International Journal of Mechanical and Sustainability Engineering Technology

Journal homepage:
https://uniexpertsacademy.com/index.php/IJMSET/index
ISSN: 3083-8363

Thermal Comfort Assessment of High Air Conditioning Setting Temperatures in Small Office Room with Fan-Assisted Ventilation

Ahmad Izhar Ishak[1], Azian Hariri[1,*]

[1] Faculty of Mechanical Engineering & Manufacturing, University Tun Hussein Onn Malaysia, 86400, Batu Pahat, Johor

ARTICLE INFO

Article history:
Received 09 August 2024
Received in revised form 17 November 2024
Accepted 17 November 2024
Available online 22 November 2024

Keywords:
Thermal comfort, PMV/PPD value, Fan-assisted ventilation, Small office spaces

ABSTRACT

Thermal comfort is essential for occupant productivity, satisfaction, and health in an interior area. Achieving appropriate thermal comfort in office environments is crucial because it has a direct impact on occupant activities. This study investigates thermal comfort in small office spaces using fan-assisted ventilation at an elevated air conditioning setpoint of 27°C. Conducted at UTHM with three male occupants, measurements were taken at a single point in the room to assess air temperature, relative humidity, air velocity, and mean radiant temperature. The study examines three ventilation scenarios: Situation 1 (air conditioner only), Situation 2 (air conditioner with portable fan), and Situation 3 (portable fan only). Results show Predicted Mean Vote (PMV) values of +0.67, -0.16, and +1.43 for Situations 1, 2, and 3 respectively, alongside Thermal Sensation Vote (TSV) ratings of 0, -1, and +0.33. These findings suggest that fan-assisted ventilation at 27°C can effectively maintain neutral to slightly warm thermal sensations, indicating energy-efficient solutions for indoor comfort in small office environments.

1. Introduction

In response to escalating concerns over global energy conservation, there is a notable trend towards optimizing HVAC systems to operate at higher temperature settings. This shift is particularly pertinent in office environments, where maintaining optimal thermal conditions is critical for ensuring occupant comfort, productivity, and overall well-being (Zhang et al., 2019; Haynes et al., 2019; AlObaid, 2021). The integration of fan-assisted ventilation with air-conditioning systems emerges as a promising strategy to achieve substantial energy savings while preserving comfort levels. Studies have underscored that individuals acclimated to warmer climates can maintain satisfactory thermal comfort with the assistance of fans, even when air conditioning setpoints are elevated to between 26°C and 29°C (Schiavon et al., 2016; Zhai et al., 2013). Moreover, research indicates that combining fan-assisted ventilation with slightly higher air conditioning settings, such as 27°C to 28°C, can effectively extend the duration of comfortable conditions throughout the workday in office settings (Zakaria et al., 2022). Despite these promising findings, a critical knowledge gap remains regarding the practical implications, potential challenges, and optimal configurations of fan-assisted ventilation systems, especially in small office environments.

* *Corresponding author.*
E-mail address: azian@uthm.edu.my

https://doi.org/10.37934/IJMSET.2.1.1120

This study aims to address this gap by focusing on the dynamics of thermal comfort under a specific high air conditioning setpoint of 27°C in an individual office room at UTHM. By employing a comprehensive approach that includes both objective measurements (such as air temperature, relative humidity, air velocity, and mean radiant temperature) and subjective assessments (through questionnaires capturing occupants' thermal sensation votes), this research seeks to evaluate the feasibility and effectiveness of fan-assisted ventilation systems in enhancing occupant comfort. The findings are anticipated to provide valuable insights into designing energy-efficient office environments that prioritize both occupant well-being and environmental sustainability. Ultimately, this research aims to contribute to the broader discourse on optimizing indoor environmental quality in commercial buildings, thereby supporting efforts towards sustainable building practices and improved workplace conditions.

