Thermal Comfort Study of Classroom Spaces in Relation to Building Orientation in Educational Buildings in Kendari City

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Abstract. Thermal comfort in architectural design is a critical factor that directly influences occupant productivity, particularly in educational settings. The World Meteorological Organization reports a trend of increasing global temperatures, projecting an average annual rise of 0.12°C by 2024. This signifies that managing temperature conditions will become progressively more challenging in the future. Consequently, the endeavor to establish a thermally suitable learning environment is Acrucial in the construction of educational edifices. This research seeks to determine the classroom orientation in educational facilities that offers optimal thermal comfort for occupants. Thermal modeling and simulation with EnergyPlus software were conducted on four classroom zones to get room temperature data for investigation. The research findings indicate that the classrooms in Zones 1, 2, and 4 maintain temperatures below 25-27°C, in contrast to Zone 3, which exceeds 27°C. Nonetheless, all these zones have a propensity for temperatures to surpass the optimal thermal comfort threshold, with maximum temperatures in each zone above 27°C. These findings emphasize the necessity of using both passive and active design solutions to improve thermal comfort in educational facilities.

Keywords: Thermal Comfort, Building Orientation, and Thermal Modeling and Simulation.

1 Introduction

Thermal comfort in building design is essential because it directly affects the productivity of the building's occupants. Studies have shown that poor indoor environmental quality, including thermal comfort, can lead to decreased productivity and negative effects on the health and comfort of occupants. Improving indoor environmental quality can increase productivity by up to 5% [1]. Furthermore, the temperature conditions in school buildings have become an issue due to the lack of understanding and appreciation of their long-term impact on student learning and health [2].

The trend of rising temperatures in the world, according to the World Meteorological Organization, with an increase of 0.12°C per year in 2024, indicates that temperature conditions will become increasingly difficult to control in the future. Therefore, it is

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important to pay attention to thermal comfort in educational buildings to create an optimal learning environment. By establishing a thermally comfortable environment, not only will students' productivity improve, but their health will also be well-maintained.

In Baker's research, it shows that small temperature changes can affect student performance, and there is a need to understand the impact of newer heating and cooling systems on student health. In addition, finding the ideal level of control over temperature and ventilation in classrooms is crucial for optimizing comfort and energy performance [3]. Baker and Bernstein (2012) emphasize the importance of considering both thermal comfort and air quality in the educational environment. Romero's subsequent research has demonstrated that students excel academically in environments that provide comfort and prevent disruption from extreme temperatures. Maintaining a temperature between 20 and 23.3°C is ideal for optimal student performance and plays an important role in student focus and performance [4].

The orientation of classrooms in educational buildings, which includes the building's placement in relation to the sun's direction and wind flow, greatly affects indoor energy use [5]. Proper orientation adjustments can reduce energy needs without sacrificing thermal and visual comfort for students and teachers [6, 7]. In this context, the study of building orientation becomes highly relevant, considering that the position of classrooms relative to the sun and wind direction can significantly impact daily energy needs.

Furthermore, other research shows that the majority of schools in warm regions have become uncomfortable places [8]. Proper management of spatial orientation can maximize the use of natural lighting and improve air circulation, thereby reducing dependence on artificial lighting and cooling systems [9]. Zahire and Altan (Zahiri and Altan 2016) Classroom studies in Tehran show that the application of passive design strategies, including southern and southeastern orientation, reduces indoor thermal levels by 4–5°K. Trebilcock, M. discovered that facing north reduces heating needs, while facing south reduces cooling needs [10]. The use of high-quality insulation can reduce heating needs, especially in the southern zone. Low infiltration rates in the southern zone and areas with the coldest temperatures also contribute to reducing heating needs. However, the use of glass does not have a significant impact on overall energy performance. These findings underscore the need for a similar study that is more specific to the local conditions of Kendari City, which has a humid tropical climate.

Kendari City, located in the equatorial region, has high temperatures throughout the year and high humidity levels, creating challenges in maintaining thermal comfort without increasing energy consumption [8]. The proper orientation of buildings can harness the potential of natural lighting, reduce the need for artificial cooling, and optimize natural ventilation. This research focuses on classrooms in the city of Kendari, which often have uniform design patterns without considering the influence of orientation.

The dimensions of school classrooms will refer to Permendikbud Number 34 of 2018, which regulates the minimum standards for educational spaces in Indonesia. Adjustments to this regulation ensure that classrooms not only meet technical requirements but also functionally support the learning process [11]. The simulation will realistically depict the ideal thermal conditions achievable by taking into account the space's dimensions, the building's orientation, and the local climate conditions.

This research aims to identify the thermal comfort orientation of classroom spaces in educational buildings for users. We anticipate that this research, through modeling and simulation with EnergyPlus, will yield practical recommendations for local authorities to support thermal comfort policies. We also expect the produced recommendations to have wider applicability to other educational buildings in tropical areas with similar characteristics. Ultimately, this research aims to support the creation of a sustainable and environmentally friendly learning environment.

