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Thermal Comfort Evaluation of the Enclosed Transitional Space in Tropical Buildings: Subjective Response and Computational Fluid Dynamics Simulation

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Abstract: This study aims to identify the thermal environment of an enclosed transitional space in a tropical educational institution and occupants' perceptions on thermal comfort. The methods applied were field survey, which covered objective measurement and subjective assessment, as well as Computational Fluid Dynamics (CFD) simulation. Comparisons were made between the empirical and predicted results. In this study, it was identified in the field assessment that most of the respondents were satisfied with the thermal environment in the enclosed lift lobby and preference was directed towards cooler environment. The predicted results showed fair agreement with the empirical results, with minor differences between the two results for the thermal and airflow conditions. Besides, a lower expectation factor in PMV index is required for thermal environment in transitional spaces. Analysis of thermal neutrality in this survey has demonstrated that the thermal conditions in the enclosed lift lobby were acceptable by 80% of the respondents. The methods applied in this study can be extended to other enclosed transitional spaces in the tropical buildings.

Key words: Thermal comfort, CFD, transitional space, lift lobby, tropics, educational institution

INTRODUCTION

Most of the thermal comfort surveys were conducted in the commonly occupied spaces such as meeting rooms, lecture halls and other building spaces which are generally associated with human occupancy, while fewer focuses were directed to the transitional areas in the built environment. The building transitional spaces are defined as the architectural area situated in-between outdoor and indoor environments, acting as both buffer spaces (Pitts and Jasmi, 2007). Some of the examples are like lift lobbies, foyers, corridors as well as other ancillary spaces not directly occupied by occupants in relation to activity of buildings (Chun *et al*., 2004). According to Pitts *et al*. (2008), such spaces generally consume more energy than other parts of building of similar size when being conditioned to achieve same comfort levels and occupants are more tolerate towards the thermal conditions. Transitional spaces are generally distinguished in two forms: opened to the environment and fully enclosed. The enclosed transitional spaces are available in few regions, such as lift lobby, passageway and other ancillary areas in a building. Out of all these spaces, the enclosed lift lobby distinguished itself as a unique form of region, where in some cases this region may have several features that are similar to commonly occupied spaces. For example, activities like setting up of sales and promotion counters, gathering point and others are occasionally performed in the lift lobby of an educational institution. Figure 1 shows the enclosed lift lobby of the Department of Mechanical and Manufacturing Engineering, University of Putra, Malaysia. Air-conditioning systems are installed in the enclosed lift lobby to ensure space cooling and sufficient ventilation rate, since natural ventilation is unacceptable due to possible disturbance on fire detection system required by UBBL (1984). However, it is not uncommon to

Fig. 1: Enclosed lift lobby in the Faculty of Engineering, UPM

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identify that most of the time the thermostat temperature set-points for air conditioners in the tropical countries are adjusted to the lowest possible, which is about 16°C. This is against the recommendations of the national standard, Malaysian Standard (MS) 1525 (2007) which suggested that the indoor temperature should be in the range of 23 to 26°C. Such behaviour has directly caused the increase in energy usage due to the fact that every 1°C decrease in the thermostat setting will result in 8% increase in the electricity cost (Aynsley, 2007) and air conditioning system is the highest consumer of energy under most circumstances (Wan *et al*., 2008).

In recent years, application of CFD in predicting conditions of built environment is increasing especially in the studies of room air motion, quality of air and smoke conditions (Stamou *et al*., 2008). In Malaysia, Samirah and Kannan (1996) applied CFD to simulate air flow and thermal comfort in naturally wind ventilated classrooms of an educational institution with different locations, configurations and outdoor environment conditions. Based on the hypothetical simulation results obtained, recommendations were made on ways to improve the ventilation of the least comfortable room. Cheong *et al*. (2003) evaluated the thermal comfort of air-conditioned lecture theatre in the tropics using objective measurement, CFD analysis and subjective assessment and recommendations were made to improve thermal comfort and reduce the CO_2. The CFD was applied for simulation of comfort parameters like temperature, air velocity and relative humidity concentration in the lecture theatre. These researches have suggested the usefulness of CFD simulation towards prediction of indoor thermal environment.

This study attempts to assess the thermal comfort perceptions of occupants in a controlled thermal environment and identify the thermal and air flow conditions in the enclosed lift lobby of an educational building via objective measurements, subjective assessment and CFD simulation. The results obtained from these measurements were analyzed and compared with existing thermal comfort standards. Optimization of energy consumption in building transitional spaces is essential for educational building in the tropics because such facility often have limited financial support and any possible reduction of electricity cost is desirable.

MATERIALS AND METHODS

This study was performed in an enclosed lift lobby of the Department of Mechanical and Manufacturing Engineering, University of Putra, Malaysia which is also part of the administration building for a period of 4 months, from August to November 2008. The lift lobby has dimensions of 7.94 m in length, 3.16 m in width and 2.7 m in height. This area was chosen because of its unique features among all transitional spaces, such as typical layout for Malaysian government buildings, may be treated as a commonly occupied area under certain occasions, subjected to building services requirements and high density of occupants travelling through the lift lobby each day. Ceiling type centralized air-conditioning split unit is installed in the lift lobby. Throughout the period of this survey, the thermostat temperature set-point of air conditioners in the lift lobbies was maintained at 26°C. This is for energy saving purposes (Malaysian Standard (MS) 1525, 2007; Aynsley, 2007) and to investigate the perception of thermal comfort of occupants in the lift lobby.

Objective measurement: For thermal environment measurements, methods and specifications of conducting field measurements were based on ASHRAE Standard 55 (2004), where parameters relating to human thermal balance were measured at 1.1 m above the floor level; 1 m inward from the centre of windows as shown in Fig. 2. Most of the test subjects gathered at the positions as marked in block arrows. Air temperature was measured using electronic temperature sensor connected to a data logger. A precision digital-thermometer was employed to measure the relative humidity. For determining the rate of air movement, a thermo-anemometer attached with low friction vane probe was used. Besides, an infrared thermal sensor was applied to measure the surface temperature of building enclosures for purpose of calculating the mean radiant temperature. These environmental parameters were recorded in 10 min interval from 9 am to 5 pm for each day of the field survey and all data were transferred to the portable computer in daily basis. Figure 3 shows the sensors and data logger applied in this study. The results obtained from objective measurement were tabulated and applied for calculation of PMV and PPD, which are useful

