative humidity increased significantly when the indoor temperature dropped to the lowest point. It also indicated that the combination of temperature and relative humidity were above the comfort zone as specified by ASHRAE Standard 55. This condition happens most likely due to the porosity of the building envelope.

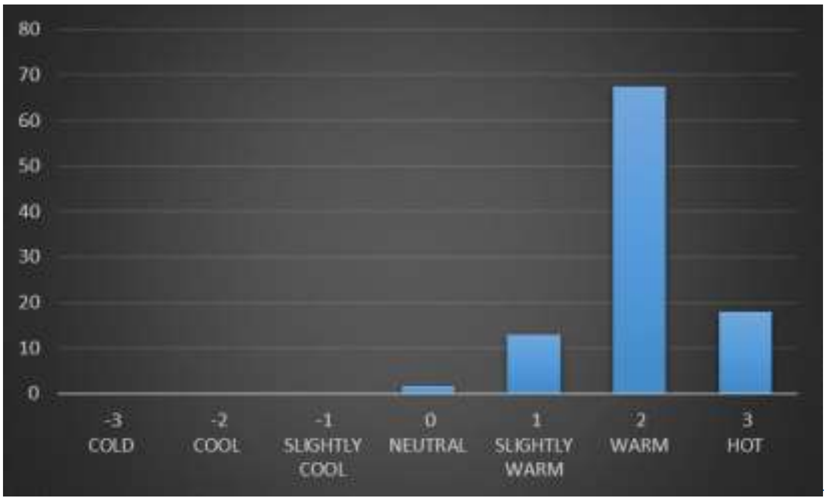

Fig. 7 Thermal sensation vote.

In addition to the indoor environmental monitoring, a questionnaire survey was also conducted and Figure 7 illustrates the results of the occupants' thermal sensation. It shows that the majority of the occupants voted 'slightly warm' sensation and 'warm' sensation. According to ASHRAE Standard 55, at least 80% of occupants' vote have to be within the central range of -1 (slightly cool), 0 (neutral) and 1 (slightly warm) of the thermal sensation seven-point scale. In this case 26 occupants out of 178 total occupants or 14.6% of occupants responded either 'neutral' or 'slightly warm'. The remaining 75.4% of occupants reported their houses either 'warm' or 'hot' in daily average indoor thermal sensation. Therefore, this case study house is perceived as thermally uncomfortable.

These findings show that the occupants experienced discomfort and overheated throughout the day due to poor indoor thermal environment of the house. The poor indoor thermal environment of the house is mainly because its heavyweight construction (cement bricks wall and reinforced concrete floor slab) which absorb and store a lot of heat energy from direct solar penetration during the day and release heat into the house throughout the night (figure 8). In addition, limited diurnal range in tropical climate will keep the house stay warm and uncomfortable, since heavyweight thermal mass is not beneficial where there is a small difference between day and night outdoor temperatures. Furthermore, the design of terrace house with long deep floor plan with limited front and back openings on the building without appropriate shading building façade caused the house overheated (Ju and Omar, 2010). Therefore, it is very important to consider the climatic building design approaches in the early stage, type of construction system and local climate adaptation strategies, in order to keep comfortable indoor thermal condition and minimize the total heat load while maintaining thermal comfort of occupants.

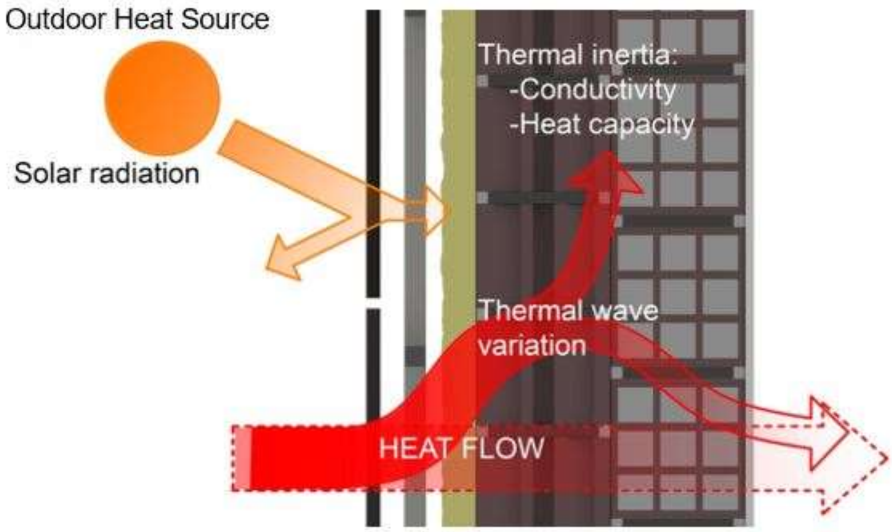

Fig. 8 Thermal mass process to absorb heat from solar radiation during the day and release heat by the night. (Aznar et al., 2018)

According to Fanger, variations of air temperature have greater influence on comfort condition in comparison with higher air velocity. Nevertheless, air movement will help to dissipate and discharge stale and warm indoor air. The indoor air velocity can be increased by opening windows and doors throughout the 24-hour cycle leaving the high level glass louvers unobstructed. This could also improve dissipation of heat by stack effect through the high level glass louvers and increase the air change rate. Installing large openings on all external walls will also aid in increasing the air change rate per hour and not obstruct air flow whenever opened. Alternatively, installing a layer of insulation underneath the existing cement tile roof and on the external walls will reduce gained heat transfer into the house from the heavy building envelope construction. Application of appropriate building shading also will control the penetration of solar heat gain and reduce building cooling load.

Conclusion

The findings address that none of the indoor thermal condition parameters were in compliance with the ASHRAE Standard 55. The study found that the average temperature, average air velocity and average relative humidity were out of the ASHRAE comfort range. This is reflected by the thermal comfort perception of the occupants who felt discomfort and overheating. All in all, comfortable indoor temperatures must be maintained in order to provide a comfortable indoor thermal environment for the occupants of the house. Therefore, the researchers proposed the incorporation of climatic design approaches with consideration of the local climatic condition, the understanding of heat transfer, thermodynamics and thermal comfort perception. This research will continue to determine the most effective approach to improve the thermal condition of this terrace house and reduce the electricity consumption for cooling purpose.

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