Thermal comfort in green Malaysian office: objective versus subjective evaluation

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Abstract. An office building in Malaysia with a green certification was examined in terms of objective and subjective evaluations of thermal comfort. In this study, thermal comfort data was collected objectively using specific instruments per the ASHRAE 55 standard, and the Predicted Mean Vote (PMV) values were computed. In addition, validated questionnaires were used to assess subjective perceptions of thermal comfort. It was found that, although the PMV model suggested a slightly cool atmosphere occupants experienced a cooler sensation than expected. The divergence highlights the inadequacies of measuring thermal comfort solely based on objective measures and stresses the necessity of incorporating occupant feedback into the assessment process. By focusing on environmental sustainability and occupant well-being, this research provides valuable insight for the management and development of future green office buildings.

1 Introduction

The emergence of green office buildings presents a strong way to address the growing demand for climate change mitigation and sustainable development. By using eco-friendly materials, reducing energy use, and conserving water, these structures are specifically designed and operated to minimize their impact on the environment. Beyond their environmental benefits, green office buildings offer many advantages to occupants and enterprises. Green buildings foster a more salubrious and efficient work environment. A number of studies [1-3] have consistently shown that components such as adequate natural light, improved indoor air quality, and the use of biophilic design elements which incorporate nature into the built environment, can significantly improve workers' well-being. Apart from the apparent health benefits, Green office building been found to have a noteworthy effect on employee productivity and satisfaction [4]. These elements consequently result in higher worker morale, decreased attrition, and improved job satisfaction all around. This is proven

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by research conducted by Ref.[5], demonstrated that workers in green buildings had a 2% increase in productivity and an enhancement of 15% in well-being.

Thermal comfort is critical to office workers' well-being and productivity. It refers to the state of being comfortable with one's surroundings, which is impacted by physiological, psychological, and environmental factors. Managing proper thermal comfort in the workplace is critical for both health and productivity. Thermal extremes can cause discomfort, anguish, and major health problems, whilst thermal discomfort can diminish focus, cognitive capacities, and irritability, all of which have a detrimental impact on work performance. In recent years, research on thermal comfort in green office buildings has increased significantly. Much of this research has focused on objective metrics like the Predicted Mean Vote (PMV) model, developed by Fanger in the 1970s [6], which predicts the average thermal perception of a group based on factors like temperature, humidity, air movement, and clothing insulation. However, the PMV model has serious drawbacks. Recent research has shown that it lacks to reflect the dynamic nature of thermal comfort, ignoring fluctuations caused by physical activity, clothing, and environmental changes [7]. Ref [8] discovered that its reliance on static inputs causes it to frequently anticipate thermal comfort incorrectly in real-world circumstances. Similarly, Ref [9] proved that its predictions are inaccurate since they do not account for individual and situational characteristics, emphasizing the need for more adaptable, context-sensitive techniques.

Scholars are now adopting subjective methods such as questionnaires and surveys to determine occupants' true perceptions of their thermal condition. This study combines objective PMV assessments with subjective feedback to provide a more sophisticated knowledge of thermal comfort. By comparing various methodologies, the study intends to detect inconsistencies between predicted and observed comfort, uncover underlying causes, and develop a thorough knowledge of thermal comfort in green office buildings. These conclusions will inform the design and operation of future green office buildings, assuring both sustainability and occupant comfort.

2 Methodology

The research was carried out at Kelana Jaya, Petaling Jaya, Selangor, at the three-story green office building Wisma REHDA for evaluating interior objective parameters and administer a survey, a first-floor office was chosen. During work hours, all four air conditioning units regulate the temperature at 24°C. The measuring point and the interior of the office are represented in Figure 1.

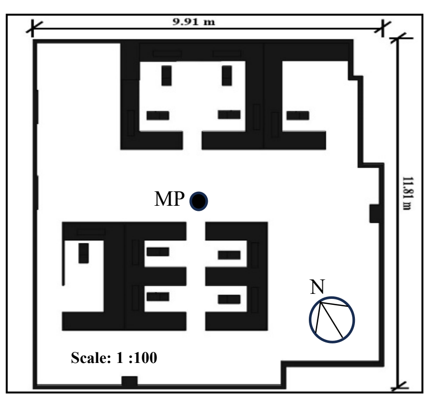

Fig. 1. The location of the measurement point, the office layout, and the green building.