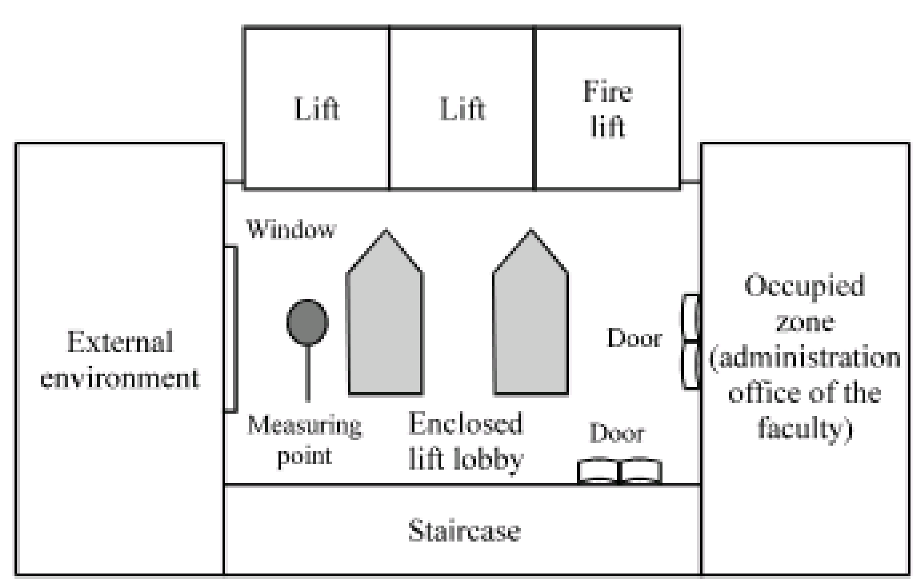

Fig. 2: Layout of enclosed lift lobby and measuring point

Fig. 3: Electronic sensors and data logger

to predict the thermal comfort conditions in the enclosed lift lobby. For the purpose of determining whether the region studied was within the acceptable range of thermal comfort, the identification of operative temperature is important. The operative temperature (T_{op}) was calculated using an equation derived in ASHRAE Standard 55 (2004) as shown below:

$$T_{op} = A\,(T_a)+(1-A)\,T_r \quad (1)$$

Where:

T_{op} = Operative temperature
T_a = Ambient air temperature
T_r = Mean radiant temperature

Some of the thermal comfort surveys conducted in the tropical countries had applied the concept of thermal neutrality among occupants. The survey of human response in South East Asia conducted by Aynsley (1999) has produced an equation for estimation of thermal neutrality based on the value of mean dry bulb temperature. This equation was also being used by Zainazlan *et al*. (2007) in their study of prospect for thermal comfort in residential building in Malaysia.

$$T_n = 17.6 + 0.31\,T_m \quad (2)$$

Where:

T_n = Thermal neutrality
T_m = Mean monthly dry bulb temperature

Subjective assessment-questionnaire surveys: For subjective assessment, the questionnaire surveys were conducted at the enclosed lift lobby. This method is widely applied in thermal comfort researches conducted worldwide, notably the work of Hwang *et al*. (2006) and Wong and Khoo (2003). The questionnaire consists of a section of subjective ratings on a variety of thermal scales and questions of human preferences towards thermal comfort, as suggested in ASHRAE Standard 55 (2004). Respondents were requested to note down how they felt at that particular moment on a seven-point ASHRAE thermal sensation scale as shown in Table 1. Next, they were asked to mark their preference on the three-point McIntyre thermal preference scale. Besides, comments of respondents' satisfaction of current thermal environment were obtained. In later parts of the questionnaire, test subjects were required to note down their respective demographics which included gender, age, height, weight, clothing, footwear, data and time when they were being interviewed.

Table 1: ASHRAE scales

Thermal sensation scale	Acceptability vote	Preference scale
-3 Cold	Acceptable	Warmer
-2 Cool	Unacceptable	No change
-1 Slightly cool		Cooler
0 Neutral		
+1 Slightly warm		
+2 Warm		
+3 Hot		

The aim in this survey was to collect a minimum of 100 samples, as showed in some of the thermal comfort surveys such as the study of Pitts *et al*. (2008). A total number of 113 persons took part in this survey. Almost all of the participants were those who entered the lift lobby from the administration offices where the thermal environment was cooler as only subjects, who had stayed in the lift lobby for more than 30 sec were invited to take part in the survey. This is because the average waiting time for users of elevator in this area was observed to be 33 sec during high occupancy periods (lunch time, tea breaks) in a day, with variance of ±17 sec.

CFD model: The development of a simulation model of the enclosed lift lobby with the same geometrical configuration is crucial in this research, as it provides a clearer idea to the researchers regarding the conditions of thermal and air movement in the region being studied. The predicted results were then compared to the findings from field survey for validation purposes (Cheong *et al*., 2003). Similar to other CFD works, the method being used in this research was to build a basic geometry of the enclosed lift lobby and to generate a relatively coarse grid so as to obtain a solution to confirm the modelling assumptions.

The ANSYS FLUENT v 6.3 software was applied in performing all the CFD computations. Iteration processes to the thermal and air movement was conducted for the lift lobby and the computational completed when convergence of outputs reached the dictated criterion. The boundary conditions for temperatures were specified in the model to represent the assessed temperatures of the lift lobby surfaces. The heat fluxes were modelled to represent the amount of heat generated by solar heat gain and lighting fixtures in the lift lobby. The mean amount of solar heat gain was based on the records of a black and white pyranometer connected to a data logging system, where the highest value was selected to represent optimum heat gain from external environment. The conditioned air temperature and flow rate were incorporated into simulation based on the actual conditions measured using thermo-anemometer.

RESULTS

Thermal comfort evaluation in enclosed lift lobby: The thermal environment of a building is essential, as thermally discomfort of occupants may results in less productivity (Olesen, 2005). The operative temperature and mean radiant temperature were calculated based on the results obtained from field survey. During this survey being conducted, two recruitment activities for new members from local students' organizations were being organized simultaneously with the field assessment in the enclosed lift lobby on 10 and 17 Oct. of the year 2008.

Objective measurement and calculation: The air temperature as measured during the field survey was within 23 to 32°C, with mean value of 28.1°C. The range of relative humidity in the lift lobby was within 63 and 78% and with the mean value of 72.6%. As for indoor air velocity, the measured value was from 0.1 to 0.20 m sec^{-1} and mean value of 0.15 m sec^{-1} received. An equation derived by ASHRAE (2001), was used for calculation of mean radiant temperature by defined plane radiant temperature in six directions for standing person. Table 2 shows the calculated mean radiant temperature in the enclosed lift lobby. These parameters were recorded with the purpose of determining the operative temperature of the investigated area. The measured value of thermal comfort parameters are as tabulated in Table 3.

Similar to other tropical countries, the highest indoor air temperatures attained in a particular day are within 11am to 2 pm. This is associated with high level of human occupants gathered and solar emission into the lift lobby.

Subjective assessment: To identify the thermal perceptions of subjects, ASHRAE scale of thermal sensation was applied with presumption of people finding their thermal environment acceptable if they place their votes within the three central categories (-1, 0, 1). Almost all of the test subjects (98%) entered the lift lobby from the administration offices and classrooms which are air-conditioned with temperature setting of 16°C. The remaining of them entered from other spaces which are exposed to the exterior environment, such as ground lift lobby, waiting passageways etc. An averaged temperature difference of ±10°C occurred between the region studied and the indoor environment and respondents were assumed to experience such changes in surrounding temperature.

