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Computational Fluid Dynamic (CFD) Analysis On Window Area Variation And Cooler Placement On Thermal Comfort In Stainless Steel Railway Carriages

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Abstract

Thermal comfort is one of the most important factors in carrying out activities, particularly during train travel. Therefore, PT KeretaApi Indonesia is trying to improve service standards by providing air conditioning on all trains of both executive and economic classes. Several factors influence thermal comfort, including temperature, air velocity, clothing insulation, radiation temperature, metabolism, and air humidity. This study aims to determine the distributions of temperature, air velocity, and airflow in stainless steel railroad cars, both the actual and its variations. Computational Fluid Dynamics (CFD) simulations were used in this research. In the CFD simulation, several carriage design variations were applied, namely, the actual design and three other designs that changed the location of the cooler and the window area, similar to a commercial airplane. This study showed that KA 3 has a better temperature distribution with an average temperature of 24.71ºC, and the airflow flows evenly throughout the carriage with an average speed of 0.50 m/s. According to SNI 03-6572-2001, KA 3 met the comfort criteria.

Keywords:
Thermal comfort, train, Computational Fluid Dynamic (CFD).

1 Introduction

PT Kereta Api Indonesia (KAI) is a land transportation service that provides short and long-distance routes. The BPS shows that train passengers increased every month. Therefore, PT KeretaApi Indonesia (KAI) is attempting to improve its passengers' service, safety, and comfort. To follow up, PT KAI strives to improve service standards by providing air conditioning on all executive and economic class training sets. This facility is expected to improve the thermal comfort of passengers during trips.

Thermal comfort is a condition in which humans feel satisfied with their surrounding environment [2-3]. Six factors affect thermal comfort: clothing insulation (n≤0.5 clo), room temperature (20.5ºC-27.1ºC), air humidity (40%–70%), airflow (0.25-0.5 m/s), human activity, and radiation temperature against the surface of the object [2-6, 10]. One way to improve thermal comfort is to improve the air conditioning system. An air conditioning system is a technique for properly regulating the temperature and humidity of air[6].

Air Conditioning (AC) is themedium required for air conditioning is Air Conditioning (AC). AC is a device used to regulate air conditions by absorbing and transferring heat using a medium (refrigerant)[7-8]. A refrigerant is a fluid that can absorb heat from a room and then be released into the surrounding environment. [9].

Researchhas been conducted on the temperature analysis and air-conditioning systems of executive trains. The cooling load was calculated using the Overall Thermal Transfer Value (OOTV) method, which was performed every hour while the train ran. Additionally, CFD simulations were conducted to determine the temperature distribution and airflow in the carriage. CFD simulation was applied to the actual carriage and four other carriage variations. The simulation results showed that KA 2 with round window geometry and two coolers, and KA 5 with round window geometry and one cooler at the center, had better temperature distribution and airflow[4].

In addition, research hasbeen conducted on the temperature distribution and airflow on panoramic trains. This researcher explained that temperature and airflow are interrelated factors in achieving comfort [3]. His method was CFD simulation, which was applied to the head and foot area plan of the panoramic train carriage. The results of this study showed that the average temperature around the head and feet was 24.178°C and 23.426°C, respectively. The airflow flowed evenly at a speed of 0.5 m/s. Therefore, the panoramic train carriage is classified as comfortable according to SNI 03-6572-2001[10].

This study aims to determine the temperature distribution, air velocity, and airflow in stainless-steel railroad cars using Computational Fluid Dynamics (CFD), both actually and in their variations. This variation can improve the thermal comfort of the carriage.

2 Research Methods

This research uses the ComputationalFluidDynamics (CFD) simulation method on the ANSYS software. CFD is a branch of fluid mechanics that uses numerics and algorithms to solve various problems[11]. This CFD simulation was applied to several geometries, including KA 1 in the actual KA geometry, KA 2,KA 3, and KA 4, which is a modified geometry of the window area and cooler placement (ACI-4001). The configurations at seat points 2, 4, 6, 9, and 11 were used to determine the average temperature and air velocity values. These are referred to as seats 2, 4, 6, 9, and 11.

