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Computational Fluid Dynamics-Based Performance Evaluation of an Air Cooler for University Classroom Conditioning: A Case Study of Classroom E304, ITERA

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ABSTRACT

The advancement of cooling technologies aims to enhance indoor comfort, but conventional air conditioners (AC) raise sustainability concerns due to high energy consumption. This study evaluated the performance of an air cooler in classroom E304, characterized by high occupancy and initial temperatures of 28–30°C with 55–57% relative humidity, exceeding comfort limits per SNI 03-6572-2001. After installing a single air cooler, CFD simulations indicated a temperature reduction to 22.50–23.08°C and relative humidity of 54.89–62.34%, within the comfort range. Model validation demonstrated high accuracy, with RMSE below 1°C and MAPE below 3%, confirming the simulation's reliability for classroom cooling design. The results demonstrate that air coolers provide an effective and energy-efficient solution for tropical classrooms.

Keywords: *air cooler; air temperature; classroom E304; Computational Fluid Dynamics (CFD); geometry*

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ABSTRACT

Perkembangan teknologi pendinginan bertujuan untuk meningkatkan kenyamanan dalam ruangan, namun pendingin udara (AC) konvensional menimbulkan kekhawatiran terkait konsumsi energi tinggi. Penelitian ini mengevaluasi kinerja *air cooler* di Ruang Kelas E304 yang memiliki tingkat hunian tinggi dan temperatur awal 28–30°C dengan kelembapan relatif 55–57%, melebihi batas kenyamanan menurut SNI 03-6572-2001. Setelah pemasangan satu unit *air cooler*, simulasi CFD menunjukkan penurunan temperatur menjadi 22,50–23,08°C dan kelembapan relatif 54,89–62,34%, berada dalam kategori nyaman. Validasi model menunjukkan akurasi tinggi, dengan RMSE di bawah 1°C dan MAPE di bawah 3%, menegaskan keandalan simulasi untuk perencanaan sistem pendinginan ruang kelas. Hasil ini menunjukkan bahwa *air cooler* merupakan solusi pendinginan efektif dan hemat energi untuk ruang kelas di iklim tropis.

Kata kunci: *air cooler*; Computational Fluid Dynamics (CFD); geometri; ruang kelas E304; suhu udara

INTRODUCTION

Thermal comfort in educational environments significantly influences concentration, cognitive performance, and learning outcomes [1]. Classroom thermal conditions are affected by air temperature, relative humidity, and air movement, where an increase in air velocity can enhance convective heat loss without reducing air temperature [2]. According to SNI 03-6390-2020 on Energy Conservation of Air Conditioning Systems in Buildings, classrooms are required to maintain a minimum dry-bulb temperature of 25°C with a relative humidity of approximately 55% to achieve optimal thermal conditions [3]. As a tropical country, Indonesia is characterized by high air temperatures and humidity, with relatively low wind speeds [4]. In addition to climatic factors, surrounding environmental conditions and building design significantly influence airflow patterns inside classrooms [5][6]. Passive strategies such as natural ventilation and lighting optimization have been reported to improve thermal comfort while reducing energy consumption in buildings [7].

Classroom cooling is still largely dominated by conventional air conditioning (AC) systems, which consume significant energy and have environmental impacts. Research on low-energy, eco-friendly alternatives remains limited. Air coolers, operating on evaporative cooling principles, offer a promising solution. Previous studies show that air coolers can lower indoor temperatures from 28.3°C to 26°C depending on window configurations [8]. Evaporative cooling absorbs heat through water evaporation, producing cooler air with fans and pumps rather than energy-intensive compressors.

This study addresses the limited evaluation of air cooler performance as an alternative cooling system for classrooms in tropical climates. It aims to assess the air cooler's impact on thermal comfort in Classroom E304 at Institut Teknologi Sumatera using indicators such as indoor temperature, relative humidity, air velocity, and comfort parameters. Computational Fluid Dynamics (CFD) is employed to model and simulate temperature distribution and airflow patterns, enabling identification of hot, cold, or poorly ventilated areas [9][10][11]. The results provide data-driven insights for designing energy-efficient and environmentally friendly cooling strategies in tropical educational buildings.

LITERATURE REVIEW

Computational Fluid Dynamics (CFD)

Computational Fluid Dynamics (CFD) is a numerical method that solves fluid flow problems using discretized control volumes and computer algorithms. In this study, CFD is employed to visualize airflow, temperature, and humidity distributions in the classroom, enabling analysis of flow properties that are difficult to capture experimentally. Based on the Navier-Stokes equations, CFD accurately predicts fluid behavior. The simulation workflow consists of three main stages: preprocessing, solving, and postprocessing [12][13]. In this study, only two conservation principles, mass and momentum, are applied, expressed through their respective governing equations, which are discussed in the following sections.

