International Journal of Mechanical and Sustainability Engineering Technology

Journal homepage:
https://uniexpertsacademy.com/index.php/IJMSET/index
ISSN: 3083-8363


# Investigation of Airflow Patterns and Thermal Efficiency in Different Ducting Configurations by using CFD

M.'Irfan.H [1], Norasikin Mat Isa [1,*], Nur'Amirah Busu [2], Azian Hariri[1], M. Amirul[1], Mohamed Hussein[2], Adebayo,D.S.[3]

[1] Energy Technologies Research Group (EnRG), Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, Malaysia
[2] Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
[3] School of Engineering and Technology, College of Engineering and Physical Sciences, Aston University, Aston Triangle, Birmingham B4 7ET, United Kingdom.

**ARTICLE INFO**

***Article history:***
Received: 18 August 2024
Received in revised form: 26 September 2024
Accepted: 30 September 2024
Available online: 01 October 2024

***Keywords:***
HVAC, ANSYS FLUENT, Variable Air Volume, Ducting System

**ABSTRACT**

Centralized air-conditioning systems are essential for maintaining thermal comfort in commercial buildings, with Variable Air Volume (VAV) systems offering superior energy efficiency but facing operational challenges such as under or over-actuated conditions in different zones. These issues can lead to discomfort and energy wastage, impacting occupant productivity and building performance. This study employs Ansys FLUENT to design and evaluate Heating, Ventilation and Air Conditioning (HVAC) ducting systems, focusing on creating two configurations for thermal comfort analysis. Simulations with varied damper sizes ensure temperatures in Chamber A achieve the optimum temperature for thermal comfort, critical for consistent indoor conditions conducive to occupant comfort and productivity. The first design achieves uniform temperature and airflow distribution, indicating efficient cooling with minimal turbulence, while the second design requires optimization to match performance. Insights from damper size simulations provide practical guidance for real-world applications, emphasizing precise ducting design's role in enhancing thermal comfort and energy efficiency. Leveraging Ansys FLUENT enables detailed analysis and practical recommendations to optimize HVAC systems, contributing to improved indoor environmental quality and operational efficiency through advanced design strategies.

## 1. Introduction

HVAC systems are generally categorized into central systems and decentralized or local systems. The classification is based on the principal equipment location which is central systems condition the entire building as a single unit, while decentralized systems condition different areas independently, treating each area within a structure as a designated unit [8]. The layout and configuration of ducting systems play a crucial role in achieving comfortable indoor environments within building HVAC

[*] *Corresponding author.*
*E-mail address: sikin@uthm.edu.my*

https://doi.org/10.37934/IJMSET.1.1.4656

systems. As technology advances in Heating, Ventilation, and Air Conditioning (HVAC), there is a growing demand for innovative duct designs that can effectively regulate indoor temperatures. This study focuses on exploring two distinct ducting arrangements aimed at enhancing thermal comfort through careful design, modelling, and analysis. Duct layouts are not just conduits for conditioned air but integral elements impacting overall indoor environmental quality, highlighting the critical role of design in improving thermal well-being. In commercial buildings, centralized air-conditioning systems are commonly used to optimize both comfort and energy efficiency. Variable Air Volume (VAV) systems, which adjust airflow based on demand rather than maintaining a constant volume, are increasingly preferred over traditional Constant Air Volume (CAV) systems.

However, VAV systems can face challenges such as under- or over-actuation in different zones, leading to thermal discomfort and energy inefficiencies that impact occupants' productivity. Other than that, Air balancing is crucial in HVAC systems to ensure precise air distribution, maintain consistent temperatures, and optimize performance, thereby preventing energy waste and ensuring comfort [6]. Optimizing energy efficiency aims to reduce costs and enhance comfort by adapting HVAC controls to varying thermal demands from weather changes and occupancy patterns. This involves real-time adjustments to heating, cooling, and ventilation, ensuring sustainable and cost-effective operation [4]. Various strategies have been developed to mitigate these issues and improve the overall thermal performance and energy efficiency of centralized HVAC systems. Advanced simulation tools like Ansys FLUENT provide robust numerical solutions for predicting and enhancing thermal performance of buildings. These simulations are instrumental in designing more efficient HVAC systems that deliver superior thermal comfort and optimize energy management. This study aims to design and analyse two types of ducting systems specifically for thermal comfort, using simulations to evaluate different damper configurations aimed at maintaining indoor temperatures in Chamber A on the best temperature of thermal comfort which is 24-degree Celsius. Dampers regulate air intake and release, enabling precise ventilation control. These components are crucial in Air Handling Units (AHUs), making them essential for businesses that prioritize comfort, health, and efficiency. By managing airflow accurately, AHUs ensure optimal indoor air quality and energy efficiency, contributing to a productive and comfortable environment [9]. The research will investigate how ducting design influences thermal comfort, aiming to provide insights for improving indoor environmental quality through innovative HVAC solutions.

