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Comparative Study of Indoor Environment in Residential Buildings in Hot Humid Climate of Malaysia

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***Abstract*—**There's a lack in understanding the indoor climate of Malaysian residential. The assumption of traditional house could provide the best indoor environment is too good to be true. This research is to understand indoor environment in three types of Malaysian residential and thermo recorder TR72Ui were placed in indoor spaces for measurement. There are huge differences of indoor environment between housing types, and building material helps to control indoor climate. Traditional house indoor climate was similar to the outdoor. Temperature in the bedroom of terrace and town houses were slightly higher than the living room. Indoor temperature was 2^{o}C lower in the rainy season than the hot season. It was hard to control indoor humidity level in traditional house compared with terrace and town house. As for conclusion, town house provides the best thermal environment to the building occupants and can be improved with good roof insulation.

***Keywords*—**Indoor environment, residential, temperature.

I. Introduction

RECENT studies show there are steady increases in energy consumption in residential sector especially for terrace house. One of the main factor that contributes towards this problem was high energy use for space cooling in providing thermal comfort to the building occupants. In fact, the contemporary house types studied have shown that good thermal comfort in hot, humid climates cannot be achieved with natural cooling and ventilation alone [2]. The prospect for thermal comfort through passive cooling is limited to the rural areas. For urban areas, thremal comfort can be improve through enough microclimate strategies within the surrounding areas of the building [6]. Moreover, it was found that most people didn't apply night ventilation due to safety reason thereby, created indoor discomfort [4]. Rescent study show that there's least effect of ventilation strategies such as fan, natural ventilation, or the combination of both natural ventilation and fan, on residential building. Moreover, wind velocity was more important compared with ventilation strategies [5]. An air flow of 0.7 ms^{-1} will give rise to comfort whereas if the air flow is more than 1.5 ms^{-1}, the space will be comfortable throughout [6]. This research was conducted in order to understand the indoor environment in Malaysian residential. Moreover, six houses that consist of two units terrace house, traditional house and town house have been selected for measurement of indoor and outdoor environment in the living room, bedroom, and porch. These houses are located in the urban and suburban setting. However, only three houses of each type will be compared and discuss in this paper.

A. Malaysia's Climate

Malaysia is located in the tropical region of Malay Archipelago of South East Asia. The average outdoor temperature was 27^{o}C with the humidity level of 70% to 85%. The rainy season in the North Western part of Malaysia occurs in October to November. The average monthly precipitation was between 200 and 400mm. The wind velocity was around 15 knot.

B. Case Studied House

For this measurement, six houses has been selected which are located in Penang, Island and Sungai Petani, Kedah. Both of these areas are located in the North-West of Malaysian Peninsular . All houses are not identical, however, each pair of house share similar characteristic and sizes.

(a) *(b)* *(c)*

Fig. 1 (a), (b), and (c) The image of traditional1, town1 and terrace1 houses

The reason why terrace house, town house and Malay traditional house have been chosen was that, these three types of house have a very interesting and unique charateristics. These three types of houses represent design evolution from the old traditional house design and strategies to a modern living. The traditional house is often regarded as a good natural ventilated dwelling in hot humid climate due to its design

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strategies and material selection. The traditional houses are oftem built on stilts with floor and wall gaps to allow maximum cross ventilation. The colonists had adopt their sence of architecture styles in buildings and modified to suit the climate context of Malaysia and introduced the town houses [3]. Unlike the traditional house, this house were built in heavy wall mass of bricks and clay tile roofing. However, the traditional house has integrated design strategies such as, timber flooring on the upper level, long louvered windows and permenant ventilation holes on top of the wall facade. Based on these, new Malaysian architects design moden living such as the terrace house to cater high demand in housing due to urban migration to the city in the early 1980's. This newly design house is built conected to each other like the town house. However, the louvered timber windows has been replaced by glass louvered windows. Today, new materials from foreign countries such as the glass casment windows and glass sliding doors are installed which didn't interact well with the design strategies and environment.

