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Indoor Air Temperature Analysis to Study Indoor Environmental Quality of a Detached Single Story Low-Cost House in Malaysia

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ABSTRACT

Thermal comfort is an important factor for a good indoor environment quality (IEQ) of a house. Generally, in low-cost housing development, thermal comfort issues are neglected. This is due to many factors but mostly for the constraint in construction cost. Poor thermal comfort could lead to an unhealthy indoor environment thus could lead to poor occupants' health. Measurement of indoor thermal comfort is essential to understand the existing situation of indoor environmental quality of low-cost houses. Therefore, the objective of this paper is to measure the thermal comfort focusing on air temperature of a selected existing detached low-cost house in Malaysia in order to determine the indoor environmental quality (IEQ). The methodology applied in this research is field measurement where a detached low-cost house was selected for measuring the thermal comfort using the thermal comfort meter and a weather station. Afterwards, a simulation has been done with IES<VE> software to validate the field measurement data. It is important to have a careful deliberation before designing or building a detached low-cost house due to its poor indoor thermal condition. Even though there is a limitation of a construction cost, the orientation of the building and planning of internal layout as well as other low-cost design strategies can be taken into consideration to build low-cost energy friendly house under Industrial Building System (IBS).

Keywords: Indoor environmental quality (IEQ); thermal comfort; field measurement; detached low-cost house; Malaysia

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INDOOR AIR TEMPERATURE ANALYSIS TO STUDY INDOOR ENVIRONMENTAL QUALITY OF A DETACHED SINGLE STORY LOW-COST HOUSE IN MALAYSIA

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Abstract

Thermal comfort is an important factor for a good indoor environment quality (IEQ) of a house. Generally, in low-cost housing development, thermal comfort issues are neglected. This is due to many factors but mostly for the constraint in construction cost. Poor thermal comfort could lead to an unhealthy indoor environment thus could lead to poor occupants' health. Measurement of indoor thermal comfort is essential to understand the existing situation of indoor environmental quality of low-cost houses. Therefore, the objective of this paper is to measure the thermal comfort focusing on air temperature of a selected existing detached low-cost house in Malaysia in order to determine the indoor environmental quality (IEQ). The methodology applied in this research is field measurement where a detached low-cost house was selected for measuring the thermal comfort using the thermal comfort meter and a weather station. Afterwards, a simulation has been done with IES<VE> software to validate the field measurement data. It is important to have a careful deliberation before designing or building a detached low-cost house due to its poor indoor thermal condition. Even though there is a limitation of a construction cost, the orientation of the building and planning of internal layout as well as other low-cost design strategies can be taken into consideration to build low-cost energy friendly house under Industrial Building System (IBS).

Keywords: *Indoor environmental quality (IEQ), thermal comfort, field measurement, detached low-cost house, Malaysia.*

1. Introduction

In Malaysia, low-cost housing always has been given least importance by both government and private sectors. Nowadays in Malaysia, housing rules have been developed and executed for mass people. To create easy access to housing facilities Malaysian government is giving the effort to provide housing for all. Besides that, another important factor is government housing policies should be reasonable in price, suitable for society and compatible with technology to achieve sustainability. According to 7th Malaysian plan [1]; 8th Malaysian plan [2] and 9th Malaysian plan [3], the Malaysian government had definite attention towards low-cost housing.

today in Malaysia. Despite all the efforts of government, occupants are still experiencing overheating problems in these houses. Most of the existing low-cost houses are having a high temperature during the daytime because of poor design [4]. Previous researchers have found that thermal comfort levels of low-cost houses are not satisfactory due to ineffective thermal design [5-7]. This paper elucidates the necessity of thermal comfort parameters to study the indoor environmental quality of low-cost houses in Malaysia. For assessing the present situation, field measurement has been done to collect the data of different parameters of thermal comfort.