From the data obtained from field survey, it is identified that nearly 80% of the subjects found the thermal environment acceptable for them, although nearly all of them entered the surveyed area from cooler regions. It is also shown in Fig. 4 that 72% of the subjects placed their votes on the three central categories of ASHRAE thermal sensation scale and assumed to be feeling comfortable with their thermal environment. Meanwhile, 14% of the respondents indicated that the surrounding was too warm and only 6% of them felt cool or cold during the survey. At the same time, it is clearly showed in the results that a high percentage of respondents preferred to be cooler in the lift lobby, where 58% of them claimed such. Thirty six percent of the subjects indicated that changes in thermal environment are not required, whereas only 6% of them stated that they prefer to be warmer.

CFD simulation: A three-dimensional model was developed using FLUENT/GAMBIT software, which

Table 2: Surrounding temperature at plane surfaces

	Plane temperature (During 12.00 pm)					
Date (08)	Ceiling (Up)	Floor (Down)	Door (Right)	Window (Left)	Lift wall (Front)	Back wall
17 Aug.	26.3	26.5	27.3	26.4	25.7	26.7
13 Sep.	26.1	26.7	26.9	27.0	25.7	27.0
21 Sep.	26.5	26.8	26.5	27.6	25.9	27.1
10 Oct.	26.4	27.0	26.8	27.7	25.7	27.4
11 Oct.	27.3	27.2	26.6	27.6	26.0	26.3
17 Oct.	27.0	27.2	27.3	26.7	25.7	26.7
3 Nov.	26.2	26.6	26.4	25.7	25.3	26.3
4 Nov.	26.1	26.3	25.9	26.0	25.1	26.1

Table 3: Mean values for thermal parameters

Date (08)	Mean air temperature (T_r)	Mean radiant temperature (T_{op})	Operative temperature (T_a)	Mean relative humidity (RH)	Mean indoor air velocity (V)
17 Aug.	28.2	26.4	27.3	70.7	0.15
13 Sep.	28.0	26.5	27.3	68.1	0.15
21 Sep.	29.1	26.7	27.9	76.9	0.15
10 Oct.	29.1	26.8	28.0	70.0	0.15
11 Oct.	28.9	26.6	27.8	72.7	0.15
17 Oct.	28.6	26.6	27.7	73.0	0.15
3 Nov.	27.0	26.0	26.5	76.3	0.15
4 Nov.	25.9	25.8	25.9	72.3	0.15