The continuity equation expresses mass conservation in differential form (Equation 1).

$$\frac{\partial p}{\partial t} + \nabla.(\rho \boldsymbol{u}) = 0 \quad \text{…. (1)}$$

where p = pressure (Pa), t = time (s), ρ = density (kg/m^3), $\boldsymbol{u}$ = fluid velocity (m/s). The mass conservation equation, written using a time derivative, describes the rate of mass accumulation or depletion within a fluid system.

The momentum equation represents the temporal rate of change of momentum plus convective transport minus forces (Equation 2).

$$\frac{\partial \rho u}{\partial t} + \nabla.(\rho \boldsymbol{uu}) =- \nabla \rho + \nabla.\tau + \boldsymbol{F} \quad \text{…. (2)}$$

where p = pressure (Pa), t = time (s), ρ = density (kg/m^3), $\boldsymbol{u}$ = fluid velocity (m/s), τ = tensor force. The momentum equation represents the temporal rate of change of physical quantities (momentum) in a fluid element as functions of space and time.

METHOD

Field data were collected to obtain classroom geometry, material specifications, and equipment conditions, with measurements of airflow, temperature, humidity, and lighting using an anemometer and a lux meter. The data were used to build geometric models and perform CFD simulations in SolidWorks on a computer, analyzing airflow, temperature, and humidity distributions. The results were evaluated to assess equipment impact on air circulation and thermal comfort (Figure 1).

Geometry Creation

This research simulation is based on the development of a thermal space geometry representing a classroom. The classroom dimensions (12×8×3 meters) are presented in Table 1, while the geometric configuration of the classroom is illustrated in Figure 2.

Figure 2 shows the 3D model of room E304 created using SolidWorks, based on direct observations to identify target measurement points. The placement of eight points for temperature and humidity measurements follows SNI 16-7062-2004 [13], determined through experimental testing at each location. This mapping ensures accurate positioning of data collection points during field measurements.

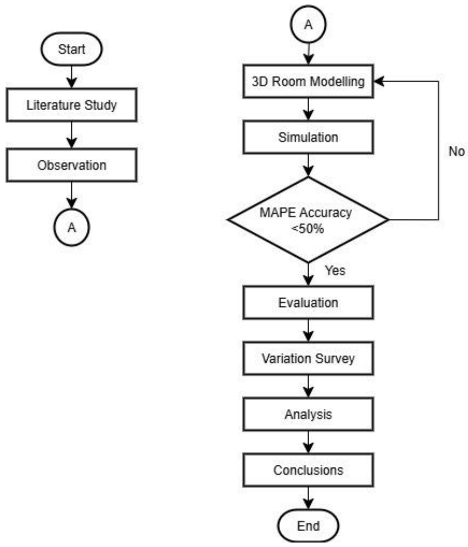


Figure 1. Flowchart of the research methodology used in this study.

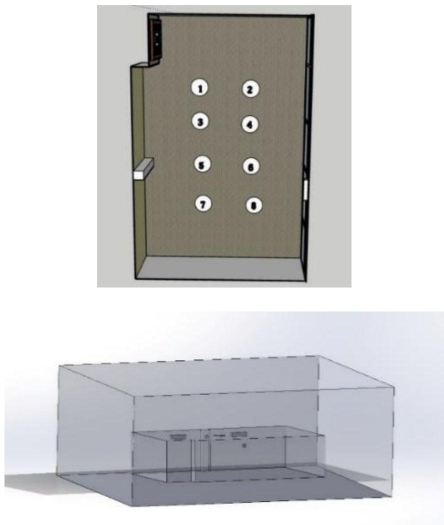


Figure 2. Three-dimensional geometric model of classroom E304 used for CFD simulation.

Table 1. Room size description.

No.	Description	Size (m)
1	Length	12
2	Width	8
3	Height	3

Determination of Material Type

The next step in this study was to determine the types of materials used in the SolidWorks simulation. Five types of materials were applied in the simulation, as presented in Table 2. The classroom walls were constructed using thick plywood, all side windows were made of full glass, and solid concrete was used as the base material for wall insulation.

Evaluation

In this study, data verification was performed by comparing simulation results with actual measurements using RMSE and MAPE. Equation 3 defines RMSE, which quantifies the average deviation between simulated and observed data, while Equation 4 defines MAPE, which measures the average percentage error between simulation and actual values.

$$RMSE = \sqrt{\sum \frac{(x-y)^2}{n}} \quad \ldots (3)$$

where x = actual (measured) value, y = simulated (predicted) value, and n = number of data points. The RMSE value will be useful in knowing some of the average differences in the data used in this study.

$$MAPE = \frac{\sum \frac{|x-y|}{x}}{n} \quad \ldots (4)$$

where x = actual (measured) value, y = simulated (predicted) value, and n = number of data points. The MAPE value is used to quantify the percentage error of the data employed in this study, with the results expressed in percentage (%). The error scale and accuracy classification based on the Mean Absolute Percentage Error (MAPE) are presented in Table 3.

