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COMPARISON OF DIFFERENT AIR CONDITION SYSTEM FOR CLASSROOM

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Abstract

Indoor air quality (IAQ) and thermal comfort in classrooms are critical factors influencing students' health, comfort, and learning performance. High occupant density, long occupancy duration, and insufficient ventilation often result in elevated carbon dioxide (CO_2) concentration, uneven airflow distribution, and thermal discomfort in classrooms. Although natural ventilation is widely used, its effectiveness is highly dependent on outdoor conditions and occupant behaviour, making it unreliable in many situations. Recent studies, particularly after the COVID-19 pandemic, emphasize the need for controlled mechanical ventilation to reduce airborne transmission risks and ensure acceptable indoor conditions. This paper presents a duct-based classroom airflow optimization approach aimed at achieving uniform air distribution and improved IAQ. Ventilation requirements are calculated based on occupancy, and an optimized rectangular duct layout is designed. Computational Fluid Dynamics (CFD) simulations using ANSYS Fluent are performed to analyse airflow patterns and velocity distribution. The results show that the optimized duct configuration significantly reduces stagnant air zones and maintains air velocity within thermal comfort limits. The proposed approach provides a simple, practical, and effective solution for improving classroom ventilation.

1. Introduction

Classrooms are among the most densely occupied indoor environments, where students and teachers spend several continuous hours each day in relatively confined spaces. Due to high occupant density and prolonged exposure time, the indoor air quality (IAQ) and thermal

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conditions of classrooms play a crucial role in influencing students' health, comfort, and learning performance. Poor IAQ has been strongly associated with adverse health symptoms such as headaches, eye irritation, fatigue, and drowsiness, as well as reduced concentration and cognitive performance among students [1-2]. These effects are particularly significant in educational settings, where sustained attention and mental alertness are essential for effective learning. Numerous field measurements and monitoring studies have reported that carbon dioxide (CO_2) concentration in classrooms frequently exceeds recommended guideline values during occupied periods [3, 7]. Since CO_2 is widely used as an indicator of ventilation adequacy, elevated CO_2 levels directly indicate insufficient fresh air supply. In many cases, concentrations above 1000 ppm are observed within a short duration after classes begin, especially in large classrooms with limited ventilation openings. Such conditions not only degrade perceived air quality but also reflect the accumulation of other indoor pollutants, further deteriorating the overall indoor environment. In practice, many educational buildings rely heavily on natural ventilation through windows and doors due to its low cost and simplicity. However, several studies have demonstrated that single-sided or uncontrolled natural ventilation is highly dependent on outdoor wind speed, temperature differences, and occupant behaviour [5, 8, 11]. During periods of extreme weather, such as hot summers or cold winters, windows are often kept closed for thermal comfort, significantly reducing air exchange rates. Similarly, during peak occupancy periods, natural ventilation alone is often unable to meet the required ventilation demand, leading to stagnant air zones and nonuniform airflow distribution within the classroom. Mechanical ventilation systems provide a more reliable and controllable solution by ensuring a consistent supply of outdoor air independent of external conditions. However, the effectiveness of mechanical ventilation is strongly influenced by duct layout, diffuser placement, and airflow distribution strategy. Poorly designed duct systems can result in uneven velocity distribution, short-circuiting of supply air, and localized drafts, which may cause thermal discomfort even when adequate ventilation rates are provided [9, 12]. Therefore, simply increasing airflow rate without proper airflow management does not guarantee improved indoor comfort or air quality. The COVID-19 pandemic further emphasized the critical role of effective ventilation in reducing airborne transmission risks in enclosed spaces such as classrooms [4, 6]. As a result, international standards and guidelines now strongly recommend increasing outdoor air supply rates and improving airflow distribution patterns in educational buildings [10]. In this context, optimizing duct-based airflow systems and validating their performance using Computational Fluid Dynamics (CFD) analysis has become increasingly important. This study focuses on the development of a simple, practical, and easily implementable duct-based ventilation layout for classrooms. The proposed approach aims to achieve uniform airflow distribution, minimize stagnant air zones, and maintain air velocities within thermal comfort limits. CFD simulations are employed to analyse airflow patterns and evaluate the effectiveness of the optimized duct configuration. The outcomes of this work contribute to providing a feasible solution for improving IAQ and thermal comfort in existing and new classroom buildings.

