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Computational Fluid Dynamics Evaluation of Nitrogen and Hydrogen for Enhanced Air Conditioning Efficiency

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Abstract: This study evaluates the potential of nitrogen and hydrogen as alternative working fluids in air conditioning systems to improve thermal comfort and optimize energy efficiency, using computational fluid dynamics (CFD) simulations. A controlled indoor environment measuring 6 m × 4.5 m × 3 m was simulated, with nitrogen and hydrogen tested at inlet velocities of 0.7 m/s, 0.8 m/s, 0.9 m/s, 1.0 m/s, and 1.1 m/s, and an inlet temperature fixed at 293 K (20℃). The analysis focused on the impact of these gases on room and outlet temperatures to assess airflow distribution, heat transfer, and thermal comfort compared to traditional air-based systems. Results indicated that nitrogen improved airflow uniformity and facilitated heat transfer but exhibited limitations in effectively reducing room temperature due to its thermal properties. In contrast, hydrogen demonstrated stable outlet temperatures across all velocities, benefiting from its higher thermal conductivity; however, room temperatures showed significant variation, particularly at higher inlet velocities. Temperature prediction errors in the CFD model ranged from 0.003% to 2.78%, suggesting high accuracy yet underscoring the need for refinement in simulation methods. The findings highlight the promise of nitrogen and hydrogen in optimizing air conditioning system performance but emphasize the necessity for further investigation into the practical implications, specifically regarding operational safety, energy efficiency, and environmental impacts.

Keywords: Alternative refrigerants; Thermal comfort; Computational fluid dynamics; Energy efficiency; Nitrogen, Hydrogen

1 Introduction

Recent advancements in air conditioning technology have sparked interest in alternative gases, such as hydrogen and nitrogen, which boast unique thermal properties. Hydrogen-based heat pumps have significantly improved energy efficiency by harnessing hydrogen's high thermal conductivity and specific heat capacity, enabling more efficient heat transfer and cooling performance than traditional air [1, 2]. Nitrogen, naturally abundant in the air, offers potential optimization in air conditioning systems due to its higher density, which helps regulate more stable airflow and improves heat dissipation and even temperature distribution. These promising characteristics of hydrogen and nitrogen hint at a bright future for air conditioning technology.

Hydrogen and nitrogen gases possess distinct characteristics that affect their ability to cool and maintain desired room temperatures. Hydrogen's lower molecular weight facilitates rapid heat transfer, leading to faster cooling rates, while nitrogen's higher density ensures smoother air circulation and uniform temperature reduction. These factors make hydrogen and nitrogen promising candidates for enhancing energy efficiency and thermal comfort in modern cooling systems [1].

CFD simulations have become essential tools for assessing these properties, providing precise modeling of airflow patterns, temperature distribution, and fluid behavior in air conditioning systems. CFD allows for identifying inefficiencies and enhancing system performance by offering detailed insights into the fluid flow and heat transfer dynamics [1]. Despite the benefits, safety concerns around hydrogen's flammability and potential leakage must be addressed. Hydrogen is highly flammable and can form explosive mixtures with air, making it a safety risk in case of leaks. However, these risks can be mitigated with proper ventilation and leak detection systems, and buoyancy-driven ventilation strategies have been proposed to reduce these potential hazards further [3]. In contrast, nitrogen presents fewer safety risks, making it a more practical choice for air conditioning systems in many situations.

The increase in global temperatures, driven by climate change, has led to a growing demand for optimizing indoor environments to achieve thermal comfort while minimizing energy consumption [2]. Air conditioning systems control building temperature, humidity, and air quality [3]. Traditionally, air, composed primarily of nitrogen and oxygen, has been the standard medium used in these systems. However, fluid dynamics and environmental engineering advancements have opened up new possibilities to explore alternative gases, such as pure nitrogen and hydrogen, which possess unique thermal properties and may improve system efficiency and environmental sustainability [4]. Using alternative gases in air conditioning systems can potentially reduce greenhouse gas emissions and contribute to the fight against climate change, making it an essential area of research for environmental engineers and sustainability professionals. This study seeks to address the limitations of previous research on alternative gases in cooling systems by incorporating new approaches not widely applied in the field. Through innovations in research methodology and advanced measurement technology, this study aims to provide more accurate and in-depth findings on the thermal performance of alternative gases in cooling systems. By doing so, it not only enhances the understanding of energy efficiency but also contributes specifically to the development of environmentally friendly cooling systems [5–7].

This study focuses on simulating the behavior of three breathable gases—air, nitrogen, and hydrogen—each examined at five different velocities: 0.7 m/s, 0.8 m/s, 0.9 m/s, 1 m/s, and 1.1 m/s. The inlet temperature for the air conditioning system was set at 293 K (20°C), a standard operational value for cooling applications [8–11]. These specific inlet velocities were chosen to reflect conditions typically in real-world air conditioning systems. Air speeds within this range are commonly used to balance effective cooling and energy efficiency. By testing these velocities, the study aims to replicate practical air conditioning scenarios and evaluate the performance of each gas under realistic conditions. Analyzing the effects of different gases at various flow rates is critical for assessing their potential to improve indoor climate control [12]. Each gas exhibits distinct physical properties, such as thermal conductivity, specific heat capacity, and density, which impact air distribution patterns, cooling efficiency, and the overall comfort experienced by occupants [13].

One of the key objectives of this study is to compare the results of the proposed in-house CFD simulations with those produced by ANSYS Fluent, a widely used tool for modeling fluid dynamics and heat transfer [14]. The simulations performed in this study utilize geometry and mesh files obtained from the official ANSYS website, ensuring consistency between the proposed simulation setup and the industry-standard simulations provided by ANSYS. Using the same mesh geometry, this comparison aims to quantify discrepancies or errors between the two approaches, ensuring the results are reliable and accurate [15].

Another essential objective of the study is to evaluate the temperature differences between the outlet of the air conditioning system and the ambient room temperature. This difference is a critical metric for assessing the cooling performance of the system and its ability to maintain optimal thermal conditions for occupants. Understanding these temperature variations, mainly when using alternative gases like nitrogen and hydrogen, could provide valuable insights into how these gases perform compared to standard air [16].

Through CFD simulations, airflow patterns, temperature distribution, and other factors, which contribute to thermal comfort, were analyzed in this study [17]. The performance of nitrogen and hydrogen as alternative cooling gases is of particular interest, as their lower molecular weight and higher specific heat capacity could result in different cooling behaviors compared to regular air [9–11]. This research also explores the practical implications of using these gases in terms of energy efficiency, safety, and environmental sustainability, which are increasingly important factors in the design of modern air conditioning systems [16, 18].

This study aims to comprehensively compare standard air and alternative gases for air conditioning systems, focusing on thermal comfort, cooling efficiency, and environmental impact [18]. By comparing the proposed CFD simulations with the ANSYS Fluent benchmarks, this study aims to establish the viability of nitrogen and hydrogen as potential candidates for energy-efficient and eco-friendly cooling solutions [19]. The findings from this research may contribute to developing next-generation air conditioning technologies that offer improved performance while addressing the challenges posed by climate change and rising energy demands [20].

