BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Volumul 71 (75), Numărul 4, 2025
Secţia
CONSTRUCŢII DE MAŞINI
DOI: 10.2478/bipcm-2025-0037

OPTIMIZING AIR CONDITIONING FLOW IN ROAD VEHICLES TO INCREASE ENERGY EFFICIENCY AND THERMAL COMFORT

BY

DARIA SACHELARIE*, GEORGE ACHIȚEI and ARISTOTEL POPESCU

“Gheorghe Asachi” Technical University of Iași,
Faculty of Mechanical Engineering, Iași, Romania

Received: July 9, 2025
Accepted for publication: October 5, 2025

Abstract. Modern HVAC systems in road vehicles are vital for maintaining thermal comfort, but also represent a significant energy consumer, especially in electric vehicles. This study investigates airflow optimization methods to improve energy efficiency and passenger comfort by combining thermodynamic modeling, CFD simulation, and intelligent control. The paper proposes an integrated approach using adaptive control strategies and advanced cabin design, focusing on dynamic airflow regulation based on real-time sensor input. A simplified mathematical model and CFD analysis were developed to evaluate airflow velocity, temperature distribution, and energy use. The simulation compared standard and optimized configurations, demonstrating that better airflow control reduces energy consumption while maintaining or improving comfort. The results confirm that airflow optimization, through predictive control and smart sensor integration, is a feasible path toward more efficient and sustainable climate control systems in vehicles. The findings support future applications in automotive design, particularly for electric and low-emission vehicles.

---

*Corresponding author; *e-mail:* daria.sachelarie@academic.tuiasi.ro

Keywords: airflow distribution, thermal modeling, CFD analysis, vehicle interior, passenger comfort.

1. Introduction

In recent decades, air conditioning systems have become a standard feature in most road vehicles, providing increased thermal comfort for passengers regardless of external weather conditions. Lahlou et al. highlighted that HVAC operation in conventional vehicles significantly increases fuel consumption and pollutant emissions, underlining its environmental and economic impact (Lahlou *et al*., 2020). In electric vehicles, Jose and Chidambaram and Lesage demonstrated through CFD and integrated simulations that air conditioning is among the largest auxiliary loads, directly reducing driving range (Jose and Chidambaram, 2021; Lesage *et al*., 2024).

Shen and Zhang further proposed a comfort–energy efficiency index to evaluate HVAC performance, showing that energy-efficient designs must balance technical optimization with thermal satisfaction (Shen and Zhang, 2023).

At the same time, Liu and Zhang introduced adaptive control methods based on passenger thermal comfort, emphasizing the importance of real-time system adjustments, while Cvok et al. applied dynamic programming to derive optimal HVAC control strategies (Liu and Zhang, 2022; Cvok *et al*., 2021). Park and Kim confirmed that predictive cabin thermal load modeling can enhance both comfort and energy efficiency in electric vehicles (Park and Kim,2020).

These studies confirm that airflow management its rate, direction, and distribution plays a pivotal role in achieving energy efficiency and comfort. For example, Fiala et al. developed a thermal comfort model specifically for vehicle occupants, while Zhao and Li numerically simulated cabin airflow, showing how distribution patterns affect perceived confort (Fiala *et al*., 2003; Zhao and Li, 2020). Similarly, Zhang and Li and Zhao and proved that intelligent algorithms such as fuzzy logic or real-time optimization can significantly reduce consumption without compromising passenger satisfaction (Zhang and Li, 2020; Zhao and Chen, 2019).

Therefore, the optimization of airflow in automotive HVAC systems is not only a technical challenge but also a necessity for sustainable mobility. The present paper builds on these findings by proposing an integrated approach based on mathematical modeling, CFD simulation, and intelligent airflow control. Our objective is to evaluate how airflow redistribution strategies and adaptive control can reduce energy consumption while maintaining or improving passenger comfort, with particular focus on applications in modern electric vehicles.

2. Current Study on Automotive Air Conditioning Systems

2.1. Key Components and Operational Parameters

Figure 1 shows the main components of a typical automotive HVAC system. Since these elements are already well established in the literature and industry practice the focus here is not on their basic description but on the operational parameters that govern system performance (Lahlou *et al*., 2020). The most relevant parameters include the cabin set temperature and airflow rate, which directly influence passenger comfort and the time required to achieve the desired microclimate; the refrigerant pressure and temperature at the compressor and evaporator, which determine the efficiency of the thermodynamic cycle and the cooling capacity; the compressor power demand, one of the main contributors to overall energy consumption, especially under high thermal loads; the fan speed and airflow distribution strategy, which affect both cabin air mixing and electrical consumption; and the ambient temperature combined with solar radiation load, external factors that strongly condition refrigerant behavior and overall HVAC efficiency (Jose and Chidambaram, 2021).