RESULTS AND DISCUSSION

Data Discussion I

In accordance with the objectives of this study, this section discusses the performance of the air cooler system in enhancing thermal comfort in a classroom environment. The evaluation is based on indoor air temperature distribution, relative humidity, air velocity, and thermal comfort parameters obtained from field measurements and CFD simulations.

Table 2. Material type [14][15].

No.	Part	Material Type	Thermal Conductivity (W/m·K)
1	Wall	Plywood	0.150
2	Window	Glass	1.000
3	Wall Bulkhead	Sandwich material	0.050
4	Door	Wooden	0.200
5	Fluid	Temperature and Air	0.025

Table 3. MAPE error scale.

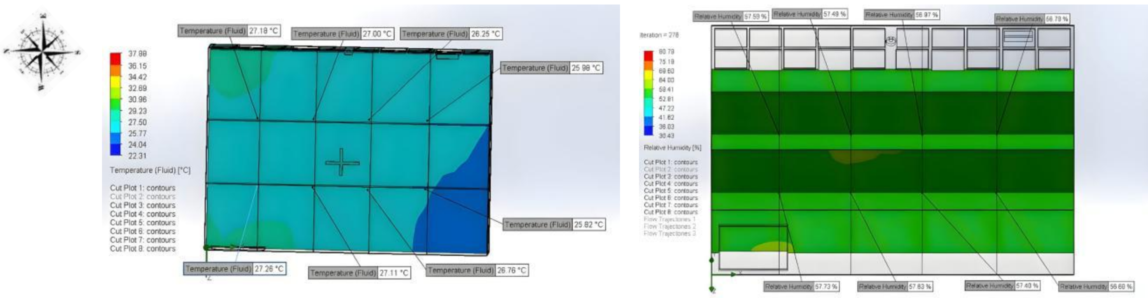
MAPE Range (%)	Description
< 10	Very Accurate
10–20	Good
20–50	Reasonable
> 50	Inaccurate

Figure 3(a) shows the classroom temperature distribution (25.82–28.25°C). The highest temperatures (27.18–28.25°C) occur in the upper-left and central areas, indicated by blue-green to light-green shades, while the lowest temperature (25.82°C) appears in the lower-right corner in dark blue. This pattern reflects the effects of airflow, the location of the cooling source, and internal heat gains on occupant comfort.

Figure 3(b) shows the classroom relative humidity distribution, ranging from 56.68% to 58.97%. The distribution is relatively uniform, depicted in dark to medium green, indicating conditions within the ideal comfort range. The highest humidity (58.97%) occurs in the upper-center area, while the lowest (56.68%) is in the lower-right corner. Variations are likely linked to local temperature differences, as cooler areas tend to have slightly higher relative humidity.

Data Discussion II

Figure 5(a) shows the CFD-simulated temperature contours in classroom E304 following air cooler installation, where the temperature is maintained within 22.50–23.08°C, exhibiting a stable and homogeneous thermal distribution with localized thermal gradients in the vicinity of the cooling outlet, indicating effective thermal regulation performance.



(a) (b)

Figure 3. Contour distributions of (a) air temperature and (b) relative humidity in classroom E304.

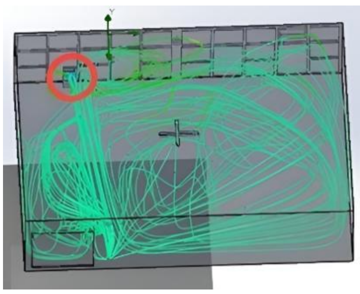
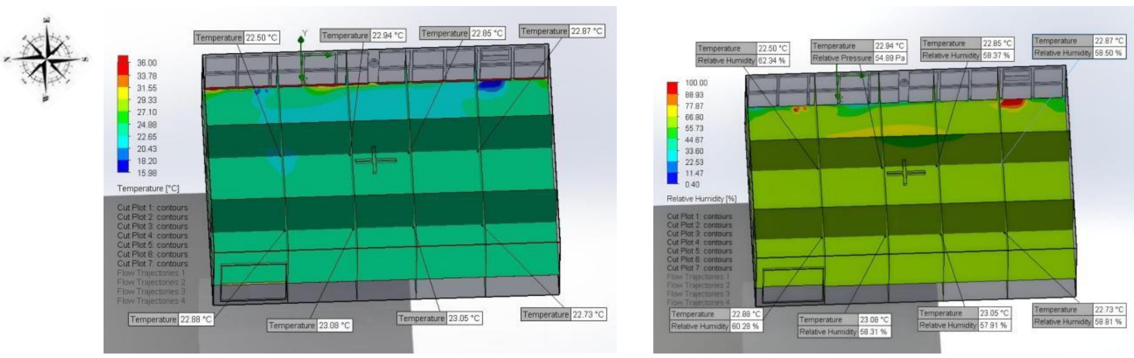


Figure 4. Schematic placement of one air cooler unit in classroom E304 for CFD simulation.



