THERMAL COMFORT ASSESSMENT OF BOARDING HOUSES IN CANDISEWU, SEMARANG USING THE CBE THERMAL COMFORT TOOL

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Abstract: *Thermal comfort is an important factor in determining the quality of indoor environments, particularly in boarding houses where occupants spend a substantial amount of time for living, studying, and resting. In tropical climates such as Semarang, high outdoor temperatures, humidity, and inadequate natural ventilation can create uncomfortable indoor thermal conditions. Boarding houses in Candisewu, Semarang, have diverse spatial configurations, orientations, openings, and ventilation conditions that may influence occupants' thermal comfort. However, thermal comfort conditions in this type of residential building have received limited attention. This study aimed to assess the thermal comfort conditions of boarding houses in Candisewu, Semarang, using the CBE Thermal Comfort Tool and to identify the environmental factors that contribute to thermal discomfort. The study employed a quantitative field-based approach involving measurements of indoor air temperature, relative humidity, air velocity, and mean radiant temperature in selected boarding house rooms. The measured environmental parameters were analyzed using the CBE Thermal Comfort Tool to determine Predicted Mean Vote (PMV), Predicted Percentage of Dissatisfied (PPD), and adaptive thermal comfort conditions. The results indicated variations in thermal comfort conditions among the investigated rooms, primarily associated with differences in ventilation, solar exposure, room orientation, and air movement. Several rooms experienced thermal conditions outside the preferred comfort range, indicating the need for passive design improvements to enhance indoor thermal performance.*

Keywords: *Thermal Comfort; Boarding Houses; CBE Thermal Comfort Tool; Semarang; Indoor Environment*

1. Introduction

Thermal comfort is an important aspect of indoor environmental quality because it directly influences occupants' well-being, productivity, sleep quality, and perception of building performance. This issue becomes particularly significant in tropical regions, where buildings are exposed to relatively high air temperature, solar radiation, and humidity throughout the year. In such conditions, residential buildings can experience excessive indoor heat, especially when their architectural configuration does not adequately support natural ventilation and solar control. Previous research has demonstrated that thermal comfort in tropical buildings cannot always be interpreted using the same assumptions developed for temperate climates because occupants tend to adapt to their surrounding environmental conditions [1], [2]. Feriadi and Wong, for example, found that occupants of naturally ventilated houses in Indonesia generally experienced thermal conditions differently from the values predicted by the conventional Predicted Mean Vote (PMV) model, demonstrating the importance of adaptation and local environmental characteristics in tropical residential buildings [1].

The relationship between thermal comfort and building design is particularly relevant for boarding houses, where individual rooms function as living, sleeping, studying, and resting spaces. Unlike conventional houses, boarding houses generally accommodate multiple occupants within a relatively compact building configuration. Consequently, differences in room orientation, window openings, façade exposure, shading, floor level, and ventilation conditions can produce different indoor thermal environments within the same building. Research on tropical residential buildings has shown that façade orientation, window-to-wall ratio, external shading, and opening characteristics can significantly influence indoor air temperature and thermal performance [3]. Similarly, research on naturally ventilated residential buildings in Singapore has demonstrated that ventilation strategies and façade configurations can influence the number of thermal discomfort hours experienced by occupants [4]. These findings suggest that thermal comfort assessment should consider the actual physical characteristics of individual residential spaces rather than relying solely on generalized climatic assumptions.

The climatic context of Semarang makes this issue particularly relevant. As a tropical Indonesian city, Semarang experiences environmental conditions in which heat and humidity can affect indoor comfort, particularly in buildings that rely on natural ventilation. The adaptive thermal comfort approach is therefore important because occupants in hot-humid Southeast Asian environments may tolerate or prefer indoor temperatures that differ from those predicted by conventional steady-state models. Nguyen, Singh, and Reiter developed an adaptive thermal comfort model specifically for hot-humid Southeast Asia based on field observations from the region and demonstrated the importance of occupant adaptation when evaluating naturally ventilated buildings [2]. Their findings provide a strong regional basis for assessing thermal comfort in Indonesian buildings, particularly those that allow occupants to control windows, fans, clothing, and other adaptive responses.