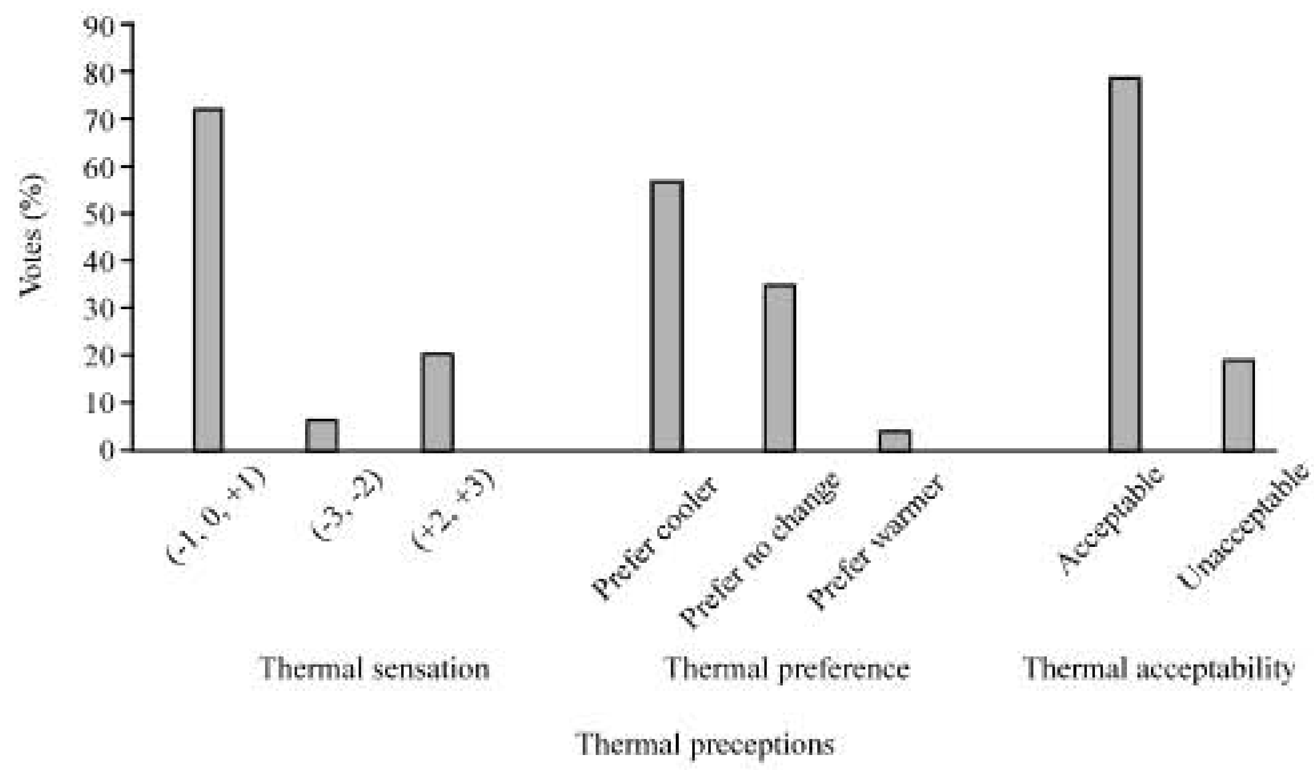

Fig. 4: Distribution of subjective thermal perceptions vote

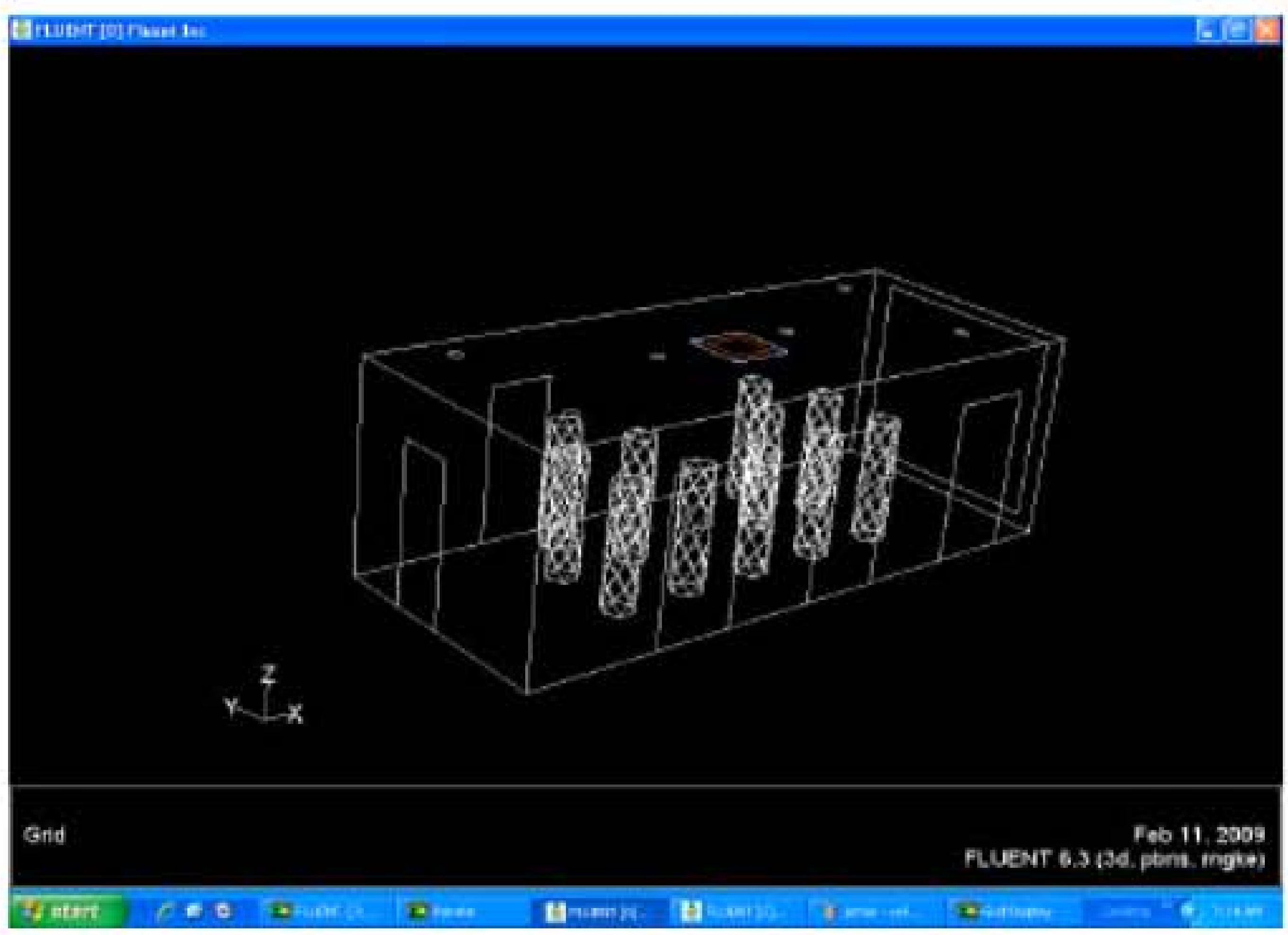

Fig. 5: Illustration of the CFD model

shares the same geometrical configuration as the actual enclosed lift lobby in the administration block of the Faculty of Engineering. The dimensions in x, y and z-axis were formulated as 7.94, 3.16 and 2.7 m, respectively. The main purpose of developing such model was to predict the thermal and air movement conditions in the enclosed lift lobby and the results obtained were then compared with the empirical results measured in the field survey.

The heat sources inserted into the geometry were solar irradiance through window and artificial lighting. Figure 5 shows the enclosed lift lobby modelled with peak occupancy of 11 individuals and functioning of artificial lights. The boundary conditions of temperatures were specified in the simulation model to represent the measured temperature of the plane surfaces. Referred to the measured outcomes from pilot studies, the boundary conditions of air conditioner's supply diffuser and extract grilles were fixed to be 20 and 26°C, respectively. The air discharge from the supply diffuser was simulated as 2.3 m sec^{-1}. The surface temperature of ceiling, floor and internal walls was set at 26°C, while temperature of lift door was set to be 25°C. For heat sources, the solar heat transmitted via window into enclosed lift lobby was represented in heat flux, which was in the rate of 20 W m^{-2}. Each of the compact fluorescent light fitting was modelled to generate 12 W of heat, according to the manufacturer's specification. Simulated results were obtained by iteration processes and the computations finished when convergences of results reached the prescribed criterion.

In this CFD simulation, the researcher selected the position where the subjective measurements were performed, which is the profile where coordinate x = 6.5 m for prediction of thermal conditions. This point is about 1.5 m inward from the window and also one of the positions where most of the respondents gathered and best represented the actual condition in the enclosed lift lobby. The predicted temperature profile is as shown in Fig. 6, where the air temperature at the selected zone was within 21 to 28°C. The surrounding temperature of the simulated occupants in the position was about 27°C. As for the ceiling mounted light fittings, the temperature profile in Fig. 7 shows that the predicted temperatures near the light fittings were within 32 to 36°C. The part of ceiling which is near to the supply diffuser was predicted

