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STUDI KENYAMANAN TERMAL RUANG KELAS ARSITEKTUR UNIVERSITAS BENGKULU MENGGUNAKAN CBE THERMAL COMFORT TOOL

THERMAL COMFORT STUDY OF ARCHITECTURE CLASSROOM AT UNIVERSITY OF BENGKULU USING CBE THERMAL COMFORT TOOL

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***Abstrak*—** Kenyamanan termal merupakan kondisi ketika seseorang merasa nyaman dalam cuaca panas dan dipengaruhi oleh faktor suhu udara, kecepatan angin, kelembapan, aktivitas pengguna, serta pakaian yang dikenakan. Penelitian ini bertujuan untuk menganalisis kondisi kenyamanan termal pada ruang kelas Program Studi Arsitektur Universitas Bengkulu dengan memanfaatkan perangkat lunak *CBE Thermal Comfort Tool*. Metode penelitian yang digunakan adalah metode kuantitatif. Tahapan penelitian meliputi pengumpulan data primer dan sekunder, kemudian menganalisis data tersebut dengan membandingkannya terhadap standar kenyamanan termal berdasarkan ASHRAE-55. Hasil simulasi menunjukkan bahwa kondisi kenyamanan pada ruang kelas belum memenuhi standar kenyamanan termal ASHRAE-55, dengan nilai *Predicted Mean Vote* (PMV) dan *Predicted Percentage of Dissatisfied* (PPD) tertinggi ditemukan pada ruang kelas B, yakni PMV sebesar 1,59 untuk pengguna perempuan dan 1,57 untuk pengguna laki-laki, serta PPD sebesar 56% dan 54%. Faktor suhu dan kelembapan menunjukkan nilai rata-rata 29,5℃ dan 70,6%. Oleh karena itu, diperlukan penambahan kecepatan angin. Penambahan kecepatan angin pada ruang kelas ini memerlukan strategi yang mencakup orientasi bangunan, posisi bukaan, dan dimensi bukaan. Implementasi strategi tersebut, berdasarkan hasil simulasi, menunjukkan bahwa ruang kelas telah memenuhi standar kenyamanan termal ASHRAE-55.

***Kata kunci*—** Kenyamanan Thermal, PMV, PPD

***Abstract*—** Thermal comfort refers to a condition in which an individual feels comfortable in hot weather and is influenced by factors such as air temperature, wind speed, humidity, user activity, and clothing. This study aims to analyze the thermal comfort conditions in the classrooms of the Architecture Study Program at the University of Bengkulu using the *CBE Thermal Comfort Tool* software. The research employed a quantitative method. The research stages included collecting primary and secondary data, followed by data analysis through comparison with the thermal comfort standards specified in ASHRAE-55. The simulation results indicate that the classroom conditions did not meet the ASHRAE-55 thermal comfort standards. The highest *Predicted Mean Vote* (PMV) and *Predicted Percentage of Dissatisfied* (PPD) values were recorded in Classroom B, with PMV values of 1.59 for female users and 1.57 for male users, and PPD values of 56% and 54%, respectively. The average temperature and humidity were 29.5℃ and 70.6%. Therefore, an increase in wind speed is necessary. Enhancing wind speed in the classroom requires strategies involving building orientation, opening placement, and opening dimensions. Implementation of these strategies, as shown by the simulation results, enabled the classroom to meet the ASHRAE-55 thermal comfort standards.

***Keywords*—** Thermal Comfort, PMV, PPD

I. INTRODUCTION

Thermal comfort refers to a condition in which individuals feel satisfied with the surrounding temperature. From a sensory perspective, it describes a state in which a person does not experience sensations of being excessively hot or cold in a particular room or area [1]. Several main factors influence thermal comfort, including air temperature, relative humidity, wind speed, and thermal radiation

[2]. These factors determine whether an environment is perceived as comfortable for humans [3]. The sensation of thermal comfort can vary significantly between individuals and is influenced by factors such as activity level, clothing, and humidity [4].

In architectural planning, designers must consider numerous aspects that affect indoor climate comfort, including air circulation speed, relative humidity, and room temperature [5]. Building materials and climate conditions influence temperature fluctuations in a room. The thermal conductivity of materials plays a critical role: the higher the thermal conductivity, the greater the temperature increase inside the room. Conversely, the reflective properties of building materials can help reduce indoor temperatures [6]. Reducing room temperature can be achieved through wall designs with low thermal transmittance values and by selecting appropriate materials and cladding designs, which help maintain cooler indoor conditions [7]. Additionally, building shape, ventilation placement, material characteristics, shading devices, and the use of grilles influence indoor thermal comfort [8].

