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Thermal Comfort Study and Ventilation Evaluation of an Office

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Abstract- This paper presents our finding pertaining to thermal comfort parameters, air exchange rate, age of air values and air exchange effectiveness in main office of Mechanical and Manufacturing Engineering Department of University Putra (UPM) Malaysia. It was an air-conditioned office. The tracer gas decay method has been applied during the experimental procedures employed to determine air exchange rate, age of air and, air exchange effectiveness simultaneously, thermal comfort variables were measured. It was found that the office was slightly cool based on ISO 7730, but result of survey revealed that staff found condition to be slightly cool to cool. The results of ventilation study indicate air flow patterns in the occupied zones which approximate "perfect mixing" and the measured air exchange rate is also indicate that the provision of outside air for ventilation is adequate.

Keywords- Thermal comfort; Survey; Tracer decay technique; age of air; air exchange rate.

1. Introduction

In recent years, Malaysia's energy consumption has increased. Malaysia has one of the fastest growing building industries worldwide, where the corresponding energy demand would significantly increase in the next coming years. Primary concern should be given to making sure that the people inside are happy and comfortable to stay – they are not too hot or too cold .Through the knowledge of thermal comfort behavior of human and energy utilization behavior of buildings, the best strategy can be adopted [1]. Since Malaysia is in the tropical regions and has high daytime temperatures of 29°C to 34°C [2] and relative humidity of 70 to 90% throughout the year, Thermal condition in study office rooms has to be considered carefully mainly because of the high occupant density in these areas and because of the negative influences that an unsatisfactory thermal environment has on learning and performance. In tropical regions, the hot and humid climate may have an adverse impact on occupant comfort indoors [3]. Both thermal comfort and air quality can have important impacts on productivity.

The negative effect of poor indoor climate conditions on the performance of the occupant is described in several earlier investigations [4]. The significance of maintaining good indoor climate is self-evident when one considers that in every modern economy a significant part of the Gross National Product (GNP) is earned by people working in office buildings. In view of the importance of thermal comfort and indoor air quality, the design challenge is to achieve acceptable indoor environmental conditions for individual building occupant [5]. Evaluation of the ventilation parameters of the air distribution system, such as air exchange rates, age of air and air exchange effectiveness are critical in establishing how well the air distributed inside room, building. The main objectives of this study are as follows:

- To evaluate the thermal comfort level of office and compare with AHRAE 55 and ISO 7730[6, 7].
- To determine ventilation parameters and compare them with ASHRAE standard 62[8].
- To determine neutral temperature in office, and
- To investigate the staff's' perception of the degree of comfort and indoor air quality in office.

2. Methodology

To determine the thermal comfort requirements for office, experimental work and survey study were carried out in an office (Figure 1,2) at the fifth level of block A office building faculty of engineering in University Putra Malaysia (UPM).

Figure 1. View of main office

Four environmental variables were measured using a measuring physical quantities instrument (BABUCA): air velocity, relative humidity, dry bulb temperature and mean radiant temperature. Physical measurements were carried out at one point inside office. The samples were recorded every one minute interval. Having measured the environmental parameters, the two personal parameters, metabolic rate and clothing insulation were estimated in accordance with ISO 7730. In this study, the metabolic rate is set to be 1.2 met [7] which is sedentary activities (office, dwelling, school, laboratory) whereas the Clo-value (thermal resistance) is set to be 0.5 where the males were wearing underpants, shirt with short sleeves, light trousers, light socks and shoes. The females were wearing 'baju kurong' which is cotton or silk with light cotton undergarments and a lightweight scarf.

To determine air exchange rate, age of air and air exchange effectiveness the method employed involves the use of tracer gas decay techniques. This technique included an initial injection of CO2 tracer gas into the air space of study office. CO2 was allowed to mix for 15 min [9, 10] to establish a uniform concentration in the air space using one mixing fan placed in the space. The concentration decay of tracer gas measured using two IAQ meters. One IAQ meter located beside the BABUCA in the middle of office and another one placed at system exhaust.

Measurements of thermal comfort parameters and tracer gas decay conducted in the middle of December, 2006.

