KARYA ILHAM PUBLISHING
CONNECTING MINDS, BRIDGING IDEAS, INSPIRING READERS

International Communication in Computational Mechanics

Journal homepage:
https://karyailham.com.my/index.php/iccm
ISSN: 3093-7205

Computational Fluid Dynamics Analysis of Cooling Strategies for Data Center Thermal Optimization

Man Djun Lee[1,*], Zeno Michael[1], Mohammad Amin Makarem[2], Azizul Hakim Samsudin[1]

[1] Fakulti Kejuruteraan Elektrik, UiTM Cawangan Johor Kampus Pasir Gudang, Masai, Johor, Malaysia
[2] School of Engineering, Taylor's University, Malaysia

ARTICLE INFO

Article history:
Received 30 October 2025
Received in revised form 8 November 2025
Accepted 23 November 2025
Available online 8 December 2025

Keywords:
HVAC; Cooling Performance; Refrigeration; Numerical Simulation Heat Transfer

ABSTRACT

The rapid expansion of data centers to support global digital infrastructure has intensified the demand for efficient and sustainable cooling strategies. Inadequate thermal management not only reduces server performance but also shortens equipment lifespan and increases operational costs. This study investigates the optimization of data centre cooling performance by comparing two ventilation configurations: conventional side-wall mounted cooling and underground floor-supply cooling through computational fluid dynamics (CFD) simulations in ANSYS Fluent. A validated three-dimensional CFD model was developed under steady-state assumptions, with mesh independence verified to ensure numerical accuracy. Multiple cases were simulated by varying inlet air temperature (10 °C, 13 °C, 15 °C) and velocity (2.0–2.4 m/s for side-wall, 0.5–0.6 m/s per inlet for underground). The results demonstrate that underground cooling consistently outperformed side-wall cooling in maintaining server inlet temperatures within the ASHRAE-recommended range (18–27 °C), achieving superior thermal uniformity across the data centre. Statistical analysis confirmed the significance of cooling method and input temperature ($p < 0.01$), with regression analysis showing a strong predictive relationship for underground cooling ($R^2 = 0.92$). In contrast, side-wall cooling exhibited unstable performance, particularly at elevated inlet velocities, where thermal stratification and hot spots were observed. Although higher underground inlet velocities further improved cooling, they also implied increased fan energy consumption. The findings identify underground floor-supply cooling as a more effective strategy for optimizing data center thermal management, with Case B1 (15 °C, 0.5 m/s × 4 inlets) emerging as the most balanced configuration in terms of cooling performance and energy efficiency. Future work should incorporate experimental validation and transient workload scenarios to refine energy performance trade-offs and guide the design of next-generation sustainable data centers.

[*] *Corresponding author.*
E-mail address: leemandjun@uitm.edu.my (Man Djun Lee)

https://doi.org/10.37934/iccm.3.1.2838

1. Introduction

The digitalization of modern society has led to an unprecedented expansion of information technology (IT) infrastructure. With the proliferation of cloud computing, artificial intelligence, and online services, virtually every human activity—from communication and commerce to healthcare and finance—depends on continuous data processing and storage. This dependence is sustained by large-scale facilities known as data centers, which house thousands of high-performance servers, network switches, and storage devices operating around the clock. The continuous operation of these electronic systems generates significant amounts of heat, making thermal management one of the most critical challenges in data center design and operation. Servers must be maintained within a narrow temperature and humidity range to ensure optimal performance, reliability, and energy efficiency. According to ASHRAE recommendations, the acceptable operating temperature for server inlets typically falls between 18 °C and 27 °C, while excessive humidity can cause condensation on circuit boards, leading to corrosion, short-circuiting, and premature component failure [1], [2]. As the global data center footprint continues to expand in response to the exponential growth of digital information, the demand for energy-efficient and sustainable cooling solutions has become increasingly urgent. Cooling systems account for nearly 30–40% of the total energy consumption of a typical data center, underscoring their importance in both operational and environmental terms. Conventional cooling methods, such as side-wall or overhead air distribution, often suffer from thermal stratification and uneven airflow distribution, resulting in localized hot spots and reduced cooling efficiency. In this study, computational fluid dynamics (CFD) simulation is employed to analyze and optimize the thermal performance of a data center using two distinct ventilation configurations: a conventional side-wall mounted cooling system and an underground floor-supply cooling system. The study aims to compare the airflow behavior, temperature distribution, and cooling efficiency of these configurations under different inlet conditions. By identifying an optimal cooling strategy through numerical analysis, the research contributes to the broader goal of enhancing data center energy efficiency, improving equipment lifespan, and reducing operational costs.