2.1 Pre-processing

This stage is the creation of a simple geometry, commonly referred to as the negative geometry of the railcar, to be applied.

2.1.1 KA 1

The KA 1 variation consists of one cooler placed at the center of the gerbong with a total of 26 rectangular windows measuring 1100×850 mm. The geometry of KA 1 is shown in Fig. 1.

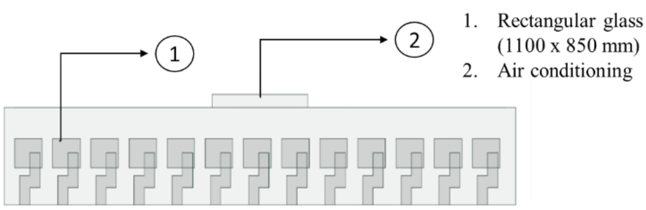


Fig. 1. Geometry KA 1.

2.1.2 KA 2

The KA 2 variation consists of two coolers at both ends with 26 rectangular windows measuring 1100×850 mm. The geometry of KA 2 is shown inFig. 2.

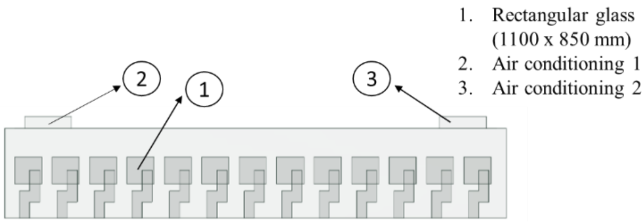


Fig. 2. Geometri KA 2.

2.1.3 KA 3

Train variation 3 consisted of one cooler located at the center of the carriage with 26 oblong windows measuring d = 375mm, p = 750 mm, and l = 350 mm. The geometry of KA 3 is shown in Fig. 3.

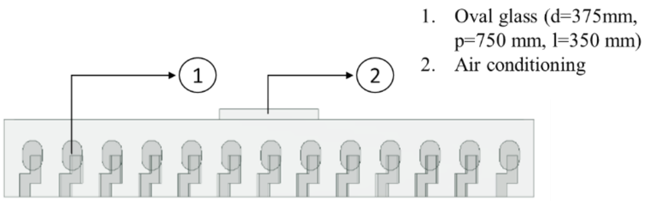


Fig. 3. Geometry KA 3.

2.1.4 KA 4

This KA 4 variation consists of two coolers at both ends of the carriage with 26 oblong windows measuring d = 375mm, p = 750 mm, and l = 350 mm. The geometry of KA 4 is shown in Fig. 4.

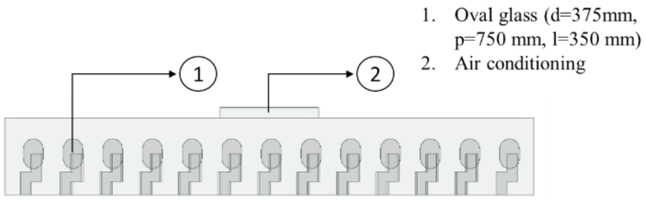


Fig. 4. Geometry KA 4.

2.2 Meshing

This meshing aims to divide the geometry into small elements to facilitate convergence[12].In this study, the number of elements were applied was 2,492,807, with an error of 0.23%. In this case, the error limit is below 10%; therefore, the meshing is acceptable[13]. The mesh-independent test graph is shown in Fig. 5.

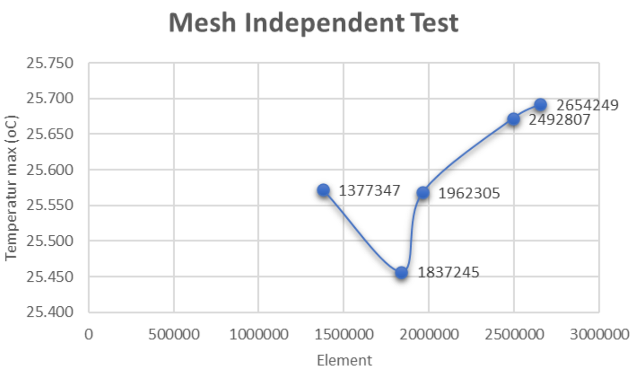


Fig. 5. Mesh-independent test graph.