1.1 Problem Statement

Based on the review of existing literature, several key challenges related to classroom ventilation have been identified. Many classrooms experience uneven airflow distribution, which leads to discomfort and ineffective cooling in certain areas. The presence of stagnant air zones with very low air movement is another common issue, allowing pollutants and carbon dioxide (CO_2) to accumulate, especially during periods of high occupancy. Studies also report elevated CO_2 concentration during peak classroom usage, indicating insufficient ventilation and poor indoor air quality. In addition, there is a heavy dependence on uncontrolled natural ventilation, which is highly influenced by outdoor weather conditions and occupant behaviour, making it unreliable in maintaining consistent indoor conditions. Although many studies focus on ventilation rates and indoor air quality assessment, limited research addresses practical and easily implementable duct layout optimization strategies for classrooms [9, 12]. This research aims to bridge this gap by proposing and validating an optimized duct-based airflow system that can improve airflow uniformity and indoor comfort in real classroom environments.

2. Methodology

The methodology adopted in this study aims to analyse and optimize airflow distribution in a classroom using a duct-based ventilation system. The approach combines ventilation requirement calculations, duct layout design, and Computational Fluid Dynamics (CFD) simulation. The overall procedure is developed based on established methods reported in classroom ventilation and indoor airflow studies [6, 9,12].

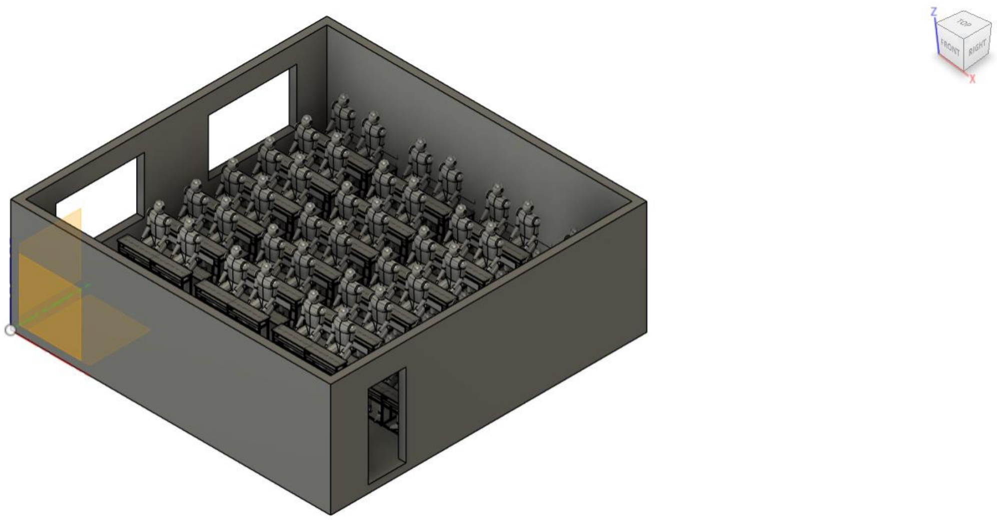

Fig. 1. CAD Model

A. Classroom Geometry and Occupancy Modeling A typical classroom geometry is considered based on standard dimensions commonly found in educational buildings. The classroom model includes the occupied zone, ceiling mounted air supply system, and a return air outlet. The number of occupants is defined according to regular classroom usage. This setup ensures that the model realistically represents actual classroom conditions and provides a reliable basis for airflow analysis.

B. Ventilation Requirement Calculation: The ventilation requirement is calculated based on the number of occupants using standard fresh air flow rates per person, as recommended in ventilation guidelines and previous studies [7, 10]. The required airflow rate is determined in terms of cubic feet per minute (CFM) and is later used as the input for duct design and CFD boundary conditions. This step ensures that the proposed system meets minimum indoor air quality requirements.

