Indoor thermal comfort assessment in office buildings in hot-humid climate

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Abstract. This paper aims to assess the user’s perception of thermal comfort and air conditioning in office buildings in Batu Pahat, Johor area. Field experiments were conducted utilizing environmental measurement and Post Occupancy Evaluation (POE) in Batu Pahat District Land Office (Pejabat Daerah) and (C2 and ORICC) office buildings in the Universiti Tun Hussien Onn Malaysia (UTHM). The environmental measurement was conducted using thermal comfort station BABUC A, whereas the POE was based on the ASHRAE 55-2010 standard. The environmental parameters included relative humidity, air temperature, and air velocity. They were measured and compared with MS-1525, ASHRAE 55, and ISO 7730 standards. Results indicated that indoor air temperature in C2 has good compliance with MS-1525, ASHRAE 55, and ISO 7730 standards and criteria with a measured comfort range of 24 °C-26 °C. Whereas for ORICC and Pejabat Daerah, temperatures were a bit lower than the suggested range. At the same time, the range of relative humidity was found to be higher than ASHRAE limits but complied with other standards. Moreover, adequate air velocity standards were not met in the three office buildings, in which they were measured within 0.4-0.5 m/s range. Furthermore, thermal comfort levels and the POE survey results indicated that users in hot tropical office buildings could acclimate to a higher indoor environment than what was suggested by standards.

1. Introduction
Malaysia's geographical location near the equator is characterized by extensive solar radiation and high daily air temperatures [1], which could lead to discomfort, diseases, and unsatisfactory climate conditions that affect human beings, living, work quality, and productivity. Due to this, most office buildings depend on air conditioning and mechanical ventilation systems to maintain a thermally comfortable indoor condition. According to Energy Commission data, energy use in commercial and residential sectors accounted for 54% of Malaysia's national electricity consumption in 2012 [2]. Gratia et al. [3] investigated 68 office buildings in Malaysia to determine factors influencing buildings' energy consumption. It was found that air conditioning system consumed around 57% of total energy, which is then followed by lighting at 19%. Therefore, reducing energy consumption in Malaysia is of paramount importance, as the country takes a step toward becoming a developed country in 2020.
Therefore, the best approach to achieve lower energy office buildings could be accomplished by understanding the behaviors of occupants' thermal comfort and their use of energy in buildings.

In 2009, Saidur [4] identified factors that contributed to increasing office building's electricity such as the weather characteristics, building design, office equipment, and indoor environmental conditions are referred as Indoors Environmental Quality (IEQ). Indoors IEQ is a concept used by building scientists to apply the best indoor conditions to a building based on several parameters such as indoor air quality, visual quality, acoustic quality, and thermal comfort. The well-suited levels of these parameters define the ideal office environment. In this study, the thermal comfort parameter is the main parameter that strongly impacts building occupants and their perceptions of the overall indoor environment. Through field measurements, POE survey, and models of comfort condition parameters, the study aims to assess indoor thermal comfort in office buildings and determine the user's level of perception and satisfaction with their office buildings.

2. Indoor thermal comfort

According to the American Society of Heating, Refrigeration Air-Conditioning Engineers (ASHRAE), and the International Organization for Standardization (ISO), thermal comfort could be defined as “that condition of mind, which expresses satisfaction with the thermal environment” [5-6]. These standards stated temperature ranges, which constitute discomfort condition levels for at least 80% of building users. Furthermore, seven factors significantly impact environmental satisfaction: air velocity, radiant temperature, dry bulb temperature, metabolic rate, water vapor pressure, and Heating, Ventilating, and Air-Conditioning (HVAC) system [7]. In addition to comfort condition parameters, Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied people (PPD).

Overall, many studies highlighted the significance of thermal comfort for office buildings. Lower comfort conditions could result in adverse effects on the occupants’ behavior, health, productivity, and production quality. However, too warm office space makes occupants feel exhausted, while too cold temperatures causes drift to occupants and distract them. According to Nicol et al. [8], there are two reasons to study and examine indoor thermal comfort in a building. Firstly, to offer a satisfactory condition for building users and secondly to regulate energy consumption.

