DESIGN AND TESTING OF CO_2 CONCENTRATION CONTROL SYSTEM IN HYUNDAI ACCENT CAR

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GENERAL INFORMATION

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KEYWORD

CO_2 control;

CO_2 poisoning in car;

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Air quality in cars;

CO_2 ratio.

ABSTRACT

This study focused on the development of a CO_2 concentration control system for automobiles to enhance user safety. Drivers often use an air conditioning system in recirculation mode for extended periods, leading to elevated CO_2 levels in the cabin, which poses a risk of gas poisoning and health issues. The author designed and tested a system that employs sensors to monitor CO_2 levels continuously. Unlike previous studies, this system integrates automatic ventilation controls and window operations to maintain a safe cabin environment. The study also examined potential gas poisoning scenarios and assessed the system's effectiveness in mitigating these risks. The results indicated a significant reduction in CO_2 levels through measures such as adjusting air intake modes and lowering windows. This research not only offers technological solutions but also raises awareness about the health safety of air conditioning users. These findings promise practical improvements to the automotive industry, ensuring safer travel for users.

1. INTRODUCTION

In the context of increasingly complex and hazardous traffic conditions, consumer concerns regarding car safety are paramount. Modern consumers prioritize not only aesthetic design and engine performance but also health safety and life protection in the event of a collision. Safety technologies, such as automatic braking systems, blind spot warnings, airbags, and driver assistance systems, have become critical factors in car selection. Additionally, global safety standards such as Euro NCAP and IIHS significantly influence purchasing decisions. Emphasizing safety not only protects users' health but also reflects the automotive industry's commitment to reducing accidents and safeguarding the community.

A key health and safety concern for consumers is the CO_2 concentration inside the vehicle. Health organizations, including the World Health Organization (WHO) and Vietnamese Ministry of Health, recommend that CO_2 levels in indoor environments should not exceed 1,000 ppm. Measurement should be implemented to reduce CO_2 concentrations in enclosed spaces, particularly those where many people gather. Studies have shown that varying CO_2 levels can negatively affect human health. For instance, CO_2 concentrations of 1,000 ppm or higher can impair cognitive performance and decision-making abilities (Azuma et al., 2018). Other studies have linked CO_2 levels as low as 1,000 ppm to inflammation, reduced cognitive abilities, bone loss, kidney stones, oxidative stress, and endothelial dysfunction (Jacobson et al., 2019).

Some studies suggest that adverse effects may occur even at lower CO_2 levels. For example, respiratory symptoms have been reported in children exposed to indoor CO_2 concentrations above 1,000 ppm (Azuma et al., 2018). Additionally, CO_2 exposure as low as 700 ppm is associated with building-related symptoms (Azuma et al., 2018). Although no specific threshold has been universally established for indoor air quality, CO_2 concentrations of 700–1,000 ppm or higher are known to potentially harm human health. Further research is needed to understand the long-term effects of low-level CO_2 exposure, especially in enclosed environments, such as automobiles (Azuma et al., 2018).

Table 1. Classification of CO_2 concentration effects (Goh et al., 2021).

CO_2 **(ppm)**	**Five levels of influence**
C_{low} - C_{high}	
340-600[a]	Good
601-1000[b]	Moderate
1001-1500	Unhealthy for sensitive group
1501-2500[a]	Unhealthy
2501-5000[c]	Very unhealthy

Based on previous studies, there is clear evidence of the negative impact of the CO_2 concentration in the vehicle cabin on human health. Therefore, it is necessary to limit the impact and warn of the CO_2 concentration in vehicles. Some studies have addressed this issue, such as building an in-vehicle air quality monitoring system that allows direct transmission of air quality data to a mobile application for monitoring (Goh et al., 2021). Another study evaluating the CO_2 concentration in a vehicle cabin showed that when the ventilation system was set to recirculation mode, the CO_2 concentration could increase to over 800 ppm within 10 min in all tested vehicles (Jung, 2013). In general, previous studies have mainly focused on the warning of current CO_2 levels in the cabin without providing specific solutions to reduce the CO_2 concentration in the vehicle. The new point in this study is that the author has established a system that directly intervenes in controlling the operation of the wind mode on the air conditioner and the window-lift system to control the increase in CO_2 concentration in the car cabin.