C. Duct System Design and Layout: Based on the calculated airflow requirement, a rectangular duct-based air distribution system is designed. A centrally located main supply duct is placed along the ceiling to distribute air uniformly across the classroom. From this main duct, multiple branch ducts are provided at equal spacing, each connected to a ceiling diffuser. This configuration is selected to minimize airflow imbalance and reduce stagnant air zones. A return air grille is positioned near the ceiling on the rear or side wall to effectively remove warm and contaminated air, following standard ventilation practices [9, 11].

D. CFD Modeling and Simulation Setup: CFD analysis is performed using ANSYS Fluent to evaluate the airflow performance of the proposed duct system. A pressure-based, steady-state solver is used, which is suitable for low-velocity indoor airflow simulations. Air is modelled as an incompressible fluid, and the standard $k-\varepsilon$ turbulence model is employed due to its wide acceptance and reliability in HVAC airflow studies [9, 12]. Boundary conditions include a velocity inlet at the supply duct, pressure outlets at the ceiling diffusers and return air grille, and no-slip conditions at all walls.

E. Result Analysis and Performance Evaluation: The CFD simulation results are analyzed using velocity contours and streamline plots to assess airflow distribution within the classroom. Particular attention is given to air velocity in the occupied zone, identification of stagnant regions, and overall airflow uniformity. The results are evaluated against recommended thermal comfort limits to determine the effectiveness of the optimized duct layout. This analysis helps validate the proposed ventilation strategy and its suitability for real classroom applications.

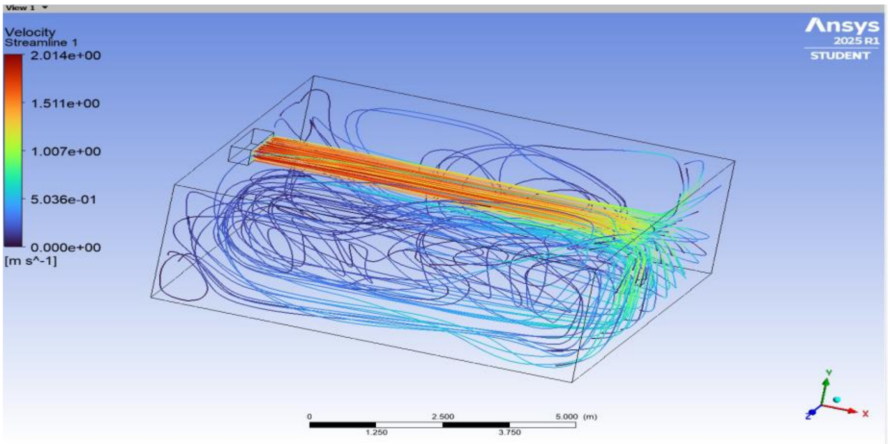

Fig. 2. Velocity streamlines

3. Results and Discussion

The airflow performance of the proposed duct-based classroom ventilation system was evaluated using CFD simulation. The results primarily focus on airflow distribution, air velocity levels in the occupied zone, and the presence of stagnant air regions. These parameters are widely recognized as key indicators of ventilation effectiveness and indoor air quality in classrooms [3, 9]. Velocity contour results show that the optimized duct layout provides uniform airflow distribution across the classroom. Air supplied through the centrally placed main duct and evenly spaced branch ducts spreads effectively throughout the occupied zone. The average air velocity in the student seating area remains within the recommended comfort range for classrooms, ensuring adequate air movement without causing discomfort or drafts. Similar observations have been reported in previous CFD-based classroom ventilation studies, where balanced duct and diffuser placement resulted in improved airflow homogeneity [9, 12]. One of the most significant improvements observed in the simulation is the reduction of stagnant air zones. In conventional or poorly ventilated classrooms, low-velocity regions are commonly found near corners, rear seating areas, and zones far from air supply points, leading to accumulation of pollutants and elevated CO2 concentration [3, 7]. In the present study, the minimum air velocity in these regions increases noticeably, indicating enhanced air circulation and effective mixing of fresh air. This reduction in stagnant zones is consistent with findings from earlier studies emphasizing the importance of supply air distribution strategy over ventilation rate alone [12, 13]. The streamline analysis further confirms smooth airflow paths from the supply diffusers toward the return air grille. The absence of short-circuiting between supply and return openings indicates efficient use of supplied fresh air. Warm and contaminated air is effectively transported toward the return outlet, supporting improved indoor air quality. Such airflow behaviour aligns with recommended ventilation principles and previous experimental and numerical investigations conducted in educational buildings [6, 10]. In comparison with naturally ventilated classrooms reported in the literature, the proposed duct-based system demonstrates superior control over airflow distribution. Natural ventilation performance is highly dependent on external wind conditions and occupant behaviour, often resulting in inconsistent ventilation rates and uneven airflow patterns [5], [8]. The mechanically assisted duct system, on the other hand, ensures stable airflow conditions independent of outdoor variations, making it more reliable for maintaining acceptable indoor environmental quality. This observation supports recent research advocating controlled mechanical ventilation as an effective solution for classrooms, particularly in high-occupancy scenarios [6, 14]. Overall, the results confirm that optimized duct layout plays a crucial role in improving classroom airflow performance. The findings demonstrate that even a simple and practical duct configuration can significantly enhance airflow uniformity, reduce stagnant zones, and improve thermal comfort. The outcomes of this study are in good agreement with previous CFD and experimental research on classroom ventilation and provide additional evidence supporting duct-based airflow optimization strategies [9, 12, 15-18].