An extensive literature review was conducted to investigate thermal conditions in office buildings in Malaysia. Some studies were conducted before the 1990s suggested that acceptable indoor air temperature for an air-conditioned office building ranges between 23-26 °C, which is similar to the value suggested by ASHRAE-1992 and ISO 7730-1994. Later, with the rise of energy consumption in non– residential sectors, several studies were conducted to investigate optimal indoor environment comfort parameters.

Abdul Shukor and Young [9] studied the indoor environment to define the comfort condition between college students in Shah Alam. The measurement showed that comfort ranges were achieved when air temperatures were between 25.0 °C and 31.4°C with 50% relative humidity. Moreover, Ahmad [10] studied thermal comfort to determine low energy in an office building; the study reported comfort ranges of 24.5°C- 28.0°C with 73% relative humidity. A similar study found that in an office building, the office is thermally comfortable with an average indoor air temperature of 23.6°C and relative humidity of 50% [11].

In Malaysia, workers' satisfaction in a Low Energy Office Building was investigated by Shaharon and Jalaludin [12], results illustrated that indoor thermal conditions were within the acceptable range as recommended by ISO7730. Also, they were lower in terms of air temperature, according to MS 1525 standards. Further, Damiati et al. [13] estimated the comfort range of temperature for air-conditioned office buildings; his study found that comfort at 25.60°C was acceptable in Malaysia, which is similar to Azizpour et al. [14] result, which was conducted in the office area of a medical center in Malaysia. These studies found that Malaysians could acclimate to a higher thermal comfort range, which could help save up to 15.80% of energy if the indoor setting temperature was increased to 1.5 °C.

In contrast, air velocity plays a significant role in achieving thermal satisfaction ranges in the workplace [15]. Although previous studies investigated a tropical climate acceptable thermal comfort range in office buildings in terms of temperature and humidity levels, there is a lack of studies that
take air velocity measurement into consideration. Therefore, in this study, we follow similar techniques used by previous researchers such as field measurement, POE survey to evaluate the office building's indoor environment. In addition to estimating PPD and PMV models to acquire comfort range perception.

3. Method and materials

3.1. Field measurements

Field measurements were conducted in an office building at Batu Pahat city, located in the Johor state's hot-humid climate region. Maximum air temperature varies between 29.5°C to 23.7°C [16], with a relative humidity of around 80%. In addition to 2308 mm of precipitation falls annually.

The measurement was carried out in a single and multi-storey office building as illustrated in figure 1. Case studies 1 and 2 investigated a single-story office building in Universiti Tun Hussien Onn Malaysia (UTHM). Case 1 and Case 2 measurements were conducted in the postgraduate students' office located in block C2 and the Office for Research Innovation and Commercialization Consultancy Management (ORICC), respectively. Furthermore, the third case study is a three-story office building used by the Batu Pahat district land office (Pejabat Daerah). Measurements were conducted on the first floor. The three case studies' selection was based on design similarity, shading devices, facade finishing materials, and structure materials.

![Figure 1. Elevation of the case study buildings.](image)

3.2. Measured parameters and instrument

Thermal comfort meter station BABUC-A from LASTEM is a portable instrument designed to offer measurements for various parameters relating to the indoor environment's quality. It was used to measure indoor air temperature, air velocity, relative humidity, and mean radiant temperature, in which air conditioning was on during the measurement period. Indoor environmental measurements were carried out in June 2015 over three days during office operation time from 9:00 am to 5.00 pm [17]. Recorded samples were taken at the center of the office space [18]. It was assumed that the overall air temperature is moderated; 'figure 2' illustrates the measured zones' layout with the station's location. Physical measurements were taken at 1.10 m height to represent the height of the human body at seated level [19]. Samples were recorded every 10 minutes for 8 hours [20].

After that, BABUC-A recorded data were processed using LSI software. In this step, the thermal comfort parameters such as cloth insulation and metabolic rate were estimated according to ISO 7730 and ASHRAE-55 standards [21]. Besides, CLO-values were set at 0.75, while the metabolic rate was set at 1.2 met, which assumes sedentary office users' activity.