2. Methodology

2.1 Office room description

The study area is in an office room within the FKMP building, featuring a single front door, three chairs, two desks, and an air conditioner controlled by a remote. To optimize equipment setup, sensors should be placed at the centre of the room, about 100 centimeters above ground level, aligning with the seated height of a person as recommended by Zhang et al. (2022). Figure 1 designates this sampling point as 'SP,' located near the lecturer's desk, serving as the focal point for positioning the equipment.

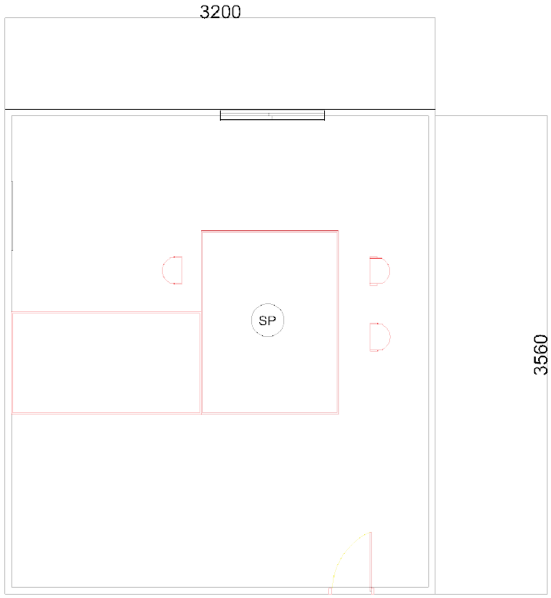

Fig. 1 *Location of the equipment*

2.2 Data Collection

Each measurement session lasts 15 minutes, serving as the timeframe for data collection. This duration allows for the assessment of individual thermal comfort levels following a 15-minute body adaptation period, as indicated by Zhang et al. (2022). The primary goal of this study is to evaluate the thermal comfort and performance of office room occupants when exposed to elevated air conditioner set point temperatures and the use of portable fans. These objectives are critical for understanding and achieving the research aims.

Table 1 outlines three different situations for the measurement sessions. The first situation involves a room equipped with both an air conditioner and a portable fan. The second situation features an office with only an air conditioner, while the third situation entails a room with solely a portable fan. These varying conditions are designed to comprehensively assess the impact of different cooling strategies on thermal comfort and occupant performance.

Table 1
Experimental set-up

No.	Situation	Duration
1	Air-conditioner	15 minutes
2	Air-conditioner + portable fan	15 minutes
3	Portable fan	15 minutes

2.3 Data Analysis

During the measurement sessions, all collected parameters and data were utilized in the calculations to determine the operative temperature. The calculation of operative temperature is crucial as it forms the basis for determining the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) values, which further quantify thermal comfort levels (Harčárová & Vilčeková, 2022). This temperature serves as a crucial indicator of the combined effects of air temperature, radiant temperature, air velocity, and humidity on thermal comfort. Following the calculation of the operative temperature, the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) values were subsequently derived. The PMV value quantifies the average thermal sensation of occupants on a scale ranging from cold (-3) to hot (+3), while the PPD value estimates the percentage of occupants likely to feel thermally uncomfortable. These metrics are essential for evaluating the thermal comfort of the office environment and were calculated in accordance with the standards outlined by Zhang et al. (2022).

Operative Temperature (ASHRAE Standard 55, 2017)

$$t_0 = At_0 + (1 - A)t_r$$

Where,
t_0 = Operative temperature
t_a = Average air temperature
t_r = Mean radiant temperature

A can be selected from the following values as a function of the average air speed V_a in table 2.

Table 2
Average air speed according to ASHRAE Standard 55-2017

$\boldsymbol{V_a}$	**<0.2 m/s**	**0.2 to 0.6 m/s**	**0.2 to 1.0 m/s**
$\boldsymbol{A}$	0.5	0.7	0.7

2.3 Questionnaire and Data Collection

To assess thermal comfort, occupants were asked to complete a questionnaire that included demographic questions such as gender, date, and location. The survey then proceeded with inquiries about thermal acceptance, preferences, and comfort in relation to variables such as relative humidity, air temperature, and air velocity. Participants were also asked how the temperature affected their ability to focus and complete tasks efficiently. To evaluate thermal acceptance, preference, and sensation, the ASHRAE-55 seven-point rating system was employed (Campano et al. 2019). Additionally, individual factors like clothing insulation and perceived heat were examined.

