Assessment of Indoor Air Temperature of a Low-cost Single Story Detached House in Malaysia

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Abstract—
Indoor air temperature is one of the most notable variables to determine indoor thermal comfort. In Malaysia, occupants' of low-cost houses still have an issue of overheating due to poor design. It is important to measure several parameters of thermal comfort in order to identify the existing indoor thermal condition of a low-cost house. The main objective of the research is to reveal the current indoor thermal condition of the typical low-cost single story detached houses. Therefore, this paper focuses on the measurement and analysis of indoor air temperature of a low-cost single story detached house in Malaysia. Field measurement was conducted using thermal comfort meters and a weather station under two different conditions: (a) windows and the door closed and (b) windows and the door opened. Results revealed that the indoor air temperature (Ta) is statistically significant with time but not with the conditions. The indoor environment condition is unsatisfactory even when the door and windows were opened. A simulation with Integrated Environmental Solutions (Virtual Environment) software to initiate a strategic design solution by changing the roof insulation materials and enlarged windows to improve the indoor thermal environment of the house. Findings show that when the window sizes were enlarged and bubble foil insulation material was added, indoor air temperature reduced to some extent but still not in the comfort range. Hence, more emphasis should be given to design layout and material selection to improve the indoor environmental quality of the low-cost single story houses of Malaysia.

Keywords—***Indoor thermal environment, indoor air temperature, low-cost single story detached house.***

I. Introduction

This paper elucidates the indoor air temperature condition of the typical low-cost single story detached house in Malaysia. Poor thermal insulation and resistance designs of these houses, lead to higher indoor air temperature during daytime [1]. Therefore, most houses of this type experienced an overheating problem. Moreover, according to Isnin et al. [2]. Existing indoor environmental quality of these houses are not good enough for the occupants [1]. Besides that, Isnin et al., and Liang [2], [3] added indoor environmental quality is also an overlooked issues of low-cost house.

The climatic condition of Malaysia has a great influence on indoor thermal condition. As one of the tropical climatic country, Malaysia has a temperature ranging 27°C and 32°C during the daytime and 21°C and 27°C during the nighttime. Building elements like windows, walls, and roof surfaces gain heat directly from solar radiation [4], [5]. Based on the data of Malaysian Meteorological Department, 23°C-27°C is the minimum and 30°C - 34°C is the maximum air temperature of daytime in Malaysia. Relative humidity is nearly 75% which is very high along with huge variation in rainfall [1].

Many architects and academicians analyzed thermal comfort issues of tropical countries. According to Department of Standards Malaysia [6], for Malaysian climate 23°C - 26°C is the recommended indoor air temperature range for a standard indoor environment design. In addition, most of the researchers recommended indoor air temperature between 25°C to 28°C [7]–[11]. Jamaludin and Izma [6] executed experiment under Kuala Lumpur climatic situation and highest indoor air temperature recorded as 32.6°C whereas highest indoor temperature in Kuching and Bayan Lepas recorded as 31.10°C and 31.60°C respectively in a master bedroom. This is clearly higher than the recommended temperature by Malaysian Standards; MS1525:2007 [6].Many research conducted on terrace houses in Malaysia showed that thermal comfort can be obtained when the temperature ranges between 23°C to 28.69°C [6], [12].

A. The recent scenario of low-cost houses in Malaysia

Despite all the efforts of the government, the quality of low-cost houses was unsatisfactory in comparison with the other residential buildings. Lacking in building standards, design layout, thermal comfort, environmental quality and material qualities are the common problems [8]. Moreover, in the case of low-cost houses, the indoor air temperature is much higher than the recommended indoor air temperature for tropical climate [8]. Previous researchers have found that thermal comfort levels of low-cost houses are not satisfactory due to ineffective thermal design [7], [8], [13]. An analytical study was done by Ibrahim et al. [14] for two typical low-cost houses of Malaysia in Betong and Saratok where field measurement has been done in different conditions. The indoor temperature has been recorded 34.2°C and 34.5°C for the Betong and Saratok houses respectively, which is far away from the recommended indoor air temperature. Although with open windows and doors there was an increased amount of air movement still indoor environmental quality is not soothing [13].

