International Journal of Mechanical and Materials Engineering (IJMME), Vol. 3 (2008), No.2, 119-126.

A PRELIMINARY THERMAL COMFORT STUDY IN TROPICAL BUILDINGS LOCATED IN MALAYSIA

Y.H. Yau
Department of Mechanical Engineering, University of Malaya
50603 Kuala Lumpur, Malaysia
Email: yhyau@um.edu.my.

ABSTRACT

A preliminary study of the thermal comfort level in several buildings at University of Malaya is presented in this paper. For the study, a subjective field survey study was conducted on thermal comfort at buildings in University of Malaya. The study is based on the analysis of 141 sets of questionnaires compiled from field survey study in nine buildings located at the University. The results of the subjective and objective data are then compared to the results acquired from the ASHRAE thermal comfort tool. This research found that most of the buildings fail to provide a thermally comfort environment to the occupants. Based on the results of the thermal comfort study, the existing old HVAC systems installed in the buildings are recommended to be retrofitted or replaced for achieving minimum thermal comfort level per ASHRAE recommendation (ANSI/ASHRAE Std 55, 2004).

Key words: Thermal comfort, field studies, thermal sensations, tropical buildings, HVAC systems.

NOMENCLATURE

AHU	Air Handler Unit(s)
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CAV	Constant Air Volume
CFD	computational fluid dynamics
HVAC	heating, ventilating and air conditioning
HVAC	heating, ventilating and air conditioning & refrigerating
$\dot{m}$	mass flow rate [kg s^{-1}]
M&E	Mechanical and Electrical
RH	Relative Humidity

1.0 INTRODUCTION

Thermal comfort control is a never-ending war in tropical hot and humid built environment, particularly, in Malaysia and Singapore. Thermal comfort exist when an individual surrounded by an environment whose temperature and relative humidity allow the person to lose, with no conscious attempt, metabolic heat at the same rate he or she produces it. In other words, thermal comfort is the characteristics of the surroundings, which affect the person's heat lost. These characteristics can be further defined as "the state of mind which expresses satisfaction with the thermal environment" (Ismail, 2007).

In Malaysia, a typical developing tropical country, heat, ventilating and air conditioning (HVAC) systems are commonly used to control the temperature, humidity, circulation, ventilation as well as purification of the air in a building. HVAC systems can maintain the comfort and productivity of the building occupants as well as conserve the energy used for heating and cooling the entire facility if designed correctly. Because the unique hot and humid climates in tropical buildings, whether the minimum comfort level could be achieved in tropical buildings is a major challenge to M&E design engineers.
A large number of field studies on thermal comfort have been conducted around the world (Wang, 2006; Schiller *et al,* 1988; Schiller, 1990; Benton *et al*. 1990; Dedear & Fountain, 1994; Howell & Stramler, 1981; Howell & Kennedy; Fishman & Pimbert, 1979; Busch, 1990; Xia *et al,* 1999; Cena & Dedear, 1990; De Paula Xavier, & Roberto, 2000). However, almost all of these research were performed in developed seasonal climate countries, with the exception that of Cheong *et. al.* (2003), which was conducted in a tropical climate in Singapore. Cheong *et. al.* (2003) evaluated the present thermal comfort conditions of an air-conditioned lecture theatre in a university using objective measurement, computational fluid dynamics (CFD) modeling and subjective evaluation. It was revealed that the measured air temperatures, air velocities and relative humidities were inside the limits of thermal comfort requirements even though temperature and relative humidity were found at the extreme of the threshold limits.

Despite the just mentioned studies, there is virtually no research work on investigating the thermal comfort level in Malaysian university buildings and their respective HVAC systems. Therefore, this investigation is required to be carried out and the major aim is to examine the thermal comfort level to the university buildings and their respective HVAC systems.

2.0 THEORY RELEVANT TO THE PRESENT RESEARCH

The theory relevant to the environmental factors that affects the thermal comfort has been described in reference (ANSI/ASHRAE Std 55, 2004). The comfort ranges for these environmental factors are summarized in the following section for convenient reference. The thermal comfort of our body depends mainly on three environmental factors (Chengel, 2007;Quiston *et al.*, 2005; ME, 1996) namely, air temperature, relative humidity and air movement (i.e. the air velocity). It is noted that normally clothed people resting or doing light work feel comfortable in the operative temperature (i.e. the average temperature of air and the surrounding surface) ranging from 22.5ºC to 25.5ºC.
Relative humidity measures the air's capability to absorb moisture that will have an effect on the quantity of heat of our body rejected by evaporation. High value of RH slows down the heat dissipation by evaporation. The evaporation process rate is higher for high temperature and low RH. From the research conducted, the desirable range of RH is less than 70 %. Note that the RH at 50 % is the most desired level. With the RH value at 50 %, human will fell neither hot nor cool, because the body does not need to activate any defense mechanism to keep the normal temperature.