Table 1. Cooling load calculation summary

Load Category	Type of Load	Heat Gain (kW)
Walls, Windows & Door	Sensible	4.45
Occupants & Equipment	Sensible	7.62
Ventilation & Infiltration	Sensible	3.57
Occupants & Air	Latent	3.35
Total Cooling Load	Sensible + Latent	24.04
Design Load (with safety factor)		≈ 26.44

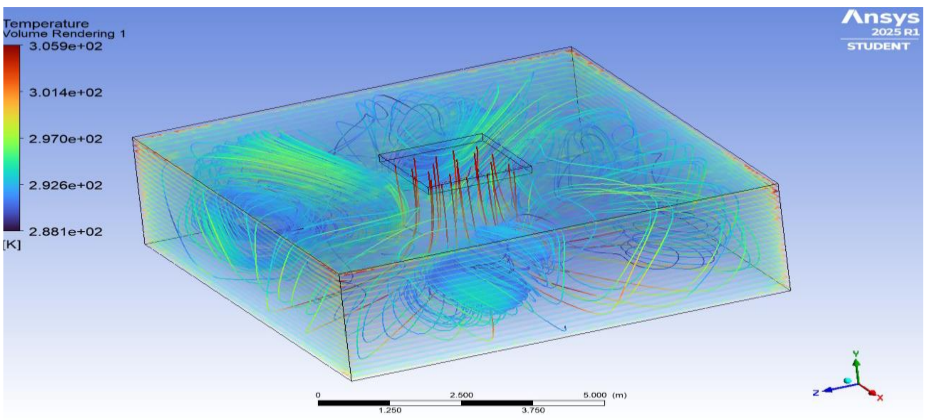

Fig. 3. Temperature counters

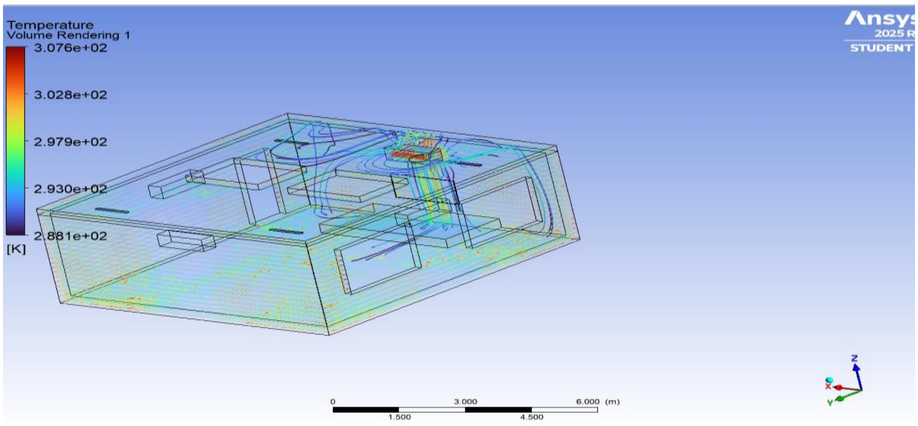

Fig. 4. Temperature volume rendering

4. Summary

This study focused on improving airflow distribution and indoor air quality in classrooms through an optimized duct-based ventilation system. A comprehensive review of existing literature highlighted common challenges such as uneven airflow distribution, stagnant air zones, elevated CO_2 levels during peak occupancy, and the limitations of natural ventilation in educational buildings. To address these issues, a practical rectangular duct layout was designed based on occupancy driven ventilation requirements. The proposed system was evaluated using Computational Fluid Dynamics (CFD) analysis in ANSYS Fluent. The simulation results demonstrated that the optimized duct configuration provides uniform airflow across the occupied zone while maintaining air velocity within acceptable comfort limits. The presence of stagnant air zones was significantly reduced, and airflow paths showed effective mixing of fresh air throughout the classroom. Overall, the findings confirm that proper duct design and placement play a critical role in enhancing classroom ventilation performance. The proposed approach offers a simple, effective, and implementable solution for improving indoor air quality and thermal comfort in educational environments.

5. Conclusions

This study presented a duct-based airflow optimization approach for improving indoor air quality and thermal comfort in classrooms. A detailed review of existing literature revealed that many classrooms suffer from uneven airflow distribution, stagnant air zones, and elevated CO_2 concentration due to insufficient or poorly controlled ventilation systems. To address these challenges, a simple and practical rectangular duct layout was designed based on occupancy-driven ventilation requirements and validated using Computational Fluid Dynamics (CFD) analysis. The simulation results confirmed that the optimized duct configuration provides uniform airflow distribution across the classroom while maintaining air velocity within recommended comfort limits. The reduction of stagnant air zones observed in the results indicates improved air circulation and effective mixing of fresh air, which is essential for maintaining acceptable indoor air quality. Streamline analysis further demonstrated efficient airflow paths and proper removal of warm and contaminated air through the return outlet, supporting findings from previous CFD and experimental studies on classroom ventilation. Overall, the results clearly indicate that proper