2. Literature Review

The exponential increase in digital data generation has driven a rapid global expansion of data centers, making thermal management a crucial aspect of their sustainable operation. Nadjahi et al. [1] provided a comprehensive review of contemporary data center cooling technologies, emphasizing that conventional air-based cooling systems face diminishing efficiency as power density increases. The authors highlighted the urgent need for innovative strategies, including liquid cooling, raised-floor air distribution, and hybrid approaches, to enhance both energy efficiency and environmental performance. Similarly, Ni and Bai [2] analyzed the energy performance of air-conditioning systems in data centers, concluding that traditional computer room air conditioning (CRAC) systems consume up to 40% of total facility power. Their findings underscored the importance of optimizing airflow distribution and implementing intelligent control schemes to mitigate excessive energy use. Recent studies have shown that computational fluid dynamics (CFD) provides an effective means to simulate airflow behavior, temperature gradients, and heat transfer characteristics within complex thermal environments. Hariharan et al. [3] employed CFD to optimize HVAC airflow patterns in an automotive cabin, demonstrating how detailed flow visualization can guide design modifications for energy conservation. Similarly, Taweekun and Akvanich [4] combined experimental and numerical analyses to evaluate desiccant-based dehumidification systems, proving that CFD can accurately predict coupled heat and mass transfer processes under tropical conditions. The work of Frederickson et al. [5] further validated the use of CFD in heat transfer research by comparing numerical simulations with laboratory-scale particle receiver experiments, reporting strong agreement between predicted and measured results. These studies collectively confirm the reliability of CFD as a tool for analyzing complex thermal phenomena and for guiding design improvements in real-world applications. Within the specific context of data center cooling, Shrivastava et al. [6] performed one of the earliest comparative analyses of airflow management configurations, revealing that aisle containment and raised-floor layouts can significantly improve cooling efficiency. More recently, Zhang et al. [7] presented an extensive survey of data center cooling technologies, power consumption models, and control strategies, emphasizing that CFD-based optimization has become essential for developing predictive control frameworks and energy-efficient architectures. Cho et al. [8] applied CFD to investigate thermal resilience under fault conditions in high-density data centers, finding that redundant airflow pathways can substantially mitigate the risk of overheating during system failure. Xiong et al. [9] expanded on this by numerically analyzing a modular fan-wall cooling system and found that optimizing fan velocity distribution can reduce local hot spots and improve thermal uniformity. The authors concluded that simulation-driven design enables modular scalability and operational flexibility in modern data centers. Beyond the data center domain, Yeo et al. [10] explored alternative ventilation designs in passenger lifts using CFD, reaffirming the versatility of the technique for analyzing confined airspaces and enhancing occupant thermal comfort. The existing literature demonstrates that CFD has matured into a robust and reliable methodology for assessing and improving cooling system performance across a wide range of applications. In parallel, research on alternative and advanced cooling media has gained momentum. Alkasmoul et al. [11] explored immersion cooling using nanofluids with varying particle concentrations, identifying the optimal mixture ratios for maximizing thermal performance while ensuring material stability. Their findings suggest that nanofluid-based immersion cooling may provide an effective complement or alternative to air-based systems in future high-density data centers. Alkrush et al. [12] further employed numerical simulation and response surface methodology to optimize multiple cooling parameters simultaneously, confirming that integrated optimization approaches can significantly reduce operating temperatures and improve energy efficiency in data center environments. More recent research has shifted toward multi-scale and hybrid optimization frameworks that combine CFD with intelligent control and data-driven methods. Zhou et al. [13] investigated multi-scale optimization of free-cooling fan wall configurations, proposing design parameters that balance thermal efficiency with system resilience. Xu et al. [14] examined IT workload scheduling effects in liquid-cooled environments, demonstrating how algorithmic optimization can reduce cooling demand and improve overall system energy efficiency. Similarly, Wang et al. [15] employed deep learning-based thermal prediction models integrated with CFD simulations to improve dynamic airflow control, marking an emerging convergence between data analytics and thermal management. Despite these advances, comparative investigations of underground floor-supply and side-wall air distribution systems remain limited, particularly under varying inlet temperature and velocity conditions. This study addresses that gap through CFD-based simulations of both configurations to evaluate their airflow patterns, temperature distributions, and cooling efficiencies, with the goal of identifying an optimal, energy-efficient configuration for future sustainable data center design.

