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Comparative Transient Air-Flow Analysis for Integral Coach Factory (ICF) and Linke Hofmann Busch (LHB) Railway Coaches

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ABSTRACT

Air-conditioning is a critical passenger comfort amenity on the Air-conditioned Indian Railways coaches. According to the data available, the Comfort Range (tolerance), and Comfort Zone (for FTA) are 23±1°C, ±5% RH, 23°C to 25°C all the time, anywhere and everywhere. The standard LHB (Linke Hofmann Busch) and ICF (Integral Coach Factory) - 2A coaches' compartments of the Indian Railways are taken into consideration for the simulations and heat load calculations are performed on the complete coach. The inside temperature of the coach was determined to be between 300 K and 303 K for LHB and ICF coaches respectively and the time required for the inlet air (294-296K) to reach the thermal comfort temperature (298K) of 25°C was recognized. It was found that the time taken to reach the comfort temperature in an ICF and LHB coach is 310 sec and 163 sec respectively. From heat load calculations it can be stated that the ICF coach has a TR of 7.4217 Tons while the LHB coach has 8.2 Tons.

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1. INTRODUCTION

Ensuring thermal comfort in passenger coaches is a crucial aspect of railway operations. The effectiveness of air-conditioning systems plays a significant role in achieving this goal. In India, with its diverse climatic conditions, maintaining optimal air-flow patterns within railway coaches is essential for passenger satisfaction and well-being [1]. People prefer slightly cooler temperatures than what they find comfortable. Standard effective temperature ranges of 23 to 25°C were discovered to provide the best thermal conditions for air conditioning. Below 22°C, over 20% of respondents reported feeling uncomfortable. [2]. This paper uses CFD analysis to investigate the temperature change in LHB and ICF 2A coaches of the Indian Railways. The comparative analysis aims to identify the key differences in air conditioning performance between LHB and ICF 2A coaches. This knowledge is instrumental in designing more efficient air conditioning systems and optimizing the placement of air vents for both LHB and ICF 2A coaches. Although comfort studies and appropriate interpretation of the results could affect people's travel comfort, comfort research in transportation is very infrequently undertaken. Maintaining thermal comfort for car users is essential to their well-being, both physically and mentally.[3][4] For hot weather, the optimal HVAC temperature is 25°C; for chilly weather, it is 26°C. In high outdoor conditions, this method can save 8–33% of energy, while in low outdoor conditions, 12–44%. In summary, the results from the Thermal Comfort Study in a Vehicle Occupant Section demonstrate that, throughout the summer, a car's passengerThe compartment may be maintained cool and comfortable by opening the windows and putting on the air conditioning system. [5] The definition of a healthy indoor climate is crucial to a passenger rail coach's performance since it affects not only how much energy it uses and how sustainable it is, but also how comfortable it is for lengthy trips.[6] Optimized air conditioning systems reduce energy consumption and contribute to environmental sustainability [7]. HVAC systems, or heating, ventilation, and air conditioning, are crucial, particularly in enclosed public spaces like buses, rail coaches, and hospitals. [8] A few variables influencing air conditioning systems are sensible heat, latent heat, room size, room location, and room function. [9][10].

According to the findings of the Thermal Comfort and Air Quality study, clothing, temperature, humidity, and exterior air ventilation are the main variables that affect how comfortable a passenger feels in the heat.[6] During the research, it was found that there is limited study done especially focusing on the comparative part, in this paper we have provided a comparative analysis of the ICF and LHB coach airflow simulations. During the comparative analysis, it was found that the main variables influencing a person's thermal comfort are the cabin's mean radiant temperature, relative humidity, air temperature, and relative air velocity, which all change depending on how many people are in the cabin.[11] In previous literature, temperature and airflow were studied numerically and experimentally for a limited human load. Thermal comfort is defined as "that state of mind which expresses satisfaction with the thermal environment" in ASHRAE standard 55.[11][12].