In summary, while most previous studies have focused on assessing the air quality in offices, public places, or indoor environments, this study aimed to measure the CO_2 concentration in car cabins and evaluate the associated health risks under various conditions. The author will conduct experiments to gather data on CO_2 levels and assess air quality. Based on the experimental results, the author will develop and calibrate control methods for the CO_2 control system to ensure optimal operation and minimize the risk of poor air quality in vehicles. Implementing this system will enhance safety, reduce the risk of CO_2-related health issues and accidents, and improve passenger comfort by maintaining an optimal air quality. Additionally, it will raise awareness about the importance of proper ventilation and help meet the evolving safety standards in the automotive industry.

2. RESEARCH METHODOLOGY

2.1. System Model Used in the Study

2.1.1. Equipment Used in the Experimental

- The CO_2 gas sensor utilized in this study was the MH-Z19B NDIR module, which has a measurement range of up to 5000 ppm and an accuracy of ± (50 ppm + 3% of the measured value). It operates at a voltage of 5V and within the temperature range of 0–50°C.

- The Arduino R3 controller was programmed to implement the most optimal control method.
- The PIR infrared sensor module, HC-SR501, was incorporated into the system to detect human presence.

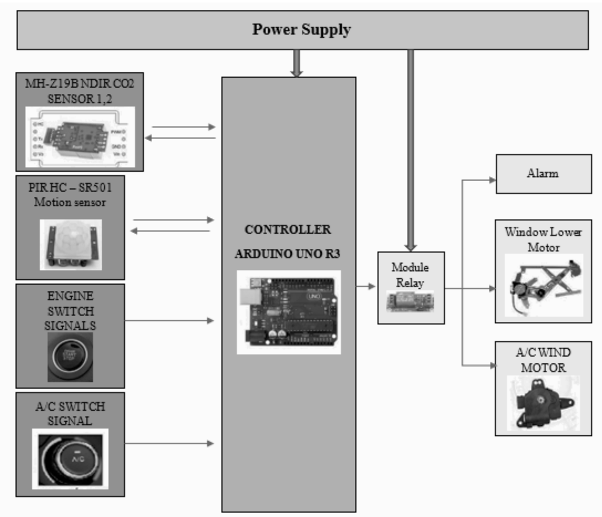

Figure 1. Block diagram of the "CO_2 Concentration Control System"

A system model for measuring and controlling the CO_2 concentration in a car (Figure 2) was utilized in this research to enhance air quality and improve the health of drivers and passengers.

Sensor Installation Plan: Given that CO_2 is approximately 1.52 times denser than air, it tends to settle in the lower layers of the car's interior. Therefore, an optimal sensor arrangement is crucial for accurate CO_2 measurement. The author was positioned the CO_2 sensor at the air outlet vents near the floor of the air conditioning system of the car, ensuring effective data collection with minimal interference.

2.1.2. Operating Principle of the CO_2 Control System in Vehicles

This study proposes a model for a CO_2 concentration control system in a vehicle using an Arduino controller and applying a fuzzy-control algorithm. To implement fuzzy logic, the input variable was defined as the CO_2 concentration measured from the sensor. The CO_2 concentration was chosen as the control threshold for the system, based on the results of several studies. Specifically, one study has shown that CO_2 concentrations of 1500-2500 ppm can significantly impair cognitive performance and the ability to perform complex decision-making tasks (Allen et al., 2015). Another study has also shown that human exposure to CO_2 concentrations ranging from 2000 ppm to 5000 ppm can lead to mild negative effects on cognitive function (Satish et al., 2012). Based on these results, the author concluded that allowing the CO_2 concentration in the vehicle cabin to exceed 2000 ppm will affect the health and safety of the driver. Therefore, we set a threshold of 2000 ppm to activate the CO_2 control system.

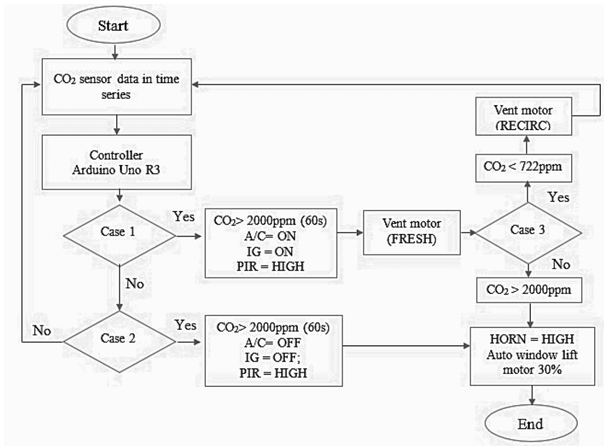

Figure 2. Control logic diagram of CO_2 concentration control system

Case 1: Engine Running and Air Conditioning System Active When the MH-Z19B sensor detects CO_2 levels above 2000 ppm and the PIR infrared sensor confirms human presence. The CO_2 control system activated the air intake motor to switch to the outside air intake mode for 7 min. The system then re-checked the CO_2 levels. If the levels remain above 2000 ppm, the outside air intake mode continues for an additional 60 s. If the CO_2 levels drop 700 ppm, the system reverts to the recirculation mode, as initially set by the driver. If the outside air intake mode fails, the system lowers the windows to ensure that the CO_2 levels remain safe.