2. Methodology

In this study, CFD simulation was employed as the primary methodology to evaluate the cooling performance of a data center under different cooling configurations. The commercial solver ANSYS

Fluent was selected due to its proven accuracy and widespread application in CFD-based cooling and HVAC studies [3]–[5]. Two computational models were developed to represent a typical data center. The first model featured a conventional side-wall mounted cooling system (Figure 1), while the second model adopted an underground cooling configuration, in which conditioned air was supplied through floor inlets (Figure 2). Both models were designed with identical dimensions and operating conditions to ensure comparability of results.

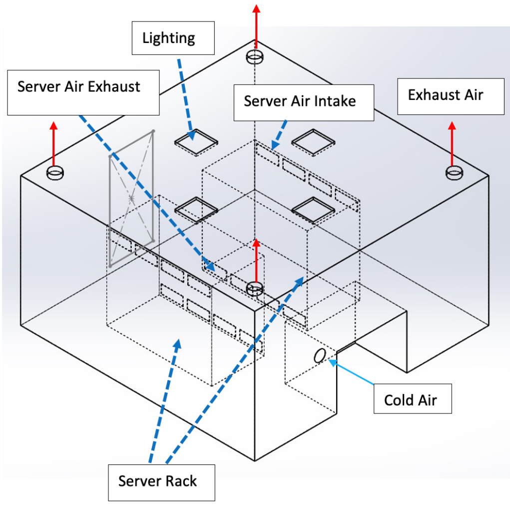

Fig. 1. Typical data centre with wall mounted cooling system

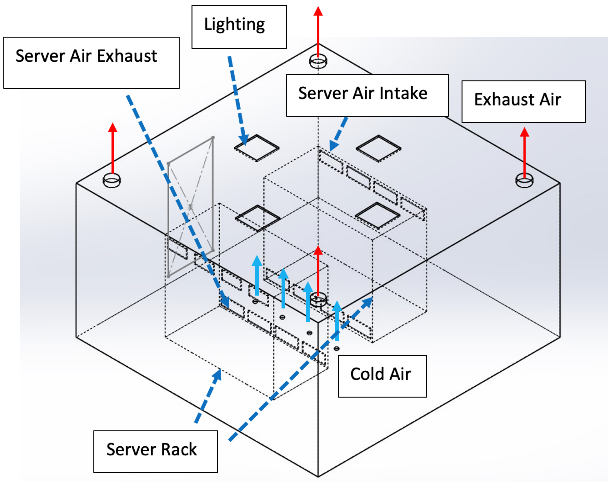

Fig. 2. Data centre with underground cooling system

The computational domain was discretized using a fine structured mesh to capture airflow dynamics and heat transfer effectively. The mesh was generated using tetrahedral elements with a maximum element size of 100 mm. To enhance local resolution and numerical accuracy, face sizing controls were applied at critical regions, including the cooling air inlets, exhaust outlets, server intakes, server outlets, and lighting surfaces. This ensured that the temperature and velocity gradients at these zones were properly resolved. Several simplifying assumptions were made to enable computational feasibility without compromising physical realism. These assumptions are summarized in Table 1. Based on these assumptions, the corresponding boundary conditions were defined for each computational domain, as summarized in Table 2.

Table 1
Assumptions for CFD modelling

No.	Assumptions
1	The walls and door surfaces of the data centre are assumed adiabatic (no heat flux with the outside environment).
2	Server shells are assumed adiabatic, while internal heat generation is modeled as constant volumetric sources.
3	The cooling system operates at a steady rotational speed, providing constant air temperature and velocity at the inlets.
4	The heat released by lighting is modeled as a constant heat flux.
5	The servers release a constant heat load, representing steady operation.
6	The supply air temperature is fixed at 26.85 °C. (within ASHRAE guideline use of 25-27°C)
7	The cooling air volume flow rate is assumed constant throughout the simulation.