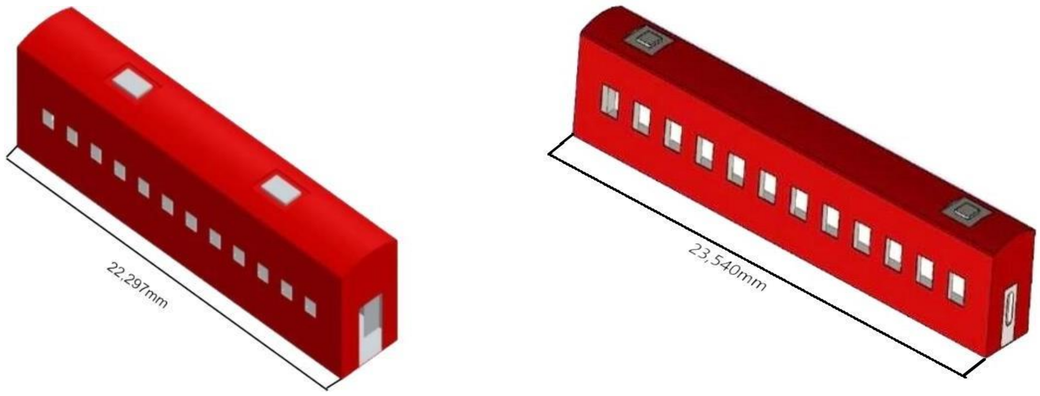
This paper focuses on ensuring a comparative thermal comfort study for the Indian Railway coaches through a comparative analysis of air conditioning performance in LHB and ICF 2A coaches using CFD analysis. The research emphasizes the importance of HVAC systems in enclosed public spaces and aims to identify key differences in airflow patterns. Despite the critical role of thermal comfort in transportation, there is limited comparative research on the air conditioning performance of LHB and ICF 2A coaches in Indian Railways, creating a gap in understanding the specific factors influencing passenger satisfaction.

Objectives of this research are:

- To conduct a comparative CFD analysis of temperature change in LHB and ICF 2A coaches.
- To identify key differences in air conditioning performance between the two coach types.

2. METHODOLOGY

Modern trains can use as much as 30 of the total energy used for heating and cooling, in part because of the growing expectations for hygrothermal comfort. [13]. A key component of railway transport's competitiveness is thermal comfort. [14]. According to prior research, the incorrect compartment design causes the thermal comfort conditions within to not be dispersed evenly, which can occasionally lead to results that suggest passengers are uncomfortable.[14]. In the above research, a numerical simulation of the Heating Load Calculations based on a passenger coach was also carried out to support the CFD simulations [14]. The model was built (Fig - 1,2) with the actual dimensions, however, the error can be anywhere between (+/- 100mm) in dimensions. The models were designed using an Aluminum Metal Sheet design using Solidworks 2023 and the ANSYS 19.2 is used for the simulations. The Dimensions of the LHB Coach are as follows - (23.54 m +/- 100mm), 3.24 m +/- 100mm and height 4.039 m +/- 100 mm, 4.25 m +- 100mm (AC 3 Tier & Vistadome) 4.366 m (Double decker) [15]. ICF Coach dimensions are - a length of 22,297 millimeters (22.297 m) including buffers, width - 3245 mm +/- 100 mm, and height of 4025 mm +/- 100 mm. [16]. The inlets and outlets of a standard tube vehicle ventilation system are located on the upper portion of the cabin. The air dispersion in this mode frequently results in significant issues with energy usage and thermal comfort.[17] This design places the inlet on the left and right sides of the compartment, above each bunk (Fig. 3). This design places the intake on the left and right sides of the compartment, above each bunk.



(a). The Integral Coach Factory (ICF) main body design along with its structural features

(b).The Linke Hofmann Busch (LHB) main body design along with its structural features

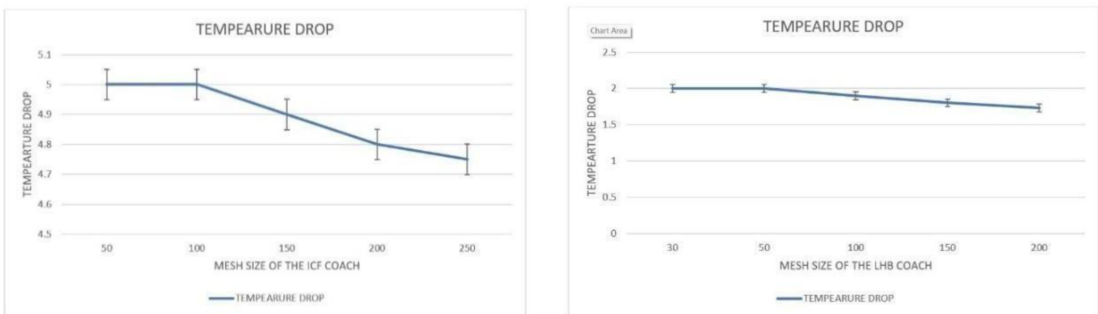
Figure 1. Main Body Designs for ICF and LHB

Regarding the heating sources, tube lights (320W) and charging points (300) were considered; additionally, berths were presumed to be the person for debt verification. Air was initially placed within the compartment (Air Compartment). Because CFD simulations can reduce time and money while preserving useful and accurate conclusions, it is commonly employed in the design of AC systems. [17][18][19] CFD approaches also have the benefit of being repeatable and enabling interactive visualization.[20]. Here for the CFD Analysis, the two compartments of both coaches are considered with the actual dimensions (+/- 100mm) of the tolerance.