duct layout and diffuser placement play a critical role in enhancing classroom ventilation performance. Compared to natural ventilation strategies, which are highly dependent on outdoor conditions and occupant behaviour, the proposed duct-based system offers consistent and reliable airflow control. The findings of this study are in strong agreement with earlier research advocating controlled mechanical ventilation as an effective solution for educational buildings. Therefore, the proposed approach can be considered a practical and implementable solution for improving indoor air quality and thermal comfort in classrooms.

6. Future Scope

Although the present study demonstrates the effectiveness of a duct-based airflow optimization strategy for classrooms, several opportunities exist for extending and enhancing this work. One important future direction is the integration of CO_2-based demand-controlled ventilation systems, where real time CO_2 sensors can adjust airflow rates based on actual occupancy levels. Previous studies have shown that such adaptive ventilation strategies can significantly improve indoor air quality while reducing unnecessary energy consumption. Another potential area of future research is the energy performance and lifecycle cost analysis of the proposed duct-based system. While this study primarily focused on airflow distribution and comfort, evaluating energy consumption, operational cost, and long-term sustainability would provide a more comprehensive assessment, as highlighted in recent ventilation and sustainability studies. This would be particularly useful for large-scale implementation in educational buildings. Future work can also explore hybrid ventilation strategies that combine natural and mechanical ventilation. Several researchers have reported that hybrid systems can take advantage of favourable outdoor conditions while maintaining reliable airflow control during unfavourable weather, offering a balance between energy efficiency and indoor comfort. Comparative studies between fully mechanical and hybrid systems would further strengthen design guidelines for classrooms. Experimental validation of the CFD results through onsite measurements in real classrooms is another important extension of this work. Field measurements of air velocity, temperature, and CO_2 concentration would help validate simulation assumptions and improve model accuracy, as suggested in earlier experimental studies on classroom ventilation. Additionally, advanced data-driven techniques such as artificial intelligence and Bayesian inference models may be employed to predict ventilation performance under varying occupancy and operating conditions, as demonstrated in recent research. Overall, these future research directions can contribute to the development of more intelligent, energy-efficient, and health-focused ventilation systems for educational buildings.

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