These dependencies between controlled climate, refrigerant dynamics, and energy use are central to understanding system performance and provide the foundation for the modeling and CFD simulations developed in the following sections.

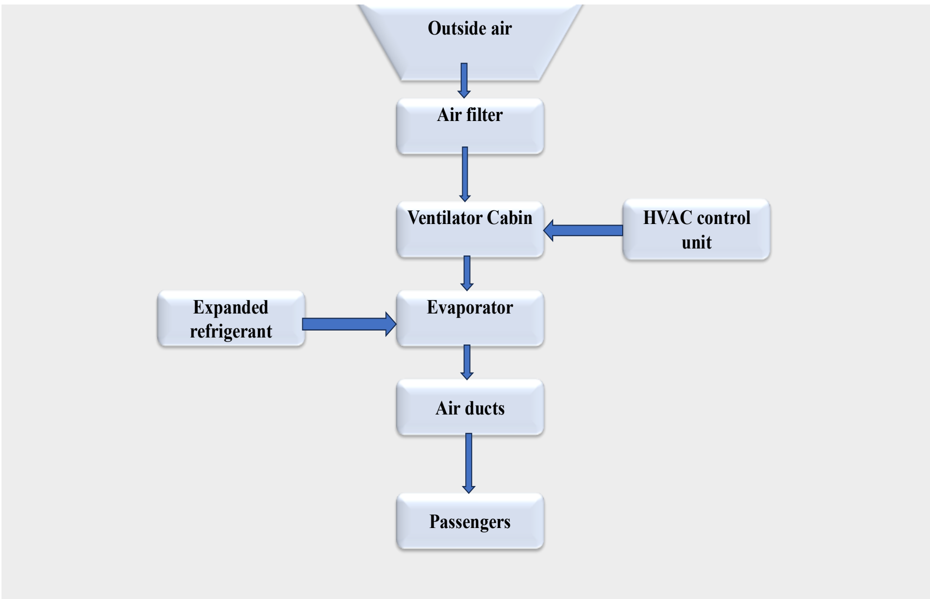

Fig. 1 – System components.

2.2. Operating Principle

The operating principle of an automotive HVAC system extends beyond the classical refrigeration cycle and must be analyzed in terms of its effect inside the passenger compartment. Conditioned air leaving the evaporator is guided through ducts and ventilation grilles into the cabin, where airflow geometry, velocity, and temperature distribution define both cooling effectiveness and passenger comfort (Lesage *et al*., 2024).

The positioning and orientation of the vents determine how air jets propagate within the confined space. Non-uniform airflow can generate hot or cold spots, whereas optimized geometry ensures a homogeneous temperature field and balanced comfort for all occupants (Liu and Zhang, 2022). Local air velocity strongly influences thermal sensation: values above 0.25 m/s may create draft discomfort near the head or upper torso, while insufficient velocity around the lower extremities can result in poor cooling efficiency (Cvok *et al*., 2021).

The interaction between airflow and the human body is also determined by local convective heat transfer coefficients, which depend on jet velocity and turbulence. Enhanced airflow improves heat removal but must be carefully regulated to avoid excessive cooling of sensitive areas (ASHRAE Standard 55-2017).

Therefore, the operating principle of the HVAC system in a vehicle cabin is not limited to the thermodynamic cycle but rather to the dynamic interaction between refrigerant performance, airflow distribution, and the thermal loads associated with human occupants. This perspective provides the framework for the CFD analyses presented in the next sections (Park *et al*., 2020; Amini *et al*., 2019).

2.3. Identified Issues

Although current HVAC systems are well-developed and automated, several technical and efficiency issues persist:

- High energy consumption: the compressor is one of the vehicle's significant energy consumer especially in extreme external temperatures. In electric cars, this consumption directly affects the driving range (Liu and Zhang, 2022).
- Slow response time: systems do not always react effectively to rapid changes in temperature or user demands, causing discomfort and energy waste.
- Inefficient airflow control*:* in many cases, the airflow is not dynamically adjusted based on occupants, cabin temperature distribution, or driving conditions. Simplified control strategies are used that do not account for the accurate airflow distribution (Cvok *et al*., 2021; ASHRAE Standard 55-2017).