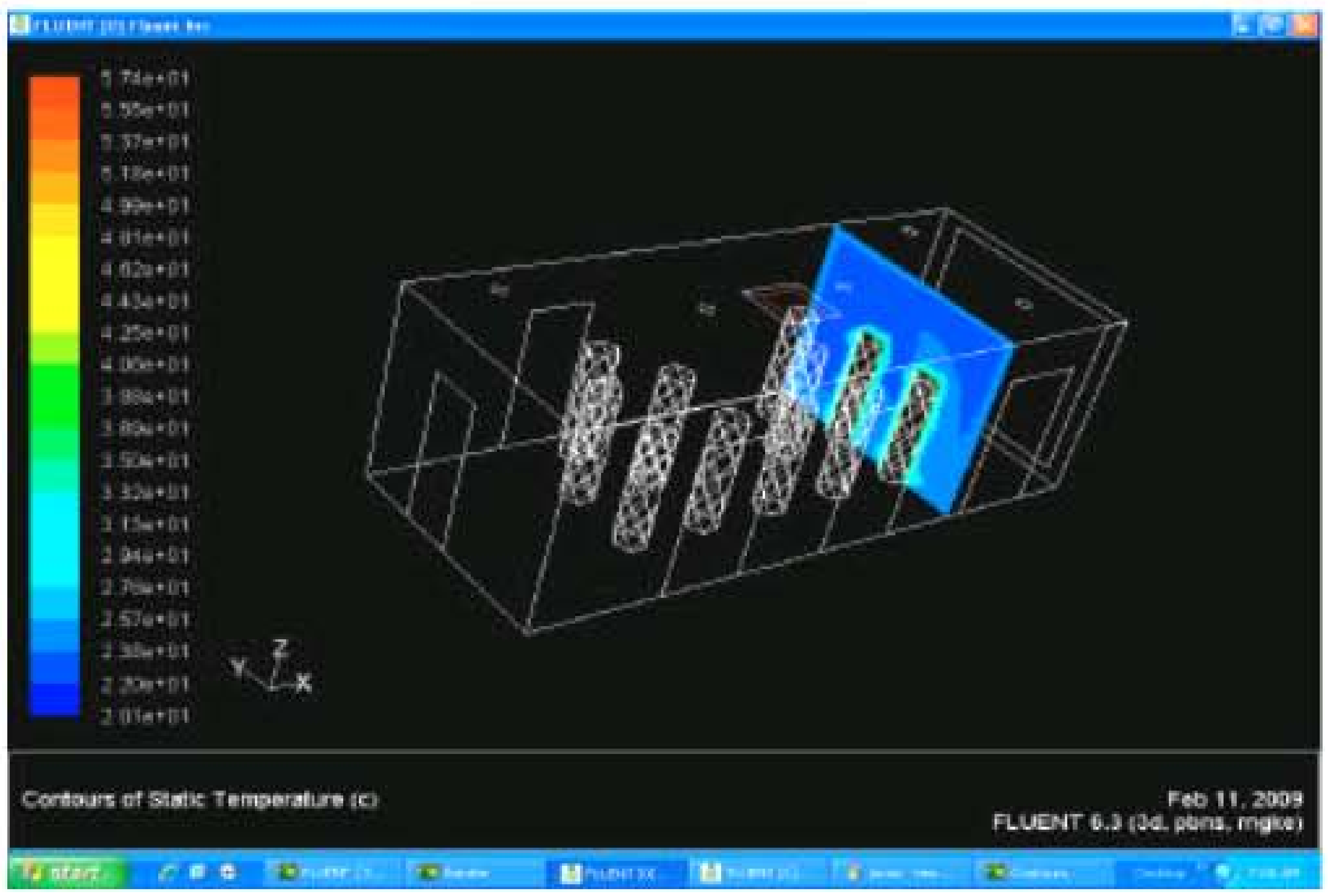

Fig. 6: Temperature profile for enclosed lift lobby at x = 6.5 m

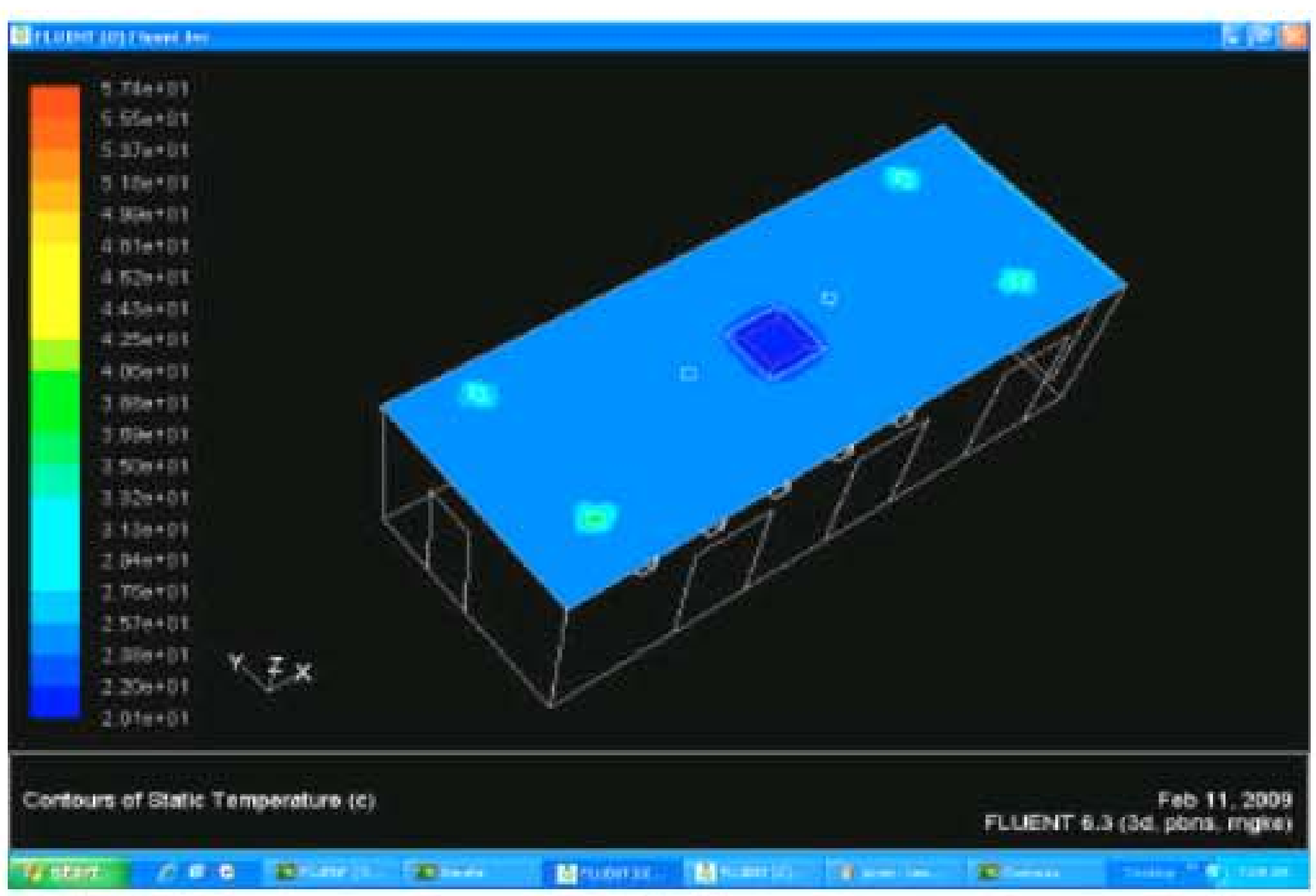

Fig. 7: Temperature profile for ceiling mounted air conditioner and light fittings