II. Methodology

In this measurement, 22 units of thermo recorder TR72Ui were used and placed at strategic locations in each house. This thermo recorder logged data of temperature and humidity where one unit of thermo recorder was placed in the bedroom and living room at 1.0 – 1.5 m from the floor, 5 cm under the ceiling, and one unit was placed outside under the porch inside an aluminum duct to protect from rain and extreme solar radiation. The TR72Ui thermo recorder has the temperature accuracy with an average of ± 0.3 (-20 to 80 ^{o}C) and humidity accuracy of ±5%RH (at 25 ^{o}C, 50%RH).

III. Results

A. Overall Data

The data of indoor environment has been collected from June 2010 to January 2011 for a period of seven months.

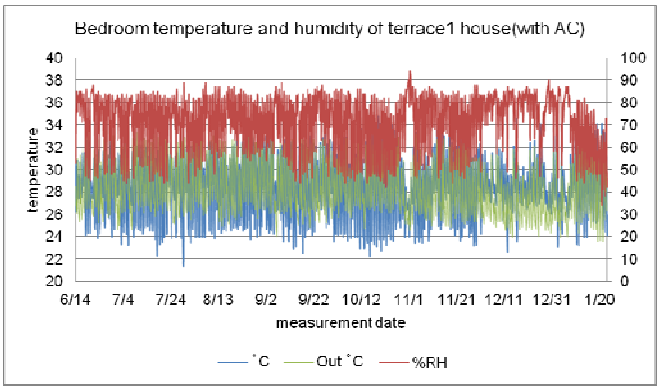

Fig. 2 The bedroom temperature and humidity of terrace1 house

These data were illustrated in Fig. 2, Fig. 3 and Fig. 4 that represent terrace1, town1, and traditional1 house respectively. It can be seen that in terrace1 house, the air conditioner is used almost every day in hot season but less in rainy season. By comparing both graphs, we can see that air conditioner causes huge temperature fluctuations in the bedroom. By referring to Fig. 2, the outdoor temperature ranges (green line) were inside the indoor temperature ranges (blue line) which indicated that the indoor temperature was lower than the outdoor. This indoor climate condition is achieved by utilizing air conditioner. In terms of temperature, the air conditioning unit in terrace1 house bedroom reduced the bedroom temperature to as low as 21^{o}C.

These graphs also demonstrate that when the temperature is high, the humidity level will be low. However, if a room is installed with air conditioner, the temperature and the humidity level will increase and decrease based on the setting. Moreover, it was found that the temperature was lower by 2^{o}C in rainy season. In terms of relative humidity, terrace1 house bedroom has bigger humidity fluctuations in which the highest humidity level was 90% and the lowest at 34%. It is believed that the reason was due to the controlled mode by air conditioner at night time which has reduced the humidity level so low. Moreover, it can be observed that in January, the bedroom charted high temperatures with low humidity levels. This might suggest that in January, after the rainy season ended the country experiences hot and dry climate condition.

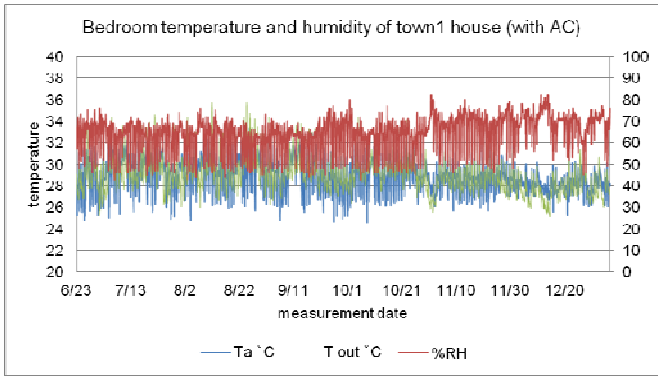

Fig. 3 The bedroom temperature and humidity of town1 house

Fig. 3 shows the data in the bedroom of town1 house. Like the terrace1 house, this house's bedroom utilized 1.5hp air conditioner. Same tendency can be seen in town1 house and terrace1 house bedroom. The, outdoor temperature of this house was higher than that of terrace1 house. There were at some points where the outdoor temperature in hot season was as high as 35.5^{o}C. There's a clear temperature difference can be seen in the bedroom of town1 house in hot and rainy seasons. In hot season, the indoor temperature lingers from 30^{o}C to 32^{o}C. On the other hand, in rainy season, the temperatures were between 28^{o}C to 30^{o}C which is 2^{o}C lower than the hot season. By comparing Fig. 2 and Fig. 3, it can be seen that there's a bigger difference of indoor and outdoor temperature of terrace1 house, compared with town1 house (by comparing blue and green lines). These show that the air conditioner in terrace1 house was set at a lower temperature.