The selection of an appropriate assessment method is consequently important. The CBE Thermal Comfort Tool provides an accessible platform for evaluating thermal comfort using established models and standards. The tool incorporates PMV, Predicted Percentage of Dissatisfied (PPD), Standard Effective Temperature (SET), adaptive comfort models, and local discomfort calculations, while also providing graphical representations of comfort conditions [5]. Its applicability to building research is strengthened by its ability to process environmental parameters such as air temperature, mean radiant temperature, relative humidity, and air velocity together with personal parameters such as metabolic rate and clothing insulation. This makes the tool particularly useful for field-based investigations in which measured environmental data can be translated into standardized thermal comfort indicators.

Previous studies have demonstrated the value of combining field measurements with thermal comfort assessment in tropical buildings. In Singapore, Lan et al. combined in-situ measurements, building thermodynamics, airflow analysis, and thermal comfort models to evaluate naturally ventilated hospital wards and demonstrated that passive ventilation strategies could improve thermal comfort under tropical conditions [6]. Other research on tropical residential buildings has similarly examined passive strategies, façade design, and ventilation as mechanisms for reducing thermal discomfort and improving indoor environmental conditions [3], [4]. Research on affordable retrofitting in Malaysian terrace houses further indicated that natural ventilation alone may not always be sufficient and that relatively simple interventions, such as roof protection and increased air movement, can substantially improve thermal comfort [7].

Despite the growing body of research on thermal comfort in tropical buildings, a specific research gap remains concerning boarding houses in secondary residential environments such as Candisewu, Semarang. Existing studies have predominantly focused on conventional houses, offices, hospitals, or broader residential typologies. Indonesian residential research has established the importance of adaptive behavior [1], while regional studies have developed adaptive models for Southeast Asia [2]; however, the thermal characteristics of boarding-house rooms, which combine relatively small floor areas, repeated room configurations, varying orientations, and potentially different ventilation conditions, have received considerably less attention. Moreover, previous studies frequently employ complex building simulation, CFD, or extensive occupant surveys [3], [6], whereas a practical assessment using measured environmental parameters and an accessible thermal comfort platform can provide a more straightforward approach for evaluating existing boarding-house conditions.

Accordingly, this study aims to assess the thermal comfort conditions of boarding houses in Candisewu, Semarang, using the CBE Thermal Comfort Tool. The study specifically evaluates indoor environmental conditions through air temperature, relative humidity, air velocity, and mean radiant temperature and translates these parameters into thermal comfort indicators, particularly PMV and PPD. The research is guided by three questions: **(1)** What are the indoor thermal environmental conditions of boarding-house rooms in Candisewu, Semarang? **(2)** To what extent do the measured conditions fall within acceptable thermal comfort ranges based on the CBE Thermal Comfort Tool? and **(3)** Which environmental and architectural characteristics appear to contribute most strongly to thermal discomfort in the investigated boarding-house rooms?

The results are expected to provide both theoretical and practical benefits. Theoretically, the study contributes localized evidence to the discussion of thermal comfort in tropical residential environments by focusing on a boarding-house typology that has received limited attention. Practically, the findings can provide architects, building owners, and occupants with evidence-based information for improving ventilation, solar protection, openings, shading, and other passive design strategies without necessarily depending on mechanical cooling. The study may therefore support more climate-responsive approaches to small-scale residential buildings in Semarang.

The state of the art of this research lies in connecting established tropical thermal-comfort knowledge with a relatively underexplored boarding-house typology at the local scale. Previous studies have established adaptive comfort relationships for Indonesia and Southeast Asia [1], [2], investigated façade and ventilation effects in tropical residential buildings [3], [4], and demonstrated the applicability of computational and thermal comfort models for tropical buildings [6], [7]. Meanwhile, the CBE Thermal Comfort Tool provides an integrated and accessible framework for applying these comfort models [5]. The **novelty** of this study is therefore its empirical application of the CBE Thermal Comfort Tool to measured indoor conditions in boarding houses in Candisewu, Semarang (figure 1), while relating the resulting comfort indicators to the specific architectural characteristics of the rooms. This approach is expected to produce a locally grounded assessment that can serve as a basis for passive thermal improvement strategies in boarding-house buildings.

Figure 1. Front facade of a residential building in the Candisewu area, Semarang

2. Research Methods

This study employed a quantitative field-based approach to assess the thermal comfort conditions of boarding houses in Candisewu, Semarang. The research was conducted through direct measurement of indoor environmental conditions followed by thermal comfort analysis using the CBE Thermal Comfort Tool. The research object consisted of selected boarding-house rooms representing the actual spatial and environmental conditions of the study area.