These limitations provide the basis for researching and implementing advanced optimization solutions at the hardware and software levels.

3. Methods of Airflow Optimization

Effective airflow optimization in automotive HVAC systems requires the integration of modern, intelligent solutions that consider real operating conditions and user preferences. Several actions may be taken to achieve system optimization, such as: use of sensors and automated control, intelligent regulation algorithms, and improvements to the cabin's physical design.

3.1. Adaptive and Automated Control

Modern HVAC systems integrate intelligent sensors to continuously monitor environmental conditions inside and outside the vehicle. Temperature, humidity, CO_2 concentration, and solar radiation sensors provide real-time input data that were directly used as boundary conditions in the CFD model of the cabin (Park and Kim, 2020).

In the optimization framework, adaptive control was modeled by dynamically adjusting fan speed and air distribution flaps in response to deviations between set-point and measured cabin temperature. For instance, when CFD results showed localized overheating, the adaptive control loop redistributed airflow toward that zone, lowering the temperature gradient without increasing overall energy consumption.

Automated control algorithms were embedded in the simulation to evaluate their effectiveness. The PID controller was used to regulate outlet air temperature by minimizing the error between desired and simulated cabin temperature. Fuzzy logic control was then applied to integrate multiple variables such as passenger load, humidity level, and solar radiation allowing the system to react under uncertain or fluctuating conditions (Amini *et al*. 2019; Zhao *et al.*, 2019).

Through this integration, the CFD-based thermal model provided the physical context (temperature and velocity fields), while the control strategies acted as optimization tools to regulate airflow and energy consumption. The combined results demonstrated that adaptive and automated control reduce compressor cycling, stabilize temperature distribution, and improve comfort indices compared to baseline operation.

3.2. Use of Control Algorithms: PID, Fuzzy Logic, AI

Airflow adjustment in automotive HVAC systems can be significantly improved by implementing intelligent control algorithms.

PID (Proportional-Integral-Derivative) control is a classic method for fine-tuning system parameters based on the error between the desired and actual cabin temperature. It provides stable regulation of outlet air temperature but shows limitations under highly dynamic operating conditions or when several interacting variables are involved.

Fuzzy logic offers more flexible control, similar to human reasoning, and allows decision-making even in incomplete or uncertain conditions. This approach is particularly suitable for multi-variable scenarios such as occupancy, humidity, and solar load, and it is widely applied in studies aiming to enhance personalized thermal comfort (Amini *et al*., 2019; Zhao *et al*., 2019).

Artificial Intelligence (AI), including machine learning algorithms and neural networks, has the capacity to anticipate comfort needs by learning from usage history, weather conditions, and passenger preferences. AI-based control strategies are increasingly considered in automotive HVAC applications for their potential to proactively optimize both comfort and energy efficiency (Fiala *et al*., 2003; Zhao *et al*., 2019).

By combining such algorithms with CFD-based analysis, airflow distribution and energy consumption can be regulated adaptively, achieving a better balance between passenger comfort and system efficiency.

3.3. Materials and Aerodynamic Design in Cabin Interior

Another essential aspect of optimizing airflow is the physical design of the ventilation system. This includes:

- Low-resistance air ducts: optimized design reduces pressure losses and allows efficient airflow with lower energy consumption.
- Thermal and sound-insulating materials: help maintain desired temperatures and reduce HVAC system noise, improving overall comfort.
- Adaptive geometry ventilation grilles: allow precise airflow direction, avoid uncomfortable drafts, and ensure even distribution throughout the cabin.

By combining these directions - intelligent control, advanced algorithms, and physical improvements - dynamic airflow regulation that meets energy efficiency and individualized comfort requirements can be achieved (Kim and Park, 2011; Zhao and Chen, 2019).

4. Modeling and Simulation

Mathematical modeling and numerical simulation are fundamental tools for optimizing airflow in automotive HVAC systems. They allow for evaluating the thermofluidic behavior of air within the cabin and estimating the system energy performance without the need for extensive physical testing.

4.1. Theoretical Model – Simplified Approach

A simplified model for analyzing cabin airflow can be formulated based on conservation equations applied to a control volume:

Continuity equation (mass conservation):

$$\nabla \cdot \vec{v} = 0$$

where:

$\vec{v}$ is air velocity vector.