As for the humidity level, there are odd sharp fluctuations of humidity level in the bedroom of this house like terrace1 house. The same explanation was due to the utilization of air conditioner which reduces the humidity level in the bedroom.

However, the maximum humidity level in town1 house was around 83% which 10% lower than the terrace1 house.

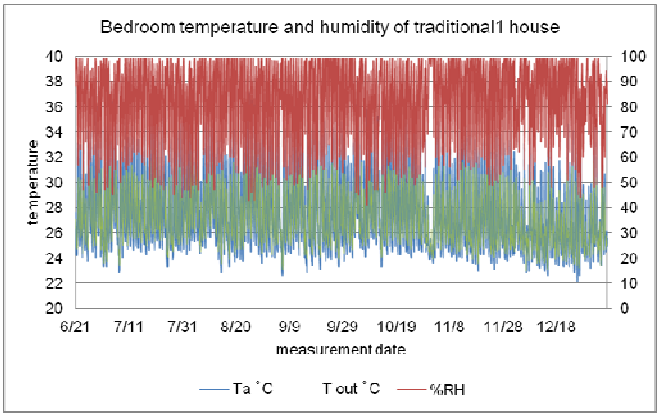

Fig. 4 The bedroom temperature and humidity of terrace1 house

It is very interesting to see the data for traditional houses that displayed totally different patterns compared with the terrace and town house. By comparing the data between terrace1 and town1 house, the traditional1 house indoor temperature and humidity were unstable and fluctuated greater than the other two type of houses. Since the main strategy of traditional house on utilizing natural ventilation with lots of wall openings and gaps, the indoor temperature and humidity swings widely that followed the outdoor climate conditions. By looking at Fig. 4, indoor temperatures in traditional houses were higher than the outdoor. It can be seen that the outdoor temperature range (green line) was inside the bedroom temperature range (blue line). It is believed that the used of thin building materials for traditional house with less wall mass, plus the black colour the facade of building walls, can easily absorbed heat during the day and heat up the indoor spaces. As a result, the traditional house was too hot during the day and too cold at night time. The number of walls that were directly exposed to the outdoors also had an impact on indoor air temperature. Although traditional house are generally more spacious in terms of size it must be noted that all four sides of this type of house are directly exposed to the outdoors [2]. However, with proper design strategies, it does prove that a natural ventilated traditional house could provide a low indoor temperature without the utilization of air conditioner. Unlike the brick wall in terrace house and town house, the heat is stored in its high thermal mass wall during the day that has a slow rate of releasing heat at night making the indoor temperature more stable with no huge temperature swing. This statement can be proved by comparing the indoor temperature measured in these three houses which is illustrated in Fig. 2, Fig. 3, and Fig. 4. There were more temperature data charted over 32°C in traditional1 house compared with terrace1 and town1 house.

In traditional1 house, there was no clear pattern of "a low temperature" in rainy season compared with hot season. However, quite a clear difference can be seen for humidity level between hot and rainy season. Moreover, traditional1 house is located in a total village suburban setting which surrounded by lush vegetation and paddy fields which contributed to the high percentage of relative humidity. The results of indoor environment in these three houses could suggest design and strategies of passive cooling that can be applied to a new modern housing model.

B. One Month Data Comparison of Indoor Environment in Three Type of Houses

Fig. 5 and Fig. 6 compare the bedroom temperature in three houses in hot and rainy seasons. As expected, in hot season, the bedroom temperature in traditional1 was the highest followed by terrace1 and town1 house. However, both terrace1 and town1 houses were installed with air conditioner in the bedroom. In fact, the indoor temperature in traditional1 was too high that charted up to 35.5°C. On the other hand, traditional1 also charted the lowest temperature of the day compared with other two types of houses. This was due to the opening and gaps of the traditional1's facade which allowed maximum cross ventilation. As a result, indoor temperature and humidity of a traditional1 at night time parallel to the outdoor temperature and humidity. However, the question arises on the effect of large temperature and humidity fluctuations. How does it affect our comfort condition?

