Analytical Studies on Levels of Thermal Comfort in Typical Low-Income Houses Design

S.H. Ibrahim, A.Baharun, M.N.Mohd Nawi and E.Junaidi

Abstract—This paper investigates the present situation of thermal comfort in typical low-income houses located in Betong and Saratok, Sarawak, Malaysia. Investigations were carried out by measuring airflow rate, temperature, relative humidity and mean radiant temperature at specific points in one chosen house of each district. Different low-income housing estates were chosen for comparisons due to the different location and position of each house. Although both of these low- income houses have similarity in design but differs in layout arrangement. Results are presented and analyzed using Corrected Effective Temperature (CET) index in two different window and door opening configurations. The results show that the modern low-income house is thermally uncomfortable under certain conditions. High internal air temperatures occurred when doors and windows were closed combined with low air velocity contributes to thermally uncomfortable environment. Once all doors and windows were opened, allowing the air movement to increase, thermal comfort was achieved although air temperatures remained high.

Keywords: *Low Cost Housing, Thermal comfort, Corrected Effective Temperature (CET), CFD Simulation*

I. Introduction

IN Malaysia, government has granted several funding for construction of many housing schemes. While the design of these houses take many factors into consideration, however the outcomes often fail to provide basic levels of thermal comfort to the occupants. Due to the poor design, the houses are often overheated during the daytime and can be too cool during the night. Study done by several researchers indicated that thermal designs of low-income housing could be ineffective and resulting from this, the majority of their occupants are not satisfied with the thermal comfort levels provided [1], [2] and [3] .

Malaysia is located within the Equatorial zone and therefore its climatic temperature is stable ranging between 27-32^{o}C during nighttime. There are large variations in rainfall according to the season but relative humidity is high throughout the year at about 75%. The wind has a low but variable speed predominantly from southerly direction. The country has abundant sunshine and associated radiation for up to 6 hours each day. Most of the radiation reaching the earth's surface is diffused due to the characteristic cloud cover.

In order for occupants to be thermally comfortable within the available space, four environmental parameters need to be present in adequate proportions [4]. These parameters are air temperature, air velocity, mean radiant temperature and relative humidity. In warm humid climate, the predominance of high humidity necessitates a steady, continuous air movement over the body to increase the efficiency of sweat evaporation and to avoid any discomfort caused by moisture forming on the skin and clothes.

Various indices have been developed by researchers in an attempt to describe the thermal comfort experienced inside a building. Some of the better known indices are the Effective Temperature Index, Equatorial Comfort index, Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD), and Corrected Effective Temperature (CET) index. Most of these have some limitations in their practical application under different climatic conditions. Perhaps the only exception to this is the CET index. This is one of the most appropriate indices to use in a hot-humid climate [2] and [3].

Studies agree that the effective temperature range for thermal comfort in a tropical climate seldom exceeds 30^{o}C with a minimum temperature not lower than 22^{o}C [5] and [6]. Therefore in this study, the effective temperature required to promote thermal comfort was taken to be in the range of 25^{o}C to 28^{o}C. Using these figures as a guide, thermal comfort may be assessed in Malaysian houses in quantifiable terms. CET is the most appropriate index compared to the others, in order to evaluate comfort temperature in hot and humid environment [2], [7] and [8]. Therefore, the results will be investigated and analyzed by using Corrected Effective Temperature (CET) index to determine the significant of each experiment toward thermal comfort level for users in the specific library. Under the Malaysian climate, as suggested by most of the researchers, a reasonable thermal comfort temperature inside a building is between 25 to 28^{o}C [1],[2],[3],[5],[7],[8]and [9].

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In order to keep the collection of site data to a minimum while at the same time evaluating thermal comfort across as much of the house as possible, Computational Fluid Dynamics (CFD) was used in this project to extend the monitoring area. CFD has been used for predicting air movement in and around buildings since the early 1970s and many researchers have applied CFD airflow and temperature analysis inside rooms. The difference between measured and simulated air temperature and air flows are typically 2% and 7% respectively [10],[11] and [12].