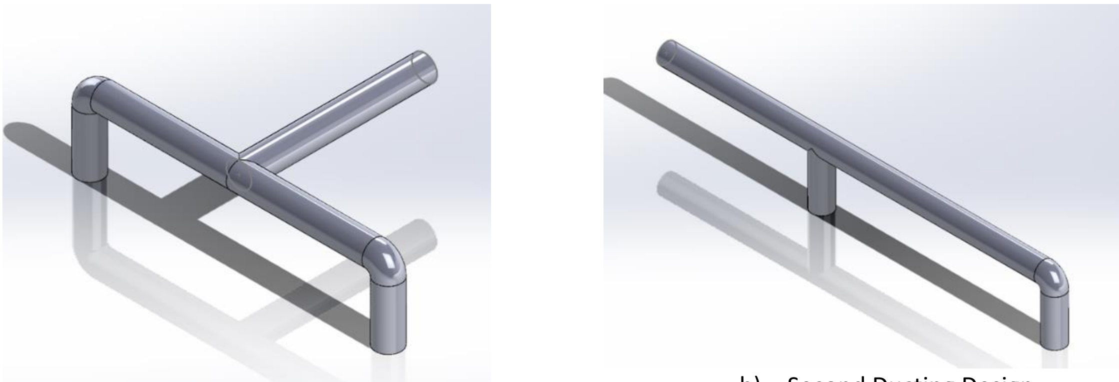
In recent years, several studies have been conducted to enhance various aspects of ventilation and air quality systems using advanced simulation techniques. For instance, research has explored aircraft cabin comfort by developing six customized ventilation systems (PVSs) aimed at improving thermal comfort metrics, achieving a notable 12% increase in relative humidity [3]. Similarly, studies on energy efficiency in building facades have utilized Computational Fluid Dynamics (CFD) simulations to analyse double-skin facade systems, highlighting the significant impact of opening size on temperature regulation within the facade cavity [1]. In the domain of operating room air quality, CFD has been employed to evaluate airflow and contaminant dispersion, demonstrating that warming blankets effectively reduce bacteria-carrying particle levels at surgical sites [5]. Research investigating damper adjustment techniques through CFD analysis of airflow distribution and resistance in HVAC ducts has identified shortcomings in traditional air balancing methods under non-fully developed flow conditions [2].

In the context of building ventilation, evaluations of cross-ventilation performance through simulations and experiments have revealed that matching the Window-to-Wall Ratio (WWR) of air ducts to that of windows significantly enhances ventilation efficiency [10]. Additionally, optimizing airflow distribution using CFD simulations has shown that the iris damper pattern outperforms butterfly and radial patterns in delivering optimal temperature and airflow distribution, making it ideal for enhancing thermal comfort in Variable Air Volume (VAV) systems [11]. Lastly, studies on diffuser modelling, utilizing numerical simulations with the FLUENT software, have successfully validated the standard k-ε turbulence model for simulating round and radial diffusers, contributing to more accurate modelling and improved diffuser design [7]. These studies collectively underscore the critical role of CFD and advanced simulation techniques in optimizing ventilation systems across various applications.

## 2. Methodology

### *2.1 Ducting Design Overview*

A well-designed ducting system is essential for the efficiency of HVAC systems, ensuring smooth airflow, accurate temperature control, and minimal energy loss. Effective ducting layout, sizing, and the integration of components such as ducts, dampers, and vents are critical for maintaining a comfortable indoor environment while reducing energy consumption and enhancing overall system performance [12]. Utilizing advanced tools like Computational Fluid Dynamics (CFD) allows for detailed analysis and optimization of duct designs, identifying and addressing issues like turbulence, pressure drops, and uneven temperature distribution. A thoughtfully designed ducting system as shown in Figure 1 not only enhances comfort and efficiency but also prolongs the lifespan of the HVAC system by preventing overuse and reducing the need for maintenance. Proper ducting design ensures that the HVAC system operates reliably and efficiently, contributing to lower operational costs and improved indoor air quality. By addressing potential issues early in the design process, CFD helps create systems that are both effective and sustainable. In summary, investing in a well-planned ducting system is crucial for achieving optimal performance and longevity in HVAC systems, ultimately providing consistent comfort and energy savings.



