An Evaluation of Thermal Comfort in Typical Modern Low-Income Housing in Malaysia

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ABSTRACT

Malaysia is facing a serious housing shortage in urban areas. To meet the demand, particularly for low-income families, the government and private corporations have launched massive building programs. Most of the housing being built is totally unsuitable for a hot and humid climate and, consequently, the houses are thermally uncomfortable most of the time. Unlike the modern houses currently being built, traditional Malay houses are designed to suit the climate and hence provide comfortable living conditions.

A study conducted by the authors was an important prototype, comparing a traditionally built house and a typical modern "modular" low-income house built in Sarawak, East Malaysia. Thermal comfort parameters were measured in both houses. The data were evaluated using a computational fluid dynamics (CFD) code and the comfort levels were assessed using the Corrected Effective Temperature (CET) Iindex method.

The provisional research confirmed that the traditionally built Malay house provided good levels of thermal comfort while the modern "modular" house did not. The work identified the critical need for some form of permanent ventilation to be provided in the modular house in order to improve its thermal comfort provision.

INTRODUCTION

In Malaysia and other developing countries, the migration of residents from rural to urban areas has created a great demand for housing. To fulfil this demand, the government has been funding the construction of many housing schemes. While the design of these take many factors into account, the houses often fail to provide basic levels of thermal comfort. Due to their poor thermal design, they often overheat during the day and can be too cool during the night for comfort. Previous studies (Madros 1998) have indicated that the thermal design 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. An attempt has been made to quantify the extent of the problem in Malaysia (UK 2000) where it is reported that two million houses may overheat and that the occupants prefer to spend their time outside the house during the day rather than inside.

Malaysia is located within the Equatorial Zone and therefore its climatic temperature is stable, ranging between 27°C and 32°C during the day and 21°C and 27°C during the night. 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 and most of the time blows predominantly from a southerly direction. The country has abundant sunshine and associated radiation for up to six hours each day. Most of the radiation reaching the earth's surface is diffused due to the characteristic cloud cover.

A number of researchers have studied the effect of various house design parameters and their influence on interior airflows in an attempt to improve the level of thermal comfort. These parameters include the orientation of the building, window size, location of interior partitions, and the effect of the overhang of the roof eaves (Givoni 1965; Ernest et al. 1991; Ifhtikar et al. 2000). This research obtained thermal

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comfort data using scale models placed in wind tunnels and consequently has limitations. Very little information is published on airflows and levels of thermal comfort actually measured inside Malaysian houses.

In order for occupants to be thermally comfortable in an interior space, it is generally accepted that four environmental parameters need to be present in adequate proportions (Givoni 1976; Markus and Morris 1980). These are air temperature, air velocity, mean radiant temperature, and relative humidity. In a 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.

Under a Malaysian climate, a reasonable thermal comfort temperature inside a house is between 25.5°C and 28.5°C (Jones et al. 1993). Other workers recommended similar values, such as 28.7°C (Humphrey 1994), 26.3°C with a clo value of 0.55 (Zain et al. 1997), and 28.5°C (Gail and De Dear 1998). The effect of room air velocity in promoting thermal comfort is well known and critical. For comfort, the indoor air velocity is recommended to range between 0.15 and 1.5 m/s (Olgyay 1963). Szokolay (1980) reported that in a hot climate, indoor air velocities of 1.0 m/s are very pleasant and are acceptable up to 1.5 m/s; above this they are unacceptable. Rajeh (1994) suggested that an air movement of 1.0 m/s will provide a satisfactory condition most of the time in terrace housing in Malaysia. Published data are reasonably consistent and most researchers agree that the temperature range for thermal comfort in a tropical climate should not exceed 28°C and that air velocities should range between 0.15 and 1.5 m/s.

Various indices have been developed by researchers in an attempt to describe the thermal comfort experienced inside a building. They generally include two or more of the environmental parameters mentioned above. Some of the better known indices are the Effective Temperature Index, Equatorial Comfort Index, Predicted Mean Vote (PMV) and the Predicted Percentage Dissatisfied (PPD), and the 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 (Houghton and Yaglou 1923; Burt and Button 1969; Hanafi 1991) and is fully reported by Koenigsberger et al. (1974).

The collection of site data required to determine the thermal comfort inside a house is both time-consuming and expensive, and its reliability is often restricted to the specific time and areas being monitored. 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 to airflow and temperature analysis inside rooms. Differences between measured and simulated air temperature and air flows being typically 2% and 7%, respectively (Tinker and Woolf 1994; Al-Garny 1999; Roberts 1999).

EXPERIMENTAL DESIGN

The main focus of the prototype study was to develop a simple, reliable methodology to determine the thermal comfort in modern low-income housing in Malaysia. For the initial phase of the work described in this paper, two specific low-income houses were selected. These were chosen because their individual designs represented the generic design aspects of both traditional and modern low-income house construction, respectively. Data were recorded such that the CET index could be determined at a number of specific locations in each house. So that the amount of site-collected data could be limited and later extrapolated to cover a larger area, CFD simulations were used.