On the other hand, thermal comfort scenario in low-cost housing is a concerning issue

2. Literature Review

Many studies already showed that thermal comfort is one of the most important aspects to assess IEQ of a residential building [8].

2.1 Thermal comfort

Thermal comfort refers to a physical state of ease which is directly related to outdoor and indoor environment. American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) Standard 55-66 (1966) described, "Comfort is the condition of mind which expresses satisfaction of an individual according to the thermal environment". It is quite impossible to predict that a person would rather have the feeling of warmth or coolness. Moreover, it depends on physiology, age, adaptation and sex [9]. Holopainen [10] stated that, "Thermal comfort describes the synthesized feeling about the body's thermal state". Hensen [11] defines, "Thermal comfort is a state in which there are no driving impulses to correct the environment by behavior and strongly related to the thermal balance of the body, which itself is influenced by environmental and personal parameters [11]. "If the indoor environmental conditions are favorable people can perform all the activities smoothly otherwise it can negatively affect the physiological and psychological states of human being" [12, 13].

2.2 Parameters of thermal comfort

There are two types of parameters which determine thermal comfort [10, 14] . Such as:

2.2.1 Environmental parameters:

- i. Air temperature; the dry-bulb temperature of the environment.
- ii. Mean radiant temperature; the uniform black-body temperature that would result in the same radiant energy exchange as in the actual environment.
- iii. Air velocity; a measure of the air speed.
- iv. Relative Humidity; percentage of water vapor in the air.

2.2.2. Personal parameters:

- i. Clothing Insulation; the thermal resistance of the clothing (I_{cl}).
- ii. Metabolic rate (met); the energy generated from the human body.

2.3 Thermal comfort models

2.3.1 Predicted Mean Vote (PMV) Index

In accordance with ASHRAE thermal sensation scale the PMV index predicts the mean response of a large group of people[9]:

Table1: Predicted mean vote sensation scale

Value	+3	+2	+1	0	-1	-2	-3
Sensation	Hot	Warm	Slightly warm	Neutral	Slightly cool	Cool	Cold

Source: [9]

Mathematically, P.O. Fanger expressed PMV as:

$$PMV = (0.303e^{-0.036M} + 0.028) L$$

where M = metabolic rate

L = thermal load;

which indicates a comfort value of skin temperature and evaporative heat loss by sweating of a person in actual activity level which is obtained from the difference between the internal heat production and the heat loss [9, 15, 16].

2.3.2 Adaptive model

For naturally ventilated spaces ASHRAE 55 standard replaced PMV model with adaptive model in 2004 [17]. The popularity of adaptive model expanded quickly because of simple equation. For predicting the comfort range, adaptive model only needs the outdoor temperature value and historical monthly data [18].

2.4 Low-cost house in Malaysia

According to Economic Planning Unit (1965,p. 182), low-cost housing was first time initiated for the well-being of low-income people in Malaysia (Malaysia 1965-First Malaysian Plan, 1966-1970). The state was responsible for the plan implementation with the financial support of the federal government. Throughout the duration of First Malaysian Plan (1966-1970) maximum low-cost housing was built for relocating the scattered town people and

for providing them houses on rent. Distribution of housing is divided into two sectors in Malaysia. One is the public sector which is conducted by multiple ministries and federal agencies. And another is the private sector where housing developers built houses under local authorities with government's surveillance [19].

In Malaysia, Syarikat Perumahan Negara Berhad (**SPNB**) is one of the companies building low-cost housing which is owned by the Malaysian Government, under the supervision of the Ministry of Finance (MOF Inc.). This company started its journey to supervise low-cost development projects and now they are building low-cost detached houses all around Malaysia for low-income people [20]. In 2002, under SPNB another scheme was started in Terengganu, named **SPNB Mesra Sdn. Bhd.** under the Rumah Mesra Rakyat 1Malaysia (RMR1M) program which is now building low-cost detached houses for those who do not have own house or have defected house.

