Exploring Thermal Comfort in Campus Co-Working Spaces: SGLC UGM

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Abstract

Thermal comfort is essential in designing learning and working environments, particularly in tropical regions such as Indonesia. This study analyzes thermal comfort in three naturally ventilated co-working spaces at the Smart Green Learning Center (SGLC), Universitas Gadjah Mada (UGM), a green-certified campus building. A confirmatory approach was applied by comparing physical measurements of air temperature, relative humidity, air velocity, and mean radiant temperature (MRT) with user perceptions obtained through questionnaires using the Thermal Sensation Vote (TSV) and comfort vote. The results reveal a mismatch between Predicted Mean Vote (PMV) predictions and TSV responses: while PMV values exceeded the ASHRAE comfort threshold, most respondents reported neutral to slightly warm sensations, with 64–96% indicating comfort. The findings underscore the need for an adaptive approach and the development of local, data-driven thermal comfort standards that consider the context of climate, culture, and user characteristics in tropical regions.

Keywords: Passive ventilation; Thermal tolerance; Indoor microclimate; User response study; Tropical building performance
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INTRODUCTION

Co-working spaces are now an integral part of the learning ecosystem in modern universities, supporting collaborative and flexible learning patterns (Sankari et al., 2018). Many campuses are beginning to adopt green building principles that emphasize energy efficiency and indoor environmental quality (IEQ), with natural ventilation often highlighted as a sustainable strategy (López-Chao & López-Peña, 2021). Although environmentally friendly, the effectiveness of natural ventilation in achieving thermal comfort within tropical climates remains a subject of debate. Several studies indicate that thermal comfort is not only influenced by physical parameters such as temperature and humidity but also by subjective perceptions and local cultural adaptations (Rahman et al., 2021).

The Predicted Mean Vote (PMV) model, developed by Fanger (1970), remains one of the most widely applied indices for thermal comfort assessment and has been adopted in international standards such as ASHRAE 55 (2017) and ISO 7730 (2005). However, growing evidence suggests that PMV may not always reflect the actual comfort conditions of building occupants in tropical regions. Research indicates that factors such as clothing habits, types of activity, and local adaptation to heat influence thermal comfort in ways not fully captured by PMV predictions (Balbis-Morejón et al., 2020). Globally, the mismatch between international thermal comfort models and real user experiences in tropical climates has become a critical research issue (Balbis-Morejón et al., 2020; Frontczak & Wargocki, 2011).

Previous studies, for example, by Hamzah, Satyarno, and Iswanto (2017), found that students in Makassar reported feeling comfortable in classroom conditions considered "warm" by PMV standards. Similar findings have been reported in India (Indraganti, 2010) and Pakistan (Rijal et al., 2008), underscoring the importance of adaptive approaches in analyzing thermal comfort in tropical settings. Adaptive models consider user experience, expectations, and long-term thermal exposure as part of the comfort evaluation (de Dear & Brager, 2002; Humphreys & Nicol, 2002). To date, no study has specifically examined thermal comfort in naturally ventilated co-working spaces within green-certified campus buildings in Indonesia, making this research a significant contribution to both academic and practical perspectives.

Despite this growing body of literature, limited studies focus on thermal comfort evaluation in university co-working spaces, which are unique as hybrid learning and working environments with long occupancy durations and light academic activities such as typing, reading, and discussions. Moreover, to the best of the authors' knowledge, no prior study has investigated thermal comfort conditions in the Smart Green Learning Center (SGLC) at Universitas Gadjah Mada, a certified green building designed for sustainable learning activities (Nadagitalia, 2024). This creates an empirical gap, as the building represents a pioneering model of sustainable campus infrastructure in Indonesia that relies partly on natural ventilation. Understanding its thermal comfort performance is therefore crucial for both

academic reference and practical applications in future green campus designs (Frontczak & Wargocki, 2011; Yang et al., 2015).

Based on this background, the present study aims to analyze thermal comfort in three naturally ventilated co-working spaces at the SGLC UGM. A confirmatory approach is employed by comparing physical microclimate data from field measurements with subjective user perceptions obtained through questionnaires. This dual approach is expected to test the applicability of PMV predictions in tropical climates and provide insights for the development of adaptive, context-based comfort standards in Indonesia.