Prior to a CFD code being used for simulation work, its reliability and accuracy should be validated. The code used in the project had been used several times in the U K and its accuracy shown to have good agreement with experimentally measured data (Al-Garny 1999; Roberts 1999; Baharun 2002). Before being used in this project, it was validated against air temperature and air velocity data measured on site in both the traditional Malay house and the modern low-income house selected for the comfort studies.

The Traditional Malay House

The detached traditional Malay house that was selected for the research was located in Kuching, East Malaysia, and is shown in Figure 1. The house was climatically responsive to the environment and according to its occupants provided good thermal comfort. The house was raised on stilts to allow underfloor ventilation and was built using a timber frame with timber floors and timber-covered walls and roof. The roof, which was uninsulated, was built with a large eaves overhang that provided shade to the walls. Roof ventilation grilles allowed air to flow into the attic space above the ceiling. The

Figure 1 *Traditional Malay house used for data collection.*

walls incorporated large window openings that extended from just above floor level to full body height. All the windows had a louvered opening at their top extending to the underside of the roof.

To validate the CFD code and the thermal comfort provision in the house, a room predominantly occupied during the day was chosen for data collection. The research area had to be limited due to the physical size of the house, and so only the front living area or "*serambi*" was monitored for data collection. The *serambi* part of the house is the projecting part shown on the left-hand side of the photograph in Figure 1.

Type-T thermocouples connected to a datalogger were used to measure air and surface temperatures at selected node points inside the house. Airspeeds were measured using a hot-wire anemometer. Relative humidity was recorded inside the house using a whirling sling hygrometer. The node point locations of the thermocouples were positioned so as to coincide with the node points in the CFD simulations. This enabled the CFD code to be validated with the experimental results.

The Modern Low–Income House

The modern low-income house selected for the study was also located in the city of Kuching. A photograph of the typical terraced housing type is shown in Figure 2. The manufacturers claim that this type of house speeds up the construction process and that the materials and technology used help to reduce internal heat gain and so provide thermal comfort. Thousands of similar houses are being built each year in Malaysia. The houses are built from lightweight, insulating materials, but there are some parameters of the design that are of some concern. The roof overhangs are narrow, giving little solar protection to the windows and walls, and the ventilation provision in the walls of the house is very limited when compared to the ventilation provision in a traditional Malay house. To economize on the design, the houses have no ceiling and they incorporate very little roof insulation. A major concern, which prompted this study, is that despite the mass building of this type of house, no technical evaluation has been done to establish that the technology provides the necessary internal airflows to provide a thermally comfortable environment for the occupants.

To evaluate the thermal comfort provision inside the modern low-income house, the same methodology as was used for the traditional Malay house was repeated.

Data Collection in the Houses

Several different monitoring configurations were undertaken in each house to investigate the factors that may affect internal airflows and temperature distributions. Air velocities and air temperatures were measured at specific node points during each data collection period, and these were initially used to validate the CFD code. Additionally, the relative humidity was recorded at the center of each house using a whirling sling hygrometer. This was an additional measurement needed to evaluate the thermal comfort provision inside the house.

Details of the monitoring positions inside the *serambi* part of the traditional Malay house are shown in Figure 3. Floor plan (a) shows the position of the windows and location of the five node points (located 1.5 m above floor level) at which air velocity and temperature measurements were made. Figures 3(b) and 3(c) show the west and south elevations of the house, respectively, while Figure 3(d) presents an isometric view of the *serambi* area.

For the experimental work in the traditional Malay house, the following window opening configurations were used. The windows were fully opened from early morning during the measurement day and remained opened during the measurement period.

- Experiment 1: All windows closed
- Experiment 2: Window (W1) open only
- Experiment 3: Windows (W1) and (W5) open only
- Experiment 4: Windows (W1) and (W3) open only
- Experiment 5: Windows (W1), (W2), (W3), and (W4) open only

Details of the modern low-income house are shown in Figure 4. Floor plan (a) shows the plan layout inside the house together with the location of the doors and windows. Also shown on the plan is the location of the six node points (located 1.5 m above the floor level) at which air velocity and temperature measurement were made. Figures 4(b) and 4(c) show the north and south elevations of the house, respectively. Figure 4(d) presents a typical isometric view of the mid-terraced house used for the measurements.

For the experimental work in the modern low-income house, the following door and window opening configurations were used. The window and door opening periods were as previously described.