II. EXPERIMENTAL DESIGN

The first two locations of the modern low-income house selected for this study are located in Betong and Saratok. Saratok district is located at 1.7400° N, 111.3370° E while Betong district is at 1.4000° N, 111.5167° E. The distance between both districts is 60 kilometres. Figure 1(a) shows the typical terraced housing type in Betong and Figure 1(b) shows the similar-type house in Saratok. Both houses comply with the generic design of a modern low-income house. There is a difference for the house in Saratok as it has undergone an extension at backside of the house.

Figure 1 (a): *The low-income house used for data collection in Betong*

Figure 1(b): *The low-income house used for data collection in Saratok*

The houses are built from lightweight, insulating materials but there are some parameters of the design which are of some concern. The pitch of the roof is only around 10^o and the roof overhangs are narrow, giving little solar protection to the walls. Furthermore, the ventilation provision in the walls of the house is very limited.

III. DATA COLLECTION IN THE HOUSES

Several different monitoring configurations were undertaken in each house to investigate the factors that may affect the internal airflows and temperature distributions. Air velocities and air temperatures were measured at specific node points during each data collection period. Thermocouples connected to a datalogger were used to measure the air and surface temperatures. Air speeds and direction were monitored using anemometers and airflow. The relative humidity was recorded at the center of each house. The mean radiant temperature was also measured using a globe thermometer.

For the experimental work in both houses, the following door and window opening configurations were used.
Experiment 1: All doors and windows closed
Experiment 2: All doors and windows opened

Details of the modern low –income house in Betong and Saratok are shown in Figures 2(a) and 2(b). Also shown on the plans is the node points (located 1.5m above the floor level) at which velocity and air temperature were measured

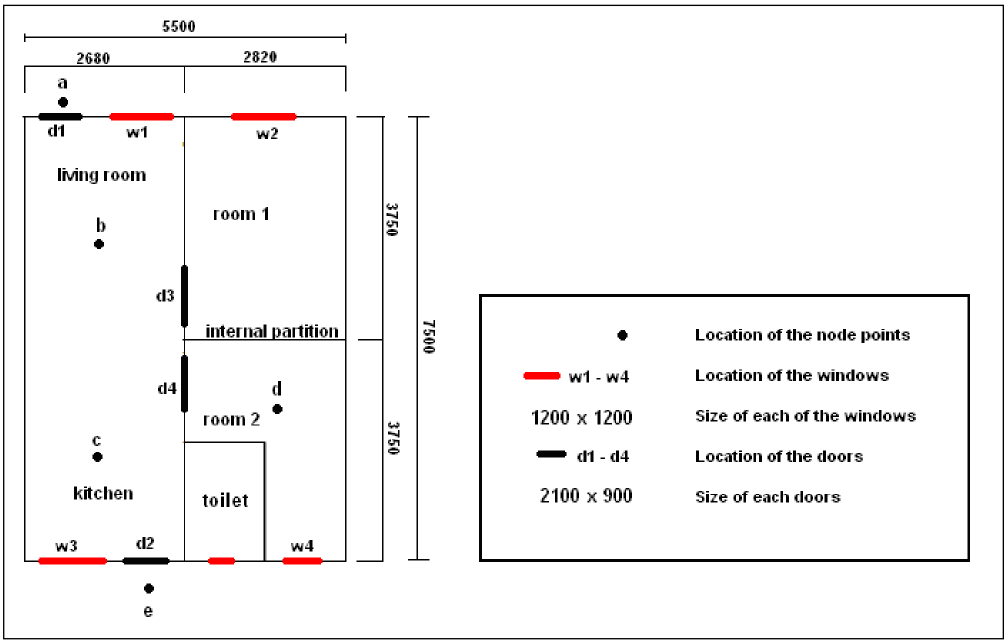


Figure 2(a): Layout plan of the house in Betong showing the locations of the nodes