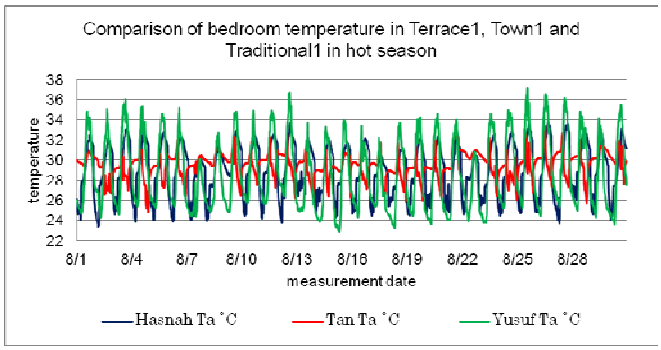

Fig. 5 Comparison of the temperature in three types of houses in hot season

Traditional1 could provide a comfortable indoor temperature at night for building occupant to sleep which was around 24°C. Moreover, in Fig. 5, it can be clearly seen that in terrace1, the use of air conditioner could reduce the bedroom temperature that match the bedroom temperature of traditional1 at night time but sometimes it was even lower.

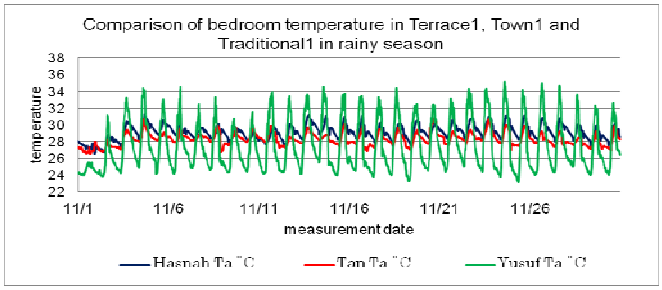

Fig. 6 The temperature in three types of houses in rainy season

The rainy season tends to have the same pattern like in the hot season. However, the maximum temperature in hot season was 2°C higher than the rainy season. It was strange to see the data on the 14th August where the bedroom temperature of the terrace1 was a little bit higher than traditional1. By looking at Fig. 6, it can be said that town1 provide more stable bedroom temperature in rainy season compared with the other two types of house.

C. Three Days Data of Dry and Rainy Season

It is important to see the temperature distribution in an indoor space as a whole, but in order to understand the actual situation, three days data are important so that a clear pattern could be seen and it's easier to compare the indoor conditions between these three houses. Data in hot season has been selected from 29th to 31st July 2010 and data for rainy season were between 6th and 8th December 2010. However, only data in hot season will be discussed.

Based on Fig. 7, the maximum outdoor temperatures were between 32°C to 33.5°C and the minimum temperature was at 26°C. In this figure, it was understood that the air conditioner in the bedroom was switched at three times indicated in the circle. There's a steep drop in the bedroom temperatures when air conditioner was switched on. Moreover, it can be seen that the bedroom temperature dropped below the minimum outdoor temperature. Based on this measurement, it was understood that air conditioner was used at night time most probably from 9 to 10 pm until early morning for sleeping.

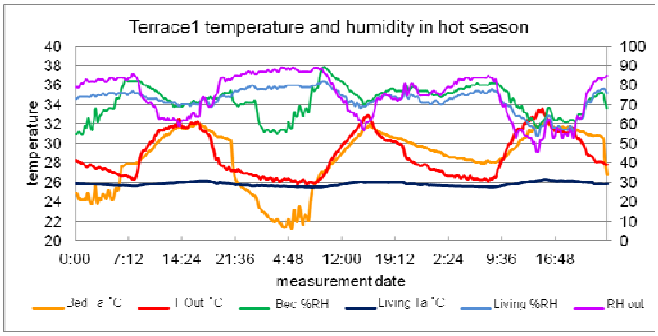

Fig. 7 Three days data in terrace1

It is interesting to see that the living room temperature that is located on the first floor was so stable which were around 26°C. This might suggest that the bedroom temperature on the second floor has increased during the day because of the heat transfer from the roof. Agung (2007) found that the indoor temperature in terrace house between 15:00 to 19:00 hours were higher than the outdoor by 2 to 3°C [1]. In terms of humidity level, the living room humidity level has the same tendency like the outdoor humidity level. However, because of air conditioner, the bedroom humidity tends to be lower at night time which is normally high.

