SSRG International Journal of Civil Engineering
ISSN: 2348-8352/ https://doi.org/10.14445/23488352/IJCE-V13I2P115

Volume 13 Issue 2, 208-225, February 2026

Original Article

Thermal Comfort Analysis of Students in Brick-Walled and Wooden-Walled Classrooms of Islamic Boarding Schools in the Tropics

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Received: 21 November 2025 Revised: 23 December 2025 Accepted: 24 January 2026 Published: 11 February 2026

Abstract *- In tropical areas, brick and wood are commonly utilised for wall construction. However, building occupants may experience temperature discomfort if inappropriate materials are used. To identify the ideal most comfortable temperature range and to increase energy efficiency, a field study was conducted in Majene City, Indonesia (tropical climate). Wooden-walled and brick-walled classrooms were used to measure environmental parameters, and questionnaires were distributed to assess students' thermal comfort. The neutral temperature of actual voting, obtained using Griffith's method and regression analysis, was compared with the result from the PMV/PPD and adaptive methods. The results showed that whereas classrooms with wooden walls had higher air temperatures, from 27.64 °C to 33.19 °C from morning to midday, classrooms with brick walls had air temperatures approximately between 27.52 °C and 30.67 °C from morning to midday. In addition, student responses indicate that brick-walled classrooms are more comfortable and have better thermal performance than wooden-walled classrooms. Griffith's method and regression analysis showed that the neutral temperatures of brick-walled classrooms (28.50 °C and 29.57 °C, respectively) were lower than those of wooden-walled classrooms (28.93 °C and 29.99 °C, respectively).*

Keywords *- Thermal comfort, Brick-walled, Wood-walled, Naturally ventilated, School classrooms.*

1. Introduction

The ASHRAE-55 standard defines "thermal comfort as that condition of mind which expresses satisfaction with the thermal environment." A condition is deemed comfortable under this requirement when at least 80% of respondents regard the surroundings as thermally acceptable [1]. ASHRAE-55 [1] and ISO 7730 [2] are among the most widely adopted guidelines for thermal comfort design worldwide. In Indonesia, thermal comfort design refers to the national standard SNI 03-6572-2001 [3].

Currently, to define thermal comfort, there are two standard methods: the first is the Fanger (PMV/PPD) [4]. The PMV-PPD method is calculated based on physical and physiological factors [4]. The second is the method proposed by de Dear et al. [5, 6] and Humphreys et al. [7, 8] (adaptive comfort). The adaptive method has the principle that people carry out strategic activities, influenced by climatic, psychological, social, technological, and cultural factors, to restore thermal comfort when changes occur that cause thermal discomfort [7].

Thermal comfort in office buildings has been linked to increased occupant performance and productivity in several prior studies [9–12]. Nevertheless, thermal comfort considerations extend beyond office buildings [10] and are also advised for various building types, including educational facilities [13]. Given differences in occupants, activities, clothing, and patterns of use relative to other building types, maintaining thermal comfort in schools and universities requires particular attention [13, 14].

Providing indoor thermal comfort is crucial, as students spend most of their time at school. An uncomfortable thermal condition in educational buildings can lead to student dissatisfaction [14]. Ideal thermal comfort conditions in classrooms have been shown in numerous studies to be a key element influencing student performance, health, and well-being [15–18]. In a study on naturally ventilated classrooms, Cen et al. [19] found that students' cognitive performance dropped by 18.1% under warm and 9.2% under slightly warm thermal sensations compared to neutral settings. In a related study, Cen et al. [20] also found that warm environments impaired cognitive abilities, with secondary school students showing a decline of up to 17% and university students a decrease of 10%. Uncomfortable thermal environments have been shown to impair productivity, lower concentration, and cause fatigue and drowsiness [21–23]. Ultimately, suboptimal classroom environments may impose long-term health burdens on students [16].

Over the past few years, numerous studies have examined classroom thermal comfort, considering seasonal factors, classroom cooling mechanisms, and educational stages [14, 15]. Many studies have examined thermal comfort across diverse climates, including in classrooms in tropical climates in Indonesia [24], Bangladesh [25], India [26], Singapore [27], and Malaysia [28]. Subtropical climates in southern Brazil [29], Australia [30], and China [31]. Temperate climate in the United Kingdom [32, 33]. And Mediterranean climate in Spain [34], Italy [35], and Portugal [34].

Hamzah et al. [24] reported that students in tropical Indonesia, with naturally ventilated classrooms, were relatively tolerant of their hot thermal environment. Using a regression method, a neutral temperature of approximately 29 °C was estimated; this was 6 °C higher than the PMV regression estimate. Similar findings in Malaysian classrooms by Firman et al. [28] reported a neutral temperature of approximately 29.3 °C, and in Indian classrooms, Mishra et al. [26] reported a neutral classroom temperature of approximately 29 °C. Wong et al. [27] also reported a neutral temperature in Singaporean classrooms of approximately 28.8 °C; the PMV value calculation was a lower temperature than the actual vote. In a subtropical climate, Custódio et al. [29] reported that the comfortable temperature of air-conditioned classrooms was approximately 21.8–22.1 °C, and that of naturally ventilated classrooms was approximately 21.8–22.1 °C in southern Brazil, and that the PMV model used in this study could not accurately predict student thermal comfort. Based on findings in subtropical Australia involving 2850 primary and secondary school students, de Dear et al. [30] reported that students considered neutral and preferred classroom conditions when the operative temperature was 22.58 °C. With a neutral temperature, the children's comfort level was lower than that of adults, around 1-2°C.

In the United Kingdom, Teli et al. [32] conducted a study involving 1300 primary school children in a temperate climate. They reported a neutral temperature in classrooms of approximately 20.8 °C, and children's comfort level was lower than that of adults, approximately 2 °C. Based on findings by Lyu et al. [33] in the United Kingdom, with a similar climate, they reported about 23.9 °C as the neutral temperature of students at the University of London. Romero et al. [34] linked clothing to differences in comfort temperature preferences, despite being in the same climate, namely the Mediterranean climate, between students at the University of Spain and Portugal. Students in Spain preferred a comfort temperature of approximately 24.70 °C, which is much cooler than in Portugal, where the preferred temperature was approximately 26.40 °C. Although thermal comfort in classrooms has been widely studied, considering the various factors that have been described, building characteristics—especially building envelope materials—are often only explained quantitatively and are set aside as secondary factors, with almost no in-depth research being conducted as the main factor in determining thermal comfort in classrooms.

The local climate [36, 37], the shape and orientation of structures [38, 39], and the properties of building materials or envelopes [40, 41] are the main determinants of indoor thermal environments. According to several studies, the primary factors influencing thermal comfort within buildings are the building envelope [40–45] and limiting excessive heat transfer from the exterior environment [44, 46]. Heat loss and energy waste in a building occur through the building envelope, which is approximately 50% or more [47]. Research conducted by Kini et al. [48] showed that careful selection of building envelopes can reduce thermal discomfort by approximately 80.75% and about 5.82 °C thermal environmental comfort can be increased, about 19.25% of the cooling load can be reduced, as well as saving energy up to 77% in summer in warm and humid climates.

Building envelope systems generally fall into one of two categories: opaque or transparent. Whereas windows and fenestration constitute the transparent system, walls, roofs, and floors constitute the opaque system [41, 49]. The building envelope's primary component, namely the walls, is very important to control external climate influences through conduction. Indoor thermal comfort can be maintained by implementing passive thermal control techniques with well-designed walls [49]. The walls of a building function to reduce the entry of heat from outside in hot areas and to reduce heat loss inside the room in cold climates. This happens as a result of the temperature differential between inside and outside the building [50]. Kuczyński's research in temperate Poland on two nearly identical buildings with only differences in wall material: traditional brick wall material vs lightweight frame wall material, showed that the building with traditional brick wall material had the best performance, reducing indoor temperatures by an average of 2.8 degrees, and reducing cooling energy requirements by 65%-75% [42]. Thus, it is feasible to meet established criteria for indoor thermal comfort by selecting appropriate wall materials and designs.

According to the 2024 Indicators for Housing and Health of Environment report by Statistics Indonesia (BPS) [51], buildings in Indonesia employ a wide variety of wall materials. In urban areas, approximately 89.96% of houses use brick walls, 8.02% use wooden boards, and 2.01% still use bamboo. In contrast, in rural areas, approximately 68.65% of houses use brick walls, 26.52% use wood/boards, and 4.82% continue to use woven bamboo. Material costs, the community's economic conditions, and the availability of local resources largely influence the variation in wall material usage. However, residential and educational buildings in Indonesia are often constructed without sufficient consideration of climate and environmental factors, thereby reducing energy efficiency and compromising thermal comfort [24, 52]. Assessing building performance in providing indoor thermal comfort is essential both before and after construction, whether for schools, offices, residences, or hotels [53].

Although numerous studies over the past decade have examined classroom thermal comfort in tropical regions [24–28], research specifically analyzing thermal comfort in brick-walled and wood-walled classrooms remains very limited. Most prior studies focused on the general thermal conditions of classrooms [24–28], student adaptation [24, 25], movement and air quality [26, 28], and clothing variations [26]. Research explicitly examining the impact of different wall materials on classroom thermal comfort is limited. Existing findings on the thermal performance of wall materials also show inconsistent results.