Beside this, another organization named **RISDA** (Rubber industry small holders development authority) is giving services to rural people to build their own houses under Ministry of Rural and Regional Development [21]. 'Rumah Bina Negara' is a latest project of RISDA which has three bedrooms and two bathrooms.

Table 2-Detail specifications of 'Bina Negara house' are as follows:

SPECIFICATION		PACKAGING
1	WALL	SIMPLE BONE STONE
		EXTERNAL / IN PLASTER
		EXTERNAL PAINT
2	TOILET/BATHROOM	WALL: CERAMIC WALL TILES 5'
		FLOOR: CERAMIC TILES
3	ROOF	METAL DECK
		FRAME (STRUCTURE OF IRON)
4	CEILING	4'X4' CEMENT FIBRE
		PAINT
5	FLOOR	CEMENT
6	DOOR	SOLID DOOR (TIMBER)
		IRON FRAME
7	WINDOW	CASEMENT WINDOW



Figure 1: Plan and specification of Rumah Bina Negara. Source: [21]

2.4.1 Standards for planning and designing a low-cost housing

Low-cost housing has some standard guidelines for construction which is noted as CIS 1: 1998 which is for 1-2 story buildings and another is CIS 2: 1998 for high rise flats composed by the Construction Industry Development Board Standard (CIDB) stated by Ismail [22]. Ismail also described CIDB has some specifications for designing and planning of a low-cost housing. Housing estates for low-income dweller is developed to minimum standards suitable for human habitation [19]. Moreover, CIS 1 and CIS 2 include requirements on layout, space and configuration between four aspects of habitation – safety, adequate infrastructure, physical and mental health, and community. Present guidelines of CIS includes:

1. A minimum floor area of 63 m²
2. Three bedrooms
3. Kitchen
4. Living and dining area

5. Store room
 6. Bathroom
 7. Toilet
- Source:[23].

2.4.2 Typical layout of low-cost housing

The government has decided that the area of the house would be 1,000 sq. ft containing three bedrooms and two bathrooms.



Figure: 2

Source: SPNB Mesra Sdn. Bhd. (2015)



Figure:3

Source: [21]

Currently, in Malaysia people-friendly home is known as the 1Malaysia people-friendly home (RMR1M), which is under the low-cost housing development. All 1Malaysia People-Friendly Homes (RMR1M) will be built using the 'Industrialized Building System' (IBS) technology with a larger built-up area without incurring additional cost to the applicants.



Figure 4: Typical floor plan layout
Source: SPNB (2015)

LAMPIRAN 2

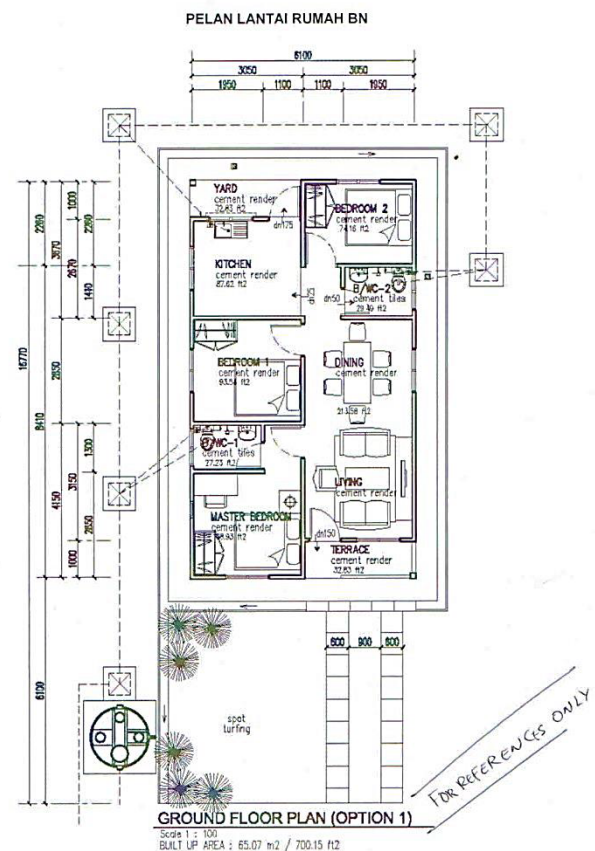


Figure 5: Typical floor plan layout
Source: [21]

3. Research Methods

Taking into account different methods of analysis, the methodology chosen for this study was field measurement where a detached low-cost house was selected for measuring thermal comfort with Delta ohm comfort meter and weather station.