Optimal thermal comfort promotes a sense of ease and calm for occupants and can enhance sleep quality, concentration, and work productivity. Studies have shown that an uncomfortable thermal environment can cause thermal stress, negatively affecting both physical and mental health [9]. In classrooms, thermal comfort directly impacts students' ability to focus [10]; higher classroom temperatures are associated with reduced concentration levels among students [11].

Thermal comfort in a space can be assessed by inputting environmental and individual parameter data into the *CBE Thermal Comfort Tool*, developed by the University of California, Berkeley's Center for the Built Environment (CBE). These parameters include air temperature, humidity, air flow rate, physical activity level, and clothing type. The tool enables comprehensive simulation and analysis of thermal comfort conditions and incorporates internationally recognized models such as the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) to generate accurate and informative results. The *CBE Thermal Comfort Tool* performs calculations in accordance with ANSI/ASHRAE and EN 16798-1 standards [12].

This study employed purposive sampling. The research was conducted in two classrooms located on the second and third floors of the Laboratory Building, Faculty of Engineering, and one classroom located on the second floor of GB V. These three rooms were selected as research objects because of their function as classrooms. However, Classrooms A and B were originally reading rooms and computer laboratories before being converted into classrooms. The selected classrooms differ in building orientation, room orientation, and ventilation type, but share similarities in the materials used for construction.

In this study on thermal comfort in three classrooms, the factors examined were air temperature, humidity, wind speed, physical activity, and clothing insulation, all of which influence PMV and PPD values. Air temperature, humidity, and wind speed were measured directly, while physical activity and clothing insulation were determined through observation of occupants. Measurements were taken under both occupied and unoccupied classroom conditions, with windows closed during data collection. This research is expected to contribute to design solutions for creating comfortable learning spaces that support the teaching and learning process.

II. LITERATURE REVIEW

A. Thermal Comfort

According to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), thermal comfort is defined as an individual's state of mind expressing satisfaction with the surrounding thermal environment.

B. Thermal Comfort Indicator

ASHRAE explains that both individual and environmental variables influence thermal comfort. The indicators of thermal comfort are presented in the following table:

Table–1. Thermal Comfort Indicator

Thermal Comfort Indicator	
Environmental Factors (External)	Temperatures
	Humidity
	Wind Speed
	Radiation Temperature
Personal Factors (Internal)	Clothing Insulation
	Metabolic Rate

1) External Factors

A factor is considered external when it originates from outside an individual and has the potential to affect that person or their environment. External influences include the following indicators.

Air temperature is measured in degrees Fahrenheit (°F) or Celsius (°C) and is classified into two categories: normal air temperature and *Mean Radiant*

Temperature (MRT), which represents the average temperature of surrounding surfaces.

Relative humidity refers to the moisture content or water vapor present in the ambient air. It is expressed as the ratio between the amount of moisture contained in the surrounding air and the maximum amount the air can hold at a given temperature [13].

Wind speeds in the range of 0.1 m/s to 0.5 m/s can affect indoor comfort, with spaces considered uncomfortable if wind speed exceeds this range.

2) Internal Factors

Internal factors are influences originating from within the individual that can affect thermal comfort. The indicators of internal factors include the following.

Clothing also influences thermal comfort. Clothing insulation is measured in *CLO* units (*Clothing Insulation Units*), where 1 CLO is equivalent to 0.155 m²·K/W. The values for clothing insulation have been established by the National Standards of Agriculture (2001) [14].

Table–2. Clothing Insulation Value Standards

Clothing Description	**Clo**	**Clothing Description**	**Clo**
Underwear		Dresses and Skirts	
Bra	0.01	Thin skirt	0.14
Women's Underwear	0.03	Thick skirt	0.23
Men's underwear	0.04	Sleeveless thin top	0.23
Kaos	0.08	Sleeveless thick top	0.27
Women's Inner Skirt	0.14	Women's Short Sleeve Shirt (Thin)	0.29
Men's Long Panties	0.15	Women's Short Sleeve Shirt (Thick)	0.33
Women's Thin Underwear	0.15	Women's Long Sleeve Shirt (Thick)	0.47
T-shirts in length	0.20		
Footwear		Sweater	
Long Socks	0.02	Sleeveless vest (thin)	0.13
Stocking	0.02	Sleeveless vest (thick)	0.22
Flip-flops	0.02	Long sleeve vest (thin)	0.25
Shoe	0.02	Jas	
Stocking	0.03	Sleeveless vest (thin)	0.10
Kneelength thick socks	0.06	Sleeveless vest (thick)	0.17
Boots	0.10	Single-layer suit (thin)	0.10
Outerwear		Single-layer coat (thick)	0.44
Sleeveless T-shirts		Two-layer (thin) coat	0.42
Short-sleeved collared T-shirt	0.17	Double-layer coat (thick)	0.48
Short sleeve shirt shirt	0.19	Sleepwear	
Long sleeve shirt shirt	0.25	Short sleeveless dresses (sheer)	0.18
Kemeja kain (flannel)	0.34	Sleeveless short dresses (thick)	0.20
Long sleeve collared T-shirt	0.34	Sleeve hospital dress (thick)	0.31
Trousers and Long Shirts		Short-sleeved robe (thin)	0.34
Lie shorts	0.06	Short-sleeved pajamas (thin)	0.42
Ponggol Pants (knee-length)	0.08	Long Sleeve Dress (thick)	0.46
Thin Trousers	0.15	Short Sleeve Long Robe (Thick)	0.48
Thick Trousers	0.24	Long sleeve pajamas (thick)	0.57
Long Sweatpants	0.28	Long sleeve robe	0.69
Pants/toad shirt	0.30		
Overalls with pants	0.49		