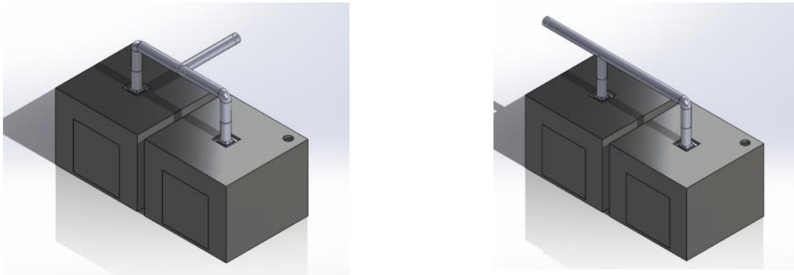
a) First Ducting Design

b) Second Ducting Design

**Fig. 1.** Ducting Design

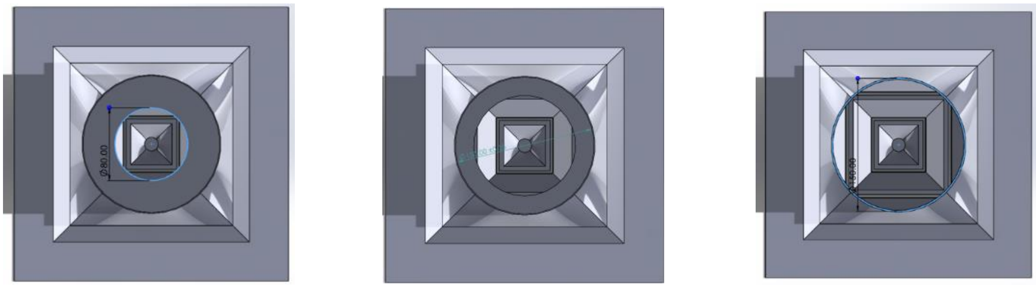
### *2.2 Simulated Fluid Domain*

Procedures The parameters provided detail the specifications for two types of ducting systems, test rigs, and damper opening used in a simulated fluid domain analysis. Two ducting systems are under evaluation, the first has an outer diameter of 152 mm and an inner diameter of 150 mm, with dimensions of 1100 mm in length, 430 mm in height, and 1770 mm in width. The second ducting system shares the same diameter but has a width of 2950 mm without a specified length. The test rigs, both 50 mm thick, measure 1574 mm in length and width, and 1219.2 mm in height, serving as controlled environments to simulate real-world conditions and assess ducting performance as shown in Figure 2. Additionally, in Figure 3, there are three damper conditions, all with an outer diameter of 152 mm but varying inner diameters which are 80 mm, 110 mm, and 150 mm, are analysed to understand their impact on airflow and temperature control within the ducting systems. This comprehensive analysis aims to optimize thermal comfort and efficiency by identifying optimal ducting and damper configurations, ensuring effective airflow, minimal energy loss, and consistent indoor comfort across different zones. These parameters are crucial for pinpointing and addressing issues such as turbulence, pressure drops, and uneven temperature distribution, thereby improving overall HVAC system performance and reliability.



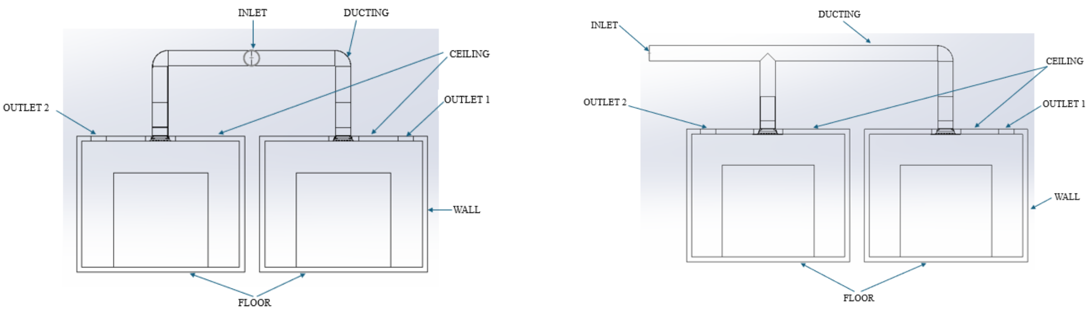
a) First Case b) Second Case

**Fig. 2.** CFD Model Domain



a) Minimum Condition b) Medium Condition c) Maximum Condition

**Fig. 3.** Opening Parameter Damper




a) First Case b) Second Case

**Fig. 4.** Boundary Selection

Figure 4 Shows boundary selection involves defining specific regions for simulation which is the inlet for airflow entry, outlet 1 and outlet 2 for airflow exits, ducting to guide the airflow, and the floor and wall to represent physical boundaries. Accurate boundary selection ensures realistic simulation results, crucial for analysing HVAC system performance and identifying areas for improvement. This approach helps in effectively addressing HVAC challenges and enhancing system efficiency.