Practically speaking, coach variable factors such as 3A, 2A, and 1A, as well as design and placements, influence the size and placement of ducts. It is understandable from Fig - 1 and Fig 3 about the main body and the compartment body that is used for CFD. The considered size of the dimensions of the inlet and outlet dimensions are 150 x 200 150 mm. Fluid simulations have become an indispensable tool for studying and understanding fluid flow behaviors, especially in these enclosed environments.[21] An air-conditioned train compartment's dynamic cooling load can be simulated through the creation of a mathematical model. [22]For trains traveling in various locations and for varying lengths of time, the dynamic cooling load calculation can offer a reliable foundation for calculating the cooling load.[22]

3. GRID INDEPENDENCE STUDY AND GOVERNING EQUATIONS

The graph you sent shows the temperature drop of the ICF and LHB coaches as a function of the mesh size of the ice coach, with different mesh sizes. The graph shows that the temperature drop of the ice coach increases as the mesh size of the ice coach decreases. The graph also shows that the temperature drop of the ice coach converges to a constant value as the grid size increases. This indicates that the proposed solution is grid-independent, which means that the size of the grid has no bearing on the solution's accuracy. The target space of the CFD model is divided into a finite number of grids for numerical analysis. A perfect grid structure is also required for accurate results. (From the graph 1 and 2) it can be understood that the temperature drop is the same (5°C) when the mesh size is 50mm and 100mm for the ICF coach and for the LHB coach it is 2°C when the mesh size is 30mm and 50mm.



(a). Grid Independence Graph for ICF

(b).Grid Independence Graph for LHB

Figure 2. Grid Independence Graphs

Table 1. ICF Nodes and Elements on the given mesh size

NODES	ELEMENTS	MESH SIZE
236601	1249707	50
46323	234199	100
17993	88317	150
9181	43448	200
5397	24662	250

Table 2. LHB Nodes and Elements on the given mesh size

NODES	ELEMENTS	MESH SIZE
601432	32224333	30
187556	958881	50
35538	177049	100
14068	68524	150
7153	33311	200

The tables above show the number of nodes and elements on a mesh for the ICF and LHB coaches in ANSYS. The LHB coach has a finer mesh, with 601432 nodes and 32224333 elements, compared to 236601 nodes and 1249707 elements for the ICF coach. This finer mesh will result in more accurate analysis results for the LHB coach, which is particularly important for evaluating its structural integrity under various loading conditions. The mesh size is a critical factor in ANSYS analysis, as it affects the accuracy of the results.[12] A finer mesh will provide more accurate results, but will also require more computational resources. The type of mesh used and the mesh size will depend on the geometry of the model, the boundary conditions applied, and the desired accuracy of the analysis. For an ANSYS analysis, the Jacobian ratio is important because it can affect the accuracy of the results.[18] A high Jacobian ratio can lead to inaccurate stresses and strains, which can affect the overall outcome of the analysis. Therefore, it is important to choose a mesh size that results in a low Jacobian ratio.

Table 3. Jacobian ratio for the ICF and LHB coaches with different mesh sizes

Mesh size (mm)	ICF Jacobian ratio	LHB Jacobian ratio
50	0.32	0.35
100	0.25	0.28
150	0.21	0.23
200	0.18	0.2
250	0.16	0.18

The table above shows the number of nodes and elements on a mesh for ICF and LHB coaches, with different mesh sizes. The Jacobian ratio is a measure of how distorted the mesh is, and it is important to consider when using ANSYS to analyze the coaches.[14] A high Jacobian ratio indicates that the mesh is distorted, which can lead to inaccurate results. The results show that the Jacobian ratio decreases as the mesh size decreases. This is because a finer mesh is less likely to be distorted. In the case of the ICF and LHB coaches, all of the mesh sizes result in a Jacobian ratio below 0.5.

To build the perfect grid, an inspection for grid independence is typically conducted.[23] In order to make use of CFD to predict the actual phenomena, a grid structure that divides the area of interest into a limited quantity of grids is necessary.[24] Fine grids have the potential to significantly raise the round-off error over the truncation error, which would lower the analysis results' accuracy.[25][26] In this study, CFD simulation was conducted using the k-epsilon- equation model. For this kind of research, it is the most widely used. A common model for predicting airflow in buildings is the classic k – model of turbulence.[27] In the presented study, physical characteristics including air temperature, pressure, and velocity randomly change with time and space. [27]

The following are the Governing equations which are mostly used

- **Continuity Equation:**
  $\partial p/\partial t + \nabla.(\rho u) = 0$ --- (1)
  This equation ensures the conservation of mass.