This was built by RISDA which is one of the old designed houses. It is important to refer that this study only focused on the thermal comfort assessment of the selected low-cost detached house based on several parameters like air temperature, wind speed, relative humidity, clothing insulation and metabolic rate to find out the indoor environmental quality of the house.

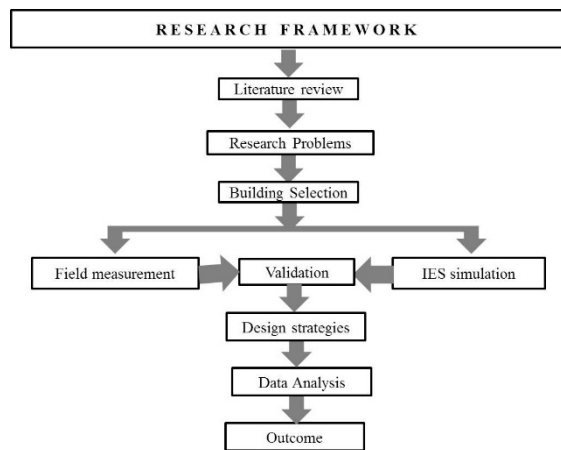


Figure 6: Research framework

3.1. Equipment calibration

Before starting the on-site field measurement, equipment were calibrated in the indoor controlled environmental atmosphere to find out the errors.

3.2. Field measurement

Field measurement has been conducted on a RISDA built low-cost single story detached house in a village named 'Kampung seberang parit' located in 'Kuala Pilah'. The house was around 623 sq. ft. having three bedrooms, one bathroom, one toilet, kitchen, dining and living room.

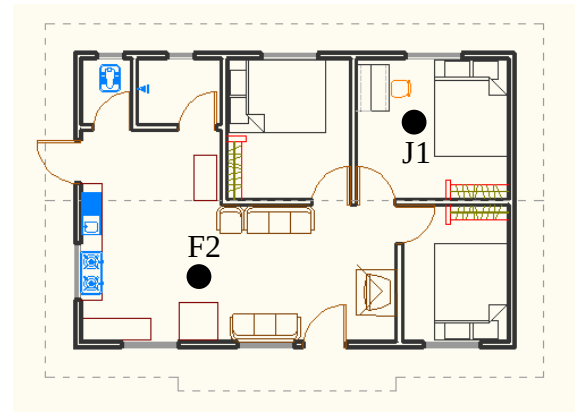


Figure 7: Placement of thermal comfort meters



Figure 8: Measured low-cost detached house. Source: Author

During field measurement, one weather station was set outside of the house and three thermal comfort meters were set in different rooms of the house. The measurement was conducted during 8.15 am to 7.15 pm. Two thermal comfort meters F2 and J2 was located in between living and dining room. Another one J1 was set in the master bedroom. As shown on the plan (figure 7) the node points of thermal comfort meters which were set 1.5m above from the floor level.

3.3. Data collection

At the end of the field measurement, measured and transferred data have analyzed and compared. Data collection was done in two different conditions. For each condition, data were collected for three days. These are the two conditions:

Condition 1: **Window** and **door** closed and **fan** off.

Condition 2: **Window** and **door** opened and **fan** off.

Air temperature, wind speed, relative humidity and PMV data were collected for these conditions.

