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CFD Analysis of Thermal Distribution and Airflow in a Confined Classroom: RoomE303, Sumatera Institute of Technology

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ABSTRACT

This study evaluates the thermal comfort of Classroom E303 at the Sumatera Institute of Technology, a west-facing room exposed to high solar heat in a tropical climate. Air temperature and relative humidity were measured at 16 points under unoccupied conditions and used as boundary inputs for computational fluid dynamics (CFD) simulations developed with SketchUp and SolidWorks. Model validation using mean absolute percentage error (MAPE) and root mean square error (RMSE) showed good accuracy at 4.41% and 1.06 °C. Baseline analysis indicates that the thermal conditions approach the upper limit of the SNI 03-6572-2001 comfort standard, reflecting a warm indoor environment. A mist-based evaporative cooling scenario reduced temperature by 2.7 °C and increased relative humidity by 16%RH, demonstrating its potential to enhance comfort. The findings confirm that CFD is an effective tool for predicting indoor thermal performance and supporting passive, energy-efficient strategies in tropical educational buildings.

Keywords: *airflow distribution; CFD simulation; energy efficiency, evaporative cooling; thermal comfort*

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ABSTRACT

Studi ini mengevaluasi kenyamanan termal Ruang Kelas E303 di Institut Teknologi Sumatera, sebuah ruangan menghadap barat yang terpapar panas matahari tinggi dalam iklim tropis. Suhu udara dan kelembapan relatif diukur di 16 titik dalam kondisi tidak terisi dan digunakan sebagai masukan batas untuk simulasi dinamika fluida komputasional (CFD) yang dikembangkan dengan SketchUp dan SolidWorks. Validasi model menggunakan *mean absolute percentage error* (MAPE) serta *root mean square error* (RMSE) dan menunjukkan akurasi yang baik sebesar 4,41% dan 1,06 °C. Analisis dasar menunjukkan bahwa kondisi termal mendekati batas atas standar kenyamanan SNI 03-6572-2001, mencerminkan lingkungan dalam ruangan yang hangat. Skenario pendinginan evaporatif berbasis kabut menurunkan suhu sebesar 2,7 °C dan meningkatkan kelembapan relatif sebesar 16%RH, menunjukkan potensinya dalam meningkatkan kenyamanan. Temuan ini mengonfirmasi bahwa CFD merupakan alat yang efektif untuk memprediksi kinerja termal dalam ruangan dan mendukung strategi pasif yang hemat energi pada bangunan beriklim tropis.

Keywords: *distribusi aliran udara; efisiensi energi; kenyamanan termal; pendinginan evaporatif; simulasi CFD*

INTRODUCTION

Thermal comfort is a crucial aspect of building performance in humid tropical regions such as Indonesia, as it affects occupants' health, comfort, and productivity. Classrooms in tropical climates often experience thermal discomfort due to high solar radiation and limited airflow, indicating the need for proper thermal evaluation [1], [2]. In Indonesia, thermal comfort criteria are regulated by SNI 03-6572-2001 and supported by recent thermal comfort index studies, which recommend effective temperature ranges of 22.8–25.8 °C with relative humidity of 55–60% [3], [4]. Computational Fluid Dynamics (CFD) has been widely applied to analyze airflow patterns and temperature distribution in classrooms to support comfort-oriented design [5]-[8].

Therefore, this study analyzes the thermal conditions of Classroom E303 in Building E at the Sumatra Institute of Technology using CFD simulations validated by field measurements through RMSE and MAPE. Thermal comfort is evaluated based on Indonesian national standards and psychrometric diagram analysis, and indoor airflow patterns are qualitatively illustrated through mist air cooler simulations. Unlike most previous CFD studies on tropical classrooms that primarily focus on natural ventilation or air-conditioning performance, this study uniquely evaluates thermal distribution under different daily time conditions (morning, noon, and afternoon) and vertical levels (1 m and 2.5 m). It investigates the influence of mist air cooler configuration and quantity as an alternative cooling strategy. These aspects constitute the novelty of this research.

METHODS

This study employs an experimental approach combined with numerical simulation using Computational Fluid Dynamics (CFD) to analyze the thermal comfort conditions in Classroom E303, Building E, at Institut Teknologi Sumatera. The primary objective is to evaluate the distribution of temperature and humidity under baseline conditions without additional cooling equipment and to compare it with mist air cooler-based simulations as a before-after illustration.