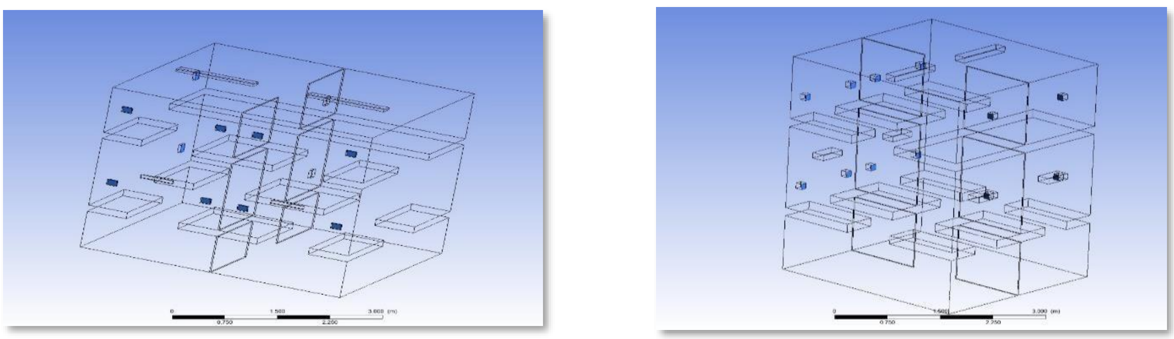
- **Navier-Stoke Equations:**
  $\partial(\rho u)/\partial t + \nabla.(\rho u) = -\nabla p + \nabla.r + \rho g$ -- (2)
  This equation governs the conservation of momentum.

- **Energy Equations:**
  $\rho Cp\,(\partial T/\partial t + u.\nabla T) = \nabla.(k\nabla T) + \rho H$ ------------------------------------- (3)
  This equation represents the conservation of energy.
  The energy equation accounts for the thermal aspects of the system and is essential for capturing heat transfer phenomena:
  $\rho Cp\,(\partial T/\partial t + u.\nabla T) = \nabla.(k\nabla T) + q'' + q''r$ --(4)

- **Species Transport Equation:**
  The cooling tower involves the presence of multiple fluids (air and water), and the species transport equation is employed:
  $\partial(\rho Yk)/\partial t + \nabla.(\rho uYk) = \nabla\nabla.(\rho Dk\nabla Yk) + mk$ ---(5)

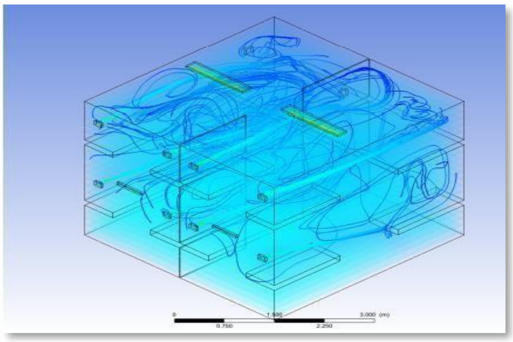
4. RESULTS AND DISCUSSION

The energy, temperature, and comfort analyses that were conducted are cited as results. Performances obtained from all of the CFD actions are compared to the actions in this section. Mesh generation, or the discretization of the area of interest, is a pre-processing step for the computational field simulation. Structured and unstructured meshes are the names given to these two fundamental types.[28] For a precise computation of fluid dynamics (CFD) simulation, proper meshing is essential. The collection of elements could be meshed once the geometry was produced. Discretization of the computational domain is necessary to ensure sufficient geometry and outcome resolution. [16][21]