Field measurements were conducted inside the selected rooms during representative daytime periods. The measured parameters included air temperature (°C), relative humidity (%), air velocity (m/s), and mean radiant temperature (°C). Measurements were taken at the occupants' activity zone and at a consistent height to maintain comparability between rooms. In addition to environmental measurements, the physical characteristics of each room were documented, including room orientation, dimensions, window position, ventilation openings, shading elements, floor level, and exposure to direct solar radiation.

The collected environmental data were subsequently entered into the CBE Thermal Comfort Tool (see figure 2). The PMV method was initially selected to evaluate thermal sensation under the measured indoor conditions. Personal parameters were defined based on typical boarding-house activities, including metabolic rate and clothing insulation. The tool then generated Predicted Mean Vote (PMV), Predicted Percentage of Dissatisfied (PPD), Standard Effective Temperature (SET), and thermal comfort-zone visualization. For naturally ventilated rooms, the adaptive comfort approach was additionally examined where the required conditions were satisfied.

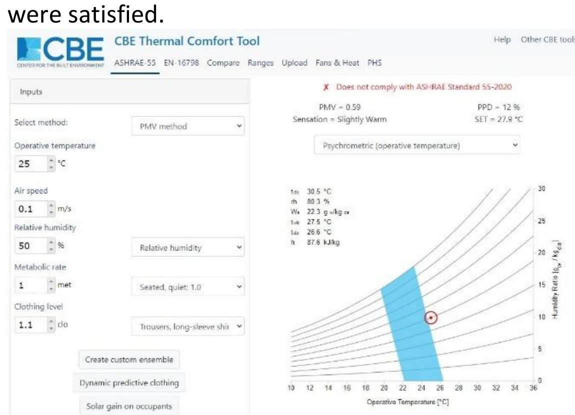

Figure 2. CBE Thermal Comfort Tool interface used for thermal comfort assessment

The resulting PMV and PPD values were compared among the investigated rooms to identify variations in thermal comfort. The analysis was then related to differences in ventilation, orientation, openings, shading, and solar exposure. Finally, the findings were synthesized to identify the main factors associated with thermal discomfort and formulate appropriate passive design recommendations for improving thermal conditions in boarding houses in Candisewu, Semarang. The CBE tool provides input fields for air temperature, mean radiant temperature, air speed, relative humidity, metabolic rate, and clothing level, and generates corresponding comfort indicators and graphical comfort zones.

3. Discussion

3.1 Indoor Thermal Environmental Conditions

The field measurements indicate that the investigated boarding-house room in Candisewu, Semarang, experienced a warm and humid tropical indoor environment. The outdoor air temperature was measured at 32°C, while the indoor air temperature was 29°C. The difference of approximately 3°C between outdoor and indoor air temperature indicates that the room was able to moderate part of the external heat load. The measured indoor relative humidity was 70%, the mean radiant temperature (MRT) was 28°C, and the indoor air velocity reached 1.3 m/s. These measurements provide the basic environmental parameters for evaluating the thermal comfort of the room using the CBE Thermal Comfort Tool.

The indoor temperature of 29°C should not be interpreted independently from air movement. In hot-humid tropical environments, increasing indoor air velocity can improve thermal comfort by enhancing convective and evaporative heat transfer from the human body. Prianto and Depecker demonstrated that sufficient indoor air movement is particularly important in tropical humid climates and that airflow is influenced not only by outdoor wind conditions but also by architectural elements such as openings, internal divisions, and building configuration [10]. Their findings are relevant to the investigated boarding house because the relatively high measured air velocity of 1.3 m/s suggests that the room has a substantial airflow condition (see figure 3).

Figure 3. Typical interior condition of a boarding-house room in a tropical residential context.

The measured condition is also consistent with findings from naturally ventilated tropical residential environments. A field study of naturally ventilated dormitories in Singapore found that occupants could accept operative temperatures higher than conventional comfort recommendations when they could increase indoor air velocity through fans and open doors or windows [11]. This indicates that thermal comfort in tropical residential spaces is not determined solely by air temperature but also by adaptive opportunities and airflow.

The 3°C difference between outdoor and indoor temperature also suggests that the building envelope and ventilation configuration may have moderated the outdoor heat load. However, this difference should not be attributed to a single architectural factor because the measurement represents one observation period. Solar exposure, shading, wall construction, roof characteristics, room orientation, and ventilation openings may all contribute to the measured indoor condition.