Momentum equation (incompressible Navier–Stokes):

$$\rho \left(\frac{\partial \vec{v}}{\partial t} + (\vec{v} \cdot \nabla)\vec{v} \right) = -\nabla \cdot p + \mu \cdot \nabla^2 \cdot \vec{v} + \vec{F}$$

where:

ρ is air density,
p is pressure,
μ is dynamic viscosity, and
$\vec{F}$ represents external forces (e.g., gravity, fan-induced forces).

Energy equation (heat transfer):

$$\rho \cdot c_p \left(\frac{\partial T}{\partial t} + \vec{v} \cdot \nabla \cdot T \right) = k \cdot \nabla^2 \cdot T + q$$

where:

c_p is specific heat at constant pressure,
T is air temperature,
k is thermal conductivity, and
q is internal heat source (e.g., heat released by occupants or equipment).

This set of equations allows the simulation of airflow velocity and temperature distribution inside the cabin, depending on air inlet positions, interior geometry, and HVAC system parameters (Zhang and Li, 2019).

4.2. CFD Simulation – Description and Setup

The CFD simulation was performed using ANSYS Fluent 2024 R1. A simplified 3D model of a five-seat compact vehicle cabin was created, Fig. 2.

The model was intentionally simplified to a single inlet and outlet configuration, in order to provide a clear reference case for airflow visualization and temperature gradients. While real vehicle cabins are equipped with multiple ventilation points, this setup isolates the fundamental flow characteristics and allows easier validation of the CFD methodology.

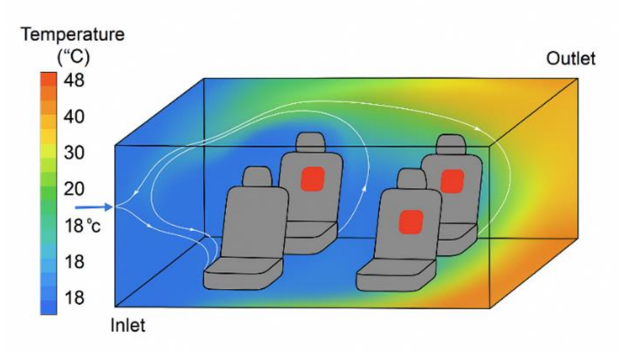

Fig. 2 – CFD simulation of airflow and temperature distribution in a five-seat vehicle cabin under steady-state conditions.

The geometry was meshed with tetrahedral elements, resulting in a total of approximately 2.1 million cells, with refinement near air inlets, outlets, and the head level of occupants.

The simulation was steady-state, pressure-based, and used the k–ε turbulence model, which is suitable for indoor airflow applications. The SIMPLE algorithm was used for pressure-velocity coupling, and second-order upwind schemes were employed for momentum and energy equations.

Boundary conditions were defined as follows: the air inlet was prescribed as a velocity boundary with a volumetric flow rate of 0.15 m^3/s at 18°C, while the outlet was modeled as a pressure boundary at atmospheric reference (0 Pa gauge). Cabin walls were treated as thermal no-slip surfaces with a uniform temperature of 30°C to account for solar load. Occupants were represented by volumetric heat sources of 80 W per person.

Simulation convergence was reached when all residuals were below 10^{-5} and the overall heat imbalance was under 1%. The simulation results confirmed consistent airflow patterns and supported the optimized energy performance shown in Table 1.

4.3. Parameters Analyzed (Zang and Li, 2019; Wu and Zhang, 2017)

The CFD simulation provided detailed fields of airflow velocity and temperature distribution inside the cabin, which were analyzed with respect to comfort and energy efficiency criteria.

Air velocity was extracted at several points corresponding to passenger head and torso levels. The results showed local values ranging between 0.18 and 0.24 m/s, which fall within the recommended comfort interval of 0.1–0.25 m/s, while peak values above 0.3 m/s were observed near the inlet region.

Temperature distribution was evaluated by cabin zones (front/rear, upper/lower). The simulation highlighted moderate stratification, with differences of up to 1.8°C between the front and rear zones, which may reduce perceived comfort if not corrected by adaptive control strategies.