### *2.3 Simulated Fluid Domain*

To set up the simulation in Ansys FLUENT, the process began with a mesh check to ensure high-quality mesh. The k-epsilon turbulence model with realizable and scalable wall functions was used, and the energy equation was activated for thermal simulations. The solver was initially configured to SIMPLEC, with gradients set to Least Squares Cell-Based. First Order Upwind was chosen for pressure, momentum, turbulent kinetic energy, and dissipation rate. The pseudo-time method was disabled, and warped-face gradient correction was enabled. Hybrid initialization was used to start the solution. The maximum iterations were set to 2000, and the simulation ran for 300 iterations to stabilize the solution before adjustments were made. Next, the solver was switched to Coupled, maintaining the Least Squares Cell-Based gradient setting. The discretization scheme was changed to Second Order Upwind for improved accuracy. The pseudo-time method was adjusted to Global Time Stepping and warped-face gradient correction remained enabled. The calculation continued until convergence, which required several hundred to a few thousand iterations. This method ensured accurate and reliable results by optimizing mesh quality and solver settings, with careful monitoring and adjustments throughout the process. The boundary conditions implemented in this simulation are shown in Table 1.

**Table 1**
Boundary Condition

| Boundary | Type | Details |
|---|---|---|
| Inlet | Velocity Inlet | Velocity: 1m/s<br>Turbulence Intensity: 8%<br>Hydraulic Diameter: 0.15m<br>Temperature: 18℃ |
| Outlet 1 | Pressure Outlet | Default |
| Outlet 2 | Pressure Outlet | Default |
| Wall | Wall-no slip | Temperature: 28.5℃ |
| Ceiling | Wall-no slip | Temperature: 27℃ |
| Floor | Wall-no slip | Adiabatic condition with zero heat flux |
| Ducting | Wall-no slip | Adiabatic condition with zero heat flux |

### *2.4 Grid Independency Test*

In Ansys FLUENT, a Grid Independence Test (GIT) was conducted using varying element sizes in body sizing to ensure high-quality meshing and dependable simulation results. The study aimed to optimize node count while maintaining result independence, testing sizes from 50 to 100 with five-unit increments. Key metrics assessed included volume-average temperature, skewness, and orthogonal mesh quality. The GIT results focusing on the first ducting design at maximum opening, revealed that an element size of 50 with 346,108 nodes achieved superior mesh quality, particularly demonstrating a skewness of 0.8279. In contrast, other configurations averaged a skewness of 0.83. This emphasizes the significant impact of adjusting element size within this range on mesh characteristics. These findings highlight the selection of 50 elements as optimal for consistent and reliable simulation outcomes in this specific study.

## 3. Results

### *3.1 Temperature Distribution Analysis*

The results contrast the first and second ducting designs under varying operational conditions which is maximum, medium, and minimum using contour plots to visualize temperature and velocity distributions. These plots provide qualitative understanding of airflow patterns and temperature gradients. The discussion in this section will delve into temperature and air velocity graphs, supported by streamlines. This comprehensive analysis aims to elucidate the differences between the two designs across different operating states, offering insights into how each design performs in terms of thermal management and airflow dynamics.

Figure 5 depicts the temperature distribution varies due to different ducting design and opening states. It compares temperature contours between the first and second ducting designs along the 0.5 m mark of the y-axis on a 2D plane. This comparison enables examination of temperature patterns for each design's air damper across maximum, medium, and minimum operational conditions. The contours visually show how temperatures are distributed spatially within the ducting systems under various settings, emphasizing potential differences in thermal behaviour between the two designs.

