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Energy Efficiency Potential in Tropical Buildings – Perspective of an Enclosed Transitional Zone

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Abstract *– The enclosed transitional spaces in buildings are subjected to certain building services requirements which contribute to the increase of energy consumption. This paper reports on the energy efficiency potential of the enclosed lift lobby of an educational institution in Malaysia via evaluation of existing environmental comfort factors and human thermal sensation. The method applied was by using field survey which consists of field physical measurement and subjective (questionnaire) assessment. For energy efficiency purpose, the indoor air temperature was maintained at 26°C together with a fixed air velocity of 0.15 m/s. A total of 113 sampling votes were collected and the human perception of thermal comfort in the enclosed lift lobby was then studied. This study shows the importance of air velocity in the enclosed transitional space in sustaining thermal comfort of occupants, and the factors which affected the thermal sensation and preference of occupants are highlighted. Besides, a significant saving of energy consumption can be obtained by maintaining the indoor temperature and air velocity at the prescribed values. These findings suggest an additional opportunity for energy efficiency improvement in tropical buildings.*

Keywords **–** Energy efficiency, lift lobby, thermal comfort, transitional spaces, tropical building.

1. INTRODUCTION

The rapid growth of energy utilization throughout the world has raised concerns over supply difficulties, exhaustion of energy resources and also heavy environmental impacts [1]. In Malaysia, the building sector consumed up to 13.1% of the nation's total energy consumption and is expected to grow further in the near future [2]. Spaces inside a building are generally distinguished into two parts: the commonly occupied and the transitional zones. The transitional spaces are the parts of buildings which have close links to the external environment, and conditions in such spaces may be perceived differently compared to commonly occupied rooms [3]. In hot and humid climates typically found in Malaysia, it is not uncommon to identify the application of air conditioning and mechanical ventilation systems inside buildings. The operation of these systems contributes notably to the energy consumption of the buildings [4], [5]. For tropical buildings, the cooling equipment account for 30 to 60% of the total energy consumption and have the largest energy saving potential [6], [7]. Some of the transitional zones in tropical buildings which are fully enclosed are installed with air conditioners for improvement of human thermal comfort. However, very few studies were conducted in the building transitional zones for energy efficiency purposes, where focus was often placed on commonly occupied regions [8]. Due to this reason, it is crucial to investigate the thermal perceptions of occupants in transitional spaces as such areas are commonly encountered in daily life and form a good opportunity for energy efficiency improvement [9].

The Malaysian Standard (MS) 1525 [10] is introduced to encourage energy efficient practices in Malaysian buildings except low-rise residential ones. This standard specifies the requirements of thermal comfort related parameters and devoted specifically to the climatic conditions of Malaysia. Besides, the ASHRAE Standard 55 [11] is referred by building system designers to provide a thermally comfortable environment to occupants. Though widely applied, yet, these standards do not clearly define the thermal comfort requirement in the transitional spaces. This paper attempts to identify the potential for energy savings by evaluating the occupants' perception of thermal comfort at a controlled and enclosed lift lobby of an educational institution in Malaysia. Field survey which consists of physical measurement and subjective assessment was applied with controlled temperature and air velocity settings. Analysis on thermal, air movement and humidity perceptions and effects on human comfort were made in this study. For the site measurement, air temperature, relative humidity and air flow rate were measured using calibrated electronic sensors. As for the subjective assessment, a questionnaire survey which comprises of environmental comfort related questions was administered to the test subjects to find out their perception of the degree of comfort in the lift lobby. The predicted mean vote (PMV) index with expectation factor, predicted percentage of dissatisfied (PPD) index and concept of thermal neutrality were applied with intention to identify the opportunity for energy savings in the enclosed lift lobby of an educational facility.

2. CHARACTERISTICS OF ENCLOSED TRANSITIONAL SPACES

A building is made up of different compartments to serve various types of human activities. The transitional

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spaces in buildings are referred as the areas situated between outdoor and indoor environments, acting as buffer spaces for both and some of the examples are like lift lobby, foyer, passageway, canopy as well as other ancillary spaces not directly occupied by occupants in relation to activities of buildings [12]. To ensure safety and comfort of occupants, these regions are usually subjected to certain level of building services requirement [13], such as air conditioning, fire protection, artificial lighting and other systems which are contributing to the increase of energy consumption in buildings. The MS 1525 specifies that the environmental conditions in Malaysian buildings should be "controlled" within certain acceptable levels. For example, the standard stipulates a "comfort cooling range" where indoor dry-bulb temperature should be maintained within the range of 23-26°C and air movement of 0.15-0.5 m/s. However, the applicability of these specifications in the transitional spaces remains a question, since the "comfort cooling range" is more likely for thermal comfort of occupants in the interior spaces associated with work or other activities whereas the travelers passing through the transitional spaces are noted to be more tolerant of variations in conditions required for comfort [3].

Among the transitional spaces, the enclosed lift lobby is commonly found in high-rise buildings and is known as the building part where people gather for usage of elevators. Also, it is usually not directly linked to the external environment. Figure 1 illustrates the enclosed lift lobby typically found in a Malaysian building. In this study, the thermal comfort of travelers in an enclosed lift lobby of a tropical educational institution was analyzed to identify the space for energy efficiency improvement.