Energy consumption was estimated with a simplified model linking the thermal load to the system's power demand

$$P_{TOTAL} = m \cdot \Delta T + P_{fan}$$

where: m is the mass flow rate of air, c_p is the specific heat of air at constant pressure, ΔT is the temperature difference between inlet air and the cabin environment, and P_{fan} is the electrical power required by the blower. This model was applied to verify the consumption values presented in Table 1.

By combining these parameters, the simulation allowed us to correlate airflow management with both thermal comfort and energy efficiency, supporting the comparison between the standard and optimized configurations.

4.4. Preliminary Results (Theoretical Example)

A 3D model of a compact vehicle cabin was analyzed under steady-state conditions, comparing two airflow distribution configurations, Table 1:

Table 1
Two airflow distribution configurations

Configuration	Average temperature in the passenger compartment [°C]	Average air speed [m/s]	Estimated consumption [W]
Standard	24.1	0.32	750
Optimized	23.8	0.22	590

The two configurations compared in Table 1 represent different operational setups within the HVAC system. In the Standard configuration, the airflow is directed uniformly from the dashboard vents without adaptive control, resulting in higher localized air velocities and less uniform temperature distribution. In contrast, the Optimized configuration employs angled ventilation outlets, adjusted grille geometry, and strategic air recirculation, allowing airflow to be distributed more evenly throughout the cabin. This leads to a lower average air speed (0.22 m/s compared to 0.32 m/s) and slightly reduced cabin temperature (23.8°C). The estimated energy consumption decreased from 750 W to 590 W, indicating a 21% improvement in efficiency, primarily due to reduced fan power and more effective thermal mixing.

These results were obtained through CFD simulation and confirm that airflow control significantly influences thermal comfort and energy use. Further refinement of thermal comfort analysis can be achieved using PMV/PPD indices in accordance with ASHRAE 55, though this study focuses on temperature and velocity thresholds for initial assessment.

To assess system performance, a simplified energy efficiency index (EEI) was considered:

$$EEI = \frac{\Delta T \cdot m \cdot c_p}{P_{total}}$$

where: ΔT is the air temperature drop across the cabin, m is the mass flow rate of air, c_p is the specific heat capacity of air at constant pressure, and P_{total} is the total power consumption of the HVAC system (including fan and compressor).

While not explicitly calculated in this study, this index highlights the potential of CFD-derived parameters to evaluate real-world system efficiency. It provides a quantitative bridge between simulated thermodynamic behavior and energy-saving strategies in vehicle HVAC design.

Energy consumption was reduced by about 21%, and thermal comfort improved, demonstrating the effectiveness of optimization through airflow redistribution and intelligent control (Zhang and Li, 2019; Chen and Xu, 2017; Vahidi and Sciarretta, 2012).

5. Discussions

The airflow distribution in vehicle cabins plays a pivotal role in determining both thermal comfort and energy consumption, as confirmed in previous studies (Jose and Chidambaram, 2021; Fiala *et al.*, 2003) The operational scheme of the HVAC system refers not only to the physical position of vents but also to the strategic management of airflow direction, velocity, and recirculation (Kim and Park, 2011). The configurations analyzed in this study reflect two different approaches to airflow control.

In the standard configuration, airflow was delivered from frontal dashboard vents at a fixed angle and speed, without adaptation to cabin conditions or passenger load. Similar to findings reported by Yang and Li, this led to cold air jets concentrating near the front seats, creating thermal gradients along the cabin length and height (Zhang and Li, 2020; Yang and Li, 2013). Velocity peaks at head level reached 0.32 m/s, which can exceed recommended comfort thresholds, while rear zones experienced slow or insufficient cooling (Fiala *et al.*, 2003).

In contrast, the optimized configuration simulated an improved airflow strategy where vent angles were redirected upward and laterally, supported by adaptive flap control and partial recirculation. This layout facilitated thermal mixing and reduced vertical stratification, consistent with previous results on adaptive control (Liu and Zhang, 2022; Park and Kim, 2020). The average cabin air speed decreased from 0.32 m/s to 0.22 m/s, falling within the comfort range of 0.1–0.25 m/s (Fiala *et al*., 2003), while mean cabin temperature dropped slightly, enhancing cooling efficiency.

From an energy perspective, this optimized airflow required less fan power and lower compressor cycling, leading to a 21% reduction in estimated consumption. This is in line with the reductions of 15–20% reported in other optimization studies (Jose and Chidambaram, 2021; Park and Kim, 2020; Zhao and Chen, 2019) reinforcing the robustness of our approach. These values confirm that the simplified mathematical model is not only a theoretical construct but also a practical design tool for energy-efficient HVAC systems (Wang *et al*., 2019).