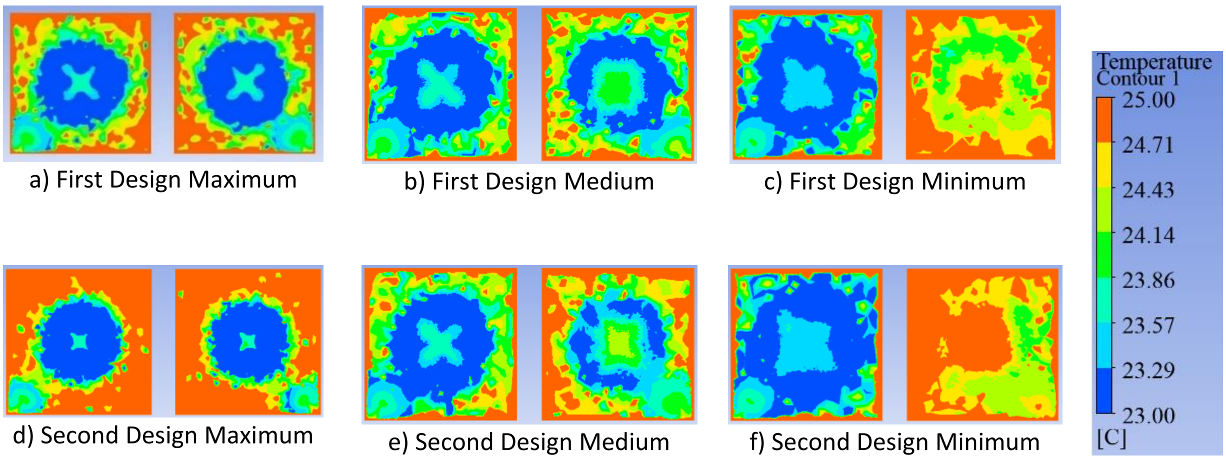



**Fig. 5.** The comparison of temperature contours for first and second ducting design at maximum, medium and minimum conditions

Figure 5 compares temperature contours on XZ Plane for two ducting designs under maximum, medium, and minimum conditions. The first row shows the first design, while the second row shows the second design. Under maximum conditions, the first design exhibits a uniform temperature distribution with the coldest areas in the lower sections, indicating effective cooling, while the second design shows a similar distribution with slight variations, suggesting less uniform cooling. Under medium conditions, the first design maintains a consistent cooling effect with minor fluctuations, indicating stable performance. The second design also displays a stable pattern but with slightly more variations, indicating moderate cooling efficiency. Under minimum conditions, the first design experiences significant fluctuations and reduced cooling efficiency, with the appearance of hot spots, while the second design has a more stable temperature profile but higher overall temperatures, suggesting decreased efficiency.

Figure 6 illustrates the mean temperature profiles of the two designs under maximum damper conditions, comparing Chamber A and Chamber B. The first design, represented by black squares, shows a stable mean temperature with minor fluctuations, suggesting uniform cooling. In contrast, the second design, represented by red circles, experiences more pronounced temperature fluctuations, indicating less uniform cooling. In medium conditions, the first design maintains a consistent mean temperature profile with only minor fluctuations, demonstrating stable cooling performance. The second design, while more stable than under maximum conditions, still exhibits some variations, indicating moderate cooling efficiency. The contour plots show that the cooling effect in the first design remains uniform but is slightly less intense, while the second design displays a similar pattern with slight differences in temperature distribution.

Under minimum conditions, the first design shows significant fluctuations in mean temperature, indicating reduced cooling efficiency. The second design, however, has a more stable temperature profile than the first design but with higher overall temperatures, suggesting decreased efficiency. The contour plots for minimum conditions indicate that the first design has significantly reduced cooling performance with the appearance of hot spots, consistent with the fluctuations observed in the graph. Overall, the analysis indicates that the first design generally provides more stable mean temperature profiles and uniform cooling performance compared to the second design. This stability is evident under maximum, medium, and minimum conditions, where the first design consistently outperforms the second design in terms of cooling efficiency and temperature distribution uniformity.

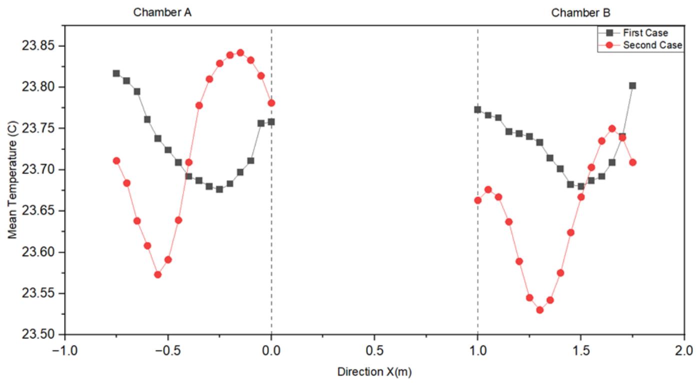



**Fig. 6.** Comparison of Mean Temperature on First and Second Ducting Design on Maximum Condition of opening damper

### *3.2 Airflow Distribution*

Accompanying discussions that further explain observations of the results are usually placed immediately below the results paragraph. Figure 7 compares the velocity contours for two ducting designs under maximum, medium, and minimum conditions, while Figure 11 illustrates the mean velocity profiles of the two designs under maximum damper conditions. In Figure 7, the first row shows the first design, and the second row shows the second design. Under maximum conditions, the first design demonstrates a uniform velocity distribution with higher velocities concentrated in the central section, indicating consistent airflow, while the second design shows a similar pattern but with noticeable fluctuations, suggesting less uniform airflow. Under medium conditions, the first design maintains a relatively consistent velocity distribution with minor fluctuations, indicating stable airflow performance, whereas the second design displays a stable pattern but with some variations, indicating moderate efficiency. Under minimum conditions, the first design experiences significant fluctuations and reduced airflow efficiency, with noticeable decreases in velocity, while the second design has a more stable velocity profile but with lower overall velocities, suggesting decreased efficiency.