2.3 Processing

At this stage, the model solver uses k-epsilon (2eqn) (Fig. 6). The boundary conditions are presented in Table 1. The iterations applied started from 500 iterations.

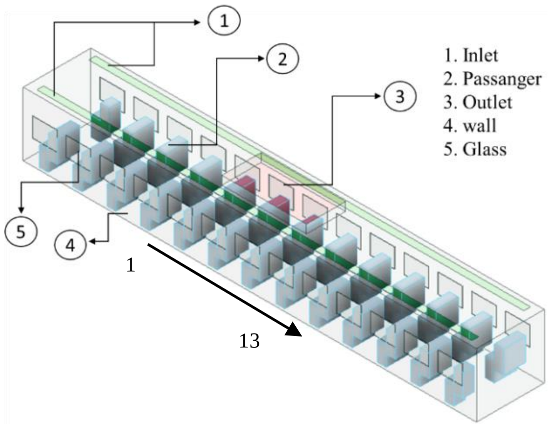


Fig. 6. Simulation domain.

Table 1. Boundary condition

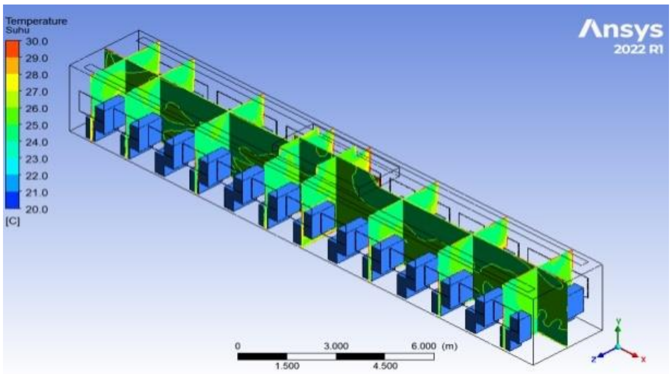
Boundary condition	Input data	Description
Inlet	v = 1 m/s T = 24ºC	Velocity inlet
Outlet	T = 27ºC	Pressure outlet
Roof	Heat flux = 2.41 W/m^2	Type: wall Material: stainless steel
Front wall	Heat flux = 0.851 W/m^2	Type: wall
Back wall	Heat flux = 0.851 W/m^2	Type: wall
Right wall	Heat flux = 2.09 W/m^2	Type: wall Material: stainless steel
Left wall	Heat flux = 2.09 W/m^2	Type: wall Material: stainless steel
Floor	Heat flux = 3.33 W/m^2	Type: wall Material: stainless steel
Right glass	Heat flux = 2.92 W/m^2	Type: wall Material: glass
Left glass	Heat flux = 2.92 W/m^2	Type: wall Material: glass
Passenger	Heat flux = 60 W/m^2	Type: wall

3 Results and Discussion

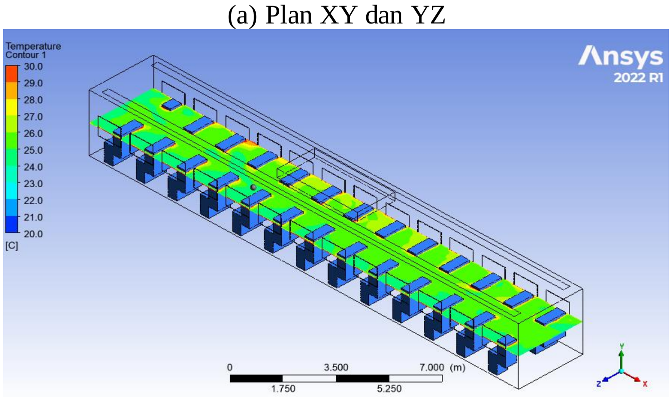
3.1 Temperature Distribution

3.1.1 KA 1

The CFD simulation results show that the maximum temperature on KA 1 is 29.50ºC, which is found in some parts close to the window. But overall, the train 1 carriage has an average temperature of 25.72ºC, with the configuration of seat 2, seat 4, seat 6, seat 9, and seat 11 consecutively 25.32ºC, 25.83ºC, 26.12ºC, 25.92ºC, and 25.42ºC. This follows the comfort criteria according to SNI 03-6572-2001 and MENKES No. 261/MENKES/SK/II/1998[3-4]. The part near the wall had a higher temperature because it was close to the solar thermal energy caused by solar thermal radiation. The area near the outlet had a high temperature because it carried hot air from the carriage to the system. The temperature distribution oftrain 1 is shown in Fig. 7.