Excessive air velocity or draft will cause the undesired local cooling of the occupant body. Occupants who are conducting light sedentary work with indoor clothing will experience the uncomfortable condition caused by draft. Occupants who are conducting high levels activity will feel less uncomfortable condition caused by draft. It is recommended to have a low level of draft because it removes the warm and moist air surrounding the body and replaces it with fresh air. Therefore, the draft should be sufficient enough to eliminate the heat and moisture with fresh outdoor air, but simultaneously, it is lower enough to be below 0.25 m/s for tropical buildings.

3. RESEARCH METHODOLOGY

This study was conducted in nine buildings located in the campus of University of Malaya. Note that the experimental data presented in this work were obtained from measurement campaigns conducted in university buildings different in architectural characteristics, geographical locations, age of buildings, dimensions, occupant capacity, HVAC & R systems and solar gains.

The selected spots are as follows:

a. Library of East Asian Studies
b. Library of Engineering Faculty
c. Museum of Asian Art
d. Office of Malay Studies Academy
e. Library of Islamic Studies Academy
f. UM book store
g. Library of the Postgraduate Studies
h. Block D, Faculty of Economy
i. Chemistry Block, Faculty of Science

The field measurements were carried out at several locations in the occupied zone within the nine buildings just mentioned at 1.0 m above the floor level. A Thermo-Hygro-anemometer was used to measure thermal comfort parameters included air velocity, room temperature and relative humidity.
The subjective measurement was conducted at nine spots mentioned above and a total of 141 sets of thermal, environmental, physical data and subjective questionnaires were successfully collected from the field work took place during the year 2006. The simple statistical method was used to evaluate the thermal comfort opinions of the respondents. The questionnaire applied in the subjective measurement was adopted from reference (ME, 1996) with slight modifications to make sure it is appropriate to tropical university buildings.
Also, the ASHRAE thermal comfort tool shown in Figure 1 was applied to evaluate the thermal conditions of the surveyed area by input the environmental conditions from the field work measurements. However, it is pertinent to mention that the mean radiant temperature is assumed to be as the air temperature in the computation below shown in Figure 1.

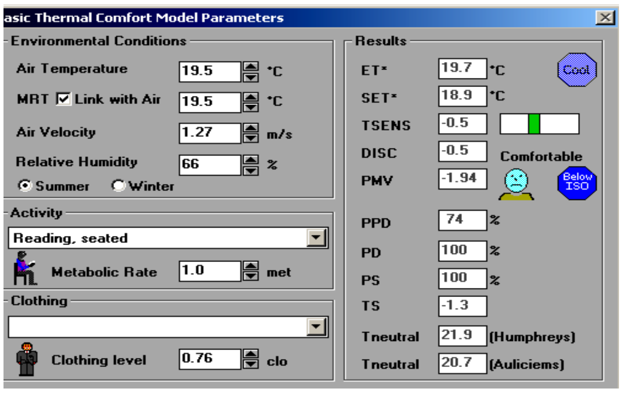

Figure 1: ASHRAE thermal comfort tool

The results of thermal conditions computed using ASHRAE thermal comfort tool are compared to the subjective survey data by varying the clothing level of the occupants appropriate to the situation in the buildings. The true thermal comfort level in the buildings could then be verified from the comparison between the subjective thermal feeling and the theoretical thermal feeling computed using the Fanger Model impeded in the thermal comfort tool.

4.0 RESULTS AND DISCUSSIONS

The following sub-sections describe and discuss the thermal comfort level results obtained from the nine buildings in University of Malaya. The thermal comfort level results collected from these buildings will be discussed separately first in the following sub-sections 4.1-4.9 because they are different in architectural characteristics, geographical locations, age of buildings, dimensions, occupant capacity, HVAC & R systems and solar gains mentioned above.

4.1 Library of East Asian studies

Figure 2 shows the percentage of thermal feeling at East Asian Studies Library. It is evident that sixty-seven percent of the respondents were satisfied with the existing air conditioning system in the library, while 33% of respondents indicated that temperature is 'a bit cool' and 'cold cool'. Note that, approximately 46.7% of the respondents need extra clothing to stay comfortably in the library.