- Experiment 1: All doors and windows closed
- Experiment 2: Door (D1) and window (W1) open only
- Experiment 3: Door (D1), window (W1), door (D2), and window (W3) open only
- Experiment 4: All doors and windows open
- Experiment 5: Door (D1), door (D4), window (W1), and window (W4) open only

Figure 2 *Typical modern low-income house used for data collection.*

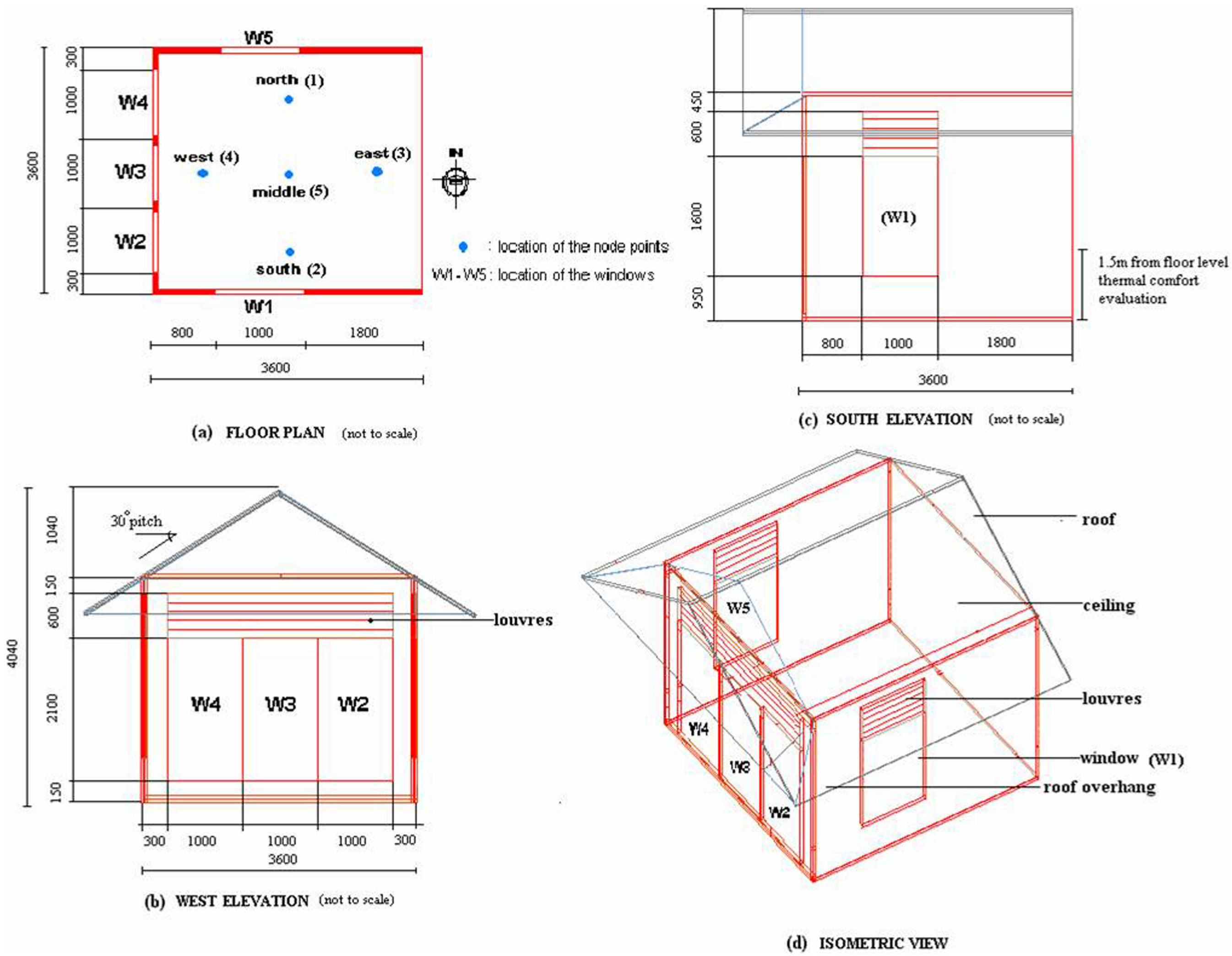

Figure 3 *Details of the traditional Malay house.*

During the data collection period in each house, outside climatic data, which included 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 temperatures under the same external conditions.

RESULTS

Air Temperature and Air Velocity Results Used to Validate the CFD Code

The measured and simulated air temperature and velocity data obtained in the traditional Malay house and the modern low-income house 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 air temperature and velocity measurements given in the tables were mean values obtained from an anemometer, integrated over a three-minute measuring period.

Discussion of the Results

It can be seen from the tables that the difference between the measured and simulated air temperatures in both houses is small, with a mean difference of 2.2% and 0.7%, respectively. The differences between the measured and simulated air velocity data are also quite small, with mean percentage differences of around 6.5%. The higher percentage errors associated with some of the air velocity measurements were due to the smallness of the measurement.