During field measurements, thermal sensation was measured using a seven-point scale, as detailed in Table 3. Occupants provided feedback on how the office room's temperature impacted their focus and overall working experience to determine its effect on productivity. Questions were designed to assess acceptance of the lowest acceptable temperature for an office setting, considering Malaysia's typical weather and relative humidity. Respondents also gave an overall evaluation of their thermal sensation, an explanation of the current state of the office space, and their impression of the thermal environment. These measures aimed to ensure that occupants could achieve thermal comfort even with the air conditioner set to a high temperature.

Table 3
Thermal Environment Scale

Thermal Sensation Vote (TSV)	
Scale	
-3	Cold
-2	Cool
-1	Slightly cool
0	Neutral
1	Slightly warm
2	Warm
3	Hot

2.4 Thermal Sensation Vote (TSV) calculation

To calculate the average value of the Thermal Sensation Vote (TSV) for this study, where the occupants are only three people, you need to follow a few straightforward steps. First, collect the TSV values from each of the three occupants, which we'll refer to as TSV1, TSV2, and TSV3. Next, sum these three TSV values to get the total TSV.

$$Total\ TSV = TSV\ 1 + TVS\ 2 + TSV\ 3$$

Finally, divide this total by the number of occupants, which is three in this case, to find the average TSV.

$$Average\ TSV = \frac{Total\ TSV}{3} = \frac{TSV\ 1}{3} + \frac{TSV\ 2}{3} + \frac{TSV\ 3}{3}$$

3. Result and Discussion

3.1 Physical Measurement Result

Thermal comfort, a complex interplay of various physical factors, is crucial for human well-being and productivity. This study investigates the impact of different cooling strategies on indoor thermal comfort, focusing on the combined effects of air conditioning and fan usage. Ghahramani et al. (2016) established that thermal comfort assessment encompasses various physical measurements, including air velocity, temperature, relative humidity, and mean radiant temperature. These parameters were measured after setting the initial room temperature to 27°C.

The analysis revealed significant variations in air velocity across the three experimental scenarios. The combined air conditioner and portable fan configuration achieved the highest air velocity at 0.41 m/s, representing a 41% increase compared to the air conditioner-only scenario (0.29 m/s). The portable fan operating in isolation demonstrated the lowest air velocity at 0.14 m/s, indicating substantially reduced air circulation efficiency. This enhanced air movement in the combined setup significantly contributed to improved thermal comfort through increased convective heat transfer and evaporative cooling potential.

Temperature measurements demonstrated notable variations across the experimental configurations. The combination of air conditioner and portable fan maintained the lowest average temperature at 26.7°C, while the air conditioner operating alone resulted in a higher temperature of 28.2°C. The portable fan-only scenario produced the highest temperature at 29.4°C. These findings indicate that the synergistic effect of combining air conditioning with portable fan operation provides superior temperature control, maintaining conditions 1.5°C below the air conditioner-only scenario and 2.7°C below the fan-only situation. This observation aligns with research by Wang et al. (2020), who demonstrated that enhanced air movement can improve cooling effectiveness at higher temperature setpoints.

The relative humidity measurements revealed crucial insights into the relationship between ventilation strategies and moisture control. The air conditioner-only configuration resulted in the highest relative humidity at 83.3%, while the combined setup maintained a more moderate 72.7%. The portable fan-only scenario recorded the lowest relative humidity at 71.0%. The elevated humidity in the air conditioner-only situation likely contributed to occupant discomfort despite moderate temperatures. This supports findings from Chen et al. (2021) that demonstrate how relative humidity levels exceeding 70% can significantly impair thermal comfort perception.