Figure 2. View of main office, BABUCA and IAQ meter

Assessment of thermal comfort in the office was based on responses to a questionnaire survey, which was administered simultaneously with the physical measurements in each condition. A total of 10 respondents participated in the survey; all of them were staff. The dominant gender distribution sampled was female (80%) The total response rate was 100%. Prior to the survey, the subjects would have been seated at their chairs for approximately 30 min [11], with mostly sedentary activities. Sufficient time for body precondition in each survey was necessary to maintain respondent's metabolic rate (M) at the same level throughout the study which was estimated to be equal to 1.2 met.

3. Results and Discussions

3.1 Evaluation of Thermal Comfort

From the thermal comfort parameters, PMV and PPD for office using InfoGap and Microsoft Excel was calculated. The range of predicted mean vote (PMV) -0.2-0 and percentage people dissatisfied (PPD) are ranged between 5-7% as shown in Figure 3. Based on ISO 7730, the comfort range was taken to be the conditions when the PMV has the values between –1 and +1. This result shows that office is thermally comfortable in this time with an average temperature of 23.6ºC and relative humidity of 50%.

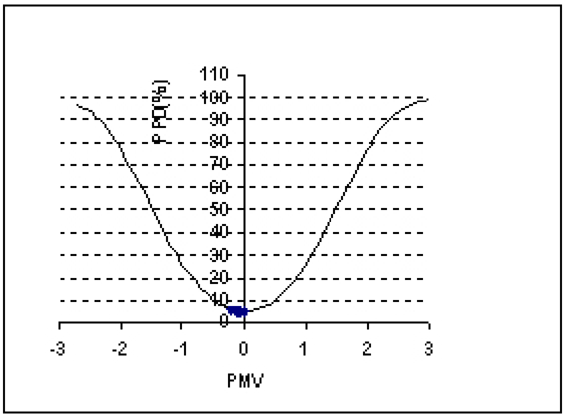

Figure 3. Air-Conditioned Office- Predicted Percentage of Dissatisfied (PPD) as a Function of Predicted Mean Vote (PMV). (ISO 7730)

The ASHRAE Standard 55-1992 states that the comfort zone for summer conditions, air temperature to be between 23ºC to 26ºC and relative humidity between 20% to 60 %. Figure 4 shows that the office is within the comfort range during working hours. It can be observed that the state of temperature for office is in line with the thermal comfort of 26°C from the guideline given by Malaysian Energy Efficient Guideline, thus thermal comfort achieved during office hours according to Malaysian Energy Efficient Guideline. The Department of Standards Malaysia [12] recommended indoor design temperature range from 23ºC to 26ºC.

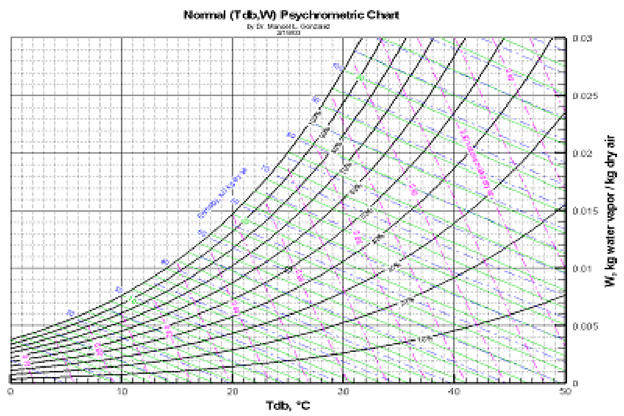

Figure 4. Thermal Comfort Range Based on Psychometric Chart – ASHRAE 55

Surveys of human thermal response in South East Asia produce the following equation (Auliciems' equation) for estimating thermal neutrality in base on the mean monthly dry bulb temperature Tm[13] :

$$T\,n = 17.6 + 0.31\ T\,m$$

It applies to both naturally ventilated and air-conditioned buildings.

Regarding this equation the thermal neutrality for office was, 25.4°C. The neutrality temperatures (24.6, 26.1ºC and 27.4ºC) for Malaysia [14] and [15] found earlier correspond well to 27.4ºC ET* obtained in Thailand and 28.5ºC in Singapore [16].