(a) Plan XY dan YZ

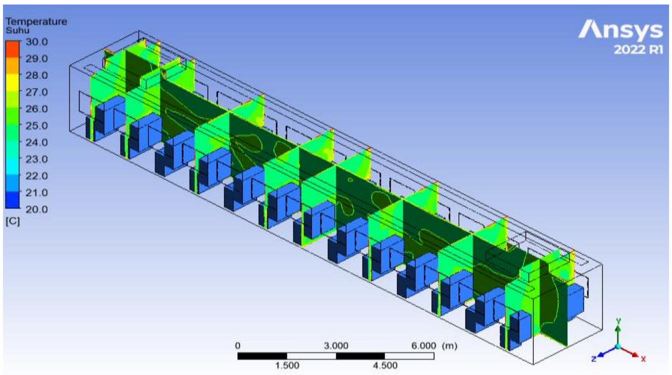


(b) Plan XZ

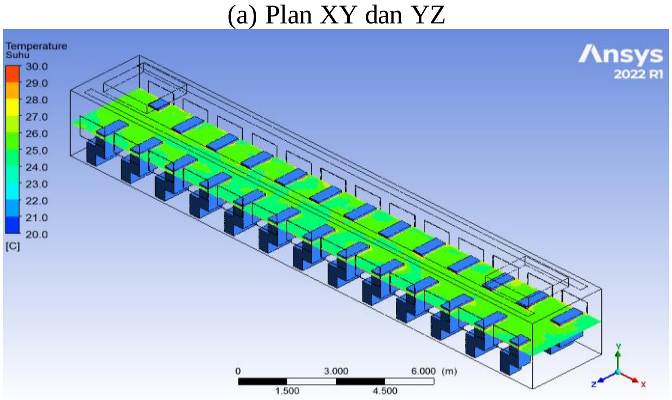
Fig. 7. Temperature distribution KA 1.

3.1.2 KA 2

CFD simulations show that the maximum temperature on train 2 reached 29.20ºC in some locations close to the wall. However, overall, the average temperature of train 2 cars is 25.92ºC. With seat configurations 2, 4, 6, 9, and 11, it reached 26.72ºC, 25.88ºC, 25.23ºC, 25.34ºC, and 26.43ºC, respectively. These findings follow the comfort standards set by SNI 03-6572-2001 and MENKES No. 261/MENKES/SK/II/1998[3-4]. The area adjacent to the wall exhibited higher temperatures owing to the exposure to solar heat radiation. Meanwhile, the area near the outlet had a high temperature because it carried hot air inside the carriage to the system. The temperature distribution oftrain 2 is shown in Fig. 8.



(a) Plan XY dan YZ

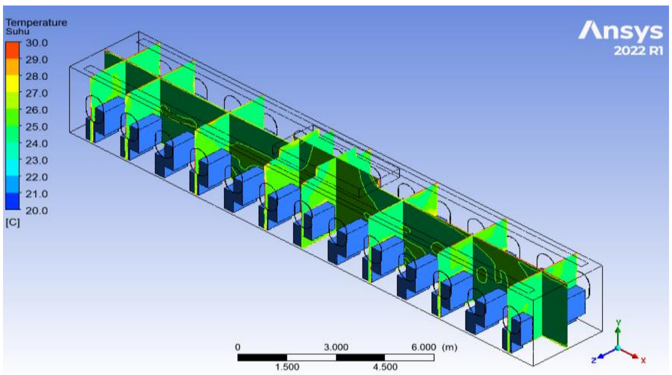


(b) Plan XZ

Fig. 8. Temperature distribution KA 2.