Fig. 1. Example of an enclosed transitional space – the lift lobby.

3. METHODOLOGY

As suggested by several thermal comfort studies conducted in the built environment, the field survey is a useful method in obtaining statistically important data. Hence, a field study was conducted for a period of 4 months, ranging from August to November of the year 2008 at the enclosed lift lobby of the Department of Mechanical and Manufacturing Engineering, University of Putra Malaysia (UPM) which is also a part of the administration building. Prior to the commencement of the formal survey, initial field visits were made to observe the conditions of the enclosed lift lobby. The lift's "traffic" analysis was made and occupants' behavior was also observed. The information obtained formed the basis for the objectives of this study, for instance the positioning of measuring instruments, development of relevant questions for travelers in the lift lobby and modification on the clothing lists in the questionnaire to make it suitable for Malaysian. The main reason for selecting the lift lobby for detail analysis was due to its unique characteristics: typical design layout for Malaysian government buildings subjected to certain level of building services provision and forms a good opportunity for energy efficiency. The lift lobby has dimensions of 7.94 m in length, 3.16 m in width and 2.7 m in height and the brief design layout is as illustrated in Figure 2. Ceiling type centralized air-conditioning split units with capacity of 1.5 HP are installed in the lift lobby for cooling and dehumidification purposes. In order to identify the applicability of MS 1525: 2007 in an enclosed transitional space, a controlled environment was being set up where throughout the period of this survey, the thermostat temperature set-point of air conditioners in the lift lobbies was maintained at 26°C which is the highest allowable operating temperature suggested in MS 1525: 2007 and the air velocity was maintained at 0.15 m/s.

3.1 Site Physical Measurement

The field physical measurement in this study was directed to parameters related to the air conditioning system, as it consumes a large portion of electrical energy in the lift lobby. The methods and specifications of conducting the field measurements were based on ASHRAE Standard 55 and MS 1525: 2007, where parameters relating to human thermal balance were measured at 1.1m above the floor level and 1.0m inward from the center of windows. The measured physical quantities were the air temperature, relative humidity, plane surface temperature and air velocity. The air temperature was measured by using an electronic temperature sensor connected to a data-logger, which provide an accuracy of ±1°C while the plane surface temperature was measured using a remote infrared thermal sensor with an accuracy of ±0.1°C. A precision digital-thermometer was employed to measure the relative humidity. For determining the rate of air flow, a thermo-anemometer with low friction vane probe attached was used and all the measuring equipment is as shown in Figure 3. The physical quantities were continuously measured and recorded from 9.00 am to 5.00 pm daily at 10 minutes interval and all data were transferred to the portable computer with sufficient backup in daily basis for further analysis. The results obtained from field survey were tabulated and applied for calculation of PMV, PPD and the thermal neutrality, which are useful to predict the thermal comfort conditions in the enclosed lift lobby.

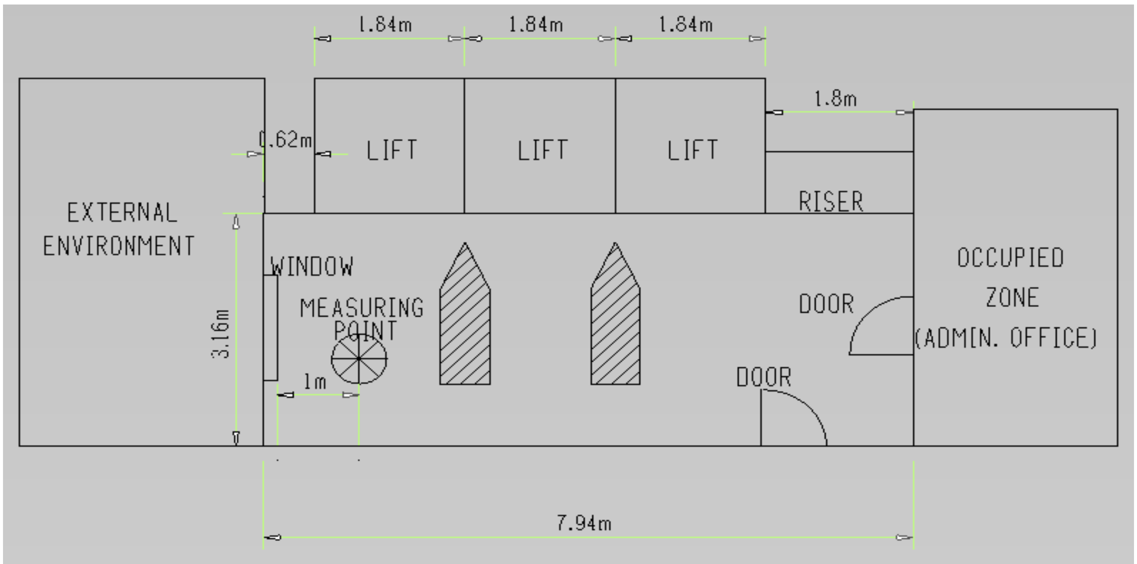

Fig. 2. Brief layout plan of the assessed lift lobby.