2 Methodology

This study uses a numerical method to model the flow and temperature of air, nitrogen, and hydrogen occurring during the mashing process. Simulations were conducted under varying conditions using the ANSYS Workbench. The room with two windows and a door was air-conditioned by the cold air coming from the vent on the ceiling, while warm air was induced out of the room by the air-conditioning (AC) vent located on the bottom of the back wall. The room dimensions are 6 m in length, 4.5 m in width, and 3 m in height. The AC inlet vent on the top fence measures 0.25 m by 0.25 m, and the AC outlet vent at the bottom of the back wall also measures 0.25 m by 0.25 m, as shown in Figure 1. The diffuser model used is shown in Figure 2. In the convergent section, as shown in Table 1, it is stated that mesh independence is reviewed based on the convergence of the mesh, convergence was achieved at 500 of 1,500 iterations. Therefore, if it has converged, mesh independence is not carried out further [21–23]. Table 2 shows the properties of boundary conditions. Figure 3 shows the flowchart of ANSYS processing steps, including room, inlet, and outlet boundaries.

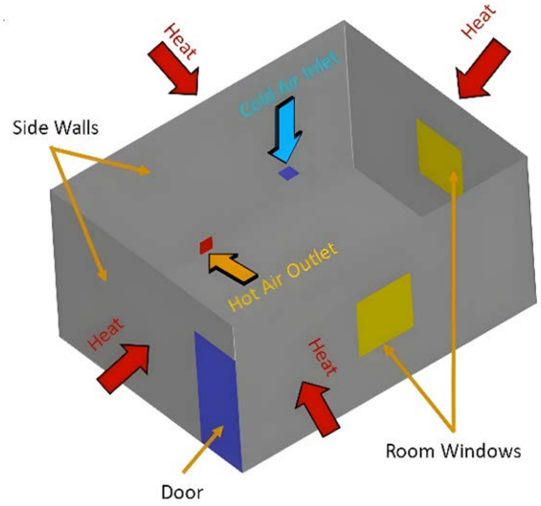


Figure 1. Boundary conditions

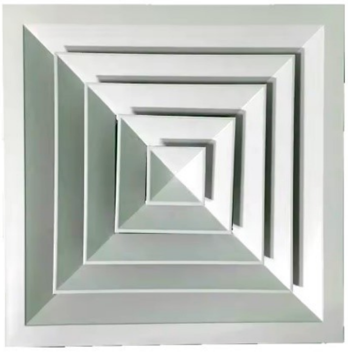


Figure 2. Square diffuser inlet air ($\theta = 45°$)

Table 1. Reliability assessment of simulation results

Parameters of Convergence	Convergence Status
Continuity	Convergence
x-velocity	Convergence
y-velocity	Convergence
z-velocity	Convergence
Energy	Convergence

Table 2. Properties of boundary conditions

Fluid	**Density** (ρ) $(\mathrm{kg/m^3})$	**Specific Heat** (Cp) $(\mathrm{J/kg \cdot K})$	**Thermal Conductivity** $(\mathrm{W/m \cdot K})$	μ **at** $0°\mathrm{C}$ $(\mathrm{mPa.s})$ $(\mathrm{Ns/m^2})$	**Critical Temperature** (K)
Air	1.225	1006.43	0.0242	1.82	132.3
Nitrogen	1.138	1040.67	0.0242	1.76	126.2
Hydrogen	0.0189	14283	0.1672	0.88	32.98

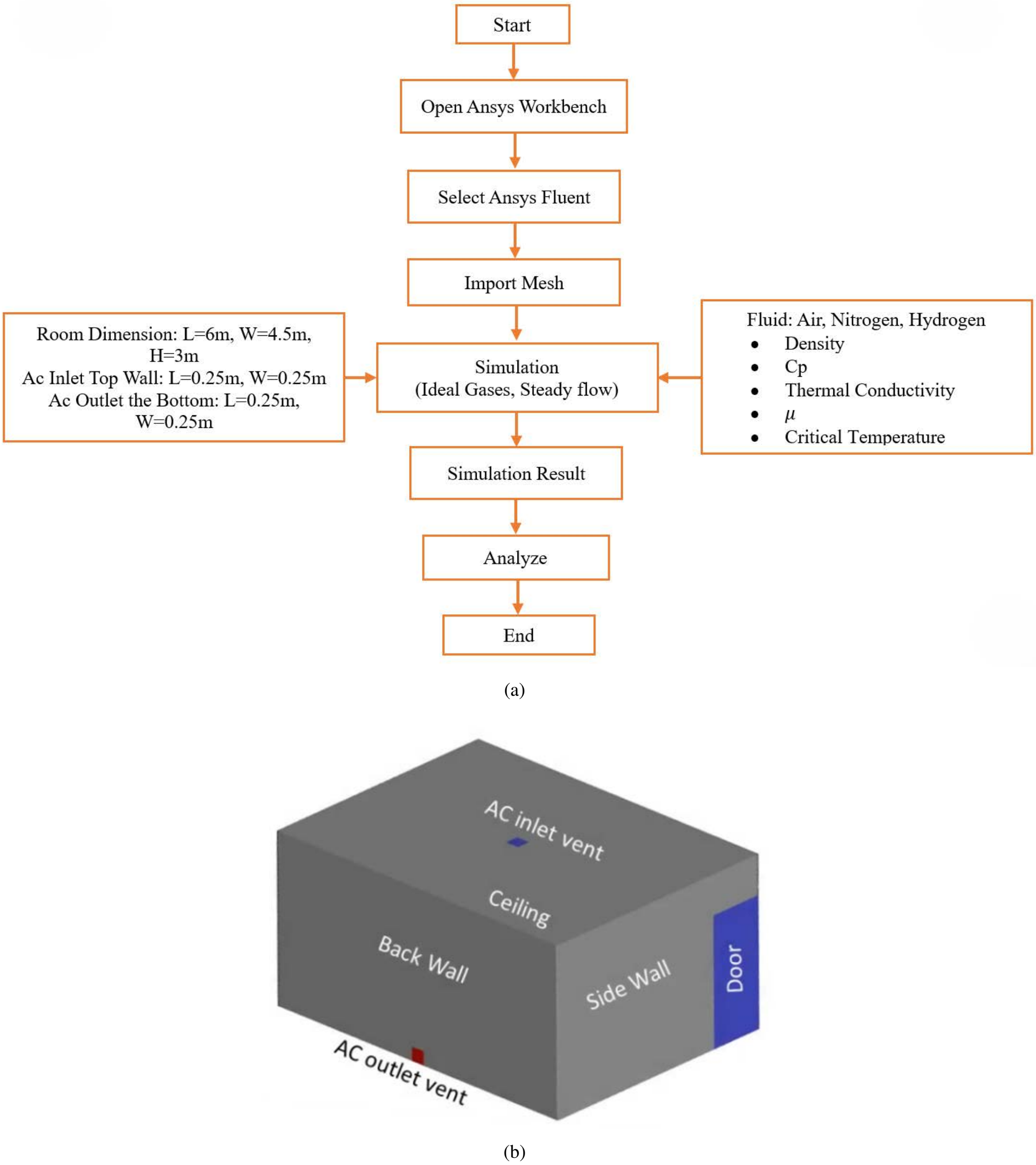


Figure 3. Flowchart of ANSYS processing steps, including room, inlet, and outlet boundaries: (a) Flowchart; (b) Detail mesh

3 Results

The simulation was conducted in an air-conditioned room with 6 m × 4.5 m × 3 m dimensions using Fluent software. The air entering the room was set at an inlet temperature of 293 K, with varying inlet velocities of 0.7 m/s, 0.8 m/s, 0.9 m/s, 1.0 m/s, and 1.1 m/s. The simulation aimed to analyze how these different air velocities affected two leading indicators: the average room temperature on critical surfaces (sidewalls, the door, and windows) and the temperature of the air exiting the room. The results showed slight variations in room temperature, ranging from 310.27 K to 310.58 K, with the lowest recorded temperature at 1.0 m/s (310.27 K) and the highest at 0.7 m/s (310.58 K). The outlet temperature remained stable, ranging from 293.45 K to 294.23 K, peaking at 0.9 m/s, suggesting that increased air velocity may slightly raise the temperature due to frictional effects or local air mixing [24].