Metabolism

Table–3. Value of Activity Metabolic Rate

Types of Activities	**Metabolic Rate**
Rest	
Stand up, relax	1,2
Lie down	0,8
Sleep	0,7
Sit down, calm down	1,0
Walk on a flat surface	
1,8m/s, 6,8km/h, 4,2mph	3,8
1,2m/s, 4,3km/h, 2,7mph	2,6
0,9m/s, 3,2 km/h, 2,0mph	2,0
Office activities	
Walk around	1,7
Lifting/packing	2,1
Archiving, standing	1,4
Archiving, sitting	1,2
Typing	1,1
Reading, sitting	1,0
Write	1,0
Driving/Flying	
Mobile	1,0 – 2,0
Heavy vehicles	3,2
Fighter	2,4
Aircraft, landing instruments	1,8

Aircraft, routine	1,2
Various Work Activities	
Cook	1,6 – 2,0
Cleaning the House	2,0 – 3,4
Sitting, Heavy movement	2,2

C. Thermal Comfort Index

1) The PMV-PPD Model

The *Predicted Mean Vote* (PMV) is a measure of how cold or warm a person feels, ranging from –3 to +3. The six parameters that determine PMV are clothing insulation, wind speed, mean radiant temperature, air temperature, humidity, and metabolic rate. The *Predicted Percentage of Dissatisfied* (PPD) represents the projected proportion of individuals likely to feel thermally dissatisfied.

Table–4. The relationship between PPD, PMV and Thermal Sensation

PMV	Thermal Sensation	PPD
+3	Hot	100
+2	Warm	75
+1	Slightly Warm	25
0	Neutral	5
-1	Slightly Cool	25
-2	Cool	75
-3	Cold	100

D. Thermal Comfort Standard Limits

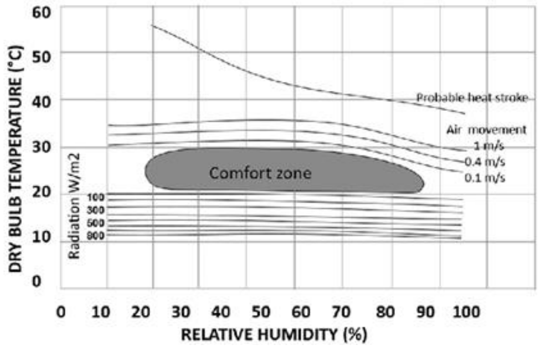
According to the National Standards Agency (2011) [15] in SNI 03-6572-2001 [14] concerning Procedures for Designing Ventilation and Air Conditioning Systems in Buildings, there are three thermal comfort limits that ensure occupants in Indonesia can feel safe and comfortable.

Table–5. Thermal Comfort Limits

Condition	Effective Temperature (TE)	Humidity (RH)
Warm Comfort Lower Threshold	25,8° C – 27,1° C 31° C	60%
Optimal Comfort Threshold	22,8 ° C – 25,8 ° C 28° C	70%
Cool and comfortable Upper Threshold	20,5 ° C – 22,8 ° C 24 ° C	50% 80%

E. Bioclimatic Chart

The bioclimatic chart, developed by Victor Olgyay, is a tool used to understand the interaction between various climatic elements—such as temperature, humidity, and wind speed—and human thermal comfort. This chart provides a visual representation of thermal comfort zones and illustrates how climatic elements influence comfort levels.



Figure–1. Bioclimatic Chart

In this chart, climatic conditions such as relative humidity and air temperature are clearly represented. If the plotted points fall within the comfort zone, the environment is considered thermally comfortable for humans. Conversely, if the points lie outside the comfort zone, adjustments are required to achieve comfort. For example, if the points are above the upper comfort zone limit, increased air movement is necessary, and the chart indicates the required wind speed in feet per minute (fpm).

