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Evaluation of thermal comfort in argo lawu new generation train using transient CFD simulation

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ABSTRACT

Thermal comfort is one of the key aspects in providing quality passenger service in railway transportation. This study aims to analyze the performance of the air conditioning system in the Argo Lawu New Generation train coach using time-based Computational Fluid Dynamics (CFD) simulation transient. The simulation was conducted on two air conditioning configurations: KA 1 (AC units at both ends of the coach) and KA 2 (a single AC unit at the center of the coach). The simulation process consists of three main stages: pre-processing, processing, and post-processing. It was performed for 180 seconds with a 1 second time interval to observe dynamic changes in temperature distribution, air velocity, and pressure. The results show that KA 2 provides a more uniform distribution of temperature and airflow, with a final average temperature of 24.8°C compared to 25.1°C in KA 1. The central placement of the AC unit proves to be more effective in maintaining balanced pressure and distributing cool air throughout the cabin. This transient CFD simulation offers a more realistic representation of the cooling system's performance and serves as a reference for future train HVAC design improvements.

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1. INTRODUCTION

Thermal comfort is one of the main aspects of passenger satisfaction in modern railway services. In long-distance trains such as the Argo Lawu New Generation, maintaining a stable cabin temperature and airflow distribution is crucial for ensuring comfort throughout the journey. Improperly designed or inefficient air conditioning (AC) systems may cause uneven temperature distribution, hot spots, and poor air circulation, resulting in thermal discomfort that reduces the overall service quality (Astuti and Maureen, 2022; Komalasih, 2017).

The indoor thermal condition of a train coach is influenced by several factors, including outside weather, passenger density, and internal heat sources from equipment and lighting (Arfan AP, 2022). If the AC system fails to balance these loads, the cooling performance will decrease, directly affecting passenger comfort (Nasrudin and Maryadi, 2019). Conventional thermal load analysis methods, such as the Cooling Load

Temperature Difference (CLTD) approach (ASHRAE, 2009), are often used in early design stages. However, these methods provide only general estimations and cannot capture detailed airflow and temperature distributions inside the cabin.

To overcome these limitations, Computational Fluid Dynamics (CFD) has been increasingly applied to predict airflow patterns and heat transfer in confined spaces. CFD provides a more accurate representation of cooling system performance compared to analytical methods, particularly in complex geometries such as train coaches (Pradana and Sulisetyono, 2019; Granda et al., 2020). Furthermore, transient CFD simulations allow time-based analysis, enabling the observation of dynamic changes in airflow, pressure, and temperature as the cooling system operates (Kachhadiya et al., 2022; Panfilov et al., 2024). Previous studies also emphasized that transient models offer more realistic insights compared to steady-state simulations, especially when evaluating cooling performance under fluctuating conditions (Alhassan et al., 2021; Palmowska and Sarna, 2022).

This study aims to analyze the cooling performance of the Argo Lawu New Generation train coach using transient CFD simulation. Two AC system configurations are compared: KA 1, with AC units located at both ends of the coach, and KA 2, with a single AC unit placed at the center. The analysis focuses on the distribution of temperature, air velocity, and pressure over a period of 180 seconds. The results are expected to provide quantitative evidence of the most effective AC layout for achieving thermal comfort and to serve as a reference for optimizing HVAC design in future Indonesian railway applications.

2. RESEARCH METHODS

This study utilizes a numerical simulation approach based on Computational Fluid Dynamics (CFD) to analyze the distribution of temperature, air velocity, and pressure inside the Argo Lawu New Generation train coach. The simulation is conducted in transient mode to capture time-dependent changes in fluid parameters. The simulation process is divided into three main stages: pre-processing, processing, and post-processing.

2.1 Pre-processing

The pre-processing stage includes geometry creation, fluid domain definition, and meshing. A 3D model of the train coach was designed using Autodesk Inventor. The geometry was simplified to create simulation-ready sketches for each configuration. The coach dimensions are listed in Table 1.