Case 2: Engine Off-Air Conditioning System Inactive If CO_2 levels rise owing to factors such as human presence, fire, explosion, or exhaust gas leaks, and the PIR sensor detects people in the car, an alarm is triggered to warn the occupants. If CO_2 levels continue to rise above 3000 ppm after 5 min, the Arduino controller lowers the windows by approximately 30% to allow outside air to enter, reduce CO_2 levels, and mitigate health risks.

2.2. Experimental Description

Vehicle: The experiment used a Hyundai Accent 2022 AT with a cabin air volume of approximately 4.4 m³. The experiment involved a person seated in a driver's seat.

Location: The experiment was conducted outdoors with a stationary vehicle. The experiments were performed in the morning, between 07:00 and 12:00. Experimental Scenarios: The author conducted experiments under various conditions, including internal air intake modes, switching to external air intake, and open or closed windows.

2.2.1. Experimental Scenarios

Internal Air Intake (RECIRC): The initial conditions were set with the air conditioning system in the RECIRC mode, one person in the car, an average cabin temperature of 27°C, and the fan speed at the lowest setting. The author measured and collected data on the gradual increase in CO_2 concentration in the cabin.

External Air Intake (FRESH): This experiment was conducted with the car doors fully closed, air conditioning system in FRESH mode, fan speed at the lowest setting, and average temperature of 27°C. The initial CO_2 concentration was approximately 2090 ppm. The purpose was to measure the gradual decrease in CO_2 concentration and evaluate air quality improvement when the control system was active.

Open Windows: This test was performed with the engine off, the air conditioning system inactive, one person in the car, and the doors initially closed. The CO_2 control system was set to lower the front windows by 30% when the CO_2 concentration reached approximately 2100 ppm. This test evaluated the effectiveness of lowering windows to improve air quality.

The CO_2 concentration data for these scenarios were collected using an MH-Z19B sensor over a period of 20–40 min. The data were sent to the Arduino R3 control module, converted to a serial format, and transmitted to the computer's COM port. Real-time data were collected every second. Microsoft Visual Studio 2022 was used to collect and save the data in Excel for analysis. These data were used to calibrate and optimize the CO_2 control system.

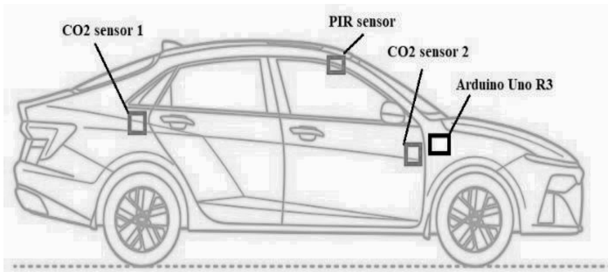

Figure 3. Device Layout Diagram on the Hyundai Accent 2022

2.2.2. Processing data from sensors

To ensure the accuracy of CO_2 concentration measurements in the car cabin, two sensors were employed to collect data, which were then sent to the Arduino controller. The average value of the real-time data from both sensors was used by the Arduino to control the actuators.

$$x_{i(TX)} = \frac{x_{i(2)} + x_{i(1)}}{2} \quad (1)$$

in which

$x_{i(TX)}$ is the CO_2 value used for the control at the (i)th second,

$x_{i(1)}$ is the CO_2 value measured by sensor 1 in the (i)th second,

$x_{i(2)}$ is the CO_2 value measured by sensor 2 at the $(i)^{th}$ second.

An average calculation was also used to determine the CO_2 concentration outside the vehicle. This was based on consecutive measurements taken every second over a 15-minute period during the experiment. This average value is utilized to set up and calibrate the CO_2 control system, and serves as a benchmark for evaluating the performance of the system.

$$Mean_{NX} = \frac{\sum_{i=1}^{900} x_{i(nx)}}{900} \approx 722\,ppm \qquad (2)$$

in which $Mean_{NX}$ is the average value of CO_2 ratio outside the vehicle

3. RESULTS AND DISCUSSIONS

3.1. RECIRC mode

Data on CO_2 concentration measurements inside the car were collected and processed, resulting in graphs that illustrate the changes in CO_2 levels.