III. METHOD

This study employed a quantitative research method, with purposive sampling used to select the research objects. The selected rooms were chosen due to their function as classrooms. Data collection was conducted through direct observation, followed by measurement of existing conditions and simulation of thermal comfort using the *CBE Thermal Comfort Tool* to determine the thermal comfort levels of the classrooms. The stages of the research are described as follows:

A. Observation

This stage involved collecting data through direct observation, which included measuring air temperature, humidity, and wind speed, as well as observing occupant activities to determine the metabolic rate of the space users. Clothing worn by the users was also observed to determine clothing insulation values.

The metabolic rate was obtained by observing classroom users and selecting from a list of common activities typically performed in the classroom. A reference table of activity types and corresponding metabolic values is provided in Table 6.

Table–6. Types of Activities and Metabolic Value

Activity	MET	Source
Sit quietly	1,0	ASHRAE-55
Sit Reading	1,0	ASHRAE-55
Write	1,0	ASHRAE-55
Typing	1,1	ASHRAE-55

The clothing insulation value was determined based on the types of clothing typically worn by classroom users. Observations were made directly in the classroom, and several common clothing types were recorded. Clothing insulation values (Clo) were calculated separately for male and female occupants using the following formulas: The formula for calculating the female Clo value is: (0.770 x (Total Clo Value) + 0.050). The formula for calculating the male Clo value is: (0.727 x (Total Clo Value) + 0.113). A reference table of clothing types and insulation values is presented in Table 7.

Table–7. Types of Clothing and Clothing Insulation Values

Types of Clothing	Clo	Source
Underwear, short-sleeved collared shirts, trousers, socks and shoes	0,46	SNI 03-6572-2001
Underwear, long-sleeved collared shirts, trousers, socks and shoes	0,63	SNI 03-6572-2001
Underwear, short-sleeved shirts, trousers, socks and shoes	0,48	SNI 03-6572-2001
Underwear, long-sleeved shirts, trousers, socks and shoes	0,54	SNI 03-6572-2001
Underwear, long-sleeved shirts, skirts, socks and shoes	0,53	SNI 03-6572-2001

B. Study Literature

The literature study involved reviewing and recording data from relevant literature on thermal comfort. These references were then used for analysis and comparison between theoretical or literature-based data and the data obtained from direct observations of the research objects.

C. Simulation

The next stage is to perform simulations using the CBE Thermal Comfort Tool software. This simulation determines the thermal comfort level of the classroom. After the simulation is conducted, results regarding the thermal comfort level in the room are obtained.

Measurements were conducted from 10 to 14 March 2025, at eight different time intervals each day, from 08:00 to 15:00 Western Indonesian Time. These eight time intervals were selected because complete data were available for them, allowing inclusion in the CBE Thermal Comfort Tool formula. At other times, the data were incomplete and therefore could not be used. The chosen time intervals also aligned with the students' learning schedule, enabling observation of variations in average thermal comfort results.

On March 10, 2025, Class A had a busy period from 14:00 to 15:00 with 18 occupants. From 08:00 to 13:00, the classroom was unoccupied, and from 12:00 to 13:00 was the break period. Class B had a busy period from 11:00 to 12:00 with 33 occupants. From 08:00 to 10:00 and from 13:00 to 15:00, the classroom was unoccupied, and from 12:00 to 13:00 was the break period. Class C had no busy period; from 08:00 to 15:00, the classroom was unoccupied, and from 12:00 to 13:00 was the break period.

On March 11, 2025, Class A had a busy period from 08:00 to 09:00 with 9 occupants. From 10:00 to 15:00, the classroom was unoccupied, and from 12:00 to 13:00 was the break period. Class B had a busy period from 13:00 to 14:00 with 37 occupants. From 08:00 to 12:00 and at 15:00, the classroom was unoccupied, and from 12:00 to 13:00 was the break period. Class C had no busy period; from 08:00 to 15:00, the classroom was unoccupied, and from 12:00 to 13:00 was the break period.

On March 12, 2025, Class A had no busy period; from 08:00 to 15:00, the classroom was unoccupied, and from 12:00 to 13:00 was the break period. Class B had a busy period from 14:00 to 15:00 with 20 occupants. From 08:00 to 13:00, the classroom was unoccupied, and from 12:00 to 13:00 was the break period. Class C had a busy period from 14:00 to 15:00 with 26 occupants. From 08:00 to 13:00, the classroom was unoccupied, and from 12:00 to 13:00 was the break period.

On March 13, 2025, Class A had a busy period from 08:00 to 09:00 with 21 occupants. From 10:00 to 15:00, the classroom was unoccupied, and from 12:00 to 13:00 was the break period. Class B and Class C had no busy periods; from 08:00 to 15:00, the classrooms were unoccupied, and from 12:00 to 13:00 was the break period.