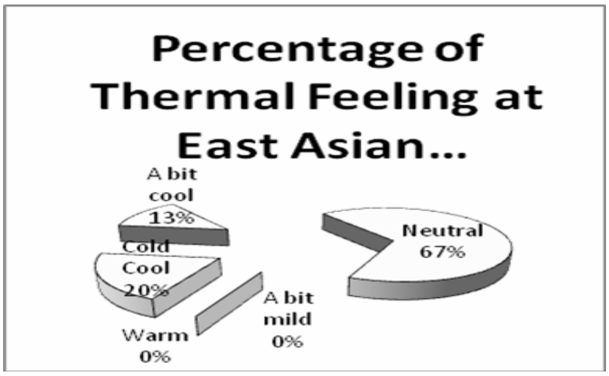

Figure 2: Percentage of thermal feeling at East Asian Studies Library

It is also observed that none of the respondent perceived the air as 'warm' and 'a bit mild'. The reasons why the respondents feel a bit cool may be attributed to the low heat generation by equipments and low metabolic rate. The survey shows that the equipments are at the low rate usage since people are seldom or never use the equipments, and thus less heat generated. The low metabolic rate is established due to light activities among the respondents.
From the fieldwork measurement, the average indoor air conditions are as follows:

DBT: 19.5°C
RH: 66.5%
Air velocity: 1.27 m/s

The indoor air conditions just mentioned above are input into the software as shown in Figure 1. It is pertinent to mention that the occupants are assumed to conduct light activities such as reading and seated. The result shows that the library is within the thermal comfort zone as shown in Figure 2. Occupants feel comfort to stay inside the building even without extra clothing such as wearing a sweater. This indicates that the result obtained from the ASHRAE thermal comfort software is not in good agreement with the subjective measurement result because the subjective measurement indicated that approximately 46.7% of the respondents need extra clothing to stay comfortably in the library. This may be due to the fact that the room temperature at 19.5°C is well below the room temperature recommended (ASHRAE, 1997).

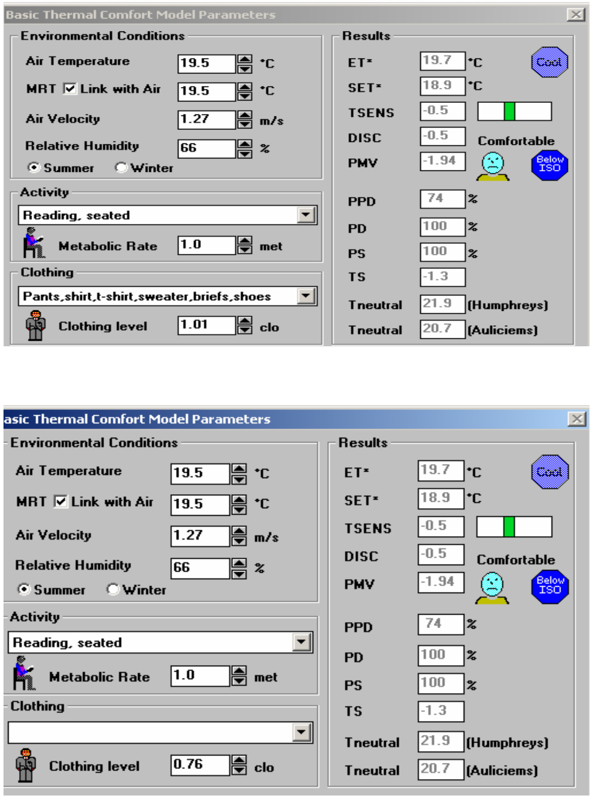

Figure 3 Thermal comfort results computed using ASHRAE Thermal Comfort Software

In addition, 93% of the occupants implied that the air inside the space did not make them feel odor or stuffy. Therefore, the thermal comfort level is within the recommended zone per ASHRAE requirement (ASHRAE, 1997).

4.2 Library of Engineering Faculty

Figure 4 shows the percentage of thermal feeling at Engineering Library. It is evident that forty-seven percent of the respondents were satisfied with the existing air conditioning system in the library, while 40% of respondents indicated that temperature is 'a bit cool' and 'cold cool'. Note that, approximately 40.0% of the respondents need extra clothing to stay comfortably in the library. It is also observed that 13% of the respondents perceived the air as 'a bit mild'.