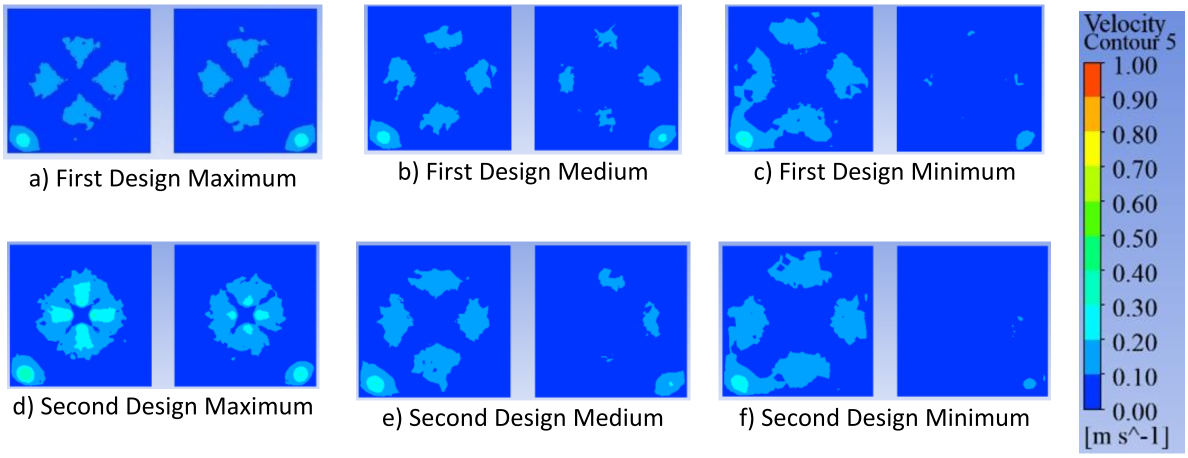



**Fig. 7.** The comparison of velocity contours for first and second ducting design at maximum, medium and minimum conditions of opening damper

Figure 8 shows the mean velocity profiles under maximum conditions, comparing Chamber A and Chamber B. The first design exhibits a steady average velocity with moderate fluctuations, indicating consistent airflow, while the second design shows more noticeable fluctuations in average velocity, suggesting less uniform airflow. Under medium conditions, the first design maintains a relatively consistent average velocity profile with minor fluctuations, indicating stable airflow performance. Similarly, the second design displays a stable average velocity profile compared to the maximum condition but with some variations, indicating moderate efficiency in airflow. The contour plots reveal that while the velocity distribution remains uniform in the first design, it is slightly less intense than under maximum conditions. Likewise, the second design shows similar velocity patterns with minor differences in distribution, corresponding to the variations seen in its velocity graph.

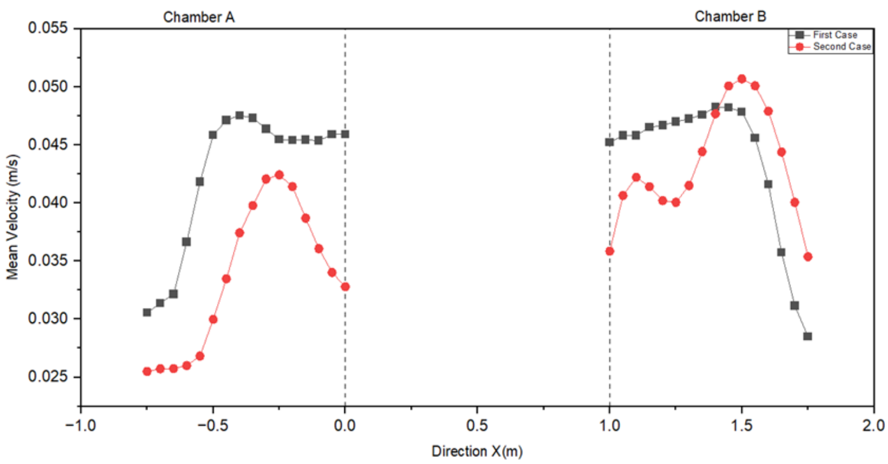
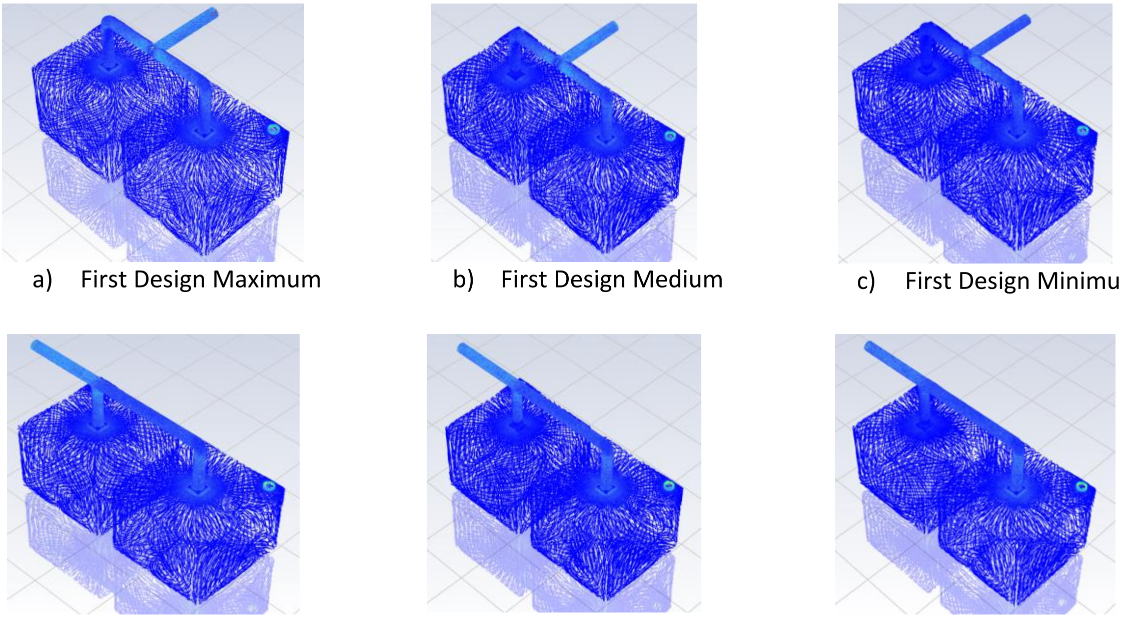