The mean percentage differences obtained over both sets of results are acceptable and compare well with similar validation work. Al-Garny (1999) and Roberts (1999) reported mean percentages difference of 0.55% on air temperatures and 6.9% on air velocities, respectively. From the results obtained and by comparison of these with other workers, it can be concluded that the CFD code could be used with some confidence in the next part of the study.

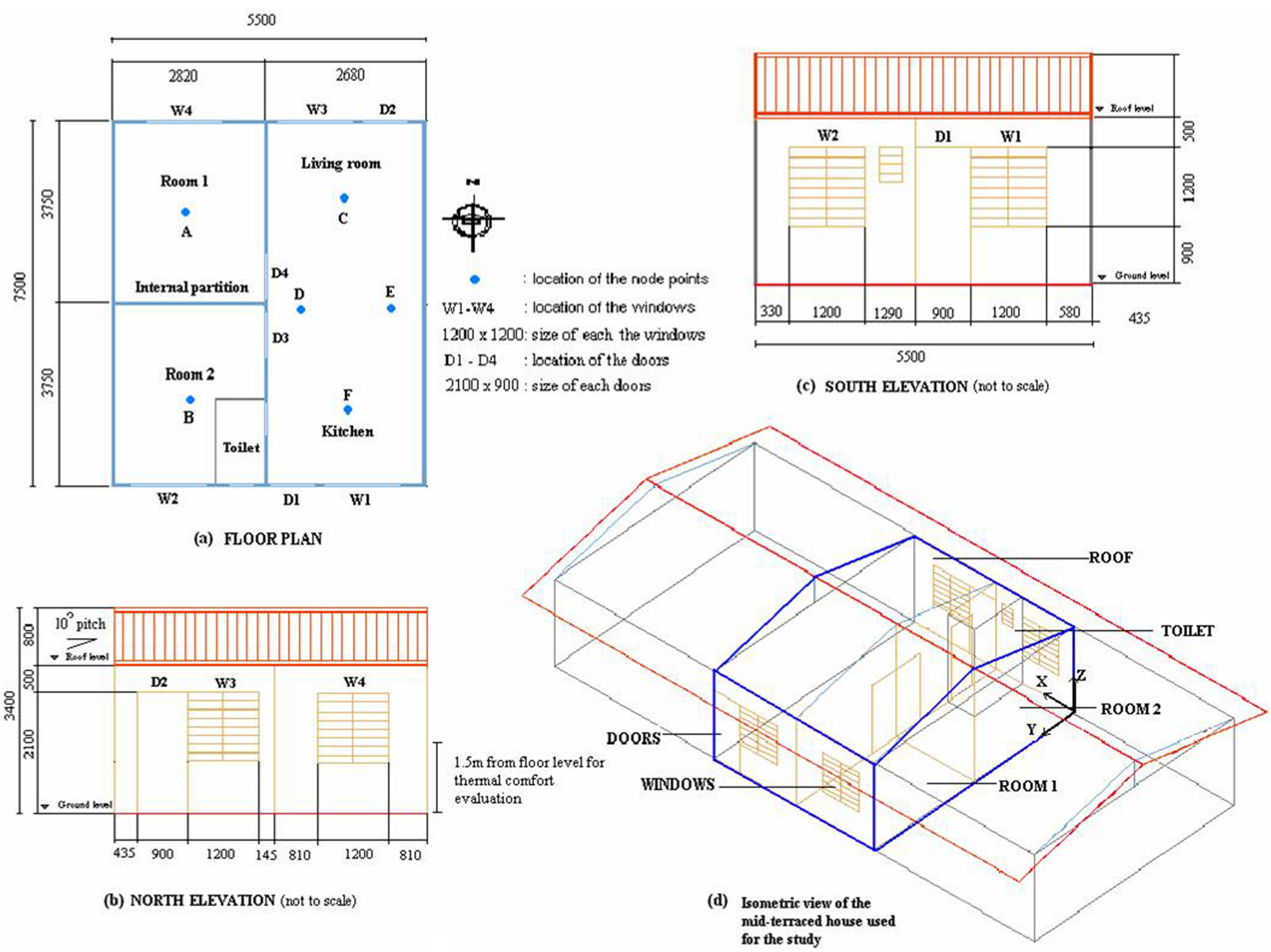

Figure 4 *Details of the modern low-income house.*

Evaluation of Thermal Comfort in the Houses

Once the accuracy of the CFD code had been established, the data were then further analyzed to determine the thermal comfort provision in each of the houses under different experimental conditions.

In addition to the experimental data collected inside the houses, the outside air (shade) temperature and air speed and direction were also measured close to the house. These data were compared with data supplied by the local meteorological office to ensure that the microclimate around each house was not significantly different to the general climate of the area. The data collected on-site are shown at the top of Figure 5 and subsequent figures. Also shown at the top of each figure is the relative humidity measured inside the house during each experiment.