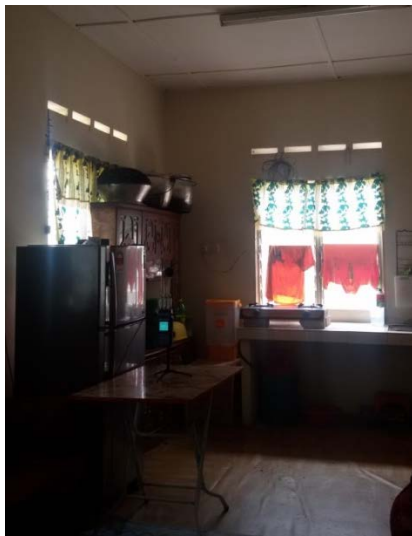


Figure 9: Position of F2

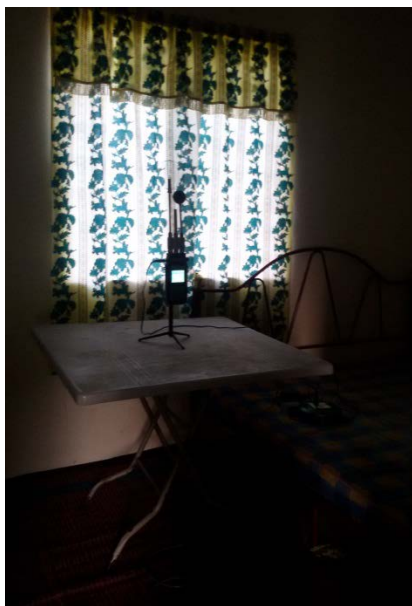


Figure 10: Position of J1

4. Analysis & 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.

4.1 Validation of IES<VE> model

The field measurement and IES<VE> model obtained data compared to do validation that will help to modify the

model to give further design suggestions. Table 3- Uncertainty estimation of the air temperature (°C) sensors as calibrated:

Sensors	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 $\pm 9.1\%$ (Table 3). The weather station was excluded from uncertainty estimation. The result revealed that the deviation(%) between IES<VE> model and field measurement data for F2, J1 are 9.1% and 2.3 respectively. This shows a balance between simulation modeling and field measurement.

4.2 Comparison between indoor air temperature and recommended temperature

According to the guidelines (Department of Standard Malaysia, 2010), for Malaysian climate, recommended temperature range for standard indoor environment design is 23°C - 26°C. That means the average standard indoor temperature is 24.5°C. For condition 1 and 2, indoor air temperature of three different times have been sorted out to compare with the recommended temperature (table 4,5 and figure 11,12).

Table 4- Condition 1: Indoor temperature and recommended air temperature (°C):

Condition- 1 Fan off and window/door closed	Indoor air temperature (C)	Indoor recommended temperature
Morning 9 am	29.2	24.5
Noon 12 pm	31.2	24.5
Evening 5 pm	33	24.5

For condition 1 and 2, respectively 29.2 degree Celsius and 29.7 degree Celsius are the lowest indoor temperature found at morning (9am) which is still higher than the recommended indoor air temperature (table 4 and table 5).

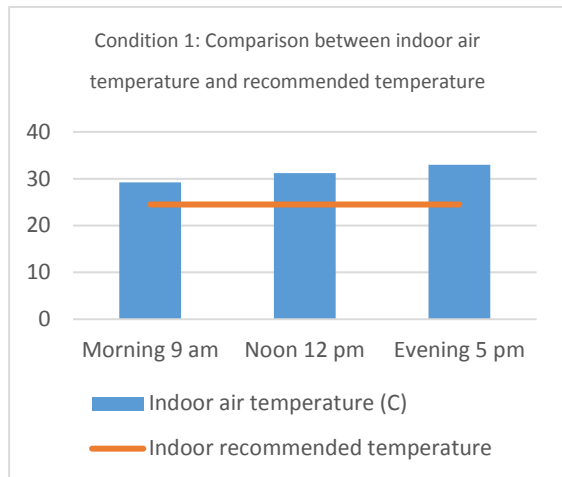


Figure 11- Condition 1: comparison between air temperature (T_a) and recommended temperature