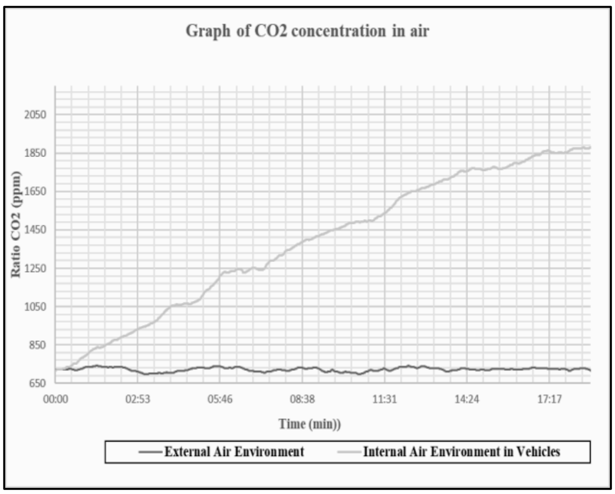

Figure 4. Graph of CO_2 ratio in the car when in RECIRC mode

The graph in Figure 4 shows a rapid increase in CO_2 levels when the air conditioner was set to recirculation mode. Over a 20-minute period, the CO_2 levels rose from 719 ppm to approximately 2000 ppm. Studies have indicated that prolonged exposure to CO_2 levels between 1000 and 3000 ppm can negatively impact on cognitive health (Zhang et al., 2016). The experimental results highlighted the potential health risks associated with continuously increasing CO_2 levels. It is important to note that the data were collected from one person in the car; with more occupants, the CO_2 levels would rise even faster. Addressing the rapid increase in CO_2 levels is crucial.

3.2. Switching to FRESH mode

To mitigate the rise in CO_2 levels, the author proposed switching the air conditioning system from RECIRC to FRESH air intake mode.

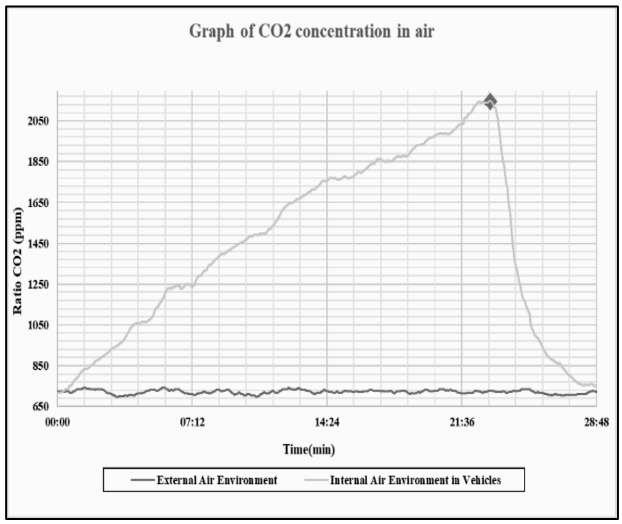

Figure 5. Graph of CO_2 ratio measured in the car when switching to FRESH mode

As shown in Figure 5, when the CO_2 control system switched the air intake mode from RECIRC to FRESH at 23 min and 27 s (with CO_2 levels at 2093 ppm), the CO_2 levels began to decrease rapidly.

Table 2. CO_2 ratio values measured in the car during the experiment.

	RECIRC		**FRESH**	
Measured CO_2 ratio (ppm)	719	2101	2093	756
Measurement time (minutes)	0.01	23.26	23.27	29.26

Based on the data in Table 2, it is evident that within just 6 min of switching the air intake mode from RECIRC to FRESH, the air quality in the car significantly improves. The CO_2 levels, which were previously at hazardous levels, decreased to approximately 756 ppm, which is which is a safe level. With the FRESH mode control method in approximately 6 min, the system helped reduce the CO_2 ratio in the cabin by approximately 64% compared to the original. This demonstrates that by configuring the CO_2 control system to switch the air intake mode of the air conditioning system, it is possible to enhance the air quality in the car and mitigate the health risks for the occupants.

3.3. Window down mode

The measurement results of this method are shown in Fig.6.