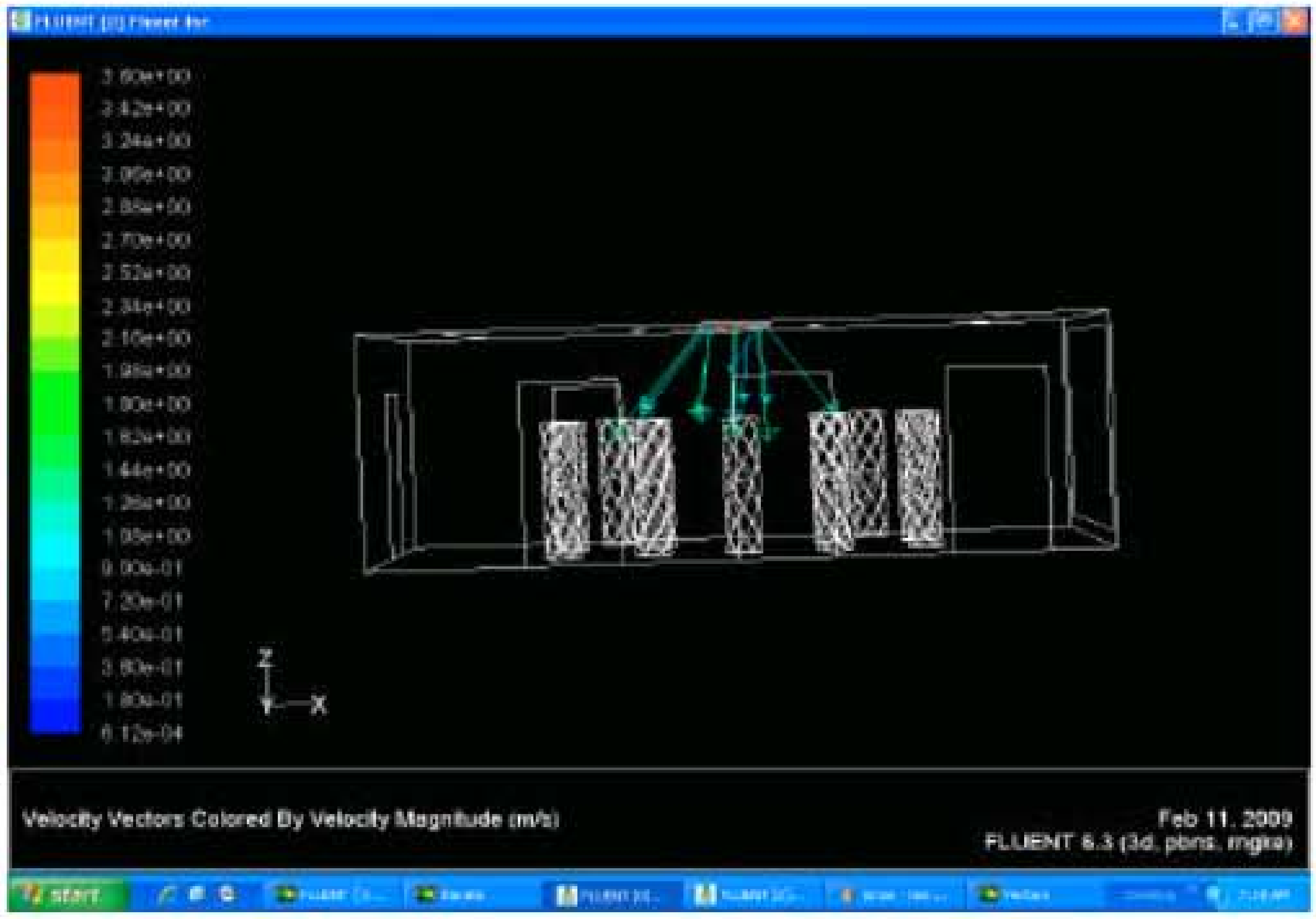

Fig. 8: Cooling air discharge from air conditioner

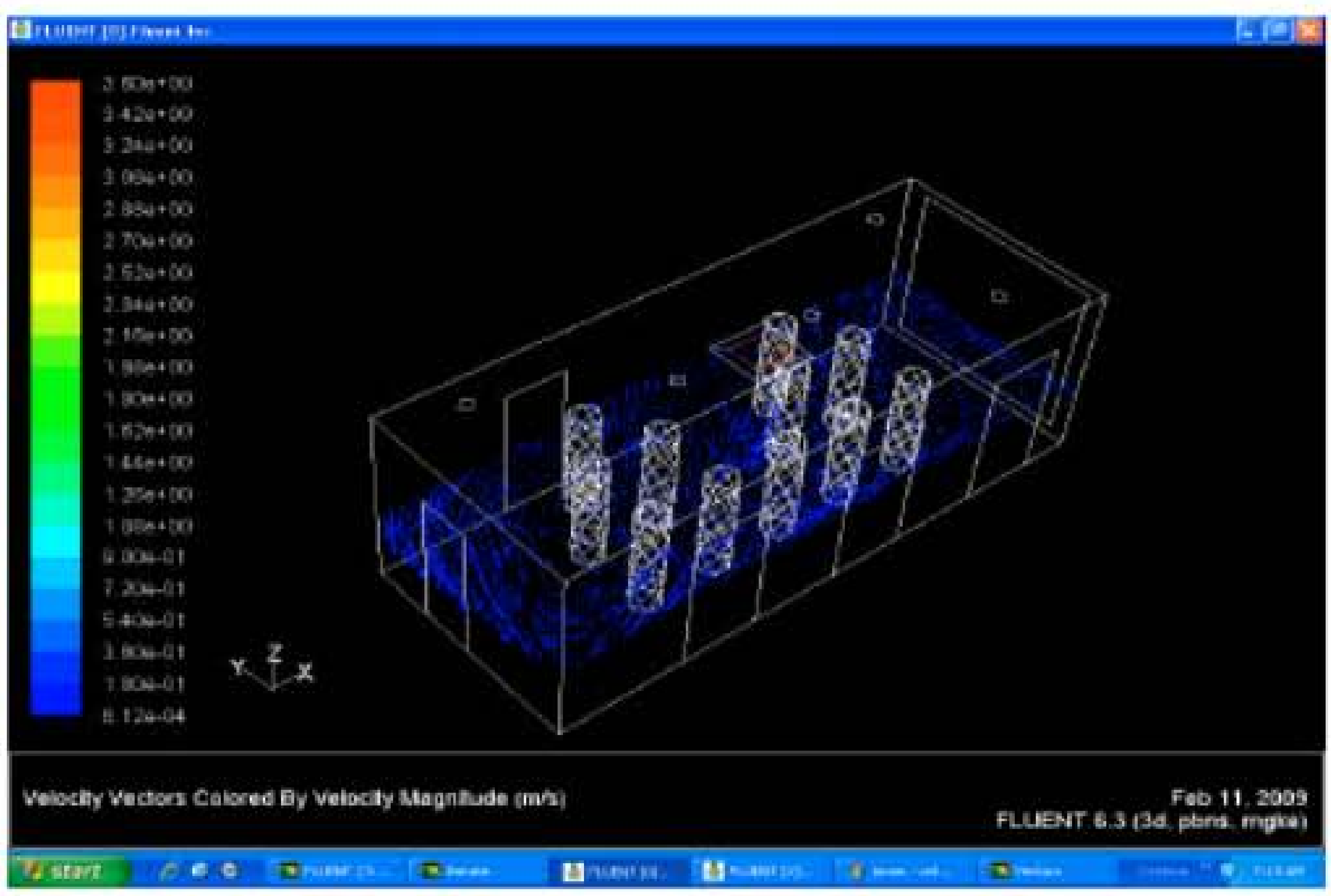

Fig. 9: Air velocity profile for enclosed lift lobby at x = 6.5 m

to be 20 to 24°C. This shows that the light fittings do not impose any significant effect on the heat gain of surrounding, as the wattage for compact fluorescent is often low.

The supply air was modeled to discharge from the 4-way ceiling mounted air conditioner at discharge angle of 45 degree at all 4 directions, as shown in Fig. 8. This reason for specifying such was because of the actual setting in the enclosed lift lobby. The air velocity profile is as shown in Fig. 9 at location of z = 1.5 m, the predicted values for air movement in the enclosed lift lobby were in the range of 0.09 to 0.18 m sec^{-1}. Generally, the rate of air movement was within the recommended threshold by Malaysian Standard (MS) 1525 (2007). It is clearly presented that simulated occupants nearer to the lift door may experienced lower air velocity. No sign of draught was found in the simulated region.