Table 1. Train Coach Dimensions

No	Component	Dimension
1	Coach body length	20000 mm
2	Total coach length include coupler	20920 mm
3	Coach body width	2990 mm
4	Roof height from rail head	3815 mm
5	Floor height from rail head	1000 mm
6	Material	*Stainless steel*
7	Capacity	50 passengers

2.1.1 KA 1 Configuration

The first configuration uses the standard layout with two AC units placed at both ends of the coach. This model features 26 rectangular windows, each measuring 1100 mm × 800 mm, as shown in Figure 1.

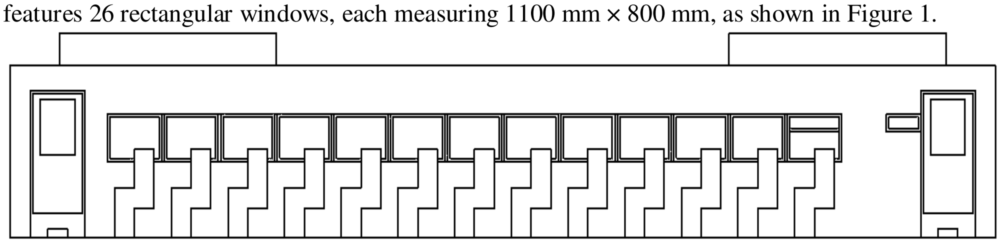

Figure 1. Geometry KA 1

2.1.2 KA 2 Configuration

The second configuration uses a single AC unit located at the center of the coach. The position and size of the windows are the same as in KA 1, illustrated in Figure 2.

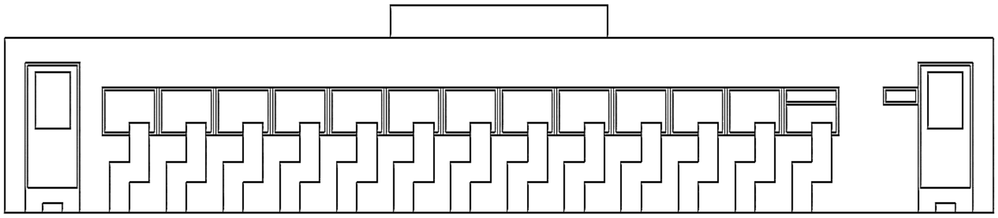

Figure 2. Geometry KA 2

Once the geometry was finalized, meshing was performed using ANSYS Fluent Meshing with the poly-hexcore method. A grid independence test was conducted for three mesh variations (low, medium, high) to ensure accuracy.

Table 2. Grid Independence Test

Configuration	Mesh Type	Element Count	Temperature (°C)	Difference (%)
KA 1	Low	1551974	24,71	-
	Medium	1807468	24,49	0,89
	High	2090743	24,41	0,34
KA 2	Low	1496072	24,37	-
	Medium	1759102	24,14	0,93
	High	2027629	24,05	0,36

Based on the table, the difference between medium and high mesh was under 0.5%, so the medium mesh was selected for optimal balance between accuracy and computational efficiency.

2.2 Processing

The simulation was performed using ANSYS Student 2024 R2 Fluent with a pressure-based solver in transient mode. The turbulence model used was k-omega SST, chosen for its capability to handle complex flow near walls and provide accurate predictions for enclosed spaces. Materials used in the simulation included air as the working fluid, stainless steel for walls and floor, glass for windows, foam for the seat material. Each material was assigned its corresponding thermal properties based on technical data. The boundary conditions used are shown in Table 3.