When compared to the reference simulation from ANSYS (with an inlet velocity of 0 m/s and an inlet temperature of 293 K), the room temperature in the no-airflow scenario was recorded at 310.44 K, indicating that natural convection contributes to baseline cooling even without forced air movement. The error calculations between the simulation results and the ANSYS reference data were conducted using the following formula for the percentage of difference with the first condition (reference by ANSYS):

$$\frac{T_{\text{Simulation}} - T_{\text{Ansys Reference}}}{T_{\text{Ansys Reference}}} \times 100\%$$

As for the inlet velocities of 0.7 m/s, 0.8 m/s, 0.9 m/s, 1.0 m/s and 1.1 m/s, the room temperature errors of air were calculated as follows:

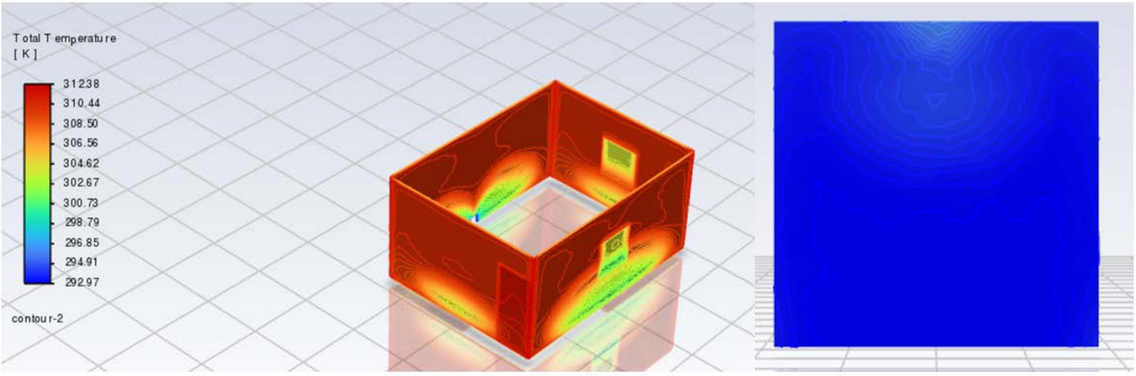
$$\frac{310.58 - 310.44}{310.40} \times 100\% = 0.045\%$$
$$\frac{310.35 - 310.44}{310.40} \times 100\% = 0.029\%$$
$$\frac{310.52 - 310.44}{310.40} \times 100\% = 0.026\%$$
$$\frac{310.27 - 310.44}{310.40} \times 100\% = 0.055\%$$
$$\frac{310.43 - 310.44}{310.40} \times 100\% = 0.003\%$$

As for the same inlet velocities, the outlet temperature errors of air were calculated as follows:

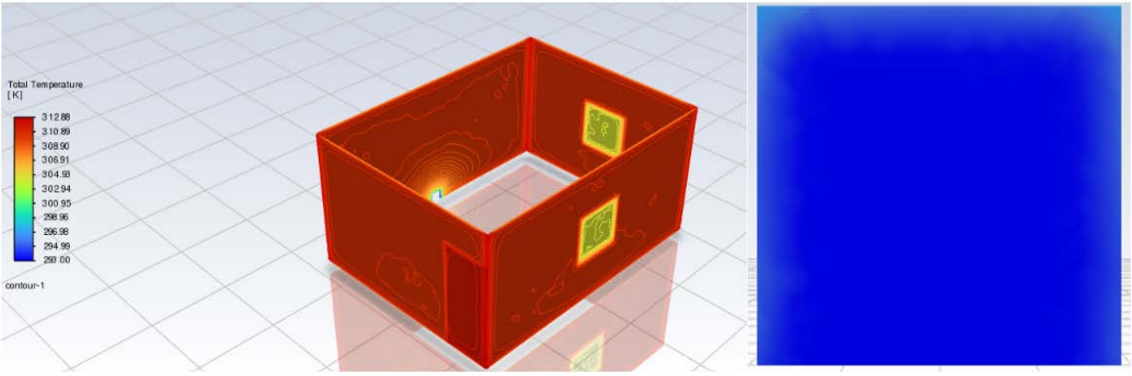
$$\frac{293.51 - 293.1}{293.1} \times 100\% = 0.014\%$$
$$\frac{293.45 - 293.1}{293.1} \times 100\% = 0.012\%$$
$$\frac{293.23 - 293.1}{293.1} \times 100\% = 0.039\%$$
$$\frac{293.47 - 293.1}{293.1} \times 100\% = 0.013\%$$
$$\frac{293.47 - 293.1}{293.1} \times 100\% = 0.013\%$$

Based on this formula, room temperature errors ranged from 0.003% to 0.055%, while outlet temperature errors ranged from 0.12% to 0.39%. These minor discrepancies indicate that the simulation results closely align with the reference values, demonstrating high accuracy in predicting cooling behavior under varying air velocities [25]. Overall, while increasing the inlet air velocity marginally enhances cooling performance, its effect on reducing room temperature becomes less significant beyond a certain threshold, making this simulation model reliable for forecasting temperature behavior in air-conditioned environments [26, 27]. However, it is essential to note that factors, such as inlet velocity and the physical characteristics of air as a fluid, influence the accuracy of the simulations. For instance, variations in inlet velocity directly affect temperature distribution and airflow patterns, while properties of air, such as specific heat capacity and thermal conductivity, determine the efficiency of heat absorption and release.

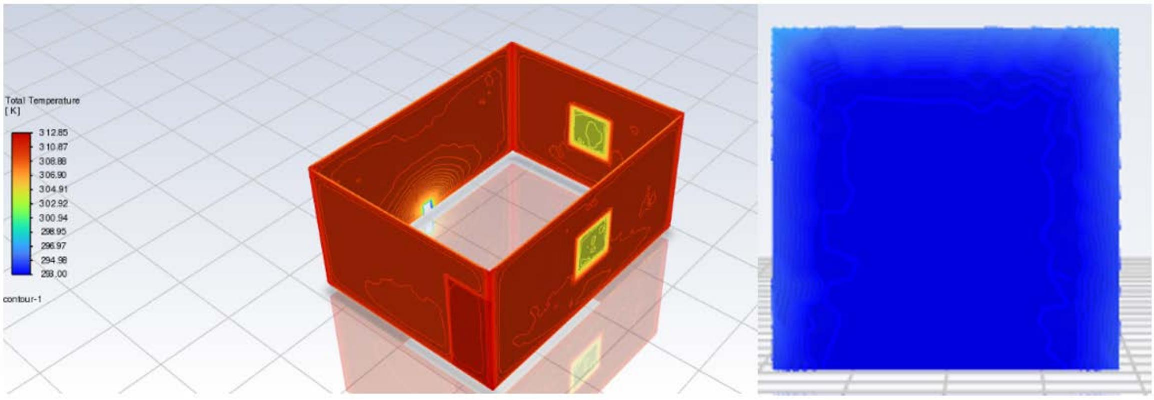
Figure 4 shows the simulation analysis conducted for an air-conditioned room with dimensions of 6 m × 4.5 m × 3 m. Nitrogen was used as the cooling fluid with an inlet temperature of 293 K, and the varying inlet velocities were 0.7 m/s, 0.8 m/s, 0.9 m/s, 1.0 m/s, and 1.1 m/s. The simulation results showed that the room temperature ranged from 310.345 K to 310.52 K, while the outlet temperature varied between 292.24 K and 294.2 K. The analysis indicates that increasing the nitrogen inlet velocity improves the distribution of air and heat transfer within the room. However, this increase did not significantly affect the reduction of room temperature due to nitrogen's relatively low specific heat capacity and the thermal resistance of the room's surfaces, which limits the heat absorption efficiency by the fluid [28]. Thus, the variables of inlet velocity and the properties of air as a fluid significantly influence the reliability of the simulation, particularly in describing temperature distribution and heat flow. Accurate representation of these variables enhances the model's realism, producing reliable simulations for practical applications in designing and optimizing air conditioning systems.