Thermal comfort indices: Most of the thermal comfort assessments conducted in commonly occupied spaces in

Table 4: Thermal comfort perceptions

	Thermal sensation vote			Thermal preference vote			Thermal acceptability vote	
Date (08)	-3, -2	-1, 0, 1	2, 3	Warmer	No change	Colder	Acceptable	Unacceptable
17 Aug.	1	7	1	2	3	4	9	0
13 Sep.	0	7	1	0	4	4	7	1
21 Sep.	3	9	0	1	8	3	12	0
10 Oct.	0	15	7	1	6	15	17	5
11 Oct.	1	9	1	0	6	5	9	2
17 Oct.	0	20	11	1	5	25	18	13
3 Nov.	1	6	2	0	3	6	8	1
4 Nov.	2	8	1	1	6	4	10	1

Table 5: Data of field measurements and thermal comfort indices

Input variable	Date (08)							
for PMV and PPD	17 Aug.	17 Sep.	21 Sep.	10 Oct.	11 Oct.	17 Oct.	13 Nov.	14 Nov.
Clothing (clo)	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
Metabolic rate (MET)	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Air temp. (°C)	28.22	28.02	29.12	29.18	28.93	28.68	27.05	25.95
Mean radiant temp. (°C)	26.73	26.86	27.04	27.21	27.20	26.90	26.28	26.10
Air velocity (m sec^{-1})	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Relative humidity	70.78	68.19	76.97	70.02	72.75	73.03	76.30	72.39
Expectation factor	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
PMV	0.55	0.55	0.70	0.70	0.70	0.65	0.45	0.30
PPD	33.00	31.00	49.00	47.00	45.00	41.00	22.00	12.00

buildings applied the PMV and PPD indices for prediction of thermal environment and these indices have not been extensively applied in the transitional spaces due to the features of transient environment in such areas. Thermal comfort perceptions shown in Table 4. However, the work of Fanger and Toftum (2002) has proposed the extension of PMV model where expectation factor of occupants was provided and this concept is deemed to be applicable in the transitional spaces as well. In this study, the indoor temperature for the lift lobby was maintained at a higher temperature as compared to other spaces. An expectation factor of 0.5 was multiplied with the calculated values of PMV and PPD for region with low expectation of air conditioning system and with assumption that people in the transitional spaces may have less expectation for experiencing conditioned air. ASHRAE Handbook-Fundamentals (2001) was referred and the respondents were required to note down their particular types of attire. The values for the clothing ensemble insulation and the metabolic rates of the subjects were 0.62 clo with a standard deviation of 0.08 and 1.2 m (70 W m^{-2}), respectively. Other related input values for the calculation were determined via field measurements and as shown in Table 5.

The range of calculated PMV index came to 0.3 to 0.7, with mean value of 0.58. This shows that the enclosed lift lobby is observed to be in the range of slightly warm category. The calculated PPD varied from 12 to 49%, with mean value of 35%. This indicates that 35% of the occupants in this survey were expected to be discomfort

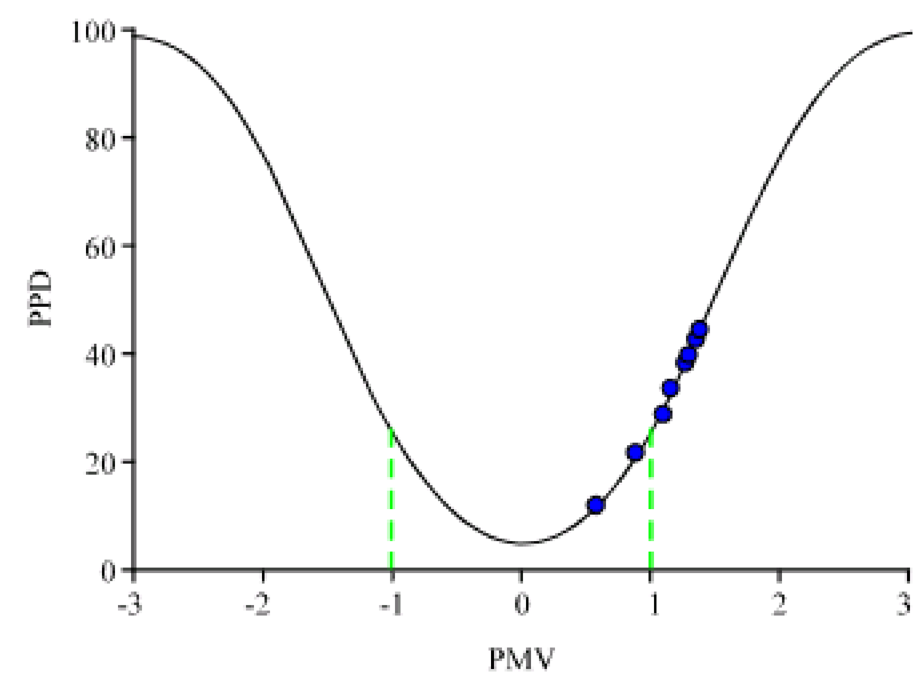

Fig. 10: PMV and PPD in the enclosed lift lobby

with the thermal environment of the enclosed lift lobby. From Fig. 10, it is identified that six out of eight days of field measurements were outside the comfort zone specified in ASHRAE Standard 55 (2004).

Thermal neutrality: The work of Aynsley (1999) has suggested T_n±2.5 K for 90% acceptability of thermal comfort and T_n±3.5 K for acceptability rate of 80%. Since the measurements were performed in daily basis, the value of daily mean dry bulb temperature was used. Take an example of the weather data for 11 Oct. provided by The Department of Meteorology, Malaysia (JMM) where the mean dry bulb temperature was 26.3°C, the thermal neutrality of the region investigated in this research can be determined as follow:

Table 6: Outdoor temperature, mean dry-bulb temperature and thermal neutrality

Date (08)	Outdoor temperature range (°C)	Mean dry-bulb Temperature (°C)	Thermal neutrality (°C)
17 Aug.	25.1-35.5	28.79	26.5
13 Sep.	24.7-33.0	28.48	26.4
21 Sep.	22.9-32.4	26.28	25.8
10 Oct.	23.5-33.3	26.56	25.8
11 Oct.	23.4-33.1	26.32	25.7
17 Oct.	24.1-32.5	26.46	25.8
3 Nov.	25.8-32.0	28.58	26.5
4 Nov.	25.3-31.0	27.72	26.2

$$T_n = 17.6 + 0.31\ T_m$$
$$T_n = 17.6 + 0.31\ (26.3) = 25.8°C$$

Table 6 shows the data of outdoor temperature, mean dry-bulb temperature and thermal neutrality. The mean value for thermal neutrality was calculated as 26.1°C. For 80% acceptability rate according to ASHRAE Standard 55 (2004), the neutral temperature should not be more than 29.6°C. The operative temperatures obtained from the field survey were within the range of 25.8 to 28.0°C, with the mean value of 27.3°C. This has proposed that the range of operative temperature in the enclosed lift lobby was within acceptable temperature zone and the thermal environment was comfortable for about 80% of the respondents. From the subjective measurement, 80% of the test subjects were satisfied with their thermal environment. Thus, the results of thermal neutrality are accordant with the subjective measurement. This also proves that the concept of thermal neutrality can be applied in the building transitional spaces as well and able to provide good approximations of actual thermal environment. To attain better thermal acceptability rate during high occupancy period, the air conditioner's thermostat can be set as 2°C lower than the predetermined setting to allow the indoor temperature to be closer to the value of thermal neutrality.