Fig. 8 shows three days measurement of temperature and humidity in town1 in hot season. Based on Fig. 8, the maximum outdoor temperatures were between 33°C to 34°C and the minimum temperature was at 28°C. It can be seen that the air conditioner in the bedroom was switched on at day time until 9 pm. At night, the bedroom, living room and the outdoor experienced almost the same temperature between 28°C to 29°C. Unlike the living room in terrace houses, the living room in this house was not so stable and can raised up to 30°C with 3°C temperature difference from the outdoor. Unlike the traditional house that experiences indoor air temperature which was higher than the outdoor, the town house is built with massive wall mass that could reduce the internal heat gain by solar radiation. As for the humidity level, it can be seen that the air conditioner reduced the humidity level in the bedroom to a lower level compared with the living room even lower than the outdoor humidity level.

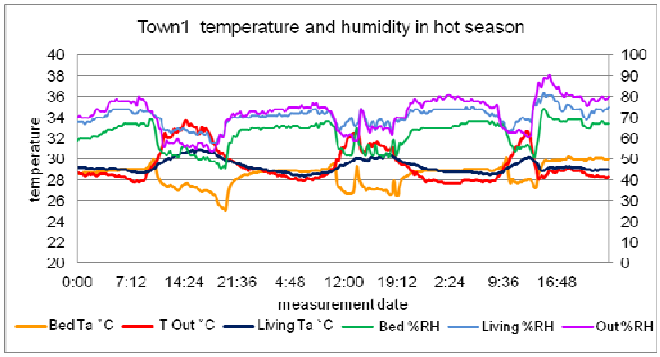

Fig. 8 Three days data in town1

Fig. 9 shows three days data of temperature and humidity in hot season of traditional1. The indoor temperature of this traditional house closed to the outdoor temperature because of this house was naturally ventilated. In day time, the indoor temperatures were higher than the outdoor by 3°C. Unlike the terrace and town house, the bedroom and the living room temperature were almost the same with the outdoor. It can be seen that the temperature increased rapidly from 7:30 am and start to reduce after 6:00 pm. The maximum indoor temperature charted in traditional1 in hot season was at 35°C. On the other hand, the minimum temperature was at 25°C. As for the humidity level, the indoor humidity was higher than the outdoor at night time, and at day time, the humidity level was lower than the outdoor. Bedroom humidity level was higher than the living room with the maximum of 100%.

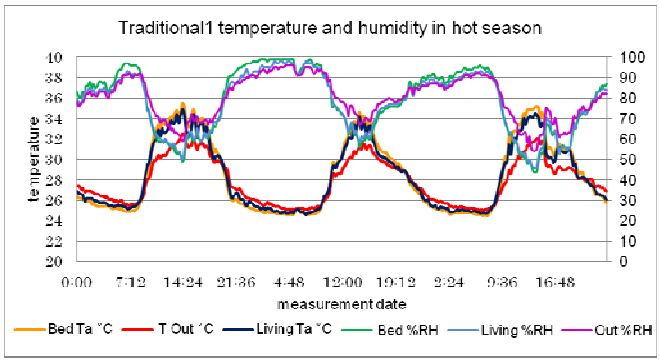

Fig. 9 Three days data in town1

D. Evaluation of the Condition of Air

It is important to evaluate the condition of air which can be described by using psychometric chart. This chat graphically represents the thermodynamic properties of moist air. Figs. 10 and 8 show the temperature and humidity conditions in hot and rainy season in three types of houses respectively. For this evaluation, the data of air conditioner utilization have been separated. It can be seen that the condition of bedroom in all housing types do not meet the thermal comfort zone proposed by ASHRAE (summer comfort zone) in hot season due to high humidity level. It can be seen that the setting temperature of air conditioner in terrace1 house was too low which part of the measured data were fit in the winter comfort zone. On the other hand, the utilization of air conditioner in town1 house was good which part of the data were in the summer comfort zone. In Malaysia, air conditioner is one of the best way in reducing temperature especially indoor humidity so that thermal comfort can be achieved. Traditional1 house experienced the biggest affect on humidity compared with other housing types.