The simulated air temperatures and airspeeds obtained at each node point by CFD analysis are again presented in each figure, and these data, when used in conjunction with the relative humidity measured inside the house, enabled the CET, or comfort temperature, to be determined (Koenigsberger et al. 1974). The CET is also shown in the figure. For purposes of comparison, the minimum (25°C) and maximum (28°C) comfort temperatures appropriate to the region are also presented on each figure.

Due to publishing restriction, only a limited number of results can be presented for each housing type, but typical sets of results obtained in the traditional Malay house are shown in Figures 5 and 6 for experiment 1, when all the windows were closed, and for experiment 5, when four adjacent windows were opened, respectively. The results shown in Figure 5 are particularly interesting because due to all the windows in the room being closed, the ingress of warm outside air into the room was restricted and as a result the air temperatures inside the house were about 1.5°C cooler than the outside air. Of equal importance is that the airspeeds in the room remained above 0.2 m/s due to the louvers (see Figure 3) that were installed above the windows, thereby promoting a gentle but permanent air movement throughout the house. It can be

Table 1. Comparison of the Measured and Simulated Air Temperature and Velocity Data Inside the Traditional Malay House

Experiment	Node Point	Location	Air Temperature (°C) Measured (°C)	Air Temperature (°C) CFD Simulated (°C)	Air Temperature (°C) Percentage Difference (%)	Air Velocity (m/s) Measured (m/s)	Air Velocity (m/s) CFD Simulated (m/s)	Air Velocity (m/s) Percentage Difference (%)
1	North	$X_{1.8}Y_{2.7}Z_{1.5}$	27.5	28.8	+6.3	0.23	0.22	-4.35
	South	$X_{1.8}Y_{0.9}Z_{1.5}$	27.8	28.9	+3.8	0.27	0.24	-11.11
	East	$X_{2.7}Y_{1.8}Z_{1.5}$	27.8	28.7	+3.4	0.20	0.18	-10.00
	West	$X_{0.9}Y_{1.8}Z_{1.5}$	27.9	28.9	+3.6	0.25	0.24	-4.00
	Middle	$X_{1.8}Y_{1.8}Z_{1 \cdot 5}$	27.6	28.8	+4.4	0.24	0.21	-12.50
2	North	$X_{1.8}Y_{2.7}Z_{1.5}$	28.8	29.1	+1.0	0.40	0.37	-7.50
	South	$X_{1.8}Y_{0.9}Z_{1.5}$	28.7	29.1	+1.3	0.51	0.49	-3.92
	East	$X_{2.7}Y_{1.8}Z_{1.5}$	28.2	29.1	+3.0	0.27	0.25	-7.41
	West	$X_{0.9}Y_{1.8}Z_{1.5}$	28.8	29.1	+1.0	0.45	0.42	-6.67
	Middle	$X_{1.8}Y_{1.8}Z_{1 \cdot 5}$	28.3	29.1	+2.0	0.48	0.44	-8.33
3	North	$X_{1.8}Y_{2.7}Z_{1.5}$	28.5	29.1	+2.0	0.47	0.41	-12.77
	South	$X_{1.8}Y_{0.9}Z_{1.5}$	28.3	29.1	+2.8	0.54	0.51	-5.56
	East	$X_{2.7}Y_{1.8}Z_{1.5}$	28.1	29.1	+3.4	0.30	0.26	-13.33
	West	$X_{0.9}Y_{1.8}Z_{1.5}$	28.3	29.1	+2.8	0.50	0.54	+8.00
	Middle	$X_{1.8}Y_{1.8}Z_{1 \cdot 5}$	28.6	29.1	+1.6	0.47	0.44	-6.38
4	North	$X_{1.8}Y_{2.7}Z_{1.5}$	28.7	29.1	+1.3	0.53	0.53	0.00
	South	$X_{1.8}Y_{0.9}Z_{1.5}$	29.0	29.1	+0.2	0.63	0.62	-1.59
	East	$X_{2.7}Y_{1.8}Z_{1.5}$	28.6	29.1	+1.6	0.41	0.39	-4.88
	West	$X_{0.9}Y_{1.8}Z_{1.5}$	29.0	29.1	+0.2	0.65	0.61	-6.15
	Middle	$X_{1.8}Y_{1.8}Z_{1 \cdot 5}$	28.8	29.1	+0.9	0.60	0.59	-1.67
5	North	$X_{1.8}Y_{2.7}Z_{1.5}$	28.3	28.9	+2.1	0.53	0.53	0.00
	South	$X_{1.8}Y_{0.9}Z_{1.5}$	28.5	28.9	+1.4	0.60	0.63	+5.00
	East	$X_{2.7}Y_{1.8}Z_{1.5}$	28.1	28.9	+2.8	0.63	0.60	-4.76
	West	$X_{0.9}Y_{1.8}Z_{1.5}$	28.8	28.9	+0.3	0.65	0.63	-3.08
	Middle	$X_{1.8}Y_{1.8}Z_{1 \cdot 5}$	28.3	28.9	+2.1	0.58	0.59	+3.51
		Mean percentage difference			+2.2			-6.10