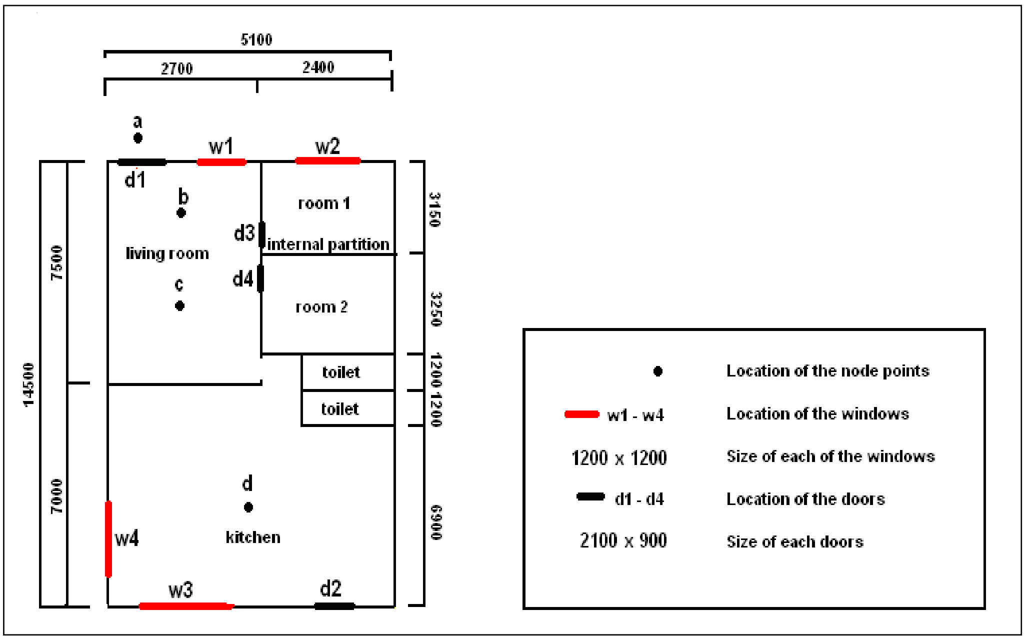


Figure 2(b): Layout plan of the house in Saratok showing the locations of the nodes

During the data collection period in each house, outside climatic data, which include wind direction, air speed and air temperature, were obtained from the local meteorological office so that the CFD code could be used to simulate the indoor airspeeds and temperature under the same external conditions.

IV. DATA ANALYSIS

The measured and simulated air temperature and velocity data obtained in the modern low-income houses in Betong and Saratok are given in Tables 1 and 2, respectively. In both tables, the coordinate location of the node points is given together with the measured and simulated values at those points and their percentage difference. The Mean Percentage Differences are 6.7 and 4.3 respectively and these are below than 10 percents. The simulations are in the acceptable values for further research to be conducted later.

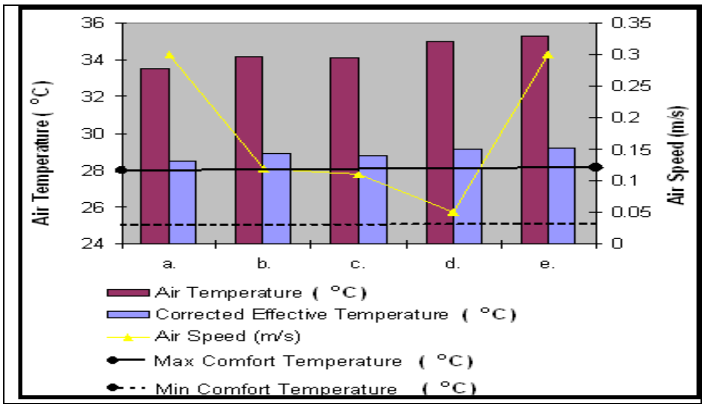
Table 1: Comparison of the Measured and Simulated Air Temperature and Velocity Data Inside the Modern Low-income House In Betong