2 Methodology

2.1 Preliminary Research

This study examines how the orientation of a building affects thermal comfort. It begins with a literature review and then uses climate data from https://climate.onebuilding.org/IDN_SL_Kendari-Haluoleo.AP.971460_TMYx to understand the local climate and environment. Figure 1 illustrates the correlation between the simulated climate data and the BMKG data. next the classroom's dimensions are standard. The findings highlight how different orientations can affect temperature regulation and airflow in classroom settings. By analyzing these variables, we aim to develop guidelines for optimizing classroom design to enhance student comfort and learning outcomes.

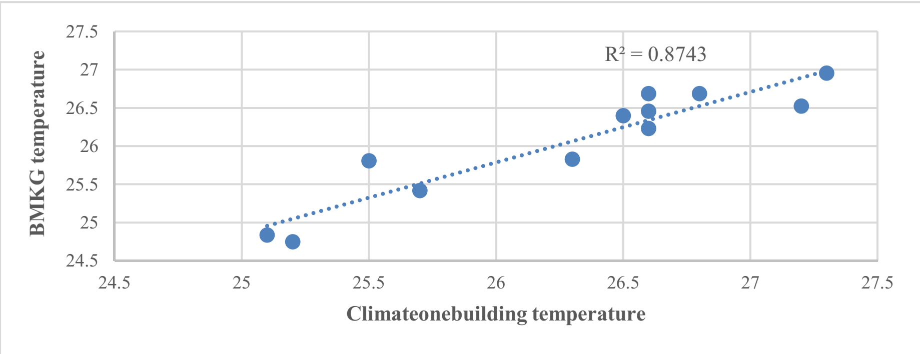

Fig. 1. The correlation exists between the temperature data from BMKG Kendari City and the temperature recorded in Climate.onebuildings.org.

2.2 Classroom Space Modeling

We are simulating the building and the classrooms in zones 1, 2, 3, and 4. Simulation with EnergyPlus software. Table 1 lists the characteristics and properties of building materials. The wall consists of three layers: the first layer is a 15 mm plaster, the second layer is a 100 mm brick masonry, the third layer is a 15 mm plaster, and the inner layer. Zinc sheets, 1 mm thick, form the roof. The ceiling uses plywood with a thickness of about 4 mm. 400 x 400 mm ceramic tiles with a 10 mm thickness make up the outermost layer of the floor, while a 50 mm concrete slab forms the innermost layer. The windows come in three different sizes, with a wall-to-window ratio of 1 for windows larger than 34%, and a wall-to-window ratio of 2 for windows and doors, with a thickness of 3 mm, without any additional shading or skin. All classrooms in this building have the same dimensions. Table 2 provides the description of the simulated classroom. We excluded classroom activities in this simulation to observe the impact of materials on room temperature. We inputted all the activities, materials, constructions, openings, and so on mentioned above (Table 2) into the simulation software to generate a model, and selected the basic model for all zones for further analysis.

Table 1. Explanation of Class Simulation Material

Component	Layer	Dimensions (mm)	U-Value [W/(m^2 °K)]
Floor	Rabat	50	1,73
	ceramic 40x40	400 x 400	1,3
Wall	Wall Plaster	15	1,73
	Brick	100	0,89
	Wall Plaster	15	1,73
Glass	Clear Glass	3	0,9
Ceiling	Tripleks	4	0,13
Roof	Zinc	1	110
Door	Wood	250	1,72

Table 2. Explanation of Classroom Space Simulation

Description	Dimension (cm)	Building			
		Zone A	Zone B	Zone C	Zone D
Floor	800 x 900	east-west	north-south	east-west	north-south
Window 1	80 x 190	east	south	east	south
Window 2	50 x 70	east	south	east	south
Window 3	130 x 200	east	south	east	south
Window 4	160 x 200	west	south	west	south
Door	200 x 120	east	south	east	south
Roof	800 x 900	east-west	north-south	east-west	north-south
Wall 1	800 x 350	north-south	east-west	north-south	east-west
Wall 2	900 x 350	east-west	north-south	east-west	north-south

We designed the classroom model using the EnergyPlus IDF Editor software and Notepad++. EnergyPlus then analyzed the built design. Permendikbud Nomor 34 Tahun 2018 has adjusted the classroom's dimensions to meet the following standards: a) use minimum room size (length 9 m, width 8 m, and height 3.5 m), b) The number and type of window, c) The EnergyPlus software (U.S. Dept. of Energy 2006) includes the ASHRAE_2005_HOF_Materials specifications for the walls, floors, and roof materials.

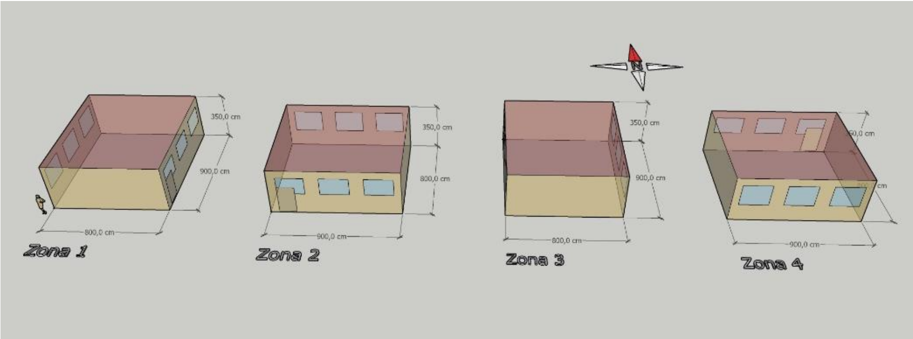

Fig. 2. Image of building position in relation to orientation.