Table 3. Boundary Condition Inputs

Component	Input Data	Boundary Type
Inlet	V = 1 m/s T = 24˚C	Velocity inlet
Outlet	T = 27˚C	Pressure outlet
Roof	Heat flux = 8,04 W/m^2	Wall
Front Wall	Heat flux = 0,85 W/m^2	Wall
Right Wall	Heat flux = 1,29 W/m^2	Wall
Rear Wall	Heat flux = 0,85 W/m^2	Wall
Left Wall	Heat flux = 1,94 W/m^2	Wall
Floor	Heat flux = 3,06 W/m^2	Wall
Right Window	Heat flux = 45,26 W/m^2	Wall
Left Window	Heat flux = 45,26 W/m^2	Wall
Passenger	Heat flux = 60 W/m^2	Wall

The initial temperature of the entire domain was set to 30°C to represent pre-cooling conditions. The simulation time was set for 180 seconds with number of time steps is 180, time step size is 1 second, maximum iterations per time step is 20. The second-order upwind scheme was used for discretization to improve accuracy, and the Coupled scheme was applied for pressure-velocity coupling to accelerate convergence and maintain numerical stability.

2.3 Post-processing

This stage involved analyzing simulation results such as temperature, air velocity, pressure distributions, and airflow patterns. Visualization was performed using contour plots and streamlines to assess flow direction and intensity. Data were taken at 60s, 120s, and 180s on cross-sections including plane XZ at -1.3 m, plane XY at inlet (-0.7 m), outlet (0 m). These were selected to analyze the fluid distribution characteristics inside the coach.

3. RESULTS AND DISCUSSION

The transient CFD simulation was conducted to analyze the performance of temperature, air velocity, and pressure distribution inside the Argo Lawu New Generation train coach. Data were collected at time intervals of 60s, 120s, and 180s to observe progressive changes during the cooling process.

Figure 3 and Figure 4 show the temperature distribution inside the passenger cabin for KA 1 (dual AC at both ends) and KA 2 (single AC at center) configurations at 180 seconds of operation. In general, both configurations were able to reduce cabin air temperature from the initial 30 °C to below 26 °C. However, KA 2 achieved a more uniform cooling effect across the passenger zone, while KA 1 showed localized hot spots near the center of the coach. Similar findings were reported in studies of thermal management in confined spaces, where central distribution reduced thermal stratification (Sabtalistia et al., 2014).

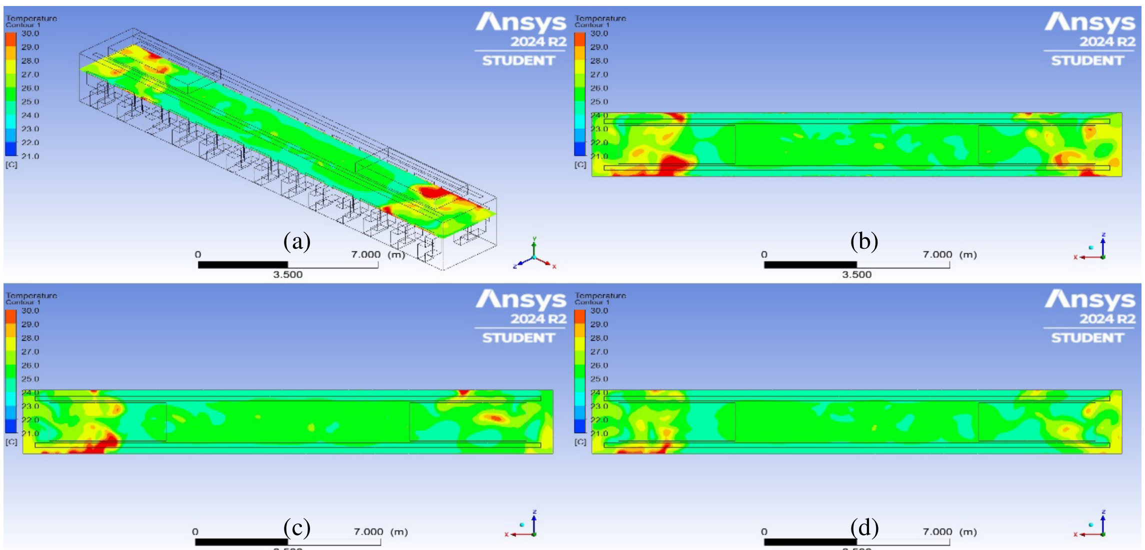

Figure 3. (a) Isometric view of temperature distribution in KA 1 (b) Temperature distribution in KA 1 at 60s (c) Temperature distribution in KA 1 at 120s (d) Temperature distribution in KA 1 at 180s.