Total Temperature
[K]
31238
310.44
308.50
306.56
304.62
302.67
300.73
298.79
296.85
294.91
292.97
contour-2

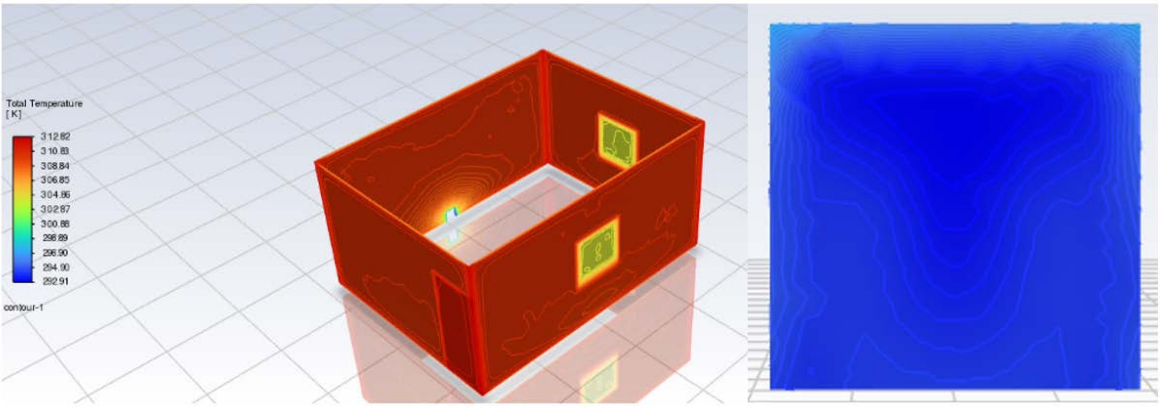
(a)


Total Temperature
[K]
312.88
310.89
308.90
306.91
304.93
302.94
300.95
298.96
296.98
294.99
293.00
contour-1

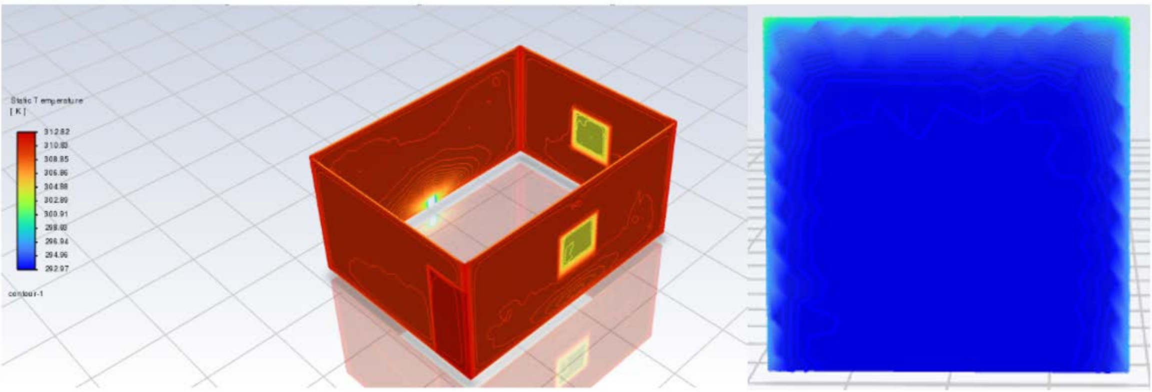
(b)


Total Temperature
[K]
312.85
310.87
308.88
306.90
304.91
302.92
300.94
298.95
296.97
294.98
293.00
contour-1

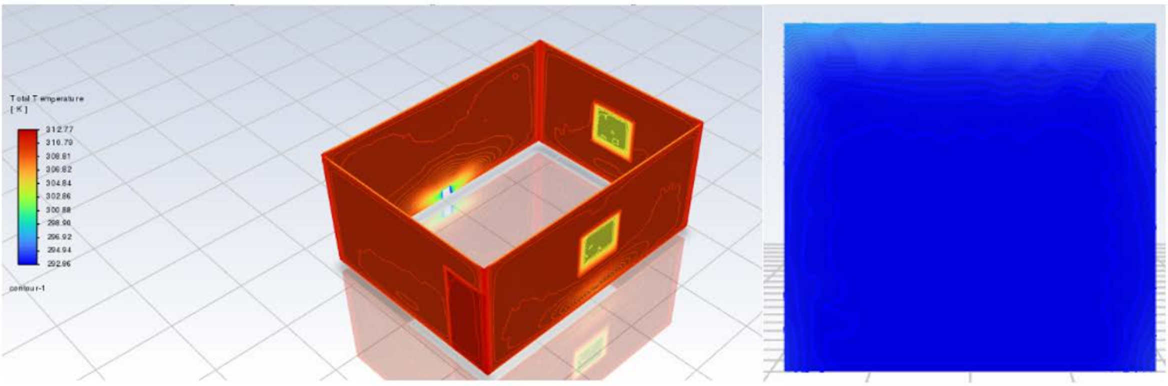
(c)


Total Temperature
[K]
312.82
310.83
308.84
306.85
304.86
302.87
300.88
298.89
296.90
294.90
292.91
contour-1

(d)



(e)



(f)

Figure 4. Temperature pattern of air: (a) 0 m/s; (b) 0.7 m/s; (c) 0.8 m/s; (d) 0.9 m/s; (e) 1.0 m/s; (f) 1.1 m/s

As for the inlet velocities of 0.7 m/s, 0.8 m/s, 0.9 m/s, 1.0 m/s, and 1.1 m/s, the room temperature errors of nitrogen were calculated as follows:

$$\frac{310.345 - 310.44}{310.40} \times 100\% = 0.031\%$$

$$\frac{310.52 - 310.44}{310.40} \times 100\% = 0.026\%$$

$$\frac{310.5 - 310.44}{310.40} \times 100\% = 0.019\%$$

$$\frac{310.46 - 310.44}{310.40} \times 100\% = 0.006\%$$

$$\frac{310.42 - 310.44}{310.40} \times 100\% = 0.006\%$$

As for the same inlet velocities, the outlet temperature errors of nitrogen were calculated as follows:

$$\frac{293.86 - 293.1}{293.1} \times 100\% = 0.026\%$$

$$\frac{293.095 - 293.1}{293.1} \times 100\% = 0.0017\%$$

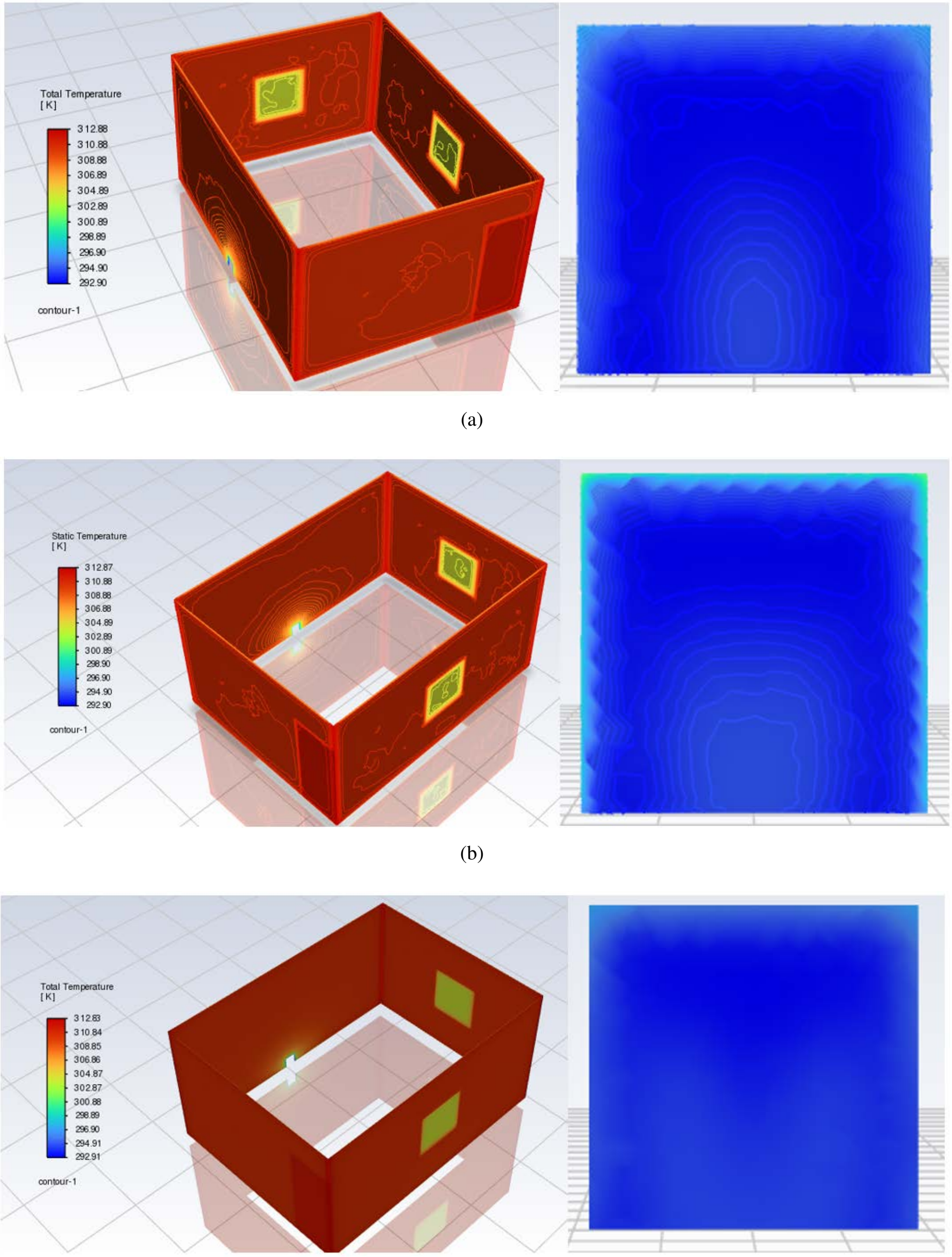
$$\frac{293.2 - 293.1}{293.1} \times 100\% = 0.375\%$$

$$\frac{293.24 - 293.1}{293.1} \times 100\% = 0.294\%$$

$$\frac{293.46 - 293.1}{293.1} \times 100\% = 0.123\%$$

The error analysis compared to the reference condition without airflow (inlet velocity of 0 m/s, room temperature of 310.44 K, and outlet temperature of 293.1 K) was calculated using percentage error. The room temperature showed minimal error, ranging from 0.003% to 0.03%, indicating high accuracy in the simulation. In contrast, the outlet temperature exhibited a more considerable error, reaching a maximum of 0.375% at an inlet velocity of 0.9 m/s, suggesting that increased nitrogen velocity has a more pronounced effect on the outlet temperature than on the room temperature. This analysis concludes that higher nitrogen flow velocities have a marginal effect on reducing room temperature but a more significant impact on heat transfer at the outlet [26].

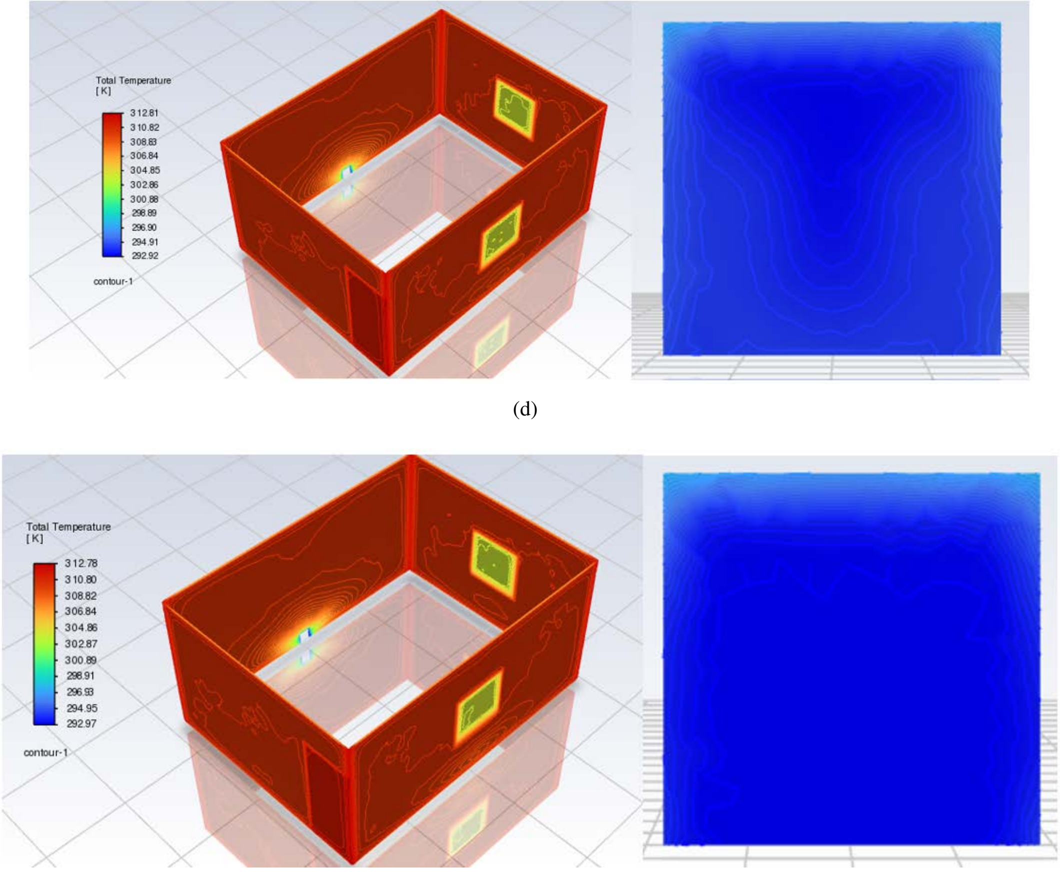
Figure 5 illustrates the simulation using nitrogen as the working fluid at various inlet velocities. The simulation depicts the temperature distribution within the room, including the temperature at the walls and door surfaces, as well as the movement of the cooling fluid. These results support the conclusion that nitrogen effectively regulates the outlet air temperature, although its efficiency in cooling the room temperature remains limited due to its thermal properties [13, 29].