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

Experiment	Node Point	Location	Air Temperature (°C)			Air Velocity (m/s)		
			Measured (°C)	CFD Simulated (°C)	Percentage Difference (%)	Measured (°C)	CFD Simulated (°C)	Percentage Difference (%)
1	A	$X_{1.4}Y_{5.6}Z_{1.5}$	31.2	30.1	-3.5	0.10	0.09	-10.00
	B	$X_{1.4}Y_{1.9}Z_{1.5}$	31.3	30.1	-3.8	0.11	0.10	-9.09
	C	$X_{4.2}Y_{5.6}Z_{1.5}$	31.2	30.1	-3.5	0.11	0.11	0.00
	D	$X_{3.5}Y_{3.8}Z_{1.5}$	31.1	30.2	-2.9	0.13	0.12	-7.69
	E	$X_{4.8}Y_{3.8}Z_{1.5}$	31.1	30.2	-2.9	0.12	0.11	-8.33
	F	$X_{4.2}Y_{1.9}Z_{1.5}$	31.0	30.2	-2.6	0.13	0.12	-7.69
2	A	$X_{1.4}Y_{5.6}Z_{1.5}$	30.5	30.2	-1.3	0.10	0.09	-10.00
	B	$X_{1.4}Y_{1.9}Z_{1.5}$	30.5	30.2	1.3	0.13	0.12	-7.69
	C	$X_{4.2}Y_{5.6}Z_{1.5}$	30.1	30.1	0.0	0.32	0.29	-9.38
	D	$X_{3.5}Y_{3.8}Z_{1.5}$	30.1	30.0	0.3	0.47	0.43	-8.51
	E	$X_{4.8}Y_{3.8}Z_{1.5}$	30.0	30.1	+0.3	0.48	0.45	-6.25
	F	$X_{4.2}Y_{1.9}Z_{1.5}$	29.9	30.0	+0.3	0.57	0.59	+3.51
3	A	$X_{1.4}Y_{5.6}Z_{1.5}$	30.2	29.7	-1.7	0.10	0.09	-10.00
	B	$X_{1.4}Y_{1.9}Z_{1.5}$	30.1	29.7	-1.3	0.10	0.09	-10.00
	C	$X_{4.2}Y_{5.6}Z_{1.5}$	29.5	29.6	+0.3	0.45	0.47	+4.44
	D	$X_{3.5}Y_{3.8}Z_{1.5}$	29.6	29.6	0.0	0.48	0.45	-6.25
	E	$X_{4.8}Y_{3.8}Z_{1.5}$	29.6	29.7	+0.3	0.45	0.42	-6.67
	F	$X_{4.2}Y_{1.9}Z_{1.5}$	29.6	29.7	+0.3	0.57	0.54	-5.26
4	A	$X_{1.4}Y_{5.6}Z_{1.5}$	30.0	30.1	+0.3	0.24	0.22	-8.33
	B	$X_{1.4}Y_{1.9}Z_{1.5}$	29.9	30.0	+0.3	0.47	0.43	-8.51
	C	$X_{4.2}Y_{5.6}Z_{1.5}$	30.1	30.0	-0.3	0.37	0.38	+2.70
	D	$X_{3.5}Y_{3.8}Z_{1.5}$	30.0	30.1	+0.3	0.47	0.50	+6.38
	E	$X_{4.8}Y_{3.8}Z_{1.5}$	29.9	30.1	+0.6	0.43	0.40	6.98
	F	$X_{4.2}Y_{1.9}Z_{1.5}$	30.0	30.1	+0.3	0.48	0.47	-2.08
5	A	$X_{1.4}Y_{5.6}Z_{1.5}$	29.9	30.0	+0.5	0.30	0.27	-10.00
	B	$X_{1.4}Y_{1.9}Z_{1.5}$	30.1	30.1	0.0	0.12	0.13	+8.33
	C	$X_{4.2}Y_{5.6}Z_{1.5}$	30.0	30.1	+0.2	0.38	0.39	-2.63
	D	$X_{3.5}Y_{3.8}Z_{1.5}$	29.9	30.1	+0.6	0.57	0.61	+7.02
	E	$X_{4.8}Y_{3.8}Z_{1.5}$	29.9	30.1	+0.5	0.52	0.49	-5.77
	F	$X_{4.2}Y_{1.9}Z_{1.5}$	30.0	30.1	+0.2	0.64	0.66	+3.13
		Mean percentage of difference			+0.7			-6.70

Wind direction	Southerly
Air speed outside the house	0.81 m/s
Air temperature outside	29.3°C
Relative humidity inside the house	82%