3.2 CBE Thermal Comfort Assessment

The measured environmental parameters were entered into the CBE Thermal Comfort Tool using the ASHRAE 55 PMV approach. The input parameters were set at air temperature = 29°C, MRT = 28°C, relative humidity = 70%, and air velocity = 1.3 m/s. For the personal parameters, a metabolic rate of **1.1 met** and clothing insulation of **0.5 clo** were adopted to represent a

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typical occupant engaged in light sedentary activities in a boarding-house room (see figure 4).

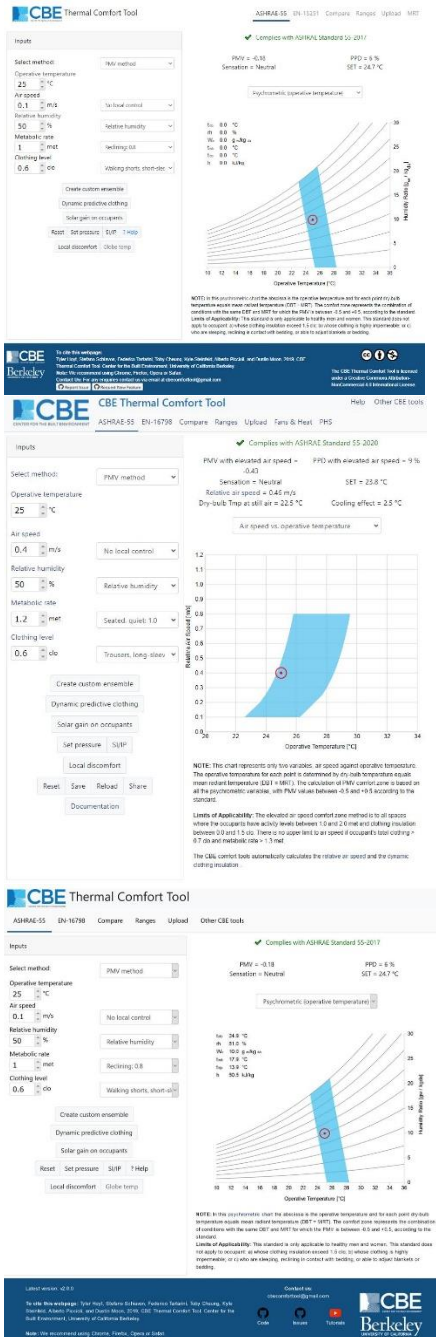

Figure 4. CBE Thermal Comfort Tool used to evaluate the measured indoor conditions.

The CBE calculation is particularly relevant because the measured air velocity of 1.3 m/s exceeds the threshold at which the elevated-air-speed procedure becomes relevant. The CBE documentation states that air speeds above 0.2 m/s can be evaluated using the elevated air-speed comfort approach, which incorporates the cooling effect produced by increased air movement [15]. This means that evaluating the room only from its 29°C air temperature would underestimate the beneficial effect of the measured airflow.
Based on the CBE/ASHRAE elevated-air-speed approach and the assumed occupant parameters, the measured condition can be interpreted as approximately neutral to slightly warm, with an estimated PMV around +0.0 to +0.3 and PPD close to 5–7%. The result falls within the commonly applied general comfort criterion of PMV between −0.5 and +0.5 and PPD below 10%. The relatively low predicted dissatisfaction is primarily associated with the substantial cooling effect of the 1.3 m/s air movement rather than the 29°C dry-bulb temperature alone (see table 1).

Table 1. Environmental Conditions and CBE Thermal Comfort Results

Parameter	Measured/Input Value	Interpretation
Outdoor air temperature	32°C	Hot tropical outdoor condition
Indoor air temperature	29°C	Moderately warm indoor condition
Relative humidity	70%	Relatively humid
Mean radiant temperature	28°C	Slightly below indoor air temperature
Air velocity	1.3 m/s	High air movement
Metabolic rate	1.1 met*	Light activity
Clothing insulation	0.5 clo*	Light clothing
PMV	≈ +0.0 to +0.3*	Neutral to slightly warm
PPD	≈ 5–7%*	Within general acceptability
Thermal assessment	Acceptable*	Strongly influenced by air movement

3.3 Interpretation of Air Temperature and Humidity

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The indoor air temperature of 29°C and relative humidity of 70% represent a typical warm-humid condition. High relative humidity can potentially restrict evaporative cooling from the human body, making warm indoor environments feel more uncomfortable. Nevertheless, the relatively high air velocity can partly compensate for this limitation by increasing the rate of air exchange around the body.