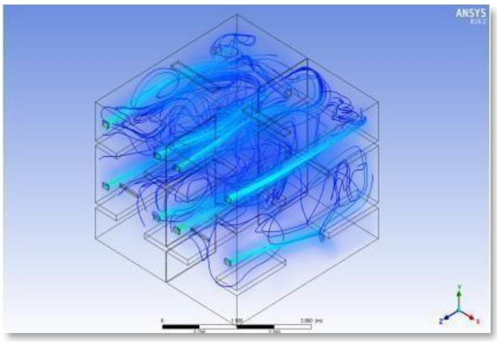


(a). ICF Inlet geometry *(b). LHB Inlet geometry*

Figure 3. Inlet Geometries of ICF and LHB



(a). Velocity Streamline for ICF



(b). Velocity Streamline for LHB

Figure 4. Velocity Streamlines of ICF and LHB

Figure 4: Velocity streamline diagram shows that the input air temperature rises to 295 Kelvin and the ICF coach time step is 310 seconds when the air temperature reaches the comfort zone, which is 298 K. The temperature of the input air is 295 Kelvin and the duration of the step for the ICF coach is 250 seconds when the air enters the comfort zone, which is 298 K. The average detected temperature drops by 1 Kelvin, or 302 K, when the air's input temperature reaches the comfort zone, which is 298 K. The time step for the ICF coach is 50 seconds. The temperature of the input air is 295 Kelvin and the duration of the step of the LHB coach is 180 seconds when the air achieves the comfort zone, which is 298. The temperature of the air entering the coach is 295 Kelvin when it reaches the comfort zone, which is 298 K.