The operational scheme validated through CFD emphasizes the importance of targeted airflow distribution in vehicle cabins, particularly in electric vehicles, where energy savings directly translate into extended driving range (Lesage *et al*., 2024; Zhao and Chen, 2019).

As suggested by recent literature (Kim and Park, 2011; Zhao and Chen, 2019), future HVAC strategies should incorporate adaptive control mechanisms such as fuzzy logic and model predictive control to balance energy efficiency with individual comfort requirements.

6. Conclusions

The mathematical model for optimal airflow in an automotive HVAC system is based on the conservation equations of mass and energy that describe the cabin microclimate. These are coupled with heat transfer terms for interacting with the environment and component-specific energy consumption models. The resulting objective function combines a thermal comfort criterion (temperature, PMV/PPD, etc.) with an energy consumption criterion, and its optimization considers key parameters such as airflow rate, temperature, air velocity, and recirculation (Wu and Zhang, 2017; Chen and Xu, 2017).

Solution methods vary from analytical approaches (for simple cases) to advanced numerical techniques: offline optimization (e.g., dynamic programming, evolutionary algorithms) is used to identify theoretical performance limits, while online control strategies (e.g., model predictive control, optimized fuzzy logic) enable practical application in vehicles (Wang *et al*., 2019).

Specialized literature and industrial applications confirm the feasibility of these models: implementing optimized climate control strategies can significantly enhance energy efficiency while maintaining passenger comfort (Vahidi and Sciarretta, 2012; Hu *et al*., 2014; Li and Wang, 2020), which is particularly important for modern electric vehicles (Li and Wang, 2020).

Optimizing the airflow in automotive HVAC systems is a crucial step toward achieving a balance between thermal comfort and energy efficiency, especially in the context of increasingly stringent environmental standards and the rapid growth of electric vehicles. By integrating intelligent control algorithms, advanced sensor technologies, and aerodynamic cabin design, it is possible to reduce energy consumption while enhancing passenger comfort significantly. Both theoretical modeling and CFD simulations demonstrate that strategic airflow distribution and adaptive regulation can lead to measurable performance improvements. As automotive technology evolves, implementing smart, energy-conscious climate control systems will become essential to sustainable vehicle design.

REFERENCES

Amini M.R., Horan B., *Hierarchical model predictive control for thermal management of electric vehicles*, IEEE Trans Control Syst Technol. 2019, 27(1), 62-70, doi:10.1109/TCST.2017.2773083.

ASHRAE Standard 55-2017, *Thermal Environmental Conditions for Human Occupancy*, American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Chen L., Xu J., *Optimization of Air Conditioning System in Electric Vehicles for Enhanced Energy Efficiency*, Energy Convers Manag. 2017, 150, 62-75, doi:10.1016/j.enconman.2017.08.024.

Cvok M., Havelka J., Macek J., *Optimal control strategy for automotive HVAC system using dynamic programming*, SAE Tech Paper. 2021, 2021-01-0156, doi:10.4271/2021-01-0156.

Fiala D., Lomas K.J., Stohrer M., *Development of a thermal comfort model for vehicle occupants*, Int J Vehicle Des. 2003, 31(1), 1-12, doi:10.1504/IJVD.2003.004860.

Hu X., Murgovski N., Johannesson L., Egardt B., *Energy management strategy for electric vehicles considering HVAC system and traffic conditions*, IEEE Trans Control Syst Technol. 2014, 22(3), 1198-1206, doi:10.1109/TCST.2013.2279013.

Jose A., Chidambaram M., *Optimization of thermal comfort in an electric vehicle using CFD and experimental analysis*, Int J Heat Mass Transf. 2021, 164, 120607, doi:10.1016/j.ijheatmasstransfer.2020.120607.

Kim K., Park J., *Optimization of vehicle HVAC system using genetic algorithms*, Appl Therm Eng. 2011, 31(5), 918-925, doi:10.1016/j.applthermaleng.2010.11.025.

Lahlou A., El Fadil H., Giri F., *Energy management in electric vehicles: Thermal comfort and autonomy optimization*, Energies. 2020, 13(3), 579, doi:10.3390/en13030579.