2.1 Objective measurement

For three months, from February 13 to April 14, 2023, measurements were taken in the office space. Appropriate locations were meticulously chosen before data collection. The measurements were obtained with accurate equipment at a sitting height of 1.1 meters from the ground, according to the procedures described in ISO 16000-1, temperature (Ta), air velocity (m/s), and relative humidity (RH) were measured. Moreover, Equation (1) from the ASHRAE 55 standard was utilized to calculate the operating temperature (Top), an index that takes into consideration air temperature, mean radiant temperature, and air velocity and it is frequently employed in thermal comfort studies.

$$T_{op}=AT_a + (1-A)\ T_{mrt} \qquad (1)$$

In this case, T_a represents the air temperature (°C), and T_{mrt} for mean radiant temperature (°C). The constant A has no dimension is a dimensionless constant. Additionally, the mean radiant temperature, T_{mrt} was computed using Equation (2).

$$T_{mrt} = T_1A_1 + T_2A_2 + \ldots + T_nA_n\ /\ (A_1 + A_2 + \ldots + A_n) \qquad (2)$$

Whereas A denotes the surface area of the room, T stands for the surface temperature. The time frame for gathering the data was 9:30 AM to 6 PM. The planned positioning of the measurement location is clearly shown in Figure 2, it makes it possible to fully understand the actual thermal comfort conditions experienced while working. To achieve precise measurements, the experiment utilized the usage of an anemometer, thermocouple thermometer, and thermo-hygrometer. Figure 2 illustrates the instruments.

Fig. 2. Schematic diagram for research methodology.

2.2 Objective measurement

Along with objective measurement of environmental parameters, a subjective questionnaire survey was employed in the present study. Office employees received online surveys, which were administered continually until April 14th, the end of the measuring time frame. According to the ASHRAE 55 Standard [10] a seven-point scale with values ranging from -3 (cold) to +3 (hot) was used to assess the items of the questionnaire. The information gathered from the questionnaire is compiled in Table 2. The ASHRAE 55 Standard scale values are: -3 (cold), -2 (cool), -1 (slightly cool), 0 (neutral), +1 (slightly warm), +2 (warm), +3 (hot). Table 1 provides a summary of the data obtained from the questionnaire.

Table 1. Questionnaire items

Section	Inquiry
Profile Details	Gender, age, job title, nearness to a window
Thermal sensation vote	How do you currently perceive your thermal environment?

2.3 Evaluation of thermal comfort index

Following the ASHRAE 55 Standard, the assessment utilised the capabilities of the Centre for Built Environment (CBE) thermal comfort tool [10]. Six input elements were taken into consideration, including air temperature, air velocity, mean radiant temperature, relative humidity, metabolic rate, and clothing insulation. PMV and Predicted Percentage of Dissatisfied (PPD) indices were used for this. In the study, every component was carefully considered. Depending primarily on sedentary activities like sitting and typing, a metabolic rate of 1.1 met was assigned to each participant [11, 12]. The values for clothing insulation were chosen from related studies [11, 13, 14], with a value of 0.61 clo. Considering these factors, the Predicted Percentage of Dissatisfied (PPD) value should not rise above 10% as the appropriate criteria for thermal comfort. In contrast, the PMV score needs to be within the range of -0.5, which denotes a slightly cooled sensation, and +0.5, which denotes a slightly warm feeling.

3 Results and discussions

3.1 Evaluation of PMV-PPD and thermal sensation votes

The study used precise equipment to collect data on velocity, air temperature, and humidity, clothing insulation and metabolic rate values were acquired from reputable studies that focused on similar environments and occupant characteristics. The operating and mean radiant temperature computed utilizing conventional formulae and entered into the online CBE thermal comfort tool [15], that determines PMV/PPD model. The CBE tool found PMV readings with value of -1.160 for the office, classifying the atmosphere as "slightly cool" on the scale of PMV illustrated in Table 2. On the other hand, a substantial level of dissatisfaction with the heat conditions was indicated by the obtained PPD value of 33%. The occupants' actual thermal comfort varied from what the PMV model predicted, which was a significantly colder atmosphere. In the office, the average thermal sensation votes (TSVs) were -1.400, as Figure 3 demonstrates, suggesting that the TSVs were higher than what the PMV model predicted. There are numerous reasons for this disparity:

- Insulating clothing, activity level, and metabolic rate are some of the variables that affect an individual's personal thermal comfort. Even in identical environmental settings, these parameters might fluctuate greatly between people [16, 17]. As a result, different people may experience varying temperatures. Office spaces can develop microclimates that are not recorded by average temperature readings due to localized air movements, such as drafts from air conditioners. The degree of thermal comfort can be greatly affected by these microclimates. It has been observed by studies [18, 19] that tiny changes in air velocity can have an impact on thermal perceptions.
- Additionally, occupants can modify their activity levels, and clothing, or use personal fans to conform to their temperature surroundings. The predicted and real thermal sensations may differ as a result of these adaptive behaviours [20].Thermal comfort can also be influenced by psychological variables, such as an individual's expectations and sense of control over their surroundings [21].
- The situation is made more difficult by humidity levels, which can make the air feel drier and colder while making occupants feel warmer [22].