This visual observation is supported by quantitative data extracted at three representative points: head level (1.2 m above floor, cabin center), mid-body level (0.8 m above floor, 2 m from coach wall), and floor level (0.2 m above floor, cabin center), as shown in Table 4.

Table 4. Temperature Comparison Between KA 1 & KA 2

Observation Point	KA 1 (°C)	KA 2 (°C)	Difference (°C)
Point A (Head)	26.8	25.4	1.4
Point B (Mid)	27.2	25.7	1.5
Point C (Floor)	25.9	25.2	0.7

The results indicate that KA 2 reduced the average cabin temperature by 1.2–1.5 °C compared to KA 1 at critical passenger zones. This confirms that KA 2 provides a better distribution of cooled air across different height levels.

Figure 5 and Figure 6 present the airflow velocity distribution for KA 1 and KA 2. Both KA 1 and KA 2 achieved airflow velocities within the ASHRAE 55-2017 comfort range of 0.1–0.25 m/s, as shown in Table 2. KA 2 produced more consistent velocity distribution, especially at head and mid-body levels, reducing stagnant zones. Previous research has highlighted that balanced airflow at occupant level is critical for maintaining perceived comfort (Suárez et al., 2017).

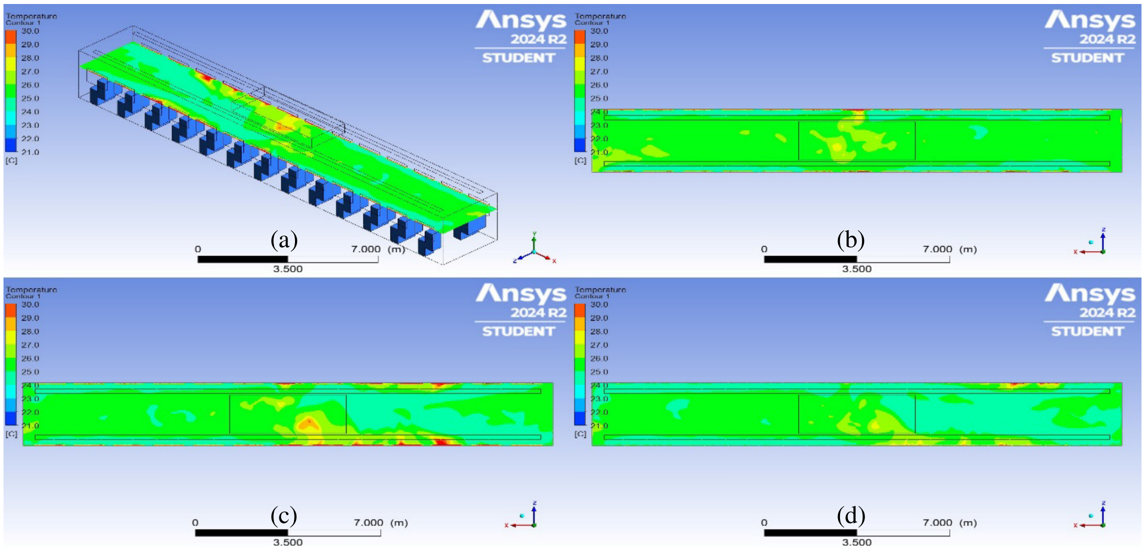

Figure 4. (a) Isometric view of temperature distribution in KA 2 (b) Temperature distribution in KA 2 at 60s (c) Temperature distribution in KA 2 at 120s (d) Temperature distribution in KA 2 at 180s