RESEARCH METHODOLOGY
Data Collection
The study was conducted at the Smart Green Learning Center (SGLC), Universitas Gadjah Mada, Yogyakarta, a green-certified academic building that combines naturally ventilated and air-conditioned spaces. Three co-working spaces were selected as case studies, each representing different floor levels and window orientations

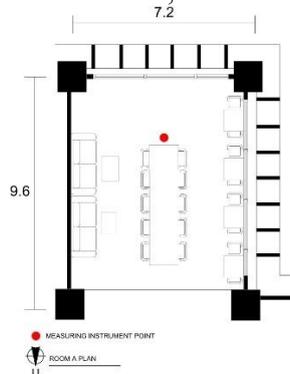   a.   Room A: 11th floor, south-west orientation. Data collection: May 7–9, 2025, 08.00–16.00 WIB.
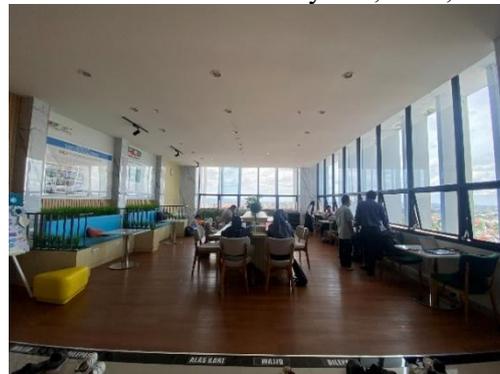

Figure 1. Room A Plan
Source: Author, 2025

Figure 2. Room A
Source: Author, 2025

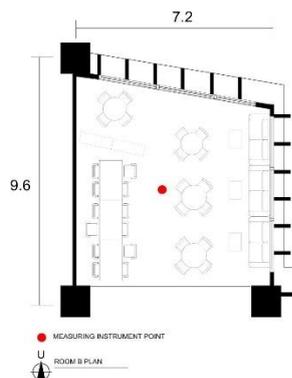   b.   Room B: 11th floor, north-east orientation. Data collection: May 21–23, 2025, 08.00–16.00 WIB.
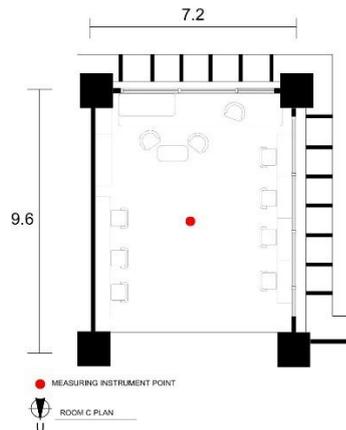

Figure 3. Room B Plan
Source: Author, 2025

Figure 4. Room B
Source: Author, 2025

    c.   Room C: 4th floor, south-west orientation and adjacent to a five-story building. Data collection: May 26–28, 2025, 08.00–16.00 WIB.

Figure 5. Room C Plan
Source: Author, 2025

Figure 6. Room C
Source: Author, 2025

Environmental parameters measured in this study include:
a. Indoor: air temperature (°C), relative humidity (%), and air velocity (m/s).
b. Indoor: air temperature (°C), relative humidity (%), and air velocity (m/s).

Measuring instruments used in this study:
a. Outdoor: HOBO RX3000 Weather Station
b. Indoor: HOBO Data Logger MX1104, Lutron AM-4234SD (anemometer), and Lutron WBGT-2010SD (thermal environment meter).

Figure 7. Outdoor Measurement Tools
Source: Author, 2025

Figure 8. Indoor Measurement Tools
Source: Author, 2025

Each room had a fixed measurement point, centrally located and placed at 80–110 cm above the floor (Valdiserri et al., 2020). Subjective thermal comfort data were collected through a questionnaire survey distributed to 25 respondents per room (75). The questionnaire adopted the Thermal Sensation Vote (TSV) scale from -3 (cold) to +3 (hot) and included questions on perceived thermal comfort (comfortable / not comfortable) along with additional questions related to thermal preferences and overall comfort perception. Respondents completed the survey after spending a minimum of 30 minutes in the room.