1) Volume - Average of Temperature (k) vs Flow-time (s) for ICF Coach

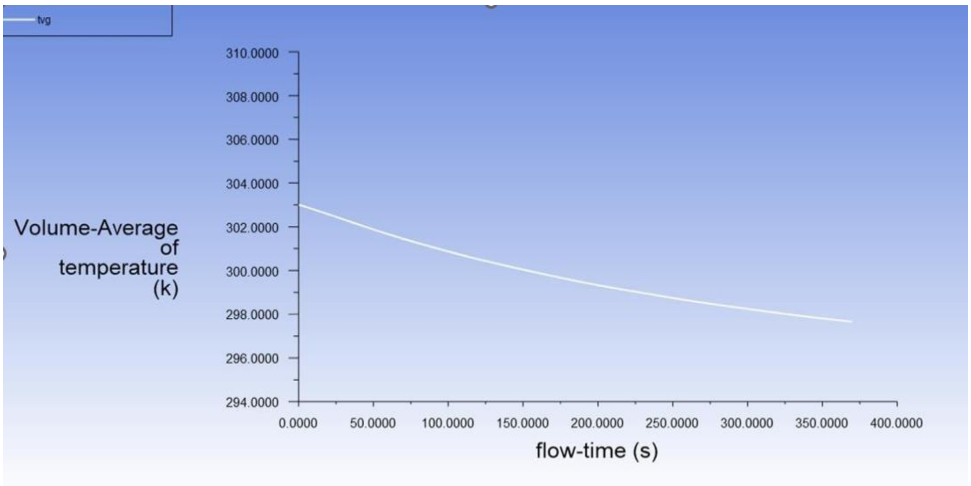


Figure 5. Temperature (k) vs Time (s) for ICF

2) Volume - Average of Temperature (k)Vs Flow-time (s) for LHB Coach

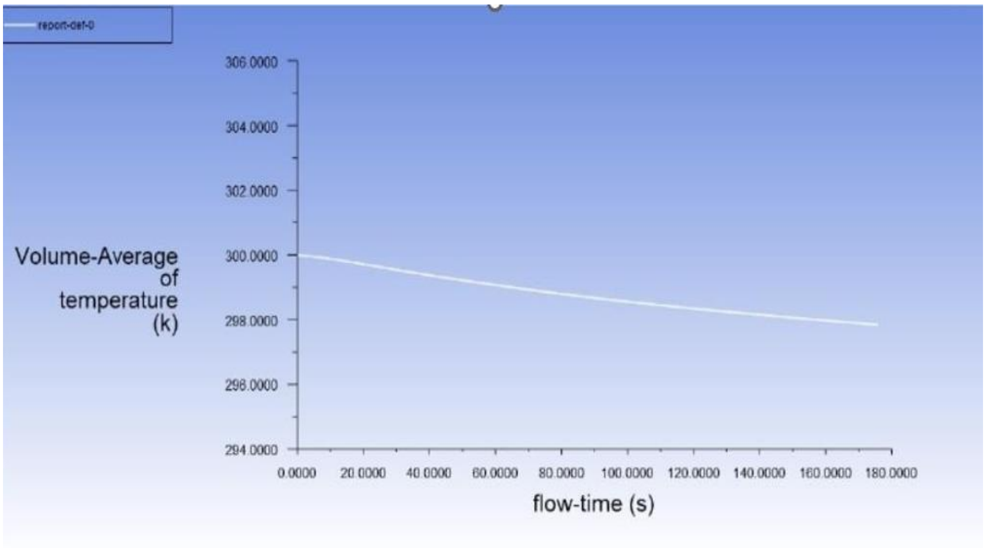


Figure 6. Temperature (k) vs Time(s) for LHB

3) Time-wise Result for ICF Coach

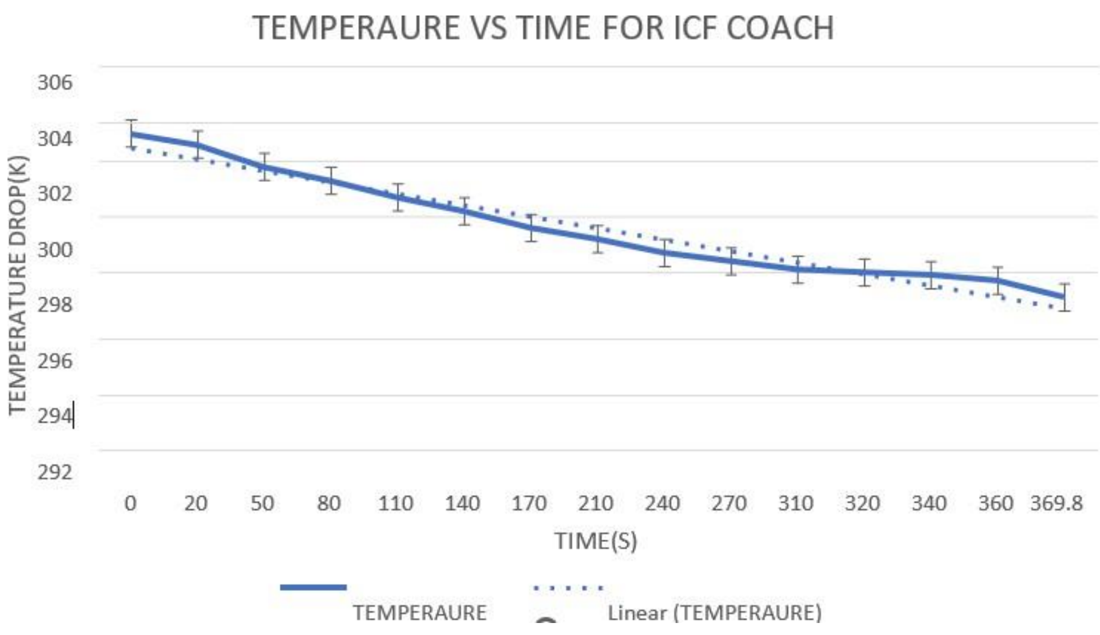


Figure 7. Time-wise result for ICF

The graph shows the temperature vs time for an ICF coach. The temperature starts at 303 K and gradually decreases over time. A thermal comfort temperature of 298 K was achieved at approximately 310 seconds. The graph shows a linear decrease in temperature over time.