Fig. 3. Data logger and measuring devices.

Table 1. Subjective rating scales.

ASHRAE scale	Air Movement scale	Humidity scale	McIntyre Scale
-3 cold	-3 much too still	-3 much too dry	Warmer
-2 cool	-2 too still	-2 too dry	No Change
-1 slightly cool	-1 slightly still	-1 slightly dry	Cooler
0 neutral	0 just right	0 just right	-
+1 slightly warm	+1 slightly breezy	+1 slightly humid	-
+2 warm	+2 too breezy	+2 too humid	-
+3 hot	+3 much too breezy	+3 much too humid	-

3.2 Subjective Assessment – Questionnaire Surveys

Questionnaire surveys were administered simultaneously with the physical measurement at the lift lobby. This type of survey is widely applied in thermal comfort studies conducted on various types of spaces, including the transitional ones [14]. The questionnaire consists of a section of subjective ratings on a variety of thermal scales and questions of human preferences towards thermal comfort with some modifications to suit the lift lobby environment. 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. Questions on thermal preference were also asked and based on the three-point McIntyre (preference) scale. The test subjects were also required to mark their perceptions on the air movement and humidity scales. Since the survey was conducted in a Malaysian building, several technical terms were translated to the Malay language to allow better understanding for the respondents about the contents in the questionnaire. Besides, comments of respondents' satisfaction of current thermal, air flow and humidity conditions 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. Only subjects who had stayed in the lift lobby for more than 30 seconds were invited to participate in the survey, as the average waiting time for users of elevator in this area was calculated to be around 33 seconds during peak hours, with variance of ±17 s. Due to the transient environment of lift lobby, it is comparatively more difficult to obtain subjective votes as compared to surveys in commonly occupied spaces. Hence, the aim of this survey was to obtain a minimal of 100 sampling votes, similar to some of the thermal comfort surveys such as the work of [3] in the transitional spaces.

4. RESULTS AND DISCUSSION

4.1 Field Physical Measurements

The main objective of this study is to identify the potential of energy saving via thermal comfort evaluation of an enclosed transitional space. Hence, the mean air temperature, air velocity, relative humidity and PMV and PPD with expectation factor were analyzed. Survey was carried out for 9 days throughout a period of 4 months and the measured values of thermal comfort parameters are as tabulated in Table 2. Due to the recruitment activities for new members from local student organizations which were conducted in the enclosed lift lobby on the 10th and 17th of October, 2008, more votes were collected on these two dates as the travelling rate and human occupancy level were high. No subjective vote was collected on 23rd of August as it was a rest day for students and staffs. A total number of 113 persons responded in this survey. By using electronic sensors connected to a data-logger, the measured air temperature was within 23 to 32°C, with a mean value of 28.1°C and the mean air temperature profile is as presented in Figure 4. The range of relative humidity was within 63% and 78% with a mean value of 72.6%. The indoor air velocity was measured to be from 0.1 m/s to 0.20 m/s, with a mean value of 0.15 m/s. In order to determine the value of mean radiant temperature, calculation was made by using plane surface temperatures measured [16]. Calculation of operative temperature was made by using the equation provided under Informative Appendix C of ASHRAE Standard 55, which utilizes the mean air temperature and mean radiant temperature.

Table 2. Sampling votes and operative temperatures in the lift lobby.

Date	Top	Total	Thermal Sensation Vote							Thermal Preference Vote			Thermal Acceptability Vote		Mean TSV
(08)	(°C)	Votes	-3	-2	-1	0	1	2	3	Warmer	No change	Colder	Acceptable	Unacceptable	
17-Aug	27.34	9	0	1	2	5	0	1	0	2	3	4	9	0	-0.22
23-Aug	27.68	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13-Sep	27.31	8	0	0	3	2	2	0	1	0	4	4	7	1	0.38
21-Sep	27.95	12	2	1	2	5	2	0	0	1	8	3	12	0	-0.67
10-Oct	28.01	22	0	0	3	4	8	4	3	1	6	15	17	5	1
11-Oct	27.80	11	0	1	2	5	2	0	1	0	6	5	9	2	0.09
17-Oct	27.66	31	0	0	2	7	11	8	3	1	5	25	18	13	1.1
3-Nov	26.53	9	0	1	0	3	3	2	0	0	3	6	8	1	0.56
4-Nov	25.89	11	1	1	4	1	3	1	0	1	6	4	10	1	-0.36
	Total	113	3	5	18	32	31	16	8	6 (5%)	41 (36%)	66 (59%)	90 (79%)	23 (21%)	0.44