Data Analysis and Processing
Data processing in this study was conducted in two stages: environmental data analysis and questionnaire data analysis.
1. Environmental Data Analysis

- Environmental data were collected through direct measurements in the three co-working spaces at SGLC UGM, including air temperature (Ta), relative humidity (RH), wind speed (v), and globe temperature (Tg).
- The mean radiant temperature (MRT) was calculated from globe temperature using a standard formula following ISO 7726 guidelines.
- Thermal comfort indices were then calculated using the Predicted Mean Vote (PMV) model developed by Fanger (1970), as standardized in ASHRAE 55 (2017) and ISO 7730 (2005). Input variables included Ta, MRT, RH, v, metabolic rate (1.1 met for light activity such as reading and typing), and clothing insulation (0.5 clo for typical indoor clothing in tropical regions).

2. Questionnaire Data Analysis
- Perception data were collected using the Thermal Sensation Vote (TSV) scale, ranging from -3 (very cold) to +3 (very warm) (Li et al., 2023).
- Respondents' answers were averaged for each room and tabulated into frequency and percentage distributions.
- In addition, respondents also provided thermal comfort votes (comfortable / not comfortable), which were analyzed to assess tolerance levels.

3. Comparative Analysis
- The TSV results were compared with PMV values derived from environmental data to identify agreement and discrepancies between predicted and perceived comfort.
- This comparison was intended to examine whether model predictions align with user comfort perceptions in naturally ventilated tropical spaces (Luo, 2023).
- The analysis applied a confirmatory approach, combining both objective and subjective indicators, to evaluate the relevance of PMV in the Indonesian tropical context.
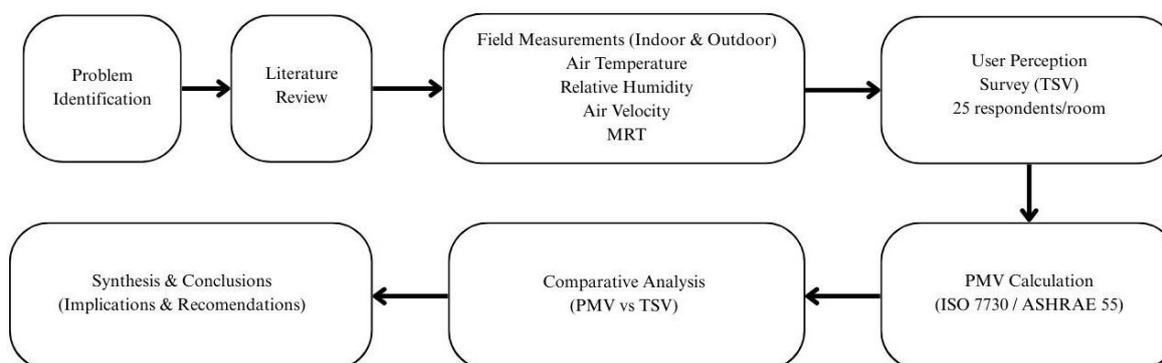

Figure 9. Methodological Flowchart
Source: Author, 2025

The methodological flowchart presented in Figure 9 summarizes the overall research process. The study begins with data collection, which includes field measurements of environmental parameters (air temperature, humidity, air velocity, and globe temperature) and user perception surveys through questionnaires. The collected data are then analyzed in two stages: environmental data analysis, where thermal indices such as MRT and PMV are calculated, and questionnaire data analysis, where TSV and comfort votes are processed. Finally, a comparative analysis is conducted to evaluate the alignment or discrepancy between PMV predictions and TSV responses. This sequential approach provides a comprehensive framework for understanding thermal comfort conditions in naturally ventilated co-working spaces within the SGLC building.