We will apply different building orientation scenarios, facing north, south, east, or west, to the same model. The schematic diagram of the simulation modeling, based on the orientation direction, is shown in Figure 2. The analysis of each orientation scenario will yield data on thermal comfort in the classroom. Output data from EnergyPlus Zone Mean Air Temperature, hourly, and Site Outdoor Air Drybulb Temperature, hourly. We will compare the room temperature output data for each orientation scenario. We analyze this data to identify the orientation that yields the lowest room temperature, thereby providing information for energy-saving efforts and identifying which rooms meet the thermal comfort criteria according to ASHRAE or SNI standards.

2.3 Location Selection

The location chosen based on IDN_SL_Kendari-Haluoleo.AP.971460_TMYx is in the city of Kendari, Southeast Sulawesi, as follows:

Field	Units	Obj1
Name		Kendari-Haluoleo.AP_SL_IDN Design_Conditions
Latitude	deg	-4,08
Longitude	deg	122,42
Time Zone	hr	8
Elevation	m	51
Keep Site Location Information		

Fig. 3. Coordinates, Time Zone, and Elevation of the Simulation Location

Fig. 4. SMK Negeri 2 Kendari

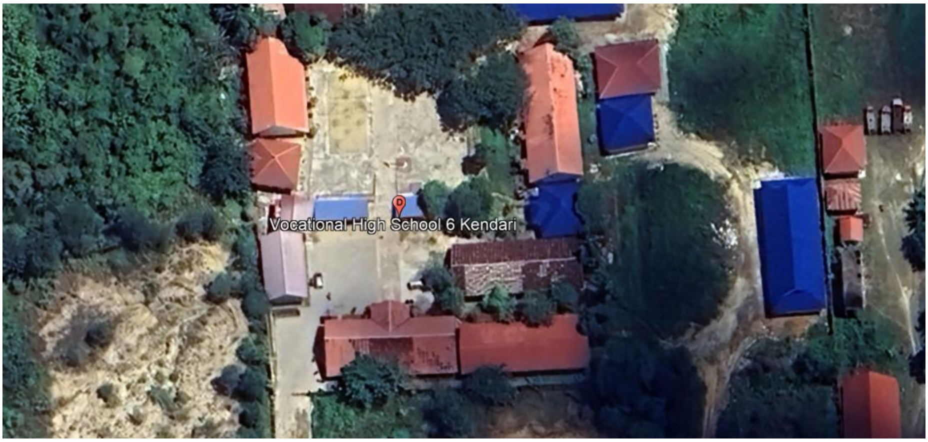

Fig. 5. SMK Negeri 6 Kendari

SMK Negeri 2 and SMK Negeri 6 Kendari are examples of buildings oriented to the north, east, south, and west. The majority of those buildings lack air conditioning systems. When entering the dry season, the outside temperature in the city of Kendari can reach 34.1°C. These conditions have the potential to cause discomfort during the learning process. Based on the Indonesian National Standard (SNI) 03-6572-2001 regarding the Design Procedures for Ventilation and Air Conditioning Systems in Buildings, the ideal classroom temperature for thermal comfort is in the range of 23°C to 27°C. Therefore, we must focus on the orientation that can facilitate the establishment of a comfortable learning environment.

3 Analysis and Discussion

3.1 Difference in Outdoor and Indoor Temperatures Hourly

Based on the research data, this study reveals that building orientation and window distribution significantly influence indoor temperature profiles in classroom spaces in the tropical climate of Kendari City. Zone 3 (north-south orientation with 3 east-facing and 2 west-facing windows) recorded the highest average temperature (27.54°C) figure 6 and an extreme maximum of 43.13°C figure 8, exceeding outdoor conditions (average 26.04°C; maximum 35.58°C). Dual solar radiation exposure from the east (morning) and west (afternoon), combined with insufficient cross-ventilation, caused significant heat accumulation. In contrast, Zone 4 (east-west orientation with 3 south-facing windows) exhibited more stable thermal performance (average 25.87°C), likely due to airflow from the open southern side and indirect sunlight exposure.

Analysis of minimum temperatures highlights the critical role of brick walls as thermal mass. All zones (figure 7) maintained higher indoor minimum temperatures (18.43-22.77°C) compared to outdoors (18.93°C), particularly in the early morning. This indicates that the brick walls effectively stored and slowly released heat, stabilizing nighttime to morning temperatures. However, this effectiveness drastically diminished during midday (09:00-15:00), with all zones experiencing significant temperature rises, especially Zone 3 (+8.43°C above average). This pattern reflects the inability of passive design to manage direct solar radiation without shading devices or active ventilation.

The extreme maximum temperature (figure 8) in Zone 3 (43.13°C) critically indicates overheating due to imbalanced window design. Direct solar radiation through unprotected east and west-facing windows increased heat gain, while limited openings on the north/south sides restricted airflow. Comparatively, Zones 1 and 2 (different orientations with similar window layouts) recorded lower maximum (39.64°C and 39.44°C), suggesting that east-west orientations with north/south openings (Zones 2 and 4) better mitigate heat accumulation through natural ventilation.