The government of Malaysia is taking steps to improve the quality of low-cost housing [15]. Moreover, housing rules have been developed for mass people to create an easy access to housing facilities. The Malaysian government is giving the effort to provide affordable housing for all. This concept was actually derived from the low-cost house residents dissatisfaction [15].

According to 7th to 9th Malaysian plan [16]–[18], Malaysian government provides definite attention towards low-cost housing. Examples of typical low-cost single story house and plan layout are shown in figure 1 and 2. Low-cost housing has some standard guidelines for construction, which is noted as Construction Industry Standard (CIS 1: 1998), which is for 1-2 story buildings composed by the Construction Industry Development Board Standard [19], [20]. A present guideline of CIS includes [21], [22]:

- A minimum floor area of 63 m2
- Three (3) bedrooms
- A kitchen
- A living and dining area
- A storeroom
- A bathroom and
- A toilet.

Fig. 1. Typical low-cost single story detached house

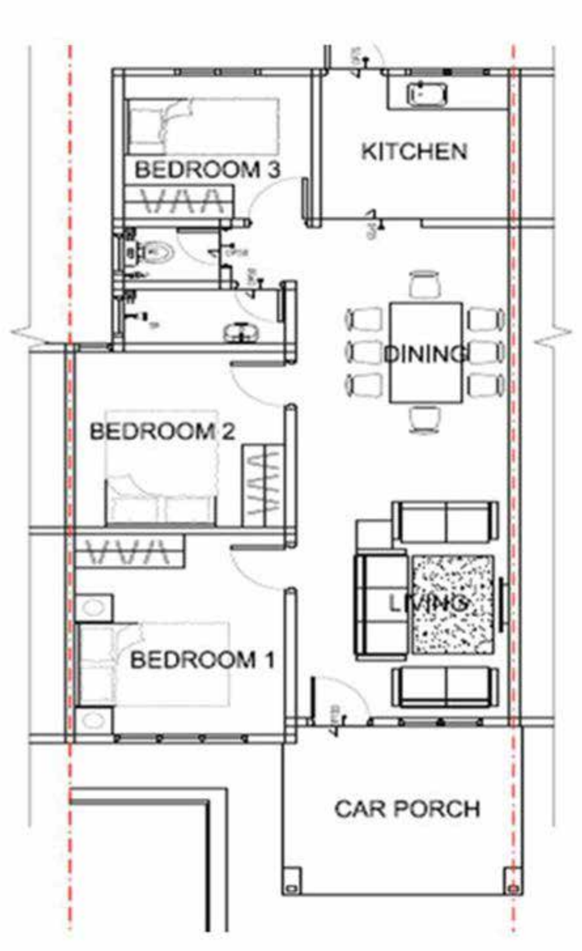

Fig. 2. Typical layout of a low-cost house.

II. Research Methods

The methodology chosen for this study was field measurement where a low-cost single story detached house was selected to measure thermal environment.

Rubber Industry Smallholders Development Authority (RISDA) built the house, which is one of the typical old designed low-cost houses. It is important to refer that this research only focused on indoor air temperature measurement of the selected low-cost detached house to find out the indoor thermal condition of the house. Air temperature is one of the most important variables to determine the human comfort [23].

A. Equipment calibration

Before any measurements were taken on-site, all of the instruments were calibrated in the indoor controlled environment to find out the errors. List of instruments and calibration exercise are shown in table 1 and figure 3.

TABLE 1 - Equipment calibration

No.	Instruments	Units
1	Delta Ohm HD32.3 WBGT-PMV	02
2	Weather station	01

Fig. 3. Calibration of all instruments in the indoor control environment

Fig 4. Surrounding condition of the low-cost single story detached house used for field measurement.

B. Field measurement

Field measurement was conducted on a low-cost single story detached house located at 'Kampung Parit Seberang', 'Kuala Pilah', Negeri Sembilan (Latitude: 2°45'9.72" Longitude: 102°13'47.27"). The size of the house is 57.88 m2 (623 ft2) with three bedrooms, one bathroom, one toilet, kitchen, dining and living room (figure 4). The measurements were conducted from 08:15 to 19:15. During field measurement, a weather station was set outside of the house to measure the outside meteorological conditions and two thermal comfort meters were set in different rooms of the house as shown in figure 5 (labeled with F2 and J1).