Figure 6. Graph of CO_2 levels in the car when the window is lowered

From the graph in Figure 6, it can be observed that the CO_2 levels in the car changed as follows: Initially, the CO_2 level started at 873 ppm and gradually increased because of the occupants' exhalation, reaching 2117 ppm after 16 min and 13 s. According to Table 1, this level of air quality is detrimental to human health if the exposure is prolonged. To avert potential dangers, the control system activated a warning bell and lowered the two front windows by 30% at 16 min and 14 s.

Table 3. CO_2 levels in the car measured when lowering the windshield

	Fully closed windshield		**Lowered windshield 30%**		
Measured CO_2 ratio (ppm)	873	2117	2108	1066	1052
Measurement time (minutes)	0,01	16,13	16,14	37,14	40,26

Upon lowering the two front windows by 30%, the CO_2 levels began to decrease, reaching 1066 ppm at 37.14 minutes. However, this reduction is not steady because the air quality depends on the amount of air entering the front doors. Between 37.14 and 40.26 minutes, the CO_2 levels fluctuate between 1066 and 1052 ppm, as shown in Table 3. This fluctuation can be attributed to the balance between the incoming outside air and CO_2 from human breath. At approximately 1000 ppm, this level does not significantly impact on the health of car occupants (Fan et al., 2023). Although this method helps control the CO_2 levels, it is slower than the FRESH mode and should be used as a backup when the FRESH mode is unavailable.

The window-lowering control method reduced the CO_2 concentration in the cabin by approximately 50% compared with the initial level within 21 min. However, compared with the FRESH mode, the time required to achieve CO_2 control was longer. In addition, lowering the car window also poses some risks, such as affecting the safety of the children in the car and the security of the vehicle. Therefore, this method should only be applied as a backup measure when the FRESH mode of the air-conditioning system cannot be implemented.

Overall, the experimental results indicate the positive impact of the CO_2 control system in cars, effectively reducing CO_2 levels and enhancing the safety and health of occupants. Additionally, the study highlights the common misconception that using an air conditioning system in the RECIRC mode for extended periods does not affect health. This underscores the importance of monitoring the air quality in cars. Integrating CO_2 control systems with car air-conditioning systems can also prevent accidents, particularly for children left in cars.

4. CONCLUSION

In this study, we developed a CO_2 concentration control system for vehicles that significantly reduces the risk of carbon dioxide poisoning for occupants. The author conducted experiments on the system's operation, utilizing control solutions such as switching to the FRESH outside air intake mode and controlling the lowering of the car windows. The experimental results demonstrated the effectiveness of the system in rapidly reducing CO_2 levels inside the vehicle. The method of controlling the intake of outside air through an air conditioning system proved to be more effective in reducing CO_2 levels and was selected as the primary control solution. Additionally, the experiment showed that lowering the windows also improved air quality, although this method takes longer and depends on the external wind speed, making it a backup solution if the air intake motor fails. The research findings demonstrated a significant reduction in CO_2 concentration within the car cabin through various methods, such as modifying the air intake of the air conditioning system, which led to a 64% decrease in CO_2 levels. Additionally, lowering the car window resulted in a 50% reduction in the CO_2 concentration.

In conclusion, integrating a CO_2 control system with a car's air conditioning system is crucial as it holds considerable potential for improving air quality and safeguarding the health of occupants. While the CO_2 control system offers numerous benefits, it also presents certain limitations, including a potential slowdown in the cooling efficiency of air-conditioning systems. Furthermore, lowering the window to reduce CO_2 levels, although effective, may raise concerns regarding travel safety and risk of theft. Nevertheless, in terms of protecting driver health, this option remains a valuable solution.

The next phase of this research will focus on enhancing the system's accuracy by transitioning to a more powerful microcontroller such as ESP32 (Espressif). This microcontroller supports Wi-Fi and Bluetooth connectivity, which makes it ideal for IoT applications. With a 32-bit processor, the ESP32 is capable of running more advanced algorithms than the Arduino, opening up new possibilities for CO_2 control systems. These include the integration of additional features such as anti-theft measures, child alarms, and air quality monitoring via a mobile application. In the future, the author aims to enhance the applicability of this research by testing the system across a range of vehicle models under various operational conditions.

REFERENCES

Allen, J.G.; Macnaughton, P.; Satish, U.; Santanam, S.; Vallarino, J.; Spengler, J.D. Associations of Cognitive Function Scores with Carbon Dioxide, Ventilation, and Volatile Organic Compound Exposures in Office Workers: A Controlled Exposure Study of Green and Conventional Office Environments. Environ. *Health Perspect*. 2016, 124, 805–812. https://doi.org/10.1289/ehp.1510037.