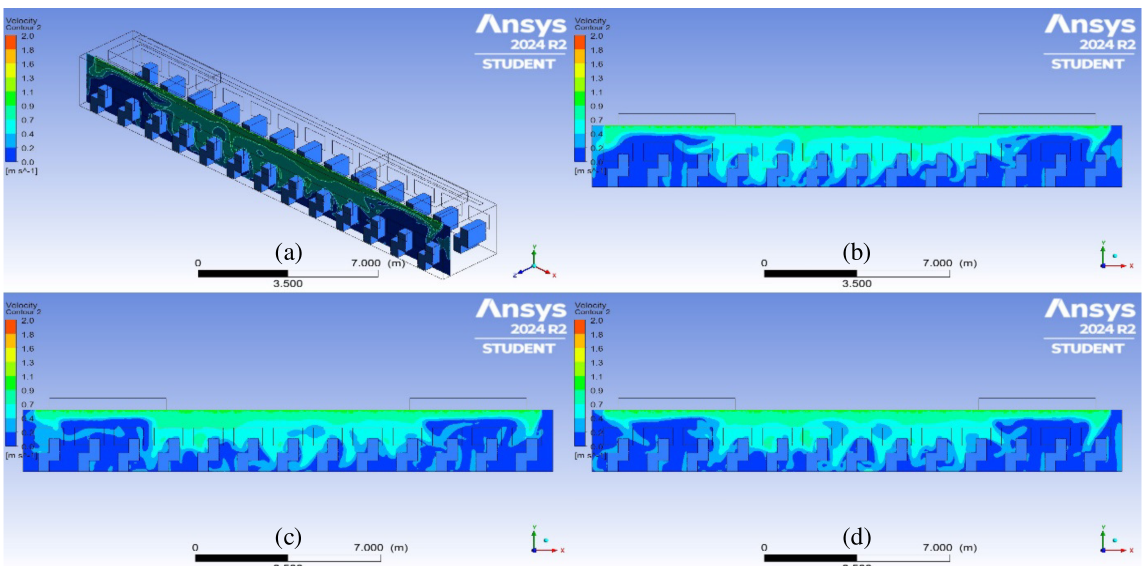

Figure 5. (a) Isometric view of air velocity distribution in KA 1 (b) Air velocity distribution in KA 1 at 60s (c) Air velocity distribution in KA 1 at 120s (d) Air velocity distribution in KA 1 at 180s

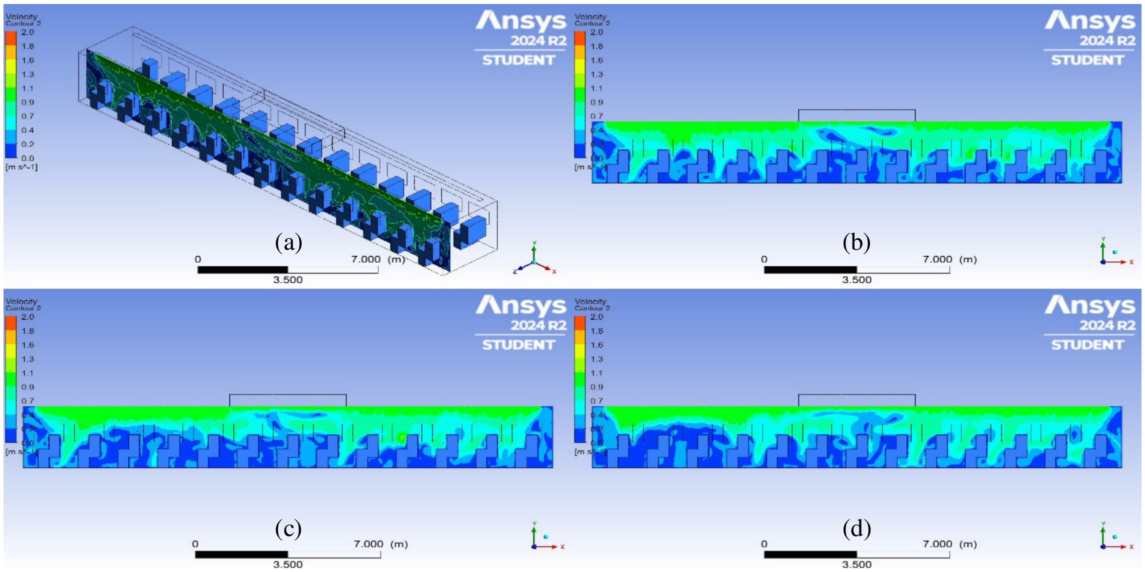

Figure 6. (a) Isometric view of air velocity distribution in KA 2 (b) Air velocity distribution in KA 2 at 60s (c) Air velocity distribution in KA 2 at 120s (d) Air velocity distribution in KA 2 at 180s