The CFD model was developed under controlled conditions with steady-state assumptions, adiabatic wall boundaries, and an unoccupied classroom scenario, in accordance with the defined research scope and limitations. These assumptions were intentionally applied to isolate the fundamental thermal behavior of the space and to minimize the influence of uncontrollable internal heat gains. However, under real classroom conditions, occupant presence, internal heat sources, and transient ventilation patterns may alter temperature distribution and airflow characteristics. Therefore, the results of this study represent idealized baseline conditions and serve as a reference for further investigations under occupied and dynamic operating scenarios.

Data Collection

To obtain an overview of the natural indoor thermal conditions, field measurements were conducted directly in the classroom. The measurements were carried out in an unoccupied room with the air conditioning (AC) and fans turned off and with window blinds fully opened. The determination of measurement points followed the principles outlined in ASHRAE Standard 55-2017 [6], ensuring that the collected data represented the entire room volume. Figure 1 illustrate the measured parameters comprised air temperature (°C), relative humidity (%), and air velocity (m/s). All measurements were conducted at 12:00 local time (WIB).

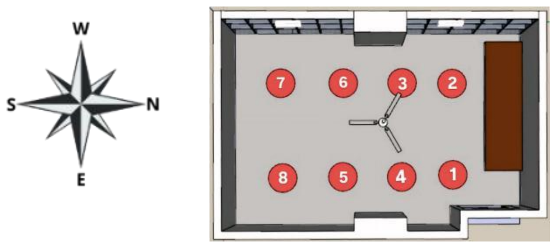

Figure 1. Positions of the eight measurement points.

CFD Modelling and Simulation

a. Geometry Development

The three-dimensional geometry of Classroom E303 was created in SolidWorks based on actual field measurements. All main architectural features, including doors, windows, openings, and interior elements, were included to represent airflow and thermal behavior accurately. The complete CFD model setup, including geometry, boundary locations, mist air cooler placement, and measurement points, is shown in Figure 2.

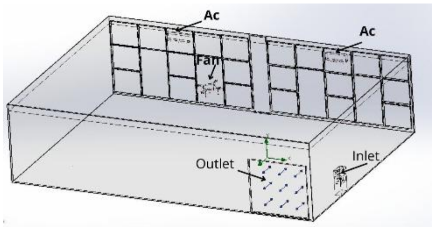

Figure 2. CFD simulation setup of Classroom E303 showing geometry, inlet and outlet locations, AC units, mist air cooler placement, and airflow direction.

b. Fluid Properties

Air was defined as the working fluid, with its thermophysical properties adjusted according to field measurement data, including ambient temperature, relative humidity, and atmospheric pressure. These parameters ensured that the simulation environment matched the real thermal conditions of the classroom.

c. Boundary Conditions

Open windows served as inlets with an air velocity set at 0.2–0.3 m/s, an inlet temperature of 30–33 °C, and relative humidity values derived from field data. Door gaps functioned as outlets with static pressure fixed at 0 Pa to represent atmospheric discharge. Wall, floor, and ceiling temperatures were assigned based on solar exposure measurements, with the west-facing wall set at 32–36 °C. All wall boundaries were modeled as adiabatic except for sun-exposed surfaces. No internal heat sources were included because the room was unoccupied during measurement.

d. Mesh Generation

The computational domain was discretized using a structured mesh with a global cell size of 0.15 m. Local mesh refinements of 0.05–0.10 m were applied around critical regions such as window and door openings to accurately capture airflow gradients and turbulence effects. The final mesh consisted of approximately 1.2–1.6 million cells, ensuring a balance between numerical accuracy and computational efficiency. The mesh configuration used in the CFD simulation is shown in Figure 3.

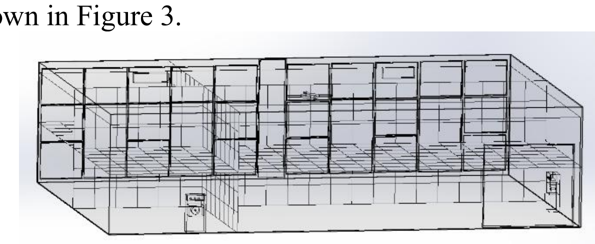

Figure 3. Computational mesh used in the CFD simulation of Classroom E303 (global view).

e. Simulation Settings

CFD analysis using the k–ε turbulence model in a steady-state flow configuration. Convergence was achieved with a residual set at 1×10^{-4}, and each simulation required between 500 and 800 iterations depending on the stability of the solution. The k–ε model has been widely applied and verified for indoor airflow studies and thermal comfort in classrooms and naturally ventilated buildings, demonstrating reliable performance in tropical environments [10], [11]. Furthermore, previous verification studies have confirmed that CFD-based thermal simulations can represent actual indoor conditions with acceptable accuracy when appropriate boundary conditions and convergence criteria are applied [12].

f. Simulation Scenarios

Two scenarios were evaluated. The first simulated baseline conditions without cooling equipment to analyze natural airflow, temperature distribution, and humidity patterns. The second scenario incorporated a misting system to assess its influence on thermal distribution. Visual outputs included 2D cut plots, contour maps, color bars, and vector arrows to illustrate airflow behavior and temperature gradients [13].