For example, Hermawan et al. [54] reported that brick-walled houses in coastal areas had less favorable thermal performance (PMV = 1.71; average indoor temperature = 29.2 °C) than wooden-walled houses in mountainous regions (PMV = 1.01; average indoor temperature = 28.7 °C) in tropical climates. Regional differences may contribute to the inconsistencies in previous studies. Furthermore, comparative studies directly comparing brick-walled and wooden-walled classrooms within the same building complex under uniform climatic conditions, room and opening configurations, and usage patterns are still rare.

This study conducted a field study at Ihyaul Ulum DDI Islamic Boarding School in Majene Regency, Indonesia, in a tropical climate zone. This case study location provided a unique opportunity to compare different building envelope systems within the same classroom building, with brick-walled classrooms located on the first level and wood-walled classrooms on the second level. Initial observations and interviews with teachers and students indicated that second-floor classrooms with wood walls felt significantly hotter during the day than brick-walled classrooms. This finding contradicts prior research [54], underscoring the need for further empirical investigation. Therefore, evaluating and comparing the thermal performance and comfort of brick-walled and wood-walled classrooms through field measurements to provide new empirical contributions to the understanding of wall material performance in educational buildings in tropical regions is the goal of this study.

2. Methodology

2.1. Research Sample and Respondent

An aerial view of Building A is presented in Figure 1 (upper left), which shows the case study building, the naturally ventilated Madrasah Aliyah building at DDI Ihyaul Ulum Baruga Islamic Boarding School (3° 30' S, 118° 57' E), Majene Regency, Indonesia. The building is shaped like an L, with five classrooms and a storage room on the first level and five classrooms with wooden walls on the second level, as shown in Figure 1 (upper right).

Four classrooms were selected as research samples based on their relatively similar characteristics, including room size, number of openings, and total opening area. The most notable differences were the wall materials and room elevation. Respondents were then selected based on the total number of students in the four sample classrooms. Classrooms with brick and wooden walls were surveyed on the same days over two days to avoid bias. Table 1 presents the classroom characteristics and survey time of the samples.

During the survey period, the weather was mostly sunny. The specific characteristics of the sample classrooms surveyed are as follows. The brick-walled classroom measures 8 m × 7 m (56 m²) and has a ceiling height of approximately 2.7 m. Window openings are located on the northeast and southwest sides, each providing a combined window and ventilation area of 8.1 m². On the southwest side, a door and additional ventilation openings have a total area of 2.25 m². Natural ventilation is facilitated by perforated vents, windows, and doors that students can open and close freely. As shown in Figure 2(a), the walls are made of brick plastered with a thin layer of cement and a layer of paint, with a total thickness of 0.15 m.

Similarly, the wood-walled classroom is also the same size as the brick-walled classroom, measures 8 m × 7 m (56 m²), and has a ceiling height of approximately 2.7 m. Window openings are located on the northeast and southwest sides, each providing a combined window and ventilation area of 8.1 m². On the southwest side, a door and additional ventilation openings have a total area of 2.25 m². Natural ventilation is facilitated by perforated vents, windows, and doors that students can open and close freely. Furthermore, the walls are constructed of painted wooden planks, with a total thickness of 0.025 m (Figure 2(b)).

Table 1. Characteristics of the surveyed classrooms and samples

No	Classrooms Name	Type Wall	Date of Survey	Number of Students
1	X Agama 1 (Classroom 1)	Brick-Walled	May 19, 2025	18
2	X Agama 2 (Classroom 2)	Brick-Walled	May 20, 2025	21
3	X Agama 4 (Classroom 3)	Wood-Walled	May 19, 2025	21
4	XI Agama 2 (Classroom 4)	Wood-Walled	May20, 2025	29
Total				**89**

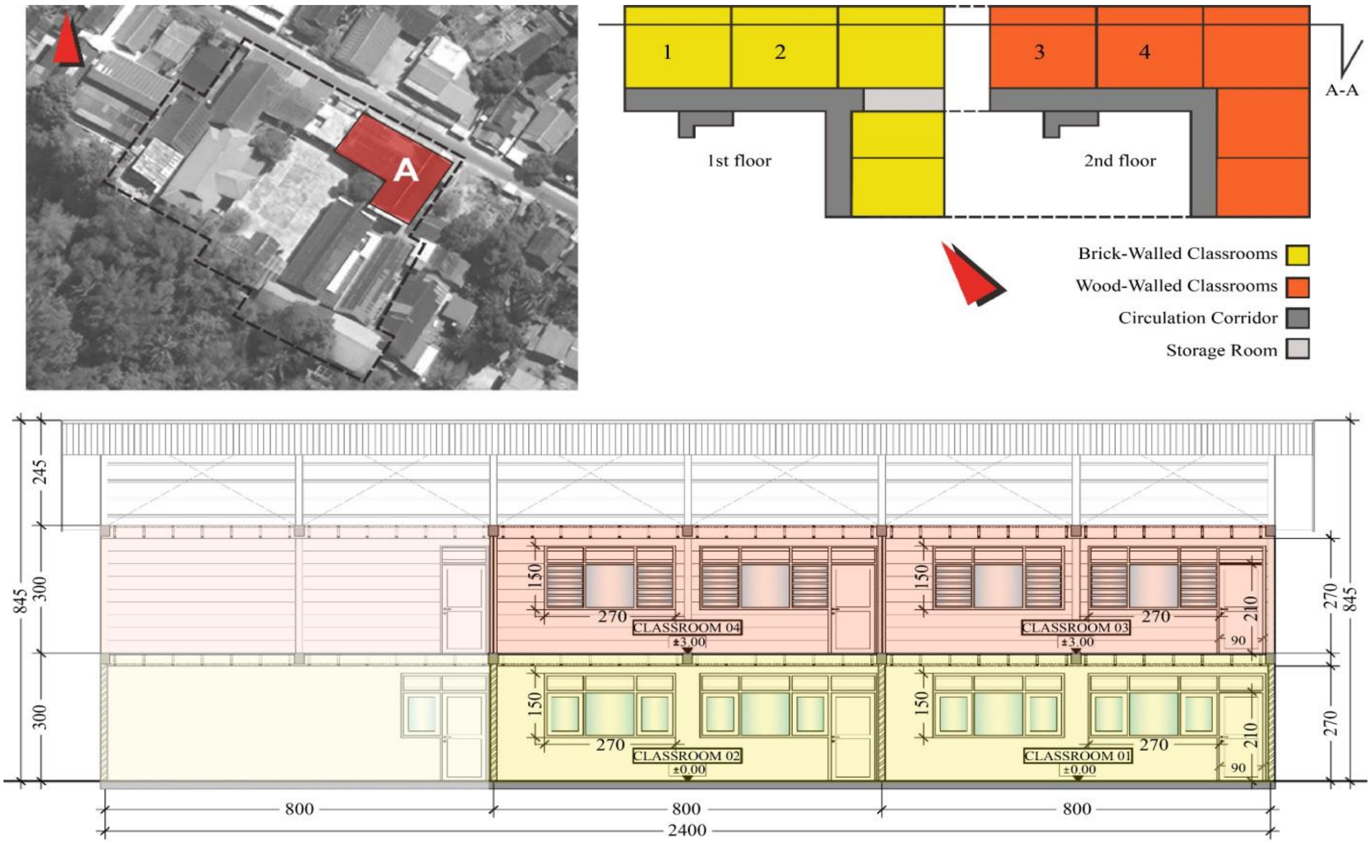

Fig. 1 The secondary school (A, surveyed) taken from Google Earth is shown on the upper left, its schematic plans are shown on the upper right, and the schematic section A-A of the surveyed school is shown on the bottom

Fig. 2 Classroom situations surveyed: (a) brick-walled, and (b) wooden-walled.

2.2. Research Instrument

The layout of the measurement instruments is shown in Figure 3(a) for the brick-walled classroom on the first floor and in Figure 3(b) for the wooden-walled classroom on the second floor. Three thermal measurement points were placed in each class, with all instruments positioned among the students to represent better the temperatures they experienced. Instrument installation is performed before class hours begin, and measurements begin at the start of the learning session and continue until the end. With all instruments placed 1 m above the floor, as shown in Figure 4.

Indoor environmental parameters were measured using three types of instruments. The WBGT & Heat Index Logger AZ 87786 (WBGT) recorded classroom globe temperature, air temperature, and humidity (Figure 4(a)). The HOBO UX100-011 (Hobo 1) recorded classroom air temperature and relative humidity (Figure 4(b)). Meanwhile, the HOBO U12-012 (Hobo 2), in conjunction with a Hot Wire Anemometer (ESV106), was employed to measure classroom air temperature, relative humidity, and air velocity (Figure 4(c)). Table 2 is a summary of the specifications of the instruments used.