4.2 Subjective Assessments

This paper presents the portion of the questionnaire survey which is related to thermal comfort only. ASHRAE scale of thermal sensation was applied with presumption of people finding their thermal environment acceptable if votes are placed within the three central categories (-1, 0, 1) of the scale. Most of the test subjects entered the lift lobby from the administration offices and classrooms which were air-conditioned with temperature setting of 16-18°C. An average temperature difference of 8-10°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 the survey, thermal sensations for majority of the respondents vary between -1 and 1 as presented in Figure 5, which indicates that most of the respondents found their thermal environment acceptable. From Table 2, about 79% of the respondents found their thermal environment acceptable. Besides, more respondents voted that their thermal environment was "acceptable" when there were less people occupying the lift lobby. By comparing the result obtained on 21-Sep and 17-Oct, it is clearly shown that with the increase in occupancy level, more people tend to be thermally uncomfortable. This is in accordance with the thermal preference vote where during higher occupancy period, more subjects preferred to be cooler. It is also demonstrated that more than half of the respondents preferred to have a cooler environment. Since about half of the votes were collected during the recruitment activities which were with higher human passage rate, the relation between thermal preference and occupancy level is correlated. This shows that in an enclosed lift lobby, the human occupancy level and travelling rate are among the major factors which greatly affect thermal comfort perception of occupants. Another phenomenon identified in this study was the abrupt temperature change experienced by the respondents was not a major factor in affecting thermal comfort in the transitional space, as claimed by a previous research [8]. This is shown in the thermal acceptability vote that most respondents who entered the lift lobby from a cooler space were generally satisfied with their thermal environment. To explain such contradiction in findings, the type of transitional spaces being studied should be distinguished first, as it is available in various architectural designs as well as usages. Although people passing through such spaces were identified to be more tolerable of variations in conditions required for thermal comfort and often "acclimatized" to the existing thermal environment [16], thermal comfort requirement in the lift lobby can be more stringent than normal passageways due to occupancy period of people, attachment with other building spaces and some other underlying factors which are related to personal cooling preferences.

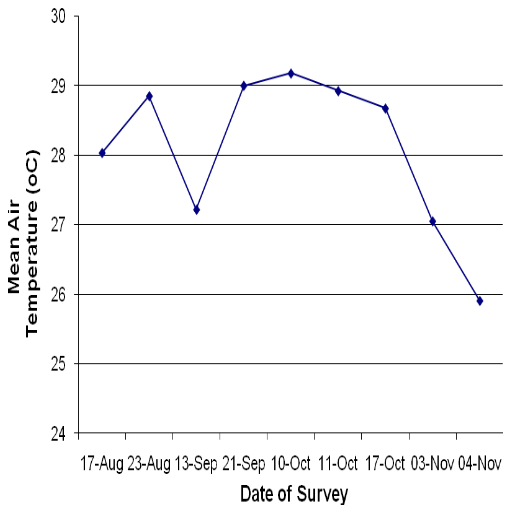

Fig. 4. Mean air temperature profile in the lift lobby.

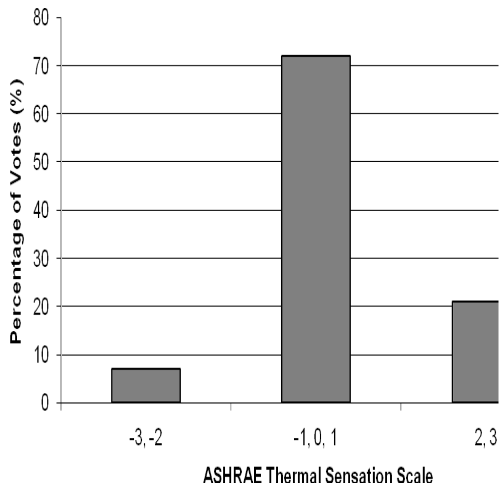

Fig. 5. Distribution of subjective thermal sensation vote.

4.3 Perception of Air Movement

The main intention to study the perceptions of respondents regarding air movement was because good air quality and adequate ventilation are important factors in governing human comfort and productivity [17]. The subjects' sensation and acceptability of air movement were assessed in this field survey. Since the region being studied was protected, enclosed and cooled via mechanical means with fixed air movement, the measured values for indoor air velocity did not vary much. At most of the time the air velocity in the enclosed lift lobby was within the recommended range of air flow rate in MS 1525: 2007. An average mean indoor air velocity of 0.15 m/s was calculated based on the data obtained from the field survey.

The 4-way ceiling mounted air conditioner was installed in the lift lobby to supply fresh air at discharge angle of 45 degree at all four directions. Table 3 presents the air movement perceptions and acceptability of the users of the lift lobby. After the votes have been analyzed, it was identified that human perception of air movement varies from one to another when encountered the same measure of air velocity, and no votes were placed in the cooler categories of 2 (too breezy) and 3 (much too breezy). About 41% of the test subjects found the air movement as undesirable. Meanwhile, most of the votes were placed within the categories of -2 (very still), -1 (slightly still) and 0 (just right) of the air movement scale and the mean air movement vote falls under "slightly still" category. Although more than three quarter of respondents (76%) voted within the three central categories of the air flow scale, this figure does not correlated nor associated with the percentage of acceptability vote. From Figure 6, it is shown that only 60% of the subjects were satisfied with the air velocity when they felt “slightly still”. This indicates that those subjects who voted their receptions of air movement under the three central groups do not necessarily to be agreeable with the conditions of air flow in the enclosed lift lobby. Besides, another phenomenon identified in this survey is similar to the findings of thermal sensation analysis, which is the effect of human occupancy level towards the perception of air movement. During peak usage periods, the test subjects responded differently compared to those in normal working hours and a significant number of them marked higher stillness of air. Ventilation in building is to support human occupancy. Hence, in such controlled region with fixed ventilation rate, human comfort is immediately affected by the change in human occupancy and travelling rate. The lowest air velocity of 0.15 m/s was found to be insufficient in maintaining human comfort in this transitional space and a higher rate of air change was required. This outcome suggests that a more detailed analysis is required for identifying the range of air velocity which is sufficient in maintaining human comfort in the lift lobby of a tropical building.