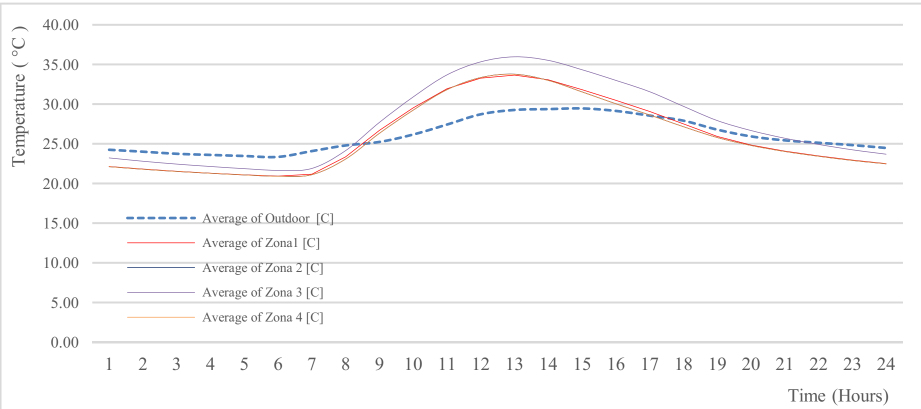

Fig. 6. Graph Comparison of average outdoor and indoor temperatures hourly over 24 hours.

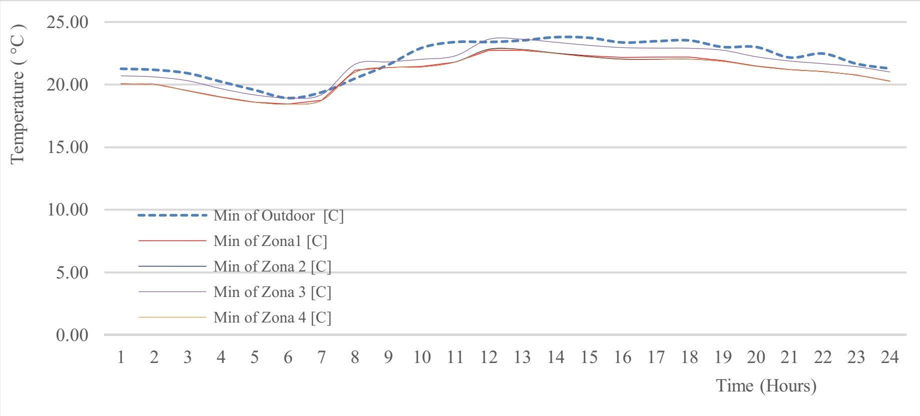

Fig. 7. Graph comparison of minimum outdoor and indoor temperatures hourly over 24 hours.

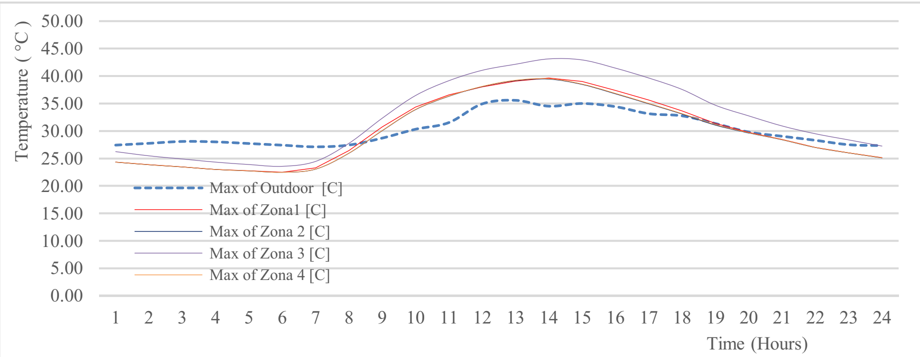

Fig. 8. Graph comparison of maximum outdoor and indoor temperatures hourly over 24 hours.

3.2 Difference in Outdoor and Indoor Temperatures Daily

Based on daily data over 31 days visualized in Figure 9 (average), temperature patterns in classrooms in Kendari City show significant variations depending on building orientation. Zone 3 (north-south orientation with east-west openings) consistently records the highest averages, such as on date 14 with a temperature of 28.21°C (Figure 9), far exceeding the outdoor average (26.23°C). This graph highlights heat accumulation in Zone 3 due to dual exposure to morning (east) and afternoon (west) sunlight, particularly during mid-month (dates 13–18) when solar radiation is intense. Meanwhile, Zone 4 (east-west orientation with south-north openings) has the lowest average, such as on date 30 (25.94°C), as its southern openings utilize cooler sea breezes, reflected in the stable trend in Figure 9.

Figure 11 (maximum) reveals extreme temperature fluctuations in Zone 3, peaking on date 17 at 43.13°C, while outdoor temperatures reached only 34.46°C. This graph emphasizes the sharp mid-month spike (dates 13-18), where the combination of east-west orientation, brick materials, and limited ventilation traps heat. In contrast, Zone 4 remains relatively stable, with a maximum temperature of 39.51°C on the same date (Figure 11). On dates 24-25, all indoor zones experience a drop in minimum temperatures (e.g., Zone 4 reaches 18.43°C in Figure 10), likely due to external factors like rain or high humidity enhancing nighttime heat dissipation.