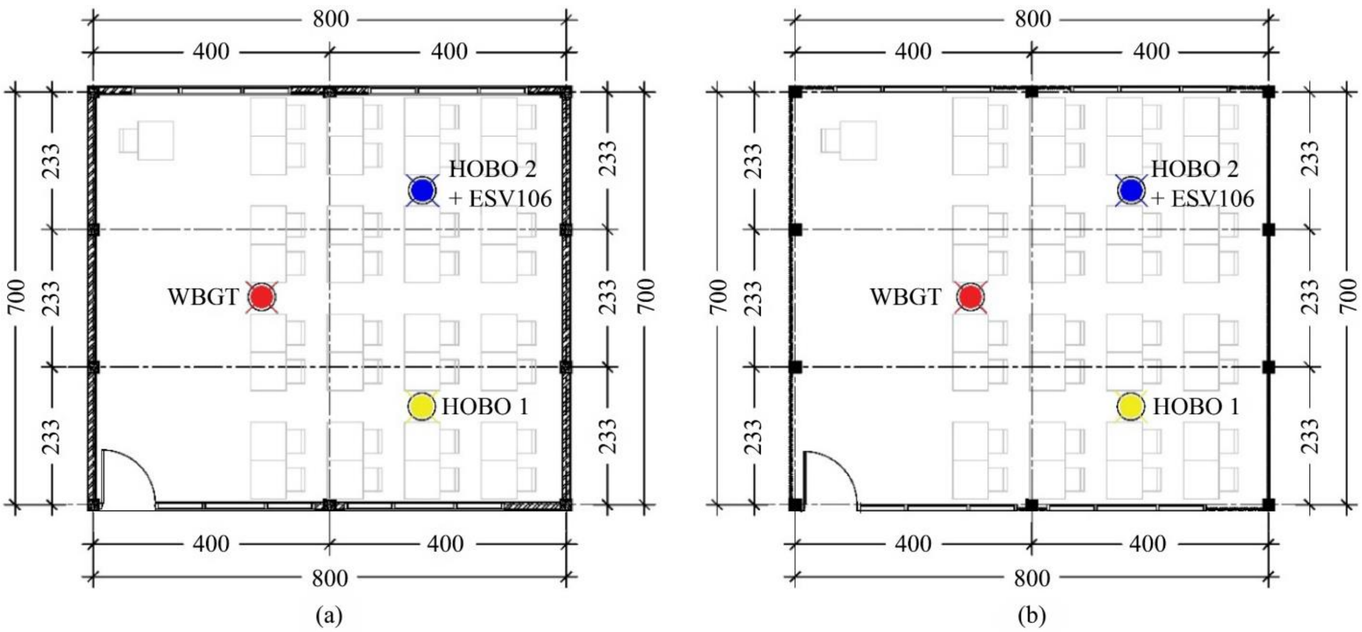

Fig. 3 Instrument points: (a) Brick-walled classroom, and (b) Wooden-walled classroom.

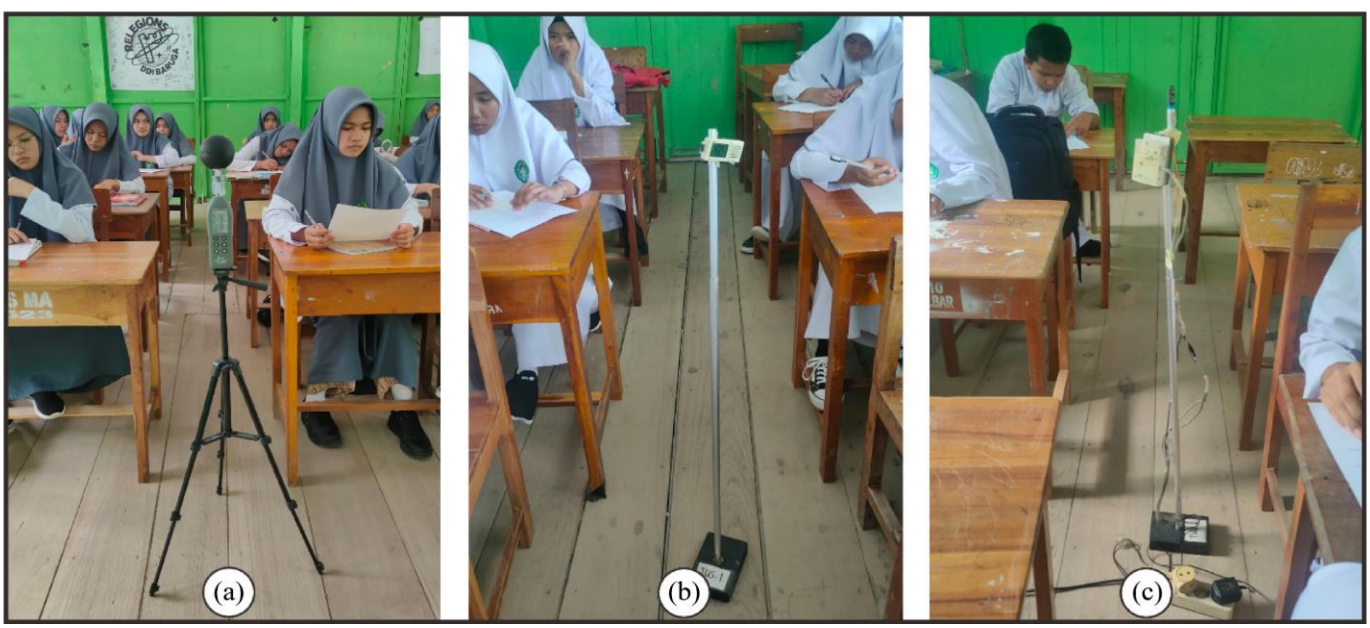

Fig. 1 Instrument situations: (a) WBGT (WBGT & Heat Index Logger AZ 87786); (b) Hobo 1 (HOBO UX100-011); (c) Hobo 2 (HOBO U12-012) + Hot Wire Anemometer (ESV106)

Table 2. Specifications of the thermal instruments for measurement are used

Instrument Name	Range	Accuracy
WBGT & Heat Index Logger AZ 87786 • Globe temperature profile • Air temperature profile • Relative humidity	• 0 ~ 80 °C • 0 ~ 50 °C • 0,1 ~ 99,9% RH	• ±0.21 °C (15~ 40 °C) • ±0.1 °C • ±3% (at 10 ~ 90 %)
Hobo UX100-011 (Hobo 1) • Air temperature profile • Relative humidity	• 20 ~ 70 °C • 5 ~ 95% RH	• ±0,21 °C • ±2,5%
Hobo U12-012 (Hobo 2) • Air temperature profile • Relative Humidity	• -20 ~ 70 °C • 5 ~ 95% RH	• ±0,21 °C • ±2,5%
Hot Wire Anemometer (ESV106) • Airflow speed	• 0,01 – 20 m/s	Not available

2.3. Data Collection

2.3.1. Objective Survey

This objective survey involved completing personal data and measuring the thermal environment. Respondents were asked to provide demographic data such as age, height, weight, clo, met, and gender, the results of which are shown in Table 3. The average height, weight, and age of students in the brick-walled classrooms were 153.9 cm, 49.8 kg, and 16 years, respectively, whereas those in the wooden-walled classrooms were 154.3 cm, 50.6 kg, and 16 years, respectively. All students wore Islamic dormitory uniforms, and all female students were required to wear a hijab. The average metabolic rate of students was 1.1 MET, and most students engaged in similar learning activities, such as sitting, writing, and reading. Some students also reported walking, standing, and relaxing as moderate activities (metabolic rates ranging from 1.2 to 1.7 MET).

Table 1. Demographic characteristics of students in brick-walled and wood-walled classrooms

		Age (Year)	Height (cm)	Weight (kg)	clo	met	Gender
BW	Mean	16	153.9	49.8	0.80	1.1	Woman = 28 Man = 11
	Median	16	152.0	50.0	0.80	1.0	
	S.D	0.6	7.3	6.8	0.04	0.3	
	Min	15	144.0	36.0	0.70	1.0	
	Max	18	172.0	65.0	0.80	1.7	
WW	Mean	16	154.3	50.6	0.80	1.1	Woman = 36 Man = 14
	Median	16	153.0	50.0	0.80	1.0	
	S.D	0.7	7.5	8.6	0.04	0.2	
	Min	15	141.0	35.0	0.71	1.0	
	Max	18	170.0	80.0	0.80	1.7	

Note: BW = Brick-Walled, WW = Wood-Walled

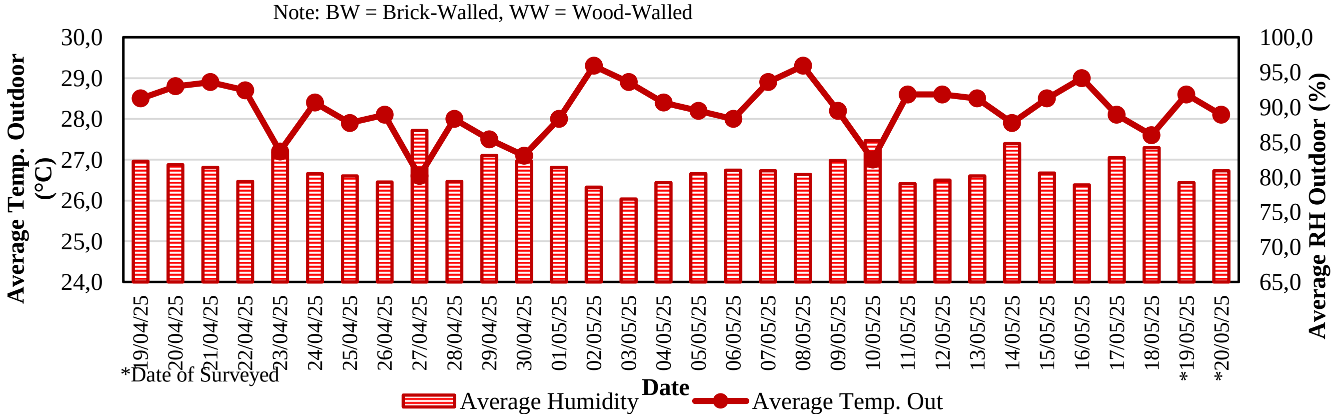

Fig. 5 Outdoor meteorological data for the 30 days preceding the survey were collected

Indoor classroom thermal environmental parameters (air temperature, air humidity, globe temperature, and air velocity) were measured at 30-minute intervals from 08:00 to 14:30. As shown in Figure 3, only three instrument points per classroom were used to record data due to limited equipment availability. Average outdoor air temperature data were obtained from the Majene Regency Meteorological Station (3° 33′ S, 118° 58′ E), approximately 6 km from the study site, as shown in Figure 5.