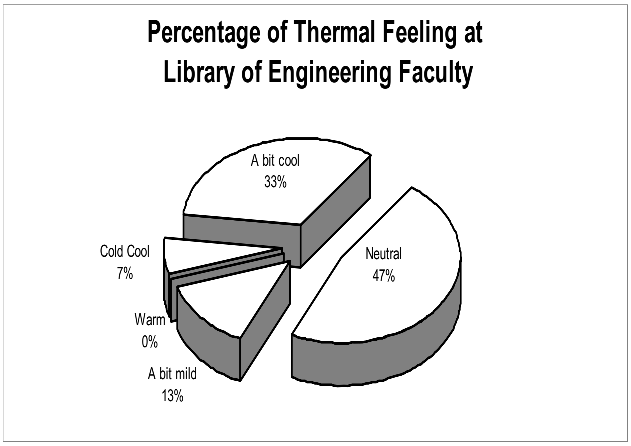

Figure 4 the percentage of thermal feeling at Library of Engineering Faculty

From the fieldwork measurement, the average indoor air conditions are as follows:

DBT: 23.8°C
RH: 48.7%
Air velocity: 2.5m/s

The indoor air conditions just mentioned above are input into the ASHRAE software. Again, it is pertinent to mention that the occupants are assumed to conduct light activities such as reading and seated. The result shows that the library is within the thermal comfort zone. Occupants feel comfort to stay inside the building even without extra clothing such as wearing a sweater. This indicates that the result obtained from the ASHRAE thermal comfort software is in good agreement with the subjective measurement result because the subjective measurement indicated that only approximately 6.0 % of the respondents need extra clothing regularly to stay comfortably in the library. This may be due to the fact that the room temperature at 23.8°C is well maintained at the room temperature requirement recommended (ASHRAE, 1997).

4.3 Museum of Asian art

Figure 5 shows the percentage of thermal feeling at the Museum of Asia Art. It is evident that only thirty-three percent of the respondents were satisfied with the existing air conditioning system in the museum, at the same time as high as 67% of respondents indicated that temperature is 'a bit cool' and 'cold cool'. Note that, approximately 60.0% of the respondents need extra clothing to stay comfortably in the museum. It was also evident that none of the respondent indicated the air as 'a bit mild' or 'warm'. From the fieldwork measurement, the average indoor air conditions are as follows:

DBT: 12.3°C
RH: 61%
Air velocity: 1.27 m/s

Again, the indoor air conditions just mentioned above are input into the ASHRAE software. However, different assumptions are applied to the simulation compared the assumptions made in sub-section 4.2. This is due to the fact that the visitors to the museum are assumed standing and relax (i.e. metabolic value is 1.2).

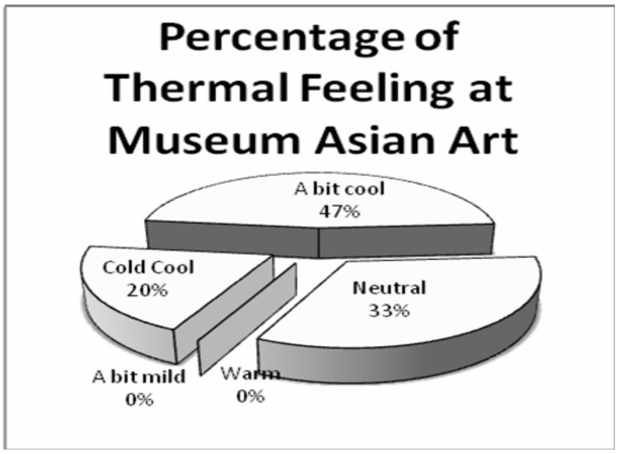

Figure 5 The Percentage of thermal feeling at Museum of Asian Art

The result shows that occupants feel uncomfortable if they are not wearing sweater. However, if the occupant stays in the museum with an additional sweater, he or she will only feel slightly uncomfortable. This result indicates that the empirical result obtained from the subjective measurement is in good agreement to the theoretical result computed from the ASHRAE thermal comfort tool. Subsequent examination on the building HVAC & R systems revealed that the reheating coil is either no longer functioning or not installed in the AHU. As a result, the room temperature is at 12.3°C, which is well below the temperature recommended by ASHRAE (ASHRAE, 1997).

4.4 Office of Malay studies academy (APM)

Figure 6 shows the percentage of thermal feeling at the office of the Malay Studies Academy (APM). It is apparent that only forty percent of the respondents were satisfied with the existing air conditioning system in the APM office, at the same time as high as 60% of respondents implied that temperature is 'a bit cool' and 'cold cool'. It was also interested to note that only 13.0% of the respondents need extra clothing to stay comfortably in the office. It was also evident that none of the respondent indicated the air as 'a bit mild' or 'warm'. However, 70% of the respondents complained on the unpleasant odor and the stuffy air inside the office. This suggested that air contaminants existed in the building.