The results of this investigation highlight the necessity of combining subjective evaluations, like TSV, with objective thermal comfort models, like PMV. Although the PMV model offers insightful information on average thermal comfort, it is unable to fully account for the range of individual experiences. This has significant effects on how office spaces are managed and designed. When designing settings that meet the various needs of inhabitants for thermal comfort, designers and facility managers should consider both subjective feedback and objective measurements.

The study's conclusions are very applicable outside of office settings, providing insightful information for a range of building types and climates. By modifying these approaches, residential structures can be designed with energy efficiency in consideration, guaranteeing tenant comfort in a variety of climates. Thermally comfortable study spaces and classrooms improve student focus and performance in educational settings. Better thermal conditions can have a favorable impact on staff happiness and patient recovery in healthcare institutions. Improved thermal comfort techniques can also improve employee productivity and the consumer experience in commercial and retail settings. Moreover, the knowledge gained from the study on psychological variables, adaptive behaviors, and localised air movements is essential for creating comfort standards that are appropriate for different climates, especially in cold and tropical areas.

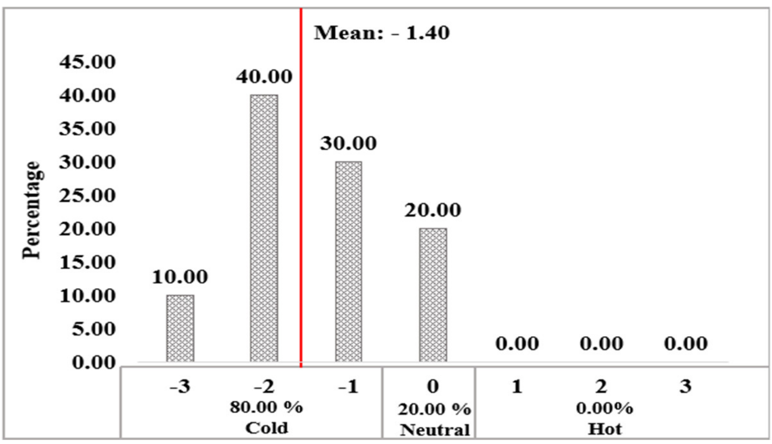

Fig. 3. Thermal sensation vote feedback.

Table 2. Assessment of environmental variables and PMV-PPD metrics.

Location	Variables	Values
Office space	T_a (°C)	22.810
	T_{mrt} (°C)	27.170
	RH (%)	69.960
	Air velocity (m/s)	1.030
	T_{op} (°C)	24.110
	PMV	-1.160
	PPD	33%
	Sensation	Slightly Cool

4 Conclusion

This study highlights the importance of including both objective measurements and subjective feedback when evaluating thermal comfort in green office buildings. The discrepancy observed between the predicted PMV values and the actual thermal sensations reported by occupants emphasizes the limitations of relying solely on objective models. Through the incorporation of subjective assessments, it is possible to acquire valuable insights into the complex and personalized aspects of thermal comfort perceptions. These perceptions can be affected by various factors, including personal preferences, adaptive behaviors, and localized microclimates. These findings have important implications for the design and operation of future green office buildings. It highlights the importance of taking a comprehensive approach that considers both quantitative and qualitative data in order to create work environments that are truly comfortable, productive, and sustainable. Additional research is necessary to further investigate the specific factors that contribute to the differences between objective and subjective assessments. One possible avenue of exploration is examining how various factors, such as age, gender, and cultural background, impact people's perceptions of thermal comfort. In addition, studying the effects of adaptive behaviors, such as modifying clothing or using personal comfort devices, could offer valuable insights for customizing thermal environments to meet individual requirements. In addition, a thorough examination of specific microclimates within the office environment may uncover discrepancies in thermal conditions that the PMV model fails to account for. By addressing these research gaps, it is possible to refine thermal comfort models and develop more effective strategies for optimizing building design and operation. Thus, it can enhance occupant well-being and satisfaction in green office buildings.

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