2.3.2. Subjective Survey

Assessing students' thermal comfort levels was the goal of the subjective survey. Adapted from Hamzah et al. [24], the questionnaire comprised four items addressing the assessment of thermal sensation, comfort, acceptance, and preference. The time of the learning sessions was 7:30 to 14:00. The questionnaire survey was conducted during the morning session (09:30 to 10:00) and the midday session (11:30 to 12:00) in order to give students enough time to acclimate to the classroom environment. According to Jia et al. [55], a minimum adaptation period of 40 minutes is recommended when evaluating thermal comfort during low activity intensities. The numerical scale used for assessing students' acceptability, preference, thermal comfort, and temperature feeling is summarized in Table 4.

2.4. Analyzing and Processing Data

2.4.1. Thermal Environment Measurement Calculation

The data analysis in this study employed a quantitative approach, involving statistical calculations and tests using SPSS 27 software. Classroom measurement data (Ta, RH, V, met, clo) and derived values (Top, MRT) were subsequently calculated. PMV and PPD indices were obtained using the online CBE Tool developed by Tartarini et al. [56]. The classroom operative temperature (Top) was calculated from the air temperature (Ta) and the indoor radiant temperature (MRT). According to the ASHRAE Standard 55-2020 [1]. Equation 1 used to calculate the classroom operative temperature (Top):

$$T_{op} = AT_a + (1 - A)MRT \quad (1)$$

The coefficient A equals 0.7, 0.6, or 0.5 for air velocity (V) ranges of 0.6–1.0 m/s, 0.2–0.6 m/s, and ≤0.2 m/s, respectively. Subsequently, the classroom indoor radiant temperature (MRT), which Equation 2 represents, was determined using the formula given in the ASHRAE Handbook [57]:

$$MRT = \left[\left(T_g + 274\right)^4 - \frac{1.1 \times 10^8 V^{0.6}}{\varepsilon D^{0.4}}\left(T_g - T_a\right)\right]^{\frac{1}{4}} - 273 \quad (2)$$

Where D represents the diameter of the black ball used, which is 0.075 m in this case, and ε is the emissivity of the black globe (0.95). The classroom operative temperature (Top) and the prevailing mean temperature outside (tpma(out)) serve as the foundation for adaptive thermal comfort estimates. Based on ASHRAE-55 2020 [1], the formula for calculating the prevailing mean temperature outside, as shown in Equation 3, is as follows:

$$t_{pma(out)} = (1 - \alpha)(t_{out-1} + \alpha^1 t_{out-2} + \alpha^2 t_{out-3} \ldots) \quad (3)$$

The mean outside temperature the day prior to the measurement is tout-1, the mean outside temperature two days prior to the measurement is tout-2, and so on; and α is the average rate of adjustment to ambient temperature variations, where α is a constant that ranges from 0 to 1. This research follows Nicol and Humphreys' study [58]: α should be 0.8.

2.4.2. Independent T-Test

In this study, the variables tested were the operative temperatures of brick-walled and wood-walled classrooms. The differences were considered statistically significant if the t-statistic's absolute value (|t value|) > t-table and Sig. (2-tailed) < 0.05.

Table 4. Numeric scale thermal perception response

Numeric Scale							
TSV (Thermal Sensation Vote)	Cold (-3)	Cool (-2)	Slightly Cool (-1)	Neutral (0)	Slightly Warm (+1)	Warm (+2)	Hot (+3)
TCV (Thermal Comfort Vote)	Much Too Cool (-3)	Too Cool (-2)	Comfortably Cool (-1)	Comfortable (0)	Comfortably Warm (+1)	Too Warm (+2)	Much Too Warm (+3)
TP (Thermal Preference)	-	-	Prefer to Increase (-1)	No Change (0)	Prefer to Decrease (+1)	-	-
TA (Thermal Acceptance)	-	-	-	Acceptable (0)	No Acceptable (+1)	-	-

2.4.3. Regression Analysis Method and Griffiths' Method

Previous studies have predicted neutral temperature values using regression analyses [24-35]. With a significance level of 0.05, Spearman's rank correlation coefficient is used for data that is not normally distributed. The dependent variables in this study are the TSV and PMV values, while the independent variable is the classroom operative temperature. However, when the number of samples is small [25], the coefficients obtained from simple regression analysis are inconsistent [53, 59]; therefore, the Griffiths' method [8, 60] was used as an alternative in this study. To calculate the neutral temperature, the Griffith equation was used, as indicated in Equation 4:

$$T_c = T_{op} + (0 - TSV)/\alpha \quad (4)$$

Where 0 is a neutral value, it can be substituted with another TSV scale that represents a neutral sensation [28], where Griffith's constant is denoted by α. In accordance with previous studies reporting higher correlations [8, 28, 34, 61], Griffith's constant of 0.5 was used in this study.

3. Results

3.1. Objective Measurement of the Classrooms' Thermal Environment

Measurements for classrooms with wood and brick walls were taken concurrently between 8:00 and 14:30 under naturally ventilated conditions. Students were allowed to close and open doors and windows in these classrooms as they saw fit. According to the findings, the mean difference in indoor air temperature (Ta) between classrooms with wood and brick walls was roughly ±1.68 °C (mean value difference), with the wood-walled classrooms having a higher temperature. The lowest temperatures in both classroom types were recorded at 08:00, measuring 27.52 °C and 27.64 °C, respectively, in the brick-walled and wood-walled classrooms. The highest temperatures occurred at 14:00, reaching 30.67 °C for the brick-walled classroom and 33.19 °C for the wood-walled classroom.

The lowest relative humidity (RH) values in both classroom types were also observed at 14:00, measuring 67.01% in the brick-walled classroom and 58.10% in the wood-walled classroom. Conversely, the highest relative humidity (RH) was recorded at 08:00, with 79.92 % in the brick-walled classroom and 79.26% in the wood-walled classroom. The mean RH difference between the two classroom types was approximately ±6.85% (mean value difference), with the brick-walled classroom exhibiting higher humidity levels. Air velocity in both classrooms was relatively low, averaging approximately 0.25 m/s. Table 5 displays the thermal conditions in the classrooms.

Figure 6 presents a more detailed comparison profile of the average operative temperature between the brick-walled and wood-walled classrooms, with measurement intervals of every 30 minutes. The operative temperature (Top) of a wooden-walled classroom is higher than that of a brick-walled classroom; the mean operative temperature differential between the two types of classroom walls was approximately 1.55°C.

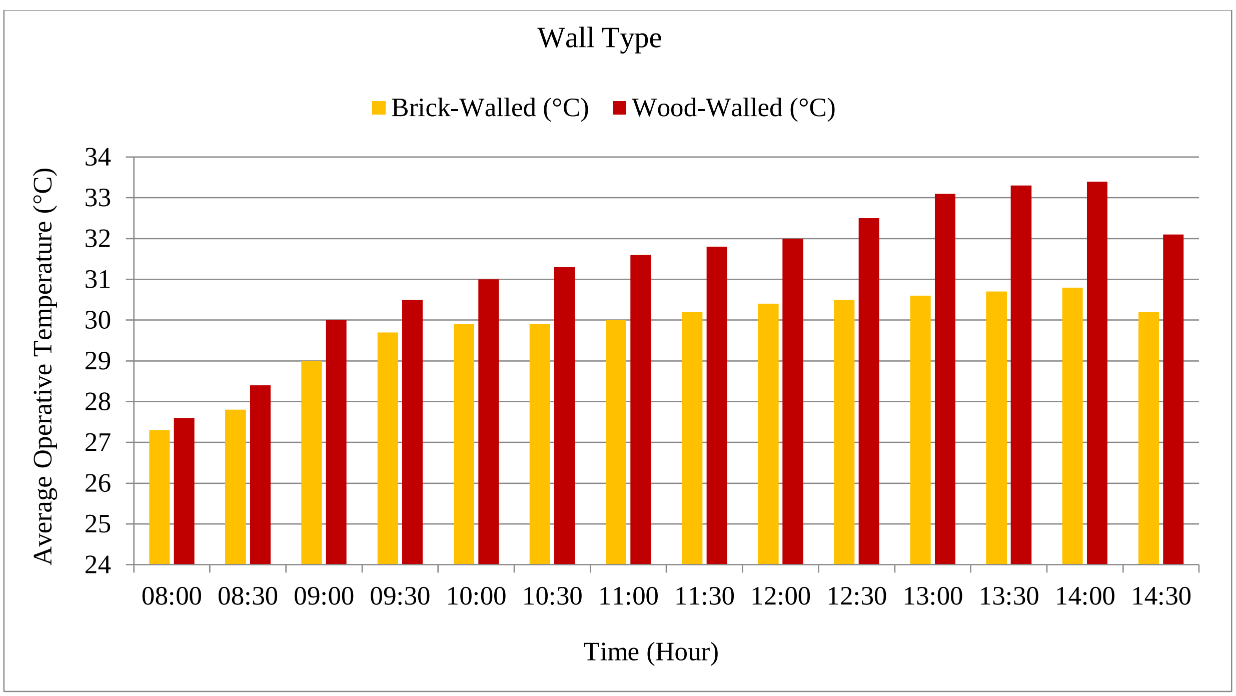

Fig. 2 Operative temperature profiles of brick-walled and wood-walled classrooms

Table 2. Thermal conditions of the classrooms that were surveyed

		T_g (ºC)	T_a (ºC)	V (m/s)	RH (%)	MRT (ºC)	T_{op} (ºC)
BW	Mean	29.78	29.65	0.32	73.92	29.98	29.78
	Median	30.10	30.00	0.26	73.81	30.30	30.10
	SD (+/-)	1.04	1.00	0.14	3.75	1.13	1.03
	Min	27.40	27.52	0.2	67.01	27.26	27.39
	Max	30.75	30.67	0.64	79.92	30.85	30.74
WW	Mean	31.34	31.33	0.24	67.07	31.35	31.33
	Median	31.70	31.69	0.25	66.35	31.46	31.70
	SD (+/-)	1.74	1.70	0.09	6.25	1.83	1.74
	Min	27.60	27.64	0.11	58.10	27.56	27.60
	Max	33.45	33.19	0.42	79.26	33.65	33.42