3.1.3 KA 3

The CFD simulation results show that the maximum temperature on train 3 reached 29.01ºC in some locations near the walls. However, overall, the average temperature of train 3 cars is 24.71ºC. Seats 2, 4, 6, 9, and 11 had temperatures of 24.31ºC, 24.93ºC, 25.16ºC, 24.61ºC, and 24.55ºC, respectively. These results comply with the comfort standards set by the SNI 03-6572-2001 and MENKES No. 261/MENKES/SK/II/1998[3-4]. Areas adjacent to the walls exhibited higher temperatures due to exposure to solar heat radiation. Conversely, areas near the outlets have high temperatures because they carry hot air to the system inside the cars. The temperature distribution oftrain 3 is shown in Fig. 9.



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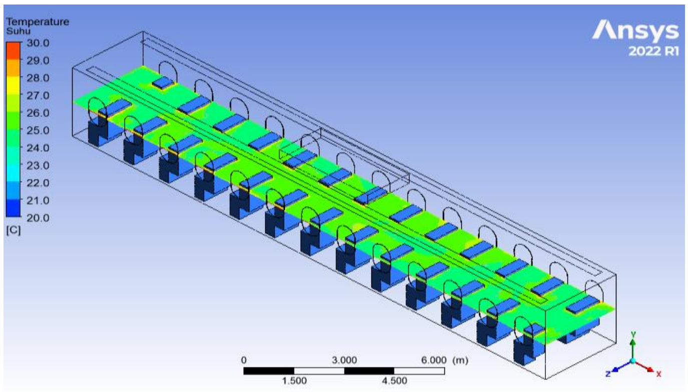
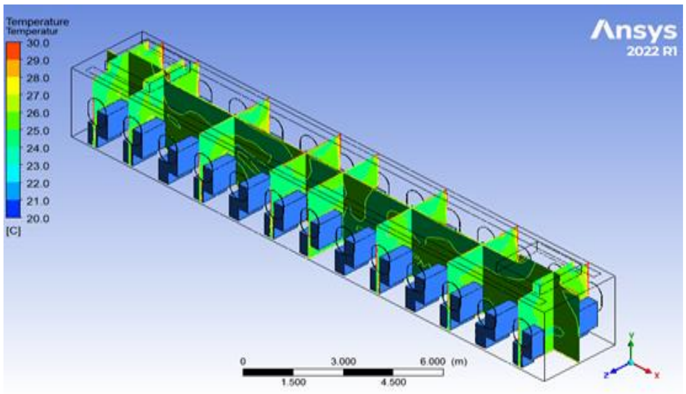


(b)

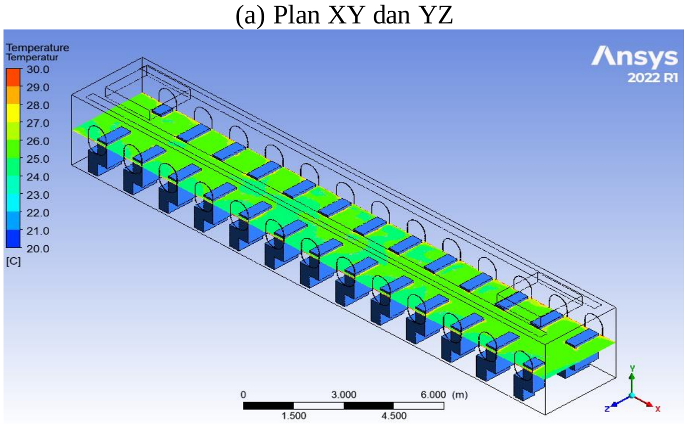
Fig. 9. Temperature distribution KA 3.

3.1.4 KA 4

The CFD simulation results show that the average temperature of KA 4 carriages is 24.86ºC, with temperatures at seat 2, seat 4, seat 6, seat 9, and seat 11 of 25.12ºC, 25.04ºC, 24.45ºC, 24.71ºC, and 25.01ºC respectively, throughout the carriage. According to the SNI 03-6572-2001 and MENKES No. 261/MENKES/SK/II/1998, whichmeets the comfort standards [3-4].The area close to the wall had a higher temperature because it was close to solar heat radiation. Becauseof the hot air flowing from the carriage to the system, the area near the outlet experienced high temperatures. The temperature distribution oftrain 4 is shown in Fig. 10.