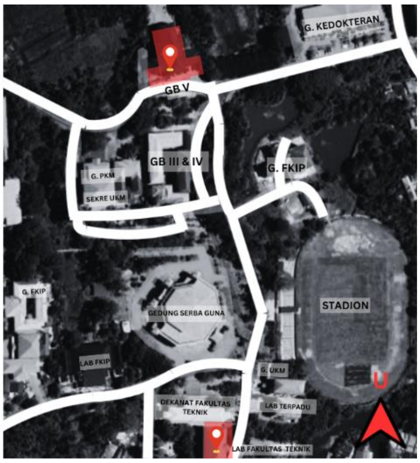
On March 14, 2025, Class A, Class B, and Class C had no busy periods; from 08:00 to 15:00, the classrooms were unoccupied, and from 12:00 to 13:00 was the break period.

IV. RESULTS AND DISCUSSION

A. *Research Location and Time*

1) Research Location

The research was conducted on Jl. WR. Supratman, Limun Cage, Muara Bangka Hulu District, Bengkulu City, at the University of Bengkulu, with latitude coordinates -3.759442 and longitude coordinates 102.272412. The research objects were three classrooms. Classrooms A and B are located on the second and third floors of the Engineering Laboratory Building, with latitude coordinates -3.758702 and longitude coordinates 102.276448, and the building is oriented along the north–south axis. Classroom C is located on the second floor of GB V, with latitude coordinates -3.755336 and longitude coordinates 102.276448, and the building is oriented along the southwest–northeast axis.



Figure–2. Research Location of the University of Bengkulu

Figure–3. Facades of Engineering Laboratory Building

Figure–4. Facades of GB V Building

2) Research Time

Data collection for measurements of air temperature, humidity, wind speed, and observation of user activities to determine the users' metabolic rates, as well as the clothing worn to calculate clothing insulation values, was conducted in the classrooms of the Architecture Study Program over five days, from March 10 to 14, 2025. Measurements were taken during student learning hours and peak classroom usage, from 08.00 to 15.00 Western Indonesian Time, with a break period at 12.00. At these specific times, complete data was obtained, allowing entry into the CBE Thermal Comfort Tool formula. At other times, incomplete data was recorded, which could not be processed in the CBE Thermal Comfort Tool.

Data on clothing insulation and metabolic values were obtained during class sessions through questionnaires distributed to students. On the first day of measurement, March 10, 2025, the number of occupants was 18 in Class A, 33 in Class B, and 0 in Class C, as there were no classes held there. On the second day, March 11, 2025, Class A had 9 occupants, Class B had 37 occupants, and Class C had 0 occupants due to the absence of classes. On the third day, March 12, 2025, Class A had 0 occupants because no classes were held, Class B had 20 occupants, and Class C had 26 occupants. On the fourth day, March 13, 2025, Class A had 21 occupants, while Classes B and C had no occupants as there were no classes. On the fifth day, March 14, 2025, all three classrooms—A, B, and C—had 0 occupants due to the absence of classes.

B. *Thermal Comfort Measurement Analysis Results*

Classroom assessments of temperature, moisture lev Classroom assessments of temperature, humidity levels, and air velocity were conducted to determine the mean values of thermal comfort parameters representing environmental (external) variables. Measurements were taken over five days, from 10 to

14 March 2025, with the measurement schedule adjusted to align with student learning hours, starting from 08:00 to 15:00 Western Indonesian Time.

Measurements were carried out using an Elitech RC-4HC and a Benetech GM8902 anemometer, placed at a height of more than 150 cm from the floor. The following table presents the results of the measurements of environmental factors (external thermal comfort in the classroom).

Table–8. Air Temperature Measurement Results with Elitech RC-4HC

Classroom	Standard ASHRAE-55	Result	Information
A	23°C - 26°C	27,5°C	Does not meet standard
B	23°C - 26°C	29,5°C	Does not meet standard
C	23°C - 26°C	28,6°C	Does not meet standard

The results indicate that none of the three classrooms meet ASHRAE standards. Classrooms A, B, and C recorded average air temperatures of 27.5°C, 29.5°C, and 28.6°C, respectively. These values exceed the standard air temperature limit, indicating non-compliance with the standard.

Table–9. Humidity Measurement Results with Elitech RC-4HC

Classroom	Standard ASHRAE-55	Result	Information
A	30%-70%	70,7%	Does not meet standard
B	30%-70%	70,6%	Does not meet standard
C	30%-70%	74,1%	Does not meet standard

The results also show that Classrooms A and B meet ASHRAE standards for humidity, whereas Classroom C does not. The average humidity levels recorded were 70.7%, 70.6%, and 74.1% for Classrooms A, B, and C, respectively. These values indicate that while some classrooms fall within the acceptable range, others exceed the humidity standard.