Note: BW= Brick-Walled, WW= Wood-Walled, T_g= globe temperature, T_a= air temperature, V= air velocity, RH= relative humidity, MRT= mean radiant temperature, T_{op}= operative temperature

3.2. Students' Subjective Responses to the Classrooms' Thermal Conditions

3.2.1. Thermal Sensation Vote (TSV)

Figure 7 displays actual votes on the thermal environment in classrooms with wood and brick walls based on the TSV (Thermal Sensation Vote) indicator.

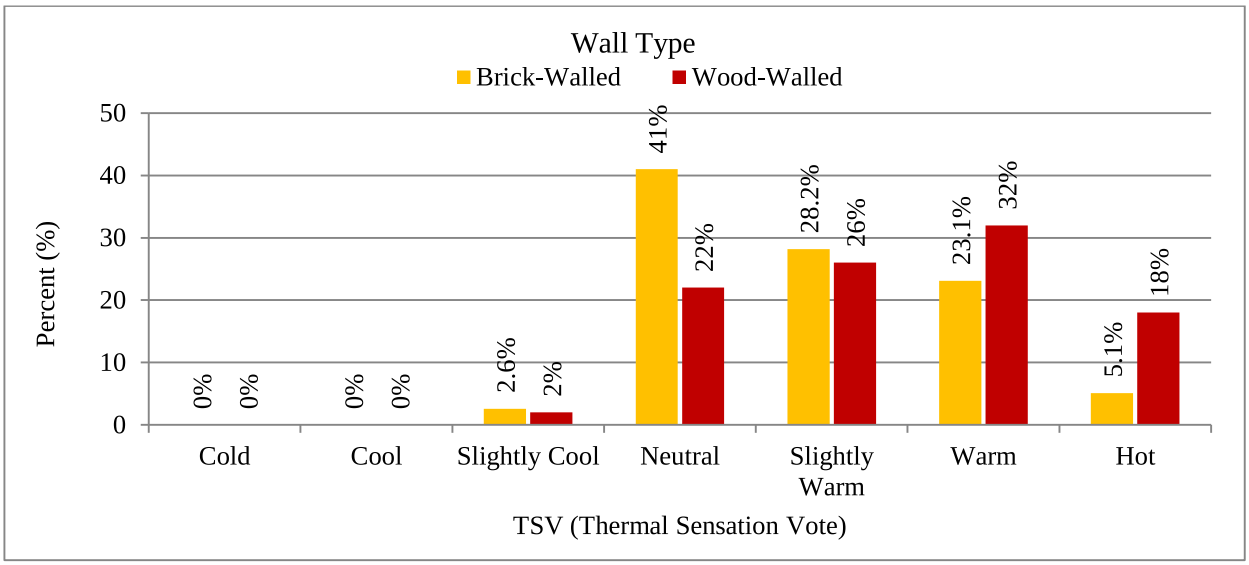

Fig. 3 Comparison chart of TSV percentage of brick-walled classrooms and wooden-walled classrooms

In both types of classrooms, the majority of students reported feelings that ranged from 0 (neutral) to +3 (hot). In the brick-walled classroom, approximately 41.0% of students selected the neutral option (0), about 28.2% and 23.1% chose slightly warm (+1) and warm (+2), around 5.1% reported hot (+3), and only 2.6 % chose slightly cool (-1). Conversely, in the wood-walled classroom, a majority (32%) reported warm sensations (+2), and approximately 18% chose hot (+3), consistent with the relatively high measured indoor temperatures. Additionally, 26% of students selected slightly warm (+1), 22% selected neutral (0), and only 2% selected slightly cool (-1).

3.2.2. Thermal Comfort Vote (TCV)

Figure 8 displays actual votes on the thermal environment in classrooms with wood and brick walls based on the TCV (thermal comfort vote) indicator. The responses indicate that 33.3% of students in the brick-walled classroom reported a comfortable vote (0), while 18% of students in the wooden-walled classroom selected the same comfortable category (0). In the brick-walled classroom, 28.2% of students voted for comfortably warm (+1), about 25.6% chose too warm (+2), 7.7% reported much too warm (+3), and around 2.6% selected comfortably cool (–1) and too cool (–2), respectively, with no students voting much too cool (–3).

About 22% of students in the classroom with the wooden walls voted comfortably warm (+1), 20% reported much too warm (+3), 36% reported too warm (+2), and just about 4% reported comfortably cool (–1). No students in the wooden-walled classroom reported it as much too cool (–3) or too cool (–2).

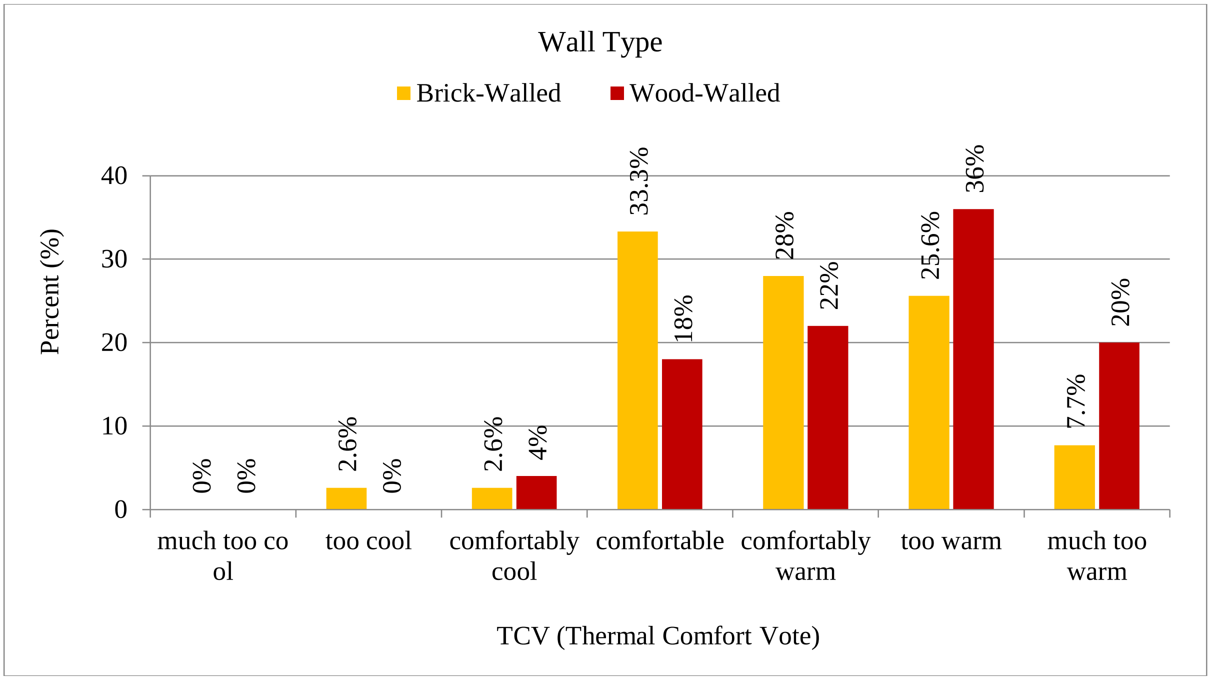

Fig. 4 Comparison chart of TCV percentage of brick-walled classrooms and wooden-walled classrooms

3.2.3. Thermal Acceptance (TA) and Thermal Preference (TP)

Actual votes based on the Thermal Acceptance (TA) indicator are shown in Figure 9. Most respondents in the brick-walled classroom (82.1%) reported accepting the thermal conditions in the classroom, whereas only a small portion (17.9%) did not accept the thermal conditions. In contrast, in the wood-walled classroom, the majority of respondents (72%) reported not accepting the thermal conditions, while only a small portion (28%) accepted them.