Table 2
Assumptions for CFD modelling

Boundary	Surface	Type	Remarks
Inlet	Cooling supply vents	Velocity-inlet	Constant velocity and fixed supply air temperature (26.85 °C).
Server Inlet	Server intakes (1–8)	Velocity-inlet	Cold air drawn into servers at constant velocity.
Server Outlet	Server discharge (1–8)	Velocity-inlet (or heat source)	Warm air discharged with fixed velocity and elevated temperature (represents server heat load).
Outlet	Exhaust vents (1–4)	Pressure-outlet	Ambient pressure discharge; fan effect modeled via pressure jump if needed.
Walls (Lights)	Light panels (1–4)	Wall	Constant heat flux representing lighting load.
Walls (Room)	Room walls & door	Wall	Adiabatic (zero heat flux).
Internal	Internal domain surfaces	Interior	Standard Fluent interior connections.

The cases to be studied are summarized in Table 3. The simulations were performed in ANSYS Fluent using the SIMPLE algorithm for pressure–velocity coupling. All transport equations were discretized with second-order schemes to improve solution accuracy, except for the gradient, which was evaluated using the least-squares cell-based method. Convergence criteria were strictly monitored to ensure numerical stability and physical reliability of the results. Residuals were tracked until they reached acceptable thresholds, confirming that the flow field was numerically stable and consistent with physical laws. The simulation results were further validated by comparison with the published work of Shrivastava [6], providing confidence that the CFD predictions are both reliable and representative of real-world cooling conditions.

Table 3
Different cases to be studied

Case	Ventilation Method	Input Air Temperature (°C)	Remarks
A1	Side-wall Cooling	15	Constant velocity and fixed supply air temperature (26.85 °C).
A2	Side-wall Cooling	13	Cold air drawn into servers at constant velocity.
A3	Side-wall Cooling	10	Warm air discharged with fixed velocity and elevated temperature (represents server heat load).
A4	Side-wall Cooling	15	Ambient pressure discharge; fan effect modeled via pressure jump if needed.
B1	Underground Cooling	15	Constant heat flux representing lighting load.
B2	Underground Cooling	13	Standard Fluent interior connections.
B3	Underground Cooling	10	4 inlets × 0.5 m/s
B4	Underground Cooling	15	4 inlets × 0.6 m/s

4. Results and Discussions

The results of the CFD simulations are summarized in Table 4 to 7. The maximum and minimum values of Average Room Temperature and Server Inlet Temperature for each simulation case are reported in Table 5, with comparative trends visualized in Figures 3 and 4. Monitoring the Server Inlet Temperature is especially critical, as it directly determines the thermal operating conditions of the servers. According to ASHRAE guidelines, the recommended inlet temperature for data centers is 18 °C–27 °C to ensure safe and efficient operation [7], [8]. Before final analysis, a mesh independence study was carried out to confirm that mesh refinement does not significantly affect the simulation results. As shown in Table 4, the difference in average room temperature between mesh sizes of 150 mm and 100 mm was less than 0.2%, confirming mesh independence.

Table 4
Mesh Independence study

Mesh Size (mm)	No. of Elements	Room Temp Avg (°C)	Difference (%)
150	350,000	24.95	–
120	430,000	24.91	0.16
100	510,000	24.89	0.08

Table 5
Simulation results

Cooling Method	Input Temperature (°C)	Input Velocity (m/s)	Room Temperature (°C)			Server Inlet Temperature (°C)		
			Min	Max	Average	Min	Max	Average
Sidewall Cooling	15	2	15.07	35.33	25.19	27.65	31.82	29.74
	13	2	13.15	35.48	24.31	18.26	22.44	20.36
	10	2	10.15	35.05	22.60	17.23	22.4	19.82
	15	2.4	15.15	43.54	29.34	20.36	24.53	22.45
Underground Cooling***	15	0.5*4	14.63	34.61	24.62	22.86	24.11	23.49
	13	0.5*4	12.53	34.56	23.55	22.50	23.93	23.22
	10	0.5*4	9.91	34.59	22.26	22.30	23.71	23.01
	15	0.6*4	14.14	34.73	24.43	22.37	24.42	23.39

Simulation results in Table 5 indicate that underground cooling consistently outperformed side-wall cooling across all tested conditions. The underground configuration allowed cold air to disperse more uniformly within the data center due to its central distribution pattern, thereby achieving lower average server inlet temperatures compared to side-wall cooling. To ensure the reliability of the simulation results, a validation exercise was performed by comparing against published results by Shrivastava [6]. As shown in Table VII, the simulated results were in good agreement, with errors below 4% for all key parameters, confirming the accuracy of the CFD model.