To further evaluate passenger comfort, air velocity values were measured at the same points used in the temperature analysis. Table 5 summarizes the results in comparison with ASHRAE 55 comfort standards.

Table 5. Air Velocuty Comparison Between KA 1 & KA 2

Observation Point	KA 1 (m/s)	KA 2 (m/s)	Comfort Range (ASHRAE 55)
Point A (Head)	0.12	0.18	0.1 – 0.25 m/s
Point B (Mid)	0.09	0.15	0.1 – 0.25 m/s
Point C (Floor)	0.07	0.12	0.1 – 0.25 m/s

Both configurations produced air velocities within the ASHRAE comfort range. However, KA 2 achieved more consistent airflow, particularly at passenger head and mid-body levels, reducing the risk of stagnant zones.

Figure 7 and Figure 8 display the static pressure distribution for both configurations. KA 1 exhibited higher pressure gradients between outlets and the cabin center, while KA 2 maintained lower gradients, supporting smoother circulation. This result aligns with studies that emphasize minimizing pressure imbalance to avoid localized discomfort (Kwong et al., 2021).

Table 6. Pressure Comparison Between KA 1 & KA 2

Observation Point	KA 1 (Pa)	KA 2 (Pa)	Difference (Pa)
Point A (Head)	1.8	2.2	0.4
Point B (Mid)	1.5	1.7	0.4
Point C (Floor)	1	1.1	0.1

Table 6 shows the static pressure at selected points inside the cabin. KA 1 exhibits slightly lower pressure gradients compared to KA 2, particularly at head level, which indicates stronger but less balanced airflow. In contrast, KA 2 maintains lower gradients, supporting smoother air circulation.

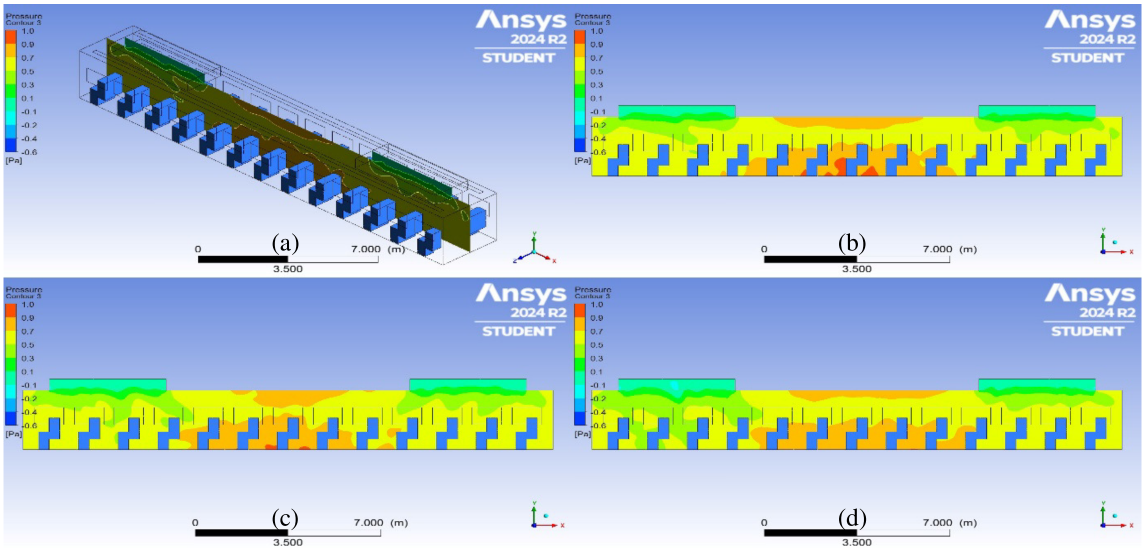

Figure 7. (a) Isometric view of pressure distribution in KA 1 (b) Pressure distribution in KA 1 at 60s (c) Pressure distribution in KA 1 at 120s (d) Pressure distribution in KA 1 at 180s