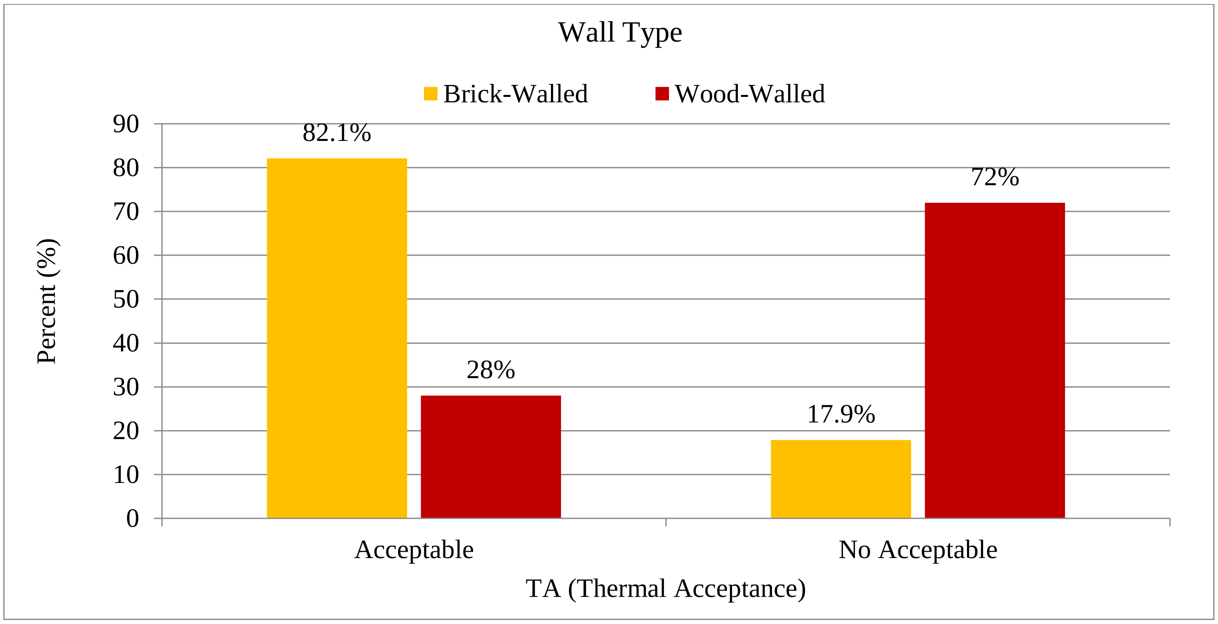

Fig. 5 Comparison chart of TA percentage of brick-walled classrooms and wooden-walled classrooms

Meanwhile, Figure 10 shows the actual votes for the thermal environment as determined by the Thermal Preference (TP) indicator. According to the result, most respondents in classrooms with brick walls (82.1%) and those with wood walls (94%), respectively, desired a decrease in indoor air temperature, while a small portion (17.9% and 6%) felt the current temperature was adequate, and none reported a request for an increase.

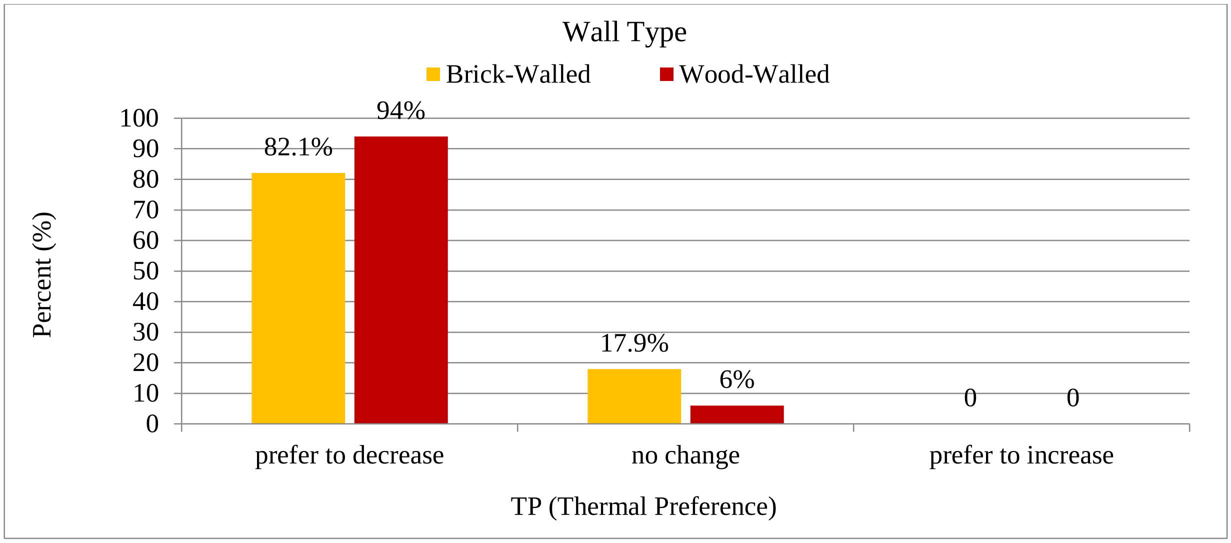

Fig. 10 Comparison chart of TP percentage of brick-walled classrooms and wooden-walled classrooms

3.3. PMV / PPD Model

Table 3. PMV and PPD of the classrooms

		PMV	PPD (%)	Sensation
BW	Mean	1.40	45.86	-
	Median	1.37	44.00	-
	SD (+/-)	0.22	11.61	-
	Min	1.05	28.00	Slightly Warm
	Max	1.65	59.00	Warm
WW	Mean	2.03	75.21	-
	Median	2.01	77.50	-
	SD (+/-)	0.43	18.10	-
	Min	1.29	40	Slightly Warm
	Max	2.71	97	Hot

Note: BW= Brick-Walled, WW= Wood-Walled, PMV= predicted mean vote, PPD= percentage predicted dissatisfied

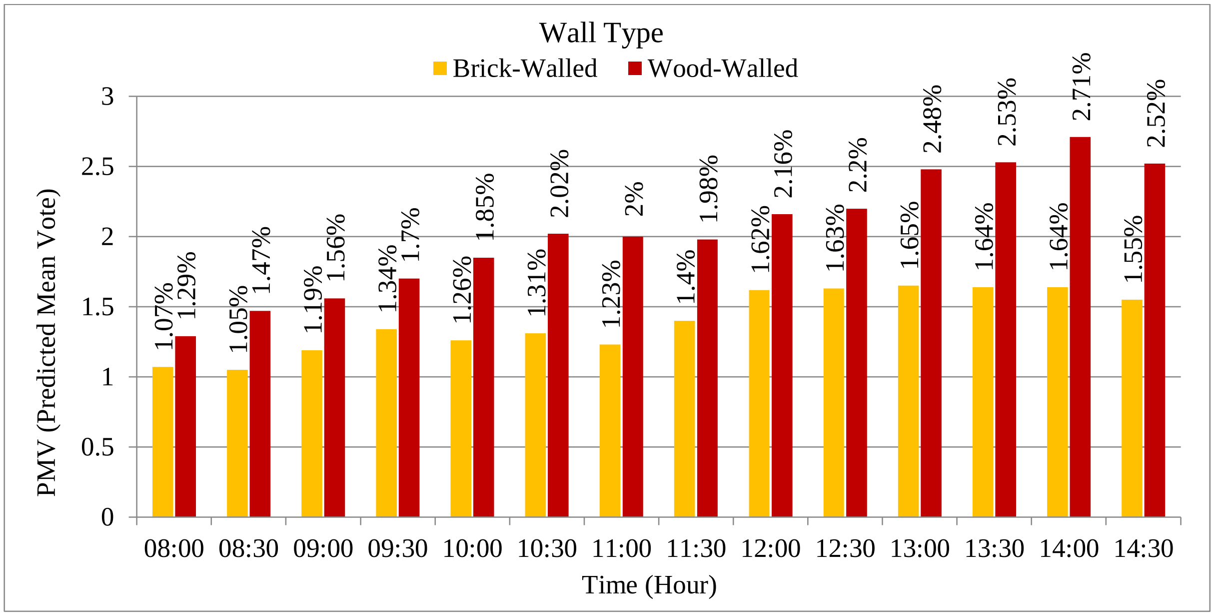

Fig. 11 Comparison chart of PMV values of brick-walled classrooms and wooden-walled classrooms