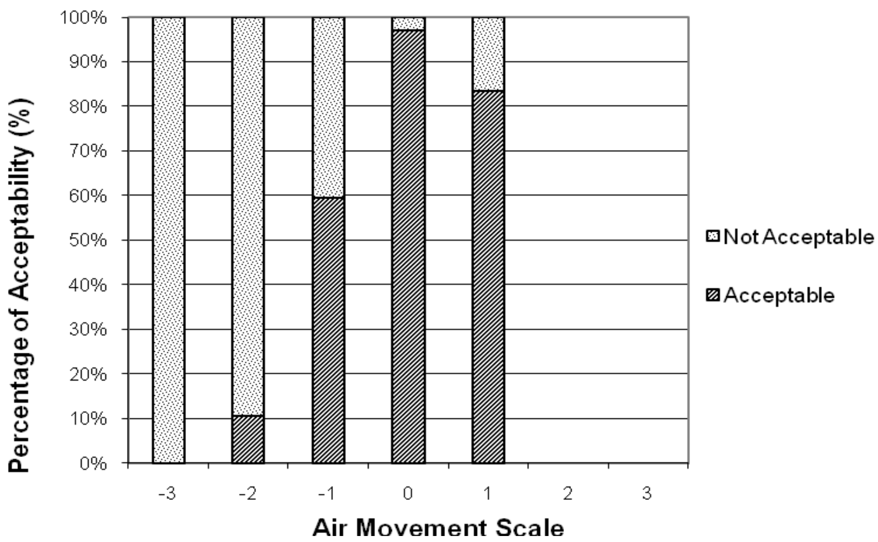

Fig. 6. Percentage of acceptability of air movement scale.

Table 3. Air movement perceptions and acceptability.

Date (08)	Air Flow Perception Vote							Air Flow Acceptability Vote	
	-3	-2	-1	0	1	2	3	Acceptable	Unacceptable
17 Aug	0	0	4	5	0	0	0	9	0
23 Aug	0	0	0	0	0	0	0	0	0
13-Sep	1	0	3	4	0	0	0	4	4
21-Sep	0	1	8	3	0	0	0	8	4
10-Oct	1	5	11	4	1	0	0	13	9
11-Oct	0	1	4	4	2	0	0	8	3
17-Oct	4	9	12	5	1	0	0	11	20
3-Nov	2	1	3	2	1	0	0	5	4
4-Nov	0	2	2	7	0	0	0	9	2
Total	8	19	47	34	5	0	0	67 (59%)	46 (41%)

4.4 Perception of Humidity Level

In this survey, the subjects’ preference and acceptability of humidity level in the enclosed transitional space were examined. As the region being investigated is a protected area and being controlled via mechanical cooling, the environmental conditions such as relative humidity are likely to vary less [18].

From the objective assessment, the range of relative humidity in the lift lobby was within 63% and 78%, and the mean relative humidity (RH) for each day of the survey is shown in Figure 7. Table 4 presents the outcome from subjective measurement for humidity performed in the enclosed lift lobby. It is clearly shown that 81% of the respondents found the humidity level of the surrounding acceptable, and 95% of the votes were placed within the three central categories of the humidity scale. Comparison was made between the physical and subjective measurements, and the results show that the more people voted their humidity perception as “unacceptable” with increase in level of human occupancy. For instance, about 26% of the respondents felt uncomfortable with the humidity level on 17-Oct, where the level of occupancy was high. The reason for such phenomenon is the amount of moisture dissipated to the ambient air by human body due to changes in environmental conditions, where 80% of the human body heat loss occurs through evaporation when air temperature is near to skin temperature [19]. In other words, the moisture gain in the air is directly proportional to the number of people being assembled in an enclosed region under normal enclosed circumstances. This may more or less inflicts a certain level of discomfort among occupants. All in all, it can be concluded that the humidity level does not exert significant effect on the travelers' comfort as the air temperature and velocity, since the respondents generally paid less attention to the humidity level. It can be observed in Figure 8 that only respondents who voted at the extreme categories (-2 and 2) of the humidity perception scale stated that the humidity condition was unacceptable, and people in an enclosed transitional space felt most comfortable when the surrounding was neutral to them. One of the reasons to explain this phenomenon is the application of air conditioner in the occupied spaces that acted as both cooling and dehumidification device, which controls the indoor humidity within acceptable level.