(a) Plan XY dan YZ



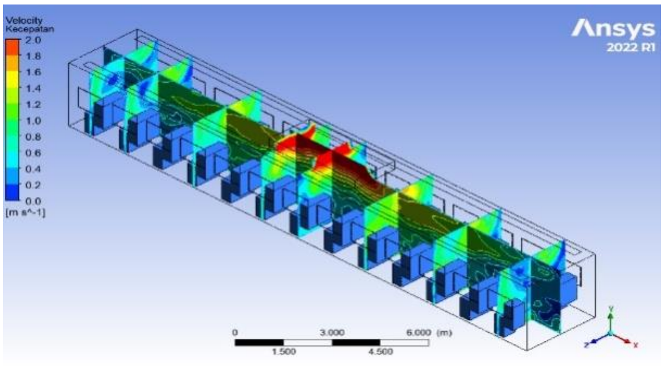
(b) Plan XZ

Fig. 10. Temperature distribution KA 4.

3.2 Velocity Distributionand Streamlining

3.2.1 KA 1

The CFD simulation results show that the KA 1 carriage has an average velocity distribution at both ends of the side of 0.32 m/s, the inlet of 0.81 m/s, and the outlet of2.04 m/s. Overall, the average air velocity on train 1 carriage was 0.71 m/s. The air starts to feel, but is still in the comfortable category[15]. The flow flowed evenly to all sides of the inlet and then returned to the outlet, as shown in Fig. 11.



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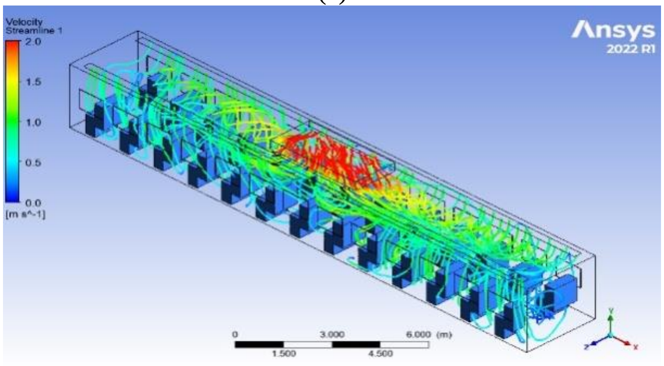
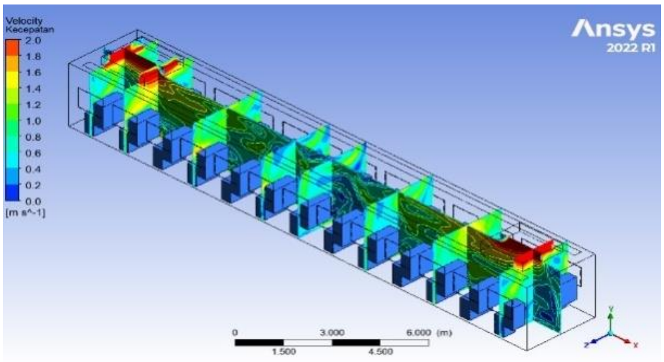


(b)

Fig. 11. (a) Velocity distribution KA 1, (b) streamlineKA 1.

3.2.2 KA 2

According to the CFD simulation results, train car 2 had an average velocity distribution of 2.03 m/s at both outlets, 1.04 m/s at the inlet, and 0.44 m/s in the center region. The average air velocity was 0.81 m/s. A sense of air is starting to emerge, but it is still comfortable [15]. As shown in Fig. 12, the flow flowed evenly throughout the inlet and then returned to the outlet.