**Fig.8.** Comparison of Mean velocity on First and Second Ducting Design on Maximum Condition of opening Damper

During minimum conditions, the first design experiences significant fluctuations in average velocity, pointing to reduced airflow efficiency. In contrast, the second design showcases a more stable velocity profile compared to the first design but with lower overall velocities, indicating decreased efficiency in airflow. The contour plots for minimum conditions depict notably reduced airflow performance in the first design, with noticeable decreases in velocity that match the fluctuations observed in its velocity graph. Overall, the analysis indicates that the first design generally provides more stable average velocity profiles and consistent airflow performance compared to the second design. This stability is evident under maximum, medium, and minimum conditions, where the first design consistently outperforms the second design in terms of airflow efficiency and velocity distribution uniformity.



a) First Design Maximum b) First Design Medium c) First Design Minimum

d) Second Design Maximum e) Second Design Medium f) Second Design Maximum

**Fig. 9.** The comparison of velocity streamlines of the first and second ducting design during all condition of opening damper

Figure 9 shows the 3D view of velocity streamline of first and second ducting design during all conditions which is maximum, medium and minimum conditions. For the first design, under maximum conditions, the streamlines indicate uniform and well-distributed airflow with strong, consistent streams throughout the system. This suggests efficient airflow performance and effective distribution. In medium conditions, the streamline patterns resemble those of the maximum conditions but with slightly reduced intensity, indicating maintained airflow strength albeit with minor differences. Under minimum conditions, the streamlines show less distinct and weaker flows, signalling reduced efficiency in airflow distribution.

Similarly, the second design exhibits streamline patterns that mirror those of the first design across different conditions. Under maximum conditions, the airflow appears strong and uniform, akin to the efficient distribution observed in the first design's maximum condition. In medium conditions, the streamlines indicate moderate airflow strength, like the first design's medium condition but with some variations. Under minimum conditions, the streamlines show less defined flows, suggesting reduced airflow efficiency like what was observed in the first design's minimum condition.

Overall, both designs demonstrate similar streamline patterns across varying operational conditions, with noticeable changes in airflow efficiency from maximum to minimum settings. The streamline images effectively illustrate how airflow patterns vary between the two split unit system designs under different operational scenarios, highlighting differences in airflow distribution and efficiency.

## 4. Conclusions

In conclusion, the project successfully achieved its main objectives related to ducting system design and thermal comfort analysis, though with varying degrees of success. The first objective, which entailed designing and analysing two ducting systems, was fully accomplished, demonstrating the first design's effective temperature control which is from 23°C to 25°C and identifying improvement areas for the second design. The second objective, which involved simulating ducting designs with various damper sizes to maintain temperatures between 18 to 20 degrees Celsius, was partially achieved: the first design consistently met the criteria, while the second exhibited variability. The third objective, which focused on analysing the effects of ducting design on thermal comfort, was fully met, revealing significant differences in airflow dynamics and temperature management between the designs. To enhance the performance of the second design, recommendations include optimizing airflow dynamics through CFD simulations, revising temperature control mechanisms, conducting further simulations and iterations, and validating improvements through real-world testing. Implementing these recommendations is expected to improve the second design's thermal comfort and operational efficiency, resulting in more consistent and comfortable indoor environments.