Table–10. Wind Speed Measurement Results with Anemometer Benetech GM8902

Classroom	Standard ASHRAE-55	Result	Information
A	> 0,2m/s	0 m/s	Does not meet standard
B	> 0,2m/s	0 m/s	Does not meet standard
C	> 0,2m/s	0 m/s	Does not meet standard

For wind speed, none of the three classrooms meet the ASHRAE-55 standard. Classrooms A, B, and C each recorded an average wind speed of 0 m/s. This is because the measurements were conducted both during and outside of learning activities, and when learning was in progress, windows were kept closed. These findings confirm that all classrooms fail to meet the wind speed standard.

Table–11. Results of Analysis of Clothing Insulation Value

Gender	Types of Clothing	Clo	Source
Female	Underwear, long-sleeved shirts, thick trousers, socks and shoes	0,49	SNI 03-6572-2001
Male	Underwear, short-sleeved collared shirts, thick trousers, socks and shoes	0,47	SNI 03-6572-2001

The analysis shows that the clothing insulation value for female occupants is 0.49 clo, calculated using the formula for summing insulation values: (0.770 × 0.58) + 0.050, where 0.58 is the total clo value for women prior to calculation. For male occupants, the clothing insulation value is 0.47 clo, calculated using the formula: (0.727 × 0.50) + 0.113, where 0.50 is the total clo value for men prior to calculation.

Table–12. Results of Analysis of Metabolism Value

Gender	Types of Clothing	MET	Source
Female	Write	1,0	ASHRAE-55
Male	Write	1,0	ASHRAE-55

The results indicate that the most frequent activity carried out by both female and male occupants is writing, with a metabolic rate value of 1.0 MET.

C. *Results of Existing Simulations*

1) Classroom A

The first research object is Classroom A, located on the second floor of the Engineering Laboratory Building with an area of 9.39 × 7.19 m². The classroom has a south–north orientation, with windows positioned on the west and east sides. The windows on the west side provide natural lighting into the room. Prior to its current use as a classroom, Classroom A functioned as a reading room.

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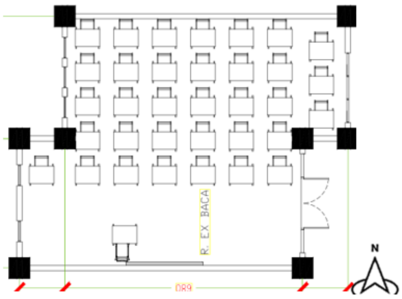
Figure–6. Existing Classroom A



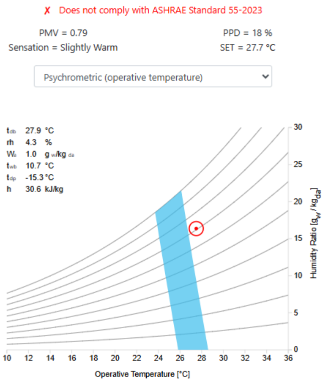
Figure–5. Floor Plan Classroom A

Figure–8. 3D Design of Classroom A

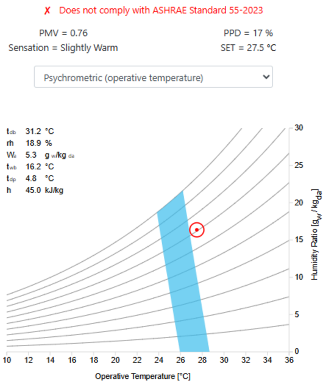
The simulation results indicate that Classroom A does not meet the standard, with PMV values for female and male occupants of 0.79 and 0.76, respectively, PPD values of 18% and 17%, and a thermal sensation classified as slightly warm.

Table–13. PMV, PPD and Class A Sensation Scores

PMV		PPD %		Sensation	
Female	Male	Female	Male	Female	Male
0,79	0,76	18	17	Slightly Warm	Slightly Warm



Figure–7. Chart CBE Thermal Comfort Tool Female



Figure–9. Chart CBE Thermal Comfort Tool Male

2) *Classroom B*

The second research object is Classroom B, located on the third floor of the Engineering Laboratory Building with an area of 9.37 × 6.95 m². The classroom has a west–east orientation, with windows positioned on the east side that allow natural light into the room. Previously, Classroom B served as a computing laboratory.