The proposed neutral temperatures are higher than 24.5ºC recommended by ASHRAE Standard 55. Result of this study like previous studies in Malaysia and south east of Asia suggest a wider thermal comfort range for Malaysian than that proposed by international standards, i.e., ASHRAE Standard 55, which indicates that Malaysian are acclimatized to much higher environmental temperatures.

3.2 Evaluation of Air Exchange Rate (ACH)

Figure 5 shows the natural Logarithm of concentration decay profile of office, from which the outside air exchange rate (ACH) is determined.

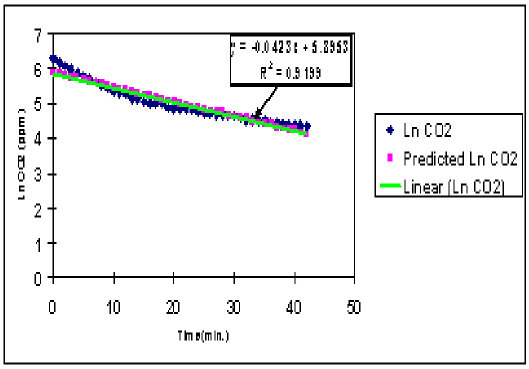

Figure 5. Variation of Local Tracer Gas Concentration vs. Time for Naturally Ventilated Study Office

Measurement was carried out when the outside air velocity was 0.28 m/s, so air infiltration could be neglected as the external wind pressure was low. The air exchange rate and the fresh air quantity are computed and tabulated in Table 1. It is seen from Table 1 that the air exchange rate is 2.4 and the amount of fresh air provision is 15.6 l/s/person on the basis of design occupant density (10 m^2/person) and 36.3 l/s/person on the basis of actual occupancy.

It is to be noted that these provisions in design occupancy is adequate based on current ASHRAE requirements of 10 l/s/person and, it is also interesting to note that based on actual occupancy, outside air provision in comparison to design occupancy is higher and also is in accordance to ASHRAE requirement.

Table 1. Measurements of Air Exchange per hour (ACH) and Outside Air Quantity for Main Office

Middle of study office						
Office	ACH (h^{-1})	Fresh air (l/s)[a] D=0.9ACH/3.6	Design occupancy: No. of persons (Occ) $E=B^b/10$	Design occupancy: l/s/Occ F=D/E	Actual occupancy: No. of persons (Occ) E'	Actual occupancy: l/s/Occ F=D/E'
Main office	2.4	109	7	15.6	3	36.3

a Based on an effective space volume of 90% (total volume less furnitures in the office).

b $B = \frac{A}{H} = 70$

Where: A is the volume of room and H is the height of office. The volume of room is A=182 m^3 and its surface area is B=70 m^2.

3.3 Evaluation of Age of Air and Air Exchange Effectiveness (AEE)

The AEE parameters are obtained from the fundamental data of age of air measurements recorded by the IAQ meter, which are presented in Table 2.

Table 2. Air Exchange Effectiveness parameters

Middle of Main Office Room			
Study Office	Exhaust, τ_E (s) A	Local, τ_L (s) B	Local ε_L A/B
Mechanically Ventilated	1462	1440	1.01

The local age of air for main office was 1440 s or 24 minute. It means that the length of the time for fresh air to remain in the office is about 24 min**.**

When there is a uniform distribution of air over the office air-space, ε_L=1. However, when there is a non-uniform distribution of air over the office air-space or in another word, some stagnant zones within office air-space, values of ε_L are significantly less than 1. A value less than 1.0 shows less than perfect mixing with some degree of stagnation. A value of ε_L>1 suggests that a degree of plug or displacement flow is present [17]. The local air change effectiveness at location for office was found to be 1.01, and this implies that there is no short-circuiting of ventilation air on a global scale. The local air change effectiveness indicated a reasonably perfect mixed air in office.