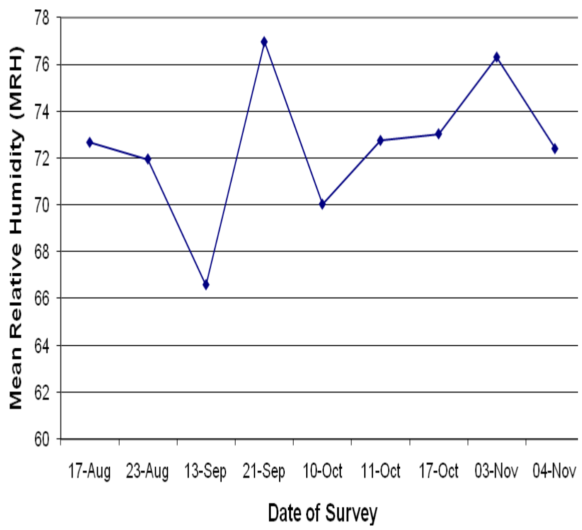

Fig. 7. Mean relative humidity profile.

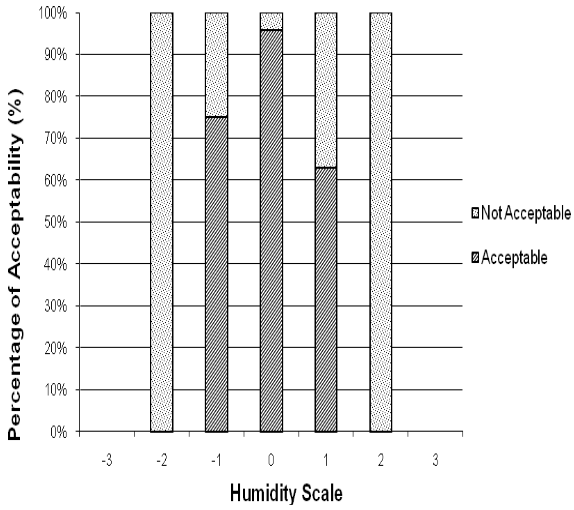

Fig. 8. Percentage of acceptability of humidity scale.

Table 4. Humidity perceptions and acceptability.

Date (08)	Humidity Perception Vote							Humidity Acceptability Vote	
	-3	-2	-1	0	1	2	3	Acceptable	Unacceptable
17-Aug	0	0	3	6	0	0	0	9	0
23-Aug	0	0	0	0	0	0	0	0	0
13-Sep	0	0	0	3	5	0	0	7	1
21-Sep	0	0	8	3	1	0	0	11	1
10-Oct	0	2	4	9	6	1	0	16	6
11-Oct	0	0	3	5	3	0	0	8	3
17-Oct	0	0	7	13	9	2	0	23	8
3-Nov	0	0	3	5	1	0	0	8	1
4-Nov	0	1	3	6	1	0	0	9	2
Total	0	3	31	50	26	3	0	91 (81%)	22 (19%)

4.5 Thermal Comfort Indices

Some thermal comfort assessments conducted in tropical buildings stated the inapplicability of Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) in tropical countries. In this study, the extension of PMV model for buildings in warm climates proposed by Fanger and Toftum was applied [20]. Calculation of thermal comfort indices, which consists of Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD), was made by employing the BASIC computer program provided in ASHRAE Standard 55. Variables in this calculation were air temperature, mean radiant temperature and relative humidity. The clothing level (clo) of test subjects was identified by the clothing list attached in the subjective questionnaire. The dressing code of Malaysian students and working staffs are somehow different as compared to people in other tropical countries, as a portion of subjects marked higher clothing level than average due to distinctive cultural practices.

The attire of the test subjects was converted to a numerical clo value with reference to ASHRAE Standard 55, and the calculated clo value was 0.62 with a standard deviation of 0.08. As the typical activity for the test subjects were standing up waiting for the arrival of elevators or having a conversation among each other, the metabolic rate as referred to ASHRAE Standard 55 is 70 W/m2 (1.2 met) for standing up, relaxed.

The values for clothing level, metabolic rates of test subjects and relative air velocity were set as constant measures. Table 5 poses the input variables, thermal comfort indices and other results of field measurements together with calculated PMV and PPD values for each day of the survey performed.

Table 5. Environmental and personal parameters for 113 samples.

Variable	Date								
	17-Aug	23-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	0.62
Metabolic Rate (Met)	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Air Temp. (°C)	28.22	27.51	28.02	29.12	29.18	28.93	28.68	27.05	25.95
Mean Radiant Temp. (°C)	26.73	26.64	26.86	27.04	27.21	27.2	26.9	26.28	26.1
Relative Air Velocity (m/s)	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Relative Humidity (%)	70.78	76.66	68.19	76.97	70.02	72.75	73.03	76.3	72.39
PMV (EF = 0.5)	0.55	0.45	0.55	0.70	0.70	0.70	0.65	0.45	0.30
PPD	33	23	31	49	47	45	41	22	12

The range of PMV index was from 0.6 to 1.4. As the building surveyed is categorized under warm climate, an expectation factor of 0.5, which is also the lowest suggested value by Fanger and Toftum, was multiplied with the calculated PMV values. As for PPD index, the outcome specifies that about 35% of the occupants in this survey were expected to be discomfort with the thermal environment of the enclosed lift lobby.