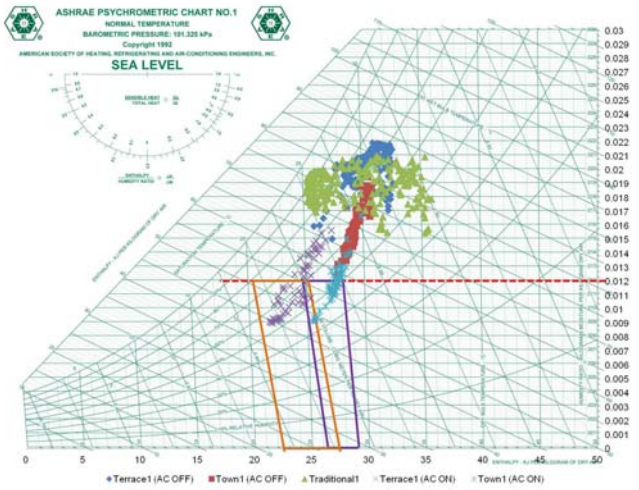

Fig. 10 The evaluation of humidity environment of the three days measured houses in hot season

At measured time, only town1 house switched on air conditioner. It can be seen that most of the data of traditional house were closed to the 90% saturation line which indicated high content of mointure in the air. By comparing Figs. 10 and Fig. 11, it can be seen that the humidity ratio in terrace1 was the highest in both season followed by traditional house and town house. It was found that most respondents in terrace house closed their windows and doors at night. Without a permenent ventilation hole on the facade it limited the cross ventilation in this house thereby created high humidity consentration of indoor air.

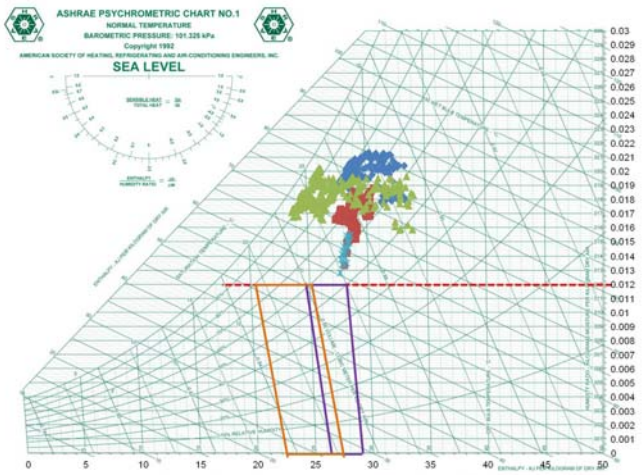

Fig. 11 The evaluation of humidity environment of the three days measured houses in rainy season

IV. Conclusion

It is found that building material helps to control the indoor climate and a proper selection of building material is needed. On the other hand, ventilation strategies using air conditioner and natural ventilation cause huge temperature swings in indoor spaces that sometimes matched the outdoor climate conditions. It is interesting to know the effect of humidity in thermal comfort. The humidity levels inside an indoor space can be as high as 100% especially during rainy season. By comparing all of the three types of houses, traditional house indoor climate is similar to the outdoor. The question arises is that “was it good?” In some cases like the traditional house the indoor temperature is higher than the outdoor. Outdoor temperature for town house is the highest of all the houses but it has the most stable indoor temperature.

Town house provides the best thermal environment to the building occupants. However, if the ceiling of the town house is well insulated, it might provide a better indoor climate and thermal comfort to the building occupants especially in the bedroom. The same strategy could be implemented to the traditional house. This research proves that traditional house didn’t provide good thermal comfort to the occupants except if the house is shaded by trees of if a proper roofing material is selected. If there is a way to control the indoor temperature during the day to maintain at 28^{o}C, traditional house will be the best house in providing the best possible indoor climate condition to the building occupants especially at night time. This research suggests that, vegetations surrounding the house and building materials selection play an important role in controlling indoor climate. As for future research, it is hope that further research can be carried out and more parameters could be compared.

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