(a) (b)

Figure 5. Air temperature distribution contour after the installation of one air cooler.

Figure 5(b) illustrates the relative humidity contour in the classroom, with values ranging from 54.89% to 62.34%, which are largely within the thermal comfort limits for densely occupied tropical spaces as specified by SNI 03-6572-2001 [16], indicating acceptable hygrothermal conditions that support occupant comfort and learning performance.

Table 4 presents the RMSE values for temperature prediction using an air cooler, showing differences between observed and predicted room temperatures ranging from 0.25 to 1.3°C, with RMSE values between 0.37 and 0.712, indicating prediction errors below 1°C and confirming good model accuracy.

Table 5 presents the MAPE values for temperature prediction using an air cooler, ranging from 1.56% to 2.61%. Since all values are below 10%, the predictions are highly accurate, indicating that the model reliably represents actual room-temperature conditions.

Table 6 presents RMSE values for relative humidity (RH) prediction using an air cooler, with deviations between observed and predicted values ranging from -2.71 to 2.71 and RMSE values ranging from 1.056 to 1.786. Since all RMSE values are below 2, the prediction errors are relatively low, indicating that the model reliably estimates actual RH conditions.

Table 4. RMSE values of air temperature prediction using the air cooler system.

Observation value (°C)	Prediction value (°C)	Difference	RMSE
24.0	22.88	1.12	0.712145
23.8	22.50	1.30	0.632772
23.5	23.08	0.42	0.430658
23.5	22.94	0.56	0.432759
23.5	23.05	0.45	0.394588
23.1	22.85	0.25	0.374299
23.2	22.73	0.47	0.422966
23.2	22.83	0.37	0.370000

Table 5. MAPE values of air temperature prediction using the air cooler system.

Temperature actual value (°C)	Temperature simulation value (°C)	$\left\lvert \frac{(y-\hat{y})}{y} \right\rvert$	MAPE (%)
24.0	22.88	0.046667	2.614612
23.8	22.50	0.054622	2.321462
23.5	23.08	0.017872	1.798008
23.5	22.94	0.023830	1.800163
23.5	23.05	0.019149	1.654459
23.1	22.85	0.010823	1.567647
23.2	22.73	0.020259	1.810345
23.2	22.83	0.015948	1.594828

Table 6. RMSE values of relative humidity prediction using the air cooler system.

Observation value	Prediction value	Difference	RMSE
58.7	60.28	-1.58	1.394153
61.5	62.34	-0.84	1.365540
57.5	58.31	-0.81	1.434532
57.2	57.91	-0.71	1.529130
57.1	58.37	-1.27	1.672356
57.6	54.89	2.71	1.786449
57.8	58.81	-1.01	1.055959
57.4	58.50	-1.10	1.100000

Table 7. MAPE values of relative humidity prediction using the air cooler system.

Actual value (%)	Simulation value (%)	$\left\lvert \frac{(y-\hat{y})}{y} \right\rvert$	MAPE (%)
58.7	60.28	-0.026920	-0.98632
61.5	62.34	-0.013660	-0.74270
57.5	58.31	-0.014090	-0.54758
57.2	57.91	-0.012410	-0.73525
57.1	58.37	-0.022240	-1.14951
57.6	54.89	0.047049	-1.43151
57.8	58.81	-0.017470	-2.58925
57.4	58.50	-0.019160	-2.88211

Table 7 presents MAPE values for relative humidity (RH) prediction using an air cooler, calculated by comparing observed and simulated values. The MAPE ranges from 0.54% to 2.88% (absolute values), all well below 10%, indicating very high prediction accuracy and strong agreement with the actual RH data.

CONCLUSION

Based on CFD simulations and field measurements conducted in classroom E304 at ITERA, the use of a single air cooler reduced the indoor temperature from 28–30°C to 22.50–23.08°C, with a relative humidity of 55–60%. These conditions comply with SNI 03-6572-2001, indicating improved thermal comfort and supporting learning activities. The CFD model demonstrated high accuracy, as indicated by RMSE values below 1°C and MAPE values below 3%, confirming its reliability for classroom cooling system design. To achieve a more uniform temperature distribution, particularly in areas distant from the cooling source, future studies are recommended to consider adding air cooler units or alternative placement strategies to optimize indoor airflow. In addition, further evaluation of air cooler performance under dry ambient conditions during the dry season is required.

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