RESULT AND DISCUSSION
Research Context and Methodological Approach
This study aims to analyze thermal comfort in three naturally ventilated co-working spaces at the Smart Green Learning Center (SGLC) UGM. The building itself represents a green campus facility that combines air-conditioned and naturally ventilated areas, providing a relevant case for testing thermal

performance in tropical settings. The co-working spaces were selected because they rely solely on natural ventilation and are intensively used by students for study and collaborative activities. The research employed a confirmatory approach by comparing objective data from microclimate measurements, air temperature, relative humidity, air velocity, and mean radiant temperature (MRT) with subjective perceptions collected through questionnaires (Vittori et al., 2021). Objective data were recorded using standardized instruments, while subjective data were collected using the Thermal Sensation Vote (TSV) scale to capture user responses. This approach was designed to test the validity of thermal comfort prediction models such as the Predicted Mean Vote (PMV), initially developed for subtropical contexts (Fanger, 1970), and to examine the relevance of adaptive comfort interpretations in Indonesia's tropical climate. The measurement of physical parameters followed international guidelines (ISO 7726, 1998), ensuring consistency with global standards while allowing contextual interpretation based on local user perceptions.

Physical Environmental Conditions

The measured physical environmental data show the following results:

Table 1. Physical Environmental Measurement Results Data

Room	Air Temperature (°C)	Relative Humidity (%)	Air Speed (m/s)	MRT (°C, ISO 7726)	MET	CLO
A	29,76	67,63	0,088	29,79	1.10	0.65
B	28,57	72,08	0,103	28,41	1.08	0.68
C	28,51	71,55	0,112	28,42	1.06	0.64

Source: Author, 2025

MRT value is calculated using the ISO 7726 formula based on globe temperature, air temperature, wind speed, and globe dimensions (diameter 7.5 cm) with an emissivity of 0.95 (ISO 7726, 1998). The formula used is as follows:

$$T_r = \left[\left(T_g + 273.15\right)^4 + \frac{\left\{1.10 \times 10^8 \cdot v^{\{0.6\}} \cdot \left(T_g - T_a\right)\right\}}{\left\{\varepsilon D^{\{0.4\}}\right\}} \right]^{\{0.25\}} - 273.15$$

Description:
- T_g: globe temperature (°C)
- T_a: air temperature (°C)
- v: air velocity (m/s)
- ε: emissivity (0.95 for black globe)
- D: globe diameter (0.075 m)

Subjective Perception: Thermal Sensation Vote (TSV) Value

The TSV value in this study was obtained from the results of a 7-point scale questionnaire, in which each respondent was asked to assess the thermal sensation they experienced. The TSV scale used is as follows:

Tabel 2. Description of TSV Value

Point Scale	TSV Value	Description
1	-3	Very Cold
2	-2	Cold
3	-1	Slightly Cold
4	0	Neutral
5	1	Slightly Warm
6	2	Warm
7	3	Very Warm

Source: Author, 2025.

The average TSV of each space is calculated using the following formula:

$$TSV_{mean} = \frac{\sum_{i=1}^{n} TSV_i}{n}$$

Description:
- *TSV*i: thermal sensation value of the i-th respondent
- *n*: total number of respondents

The questionnaire results from 75 respondents showed different perceptions of thermal comfort in the three co-working spaces, as shown in Table 3 below:

Tabel 3. TSV Results

Room	Average TSV	Description	Comfortable Respondents (%)
A	-0,013	Neutral- Slightly Cold	88%
B	0,813	Neutral- Slightly Warm	64%
C	-0,267	Neutral- Slightly Cold	96%

Source: Author, 2025.

Room A has the lowest air temperature among the three rooms, showing a TSV value of -0,013, which indicates a slightly cold temperature. In contrast, Room C, with a TSV value of -0,267, shows a similar but slightly colder environment and the closest TSV value to neutral. This pattern indicates that the user's heat perception aligns with the air temperature, but overall comfort remains influenced by other factors such as airspeed and adaptation to tropical environments. Room B, with a TSV value of 0,813, is slightly warm, and shows a lower percentage of comfortable respondents (64%), highlighting that airspeed and environmental adaptation may play a larger role in comfort.

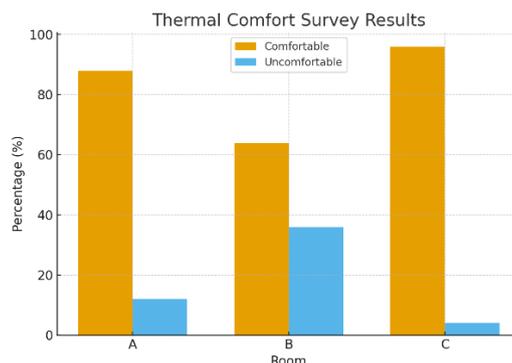### Subjective Perception: Thermal Comfort Vote (Comfort vs Not Comfort)

In addition to thermal sensation votes, respondents were also asked to directly evaluate whether they felt comfortable or not in the co-working spaces. This question provides a more unambiguous indication of thermal acceptability, which complements the sensation-based data. According to de Dear & Brager (2002), thermal acceptability is an essential indicator of adaptive comfort, as occupants in naturally ventilated buildings often tolerate conditions that deviate from model predictions.