While comparing these results to the values obtained from questionnaire assessment, disagreement happened between the calculated PMV with expectation factor and the mean thermal sensation mentioned by test subjects, which is 0.56 against 0.44. Some researchers claimed that this is primarily due to the overestimate of the PMV model which predicted slightly warm when the respondents actually felt neutral at certain temperatures. This also proposed that the PMV with expectation factor still overestimate the actual thermal sensation of occupants in the tropical buildings. The results obtained show that for building transitional spaces, the occupants in enclosed transitional zone may have lower expectation on the cooling sensation. This has suggested a lower expectation factor (< 0.5) for the transitional spaces in tropical buildings if such thermal comfort index is to be applied. For PPD index, while comparing with the finding of field survey where 28% of the respondents voted outside the three central categories of the ASHRAE scale, and a 7% difference is obtained. The main factor that contributed to this dissimilarity is the overestimation of the PPD index which predicted warmer temperature than actual thermal sensation [21]. Also, the overestimation of PMV tends to encourage the use of more air conditioning than necessary [22], especially in the tropical countries. This is evidenced inside the Malaysian buildings where most of the time the indoor temperature is maintained at a lower than necessary value, since most of the occupants were influenced by the concept introduced by the air-conditioning manufacturers where "cooler is better".

4.6 Thermal Neutrality

Some previous thermal comfort surveys conducted in the tropical countries have applied the concept of thermal neutrality. According to ASHRAE Handbook - Fundamentals, thermal neutrality is the condition where no heat exchange of a person with his immediate surrounding occurs. The survey of human response in South East Asia conducted by [23] has produced an equation for estimation of thermal neutrality based on the value of mean dry bulb temperature as shown in equation below:

$$T_n = 17.6 + 0.31\,T_m \qquad (1)$$

where T_n is the Thermal neutrality and T_m is the Mean dry bulb temperature. Aynsley's work has suggested T_n ± 2.5 K for 90% acceptability of thermal comfort and T_n ± 3.5 K for acceptability rate of 80%.

Table 6 presents the data of outdoor dry-bulb temperature, mean dry-bulb temperature and thermal neutrality for 9 days of the survey performed. The mean value for thermal neutrality was calculated as 26.02°C. For 80% acceptability, the range of thermal neutrality was between 22.52 to 29.52°C. Comparison was made with previous studies conducted in tropical buildings and it was identified that the mean thermal neutrality for this study is notably lower than the results obtained in Singapore by [24] and [25] in southern China. One possible explanation for such difference is because the previous studies as mentioned have noted significant rate of thermal adaptation by occupants as compared to this study. This has indirectly suggested that adaptation to the thermal environment in the transitional spaces is less prominent than commonly occupied spaces in buildings, as travelers may just walk through and the occupancy period is usually short. From the field survey, the operative temperatures obtained were within the range of 25.89 to 28.01°C, with the mean value of 27.31°C. This shows that the range of operative temperature in the enclosed lift lobby was within the acceptable zone, and the thermal environment was comfortable for about 80% of the respondents. From the subjective measurement, 79% of the test subjects were satisfied with their thermal environment. Therefore, the results of thermal neutrality are in accordance with the field measurement with slight overestimation. It is an option to lower the return air temperature setting of air conditioners for 1 to 2°C to provide a more acceptable thermal environment for the occupants during high occupancy periods in a day. However, the energy implication should be carefully considered as every deduction in temperature in thermostat settings may increase the energy consumption [25].

Table 6. Outdoor dry-bulb temperature, mean dry-bulb 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	26.52
23-Aug	23.6 – 30.9	25.29	25.44
13-Sep	24.7 – 33.0	28.48	26.43
21-Sep	22.9 – 32.4	26.28	25.75
10-Oct	23.5 – 33.3	26.56	25.83
11-Oct	23.4 – 33.1	26.32	25.75
17-Oct	24.1 – 32.5	26.46	25.80
3-Nov	25.8 – 32.0	28.58	26.46
4-Nov	25.3 – 31.0	27.72	26.19

4.7 Energy Savings Potential

It was suggested that the building transitional spaces can help to save energy if they could be developed according to respective climatic needs [27]. For tropical buildings, the upper temperature limit for thermal comfort may be higher than the value specified in ASHRAE Standard 55. The results from field survey have presented that most of the respondents were thermally comfortable with preference on higher air flow rate. According to MS 1525, the desirable range of temperature within a built environment is 23°C to 26°C and acceptable air velocity is in the range of 0.15 to 0.50 m/s. Some countries in the tropics have adopted similar practice, where the recommended nationwide indoor set point for Thailand is 26°C [26]. It was identified that every increase of 1K in thermostat settings may conservatively decrease the energy consumption of 6% after deducting the amount of energy spent on providing additional air flow rate [28]. Besides, further 10% of energy saving can be obtained by raising the thermostat set-point to the neutral temperature, which is about 26°C in the tropical countries [15].