The combination of lower humidity (72.7%) and increased air velocity (0.41 m/s) in the combined setup created more favourable conditions by enhancing evaporative cooling potential and improving overall thermal sensation. However, despite maintaining the lowest relative humidity, the portable fan-only configuration could not compensate for the elevated temperature, resulting in thermal discomfort. This relationship demonstrates the complex interplay between humidity, temperature, and air movement in determining overall thermal comfort conditions.

Table 4
Thermal Environment Scale

	Situation 1	Situation 2	Situation 3
Air Velocity (m/s)	0.29	0.41	0.14
Temperature (°C)	28.2	26.7	29.4
Relative Humidity (%RH)	83.3	72.7	71.0
Mean Radiant Temperature (°C)	27.6	26.3	28.8
Predicted Mean Vote (PMV)	0.67	-0.16	1.43

The results of this study, as depicted in Figures 2, 3, and 4, highlight the significant impact of cooling strategies on indoor thermal comfort. The PMV index, a widely accepted metric for assessing thermal sensation, provides valuable insights into the effectiveness of different approaches. The combined setup of air conditioning and portable fans (Situation 2) emerged as the most effective strategy, achieving a PMV value closest to neutral. This indicates a balanced thermal environment attributed to the synergistic effect of improved air circulation, temperature control, and humidity levels. In contrast, the air conditioner-only scenario (Situation 1) resulted in a slightly warm thermal sensation, while the portable fan-only scenario (Situation 3) led to a significantly warm thermal sensation.

While the specific factors contributing to these results require further analysis, the combined setup likely achieved a more balanced thermal environment by optimizing air circulation, temperature control, and humidity levels. Future research should explore the impact of personalized factors, dynamic environments, energy efficiency, and health and well-being on thermal comfort perception and performance to optimize indoor thermal comfort further. Additionally, a bar graph in Figure 5 summarizes the PMV data across all three situations, visually comparing the thermal comfort levels achieved. This graphical representation enhances understanding of how different cooling strategies impact occupant comfort in office environments.