		Air Temperature (^oC)			Air Velocity (m/s)		
Experiment	Node Point	Measured (^oC)	CFD Simulated (^oC)	Percentage Difference (^oC)	Measured (m/s)	CFD Simulated (m/s)	Percentage Difference (m/s)
1	a	33.5	33.7	+0.59	0.30	0.26	-15.38
	b	34.2	34.5	+0.86	0.12	0.11	-9.09
	c	34.1	34.6	+1.44	0.11	0.12	+8.33
	d	35.0	34.9	-0.28	0.05	0.06	+16.67
	e	35.3	35.7	+0.84	0.30	0.26	-15.38
2	a	33.5	33.3	-0.60	0.59	0.60	+1.66
	b	33.2	33.5	+0.89	0.45	0.48	+6.25
	c	33.3	33.5	+0.59	0.45	0.43	-4.65
	d	33.8	33.4	-1.19	0.35	0.35	0.00
	e	34.5	34.2	-0.87	0.62	0.65	+4.61
Mean Percentage Difference			+2.27			-6.98	

Table 2: Comparison of the Measured and Simulated Air Temperature and Velocity Data Inside the Modern Low-income House in Saratok

		Air Temperature (^oC)			Air Velocity (m/s)		
Experiment	Node Point	Measured (^oC)	CFD Simulated (^oC)	Percentage Difference (%)	Measured (m/s)	CFD Simulated (m/s)	Percentage Difference (m/s)
1	a	30.6	30.8	+0.64	0.53	0.55	+3.63
	b	34.5	35.3	+3.66	0.12	0.10	-20.00
	c	34.2	34.0	-0.58	0.12	0.14	+14..28
	d	33.0	33.2	+0.6	0.11	0.12	+8.33
2	a	30.6	30.8	+0.64	0.53	0.55	+3.63
	b	32.3	31.9	-1.25	0.39	0.36	-8.33
	c	32.1	32.1	0.00	0.36	0..36	0.00
	d	31.9	31.7	-0.63	0.35	0.36	+2.77
Mean Percentage Difference			+3.08			+4.31	

The simulated air temperatures and air velocities obtained at each node point by CFD analysis are presented in Figures 3(a) and 3(b), and these data, when used in conjunction with the relative humidity measured inside the house, enabled the CET to be determined [13]. The CET values are also shown in the figures. For comparison purposes, the minimum (25^oC) and maximum (28^oC) thermal comfort range are also shown in each figure.



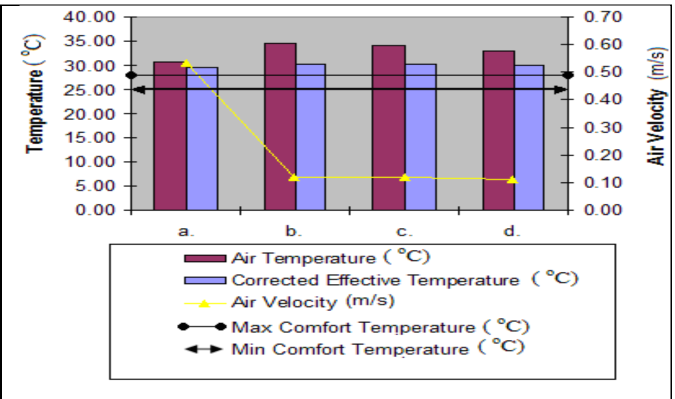


Figure 3(a) Bar chart to illustrate the relationship between measured parameters and CET when all the windows and doors are closed in Betong

Figure 3(b) Bar chart to illustrate the relationship between measured parameters and CET when all the windows and doors are closed in Saratok

The data were recorded when all the doors and windows were closed, for houses in Betong and Saratok, respectively. During the time of the measurement, the outdoor air temperature was 33.5°C for the house in Betong and 30.6°C for the house in Saratok. The simultaneous indoor air temperature for the house in Betong was measured at 34.2°C while the house in Saratok was measured at 34.5°C. The increase was mainly due to the solar heat which conducts through the roofing material and elevates the internal ceiling temperatures which then radiates into the room below. Additionally, the dark colour of the surface of the roof at both locations absorbs more solar energy and this made the condition worse.