3.3. Post Occupants Evaluation

Another instrument utilized was Post Occupants Evaluation (POE) questionnaire [17]. It was designed according to ASHRAE standards. The participants were asked to rate their perception using a rating scale (very satisfied to very dissatisfied) towards the type of activity, cloth information, and perception of indoor environmental parameters. The number of workers in each building was estimated before distributed the survey. Respondents consisted of 43 participants, of which 21 participated in the Pejabat Daerah building, and 12 and 10 participate in C2 and ORICC, respectively. Collected
information through a questionnaire was analyzed using SPSS software (Statistical Package for the Social Science). Then, the results were transformed into MS office and Excel spreadsheets to prepare the graphs.

4. Results and discussion

4.1. Field measurement

Indoor environmental parameters required to estimate the thermal comfort range for the mechanical ventilation system (air conditioning on) were measured and compared with the recommended acceptable range suggested by ISO 7730, ASHRAE, and MS-1525 [5-6,22] standards. These parameters consisted of air temperature, air velocity, relative humidity, and mean radiant temperature. Based on table 1, the average air temperature for C2 was within acceptable comfort range according to standards, ranging between 24 °C and 26 °C, whereas in ORICC and Pejabat Daerah cases, the temperature was a bit lower than the suggested range. Moreover, the measured average relative humidity of three-office spaces fell within the comfort range for ISO 7730 and MS1525. However, three office zones had higher humidity percentages according to ASHRAE standards. Moreover, according to Olesen & Brager [23], office building's humidity has less or no effect on the range of thermal comfort. Therefore, measured percentages will not affect the office's overall thermal comfort range. At last, air velocity at 1.1 m height had an average of 0.10 m/s for C2 and Pejabat Daerah, whereas, for ORICC, it was 0.00 m/s. Thus, it was lower than the recommended speed. This is possibly due to the low number of air changes during the measured period. A study by Szokolay [24] stated that air movement of 1.0 m/s to 1.5 m/s is the best range to gain comfort in a hot, humid climate. Low air velocity could cause a source of discomfort for office users in a tropical climate. Further, Wahab et al. [25] stated that the building's indoor thermal level could not be achieved without suitable indoor air temperature and natural air velocity.
Table 1. Comparison of the environmental parameters with standards.

| Parameters              | C2     | ORICC  | Pejabat Daerah | MS-1525 | ASHRAE | ISO 7730 |
|-------------------------|--------|--------|----------------|---------|--------|----------|
| Air temperature (°C)    | 24.50  | 22.3   | 22.2           | 24-26   | 23-26  | 23-26    |
| Relative humidity (%)   | 63.80  | 56.40  | 61.20          | 50-70   | 50     | 30-70    |
| Air velocity (m/s)      | 0.10   | 0.00   | 0.10           | 0.15-0.50 | < 0.15 | < 0.40   |

4.2. Thermal comfort level

PMV and PPD estimation of mechanically ventilated office spaces located in the Batu Pahat state was conducted using measured thermal comfort parameters and the InfoGap software. The calculation ranges of C2, ORICC, and Pejabat Daerah were compared with ISO 7730 and ASHRAE standards, as seen in table 2. The range of PMV according to ISO 7730 and ASHARE standards was between -1 and +1 and -0.7 and + 0.70 (+ slightly cold to + slightly warm), respectively. Besides, the average PMV for C2, ORICC, and Pejabat Daerah was + 0.68, + 0.13, and + 0.74, which indicates that three-office space indoor thermal sensation perception is neutral, which corresponds to an average of 16%, 5.5%, and 16.7% PPD, respectively. Based on the indoor parameters' measurement shown in table 1, ORICC space has a lower PPD at 22 °C air temperature and humidity of 56%. Also, no air movement existed within higher PPD of C2 and Pejabat Daerah. Albeit, the comfort range of ORICC did not fall within the comfort range in terms of temperature and air velocity. However, PPD ranges could indicate the office users' satisfaction with the indoor thermal condition during the field measurement.