Model Validation

Previous studies have also used MAPE and RMSE to validate CFD simulations in naturally ventilated or passively cooled buildings [14]. These indicators are widely accepted for evaluating the agreement between measured and simulated thermal data [15].

$$\text{MAPE} = \frac{1}{n}\sum_{i=1}^{n}\frac{|x_i-y_i|}{|x_i|}\times 100\% \quad (1)$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(x_i-y_i)^2}{n}} \quad (2)$$

where x_i is the actual measurement data, y_i is the simulation data, and n is the number of measurement data. Through these two parameters, a quantitative measure of how well the simulation model represents real conditions is obtained. Furthermore, the simulation results are analyzed with reference to the SNI 03-6572-2001 thermal comfort standard to assess whether the thermal conditions of the classroom meet the established comfort criteria [3].

Equipment and Materials

Some of the tools and devices used in this study include a Lux Meter to measure light intensity in Some tools and devices used in this study include a lux meter to measure light intensity in lux units (as additional environmental data). A humidimeter to measure relative humidity in the room, SolidWorks for modeling and simulating temperature and humidity distribution, and a computer/laptop for data processing, 3D modeling, and CFD simulation processes.

The simulation was conducted numerically without additional experiments using physical cooling equipment. Only additional simulations with the equipment were included as visualizations to compare the thermal conditions of the room before and after the application of the misting system.

RESULTS AND DISCUSSION

Temperature Measurement Result Without the Use of Tools

According to SNI 03-6572-2001, the recommended thermal comfort range is 22.8–25.8 °C with 55–60% relative humidity [3]. Field measurements conducted on 30 January 2025 at 12:00 pm WIB recorded an average temperature of 25.5 °C and relative humidity of 57.66% at 1 m height, indicating conditions at the upper limit of thermal comfort. While the temperature complies with the standard, the slightly lower humidity suggests a tendency toward dry indoor air [3]. These measured values were used as reference data and boundary conditions for CFD modeling to analyze temperature and humidity distribution in Classroom E303.

Table 1. Measurement results without the use of a mist air cooler at 12:00 PM.

Measurement Points	DB (°C)	RH (%)
1	25.8	57.6
2	25.7	57.6
3	25.3	57.8
4	25.5	57.5
5	25.4	58.4
6	25.5	57.6
7	25.4	57.4
8	25.4	57.4
Average	25.5	57.7

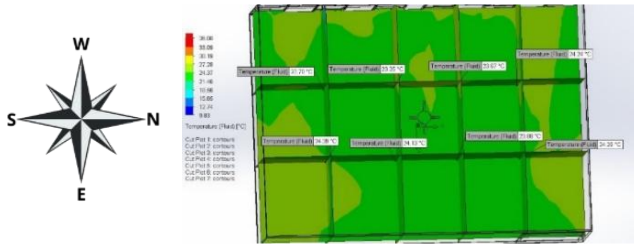

Figure 4. Simulation results of temperature distribution without the use of tools at a height of 1 m.

CFD results (Figure 4) show temperature variations of 23.25–24.39 °C, with higher values near the west-facing wall due to solar heat gain and lower values in central areas influenced by airflow patterns. This non-uniform distribution is typical of naturally ventilated tropical classrooms. Model validation using MAPE (3.98–8.82%) and RMSE (1.02–5.06 °C) indicates good agreement with field measurements, with all errors below the 20% tolerance limit, as summarized in Table 2. Slightly higher deviation at boundary points is attributed to increased turbulence effects.

Table 2. Results of Temperature Evaluation in Room E303

Measurement Points	Actual Data (°C)	Simulation Data (°C)	MAPE (%)	RMSE
1	25.8	24.29	5.85	1.51
2	25.7	24.24	5.68	1.46
3	25.3	23.67	6.44	1.63
4	25.5	23.88	6.35	1.62
5	25.4	24.13	5.00	1.27
6	25.5	23.25	8.82	2.25
7	25.4	23.70	6.69	1.70
8	25.4	24.39	3.98	1.01
Average	25.5	23.94	6.10	1.56

From the occupant's perspective, the temperature distribution without cooling assistance may cause a slightly warm sensation, particularly near the west-facing wall exposed to solar radiation. Although the average temperature is still within the comfort range, spatial non-uniformity may lead to localized discomfort and reduced concentration during learning activities.