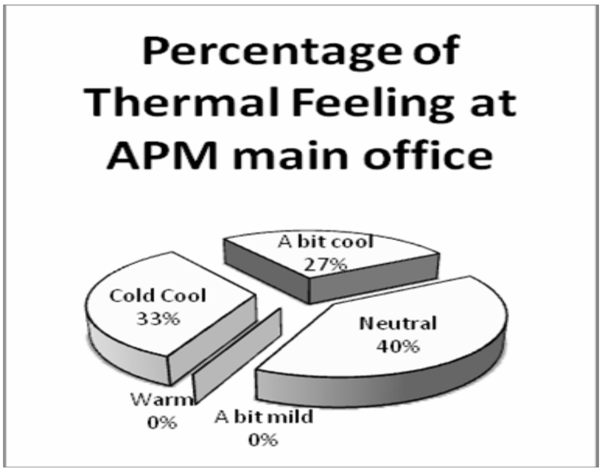

Figure 6 the percentage of thermal feeling at the office of the Malay Studies Academy (APM)

Nevertheless, from the fieldwork measurement, the average indoor air conditions for Zone A are as follows:

DBT: 18.6°C
RH: 64%
Air velocity: 2.80 m/s

The same simulation was conducted using the ASHRAE software. Again, the same assumptions are applied to the simulation described in sub-section 4.1. The result shows that occupants feeling cool even if they are wearing sweater. This result confirmed that the empirical result obtained from the subjective measurement is again in good agreement to the theoretical result computed from the ASHRAE thermal comfort tool. Subsequent examination on the building HVAC & R systems revealed that the constant air volume (CAV) system is installed in the AHU. As a result, the same cooling load will be applied to the space regardless the occupancy rate in the office. This will inevitably reduce the room temperature to 18.6°C as recorded from the field measurement, which is well below the temperature recommended (ASHRAE, 1997).

In addition, the fieldwork measurement was also conducted for Zone B of the office, and the average indoor air conditions for Zone B recorded are as follows:

DBT: 18.3°C
RH: 62%
Air velocity: 1.22 m/s

Again, the result showed that the office was in cool and slightly uncomfortable conditions. Therefore, a general conclusion could be made that the APM office did not meet the thermal comfort criteria required by ASHRAE (ASHRAE, 1997).

4.5 Library of Islamic studies academy

Figure 7 shows the percentage of thermal feeling at the office of the Library of Islamic Studies Academy. It is apparent that only forty percent of the respondents were satisfied with the existing air conditioning system in the library, simultaneously as high as 60% of respondents implied that temperature is 'a bit cool'. It was also interested to note that approximately 67.0% of the respondents need extra clothing to stay comfortably in the office. It was also evident that none of the respondent indicated the air as 'a bit mild' or 'warm'. Nevertheless, 87.0% of the respondents complained on the unpleasant odor and the stuffy air inside the office. This suggested that air contaminants existed in the library due to high RH at 84%.

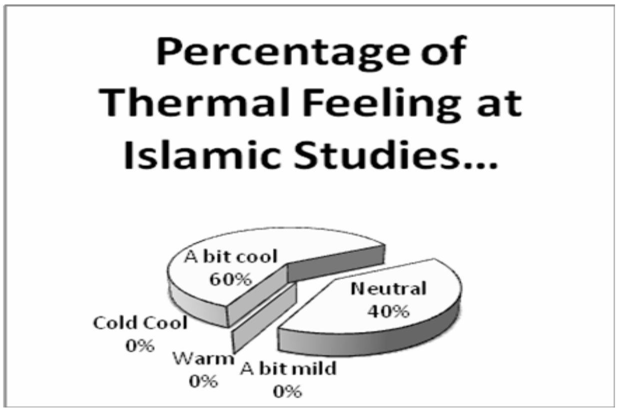

Figure 7 the percentage of thermal feeling at the office of the Library of Islamic Studies Academy

Again, the same simulation was conducted using the ASHRAE software with the same applied to the simulation described in sub-section 4.1. The result shows that majority of the occupants feeling cool even if they are wearing sweater. This result suggested that the empirical result obtained from the subjective measurement is again in good agreement to the theoretical result computed from the ASHRAE thermal comfort tool.

Also, the fieldwork measurement was conducted for the library, and the average indoor air conditions for the space recorded are as follows:

DBT: 16.0°C
RH: 84%
Air velocity: 3.47m/s

Again, the indoor air conditions for the library just mentioned above are input into the ASHRAE software with the same assumptions made in sub-section 4.1. The result again shows that occupants feel uncomfortable even though they are wearing sweater. This result further suggests that the empirical result obtained from the subjective measurement is in good agreement to the theoretical result computed from the ASHRAE thermal comfort tool.