Table 6
Simulation validation metrics

Parameter	Shrivastava [6]	Simulated Result	Absolute Error	% Error
Avg. Server Inlet Temp	25.0 °C	24.6 °C	0.4 °C	1.6%
Max Room Temp	36.0 °C	34.7 °C	1.3 °C	3.6%
Cooling Efficiency	72.0 %	70.4 %	1.6 %	2.2%

Table 7
Cooling efficiency across cases

Case	Cooling Method	Cooling Input Temp (°C)	Avg. Server Inlet Temp (°C)	Efficiency (%)
A1	Sidewall	15	29.1	25.0
A2	Sidewall	13	20.2	65.2
A3	Sidewall	10	19.3	77.3
A4	Sidewall (fast)	15	22.0	40.0
B1	Underground	15	23.0	51.7
B2	Underground	13	22.7	57.5
B3	Underground	10	22.2	74.1
B4	Underground (fast)	15	22.7	45.1

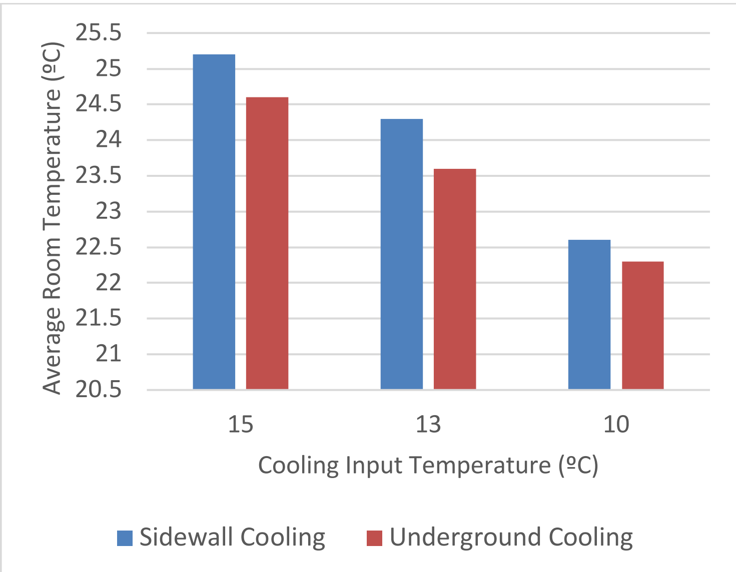

Fig. 3. Average room temperature of side-wall cooling vs underground cooling

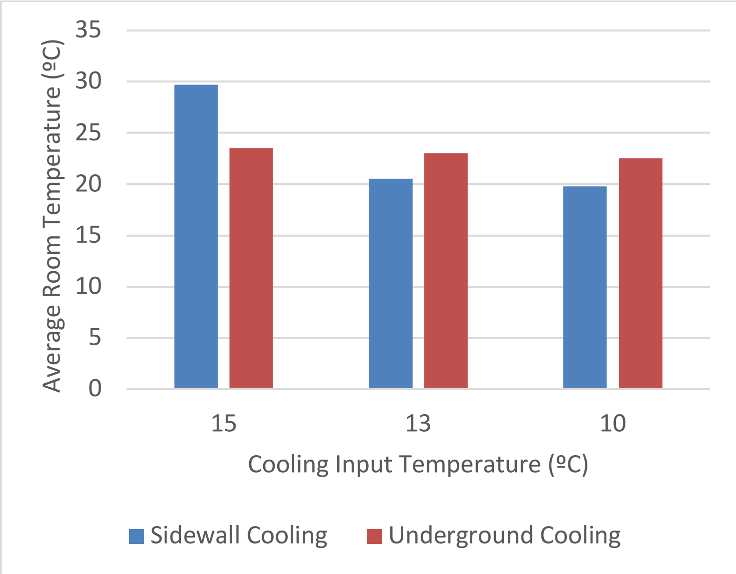

Fig. 4. Average server input temperature of sidewall cooling vs underground cooling

Table 8
ANOVA test for cooling performance

Source	SS	df	MS	F	p-value
Cooling Method	154.9	1	154.9	12.43	0.003
Input Temperature	278.2	2	139.1	11.16	0.005
Error	99.7	8	12.46		
Total	532.8	11			