Goh, C.C.; Kamarudin, L.M.; Zakaria, A.; Nishizaki, H.; Ramli, N.; Mao, X.; Syed Zakaria, S.M.M.; Kanagaraj, E.; Abdull Sukor, A.S.; Elham, M.F. Real-Time In-Vehicle Air Quality Monitoring System Using Machine Learning Prediction Algorithm. *Sensors*. 2021, 21, 4956. https://doi.org/10.3390/s21154956.

Azuma, K., Kagi, N., Yanagi, U., & Osawa, H. (2018). Effects of low-level inhalation exposure to carbon dioxide in indoor environments: A short review on human health and psychomotor performance. *Environment International*, 121(Pt 1), 51–56. https://doi.org/10.1016/j.envint.2018.08.059.

Jacobson, T. A., Kler, J. S., Hernke, M. T., Meyer, K. C., Funk, W. E., & Braun, R. K. (2019). Direct human health risks of increased atmospheric carbon dioxide. *Nature Sustainability*, 2(8), 691–701. https://doi.org/10.1038/s41893-019-0323-1.

Zhang, X., Lian, Z., Wargocki, P., & Thyregod, C. (2016). Effects of exposure to carbon dioxide and bioeffluents on perceived air quality, self-assessed acute health symptoms, and cognitive performance. *Indoor Air*, 27(1), 47–64. https://doi.org/10.1111/ina.12284.

Fan, Y., Cao, X., Zhang, J., Lai, D., & Pang, L. (2023). Short-term exposure to indoor carbon dioxide and cognitive task performance: A systematic review and meta-analysis. Building and Environment, 237, 110331. https://doi.org/10.1016/j.buildenv.2023.110331.

Jung, H. (2013, April 8). *Modeling CO_2 Concentrations in Vehicle Cabin*. https://doi.org/10.4271/2013-01-1497

Satish, U., Streufert, S., Hotchi, T., Fisk, W. J., Shekhar, K., Mendell, M. J., & Sullivan, D. (2012). Is CO_2 an Indoor Pollutant? Direct Effects of Low-to-Moderate CO_2 Concentrations on Human Decision-Making Performance. *Environmental Health Perspectives*, *120*(12), 1671–1677. https://doi.org/10.1289/ehp.1104789.

THIẾT KẾ VÀ THỬ NGHIỆM HỆ THỐNG KIỂM SOÁT NỒNG ĐỘ KHÍ CO_2 TRONG XE Ô TÔ HYUNDAI ACCENT

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THÔNG TIN CHUNG

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TÓM TẮT

Nghiên cứu này tập trung vào việc phát triển hệ thống kiểm soát nồng độ CO_2 cho ô tô để tăng cường sự an toàn cho người dùng. Người lái xe thường sử dụng hệ thống điều hòa không khí ở chế độ tuần hoàn trong thời gian dài, dẫn đến nồng độ CO_2 trong cabin tăng cao, gây ra nguy cơ ngộ độc khí và các vấn đề về sức khỏe. Tác giả đã thiết kế và thử nghiệm một hệ thống sử dụng các cảm biến để liên tục theo dõi nồng độ CO_2. Không giống như các nghiên

TỪ KHOÁ

Kiểm soát CO_2;

Ngộ độc CO_2 trong xe;

Chế độ lấy gió điều hòa;

Chất lượng khí trên xe;

Tỉ lệ khí CO_2.

cứu trước đây, hệ thống này tích hợp các điều khiển thông gió tự động và hoạt động của cửa sổ để duy trì môi trường cabin an toàn. Nghiên cứu cũng xem xét các tình huống ngộ độc khí tiềm ẩn và đánh giá hiệu quả của hệ thống trong việc giảm thiểu những rủi ro này. Kết quả cho thấy nồng độ CO_2 giảm đáng kể thông qua các biện pháp như điều chỉnh chế độ lấy gió và hạ thấp cửa sổ. Nghiên cứu này không chỉ đưa ra các giải pháp công nghệ mà còn nâng cao nhận thức về an toàn sức khỏe của người sử dụng điều hòa không khí. Những phát hiện này hứa hẹn những cải tiến thiết thực cho ngành công nghiệp ô tô, đảm bảo việc di chuyển an toàn hơn cho người dùng.