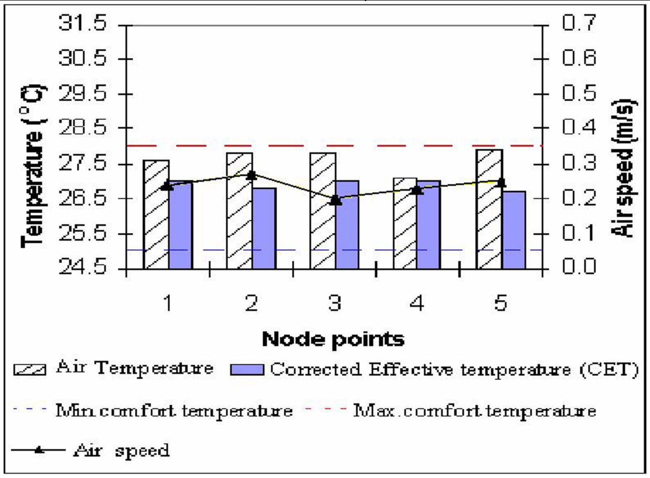

Figure 5 *Result of indoor environmental conditions in the traditional Malay house (all windows closed).*

Wind direction	Southerly
Air speed outside the house	0.66 m/s
Air temperature outside	29.0°C
Relative humidity inside the house	82%

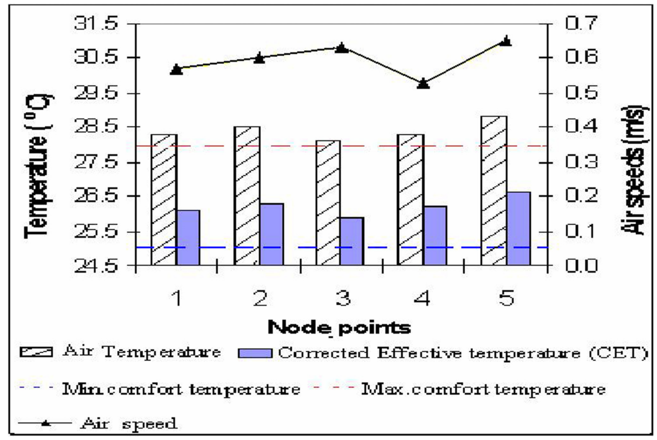

Figure 6 *Result of indoor environmental conditions in the traditional Malay house (adjacent windows opened).*

observed that all the calculated CET values lay between 25°C and 28°C, indicating that thermal comfort existed at all the locations in the room at which measurements were taken. By extrapolating results obtained from the CFD simulation work to other parts of the room, the CET index at any other location could be determined. Using this technique it was established that thermal comfort was provided across the entire room area (Ibrahim 2004). The results shown in Figure 6 are for experiment 5 in which nearly all the windows in the room were opened. Due to the open windows, the outdoor air velocity carried warm air into the room relatively unimpeded and this increased the temperature of the room air to almost the same as that of the outside. The airspeed in the room also increased until it was almost the same as the outside wind speed. Although the air temperature in the room exceeded the maximum comfort temperature, room airspeeds of 0.6 m/s compensated for this and the CET remained within the comfort zone. Further use of the data obtained from the CFD analysis once again confirmed that thermal comfort was provided across the entire room and not only at the locations monitored.

Typical sets of results obtained in the modern low-income house are presented in Figures 7, 8, and 9. Data presented in Figure 7 were recorded when all the doors and windows in the house were closed. During the time of the measurement, the outdoor air temperature was 30°C but the simultaneous indoor air temperature was measured at 31°C. The increase was mainly due to the solar heat gain transmitted through the roof. Indoor airspeeds were very low at 0.1 m/s (the lowest measurement possible by the anemometer) and the effect of this, when combined with the high air temperature, was to increase the CET value above the comfort zone in all the rooms in the house. The lack of adequate ventilation provision in modern low-income terrace housing has been reported previously as a design problem (Rajeh 1994; Adam 1997) and one that certainly needs addressing in the light of this research.

When some of the doors and windows in the modern low-income house were opened, such as opposite doors and windows in the kitchen/living room area, the indoor air temperature remained around 30°C but the indoor air velocity increased in some of the rooms. The data are shown in Figure 8 where it can be seen that by opening certain doors and windows in the house, the airflow increased and comfort conditions were provided in some parts of the house. In rooms where the windows remain closed and airspeeds remained low, then thermal comfort was not achieved.

By opening all the doors and windows in the modern low-income house, the indoor air temperature remained about the same as the outdoor air temperature but the air speed in all the rooms increased. The in Figure 9 show that, due to the improved airspeeds throughout the house, thermal comfort is provided in all the rooms. It is interesting to note that in room 1 (node point A), which was located on the leeward side of the building and, hence, had a restricted ingress of outside air, a thermal comfort temperature was only just achieved.