## Acknowledgement

The authors would like to thank Universiti Tun Hussein Onn Malaysia (UTHM) for the full support of the research work. This work was financially supported by the TIER 1 Grant Scheme Vot No. Q394.

## References

[1] Atef Ahriz. (2022, May). (PDF) the use of double-skin façades to improve the energy consumption of high-rise office buildings in a Mediterranean climate (csa). https://www.researchgate.net/publication/360611843_The_Use_of_Double-Skin_Facades_to_Improve_the_Energy_Consumption_of_High-Rise_Office_Buildings_in_a_Mediterranean_Climate_Csa https://doi.org/10.3390/su14106004

[2] Busu, N., Isa, N. M., Hariri, A., & Hussein, M. (n.d.). Air damper effect on temperature and airflow distribution in enhancing thermal comfort performance. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences. https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/article/view/826

[3] Chanfiou Ahmed Mboreha, Wright, S. J., Hinninghofen, H., Pang, L., Cui, W., Zhang, Z., Henkes, R. A. W. M., Chanteloup, V., Liu, W., Zhang, T. (., You, R., Spengler, J. D., Sun, Z., Fan, J., … Jacobs, P. (2021, September 24). Investigation of thermal comfort on innovative personalized ventilation systems for aircraft cabins: A numerical study with computational fluid dynamics. Thermal Science and Engineering Progress. https://www.sciencedirect.com/science/article/pii/S2451904921002420?casa_token=Xzx94kyg8G0AAAAA%3APWe8FBOgKpLUboIinAWkIdXghBcQnjKub9mdkvUX4nb8b-1HZ_5ZmElFZ5VmsW5fIxwCxAWY0ulL

[4] Cihan Turhan, Cucchiella, F., Ferreira, P. M., Dai, Y., Brager, G., Nicol, J. F., Corgnati, S. P., Ghahramani, A., Turhan, C., Chen, K., Soyguder, S., Hussain, S., Yan, H., Yang, L., … Nouvel, R. (2021, July 23). Development of a personalized thermal comfort driven controller for HVAC systems. Energy. https://www.sciencedirect.com/science/article/pii/S0360544221018168?casa_token=0mMPJrmMcRsAAAAA%3AHpOc3o2vl32n_CWAztnk1Qes_mTwmTaSmdCqXgIQddyZxZMJaHejzAcFj_ebowh_O7857aaLfCPV

[5] Computational fluid dynamics for building air flow prediction-current status and capabilities -sciencedirect.(n.d.-a). https://www.sciencedirect.com/science/article/abs/pii/036013239290033L

[6] Cui, C. (2019, January 1). Air Balancing Technology in HVAC applications. Home. https://dr.ntu.edu.sg/handle/10220/48071

[7] Ramy H. Mohammed, Aziz, M. A., Koskela, H., Cehlin, M., Posner, J. D., Hu, S. C., Abanto, J., Chen, Q., Nielsen, P. V., & Weiran, X. (2013, May 21). A simplified method for modeling of round and square ceiling diffusers. Energy and Buildings. https://www.sciencedirect.com/science/article/abs/pii/S0378778813002971?via%3Dihu

[8] Seyam, S. (2018, November 5). Types of HVAC systems. IntechOpen. https://www.intechopen.com/chapters/62059 https://doi.org/10.5772/intechopen.78942

[9] Team, S. (2021, August 25). Air Handling Unit: Complete explanation - part 1. https://www.skillcatapp.com/post/air-handling-unit-complete-explanation-part-1

[10] Ulum, M. S., Arminda, W., Kamaruddin, M., & Satria, W. D. (2023). Ventilation Performance of Air Duct in Double Loaded Corridor Building: A Case Study. Civil Engineering Journal, 9(10), 2445-2455. https://doi.org/10.28991/CEJ-2023-09-10-06

[11] Wang, Y., Gao, R., Liu, M., Jing, R., Tian, Y., Li, A., & Li, H. (2023, December 23). Advancing air balancing in HVAC systems: CFD analysis of non-fully developed flows and GPR-based prediction of damper degrees. SSRN. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4673910 https://doi.org/10.2139/ssrn.4673910

[12] Wilcox, D. (2020, September 8). The main components of a commercial HVAC system: Compressors Unlimited - remanufactured compressor leader. Compressors Unlimited. https://www.compressorsunlimited.com/the-main-components-of-a-commercial-hvac-system/