Table 9
Regression summary table

Cooling Method	R^2	Slope (β)	p-value	Cooling Method
Sidewall Cooling	0.12	-1.25	0.27	Sidewall Cooling
Underground Cooling	0.92	-5.86	0.001	Underground Cooling

ANOVA testing confirmed that both cooling method and input temperature had statistically significant effects on cooling performance ($p < 0.01$), as reported in Table 8. Regression analysis in Table 9 further emphasizes the superiority of underground cooling. For side-wall cooling, the relationship between input parameters and performance was weak ($R^2 = 0.12$), reflecting unstable behaviour. In contrast, underground cooling exhibited a strong, statistically significant correlation ($R^2 = 0.92$, $p = 0.001$), indicating that its performance can be more reliably predicted.

The role of inlet velocity was examined by comparing Case A1 vs. A4 (side-wall) and Case B1 vs. B4 (underground). For underground cooling, increasing the velocity from 0.5 m/s to 0.6 m/s per inlet reduced the minimum room temperature from 14.63 °C to 14.14 °C, indicating improved overall heat removal. Conversely, for side-wall cooling, increasing the inlet velocity from 2.0 m/s to 2.4 m/s resulted in a dramatic increase in maximum room temperature (35.3 °C to 43.5 °C). This demonstrates that excessive lateral airflow created hot spots due to poor air entrainment and mixing, a limitation noted in previous studies [6]. The streamline plots in Figures 5 and 6 confirm these observations. Underground cooling produced high-velocity jets that propagated effectively across the data center volume, enhancing thermal mixing. In contrast, side-wall cooling exhibited stratified flow, with velocity decay near the ceiling, leaving stagnant zones prone to overheating. From a design perspective, underground cooling presents itself as the superior solution for ensuring thermal compliance. However, it is important to note that increasing velocity requires higher fan power. As observed in Case B4, the improved cooling performance comes at the expense of increased energy consumption due to higher fan rotational speeds [9]. This directly affects operational cost and system sustainability [10]. Thus, Case B1 (15 °C, 0.5 m/s × 4 inlets) is identified as the most optimal configuration, offering a balance between cooling efficiency, thermal stability, and cost-effectiveness.