Indoor air velocities was very low at around 0.1 m/s (the lowest measurement possible by the anemometer) and the effect of this, when combined with the high air temperature was an increase of CET value above the comfort zone in all the rooms in both houses. Outside air could not contribute to any internal air movement due to the absence of permanent ventilation when all the windows and doors were closed in both houses. In both houses, the absence of air movement causes the air temperatures at all the measurement points inside the house to exceed 31°C. Although the air velocities in both houses are within the desired range for tropical climates [14], due to the higher air temperatures, thermal comfort is not achieved in both houses. The lack of adequate ventilation provision in modern low-income housing has been reported previously as a design problem [3] and [15] and one that certainly needs addressing in the light of this research.

Data presented in Figures 4(a) and 4(b) shows the improvement of air movement is generated throughout both houses when all the doors and windows are opened with air velocities in all the rooms increasing. Air temperature remained about the same as those outside but the improved air movement lowers the CET to within the comfort zone. Due to restrictions, room 1 in both houses were not measured but from past research done, it has been found that air velocities will remain low as the partition between room 1 and 2 in both houses acted as a barrier to airflow. The CET in room 1 of both houses will be on the borderline on the upper comfort zone.

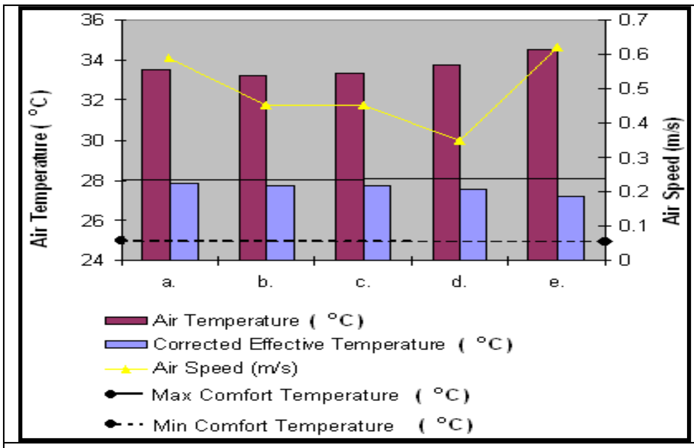


Figure 4(a) Bar chart to illustrate the relationship between measured parameters and CET when all the windows and doors are opened in Betong

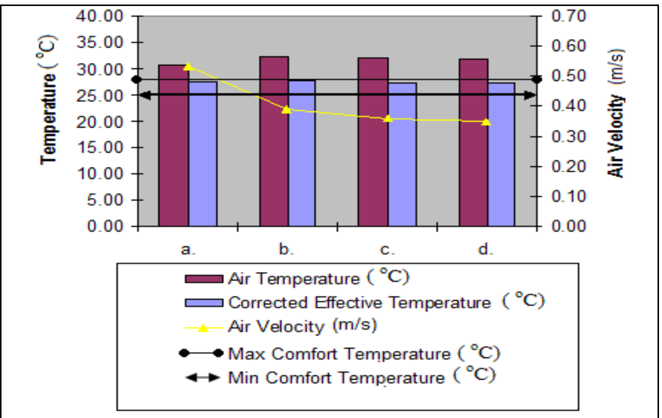


Figure 4(b) Bar chart to illustrate the relationship between measured parameters and CET when all the windows and doors are opened in Saratok

V. CONCLUSIONS

This study confirms the fact that the modern low-income house is thermally uncomfortable under certain conditions. The investigation carried out showed that internal air temperatures is high above the comfort temperature when doors and windows were closed and that when combined with low airspeeds, produced a thermally uncomfortable environment. Once all doors and windows were opened, allowing the air movement to increase, thermal comfort was achieved although air temperatures remained high.

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