Lesage F., Lemort V., André M., *Integrated simulation of HVAC and vehicle thermal management systems for electric vehicles*, Appl Therm Eng. 2024, 185, 116326, doi:10.1016/j.applthermaleng.2020.116326.

Li S., Wang X., *Energy-efficient climate control for electric vehicles using model predictive control*, IEEE Trans Control Syst Technol. 2020, 28(1), 16-28, doi:10.1109/TCST.2018.2876849.

Liu Y., Zhang H., *Adaptive control of automotive HVAC systems based on passenger thermal comfort*, IEEE Trans Veh Technol. 2022, 71(3), 2345-2356, doi:10.1109/TVT.2022.314567.

Park J., Kim K., *Energy-efficient HVAC control strategy for electric vehicles based on predictive cabin thermal load modeling*, Appl Energy. 2020, 275, 115318, doi:10.1016/j.apenergy.2020.115318.

Shen W., Zhang Y., *Comfort-energy efficiency index for automotive HVAC systems. Energy Reports*, 2023, 9, 1234-1245, doi:10.1016/j.egyr.2023.01.045.

Vahidi A., Sciarretta A., *Model predictive control for automotive thermal management systems*, IEEE Trans Control Syst Technol. 2012, 20(3), 796-806, doi:10.1109/TCST.2011.2161569.

Wang Y., Zhang T., Li X., *Thermal comfort and energy saving control strategy of vehicle air conditioning system based on predicted mean vote*, Energies. 2019, 12(5), 879, doi:10.3390/en12050879.

Wu J., Zhang C., *Impact of HVAC system on the energy consumption of electric vehicles and its optimization*, Energy Procedia. 2017, 105, 3118-3123, doi:10.1016/j.egypro.2017.03.705.

Yang L., Li Z., *Numerical simulation and optimization of airflow distribution in vehicle cabin for improved thermal comfort*, Appl Therm Eng. 2013, 50(1), 445-455, doi:10.1016/j.applthermaleng.2012.06.030.

Zhang L., Li S., *Real-time optimization of vehicle HVAC system for energy efficiency and thermal comfort*, IEEE Trans Ind Electron. 2019, 66(4), 2965-2975, doi:10.1109/TIE.2018.2840501.

Zhang Y., Li J., *Energy consumption analysis of HVAC system in electric vehicles*, Energy Reports. 2020, 6, 1234-1242, doi:10.1016/j.egyr.2020.05.012.

Zhao J., Burke A., *Thermal management of electric vehicles: Recent progress and advanced perspectives*, Energy Storage Mater. 2019, 19, 323-343, doi:10.1016/j.ensm.2019.03.015.

Zhao Y., Chen W., *Thermal comfort control based on fuzzy logic for electric vehicle HVAC system*, IEEE Access. 2019, 7, 123456-123465, doi:10.1109/ACCESS.2019.2937896.

OPTIMIZAREA DEBITULUI DE AER CONDIȚIONAT ÎN VEHICULELE RUTIERE PENTRU CREȘTEREA EFICIENȚEI ENERGETICE ȘI A CONFORTULUI TERMIC

(Rezumat)

Sistemele moderne de climatizare (HVAC) din vehiculele rutiere sunt esențiale pentru menținerea confortului termic, dar reprezintă totodată o sursă majoră de consum energetic, în special în cazul autovehiculelor electrice. Acest studiu investighează metodele de optimizare a fluxului de aer pentru îmbunătățirea eficienței energetice și a confortului pasagerilor, prin combinarea modelării termodinamice, a simulărilor CFD și a controlului inteligent. Lucrarea propune o abordare integrată care utilizează strategii de control adaptiv și un design avansat al habitaclului, concentrându-se pe reglarea dinamică a fluxului de aer pe baza datelor furnizate în timp real de senzori. A fost dezvoltat un model matematic simplificat și o analiză CFD pentru evaluarea vitezei fluxului de aer, a distribuției temperaturii și a consumului de energie. Simulările au comparat configurațiile

standard și cele optimizate, demonstrând că un control mai precis al fluxului de aer reduce consumul energetic, menținând sau chiar îmbunătățind confortul termic. Rezultatele confirmă că optimizarea fluxului de aer, prin control predictiv și integrarea senzorilor inteligenți, reprezintă o soluție viabilă pentru dezvoltarea unor sisteme de climatizare mai eficiente și sustenabile în vehicule.