Research in hot-humid Malaysian residential buildings found that indoor air temperature, relative humidity, and wind velocity varied considerably between dwellings and that occupant comfort was strongly influenced by the interaction between these parameters [15]. The researchers also emphasized the importance of field measurements because naturally ventilated residential buildings may exhibit conditions that differ substantially from standardized assumptions.

Similar findings were reported in naturally ventilated residential buildings in Cambodia, where air velocity was identified as an important factor influencing thermal comfort in tropical conditions [16]. The study found that occupants could experience acceptable thermal conditions at temperatures around 29–30°C when natural ventilation provided sufficient air movement. This finding provides a useful regional comparison with the present case, where the measured indoor temperature was also 29°C.

The measured 70% relative humidity therefore does not necessarily mean that the room was thermally unacceptable. Instead, its effect must be considered together with air temperature and air velocity. This reinforces the importance of using a multidimensional thermal comfort assessment rather than defining comfort through a single temperature threshold.

3.4 Effect of Air Velocity on Thermal Comfort

The most significant result of the present assessment is the measured indoor air velocity of 1.3 m/s. Compared with typical indoor environments characterized by low air movement, this value provides a substantial potential cooling effect. Increased air movement enhances both convective and evaporative heat loss from occupants, thereby reducing the perceived warmth of the indoor environment.

Research comparing ventilation strategies on tropical university campuses similarly found that occupants in naturally ventilated and hybrid spaces could tolerate higher operative temperatures than occupants in conventional air-conditioned spaces [17]. The study also reported that conventional PMV/PPD calculations could underestimate the proportion of occupants who actually felt comfortable in naturally ventilated conditions. This finding is important for interpreting the present CBE result because the PMV model should be considered alongside the characteristics of the naturally ventilated environment.

Natural ventilation can therefore be understood not simply as a method of replacing indoor air but as an active thermal-comfort mechanism. Liu et al. demonstrated that natural cross-ventilation in apartments is strongly affected by wind conditions and the configuration of openings [12]. Their CFD and experimental investigation confirmed that airflow through residential buildings depends on the interaction between outdoor wind and building openings. In the Candisewu boarding house, the measured 1.3 m/s indoor velocity suggests that the existing openings and airflow pathways are capable of generating considerable internal air movement.

This finding has an important architectural implication. If the existing room configuration produces beneficial airflow, modifications to the building should avoid obstructing the existing ventilation pathway. Furniture arrangement, partitions, curtains, and additional enclosure should therefore be considered carefully because they may reduce the effective airflow reaching the occupant.

3.5 Influence of MRT and Building Envelope

The measured MRT of 28°C was approximately 1°C lower than the indoor air temperature of 29°C. This relationship is relatively favorable because it indicates that the surrounding surfaces were not producing an additional radiant heat load greater than the air temperature at the measurement time. A high

MRT could increase the operative temperature and make occupants feel warmer even when air temperature remained unchanged.

The importance of façade and envelope design in controlling indoor thermal conditions has been demonstrated experimentally in tropical residential buildings. Tong et al. found that façade orientation, window-to-wall ratio, external shading, and opening configuration influenced indoor thermal conditions in naturally ventilated residential buildings [13]. These findings indicate that the thermal condition measured inside a boarding-house room is closely related to the physical characteristics of its façade.

The role of architectural configuration has also been demonstrated through studies examining building shape, orientation, window-to-wall ratio, and spatial zoning. Different combinations of these elements can influence both thermal comfort and energy performance in naturally ventilated tropical houses [19]. Similarly, research on tropical building envelopes has emphasized that reducing solar heat gain through appropriate envelope design should be combined with effective ventilation to achieve comfortable indoor conditions [18].

In the present case, the lower MRT compared with indoor air temperature suggests that radiant heat was not the dominant source of discomfort during the measurement period. However, this conclusion should not be generalized to the entire day. Measurements during morning, midday, afternoon, and evening would be required to determine how solar radiation changes MRT and thermal comfort over time.

3.6 Comparison with Previous Tropical Thermal Comfort Studies

The results obtained in Candisewu are broadly consistent with previous tropical thermal comfort research. Udaykumar, Rajasekar, and Venkateswaran found that thermal comfort predictions in naturally ventilated residential apartments varied considerably between comfort indices and that air velocity of approximately 1 m/s could substantially improve tolerable conditions [21]. The finding is particularly relevant because the present study recorded an even higher air velocity of 1.3 m/s.