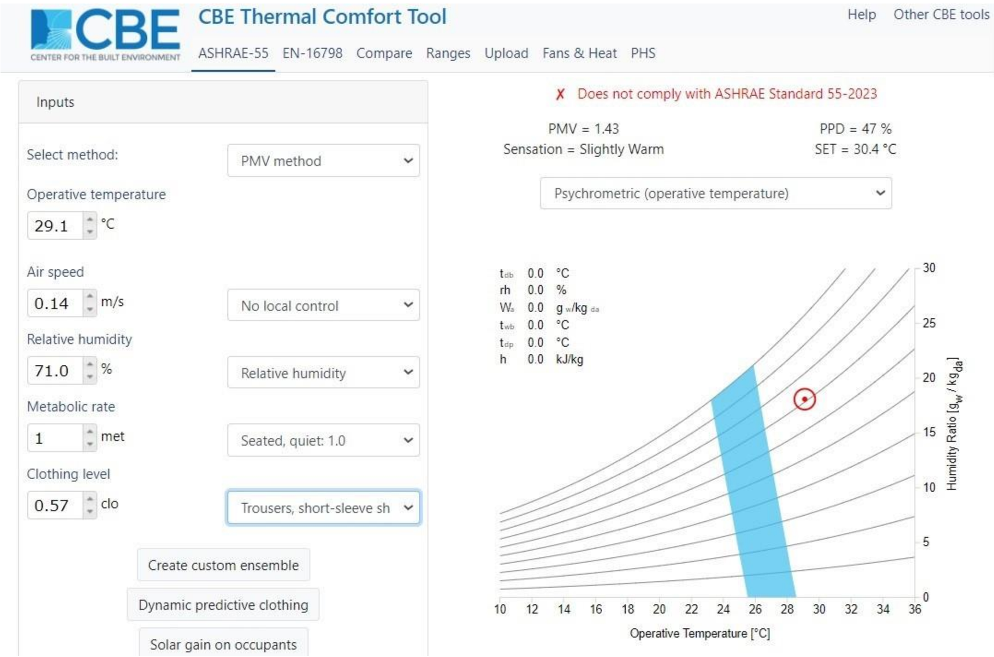

Fig. 2 *PMV result for situation 1*

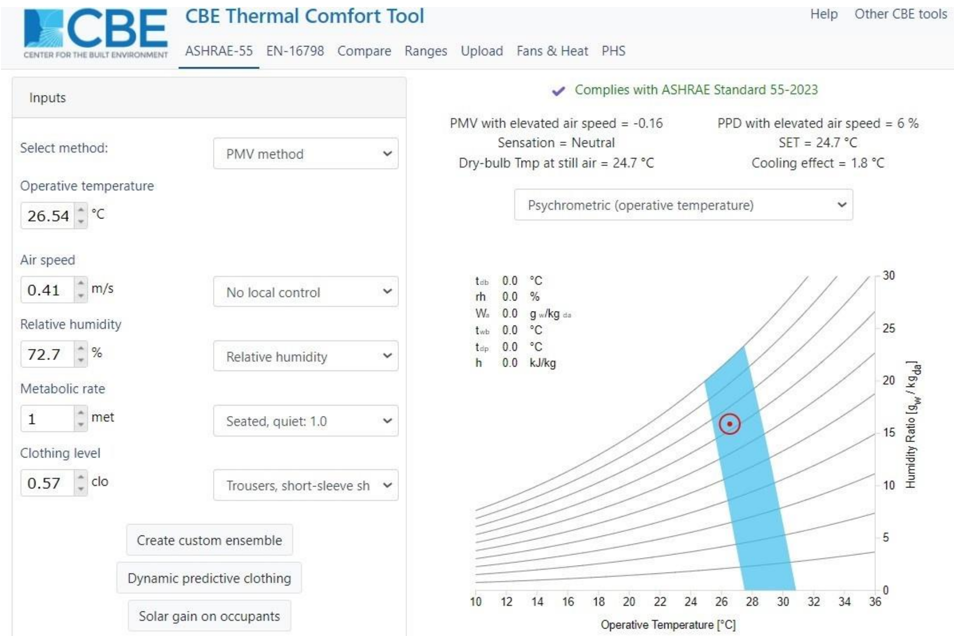

Fig. 3 *PMV result for situation 2*

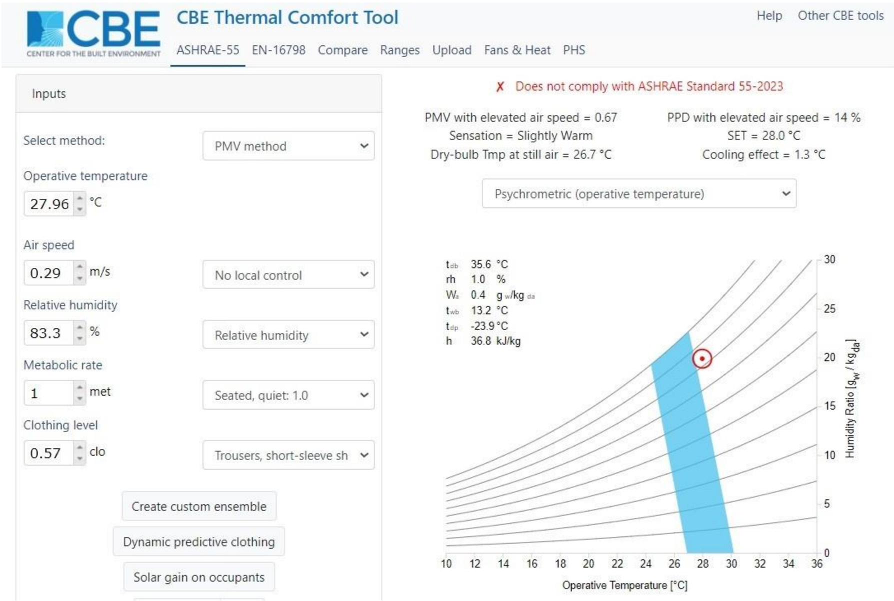

Fig. 4 *PMV result for situation 3*

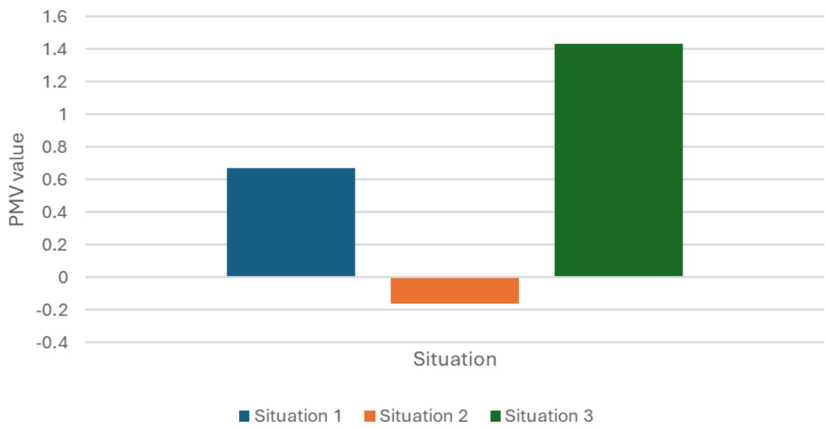

Fig. 5 *Value of Predicted Mean Vote (PMV) of all situations*

3.1 Subjective Measurement Result

The subjective measurements were conducted using surveys and questionnaires, including the Thermal Sensation Vote (TSV), to assess thermal comfort. This vote allows occupants to express their perception of thermal sensation, which correlates with the Predicted Mean Vote (PMV) findings. By comparing TSV results with PMV values, this study gains insights into how accurately occupants' subjective experiences align with objective thermal comfort assessments. This approach provides a comprehensive understanding of the thermal environment's effectiveness in meeting occupants' comfort needs.

Figure 6 presents the results obtained from the Thermal Sensation Vote (TSV) for three distinct cooling situations. In Situation 1, where only an air conditioner was used, occupants' TSV ratings ranged from slightly warm (+1) to neutral (0) to slightly cool (-1), with one vote for each category. Physical measurements recorded an air velocity of 0.29 m/s, a temperature of 28.2°C, a relative humidity of 83.3%, a mean radiant temperature of 27.6°C, and a PMV of 0.67, suggesting a slightly warm environment. The discrepancy between TSV and PMV highlights how high humidity can influence thermal perception.