4.6 Book store of University of Malaya

Figure 8 shows the percentage of thermal feeling at the Book Store of University of Malaya. It is apparent that only nine percent of the respondents were satisfied with the existing air conditioning system in the store, concurrently as high as 91% of respondents implied that temperature is ‘a bit cool’ or ‘cold cool’. It was also important to note that approximately 90.0% of the respondents need extra clothing to stay comfortably in the office. This is attributed to the low room temperature at 18.4 °C. It was also evident that none of the respondent indicated the air as ‘a bit mild’ or ‘warm’. On the other hand, only 43.0% of the respondents complained on the unpleasant odor and the stuffy air inside the office. This suggested that air contaminants were not significant in the store compared relatively to other spots discussed in sub-sections 4.1-4.5.

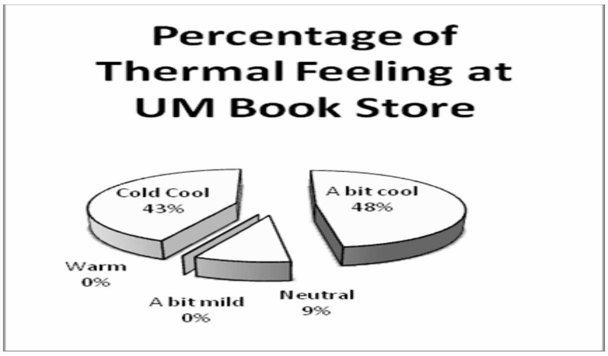

Figure 8 the percentage of thermal feeling at the Book Store of University of Malaya

From the fieldwork measurement that the average indoor air conditions are as follows:
DBT: 14.4°C
RH: 74.0 %
Air velocity: 3.00 m/s
It is observed that the result computed from thermal comfort tool shown the library is in the cold zone for normal clothing level. This result implied that the theoretical results agreed well with the empirical results. A subsequent investigation to the HVAC & R systems revealed that the building has two HVAC systems in the library, which are water package unit and cascade unit. It seems that the reheating coil is either no longer functioning or not installed in the HVAC systems. This is probably due to the energy saving measure in the HVAC system. In turn, the overcooled air could not be reheated to the temperature at 24.0°C in the space as recommended (ASHRAE, 1997).

4.7 Library of Postgraduate Studies (IPS)

Figure 9 presents the percentage of thermal feeling at Block D, Faculty of Economy. It is evident that 74% of respondents implied that temperature is ‘neutral’. This result suggested that majority of the occupants were feeling comfortable in the building It was also noted that approximately 67% of the respondents need extra clothing to stay comfortably in the office. This is attributed to the slightly low room temperature at 17.9 °C. It was also interesting to note that 13% of the respondents indicated the air as ‘a bit mild’. However, there is also 13.0% of the respondents implied that the air as ‘a bit cool’. This confirms the suggestion that a person is not a passive receiver of sense thought but is an active participant in dynamic balance with the thermal surrounding (Humphreys & Nicol, 1998; Brager & Dedear, 1998). In addition, only 33.0% of the respondents complained on the unpleasant odor inside the office. This suggested that air contaminants again were not significant in the store compared relatively to other spots discussed in sub-section 4.4.

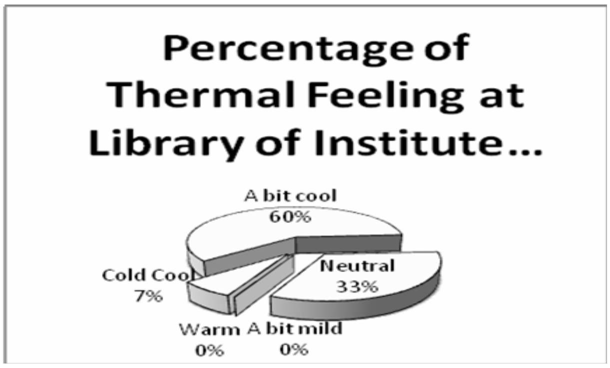

Figure 9 the percentage of thermal feeling at the Library of Institute of Postgraduate Studies

It is evident from the fieldwork measurement that the average indoor air conditions are as follows:
DBT: 17.9°C
RH: 70.0 %
Air velocity: 1.77 m/s
It is observed that the result computed from thermal comfort tool shown the office at Block D is in the cool zone for normal clothing level. This result indicated that the theoretical results agreed well with the empirical results.