Simulation of Humidity Distribution in Room E303 Without Using Tools

As shown in Figure 5, the humidity simulation results range from 49.51% to 50.22%, noticeably below SNI comfort requirements. The lower humidity is consistent with high solar heat gain and low moisture input due to the absence of a humidifying system. Although variations between points are minimal, the overall dry condition may reduce thermal comfort.

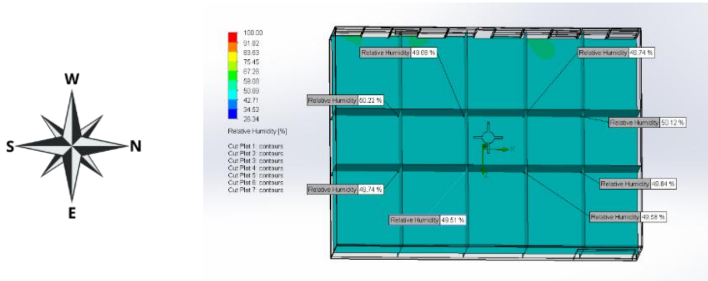

Figure 5. Simulation results of humidity distribution without the use of the E303 room device at a height of 1 m.

To evaluate the level of conformity between the simulation results and the measurement data, MAPE and RMSE calculations were performed. A comparison of the actual and simulated values at each measurement point is shown in Table 3, with the result that MAPE values range from 12.50 to 15.22%, and RMSE ranges from 7.18 to 8.89% RH. Although humidity errors are higher than temperature errors, they remain acceptable. This behavior is consistent with previous CFD studies, where humidity prediction tends to show greater deviation due to the sensitivity of moisture transport modeling and limited vapor-source boundary definitions.

Table 3. Results of the E303 room humidity evaluation.

Measurement Points	Actual Data (°C)	Simulation Data (°C)	MAPE (%)	RMSE
1	57,6	49.84	13.47	7.76
2	57,6	50.12	12.99	7.48
3	57,8	49.58	14.22	8.22
4	57.5	49.74	13.49	7.76
5	58.4	49.51	15.22	8.89
6	57.6	49.68	13.75	7.92
7	57.4	50.22	12.51	7.18
8	57.4	49.74	13.35	7.66
Average	57.7	49.80	13.63	7.86

Simulation of Temperature Using a Mist Air Cooler

An additional simulation was conducted to evaluate the effect of a mist air cooler on temperature and humidity distribution in Classroom E303. The simulation used the same room configuration, time, and measurement points, with the mist air cooler operated at maximum intensity, to enable direct comparison of thermal conditions before and after cooling intervention. Figure 6(a) shows the temperature trend at a height of 1 m, while Figure 6(b) illustrates the simulated temperature distribution under the mist air cooler condition.

The evaporative cooling scenario shows a significant decrease in temperature to 21.36–22.79 °C, with an average close to 22 °C, indicating a decrease of approximately 2.7 °C due to the conversion of sensible heat into latent heat during the evaporation process. The temperature distribution is more uniform, indicating effective air dispersion from the mist cooler, although slightly higher temperatures remain on the opposite side of the device, highlighting the importance of placement. Model validation showed excellent agreement with field measurements, with MAPE values of 1.34–5.90% and RMSE values of 0.31–1.34 °C (Table 4), indicating better accuracy compared to baseline conditions due to more stable and predictable airflow patterns.

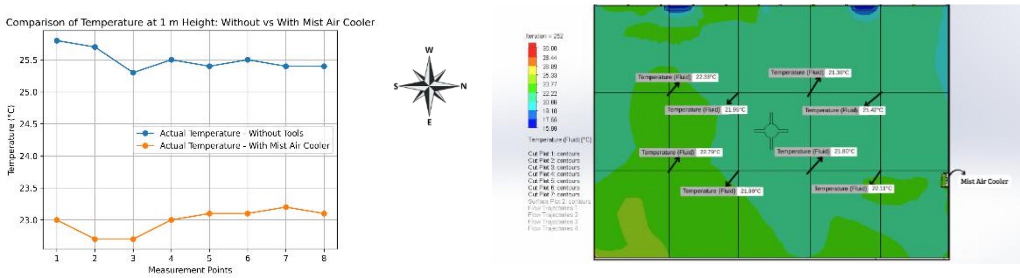

Figure 6. (a) Temperature trend at 1 m height showing the comparison between conditions without and with the mist air cooler. (b) Simulation results of E303 temperature distribution using an air cooler.