Figure 10 (minimum) reinforces the analysis of heat retention based on orientation. Zone 1 and Zone 3 tend to retain heat longer, as seen on dates 13-14 in Zone 3, where minimum temperatures were 20.03-20.56°C (Figure 10), while outdoor temperatures dropped to 21.48°C. This graph illustrates how brick walls in these zones store daytime heat and release it slowly at night. However, on dates 24–25, Zone 4 records the lowest minimum temperature (18.43°C), even lower than outdoors (18.93°C), due to its north-south openings enabling smoother airflow and faster natural cooling (Figure 10).

Figure 9, 10, and 11 collectively confirm that mid-month (dates 13-18) is a critical period with extreme temperatures, particularly in Zone 3, as shown by peak averages (Figure 9), maximum (Figure 11), and minimum (Figure 10). Meanwhile, late-month (dates 24–31) shows significant drops in minimum temperatures across all zones (Figure 10), influenced by external climatic conditions. The integration of these graphs underscores how building orientation and opening designs not only affect daily temperatures but also a room's response to weather changes. For mitigation, classroom designs should prioritize shading for east/west openings (Zone 3) and optimize cross-ventilation (Zone 4), as evidenced by the contrasting trends across the graphs.

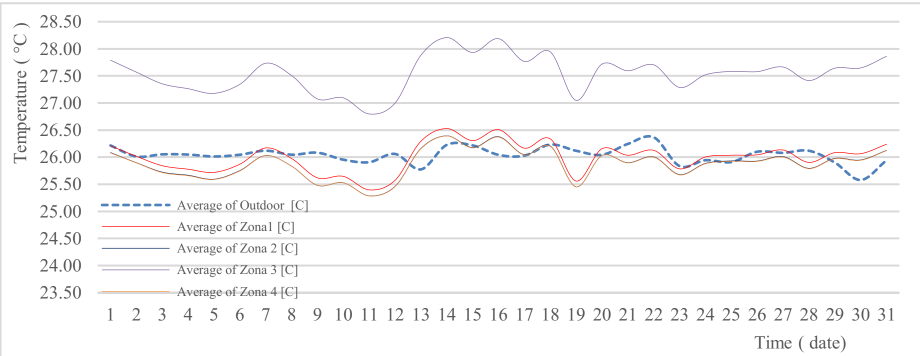

Fig. 9. Graph comparison of the average outdoor and indoor temperatures daily over 31 days.

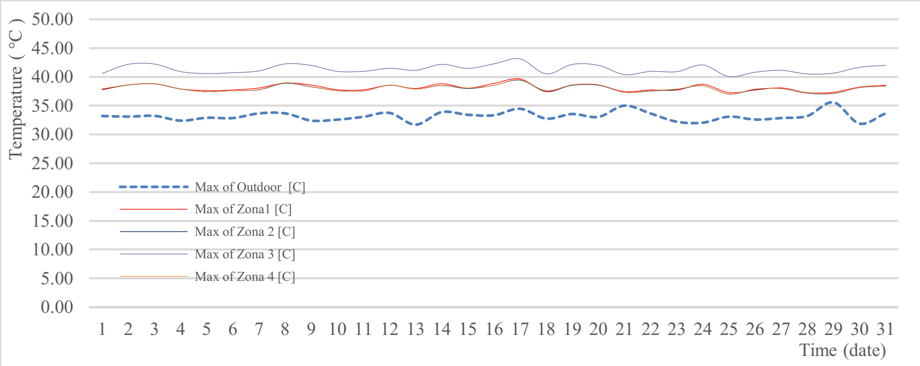

Fig. 10. Graph comparison of maximum outdoor and indoor temperatures daily over 31 days.

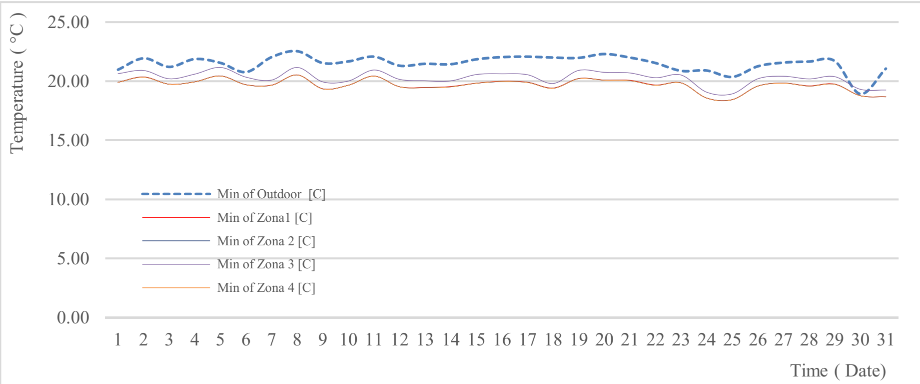

Fig. 11. Graph comparison of minimum outdoor and indoor temperatures daily over 31 days.