A common practice in Malaysia is the operating of air conditioners throughout office hours, which is from 8.00 a.m. to 6.00 p.m. daily except weekends. In order to conserve energy usage and maintain good thermal environment, the thermostat setting of the air conditioner attached to the enclosed lift lobby was maintained at 26°C, which was 10°C difference as compared to common practice of 16°C to 18°C since nearly 79% of the respondents reported that they were thermally comfortable with the conditions of enclosed lift lobby. The peak load condition for air conditioner occurs at maximum fan and compressor works, and load condition is directly proportional to the amount of cooling required. The lowest thermostat set-point for most commercial air conditioning system in Malaysia is computed as 16°C. In order words, the peak working condition may occur at this temperature set-point with highest fan speed. Hence, by setting the thermostat set-point at 26°C and maintaining low air speed throughout the field survey, the savings in kWh incurred can be identified. The amount of energy savings in the lift lobby which utilizes a 1.5 HP (about 1500W) air conditioner, can be determined using simple calculations as follow:

Maximum total input power = 1500 W or 1.5 kW

Total operating hours for air conditioners per day = 10 hours

Total amount of energy consumption per day = 1.5 kW x 10 hours = 15 kWh

By assuming 6% saving in input power for each 1°C increase in thermostat setting and constant working (peak) load for compressor and fans, 10°C temperature rise will have a reduction of 60% in total energy consumption. Thus, the energy being used by air conditioning system is only 40% of 15 kWh, which is about 6 kWh. The administration block of the faculty of engineering has a total of 7 floors which share similar architectural design and application of building services systems. By ignoring the ground level which is connected to the external environment, total reduction of energy consumption concerning usage of air conditioners in the enclosed lift lobbies is 54 kWh, with 9 kWh of savings for each air conditioner.

Since electricity charges are made in monthly basis, the amount of energy savings per month can be calculated as follow:

With thermostat setting of 16°C,

Total energy consumption per month (5 working days per week) = 22 x 15 kWh = 330 kWh

Total consumption for 6 units of air conditioners = 330 kWh x 6 = 1980 kWh

With thermostat setting of 26°C,

Total energy consumption per month (5 working days per week) = 22 x 6 kWh = 132 kWh

Total consumption for 6 units of air conditioners = 132 kWh x 6 = 792 kWh

Total savings in electrical usage = 1980 kWh – 792 kWh = 1188 kWh

The electricity cost for school/educational institution in Malaysia falls under commercial category; Tariff B – Low voltage commercial tariff. For this category, overall monthly consumption between 0 to 200 kWh will be charged 37 cent (about USD 0.12) per kWh. For overall monthly consumption more than 200 kWh, the cost for each kWh is 39.7 cent (about USD 0.13). Thus, with the total savings of 1188 kWh per month, the estimated cost savings is as calculated below:

Estimated savings per month = (Power consumption at T = 16°C) - (Power consumption at T = 26°C)
= (1980 x 0.397) – (792 x 0.397)
= 786.06 – 314.42
= RM 471.64 @ USD 146.86

It should be noted that the amount of energy savings obtained have compensated for the increase in air speed, as favored by some of the test subjects. This is because higher air velocity sensed by the occupants will provide a higher evaporative cooling of the body and thus enhancing thermal comfort. In other words, more savings can be achieved by maintaining lower fan speed. In the case of protected lift lobby where application of natural ventilation is impractical, further reduction of cooling load can be achieved via introduction of shading materials in the windows [29], replacement of old light bulbs with CFL and so forth. These may lessen the amount of heat gain in the lift lobby and subsequently reducing energy consumption of air conditioners without sacrificing human thermal comfort in the enclosed transitional spaces in tropical buildings.

5. CONCLUSION

This study shows that about 60% of the energy consumption in the enclosed lift lobby can be saved while maintaining thermal comfort of travelers. The temperature setting of 26°C as suggested in MS 1525 was identified to be able to provide a thermally comfortable environment to most of the users. Based on the results obtained, air movement was found to be one of the main factors in governing human thermal comfort in an enclosed and controlled lift lobby, and the low velocity of 0.15 m/s was considered by most respondents to be insufficient to sustain human comfort. Also, occupants passing through the transitional space generally pay less attention to the humidity condition. Abrupt temperature change, surprisingly, was not a major element in affecting thermal comfort, as most of the respondents to this study found their thermal environment acceptable.

The thermal sensation and preference of occupants in the enclosed lift lobby were identified to be greatly affected by the occupancy level, and the thermal comfort requirement in the transitional spaces is different from one to another depending on respective usages. The PMV index applied with expectation factor, still overestimated the actual thermal sensation of the occupants. This has suggested that a lower expectancy factor is required, if the index is to be applied for thermal comfort survey in the transitional spaces.

A neutral temperature of 26.02°C was obtained in this survey and results from the field survey showed that 79% of the participants found the thermal environment acceptable. This shows that the return air temperature setting of air conditioner can be set higher than the common practice, and hence suggested an opportunity for energy savings. As the enclosed transitional spaces are often associated with building services which require electrical energy, more studies should be directed to the transitional spaces in tropical buildings for purpose of energy efficiency improvement.

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