Table 2. Comparison of the PMV and PPD value with standards.

| Parameters | C2     | ORICC  | Pejabat Daerah | ASHRAE  | ISO 7730 |
|------------|--------|--------|----------------|---------|----------|
| SET range (°C) | 24.50  | 22.3   | 22.2           | 23      | 23       |
| PMV        | 0.68   | 0.13   | 0.74           | ≥ + 0.70| ≥ +1     |
| PPD %      | 16.12  | 5.51   | 16.72          | ≥ 10%   | ≥ 10%    |

4.3. User’s perception of indoor thermal condition

Figures 3 and 4 illustrate the results of the user’s perception towards air temperature, relative humidity, air movement, and overall satisfaction towards the indoor condition in their office space. As presented in ‘figure 2’, more than 81.7 and 76% of the occupants in C2 and Pejabat Daerah were satisfied with air temperature, whereas, in the ORICC building, more than half of occupants voted for a neutral scale. The result of indoor air temperature in table 1 stated that ORICC and C2 corresponded with the result of the evaluation. In contrast, Pejabat Daerah occupants were satisfied with the temperature even when the temperature was a bit lower than the recommended temperature for an air-conditioned office building. Figure 2 shows that 62% and 42% of the users in Pejabat Daerah and C2 were satisfied with humidity, while, in the ORICC's office space, 67% of the users were dissatisfied. Given that the relative humidity from the indoor measurement for C2, ORICC, and Pejabat Daerah was 63%, 56%, and 61%, respectively, it is found that indoor measurement results have a strong correlation with the results of POE.

Figure 3 highlights users' perception of the indoor air velocity and the three office spaces' overall indoor thermal condition. As shown in 'figure 3' the absence of the air movement in ORICC space makes almost 45% of the occupants rated dissatisfied in the Thermal Vote scale. 58% of Pejabat Daerah and C2 users were satisfied and neutral with the airspeed in their workspace. In terms of users' indoor thermal condition perception, C2 and Pejabat Daerah are satisfied with 48% and 41.7%, respectively, while 63% of the users in ORICC rated neutral. Based on PPD calculation analysis shown in table 2 and occupant's thermal sensation perception vote in (figure 3 and 4), it indicates that
occupants who vote for the satisfy scale in Pejabat Daerah still find their workspace comfortable even when thermal sensation state the opposite. While in C2 and ORICC the PPD, most occupants in ORICC and C2 voted for dissatisfaction and neutral, respectively.

![Graph A](image1.png) ![Graph B](image2.png)

**Figure 3.** (A) Users’ perception towards indoor air temperature, (B) Users’ perception towards indoor relative humidity.

![Graph A](image3.png) ![Graph B](image4.png)

**Figure 4.** (A) Users’ perception of indoor air velocity, (B) Users’ perception of the indoor condition.

5. Conclusion

This study carries out to assess the indoor thermal comfort in an air-conditioned office building in Malaysia. It investigated the relationship between thermal comfort range and user's indoor thermal conditions perception in mechanically ventilated office spaces. Results featured a wired range of indoor thermal comfort indicators beyond the room’s temperature, with several indoor parameters such as humidity, air velocity, CLO-values, and the metabolic rate. The combination of these parameters is recommended to better identify PMV and PPD for the office space's indoor comfort range. Based on the results, there is a positive relationship between indoor measurements and the POE questionnaire in C2 and Pejabat Daerah workspaces. However, the opposite was found regarding the third case (ORICC workspace). The calculation of PMV of C2, ORICC, and Pejabat Daerah from measured indoor parameters was ISO 7730 and ASHRAE compliant. Besides, in terms of PPD, only ORICC office had a 10% lower acceptable percentage compared to other office spaces that did not comply with the standards.

A report by the Department of Occupational Safety and Health in Malaysia stated that most people feel comfortable in their office at air temperature 20-28 °C and 40-60% for humidity. For the air movement, for individuals, 10 l/s of fresh air is recommended. However, it was noted that the ISO 7730 and ASHRAE recommended different indoor comfort ranges. Therefore, adoption of the range...
suggested by international standards to assess the indoor thermal comfort could affect the results of PMV and PPD for office buildings in a tropical climate as shown in C2, ORICC, and Pejabat Daerah. In a nutshell, based on indoor measurement results of air velocity, adjusting the ventilation in C2, ORICC, and Pejabat Daerah by adopting natural ventilation to avoid the health effect caused by low air movement when the humidity is low or high is recommended.

6. References

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