Figure–10. Existing Classroom

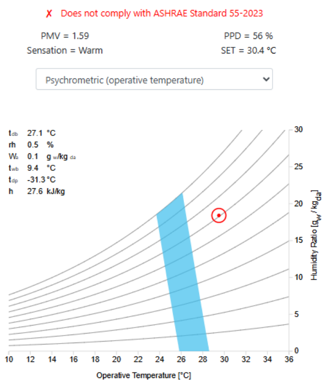
Figure–11. Floor Plan Classroom B

Figure–12. 3D Design of Classroom B

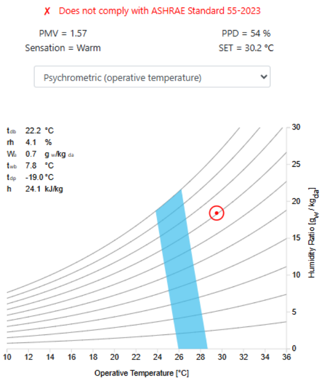
The simulation results indicate that Classroom B does not meet the standard, with PMV values for female and male occupants of 1.59 and 1.57, respectively, PPD values of 56% and 54%, and a thermal sensation classified as warm.

Table–14. PMV, PPD and Class B Sensation Scores

PMV		PPD %		Sensation	
Female	Male	Female	Male	Female	Male
1,59	1,57	56	54	Warm	Warm



Figure–14. Chart CBE Thermal Comfort Tool Female

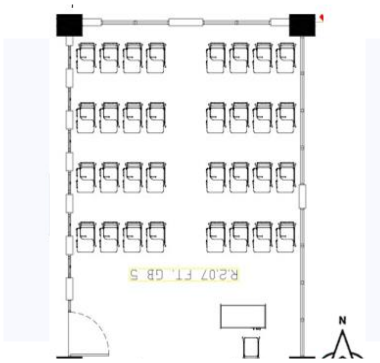


Figure–15. Chart CBE Thermal Comfort Tool Male

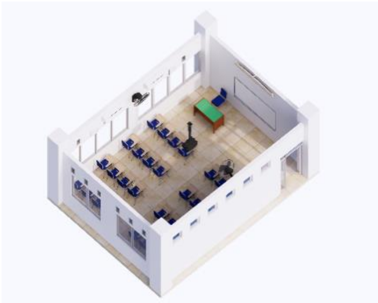
3) *Classroom C*

The third research object is Classroom C, located on the second floor of the GB V Building, which functions as a learning facility. The classroom has an area of 7.5 × 5.5 m² and is oriented from southeast to northwest. The windows are positioned on the northwest and northeast sides, providing natural lighting to the room.

Figure–16. Existing Classroom C



Figure–13. Floor Plan Classroom C

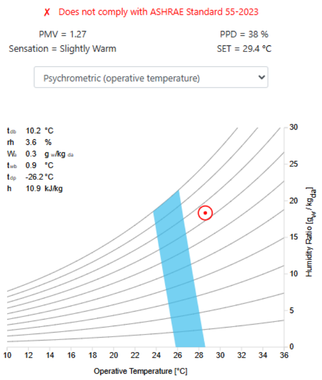


Figure–17. 3D Design of Classroom C

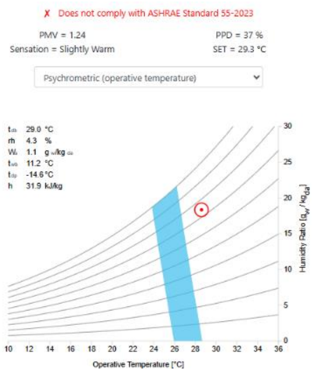
The simulation results indicate that Classroom C does not meet the standard, with PMV values for female and male occupants of 1.27 and 1.24, respectively, PPD values of 38% and 37%, and a thermal sensation classified as slightly warm.

Table–15. PMV, PPD and Class C Sensation Scores

PMV		PPD %		Sensation	
Female	Male	Female	Male	Female	Male
1,27	1,24	38	37	Slightly Warm	Slightly Warm



Figure–18. Chart CBE Thermal Comfort Tool Female



Figure–19. Chart CBE Thermal Comfort Tool Male

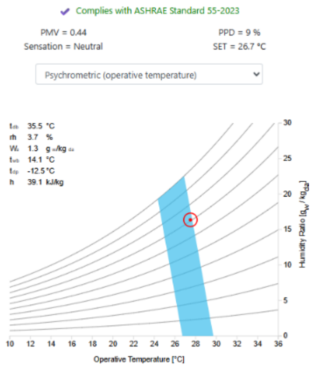
D. *Thermal Comfort Improvement Simulation Results*

1) *Classroom A*

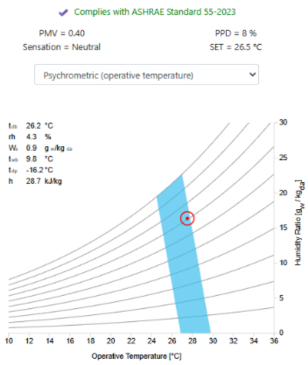
Thermal comfort improvement simulations were conducted using the bioclimatic chart analysis developed by Olgyay (1963). To restore comfort, an increase in wind speed of 0.2 m/s is required. The resulting PMV values for female and male occupants were 0.44 and 0.40, respectively, with PPD values of 9% and 8%, and a neutral thermal sensation.