4.8 Block D, Faculty of Economy

Figure 10 presents the percentage of thermal feeling at Chemistry Block, Faculty of Science. It is evident that only 33% of respondents implied that temperature is ‘neutral’ but 67% of respondents implied that temperature is ‘a bit cool’. This result suggested that

majority of the occupants were feeling uncomfortable in the building. It was also noted that approximately 74% of the respondents need extra clothing to stay comfortably in the office. This is attributed to the very low room temperature recorded at 13.6 °C. It was also noted that none of the respondents indicated the air as 'a bit mild', 'cold cool' or 'warm'. It is likely that the reheating coil is either no longer functioning or not installed in the HVAC systems. In addition, 87.0% of the respondents complained on the unpleasant odor inside the office. A close examination to the system revealed that no outdoor air is used in the system; instead the return air and the air above the ceiling are mixed in the mixing box (plenum return system) where mixing air is recycled continuously. This suggested that air contaminants were not diluted due to fresh air was not introduced to the HVAC system.
It is evident from the fieldwork measurement that the average indoor air conditions are as follows:

DBT: 13.6°C
RH: 75.0 %
Air velocity: 1.72 m/s

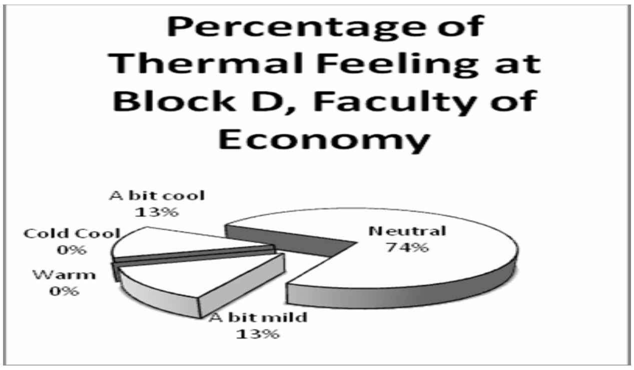

Figure 10 the percentage of thermal feeling at Block D, Faculty of Economy

It is observed that the result computed from thermal comfort tool shown the Chemistry Block is in the cold zone for normal clothing level. This result implied that the theoretical results agreed well with the empirical results. A subsequent investigation to the HVAC & R systems revealed that the AHU has not been installed with a reheating coil in the building. This is again probably due to the energy saving measure in the HVAC system as described in sub-section 4.8. In turn, the overcooled air could not be reheated to the temperature at 24.0°C in the space as required by ASHRAE (Quiston *et al,* 2005).

4.9 Chemistry block, Faculty of Science

Figure 11 presents the percentage of thermal feeling at Chemistry Block, Faculty of Science. It is evident that only 33% of respondents implied that temperature is 'neutral' but 67% of respondents implied that temperature is 'a bit cool'. This result suggested that majority of the occupants were feeling uncomfortable in the building. It was also noted that approximately 74% of the respondents need extra clothing to stay comfortably in the office. This is attributed to the very low room temperature recorded at 13.6 °C. It was also noted that none of the respondents indicated the air as 'a bit mild', 'cold cool' or 'warm'. It is likely that the reheating coil is either no longer functioning or not installed in the HVAC systems. In addition, 87.0% of the respondents complained on the unpleasant odor inside the office. A close examination to the system revealed that no outdoor air is used in the system; instead the return air and the air above the ceiling are mixed in the mixing box (plenum return system) where mixing air is recycled continuously. This suggested that air contaminants were not diluted due to fresh air was not introduced to the HVAC system.
It is evident from the fieldwork measurement that the average indoor air conditions are as follows:

DBT: 13.6°C
RH: 75.0 %
Air velocity: 1.72 m/s

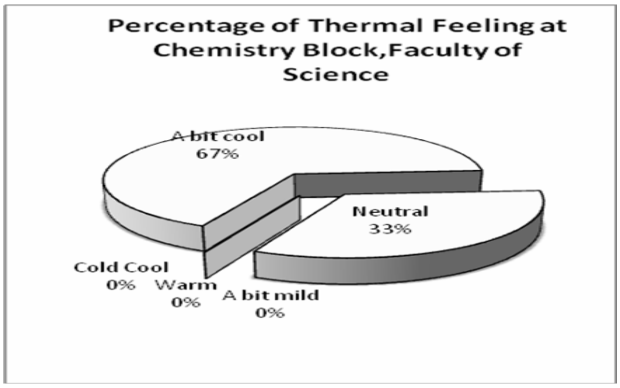

Figure 11 the percentage of thermal feeling at Chemistry Block, Faculty of Science

It is observed that the result computed from thermal comfort tool shown the Chemistry Block is in the cold zone for normal clothing level. This result implied that the theoretical results agreed well with the empirical results. A subsequent investigation to the HVAC & R systems revealed that the AHU has not been installed with a reheating coil in the building. This is again probably due to the energy saving measure in the HVAC system as described in sub-section 4.8. In turn, the overcooled air could not be reheated to the temperature at 24.0°C in the space as required by ASHRAE (Quiston *et al,* 2005).