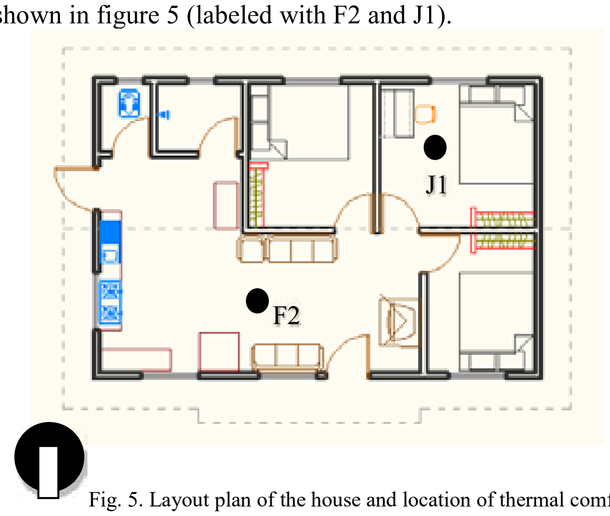

Fig. 5. Layout plan of the house and location of thermal comfort meters.

Figure 6 shows the location of both thermal comfort meters. Thermal comfort meter labeled with F2 was located in between living and dining rooms and J1 was set in the master bedroom at the position of 1.5m from the floor level.

Fig. 6. The position of J1 and F2 thermal comfort meters

C. Data collection

At the end of the field measurement, measured and transferred data have analyzed and compared. Different studies on thermal condition assessment have been done under different conditions [1], [13]. In this research, data collection was done under two different conditions. For each condition, data were collected for three days. These are the two conditions:

Condition 1: Windows and door closed
Condition 2: Windows and door opened

Air temperature, wind speed, relative humidity and PMV data were collected for both conditions. Nevertheless, only air temperature data are discussed in this paper. All data were analyzed using statistical software Microsoft Excel and SPSS.

D.Integrated environmental solutions <virtual environment> simulation

IES<VE> is one of the efficient simulation software which can carry out a detailed analysis of thermal performance [24], [25]. Three different design strategies were simulated with three different models to achieve a good thermal environmental condition for the house. Amendments were done on the base model accordingly. Window sizes were

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enlarged and different insulation materials like, bubble foil and glass wool were used in the roof for the simulation model 1, 2 and 3 respectively.

III. Analysis and Results

In this paper, the main emphasis is on indoor air temperature of the selected low-cost house. The results have been analyzed to compare the indoor air temperature of condition 1 and condition 2 with the recommended temperature for the region.

A. Validation of IES<VE> model

Validation is a major issue for a thermal simulation program. Hensen [14] compared different models and disclosed that IES<VE validation is one of the best. For that reason, the field measurement data and IES<VE> model obtained data validated to modify the model to give further design suggestions.

TABLE 2- Uncertainty estimation of the indoor air temperature (°C) sensors as calibrated:

	F2	J1
Diff of temp (°C)	3.2	0.7
Deviation (%)	9.1	2.3

Maximum uncertainty in calibrated data found ±3.2 (°C) where standard deviation was ±9.1% (Table 2 and Figure 7). The weather station was excluded from uncertainty estimation. The result revealed that the deviation(%) between IES<VE> model and field measurement data for F2 and J1 are 9.1% and 2.3% respectively.

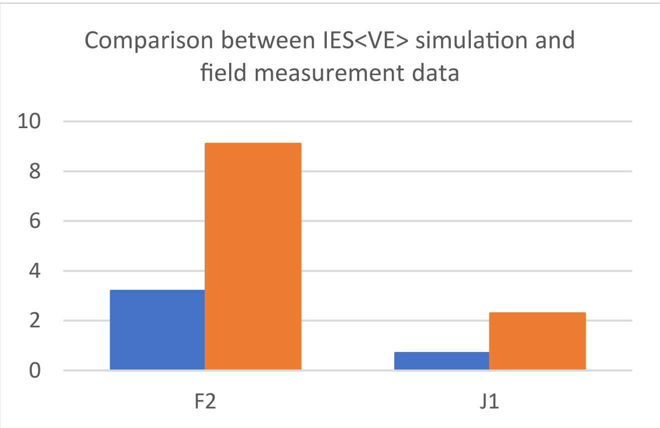

Fig.7.The comparison of indoor air temperature (°C) between IES<VE> model and field measurement data