(a)

(b)

(c)



(d)

(e)

Figure 5. Temperature pattern of nitrogen: (a) 0.7 m/s; (b) 0.8 m/s; (c) 0.9 m/s; (d) 1.0 m/s; (e) 1.1 m/s

Figure 5 shows an analysis focusing on the fluent AC simulation of an air-conditioned room with dimensions of 6 m × 4.5 m × 3 m, using hydrogen as the cooling fluid. The inlet temperature was set at 293 K, with varying inlet velocities of 0.7 m/s, 0.8 m/s, 0.9 m/s, 1.0 m/s, and 1.1 m/s. The simulation measured two primary indicators: room temperature (including sidewalls, door walls, and window walls) and outlet temperature. The room temperature ranged from 301.8 K to 308.8 K, while the outlet temperature remained constant between 293.14 K and 293.15 K [15]. The minimal change in outlet temperature across different velocities indicates stable thermal behavior, likely due to hydrogen's high thermal conductivity [30, 31]. The analysis of the inlet velocity for nitrogen shows how this variable significantly influences the simulation accuracy. As the inlet velocity increases, the turbulent flow of nitrogen enhances mixing and heat transfer, which can affect the thermal distribution within the room. However, since hydrogen has high thermal conductivity, the changes in outlet temperature remain minimal, suggesting that while higher inlet velocities improve overall heat transfer efficiency, they have less effect on the final outlet temperature. This observation highlights the relationship between fluid properties and flow dynamics, underscoring the importance of accurately modeling inlet velocities in simulations to achieve reliable results.

Figure 6 shows the temperature pattern of hydrogen. As for the inlet velocities of 0.7 m/s, 0.8 m/s, 0.9 m/s, 1.0 m/s, and 1.1 m/s, the room temperature errors of hydrogen were calculated as follows:

$$\frac{301.815-310.44}{310.40}\times 100\% = 2.78\%$$

$$\frac{301.8-310.44}{310.40}\times 100\% = 2.78\%$$

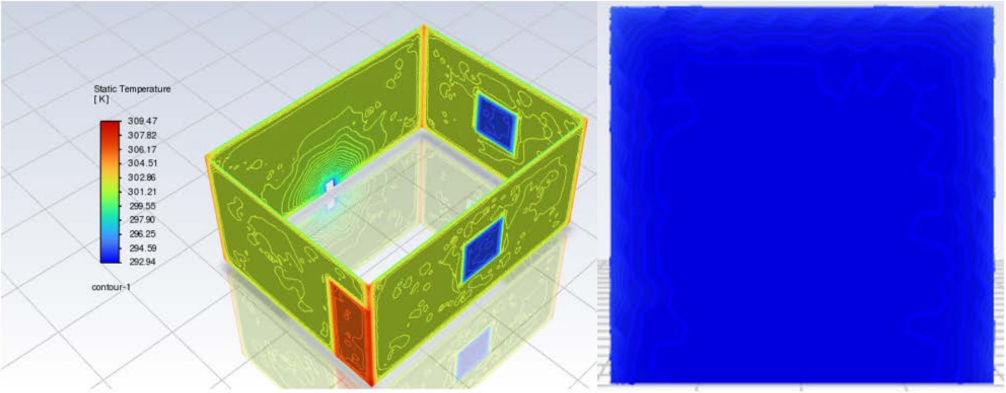
$$\frac{301.95-310.44}{310.40}\times 100\% = 2.73\%$$

$$\frac{301.804-310.44}{310.40}\times 100\% = 2.78\%$$

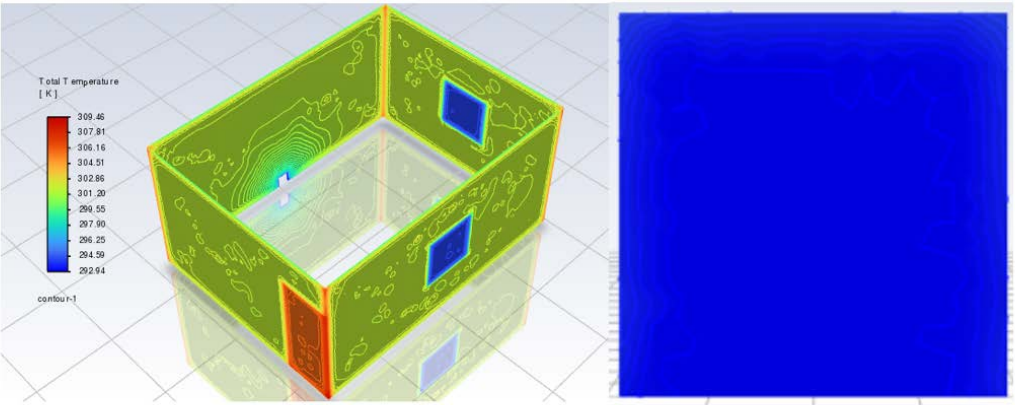
$$\frac{308.8-310.44}{310.40}\times 100\% = 0.53\%$$

As for the same inlet velocities, the outlet temperature errors of hydrogen were calculated as follows:

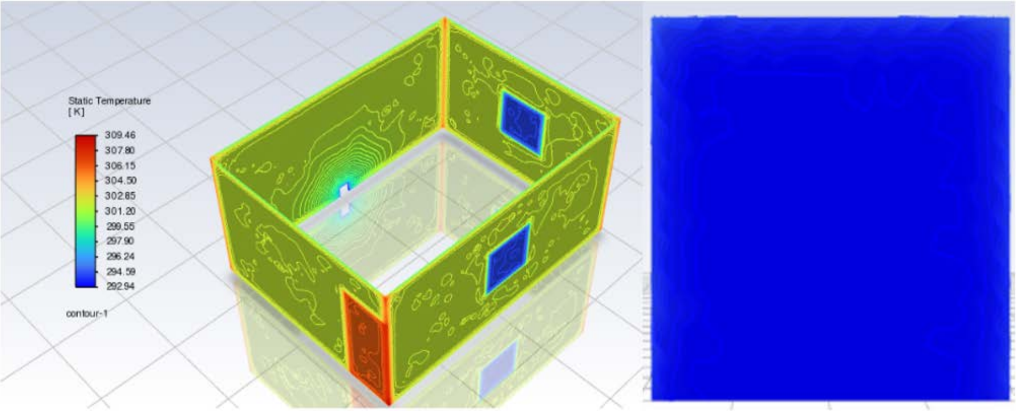
$$\begin{gathered}
\frac{293.15-293.1}{293.1}\times 100\% = 0.017\% \\
\frac{293.14-293.1}{293.1}\times 100\% = 0.014\% \\
\frac{293.15-293.1}{293.1}\times 100\% = 0.017\% \\
\frac{293.15-293.1}{293.1}\times 100\% = 0.017\% \\
\frac{293.15-293.1}{293.1}\times 100\% = 0.017\%
\end{gathered}$$