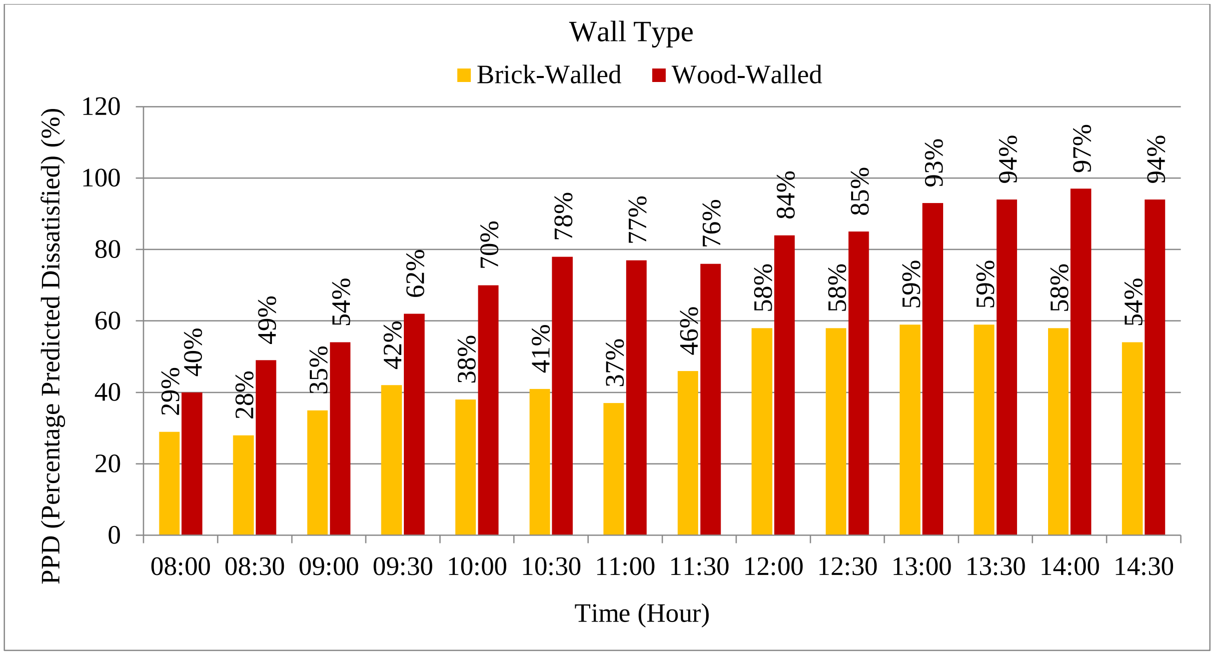

Fig. 12 Comparison chart of PPD percentages for brick-walled classrooms and wooden-walled classrooms

Table 6 presents the calculated PMV and PPD results. The PMV value in wooden-walled classrooms (+2.03 average value) is higher when compared to the PMV value of brick-walled classrooms (+1.40 average value), and the PPD value in wooden-walled classrooms (75.21% average value) is higher when compared to the PPD value of brick-walled classrooms (45.86% average value). This shows that based on PMV and PPD, students in brick-walled classrooms are more satisfied with their thermal condition compared to students in wooden-walled classrooms. More detailed PMV values and PPD percentages for brick-walled and wooden-walled classrooms at 30-minute intervals are presented in Figures 11 and 12.

3.4. Adaptive Thermal Comfort Model

Figure 13(a) displays the adaptive model's computed outcome, based on the ASHRAE-55 2020 standard [1]. According to Equation 3, the calculated prevailing mean outdoor air temperature was approximately 28.27 °C, with mean operative temperatures for the brick-walled and wood-walled classrooms approximately 29.78 °C and 31.33 °C, respectively, and were then compared. The wood-walled classroom failed to meet both the 90% and 80% acceptance requirements, whereas the brick-walled classroom met the 80% acceptance threshold but not the 90% acceptance criterion, according to the ASHRAE-55 2020 adaptive model [1].

3.5. Neutral Temperature

3.5.1. Regression Method

Figure 13(b) displays the linear regression and scatterplot between the dependent variable, TSV and PMV values, and the independent variable, operative temperature (Top), for both brick-walled and wooden-walled classrooms. The brick TSV and wood TSV data were non-normally distributed. Thus, a non-parametric Spearman correlation analysis was employed to investigate the connection between TSV values and classroom operative temperature.

The operative temperature of classrooms with brick walls and the brick TSV value were shown to be significantly positively correlated ($\rho = 0.722$, $p < 0.001$; Spearman correlation), indicating that increasing the operative temperature of warmer brick-walled classrooms was associated with higher brick TSV values. The association between the brick TSV values and the corresponding operative temperature for the brick-walled classrooms was then determined using a linear regression analysis. The regression equation that results from the statistically significant regression model ($R^2 = 0.340$, $F = 19.046$, $p < 0.001$) is as follows:

$$TSV_{brick} = 1.4T_{op} - 41.31 \quad (5)$$

According to Equation 5, the operative temperature of the brick-walled classrooms, which is equivalent to TSV brick = 0 (neutral temperature), is 29.51 °C. This suggests that this temperature is intended to make responders feel at ease.

The operative temperature of classrooms with brick walls and the wood TSV value were shown to be significantly positively correlated ($\rho = 0.515$, $p < 0.001$; Spearman correlation), indicating that increasing the operative temperature of warmer wooden-walled classrooms was associated with higher wood TSV values. The association between the wood TSV values and the corresponding operative temperature for the wooden-walled classrooms was then determined using a linear regression analysis. The regression equation that results from the statistically significant regression model ($R^2 = 0.148$, $F = 8.335$, $p = 0.006$) is as follows:

$$TSV_{wood} = 0.87T_{op} - 26.09 \quad (6)$$

According to Equation 6, the operative temperature of the wood-walled classrooms, which is equivalent to TSV wood = 0 (neutral temperature), is 29.99 °C. This suggests that this temperature is intended to make responders feel at ease.

The operative temperature of classrooms with brick walls and the brick PMV value were shown to be significantly positively correlated ($r = 0.867$, $p < 0.001$; Pearson correlation), indicating that increasing the operative temperature of warmer brick-walled classrooms was associated with higher brick PMV values. The association between the corresponding operative temperature for the brick-walled classrooms and the brick PMV values was then determined using a linear regression analysis. The regression equation that results from the statistically significant regression model ($R^2 = 0.752$, $F = 36.416$, $p < 0.001$) is as follows:

$$PMV_{brick} = 0.25T_{op} - 6.03 \quad (7)$$

According to Equation 7, the operative temperature of the brick-walled classrooms, which is equivalent to PMV brick = 0 (neutral temperature), is 24.02 °C. This suggests that this temperature is intended to make responders feel at ease.

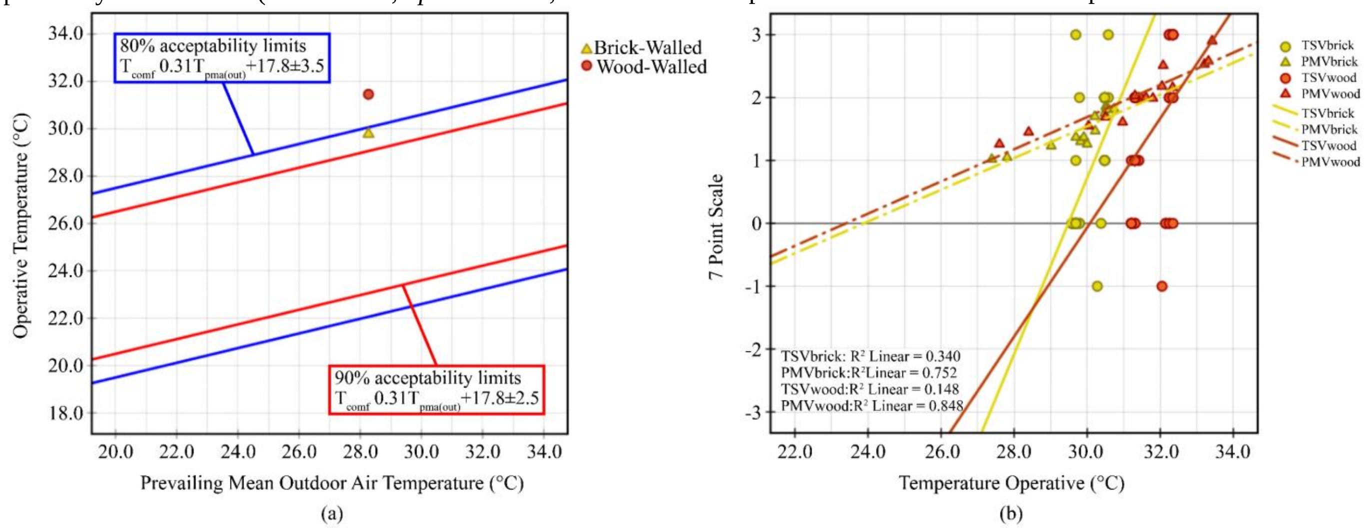

Fig. 13(a) Adaptive thermal comfort model in free-running brick-walled and wood-walled classrooms, and (b)The scatterplot and linear regression of T_{op} with TSV and PMV in brick-walled and wood-walled classrooms.

The operative temperature of classrooms with wood walls and the wood PMV value were shown to be significantly positively correlated ($r = 0.921$, $p < 0.001$; Pearson correlation), indicating that increasing the operative temperature of warmer wooden-walled classrooms was associated with higher wood PMV values. The association between the corresponding operative temperature for the wooden-walled classrooms and the wood PMV values was then determined using a linear regression analysis. The regression equation that results from the statistically significant regression model ($R^2 = 0.848$, $F = 67.101$, $p < 0.001$) is as follows:

$$PMV_{wood} = 0.26T_{op} - 5.99 \quad (8)$$

According to Equation 8, the operative temperature of the wood-walled classrooms, which is equivalent to PMV wood = 0 (neutral temperature), is 23.03 °C. This suggests that this temperature is intended to make responders feel at ease.

3.5.2. Griffiths' Method

Based on the existing literature, the Griffith method in this study applied a constant value of α = 0.50. The neutral temperature for both classroom types, brick-walled and wood-walled, was calculated separately, resulting in 28.50°C for brick-walled classrooms and 28.93 °C for wood-walled classrooms. In brick-walled classrooms, the neutral temperature was approximately 1.01 °C lower according to the TSV brick regression model (29.51 °C). Similarly, for wood-walled classrooms, the neutral temperature was approximately 1.06 °C lower according to the TSV wood (29.99 °C) regression model. These results differ considerably from the neutral temperature derived from the regression models for PMV brick (24.02 °C) and PMV wood (23.03 °C), with differences of 4.48 °C and 5.90 °C, respectively. Similar to previous research in the same climate zone [24–28], with a neutral temperature variation of 28.9 to 30.5 °C, this indicates that in tropical climates that tend to be hot, students are more tolerant [24, 28]. Table 7 presents a summary of the comparison with previous findings.