Table 4- Condition 2: Indoor temperature and recommended air temperature ($^{\circ}\text{C}$):

Condition-2 Fan off and window/door opened	Indoor air temperature (C)	Indoor recommended temperature
Morning 9 am	29.7	24.5
Noon 12 pm	33.1	24.5
Evening 5 pm	31.4	24.5

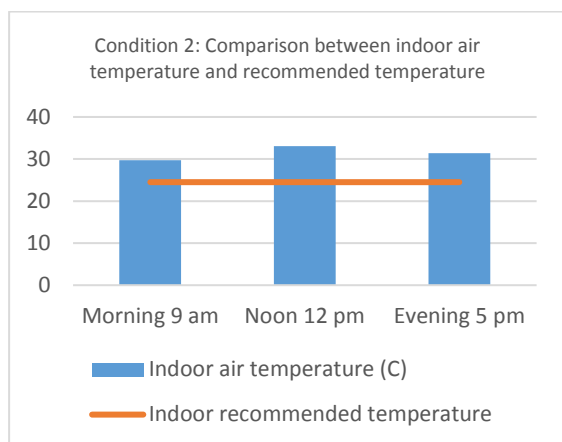


Figure 12- Condition 2: comparison between air temperature (T_a) and recommended temperature

In both conditions, the indoor temperature is not in the range nor comfortable.

4.3 Indoor air temperature in different conditions

Table 5 shows, maximum indoor air temperature for condition 1 found 34.8°C and minimum 28.5°C . After opening the windows, during condition 2, the maximum temperature dropped down 3.2°C . Interestingly the minimum temperature dropped only 0.9°C during condition 2.

Table 5- Indoor air temperature in different conditions ($^{\circ}\text{C}$):

Condition 1- Window close & Fan off (12 Aug-15 Aug)	Ta (9am)	Ta (12pm)	Ta (5pm)
13.08.2016	28.5	31.9	33.6
14.08.2016	30	33.2	34.8
15.08.2016	29.7	33	34.2
Condition 2- Window open & Fan off (23 Aug- 26 Aug)			
24.08.2016	27.9	30.4	31.5
25.08.2016	28	31.5	31.3
26.08.2016	27.6	31.6	28.5

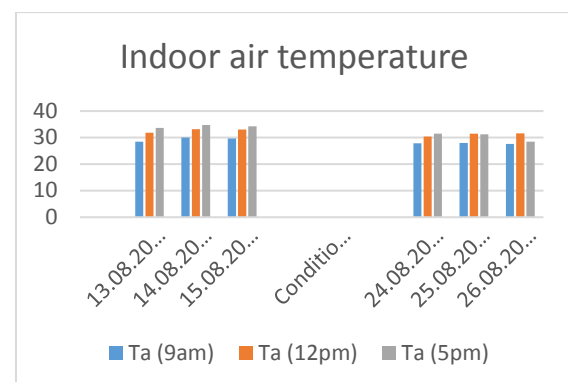


Figure 13- Indoor air temperature (T_a) analysis

5. Discussion & Conclusion

This paper concludes with the discussion on the investigations on indoor temperature to show the present scenario of typical low-cost houses. The results show that the indoor temperature is not in the range of recommended temperature. For improving the indoor environmental quality of a low-cost house indoor air temperature should be reduced for better productivity of the occupants. Though after opening the windows and door the temperature dropped but the situation is not satisfactory nor in the range. Hence, there is a need of alteration in

the materials and design strategies to make the IEQ of the house more livable. This finding will help the investors and the builders to make the low-cost houses more efficiently. This paper only focused on the indoor temperature issue of low-cost houses. Therefore, further research should be carried on in future in order to have a brief understanding of IEQ of low-cost houses in Malaysia.

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