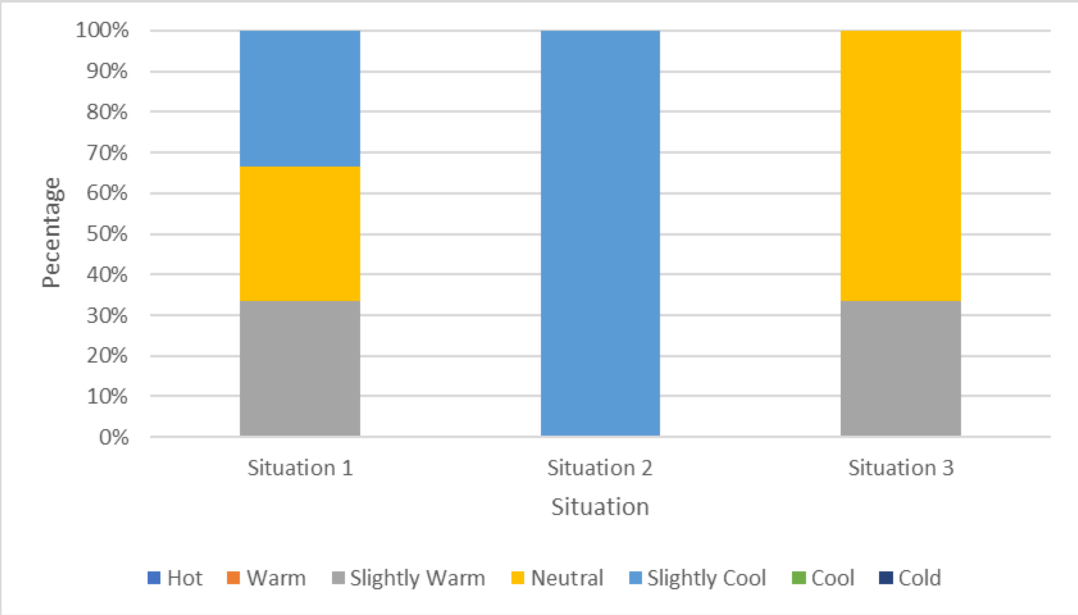

Fig. 6 *Thermal Sensation Vote (TSV)*

Situation 2 combined an air conditioner with a portable fan, resulting in unanimous TSV votes for “slightly cool” (-1). This situation featured the lowest temperature (26.7°C) and mean radiant temperature (26.3°C), increased air velocity (0.41 m/s), and a relative humidity of 72.7%. The PMV of -0.16 indicated a slightly cool environment attributed to enhanced cooling effects from increased air movement.

In Situation 3, where only a portable fan was utilized, TSV results showed two votes for neutral (0) and one for slightly warm (+1). Physical measurements included the highest temperature (29.4°C), lowest air velocity (0.14 m/s), a relative humidity of 71.0%, and a mean radiant temperature of 28.8°C, with a PMV of 1.43 indicating a warm environment. The portable fan alone proved insufficient to mitigate high temperatures, resulting in perceived warmth. This analysis demonstrates how TSV aligns with PMV findings, reflecting occupants’ subjective experiences of thermal comfort under different cooling conditions.

3.2 Summary of Findings

Based on Table 5, the findings reveal notable differences between the Predicted Mean Vote (PMV) and the Thermal Sensation Vote (TSV) across three different thermal control situations. In Situation 1, where only an air conditioner was used, the PMV was calculated to be +0.67, indicating a slightly warm environment. However, the TSV results showed one vote for slightly warm (+1), one vote for neutral (0), and one vote for slightly cool (-1), resulting in an average TSV of 0, indicating a neutral perception overall. This discrepancy between the slightly warm PMV and the neutral TSV could be due to factors such as high humidity, which may have made the environment feel less warm than the PMV suggested.

In Situation 2, where both an air conditioner and a portable fan were used, the PMV was -0.16, indicating a slightly cool environment. The TSV results showed all occupants voting 'slightly cool' (-1), with an average TSV of -1. This difference indicates that the combination of the air conditioner and the portable fan enhanced the cooling effect perceived by the occupants, making the environment feel cooler than what the PMV predicted.

In Situation 3, where only a portable fan was used, the PMV was +1.43, indicating a warm environment. The TSV results included two votes for neutral (0) and one vote for slightly warm

(+1), leading to an average TSV of +0.33. This close alignment between the warm PMV and the slightly warm TSV suggests that the portable fan provided some relief but was not enough to significantly offset the high temperature, resulting in a generally warm perception.