5.0 CONCLUDING SUMMARY

In this paper the preliminary study of the thermal comfort level in several buildings at University of

Malaya was established for a tropical climate. The results would benefit both the M&E designer and maintenance personnel. The results of this work also could be used as an important guide for building services engineers and researchers who are intending to design HVAC systems for meeting minimum thermal comfort level operating in tropical countries. The main conclusions from this work are:

1. The thermal comfort assessment showed that only library of engineering faculty and library of East Asian studies provide an acceptable thermal comfort environment to the occupants.
2. This result suggested that majority of the occupants were feeling uncomfortable in the university buildings.
3. A subsequent investigation to the HVAC & R systems revealed that the AHU has not been installed with a reheating coil in a number of the university buildings. This is probably due to the energy saving measure in the HVAC systems.
4. The respondents complained on the unpleasant odor inside the office in a number of the university buildings. A close examination to the system revealed that no outdoor air is used in the system; instead the return air and the air above the ceiling are mixed in the mixing box (plenum return system) where mixing air is recycled continuously.
5. Similar investigation can be extended to all the other air-conditioned buildings at all public and private universities in Malaysia. The final outcomes from these investigations inevitably will enhance the technical know-how of designing HVAC&R systems in tropical buildings.

ACKNOWLEDGEMENTS

The author would like to thank University of Malaya for the financial support provided for Research Project FS120/2008B.

REFERENCE

ASHRAE 1997. ASHRAE Handbook Fundamental SI Edition. Atlanta, GA 30329, USA. Pp. 26.1-26.53.

ANSI/ASHRAE Std. 2004. ANSI/ASHRAE Standard 55: Thermal environmental conditions for human occupancy, American Society of Heating, Refrigerating and Air Conditioning Engineers Inc, Atlanta, USA.

Benton, C.C., et al.1990. A field measurement system for the study of thermal comfort. ASHRAE Transactions, 96(1), pp. 623–33.

Brager, G.S, De Dear, R.J. 998. Thermal adaptation in the built environment: a literature review. Energy and Buildings, 27(1), pp. 83–96.

Busch, J.F. 1990. Thermal responses to the THAI office environment. ASHRAE Transactions, 96(1), pp. 859–72.

Cena, K, Dedear, R.J. 1999. Field study of occupant comfort and office thermal environments in a hot, arid climate. ASHRAE Transactions; 105(2), 204–17.

Chengel, Y. A. 2007. Heat and mass transfer, 3rd Ed., McGraw Hill.

Cheong et al. 2003. Thermal comfort study of an air-conditioned lecture theatre in the tropics. Building and Environment, 38, pp. 63-73.

Dedear, R.J. 1994. Fountain ME. Field experiments on occupant comfort and office thermal environments in a hot-humid climate. ASHRAE Transactions, 100(2), pp. 457–75.

Depaula Xavier AA, Roberto L. 2000. Indices of thermal comfort developed from field survey in Brazil. ASHRAE Transactions, 106(1), pp. 45–58.

Fishman DS, Pimbert SL. 1979. Survey of the subjective responses to the thermal environment in offices. In: Fanger PO, Valbjorn O, editors. Indoor climate. Copenhagen: Danish Building Research Institute, pp. 677–98.

Howell, W.C. and Kennedy, P.A. 1997. Field validation of the Fanger thermal comfort model. Human Factors 1979; 21(2):229–39.

Howell, W.C. and Stramler C.S. 1981. The contribution of psychological variables to the prediction of thermal comfort judgments in real world settings. ASHRAE Transactions, 87(1). pp. 609–21.

Humphreys, M. A., Nicol, J.F. 1998. Understanding the adaptive approach of thermal comfort. ASHRAE Transactions, Part 1B, 104, pp. 991–1004.

Ismail M. B., 2007. An approach to investigate and remedy thermal-comfort problems in buildings, Building and Environment, 42, pp. 2124-2131.

ME, 1996. Ministry of the Environment. Guidelines for Good Indoor Air Quality in Office Premises. Institute of Environmental Epidemiology, Ministry of the Environment, October 1996.

Quiston, M., Parker, F.C., Spitler, J.D. 2005. Heating, Ventilating, and Air Conditioning: Analysis and Design. 6th Ed. John Wiley & Sons, Inc.

Schiller, G.E., et al. 1988. A field study of thermal environment in office buildings. ASHRAE Transactions, 94(2), pp. 280–308.

Schiller. G.E. 1990. A comparison of measured and predicted comfort in office buildings. ASHRAE Transactions, 96(1), pp. 609–22.

Wang, Z. 2006. A field study of the thermal comfort in residential buildings in Harbin., Building and Environment, 41, pp. 1034-1039.

Xia, Y.Z., et al. 1999. Thermal comfort in naturally ventilated houses in Beijing. HV&AC, 29(2), pp.1–5.