B. Comparison between indoor air temperature and recommended temperature

According to the guidelines of Department of Standard Malaysia, for Malaysian climate, recommended temperature range is 23°C - 26°C. That means the average standard indoor temperature is 24.5°C. For Condition 1 and 2, indoor air temperatures of three different times have been arranged to compare with the recommended temperature (table 3, 4 and figure 7, 8).

TABLE 3 - Condition 1: Indoor temperature and recommended air temperature (°C):

Condition 1: (Windows/door closed)	**Temperature**	
	Indoor air temperature (°C)	Indoor recommended temperature (°C)
Morning 0900	29.2	24.5
Noon 1200	31.2	24.5
Evening 1700	33.0	24.5

TABLE 4 - Condition 2: Indoor temperature and recommended air temperature (°C):

Condition:2- 23.08.2016 Windows/door opened	**Temperature**	
	Indoor air temperature (°C)	Indoor recommended temperature (°C)
Morning 0900	29.7	24.5
Noon 1200	33.1	24.5
Evening 1700	31.4	24.5

For Condition 1 and 2, 29.2℃ and 29.7℃ are the lowest indoor temperature found at morning (0900) which is still higher than the recommended indoor air temperature.

C. Pearson Correlation test

The Pearson correlation test has been carried out to show the efficacy of time and condition on indoor air temperature. Table 5 shows that indoor air temperature is highly correlated with time which means indoor air temperature increased throughout the day (Table 5).

TABLE 5 - Pearson Correlation test for different variables with time and conditions

		Time	Conditions	Indoor air temp.	Air velocity
Indoor air temp.	Pearson Correlation	.705**	-.118	1	-.068
	Sig. (2-tailed)	.000	.324		.571
	N	72	72	72	72

**. Correlation is significant at the 0.01 level (2-tailed).

D. IES<VE> Simulation with different design strategies

After statistical analysis, indoor air temperature has analyzed with three different simulation models. Indoor air temperature is compared for three different times of a day: Morning (0900), noon (1200) and afternoon (1700). Results are illustrated in Table 6 and Figure 8. In the first model, openings size was increased to 4.5% from the original size. In second and third models, roof insulation materials were placed like, bubble foil and glass wool. The indoor air temperature dropped down to 30.2°C when the window sizes were enlarged and bubble foil insulation material used. It means the indoor air temperature decreased 0.9°C. On the other side, while glass wool insulation used in the simulation, the temperature dropped down to 30.4°C which indicates 0.7°C reduction of indoor air temperature.

TABLE 6 – Master bed indoor air temperature analysis with three different IES<VE> simulation models: Condition 1

Condition 1				
Time	Field measurement	With Larger openings	With roof insulation (Bubble foil)	With roof insulation(Glass wool)
9:00 AM	29.2°C	27.7°C	27.3°C	27.4°C
12:00 PM	31.2°C	30.8°C	31.0°C	31.2°C
5:00 PM	33°C	32.1°C	32.4°C	32.5°C
Avg.	33°C	30.2°C	30.2°C	30.4°C