Table 4. Summary of the comparison with previous findings

Study	Climate	Country	Time of Survey	Building Type	N	Age	Tn (°C)
This study	Tropical	Indonesia	May 2025	SC	89	15-18	BW= 28.50 ~ 29.51 WW= 28.93 ~ 29.99
Hamzah et al. [24]	Tropical	Indonesia	Aug. 2017	SC	1594	11-18	29
Talukdar et al. [25]	Tropical	Bangladesh	Jul. to Aug. 2017	UN	579	18-24	30.5
Mishra et al. [26]	Tropical	India	Aug. to Oct. 2013	UN	67	19-26	29
Wong et al. [27]	Tropical	Singapura	Aug. 2001	SC	506	13-50	28.9
Firman et al. [28]	Tropical	Malaysia	Feb. to Jun. 2023	SC	1202	13-16	29.3
Custódio et al. [29]	Subtropical	Brazil	Sep. 2022 to Jul. 2023	UN	2034	22	NV= 19.8 & 21.4, AC= 21.8 & 22.1
Dear et al. [30]	Subtropical	Australia	Summer 2013	SC	2850	10-18	22.5
Wang et al. [31]	Subtropical	China	Mar. to Dec. 2016-2019	UN	1973	19-29	S= 26.2 W= 22.4
Teli et al. [32]	Temperate	United Kingdom	Mar. to Aug. 2011	SC	1300	7-11	20.8
Lyu et al. [33]	Temperate	United Kingdom	Mar. 2023	UN	251	+18	23.9
Romero et al. [34]	Mediterranean	Spain	May to Jul. 2022	UN	786	18-+30	24.70
	Mediterranean	Portugal	May to Jul. 2022	UN	350	18-+30	26.40
Torriani et al. [35]	Mediterranean	Italy	Nov. to Mar. 2018-2021	SC & UN	1548	PS= 6-10 MS= 11-13 HS= 14-18 U= +18	PS= 20.6 MS= 21.7 HS= 23.1 U= 23.6

Note: BW = Brick-Walled, WW = Wood-Walled, NV = Naturally ventilated, AC = Air conditioning, S = Summer, W = Winter, PS = Primary school, MS = Middle school, HS = High school, U = University, SC = School

Table 8. Independent T-test results for brick-walled and wood-walled classrooms

Group		df	t	Sig. (2-tailed)	Description
Average Temp. Operative	BW	26	-2.875	0.008	Significance
	WW				

4. Discussion

The thermal conditions of the surveyed brick-walled and wood-walled classrooms indicated a hot indoor environment. Such conditions may potentially impair students' comfort, performance, productivity, and academic achievement [15, 17, 21–24], particularly in wood-walled classrooms, which exhibited temperatures approximately 1.68 °C higher than those in brick-walled classrooms.

Table 8 presents the Independent T-test for classrooms with wood and brick walls. The computed t-value is -2.875 (|t-value| > t-table), which is different from the critical t-table of ±2.056, and the significance value is less than 0.05. As per the analysis, which was carried out using SPSS 27 at a significance level of $\alpha = 5\%$.

The operative temperature of classrooms with wood walls and classrooms with brick walls differs statistically significantly, as can be determined. Based on the findings, the observed differences were primarily influenced by the variation in wall materials used [40, 41, 49, 50]. Materials, including steel and wood, are classified as low thermal mass materials, while building materials like concrete and brick masonry are classified as high thermal mass materials [45]. Buildings constructed with low thermal mass materials tend to experience a more rapid temperature increase compared to those made with high thermal mass materials. It has been demonstrated that using cellular concrete walls in place of lightweight timber framing can effectively lower summertime average and maximum daily temperatures in temperate climates [42, 45]. Conversely, switching from heavy to lightweight construction may increase the cooling energy demand by up to 16% [42]. These findings are consistent with the present study, which revealed that classrooms with wooden walls experienced faster temperature rises during midday compared to those with brick walls. Although at night, the low thermal mass construction showed better performance in reducing the cooling load by 35.9% than the medium and high thermal mass construction [62]. It should be noted that the operating hours of classrooms and residential homes are different; classrooms usually operate from morning until noon, so heavy thermal mass materials are more recommended than light thermal mass materials.

Additional potential factors that could affect the thermal conditions in both kinds of classrooms, including the local climate [36, 37], room shape and size, as well as building orientation and openings [38, 39], were not considered, as the sampled classrooms shared similar characteristics in terms of shape, size, orientation, and openings. Meanwhile, aspects such as wall material thickness [50], floor elevation [49, 63], and occupant density [64] might be considered in the next studies.

Brick-walled classrooms had a mean TSV of 0.87 (SD = 0.16). Students in these classrooms reported their thermal sensation votes with approximately 71.8% falling within the three central categories (from -1 to +1), and 29.2% giving extreme responses in the hot sensation categories (from +2 to +3). On the other hand, the mean TSV in wooden-walled classrooms was 1.42 (SD = 0.15). Within the three main categories, students in these classes reported casting about 50% of their ballots (from -1 to +1), while the remaining 50% were extreme responses in the hot sensation categories (from +2 to +3). This indicates that students in wooden-walled classrooms perceived hotter thermal sensations compared to those in brick-walled classrooms, which is consistent with the measured temperature differences between the two classroom types.

The neutral temperature derived from actual votes (TSV) using both the regression method and Griffiths' method showed relatively close results: 29.51 °C and 28.50 °C for the brick-walled classroom, and 29.99 °C and 28.93 °C for the wooden-walled classroom, respectively. These differences may be attributed to the inaccuracy of the regression method due to the small sample size and narrow temperature range [25]. A greater discrepancy was observed in neutral temperatures estimated through PMV regression, which predicted neutral temperatures of 24.02 °C and 23.03 °C for brick-walled and wooden-walled classrooms, respectively. In naturally ventilated buildings, PMV is less reliable at predicting thermal sensation; it tends to overestimate reactions in hotter climes [24] and underestimate them in colder ones [33]. Meanwhile, in this study, the adaptive approach projected comfortable temperatures between 23.06 °C and 30.06 °C with an 80% acceptance limit, and between 24.06 °C and 29.06 °C with a 90% acceptance limit. It has been demonstrated that this is a naturally ventilated classroom; this adaptive approach is more suitable and accurate for predicting thermal comfort than the PMV/PPD method [29, 65]. This is because the thermal comfort of naturally ventilated classrooms is significantly influenced by outdoor temperature [29].

The small sample size and the inability to cover a wider temperature range for questionnaire distribution are limitations of this study. The study also did not consider measurements during the rainy season, which could impact students' thermal comfort levels [29]. The assumption is that wood, as a material with low thermal mass, can cool classrooms more quickly during the rainy season, resulting in different comfort levels during the dry season.

5. Conclusion

Ensuring interior thermal comfort is crucial in hot and humid conditions. Selecting the appropriate classroom wall to enhance thermal comfort is one of the most crucial strategies because it is one of the main elements affecting indoor thermal conditions. This study evaluates thermal comfort in classrooms with wood and brick walls using questionnaire surveys and field measurements made at the beginning of the dry season in 2025. The main conclusions are summarized as follows:

1. Classrooms with wood walls had a higher mean operative temperature (31.33 °C) than those with brick walls (29.78 °C).
2. A "slightly warm" feeling was indicated by an average TSV of 0.87 in the brick-walled classrooms, whereas a "warm to hot" feeling was indicated by an average TSV of 1.42 in the wood-walled classrooms.
3. TA distribution revealed greater thermal tolerance among students in brick-walled classrooms, with 82.1% thermal acceptability, compared to only 28% in wood-walled classrooms.
4. It was discovered that the PMV index overestimated the actual TSV responses, making it inappropriate for forecasting thermal comfort in classrooms with natural ventilation, with mean values of 1.40 for brick-walled classrooms and 2.03 for wood-walled classrooms.
5. According to the adaptive model, brick-walled classrooms meet the 80% acceptance threshold but not the 90% acceptance criterion, while wood-walled classrooms failed to meet either criterion.
6. The neutral temperature derived from actual TSV values using the regression method was 29.57 °C for brick-walled classrooms and 29.99 °C for wood-walled classrooms, whereas Griffith’s method yielded 29.50 °C and 28.93 °C, respectively.

Overall, the findings indicate that wood, with its material properties that absorb heat more quickly, is not a suitable wall construction material in hot and humid areas, especially in classrooms. Classroom usage patterns are generally used from morning to noon, causing classrooms to heat up more quickly during operational hours. Therefore, the selection of wood materials is not recommended for classroom building envelopes in hot and humid climates. Meanwhile, concrete and brick walls offer more appropriate thermal performance to withstand excessive heat buildup during classroom operational hours. The results of this study can provide practical recommendations and evaluations in the selection of building envelope materials that are often overlooked and sidelined in classroom planning in hot and humid climates, especially in Indonesia.

Acknowledgments

The Building Science and Technology Laboratory supported this study at Hasanuddin University's Department of Architecture. Then, to all teachers and students at the Ihyaul Ulum DDI Baruga Islamic Boarding School. The authors express their gratitude.

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