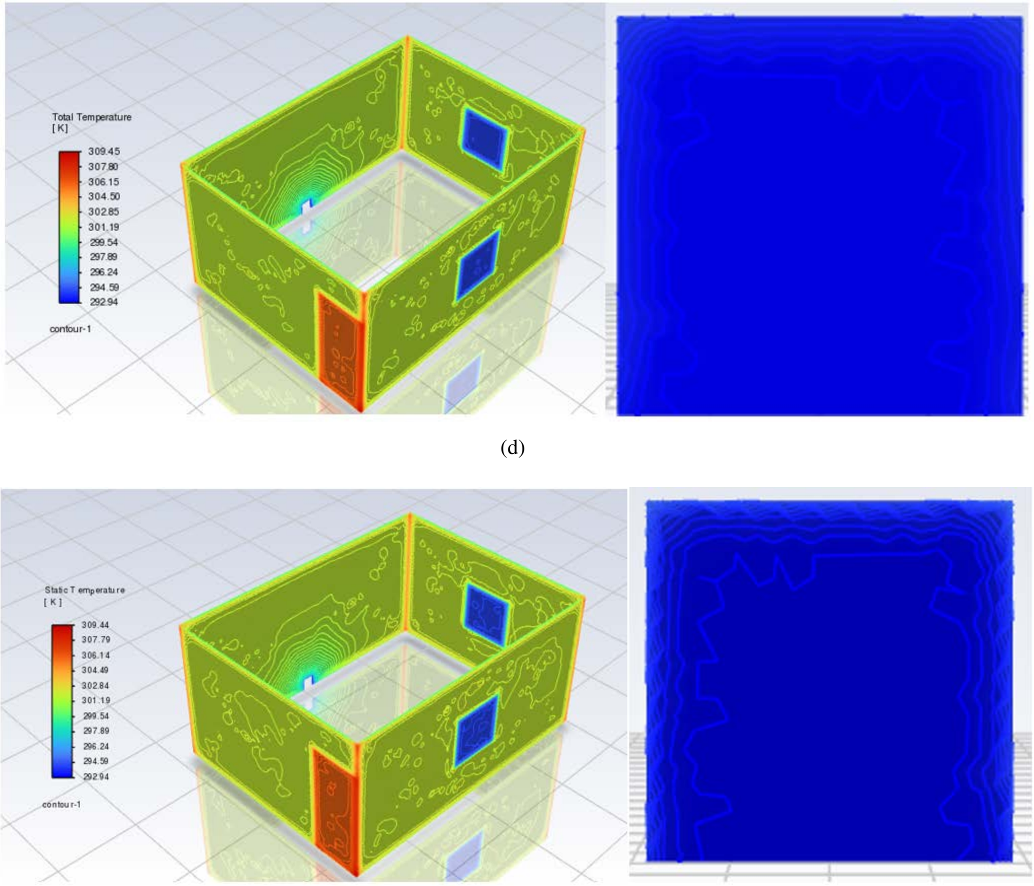
(a)



(b)



(c)



(d)

(e)

Figure 6. Temperature pattern of hydrogen: (a) 0.7 m/s; (b) 0.8 m/s; (c) 0.9 m/s; (d) 1.0 m/s; (e) 1.1 m/s

The results showed that an increase in the inlet velocity of hydrogen did not significantly affect the outlet temperature, as it remained almost unchanged. However, room temperature displayed more variation, particularly at an inlet velocity of 1.1 m/s, where it peaked at 308.8 K. This suggests that at higher inlet velocities, advection dominates over convection, leading to increased room temperature rather than improving cooling efficiency [15]. The outlet temperature stability is attributed to hydrogen's ability to efficiently transfer heat, keeping the exit air temperature consistent despite increased airflow [32].

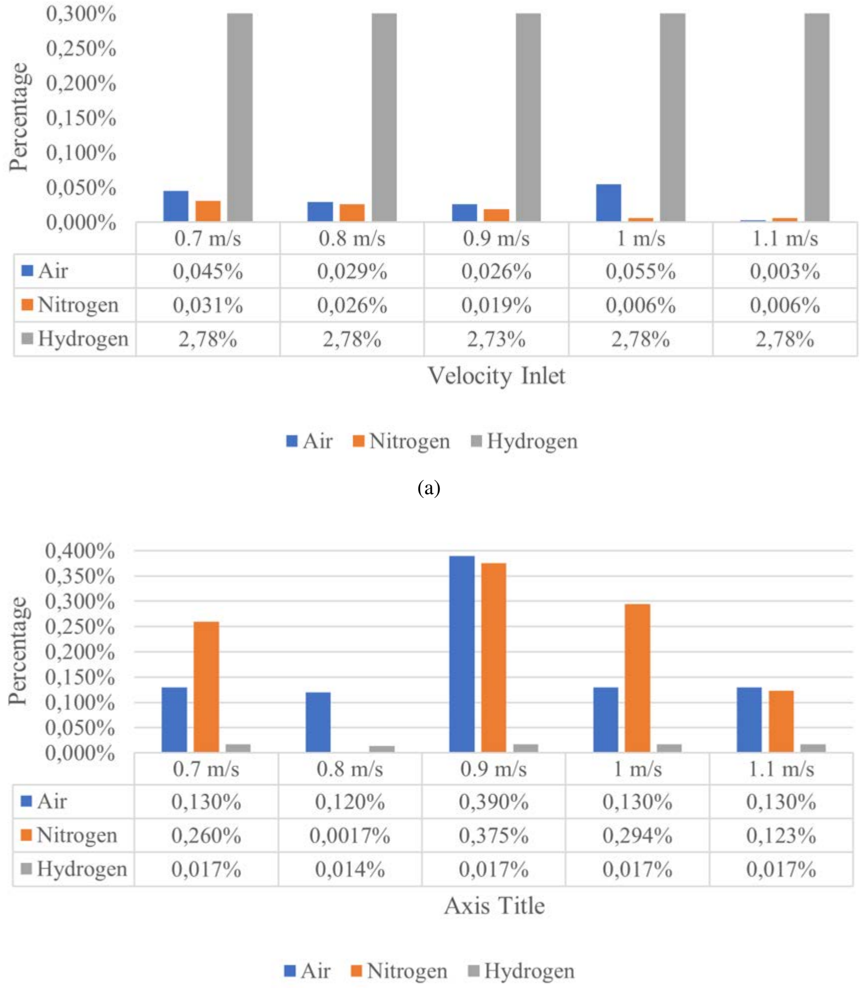
Error calculations revealed low errors compared to the reference condition with an inlet velocity of 0 m/s (room temperature of 310.44 K and outlet temperature of 293.1 K). The room temperature error ranged between 0.53% and 2.78%, while the outlet temperature error was as low as 0.014% to 0.017%. These results confirm the high accuracy of the simulation in predicting temperature variations at different inlet velocities. The overall findings show that while increased airflow improves cooling marginally, its effect is more noticeable at room temperature. In contrast, the outlet temperature remains stable due to the thermal properties of hydrogen [13, 33].

4 Analysis

In this study, the simulation results reveal distinct temperature distribution patterns for air, nitrogen, and hydrogen, influenced by the thermal properties of each gas. Air, as the standard cooling medium, has a specific heat capacity of 1006.43 J/kg·K, allowing it to absorb and store heat efficiently, resulting in a relatively uniform temperature distribution throughout the room. In contrast, nitrogen, with a higher specific heat capacity of 1040.67 J/kg·K, should theoretically possess better heat absorption and transfer capabilities. However, despite increased air velocities, the temperature range for nitrogen in the simulation remained limited between 310.345 K and 310.52 K, indicating that the thermal resistance of the room's surfaces restricts nitrogen's heat absorption efficiency [34].

Hydrogen, characterized by its high thermal conductivity, demonstrated better stability in outlet temperature, ranging from 293.14 K to 293.15 K. However, the room temperature for hydrogen peaked at 308.8 K at an inlet velocity of 1.1 m/s, indicating that advective dominance could lead to increased room temperature at higher inlet velocities. This finding suggests that while hydrogen efficiently transfers heat, an increase in airflow does not necessarily contribute to a significant reduction in room temperature. The differences in temperature distribution patterns have important implications for the design and optimization of air conditioning systems, as understanding the thermal behavior of each gas under varying conditions allows for more accurate predictions of system performance, providing valuable insights for enhancing thermal comfort in indoor environments [34].