Table 4. MAPE and RMSE result of temperature distribution simulations using the tool.

Measurement Points	Actual Data (°C)	Simulation Data (°C)	MAPE (%)	RMSE
1	23.0	22.11	3.87	0.89
2	22.7	21.42	5.64	1.28
3	22.7	21.36	5.90	1.34
4	23.0	21.80	5.22	1.20
5	23.1	21.99	4.81	1.11
6	23.1	21.95	4.98	1.15
7	23.2	22.39	3.49	0.81
8	23.1	22.79	1.34	0.31
Average	22.99	21.98	4.41	1.01

Simulation of humidity distribution using a mist air cooler

The misting system raises humidity to 61–66.45% (Figure 7), placing the room above the upper comfort limit for RH according to SNI. This humidity increase is expected due to evaporative cooling, where moisture addition accompanies the temperature drop. Although humidity levels slightly exceed the comfort range, evaporative systems typically operate within such boundaries, especially in tropical climates where occupants often tolerate higher humidity when accompanied by lower temperatures.

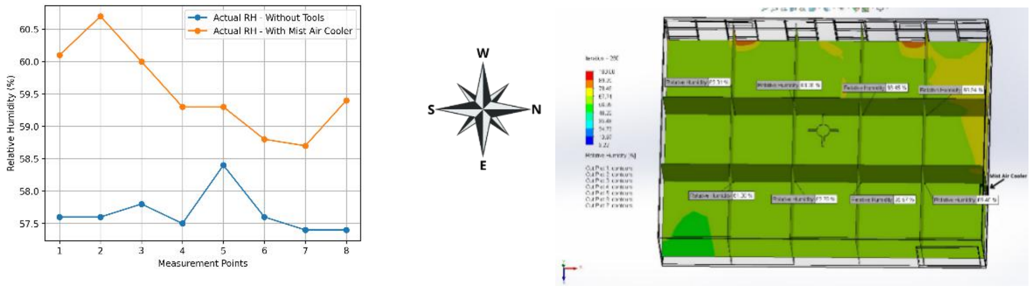

Figure 7. (a) Relative humidity trend at 1 m height showing the comparison between conditions without and with the mist air cooler. (b) Simulation results of E303 relative humidity distribution using a mist air cooler.

Simulation results show that relative humidity in Classroom E303 increased to 61.00–66.45% and was relatively evenly distributed, indicating effective moisture dispersion by the mist air cooler. According to SNI 03-6572-2001, this condition falls within the high-comfort category but may cause stuffiness for some occupants, highlighting the need for humidity control. Model validation confirms acceptable agreement with field data, with MAPE values of 5.89–10.75% and RMSE of 3.49–6.45%RH (Table 5). Psychrometric analysis indicates that evaporative cooling shifts energy from the sensible to the latent component, lowering temperature while increasing humidity. From the occupants comfort perspective, thermal sensation improves due to temperature reduction, but humidity regulation remains necessary to avoid discomfort.

Table 5. MAPE and RMSE results of humidity distribution simulation in room E303

Measurement Points	Actual Data (°C)	Simulation Data (°C)	MAPE (%)	RMSE
1	60.1	65.40	8.82	5.30
2	60.7	66.34	9.29	5.64
3	60.0	66.45	10.75	6.45
4	59.3	65.57	10.57	6.27
5	59.3	62.79	5.89	3.49
6	58.8	63.26	7.58	4.46
7	58.7	62.31	6.15	3.61
8	59.4	61.00	2.69	1.60
Average	59.5	64.14	7.72	4.85

CONCLUSION

The initial thermal condition of Classroom E303 falls into the comfort–low category, with temperature within the SNI range but relative humidity below the standard. The CFD model demonstrates good accuracy (temperature MAPE 4.41%, RMSE 1.06 °C; humidity MAPE 7.72%, RMSE 4.85%RH), confirming its reliability in predicting indoor thermal behavior. The mist-based evaporative cooling system effectively reduces temperature by 2.72 °C but increases relative humidity above the comfort limit, shifting the room condition toward a comfort–high category. With proper adjustment, such as optimizing spray flow rate, intermittent pump cycling, or sensor-based activation, the system can be calibrated to achieve the optimal SNI comfort range. Future work should include simulations under occupied-room conditions, mist air cooler discharge variations, and multi-inlet ventilation designs to refine thermal control in tropical educational buildings.

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