3.4 Evaluation of questionnaire

Figure 6 shows the profile of Thermal Vote cast on the ASHRAE scale for air-conditioned office. From the relative frequency of votes in each category can be seen that the thermal centered on -1 to-2.

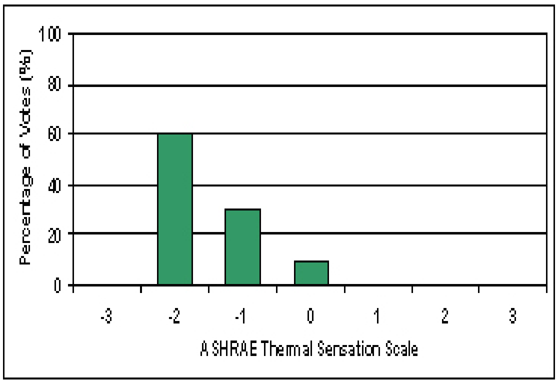

Figure 6. Relative Frequency of ASHRAE Thermal Votes

Figure 7 gives a comparison of the various methods of assessing acceptability. By equating the central three categories of the ASHRAE 55 scale with the notion of acceptability, 40% of the staff is assumed to be satisfied with the thermal condition in their office. The direct vote of acceptability is 60%. In contrast, the thermal preference scale appears to be only 20% of the respondents. Different results can obtain from different method of measurements and it is similar to other studies [3 and 18].

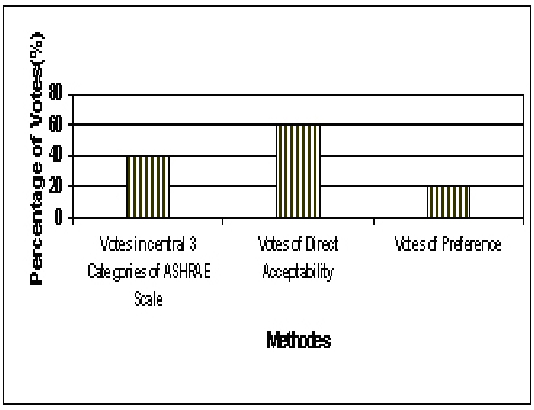

Figure 7. Comparisons of Various Methods of Assessing Thermal Acceptability

As a sample graph, Figure 8 shows the opinions of staff on the air quality in main office. Staffs were satisfied with the air quality, so air quality in the office room was within tolerable limits for staff. ASHRAE Standard 62 defines acceptable air quality as conditions in which more than 80% of people do not express dissatisfaction, the information obtained from the measurement and questionnaire show that main office has good air quality.

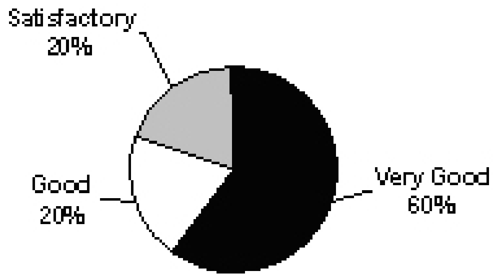

Figure 8. Distribution of Air Quality

4. Conclusions

- Objective measurement of the office showed that office had thermal conditions falling within the comfort zone of ASHRAE standard 55 and ISO 7730.

- It is seen that the outside air change rate (ACH) value are sufficient based on design and actual occupancy in office. Experimental measurement and survey showed that office has good indoor air quality.

- In the case of air exchange effectiveness, it is observed that the air exchange effectiveness value in office was close to one implying no serious problems of short circuiting of ventilation air in this office and that the ventilation air is well mixed.

- The neutrality temperature is higher than the ASHRAE Standard 55. Results suggest a wider thermal comfort range for Malaysian than that proposed by international standards. Therefore adopting the international Standards for interior comfort conditions for the Malaysian hot and humid tropical climate may lead to overcooling and energy waste.

- It is found that different results can obtain from different method of measurements of assessing acceptability. A comparison of votes on the ASHRAE scale with those on the direct cleared that there are people who vote beyond the center three category and yet find their environment acceptable. In this study revealed that based on Standards office was comfortable, but most of occupants found thermal condition in their environment uncomfortable (cool).

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