Tabel 4. Percentage of Respondents Reporting Comfort vs Discomfort

Room	Comfortable	Not Comfortable
A	88%	12%
B	64%	36%
C	96%	4%

Source: Author, 2025.

The results show that Room C had the highest comfort percentage, with 96% of respondents stating that they felt comfortable. Room A also showed a high acceptance rate of 88%. In contrast, Room B displayed a lower comfort level, with only 64% of respondents reporting comfort and 36% expressing discomfort. This suggests that spatial orientation and environmental settings may have influenced user perception in Room B.

Figure 10. Thermal Comfort Vote (Comfort vs Discomfort)
Source: Author, 2025

The graphical distribution confirms the differences between rooms, where Room C consistently shows the strongest comfort perception, followed by Room A, while Room B demonstrates a more divided user experience. Furthermore, when compared with the TSV results, the comfort vote highlights an interesting contrast. Although the average TSV values indicated neutral to slightly warm sensations (Room A = –0.013, Room B = 0.813, Room C = –0.027), most users still declared themselves comfortable. For instance, in Room A, the TSV was nearly neutral, but 88% of respondents voted "comfortable." Even in Room B, where TSV suggested slightly warm conditions, almost two-thirds of users still perceived the space as comfortable. This difference emphasizes that while TSV reflects thermal sensation, the comfort vote reflects acceptability in the context of local culture, activity type, and user expectations. Previous studies have noted similar findings in tropical climates, where occupants report higher tolerance for warm conditions compared to the thresholds predicted by PMV or sensation-based models (Hamzah et al., 2017; Indraganti, 2010). Thus, thermal comfort in tropical naturally ventilated buildings should be evaluated not only through sensation indices but also through direct acceptability measures.

Overall, the comfort vote results confirm that users tend to accept warmer conditions than predicted by sensation scales alone. This finding provides a strong basis for the following analysis, namely the comparison between PMV predictions and TSV perceptions, to further explore how predictive models align with actual user comfort in tropical naturally ventilated spaces.

Comparison of PMV and TSV
The Predicted Mean Vote (PMV) model predicts thermal comfort based on environmental parameters and human characteristics. In this study, the PMV value is calculated based on the Fanger (1970) approach by considering air temperature (Ta), average radiation temperature (Tr), humidity (through partial pressure of water vapor Pa), airspeed (v), metabolic rate (M), and clothing insulation value (CLO). The general formula for PMV is as follows:

$$
\begin{aligned}
PMV = &\left[0.303 \cdot e^{\{-0.036M\}} + 0.028\right] \\
&\cdot \left[(M - W) - 3.05 \cdot 10^{\{-3\}} \cdot [5733 - 6.99(M - W) - Pa] - 0.42\right. \\
&\cdot [(M - W) - 58.15] - 1.7 \cdot 10^{\{-5\}} \cdot M \cdot [5867 - Pa] - 0.0014 \cdot M \\
&\cdot (34 - Ta) - 3.96 \cdot 10^{\{-8\}} \cdot f_{\{cl\}} \cdot \left[(T_{\{cl\}} + 273)^4 - (T_r + 273)^4\right] - f_{\{cl\}} \cdot h_c \\
&\left. \cdot \left(T_{\{cl\}} - Ta\right)\right]
\end{aligned}
$$

Description:
- *M*: metabolic rate (W/m²)
- *W*: external work (usually 0 W/m²)
- *Ta*: air temperature (°C)
- *Tr*: mean radiant temperature (MRT) (°C)
- *Pa*: partial pressure of water vapor (Pa)

- *fcl*: ratio of clothing surface area to body
- *Tcl*: clothing surface temperature (°C)
- *hc*: convection heat transfer coefficient (W/m²K)

The PMV value is then compared with the average TSV value obtained from the perception of room users.