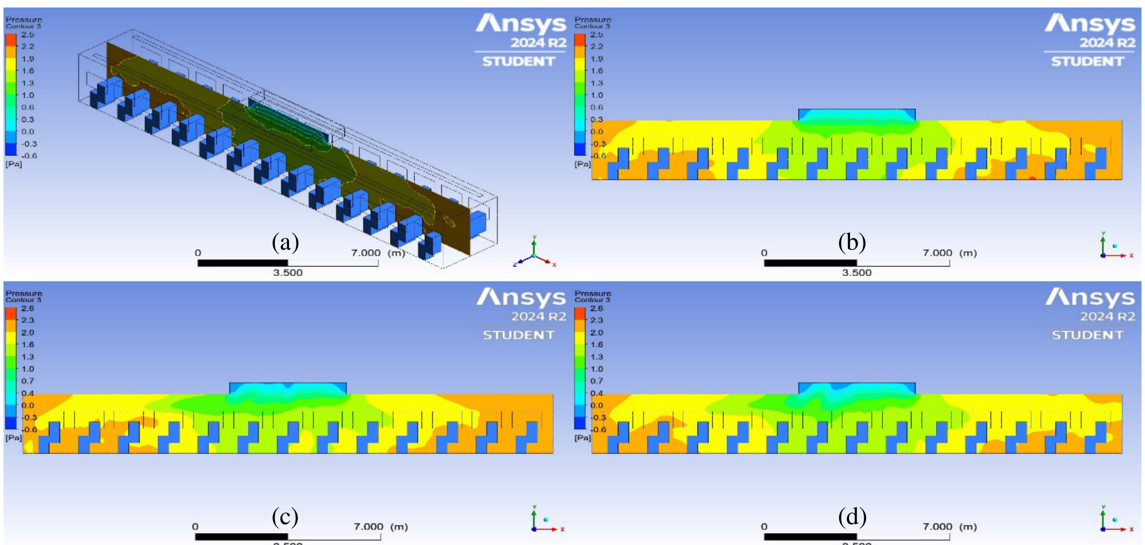

Figure 8. (a) Isometric view of pressure distribution in KA 2 (b) Pressure distribution in KA 2 at 60s (c) Pressure distribution in KA 2 at 120s (d) Pressure distribution in KA 2 at 180s

4. CONCLUSION

Based on the transient CFD simulation of the Argo Lawu New Generation train coach, it can be concluded that the KA 2 configuration, with a single AC unit placed at the center of the coach, provides better thermal comfort compared to the KA 1 configuration with dual units at both ends. The results show that KA 2 achieves a lower and more uniform cabin temperature (25.2–25.7 °C with a standard deviation of ±0.5 °C) compared to KA 1 (26.8–27.2 °C with a standard deviation of ±0.4 °C). In terms of airflow, both configurations fall within the ASHRAE 55-2017 comfort range (0.1–0.25 m/s), but KA 2 demonstrates more consistent velocity distribution across passenger zones. Furthermore, KA 2 maintains lower pressure gradients, resulting in smoother circulation patterns inside the cabin. Therefore, the central placement of the AC unit is recommended as a more effective configuration for optimizing passenger comfort in Indonesian railway applications.

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NOMENCLATURE

T : Temperature (°C)
V : Air velocity (m/s)
P : Pressure (Pa)
Q : Heat flux (W/m^2)
Cp : Specific heat of air (J/kg·K)
ρ : Density of air (kg/m^3)
μ : Dynamic viscosity (Pa·s)
k : Thermal conductivity (W/m·K)
Δt : Time step (s)

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