Table 5
Comparison between Physical Measurement and Subjective Measurement

Situation	Physical Measurement (PMV)	Subjective Measurement (TSV)
1	+ 0.67	**0**
2	- 0.16	**- 1**
3	**+ 1.43**	**+ 0.33**

4. Conclusion

This study evaluated thermal comfort in a closed indoor office with three occupants across three conditions: using an air conditioner alone (Situation 1), combining an air conditioner with a portable fan (Situation 2), and using a portable fan only (Situation 3). Situation 2 provided the most favorable conditions with a temperature of 26.7°C, air velocity of 0.41 m/s, and relative humidity of 72.7%, resulting in a Predicted Mean Vote (PMV) of -0.16 indicating slight coolness. Subjectively, all occupants voted "cool" in the Thermal Sensation Vote (TSV), with high comfort ratings. Situation 1 exhibited moderate conditions with a temperature of 28.2°C, air velocity of 0.29 m/s, and relative humidity of 83.3%, leading to a PMV of 0.67 indicating slight warmth, mixed TSV responses, and varied comfort ratings. Situation 3, with a temperature of 29.4°C, air velocity of 0.14 m/s, and relative humidity of 71.0%, had a PMV of 1.43 indicating significant warmth, reflected in subjective "slightly warm" TSV responses and lower comfort ratings. Integrating objective measurements with subjective assessments underscored the effectiveness of combining cooling methods (Situation 2) to enhance thermal comfort, highlighting the need for a comprehensive approach in managing indoor climate.

Acknowledgement

The authors wish to express their sincere gratitude to the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, for providing access to research facilities, particularly the research lab located at C6-014 in block C6. Special thanks are extended to Encik Mohd Azizi bin Mohd Afandi for his invaluable assistance as the lab assistant, whose support was instrumental in successfully completing the research activities.

References

1. Zhang, C., Kuppannagari, S., Kannan, R., & Prasanna, V. (2019). Building hvac scheduling using reinforcement learning via neural network based model approximation.. https://doi.org/10.1145/3360322.3360861
2. Haynes, B., Suckley, L., & Nunnington, N. (2019). Workplace alignment. Facilities. https://doi.org/10.1108/f-07-2018-0082

3. AlObaid, A. (2021). Implications of glazed facades on occupants' productivity in office buildings "a review of the literature". Engineering Research Journal - Faculty of Engineering (Shoubra), 49(1), 190- 196. https://doi.org/10.21608/erjsh.2021.227479
4. Schiavon, S., Yang, B., Donner, Y., Chang, V., & Nazaroff, W. (2016). Thermal comfort, perceived air quality, and cognitive performance when personally controlled air movement is used by tropically acclimatized persons. Indoor Air, 27(3), 690-702. https://doi.org/10.1111/ina.12352
5. Zhai, Y., Zhang, H., Zhang, Y., Pasut, W., Arens, E., & Meng, Q. (2013). Comfort under personally controlled air movement in warm and humid environments. Building and Environment, 65, 109-117. https://doi.org/10.1016/j.buildenv.2013.03.022
6. Zakaria, M., Amran, M., Rozmi, S., Yasin, M., Leng, P., & Hanipah, M. (2022). Thermal comfort assessment of an office room under high air conditioning setting temperatures with fan-assisted ventilation. International Journal of Integrated Engineering, 14(6). https://doi.org/10.30880/ijie.2022.14.06.035
7. Zhang, J., You, Q., Ren, G., & Ullah, S. (2022). Projected changes in mild weather frequency over china under a warmer climate. Environmental Research Letters, 17(11), 114042. https://doi.org/10.1088/1748-9326/ac9c70
8. Harčárová, K. and Vilčeková, S. (2022). Indoor environmental quality in green certified office buildings. Iop Conference Series Materials Science and Engineering, 1252(1), 012054. https://doi.org/10.1088/1757-899x/1252/1/012054
9. Campano, M., Domínguez-Amarillo, S., Fernández-Agüera, J., & Sendra, J. (2019). Thermal perception in mild climate: adaptive thermal models for schools. Sustainability, 11(14), 3948. https://doi.org/10.3390/su11143948
10. Ghahramani, A., Castro, G., Becerik-Gerber, B., & Yu, X. (2016). Infrared thermography of human face for monitoring thermoregulation performance and estimating personal thermal comfort. Building and Environment, 109, 1-11. https://doi.org/10.1016/j.buildenv.2016.09.005