Table–16. PMV, PPD and Class A Sensation Scores

PMV		PPD %		Sensation	
Female	Male	Female	Male	Female	Male
0,44	0,40	9	8	Neutral	Neutral



Figure–20. Chart CBE Thermal Comfort Tool Female



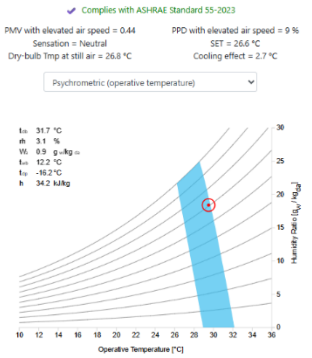
Figure–21. Chart CBE Thermal Comfort Tool Male

2) *Classroom B*

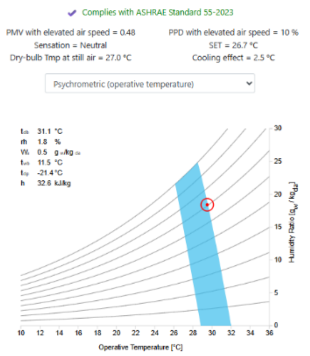
Thermal comfort improvement simulations using Olgyay's (1963) bioclimatic chart analysis indicate that an increase in wind speed of 0.6 m/s is required to restore comfort. The resulting PMV values for female and male occupants were 0.44 and 0.48, respectively, with PPD values of 9% and 10%, and a neutral thermal sensation.

Table–17. PMV, PPD and Class B Sensation Scores

PMV		PPD %		Sensation	
Female	Male	Female	Male	Female	Male
0,44	0,48	9	10	Neutral	Neutral



Figure–22. Chart CBE Thermal Comfort Tool Female



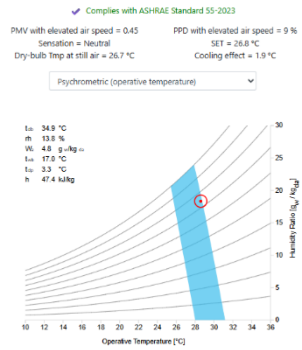
Figure–23. Chart CBE Thermal Comfort Tool Male

3) Classroom C

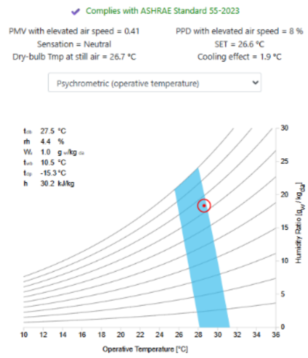
Thermal comfort improvement simulations using Olgyay's (1963) bioclimatic chart analysis indicate that an increase in wind speed of 0.4 m/s is required to restore comfort. The resulting PMV values for female and male occupants were 0.45 and 0.41, respectively, with PPD values of 9% and 8%, and a neutral thermal sensation.

Table–18. PMV, PPD and Class C Sensation Scores

PMV		PPD %		Sensation	
Female	Male	Female	Male	Female	Male
0,45	0,41	9	8	Neutral	Neutral



Figure–24. Chart CBE Thermal Comfort Tool Female



Figure–25. Chart CBE Thermal Comfort Tool Male

V. CONCLUSION

A. Conclusion

Based on the results of the analysis and simulations conducted, it can be concluded that the level of thermal comfort in the classrooms of the Architecture Study Program at the University of Bengkulu is as follows.

The thermal comfort levels of the studied classrooms do not comply with the ASHRAE-55 standard. The average PMV values and thermal comfort sensations for female and male occupants were 0.82 and 0.79, respectively, in Classroom A (slightly warm), 1.60 and 1.58 in Classroom B (warm to slightly warm), and 1.29 and 1.26 in Classroom C (warm to slightly warm).

Thermal comfort evaluation was conducted using the CBE Thermal Comfort Tool software. Improvements in thermal comfort for Classrooms A, B, and C were determined using Olgyay's (1963) bioclimatic chart analysis. To restore comfort, an increase in wind speed between 0.2 m/s and 0.6 m/s was required. Following simulation, Classrooms A, B, and C achieved thermal comfort levels in compliance with the ASHRAE-55 standard.

B. Recommendations

The findings of this research are expected to contribute to solutions for designing comfortable indoor spaces that support the teaching and learning process.

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