3.3 Difference in Outdoor and Indoor Temperatures Monthly

In the average temperature graph (Figure 12), Zone 3 consistently remains the hottest zone throughout the year, especially from September to November, with temperatures reaching 28.52-29.16°C 2-3°C higher than outdoor temperatures (25.81-26.95°C). The peak occurs in November (29.16°C), driven by its north-south orientation with east and west-facing windows exposed to intense morning and afternoon sunlight. This dual exposure causes heat accumulation trapped in brick walls, exacerbated by the dry season in Kendari (August–November) with maximum solar radiation. Meanwhile, Zone 4 (east-west orientation, south-facing windows) remains relatively stable at 26.52–27.18°C during the same period, as the south-facing windows avoid direct sunlight in a tropical climate.

Minimum temperature data (Figure 13) shows August as the coldest month, particularly in Zone 4 (18.43°C), 1.93°C lower than the outdoor temperature (20.36°C). This occurs due to the combination of strong easterly monsoon winds (June–August) and excessive ventilation in Zone 4 (three south-facing windows + two north-facing windows). The moist night air and wind flow accelerate room cooling, while brick material has low heat retention. On the other hand, Zone 3 remains warm (18.93°C) due to daytime heat accumulation from east/west-facing windows, although this poses a risk of thermal discomfort during the day.

The maximum temperature graph (Figure 14) confirms November as the hottest month, particularly in Zone 3 (43.13°C), significantly exceeding outdoor temperatures (34.46°C). This phenomenon is linked to the sun's position south of the equator (September-March), directly illuminating the east and west-facing windows of Zone 3. This high radiation is intensified by the lack of protective vegetation and dark brick surfaces that absorb heat. Conversely, Zone 2 (east-west orientation, north-facing windows) has a lower maximum temperature (39.44°C) because its north-facing windows receive indirect sunlight, although it remains critical due to limited ventilation (only three windows).

From June to August, outdoor temperatures drop significantly (24.75-25.42°C), but indoor zone responses vary. Zone 1 (north-south orientation, west-facing windows) experiences an average decrease to 25.15°C in July, 0.6°C cooler than outdoors (24.75°C), due to westerly winds entering through three glass windows. However, Zone 3 remains hot (26.53-26.99°C) because its west wall receives intense afternoon sunlight. This period highlights that passive design (such as west-side shading in Zone 3) is crucial for heat mitigation, even in the tropical "wet" season.

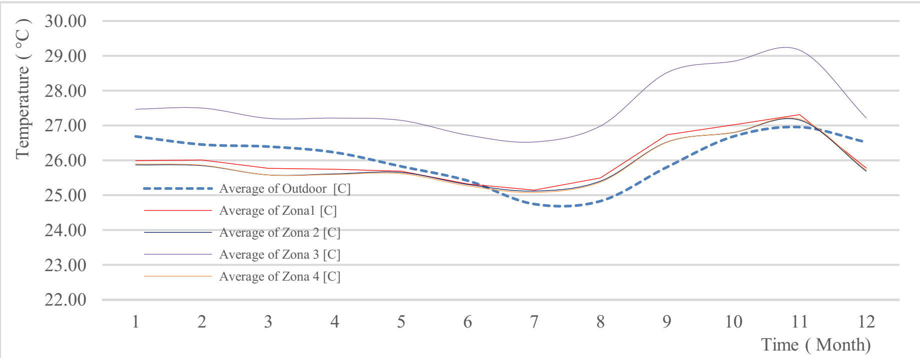

Fig. 12. Graph comparison of average outdoor and indoor temperatures monthly over the year.

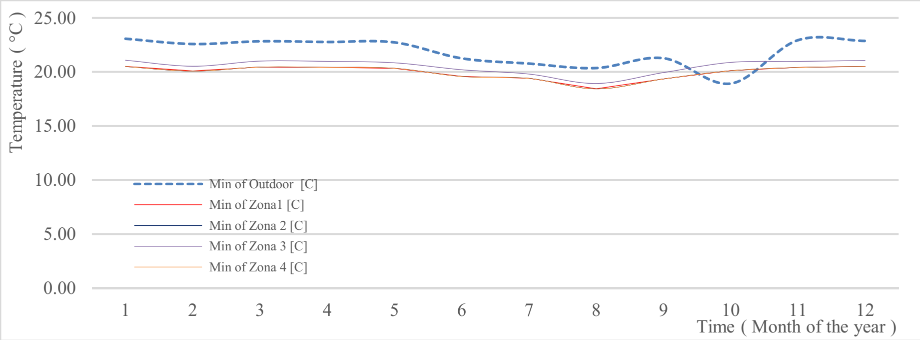

Fig. 13. Graph comparison of minimum outdoor and indoor temperatures monthly over the year.