Tabel 5. Comparison of PMV and TSV Values

Room	PMV (Model)	TSV (Respondent)
A	1,77	-0,013
B	1,36	0,813
Room	**PMV (Model)**	**TSV (Respondent)**
C	1,29	-0,027

Source: Author, 2025

The comparison between PMV values (model-based) and TSV values (respondent-based) highlights a consistent gap across the three co-working spaces (Table 5). While the PMV values for all rooms exceed the upper limit of the ASHRAE comfort range (+0.5), the TSV values reported by users remain close to neutral.
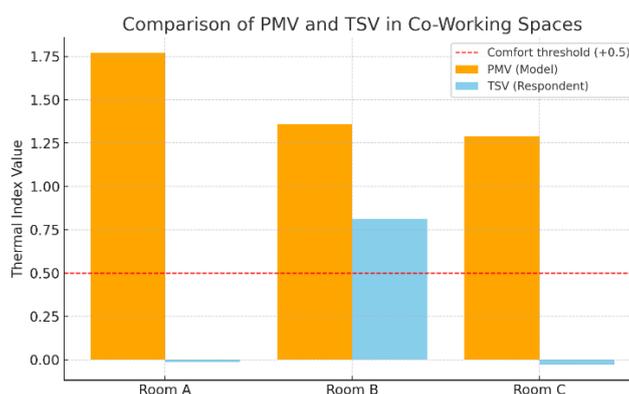
Figure 11. Comparison of PMV and TSV Values per Room
Source: Author, 2025

Room A recorded the highest PMV at 1.77, which suggests very warm conditions and potential discomfort. However, respondents reported a TSV of –0.013, indicating that most users still perceived the space as neutral. Room B showed a PMV of 1.36, yet the TSV value was 0.813, reflecting that user felt slightly warm but still within a tolerable range. Room C, with a PMV of 1.29, again showed a near-neutral TSV of –0.027, suggesting that despite the model's prediction of warm conditions, users did not perceive significant discomfort. In numerical terms, the mean difference between PMV and TSV across the three rooms was approximately 1.3 scale units, indicating a substantial deviation between predicted discomfort and user-reported sensations. Room A showed the most significant discrepancy ($\Delta = 1.78$), while Room C showed the smallest ($\Delta = 1.32$), but in all cases the gap remained above one full scale unit. These results indicate that the PMV model tends to overestimate discomfort in tropical, naturally ventilated spaces. Users' subjective experiences suggest a higher tolerance for warm conditions, which is consistent with adaptive comfort theories. This phenomenon aligns with the findings of Hamzah et al. (2017) in Makassar, where students reported feeling comfortable despite PMV values suggesting warm conditions. Similar observations have also been made in India (Indraganti, 2010) and Pakistan (Rijal et al., 2008), further supporting the argument for adaptive approaches (de Dear & Brager, 2002; Humphreys & Nicol, 2002). Although PMV has limitations in representing comfort under tropical conditions, it remains a valuable reference when adjusted for local adaptation factors such as clothing habits, activity levels, and user expectations. This consistent divergence is in line with previous findings that predictive indices such as PMV often misrepresent actual user comfort in tropical contexts,

particularly under natural ventilation (de Dear & Brager, 2002; Humphreys & Nicol, 2002; Indraganti, 2010; Rijal et al., 2008; Hamzah et al., 2017). These discrepancies between PMV predictions and TSV perceptions highlight that user comfort in tropical naturally ventilated spaces cannot be fully explained by model indices alone. To better understand this phenomenon, it is essential to examine how users adapt to the prevailing outdoor climate conditions, which will be discussed in the following section.