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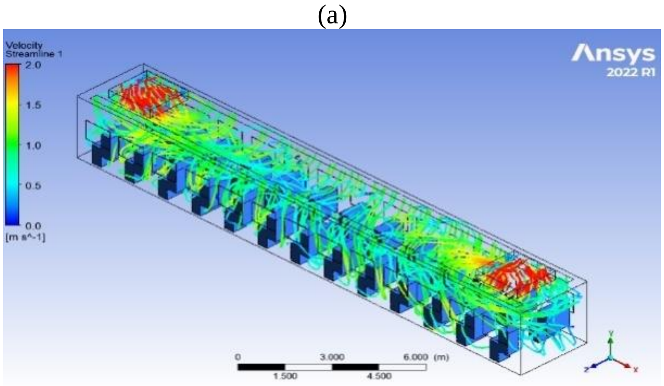
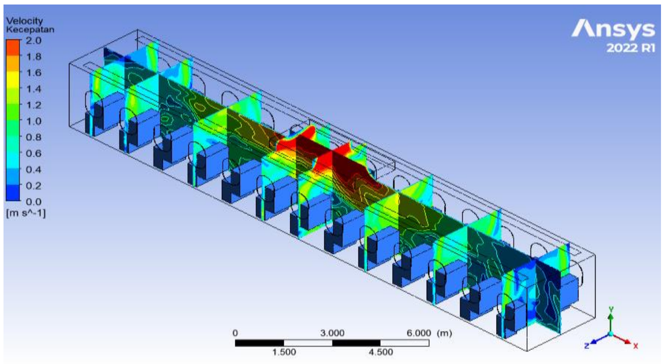


(b)

Fig. 12. (a) Velocity distribution KA 2, (b) streamline KA 2.

3.2.3 KA 3

CFD simulations show that the average velocity distribution at both ends of the side of the KA 3 carriage reaches 0.43 m/s, while at the inlet, it is 0.85 m/s, and the outlet is 2.01 m/s. The average air velocity across the train 3 cars reached 0.50 m/s. Although air has begun to feel, it is still within the comfort category[15]. The airflow flowed evenly on all sides from the inlet and back to the outlet, as shown in Fig. 13.



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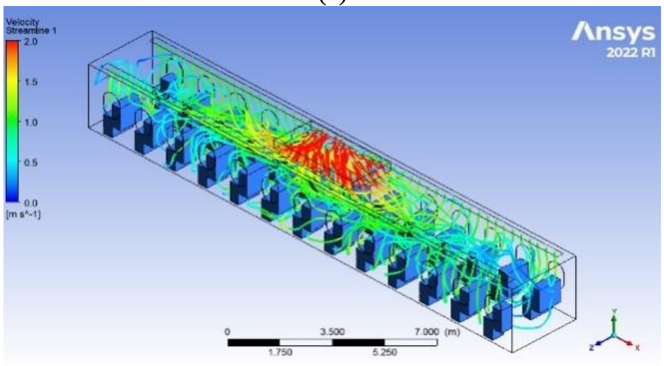
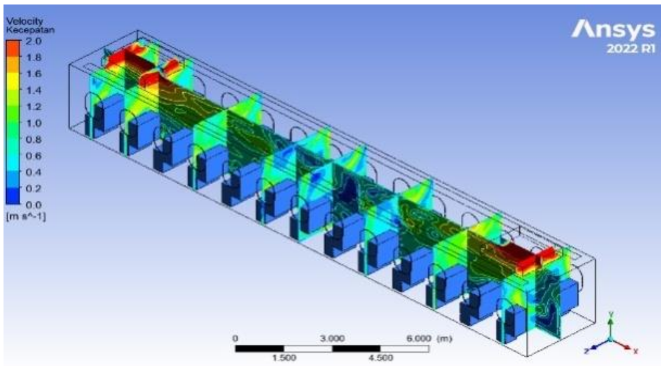


(b)

Fig. 13. (a) Velocity distribution KA 3, (b) streamlineKA 3.

3.2.4 KA 4

The CFD simulation results show that KA 4 cars have an average velocity distribution of 2.03 m/s at both outlets, 1.21 m/s at the inlet, and 0.43 m/s in the central area. The average total air velocity of the train 4 cars is 0.6 m/s. The atmosphere remains comfortable [15], although the air starts to feel, the atmosphere remains comfortable. Fig. 14 shows the airflow flowing evenly across the inlet side before returning to the outlet.