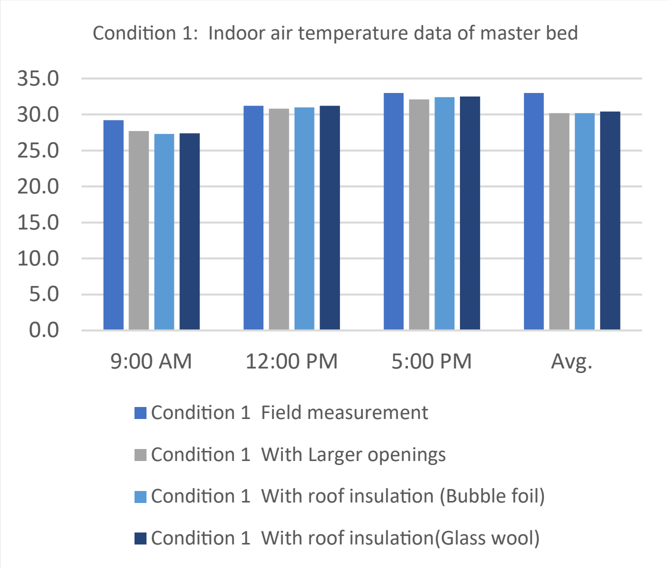

Fig.8.Changes in indoor air temperature of master bed in different simulations (Condition 1)

TABLE 7 – Indoor air temperature analysis with three different simulation models: Condition 2

Condition 2				
Time	Field measurement	With Larger openings	With roof insulation (Bubble foil)	With roof insulation(Glass wool)
9:00 AM	29.7°C	27.2°C	27.2°C	27.2°C
12:00 PM	33.1°C	31.2°C	31.2°C	31.2°C
5:00 PM	31.4°C	31.8°C	31.9°C	31.9°C
Avg.	31.4°C	30.1°C	30.1°C	30.1°C

The average indoor air temperature dropped down to 30.1°C for all types of changes in the simulation with condition 2 (Figure 9). It means the temperature decreased 0.1°C from the simulation with condition 1. But for both cases, simlation results are not satisfactory nor in the range.

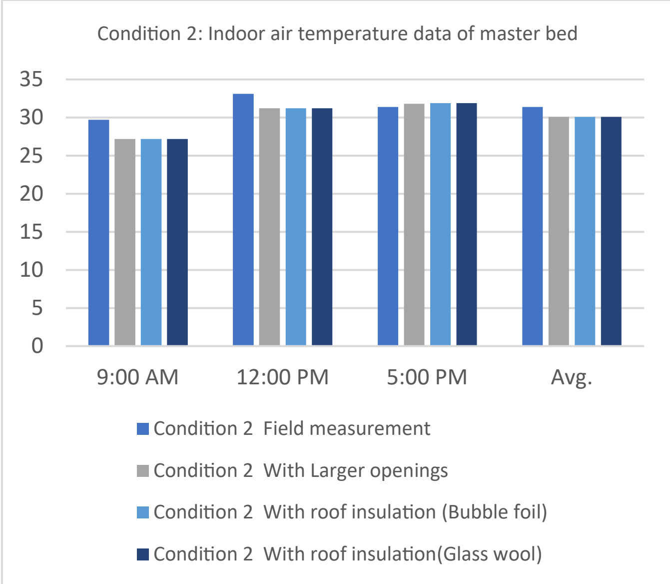

Fig.9.Changes in indoor air temperature in different simulations (Condition 2)

Figure 8 and 9 are showing the indoor air temperature data of master bed obtained from field measurement and different simulation models. In all cases, field measured, indoor air temperature values are higher than the simulated model obtained values. With the larger windows temperature decreased almost 1.5°C for both conditions. However, installation of the roof insulation materials went well for condition 1 as all the windows were closed and the heat could not enter directly through the windows. But interestingly for condition 2, the temperature increased at the evening. Applying different strategies can reduce the temperature to some extent but these strategies need to be improved or combined with other strategies to achieve a comfortable thermal environment inside the house.

IV. CONCLUSION

The results from statistical analysis and IES<VE> simulation model analysis show that the indoor air temperature is not in the range of recommended air temperature. For improvement of the indoor thermal condition of a low-cost house. Indoor air temperature should be reduced for more conductive thermal environment for the occupants. Though after windows and door were opened the indoor air temperatures were dropped, nevertheless the situation is not satisfied nor in the suggested indoor air temperature range. Hence, there is a need for alteration in the materials and implementation of new design strategies to make the indoor thermal environment of these houses livable. The findings offer guidelines for the developers and builders to make the decision in building the low-cost houses more efficiently. This research is only focused on the indoor air temperature issue of the single-story detached low-cost houses of Malaysia. Therefore, further research should be evolved in near future in order to improve the indoor thermal quality of low-cost houses in Malaysia.

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