CONCLUSIONS

The results of the prototype evaluation showed that thermal comfort was achieved in the traditional Malay house

Wind direction	Southerly
Air speed outside the house	0.64 m/s
Air temperature outside	30.0°C
Relative humidity inside the house	70%

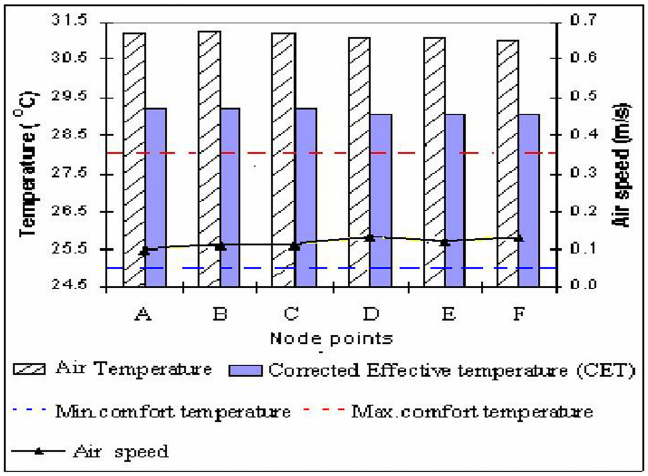

Figure 7 *Result of indoor environmental conditions in the modern low-income house (all doors and windows closed).*

Wind direction	Southerly
Air speed outside the house	0.68 m/s
Air temperature outside	29.7°C
Relative humidity inside the house	68%

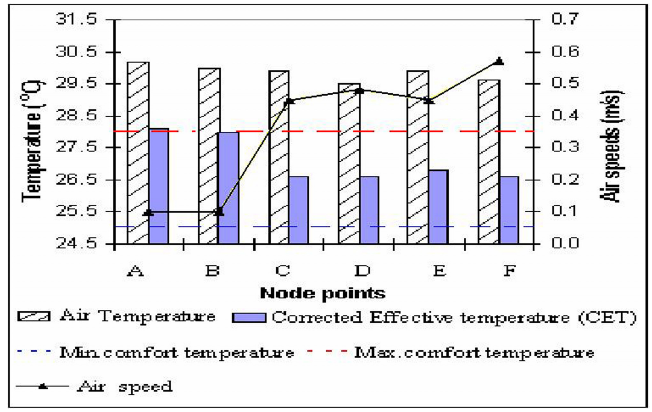

Figure 8 *Result of indoor environmental conditions in the modern low-income house (opposite doors and windows opened).*

Wind direction	Southerly
Air speed outside the house	0.65 m/s
Air temperature outside	30.1°C
Relative humidity inside the house	72%

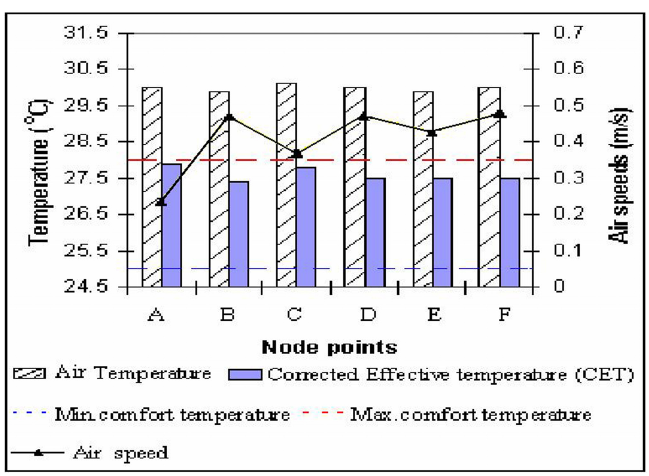

Figure 9 *Result of indoor environmental conditions in the modern low-income house (all doors and windows opened).*

throughout the monitoring period. This finding agreed with other workers and was attributed to its design, which promoted good air movement throughout the house irrespective of any open windows, etc.

In contrast to this, the research confirmed that the modern low-income house was thermally uncomfortable under certain conditions. The investigation showed that high internal air temperatures occurred when doors and windows were closed and that when combined with low airspeeds, the house became thermally uncomfortable. Once all doors and windows in the house were opened, allowing the air movement to increase, then although air temperatures remained high and thermal comfort was achieved.

The work, although limited at present, highlighted the fact that typical modern low-income housing design in parts of Malaysia lacks sufficient permanent ventilation to provide thermal comfort. If thermal comfort is to be provided, then all the doors and windows in the house must be opened. This, of course, poses its own inherent security risk. The main recommendation of the work is that future modern, low-income house designs, similar to the one studied, should be modified to incorporate sufficient secure ventilation grilles to provide a permanent air movement throughout the house and hence promote reasonable levels of thermal comfort.

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