The variations in temperature distribution observed in this study can significantly impact thermal comfort and energy efficiency within indoor environments. For thermal comfort, uneven temperature distribution can create either too-hot or too-cold zones, potentially making occupants uncomfortable. For example, areas near air inlets may become excessively cold. At the same time, zones farther away could remain warm, resulting in an uneven thermal experience that could lead to discomfort for individuals in the space. From an energy efficiency perspective, these temperature variations can influence the workload on heating or cooling systems. If certain areas of a room are significantly warmer, the air conditioning system must work harder to maintain a comfortable overall temperature, leading to increased energy consumption. Conversely, understanding the temperature distribution patterns may provide opportunities for optimizing energy use. For instance, strategic airflow placement can mitigate hot spots and improve the overall efficiency of the cooling system, potentially reducing energy demands while enhancing occupant comfort. Overall, the insights gained from this study highlight the importance of considering temperature distribution in designing and operating air conditioning systems to achieve both comfort and efficiency [34, 35]. Figure 7 shows the percentage difference in room and outlet temperatures.



	0.7 m/s	0.8 m/s	0.9 m/s	1 m/s	1.1 m/s
■ Air	0,045%	0,029%	0,026%	0,055%	0,003%
■ Nitrogen	0,031%	0,026%	0,019%	0,006%	0,006%
■ Hydrogen	2,78%	2,78%	2,73%	2,78%	2,78%

(a)

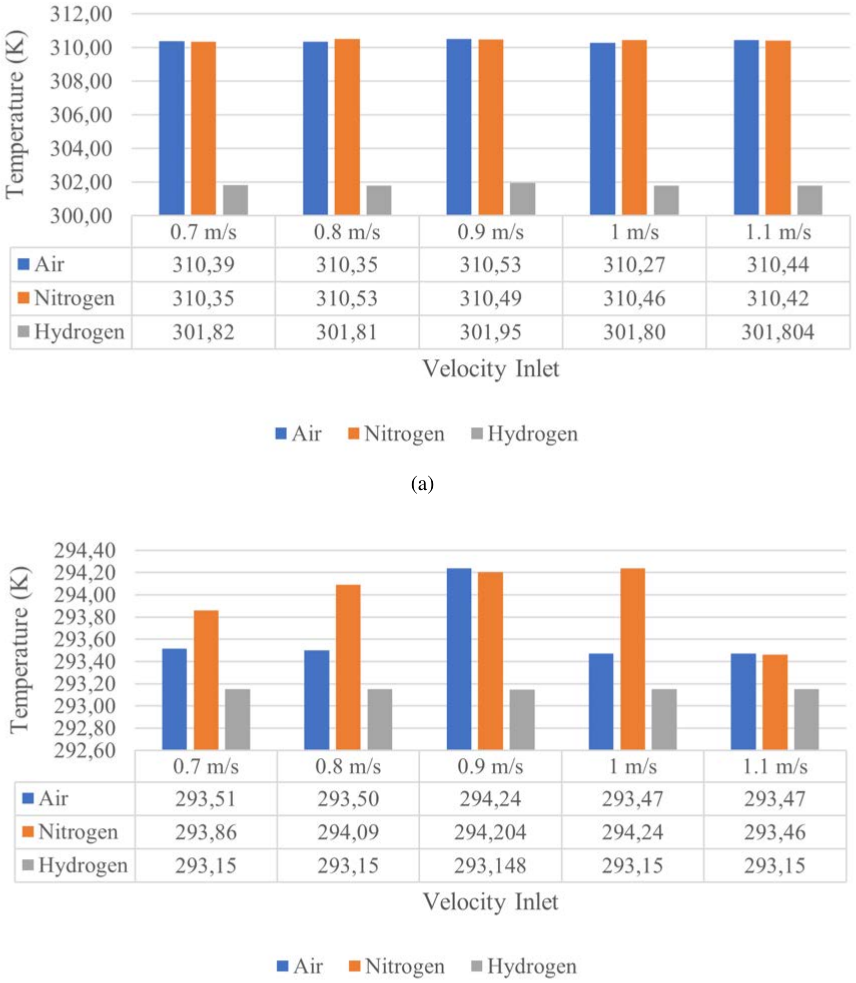
	0.7 m/s	0.8 m/s	0.9 m/s	1 m/s	1.1 m/s
■ Air	0,130%	0,120%	0,390%	0,130%	0,130%
■ Nitrogen	0,260%	0,0017%	0,375%	0,294%	0,123%
■ Hydrogen	0,017%	0,014%	0,017%	0,017%	0,017%

(b)

Figure 7. Percentage difference in (a) room temperature and (b) outlet temperature

Figure 8 shows the analysis. The total variability in the data was quantified through the Total Sum of Squares (SST), which represents the overall deviations of each observation from the grand mean. The SST value of 1713.11 indicates considerable variability within the dataset, suggesting that multiple factors, including temperature type and air velocity or unexplained error, may contribute to the observed variation. The Sum of Squares for Temperature Type (SSA), which measures the variation attributable to differences between room and outlet temperatures, was

1464.71. This high SSA value demonstrates that the type of temperature—whether room or outlet—is a significant source of variability in the measurements. This result suggests that the temperature type plays a prominent role in explaining the differences observed in the data.



(a)

(b)

Figure 8. Comparison of the fluid at the inlet velocity with the lowest (a) room temperature and (b) outlet temperature

Table 3. ANOVA analysis of two factors

Temperature / Velocity	0.7 m/s	0.8 m/s	0.9 m/s	1 m/s	1.1 m/s
Room Temperature	310.39	310.35	310.53	310.27	310.44
	310.35	310.53	310.49	310.46	310.42
	301.82	301.81	301.95	301.80	301.804
Outlet Temperature	293.51	293.50	294.24	293.47	293.47
	293.86	294.09	294.204	294.24	293.46
	293.15	293.15	293.148	293.15	293.15
Result Analysis					
SST (Total Sum of Squares): 1713.11					
SSA (Sum of Squares for Temperature Type): 1464.71					
SSB (Sum of Squares for Velocity): 0.312582					
SSE (Error Sum of Squares): 248.085					
F-statistic for Temperature Type (Factor A): 141.698					
F-statistic for Velocity (Factor B): 0.00755987					

The Sum of Squares for Velocity (SSB), which accounts for the variability due to changes in air velocity, was found to be 0.312582. This low value implies that air velocity minimizes the overall variability in the dataset. The small contribution of velocity suggests that changes in air velocity across the tested range (0.7 m/s to 1.1 m/s) do not significantly impact the temperature readings. The remaining unexplained variability, represented by the Error Sum of Squares (SSE), was 248.085. This indicates that either temperature type or air velocity cannot explain a portion of the overall variability in the data. The residual variation may be due to random noise or other unmeasured factors influencing the temperature readings [36].

In contrast, the F-statistic for velocity (Factor B) was 0.00755987, suggesting that changes in air velocity have no statistically significant effect on the temperature measurements. This low F-value implies that air velocity does not meaningfully alter the temperature readings within the velocity range tested, making it a minor factor in this experimental setup. Table 3 shows the ANOVA analysis of two factors.

5 Conclusions

This study demonstrates that the simulation results have a high degree of accuracy with minimal percentage errors, ranging from 0.003% to 2.78%, in predicting temperature changes in cooled environments. These findings have significant implications for understanding the potential use of alternative gases to enhance energy efficiency and occupant comfort in modern air conditioning designs. However, safety, cooling efficiency, and environmental impact must be considered before further implementation. Future research should explore innovative gas combinations, cooling strategies, and empirical studies in real-world settings to validate these simulation results. Overall, this study offers valuable insights into applying alternative gases in air cooling while identifying opportunities and challenges associated with their use.

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

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Conflicts of Interest

The authors declare no conflict of interest.

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