4) Time-wise result for LHB Coach

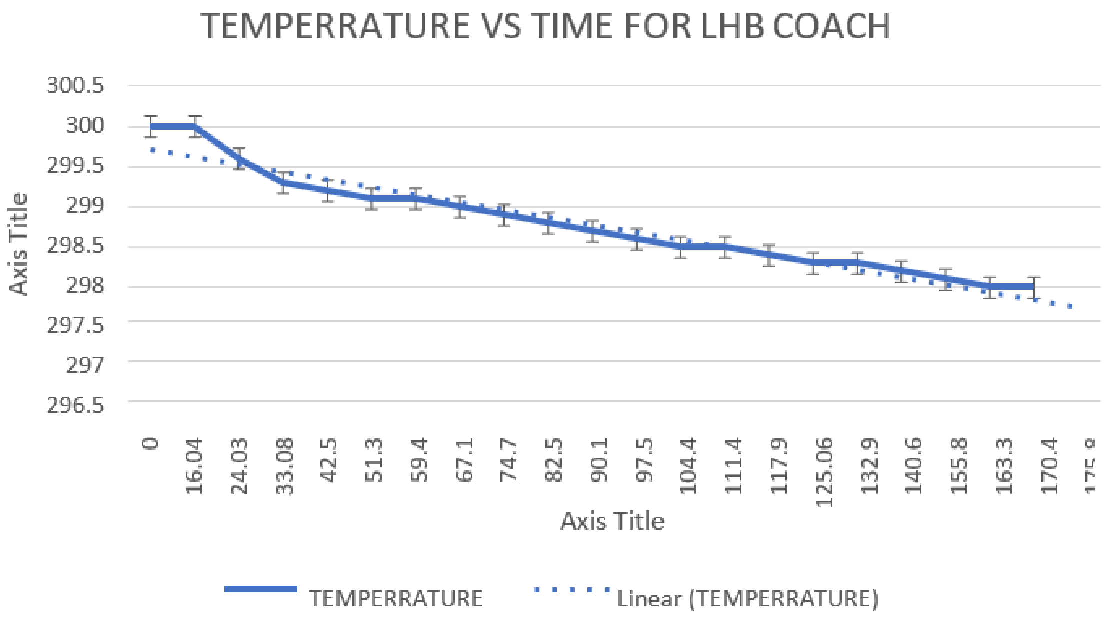


Figure 8. Time-wise result for LHB

The graph shows the temperature vs time for an LHB coach. The temperature starts at 300 K and gradually decreases over time. A thermal comfort temperature of 298 K was achieved at approximately 170.4 seconds. The graph shows a linear decrease in temperature over time.

5. CONCLUSION

This study investigated the thermal comfort experienced by passengers in ICF and LHB coaches, with a particular focus on the efficiency and effectiveness of their air conditioning systems. By conducting individual analyses for each coach type, we gained valuable insights into the distribution of air performance and the time required to achieve a comfortable temperature of 298 K (25°C). The findings revealed significant differences between the two coach types. While both coaches eventually reached the desired temperature, the LHB coach achieved it significantly faster, taking only 180 seconds compared to 375 seconds for the ICF coach. This disparity suggests potential inefficiencies in the ICF coach's air conditioning system design or its distribution of cool air. Furthermore, the analysis revealed that the LHB coach has a higher heating load of 8.2 tons compared to the ICF coach is 7.4217 tons. This difference is attributed to various factors such as the LHB coach's larger size, higher passenger occupancy, and potential differences in window design.

DECLARATION OF COMPETING INTEREST:

The authors declare that they have no discernible competing financial interests or personal connections that may have been interpreted as influencing the findings of the study published in this publication.

REFERENCES

[1] Mohammad Aliahmadipour, Morteza Abdolzadeh, Khosro Lari, Air flow simulation of HVAC system in compartment of a passenger coach, Applied Thermal Engineering, Volume 123, 2017, Pages 973-990, ISSN 1359-4311, https://doi.org/10.1016/j.appltherm aleng.2017.05.086

[2] Buonocore, Carolina , De Vecchi, Renata, Scalco, Veridiana, Lamberts, Roberto Thermal preference and comfort assessment in air-conditioned and naturally-ventilated university classrooms under hot and humid conditions in Brazil 211 10.1016/j.enbuild.2020.109783 JO - Energy and Buildings.

[3] Palmowska, Agnieszka and Sarna, Izabela. "CFD Modelling of Thermal Comfort in the Passenger Coach" Architecture, Civil Engineering, Environment, vol.15, no.4, 2022,pp.133-146. https://doi.org/10.2478/acee-20 22-0044

[4] Nastase I., Danca P., Bode F., Croitoru C., Fechete L., Sandu M. Coşoiue I, C. (2022). A regard on the thermal comfort theories from the standpoint of Electric Vehicle design — Review and perspectives, Energy Reports, 8, 10501–10517.

[5] Chunling Qi, Yaxin Helian, Jiying Liu, Linhua Zhang, Experiment Study on the Thermal Comfort inside a Car Passenger Compartment, Procedia Engineering,Volume 205, 2017, Pages3607-3614,ISSN 1877-7058 https://doi.org/10.1016/j.proeng .2017.10.211.20

[6] Xiaojiang Ye, Hongli Lu, Dong Li, Biying Sun & Yuanmou Liu (2004) Thermal Comfort and Air Quality in Passenger Rail Cars, International Journal of Ventilation, 3:2, 183-192, DOI: 10.1080/14733315.2004.11683913

[7] Kofi Owura Amoabeng, Richard Opoku, Samuel Boahen, George Yaw Obeng, Analysis of indoor set-point temperature of split-type ACs on thermal comfort and energy savings for office buildings in hot-humid climates, Energy and Built Environment, Volume 4, Issue 3, 2023, Pages 368-376, ISSN2666-1233, https://doi.org/10.1016/j.enbenv .2022.02.006.

[8] Alhassan, Musa & Aliyu, Aliyu & Mishra, Rakesh & Mian, Naeem. S.. (2021). Air Quality Management in Railway Coaches. 1-5. https://doi.org/10.1109/ICMIAM54 662.2021.9715208

[9] Chala, Girma, Joe, Lee Maárof, M. 2021/03/31. Investigation of Cooling Condition of a Room with Air-Conditioning Working Concurrently with Air Supply and Discharge Systems – A Case Study

[10] S. Z. Mohd, “Case Study on Solar Air Conditioning Absorption System”, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia, 2017

[11] K. Karthik, Mr. S Mohamed Nasrulla, T. Kamesh Raj, N. Karthick, S. Krishnakanth (2021) “COMPARATIVE CFD ANALYSIS ON CONDITIONED AIR FLOW AND TEMPERATURE DISTRIBUTION IN METRO TRAIN FOR DIFFERENT CITIES OF INDIA ”, International Journal of Modern Agriculture, 10(1), pp. 245 – 256

[12] ASHRAE, Standard 55-Thermal Environmental Conditions for Human Occupancy, ASHRAE Inc, Atlanta, 1992.