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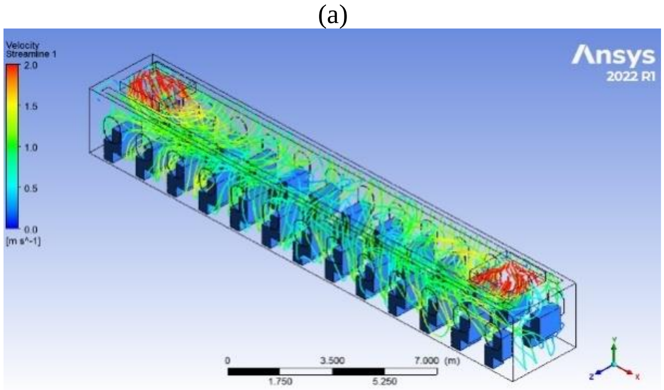

(b)

Fig. 14. (a) Velocity distribution KA 4 (b) Streamline KA 4.

3.3 Relationship between Temperature and Air Speed

Based on Fig. 15, the relationship between temperature and air velocity is such that if turbulence occurs, the flow velocity will be greater, causing the temperature to increase. Therefore, the areas close to the outlet have higher temperatures and velocities. In addition, the indoor temperature was influenced by the applied window area. Based on Fig. 16, the larger the window area, the greater the room temperature generated bythe heat from solar radiation. The placement of the cooler also affected airflow distribution. The cooler in the middle had a more even airflow distribution than that at the two ends. This is because the incoming airflow from the ducting will only reach one point (central). As a result, the resulting temperature was more stable throughout the room.

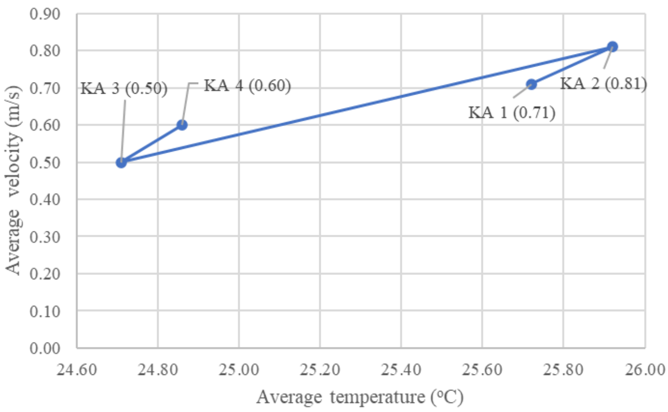

Fig. 15. Graph of the relationship between temperature and air velocity.

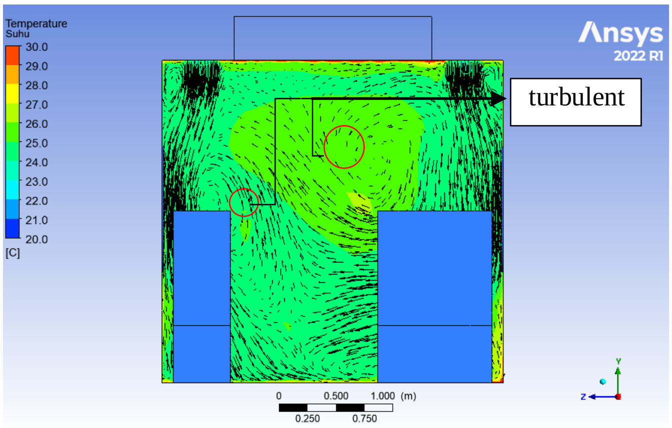

Fig. 16. Velocity vector against temperature.

4 Conclusion

Based on the CFD simulation results for the stainless-steel railway carriage, the actual carriage, KA 1, has an average temperature distribution of 25.72, and the flow flows evenly throughout the carriage with an average air velocity of 0.71 m/s. In the variations, KA 2, KA 3, and KA 4 have average temperature of 25.92°C, 24.71°C, and 24.86°C, respectively. In addition, the air velocitieswere 0.81, 0.50, and 0.6 m/s.

In this case, the KA 3 variation had a better average temperature distribution than the others, with the flow flowing evenly throughout the carriages. In this case, KA 3 can improve services, particularly thermal comfort during travel. Overall, the simulation results applied to all geometries reached comfort standards according to SNI 03-6572-2001 and MENKES No 261/MENKES/SK/II/1998.

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