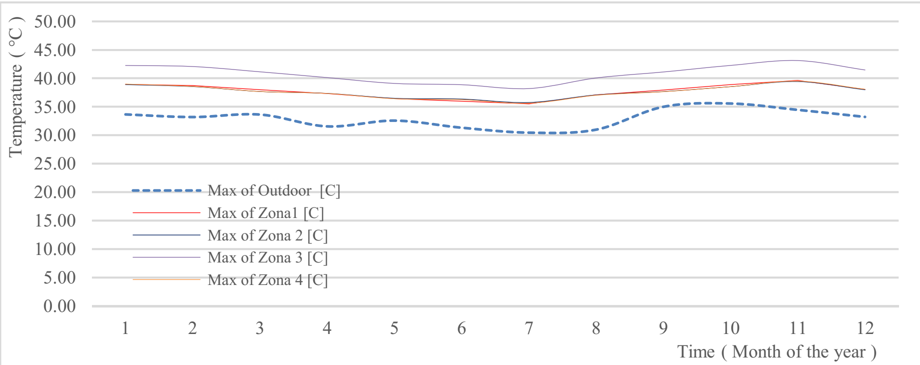

Fig. 14. Comparison of maximum outdoor and indoor temperatures monthly over the year.

3.4 Discussion

In this simulation, the difference in time periods, whether hours, days, or months, over the course of a year has provided simple access to information regarding the differences in temperature conditions, both indoors and outdoors. The hourly period over the course of a year will provide measurable information regarding the classroom temperature during effective learning hours. The effective use of classrooms is between 07:00-12:00 and 13:00-15:00. The simulation results show that the average temperature increases from 07:00 to 13:00, with the second learning hour remaining stable above 30°C until 16:00. Consequently, this condition does not meet the SNI comfort standards, where the threshold is 23-27°C. Similarly, with the maximum temperature occurring at 14:00, the temperature reached 43.13°C in zone 3. As explained in Table 1, the orientation of the window openings in Zone 3 faces east-west. The simulation results show that the peak solar radiation occurs at 14:00, with an average of 645 W/m2. O'Brien stated that buildings exposed to solar radiation with window openings facing east and west can affect the use of shading, glare prevention, and solar energy enhancement [12]. O'Brien further stated that the orientation of the building facade and the depth of sunlight penetration can affect the amount of solar radiation transmitted through the windows. Additionally, according to Huang, the use of energy-efficient window designs, such as low-e glass, can significantly reduce heat absorption through windows [13]. Direct observation results indicate that we apply insulation (curtains) to reduce radiation on the window section. Some studies show that excessive exposure to solar radiation can cause long-term health problems, such as an increased risk of skin cancer. Students and teachers need natural lighting for comfort and productivity, but this can reduce it. The simulation in this study did not involve changes to the materials or the addition of an outer building skin to prevent radiation. The research only want to indicate the ideal direction in designing classrooms.Therefore, to address the issue of excessive solar radiation without sacrificing the natural lighting required by classroom occupants, further research is necessary. Possible solutions that can be considered include the use of insulation materials that can absorb solar radiation without blocking incoming light or the arrangement of efficient and environmentally friendly artificial lighting. Therefore, we can design classrooms to ensure their occupants remain comfortable and productive.

The simulation's monthly period analysis over a year will provide us with information on the efficient use of classrooms. The academic calendar explains the stages of students entering school up to the exam schedule and holidays. In January, the beginning of the school term after the mid-semester break, the average room temperature is 26°C for all four zones and still falls within the SNI standard category. The temperature will remain stable until September, ranging from 25-27°C. In April and May, based on the data, the temperature tends to be moderate, neither too hot nor too cold, both indoors and outdoors. However, it is important to pay attention to the maximum temperature data. If April/May sees days with high maximum temperatures, it could disrupt students' comfort during exams. The holiday period (May-June) aligns with the transition towards July, a time when the average and maximum outdoor temperatures tend to decrease. However, it is important to note that data shows the minimum temperature in the indoor space actually occurs in August. Even though it's a holiday, school activities during these months require monitoring the indoor temperature conditions.

The beginning of the new school year coincides with the lowest temperatures, both average and maximum, in the outdoor space. However, interestingly, the lowest maximum temperature indoors also occurs in July, with a very significant increase (7.74°C in zone 3). This means that, although it is relatively cool outside, the interior can be very hot. This should be a major concern, particularly if teaching activities begin in early July. Temperature Peak (October/November). Data shows that the maximum temperature (Figure 14), both outdoors and indoors, peaks in October/November. This period usually falls in the middle of the odd semester. During this period, we need to pay special attention to the thermal comfort of students and teachers in the classroom. To minimize significant temperature differences between indoor and outdoor spaces, it is important to optimize ventilation in the building by using openings such as skylights on the roof to allow cool air in and replace the hot air inside. The proper placement of roof ventilation openings on the east and west sides of the building can facilitate airflow and reduce heat accumulation. Additionally, using double-glazed doors and windows with a mesh layer on the outer layer can help control wind speed and maintain indoor comfort. By incorporating proper ventilation to allow the exchange of hot indoor air with cooler outside air, we can manage the heat that accumulates between the roof and the ceiling. Monitoring humidity and air temperature is crucial for effective temperature regulation. The intensity of solar radiation can affect indoor air temperature, with direct sunlight causing higher heat entry through radiation compared to shaded areas. Effective heat management strategies are crucial to prevent excessive temperature increases indoors [14].

Therefore, we need to adjust the air conditioning system to maintain a comfortable classroom temperature for the teaching and learning process. Additionally, evaluating the building design and room ventilation is necessary to minimize significant temperature differences between the inside and outside spaces. Thus, we can maintain ideal temperature conditions at all times, ensuring optimal learning without disruption from external weather conditions.