User Adaptation to Climate

Outdoor temperature plays a significant role in shaping users' adaptive responses to indoor thermal conditions. During the observation period, the average outdoor temperature was 27.07 °C, with a daily fluctuation between 25.37 °C and 28.42 °C (Figure 12). This range illustrates the relatively stable tropical climate to which building users are continuously exposed.
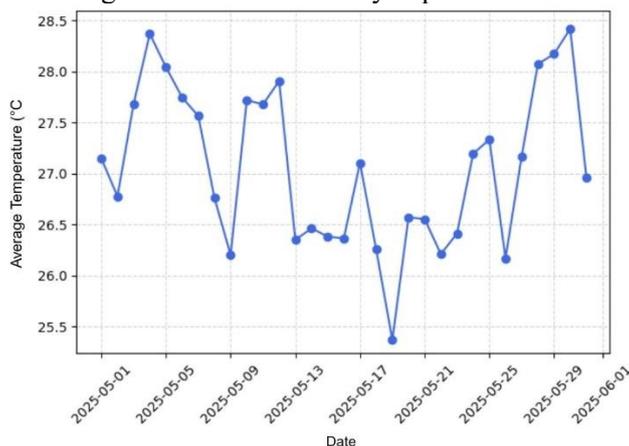

Figure 12. Outdoor Temperature Trend in May
Source: Author, 2025

Based on the adaptive approach (de Dear & Brager, 1998), the neutral temperature can be estimated using the formula:

$$Tn = 0.31 \times Ta_{avg} + 17.8 \approx 26.19°C$$

However, most respondents reported feeling comfortable at indoor temperatures of 29–30 °C, which is higher than the theoretical neutral point. This discrepancy suggests that users have developed a higher tolerance through adaptation. Supporting this, 64% of respondents used the space for more than two hours, engaging in light activities such as sitting, typing, and reading. Additionally, 68% were bachelor's students, with the remainder from graduate and postgraduate levels, both groups being relatively more adaptable to warmer environments.

These findings align with studies by Yang et al. (2015) and Brager & de Dear (1998), which indicate that long-term thermal exposure influences comfort expectations. Thus, thermal comfort in this context is shaped not only by absolute indoor temperatures but also by physiological and psychological adaptation, consistent with the adaptive comfort framework (de Dear & Brager, 2002; Humphreys & Nicol, 2002).

Synthesis of Findings

The findings of this study consistently show a discrepancy between PMV values, as predicted by the model, and the thermal sensations reported by users. While PMV values in all three rooms indicate warm conditions above the ASHRAE comfort threshold (+0.5), the TSV values remain close to neutral. In addition, most respondents voted that the rooms were "comfortable," even when PMV suggested discomfort. This gap highlights that the PMV model, initially developed in subtropical contexts, may not fully capture thermal comfort conditions in tropical climates, particularly in naturally ventilated spaces. The results also indicate that university users, whose activities are generally light (typing, reading, and discussions) and last for more than two hours, exhibit a higher tolerance to elevated indoor temperatures.

Furthermore, outdoor temperature data support the adaptive comfort approach, showing that respondents perceive thermal neutrality at higher indoor temperatures (around 29–30 °C) compared to the theoretical neutral temperature calculated from adaptive models (~26 °C). This aligns with previous studies in Indonesia (Hamzah et al., 2017) and international adaptive comfort theories (de Dear & Brager, 2002; Nicol & Humphreys, 2002), which emphasize that context, expectations, and long-term adaptation to local climate conditions shape thermal comfort.

Taken together, these results suggest that thermal comfort in tropical buildings cannot be evaluated solely based on mathematical models such as PMV. A contextual approach that incorporates both objective measurements and subjective user perceptions, grounded in local empirical data, is necessary to support the design of naturally ventilated learning spaces that are genuinely comfortable and aligned with the realities of tropical climates.

CONCLUSION

This study highlights the importance of considering local context when assessing thermal comfort in tropical environments with natural ventilation. The findings suggest that comfort cannot be measured solely through predictive models such as PMV, as user perception is shaped by thermal experience, duration of stay, type of activity, and expectations of the space. This reinforces the need for an adaptive approach that is more responsive to real-world conditions.

While international references such as ASHRAE and ISO provide practical guidelines, it is also vital to consider existing Indonesian standards, such as SNI 6390:2011 on thermal comfort and SNI 03-6572-2001 on ventilation and air-conditioning. An approach based on empirical data and user perceptions is key to creating work and learning spaces that are thermally appropriate, healthy, and contextually relevant for tropical environments.

Future research is expected to explore two directions: first, examining the contextual application of existing standards across various building typologies and tropical sub-climates; and second, evaluating the necessity of revising or adapting SNI or international standards to better represent user comfort in naturally ventilated tropical spaces.

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