DISCUSSION

Field measurements: In this survey, about 80% of the respondents were comfortable with their thermal environment. The main reason for not distinguishing the thermal sensation of people entering the lift lobby from cooler regions and those from warmer sites in this study was the comparatively much smaller number of latter case. The cause for such circumstances is that the students and staffs entered the enclosed lift lobby from other offices which are air-conditioned. A self-contradictory phenomenon was discovered as a significant number of subjects voted on the utmost point of the thermal sensation scale, but rated their perceptions as comfortable. Moreover, some of the respondents stated that the thermal environment was acceptable to them, but preferred to be cooler/warmer in the thermal preference scale. These findings reflected the research done by Feriadi and Wong (2004), where people in the hot and humid climate generally prefer cooler environmental condition. Besides, it is identified that the past thermal experience had strongly influenced the occupants' thermal sensation. Also, such drastic change in thermal experience had caused some of the occupants to be thermally uncomfortable and tolerant of variation in conditions needed for comfort was not given even though the duration of staying at the enclosed lift lobby was calculated to be less than a minute. Such thermal shock condition should be avoided as it may affect the satisfaction of occupants in buildings.

As shown in Table 4, the respondents' thermal sensation move towards the warmer side as number of occupants increased in the enclosed lift lobby and higher percentage of the respondents marked preference of colder environment. Such phenomenon is clearly shown in data collected on 10. and 17 Oct., where higher percentage of occupants voted in the warmer categories. This outcome has testified that one of the main factors which greatly affected thermal comfort perception of occupants in the enclosed lift lobby is the human occupancy level. Colon *et al*. (2004) stated that heat is being generated by human body and continuously lost to the surrounding, which in certain extent cause a rise in internal temperature of the lift lobby during survey being performed. Due to that reason, it is suggested that the temperature setting of air conditioner in the lift lobby can be lowered only on high human occupancy time, or during events which required participation of a substantial number of occupants. Also, there are certain underlying factors which possibly contributed to the thermal discomfort of occupants, such as perception of human in crowded places and personal fondness within a building. Further investigations in these areas are required.

Validation of CFD simulation with empirical results: As shown in Fig. 6, the predicted air temperature at the selected zone was within 21 to 28°C. The air temperatures measured during the field survey were in the range of 26 to 29°C, with the mean value of 28.1°C. A difference of 0.5°C between the mean measured and simulated results was found. This result shows that the prediction of thermal conditions is accurate with minor variation, as the actual thermal environment was slightly undervalued in the simulation.

For air velocity in the enclosed lift lobby, the mean value for measured air flow rate was 0.15 m sec^{-1}. The predicted result showed 0.18 m sec^{-1} at coordinate x = 6.5 m, which is closer to the maximum air flow rate measured during the field survey where v = 0.2 m sec^{-1}. This is within the acceptable range of air movement specified by MS 1525 (2007), which is 0.15 to 0.50 m sec^{-1}. Similar to the prediction of thermal environment, the outcome from CFD simulation slightly overestimated the air flow rate. For both parameters, the percentages of difference were 1.78 and 16.77%, respectively. From the study of Cheong *et al*. (2003) which was performed in the tropical classroom, the values of both air temperature and velocity were overestimated by using CFD, even in steady environment where uncertainties are generally lesser than transient environment.

There are few reasons for such slight disagreements and one of the main causes was the selection of temperature for formation of boundary conditions. For example, the temperatures of supply and exhaust grilles were set at a difference of 6°C. In the simulation process, this may not be accurate as the temperature for return air may be higher than 26°C. The surface temperature of walls and ceiling were fixed to a constant temperature, which may have certain effect on the predicted results. Also, the simulation was made in steady condition, whereas the actual conditions in the lift lobby resemble a mixing situation where most of the time it is in transient environment. This has also influenced the accuracy of results. However, since the outcomes from simulation were generally comparable to the empirical ones, it can be concluded that fair agreement between the simulated and measured results was obtained in this study.

Results of subjective measurement, PMV and PPD: While comparing the thermal comfort indices with the values obtained from questionnaire assessment, disagreement happens between the calculated PMV value and the mean thermal sensation mentioned by test subjects, which is 0.58 against 0.44. This is primarily due to the overestimation of the PMV model which predicted slightly warm when the respondents actually felt neutral at certain temperatures and this result has suggested a lower expectation factor for transitional spaces in the tropical buildings. For PPD index, it was calculated that 35% of the subjects would be uncomfortable with the thermal environment. Twenty eight percent of the respondents voted outside the three central categories of the ASHRAE scale and a 7% difference is obtained with the result from predicted value. The main factor that contributed to this dissimilarity is the overestimation by the PPD indices which predicted warmer temperature than actual thermal sensation (Wong and Khoo, 2003; Samira and Kannan, 1996). Also, this can be explained in terms of thermal adaptation, where people in the tropical countries are generally more tolerant towards their thermal environment than people living in temperate regions (Brager and Dear, 1998), although most of the time cooler environment is favoured. The overestimation of PMV tends to encourage the use of more air conditioning than necessary (Nicol, 2004), especially in the tropical countries. This phenomenon is more evidenced when the people in the tropics generally prefer cooler environment due to their prior experience where most of the time the building's interior is air-conditioned. Besides, students in the tropical universities may have different perception on thermal environment and each individual may have own preference towards desirable surroundings.

CONCLUSION

From the results of field measurements, it is clearly demonstrated that about 80% of the occupants found their thermal environment acceptable. This is in fair agreement with the range of thermal neutrality calculated. Some level of thermal adaptation was showed by the occupants. However, most of them placed their preference in cooler environment. It is suggested that the thermostat setting of air conditioner can be lowered by 2°C during events which require high level of human occupancy. From the coordinate which best represented the actual environment, the predicted results by using CFD simulation showed that the thermal and air flow conditions for test subjects were acceptable and agreeable with the empirical results, although slight overestimation of actual environment was found in this study. This has suggested the applicability of computer simulation in prediction of thermal environment in the building transitional spaces and possible overestimation of actual environment should be noted. The PMV-PPD indices with current expectation factor overvalued the thermal conditions of the lift lobby and lower expectation factor for thermal environment can be considered. The personal preference of test subjects on thermal environment is worthy for further investigation. Besides, more data can be gathered to get more statistically significant outcomes. The methods presented in this research can serve as a guide in other studies of environmental comfort in transitional spaces with different characteristics and architectural designs.

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