Table 3. Recap of Temperature Differences in Each Zone

Temperature °C											
Zone 1			Zone 2			Zone 3			Zone 4		
Avg	max	min	Avg	max	min	Avg	max	min	Avg	max	min
26,00	39,64	18,44	25,88	39,44	18,44	27,54	43,13	18,93	25,85	39,51	18,43

4 Summary

Research findings indicate that building orientation has a significant impact on the thermal comfort of classrooms. EnergyPlus simulations reveal that classrooms in zones 1, 2, and 4 tend to have lower temperatures compared to zone 3, although all zones remain above the ideal comfort threshold. This difference is suspected to be related to solar radiation exposure and airflow, which are influenced by building orientation. These results confirm that selecting an orientation that minimizes direct solar exposure during summer is a key strategy for enhancing thermal comfort.

Although factors such as ventilation, building materials, and temperature control also play a role, this study specifically highlights that optimizing building orientation can serve as a fundamental basis for classroom planning. The recommended optimal orientations from this study (zones 1, 2, and 4) are expected to serve as an initial reference, which can then be combined with other supporting strategies to create a more holistically comfortable learning environment.

References

1. A. M. Bueno, A. A. de Paula Xavier, and E. E. Broday, "Evaluating the con-nection between thermal comfort and productivity in buildings: A systematic literature review," Jun. 07, 2021, MDPI AG. doi: 10.3390/buildings11060244.

2. M. K. Singh, S. Kumar, R. Ooka, H. B. Rijal, G. Gupta, and A. Kumar, “Status of thermal comfort in naturally ventilated classrooms during the summer season in the composite climate of India,” Build Environ, vol. 128, pp. 287–304, Jan. 2018, doi: 10.1016/J.BUILDENV.2017.11.031.
3. L. Baker and H. Bernstein, “The Impact of School Buildings on Student Health and Performance,” 2012. [Online]. Available: www.mcgraw-hillresearchfoundation.org
4. P. Romero, V. Valero-Amaro, S. Rubio, and M. T. Miranda, “An Analysis of Thermal Comfort as an Influencing Factor on the Academic Performance of University Students,” Educ Sci (Basel), vol. 14, no. 12, Dec. 2024, doi: 10.3390/educsci14121340.
5. H. Rosenlund, “Climatic Design of Buildings using Passive Techniques,” Building Issues, vol. 10, no. 1, 2000, Accessed: Jan. 02, 2025. [Online]. Available: https://www.researchgate.net/publication/238104641_Climatic_Design_of_Buildings_using_Passive_Techniques
6. L. R. Jia, J. Han, X. Chen, Q. Y. Li, C. C. Lee, and Y. H. Fung, “Interaction between thermal comfort, indoor air quality and ventilation energy consump-tion of educational buildings: A comprehensive review,” Dec. 01, 2021, MDPI. doi: 10.3390/buildings11120591.
7. A. Zhang, R. Bokel, A. van den Dobbelsteen, Y. Sun, Q. Huang, and Q. Zhang, “The effect of geometry parameters on energy and thermal perfor-mance of school buildings in cold climates of China,” Sustainability (Swit-zerland), vol. 9, no. 10, Sep. 2017, doi: 10.3390/su9101708.
8. M. Shrestha and H. B. Rijal, “Investigation on Summer Thermal Comfort and Passive Thermal Improvements in Naturally Ventilated Nepalese School Buildings,” Energies (Basel), vol. 16, no. 3, Feb. 2023, doi: 10.3390/en16031251.
9. B. J. Al-Khatatbeh and S. N. Ma’Bdeh, “Improving visual comfort and ener-gy efficiency in existing classrooms using passive daylighting techniques,” in Energy Procedia, Elsevier Ltd, 2017, pp. 102–108. doi: 10.1016/j.egypro.2017.10.294.
10. M. Trebilcock, B. Piderit, J. Soto, and R. Figueroa, “A parametric analysis of simple passive strategies for improving thermal performance of school class-rooms in Chile,” Archit Sci Rev, vol. 59, no. 5, pp. 385–399, Sep. 2016, doi: 10.1080/00038628.2016.1150251.
11. O. Veronica Kingsley, “Management of learning facilities,” 2019. [Online]. Available: www.prosoc.eu
12. W. O’Brien, K. Kapsis, and A. K. Athienitis, “Manually-operated window shade patterns in office buildings: A critical review,” Build Environ, vol. 60, pp. 319–338, Feb. 2013, doi: 10.1016/J.BUILDENV.2012.10.003.
13. Y. Huang, J. lei Niu, and T. ming Chung, “Comprehensive analysis on ther-mal and daylighting performance of glazing and shading designs on office building envelope in cooling-dominant climates,” Appl Energy, vol. 134, pp. 215–228, Dec. 2014, doi: 10.1016/J.APENERGY.2014.07.100.
14. G. Hardiman and S. S, “ADAPTASI TAMPILAN BANGUNAN KOLONIAL PADA IKLIM TROPIS LEMBAB (Studi Kasus Bangunan Kantor PT KAI Semarang),” 2013.