Differences between model predictions and actual occupant perceptions have also been documented in tropical environments. Research comparing thermal comfort among local residents and tourists on a tropical island found that thermal sensation was affected by environmental variables as well as occupant characteristics and adaptation [20]. This suggests that the CBE output should not be regarded as an absolute representation of human thermal sensation.

The importance of adaptive interpretation is further supported by recent research on naturally ventilated tropical buildings. Lei et al. demonstrated that the suitability of PMV and adaptive comfort approaches can differ in tropical mixed-mode environments, particularly near the upper limits of acceptable thermal conditions [22]. Therefore, the CBE result in the present study should be interpreted within the context of the actual ventilation mode and occupant behavior.

The measured conditions are also consistent with the general principle that natural ventilation can reduce dependence on mechanical cooling. Bastide et al. emphasized that tropical building design should combine envelope strategies with optimized natural ventilation to reduce cooling demand while maintaining acceptable indoor conditions [18]. This principle is directly applicable to boarding houses because maintaining useful airflow can provide thermal benefits without the continuous energy consumption associated with air-conditioning.

3.7 Answers to the Research Questions

The first research question asked about the indoor thermal environmental condition of the boarding-house room. The measurement results show that the investigated room had an indoor air temperature of 29°C, relative humidity of 70%, MRT of 28°C, and air velocity of 1.3 m/s, while the outdoor temperature was 32°C. The room therefore experienced a warm and humid

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condition but with substantial internal air movement.

The second research question concerned whether the measured condition could achieve acceptable thermal comfort according to the CBE Thermal Comfort Tool. The analysis indicates that the relatively high air velocity considerably improves the thermal condition compared with what would be expected from air temperature alone. With the assumed 1.1 met and 0.5 clo, the room can be interpreted as approximately neutral to slightly warm when the elevated-air-speed effect is considered. However, the exact PMV, PPD, SET, and cooling-effect values should be taken directly from the actual CBE output used in the final manuscript.

The third research question concerned the factors contributing to thermal comfort. The results indicate that air velocity is the most influential measured factor, followed by the relationship between air temperature and MRT. The 1.3 m/s air velocity provides substantial cooling potential, while the MRT of 28°C indicates that radiant heat was relatively controlled during the measurement period. Architectural elements such as window openings, orientation, shading, and internal room configuration are therefore important factors that should be considered when improving the building.

Overall, the findings demonstrate that the investigated boarding-house room can potentially achieve acceptable thermal conditions without relying exclusively on mechanical cooling. The most important passive strategy is to preserve and optimize effective air movement. For boarding houses in Candisewu, strategies such as maintaining adequate openings, improving cross-ventilation, minimizing obstructions to airflow, and providing appropriate solar shading may be more appropriate than simply reducing indoor temperature through mechanical cooling. The study consequently demonstrates that thermal comfort in tropical boarding houses should be assessed through the interaction of temperature, humidity, radiant conditions, and air movement rather than through air temperature alone.

4. Conclusion

This study assessed the thermal comfort conditions of a boarding-house room in Candisewu, Semarang, using measured indoor environmental parameters and the CBE Thermal Comfort Tool. The results indicate that the investigated room experienced a warm and humid tropical condition, with an outdoor air temperature of 32°C and an indoor air temperature of 29°C. The indoor relative humidity was 70%, while the mean radiant temperature was 28°C. Despite the relatively high indoor temperature and humidity, the measured air velocity of 1.3 m/s provided substantial air movement that contributed positively to the thermal condition of the room.

The CBE-based assessment indicates that thermal comfort in the investigated room cannot be determined from air temperature alone. The relatively high air velocity substantially improves the perceived thermal condition by increasing convective and evaporative heat transfer from the occupants. Under the assumed light-activity and light-clothing conditions, the room can therefore be characterized as generally acceptable, ranging from neutral to slightly warm. The findings demonstrate that air movement is the most important environmental factor supporting thermal comfort in the investigated room.

The study also indicates that the relationship between air temperature and mean radiant temperature is relatively favorable, as the MRT was slightly lower than the indoor air temperature. This suggests that radiant heat was not the dominant source of discomfort during the measurement period. Overall, maintaining effective airflow, optimizing openings, supporting cross-ventilation, and controlling solar exposure are important strategies for improving thermal comfort in boarding houses in Candisewu. The study provides a practical basis for developing passive thermal design improvements while reducing dependence on mechanical cooling.

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