[13] Barone, G., Buonomano, A., Forzano, C., & Palombo, A. (2020). Enhancing trains envelope – heating, ventilation, and air conditioning systems: A new dynamic simulation approach for energy, economic, environmental impact, and thermal comfort analyses. Energy, 204, 117833. https://doi.org/10.1016/j.energy. 2020.117833

[14] L. Pang, J. Zhang, X. Wan Yan, et al., Field study of neutrality cabin temperature for Chinese passenger in economy class of civil aircraft, J. Therm. Biol. 78 (2018) 312–319

[15] https://ser.indianrailways.gov.in/uploads/files/1514285051142-Rehresh er%20Course%20book.pdf

[16] https://indianrailways.gov.in/rai lwayboard/uploads/DATA/AKA SH/PWP.pdf

[17] Zhiyuan Chang, Ke Yi, Weiwei Liu, A new ventilation mode of air conditioning in subway vehicles and its air distribution performance, Energy and Built Environment, Volume 2, Issue 1, 2021, Pages 94-104, ISSN 2666-1233, https://doi.org/10.1016/j.enbenv .2020.06.005.

[18] J. F. Karlsson and B. Moshfegh, “Investigation of indoor climate and power usage in a data center,” Energy and Buildings, vol. 37, no. 10, pp. 1075–1083, 2005.

[19] J. Cho, T. Lim, and B. S. Kim, “Measurements and predictions of the air distribution systems in high compute density (Internet) data centers,” Energy and Buildings, vol. 41, no. 10, pp. 1107–1115, 2009.

[20] L. Yang, M. Ye, and B.-J. he, “CFD simulation research on residential indoor air quality,” Science of the Total Environment, vol. 472, pp. 1137–1144, 2014.

[21] Qinghe Yao , 1 Hang Bai,1 Trevor Hocksun Kwan,1 and Kiwamu Kase2 . A Parametric Study and Optimization of an Air Conditioning System for a Heat-Loaded Room. Hindawi .Mathematical Problems in Engineering Volume 2018, Article ID 2385691, 10 page https://doi.org/10.1155/2018/2385691

[22] Weiwei Liu, Qihong Deng, Wenjie Huang, Rui Liu, Variation in cooling load of a moving air-conditioned train compartment under the effects of ambient conditions and body thermal storage, Applied Thermal

Engineering, Volume 31, Issues 6–7, 2011, Pages 1150-1162, ISSN 1359-4311, https://doi.org/10.1016/j.appltherm aleng.2010.12.010.

[23] JOUR Tangchirapat, Weerachart Lee, Minhyung Park, Gwanyong Park, Changyoung Kim, Changmin 2020 2020/12/24 Improvement of Grid Independence Test for Computational Fluid Dynamics Model of Building Based on Grid Resolution 8827936 2020

[24] R. Zhang, Y. Zhang, K. P. Lam, and D. H. Archer, "A prototype mesh generation tool for CFD simulations in architecture domain," Building and Environment, vol. 45, no. 10, pp. 2253–2262, 2010.

[25] JOUR Tangchirapat, Weerachart Lee, Minhyung Park, Gwanyong Park, Changyoung Kim, Changmin 2020 2020/12/24 Improvement of Grid Independence Test for Computational Fluid Dynamics Model of Building Based on Grid Resolution 8827936 2020

[26] J. Tu, G. H. Yeoh, and C. Liu, Computational Fluid Dynamics: A Practical Approach, Butterworth-Heinemann, Oxford, UK, 2018.

[27] Andrzej Raczkowski 1,* , Zbigniew Suchorab1 , and Przemysław Brzyski2 . Computational fluid dynamics simulation of thermal comfort in a naturally ventilated room. MATEC Web of Conferences 252, 04007 (2019). CMES. https://doi.org/10.1051/matecco nf/201925204007

[28] Liu Y, Long Z, Liu W. A semi-empirical mesh strategy for CFD simulation of indoor airflow. Indoor and Built Environment. 2022;31(9):2240-2256. doi:10.1177/1420326X221089825