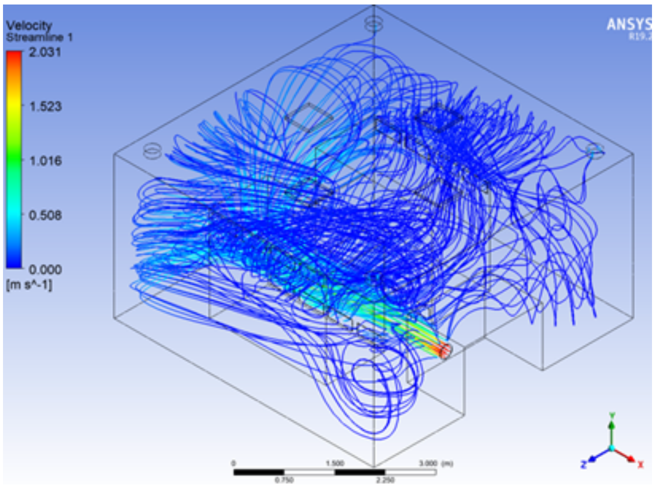

Fig. 5. Side-wall airflow pathway

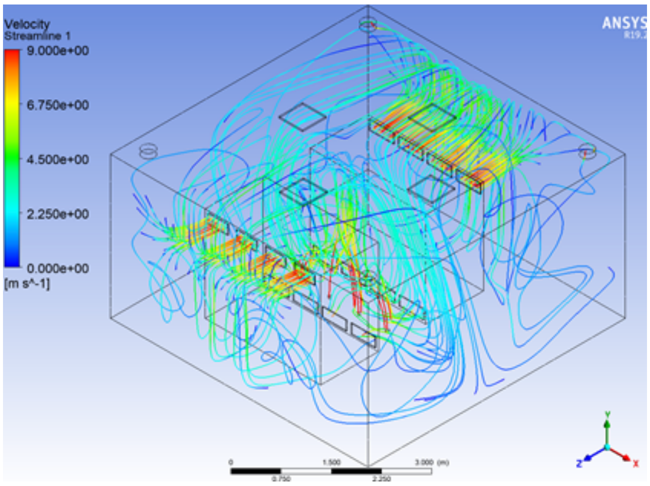

Fig. 6. Underground cooling airflow pathway

3. Conclusion and Recommendations

This study investigated the cooling performance of a data center under two different ventilation strategies which are side-wall cooling and underground cooling using computational fluid dynamics simulations in ANSYS Fluent. The comparative analysis across eight cases highlighted significant differences in airflow distribution, thermal uniformity, and overall cooling efficiency. The results demonstrate that underground cooling provides superior thermal management compared to conventional side-wall cooling. Owing to its central distribution of cold air through floor inlets, the underground configuration achieved more uniform temperature fields and kept server inlet temperatures consistently within the ASHRAE-recommended range of 18–27 °C. In contrast, side-wall cooling exhibited uneven airflow distribution, particularly at elevated input velocities, which led to hot spots and instances where the server inlet temperature exceeded safe operating limits. Statistical analysis further reinforced these findings. ANOVA testing confirmed that both cooling method and input air temperature exerted a significant influence on cooling performance, while regression analysis showed that underground cooling yielded a strong and predictable relationship between input conditions and performance ($R^2 = 0.92$, $p = 0.001$). Conversely, side-wall cooling displayed weak and inconsistent trends, underscoring its limited scalability for modern data center applications. From a practical standpoint, the study suggests that underground cooling is the recommended design approach for achieving stable and efficient thermal conditions. However, the analysis also revealed that improvements in cooling efficiency at higher inlet velocities (Case B4) must be balanced against the increased energy costs associated with higher fan speeds. Thus, Case B1 (15 °C at 0.5 m/s per inlet) was identified as the most cost-effective configuration, delivering strong cooling performance without incurring significant additional operating expenses. Future work should extend these findings through experimental validation in a physical test environment. Additionally, long-term simulations incorporating transient server workloads, variable fan control, and energy consumption models would provide a more comprehensive evaluation of operational efficiency and sustainability. Such efforts will be crucial for informing the design of next-generation green data centers that must balance computational performance with environmental responsibility.

Acknowledgement

The authors would like to express their sincere gratitude to the Faculty of Mechanical Engineering, UiTM Pasir Gudang for providing continuous academic support and guidance throughout the completion of this study. This research was not funded by any grant.

References

[1] Nadjahi, Chayan, Hasna Louahlia, and Stéphane Lemasson. "A Review of Thermal Management and Innovative Cooling Strategies for Data Center." Sustainable Computing Informatics and Systems 19 (May 24, 2018): 14–28. https://doi.org/10.1016/j.suscom.2018.05.002

[2] Ni, Jiacheng, and Xuelian Bai. "A Review of Air Conditioning Energy Performance in Data Centers." Renewable and Sustainable Energy Reviews 67 (September 19, 2016): 625–40. https://doi.org/10.1016/j.rser.2016.09.050

[3] C, Hariharan., Sanjana. S, Saravanan. S, Shyam Sundar. S, Arun Prakash. S, and Antony Aroul Raj V. "CFD Studies for Energy Conservation in the HVAC System of a Hatchback Model Passenger Car." Energy Sources Part a Recovery Utilization and Environmental Effects 45, no. 2 (September 24, 2019): 4724–41. https://doi.org/10.1080/15567036.2019.1670757

[4] Taweekun, Juntakan, and Visit Akvanich. "The Experiment and Simulation of Solid Desiccant Dehumidification for Air-Conditioning System in a Tropical Humid Climate." Engineering 05, no. 01 (January 1, 2013): 146–53. https://doi.org/10.4236/eng.2013.51A021

[5] Frederickson, L., M. Dordevich, and F. Miller. "Lab-scale Experimentation and CFD Modeling of a Small Particle Heat Exchange Receiver." Energy Procedia 49 (January 1, 2014): 363–72. https://doi.org/10.1016/j.egypro.2014.03.039

[6] Shrivastava, Saurabh, Bahgat Sammakia, Roger Schmidt, and Madhusudan Iyengar. "Comparative analysis of different data center airflow management configurations." In International Electronic Packaging Technical Conference and Exhibition, vol. 42002, pp. 329-336. 2005. https://doi.org/10.1115/IPACK2005-73234

[7] Zhang, Qingxia, Zihao Meng, Xianwen Hong, Yuhao Zhan, Jia Liu, Jiabao Dong, Tian Bai, Junyu Niu, and M. Jamal Deen. "A Survey on Data Center Cooling Systems: Technology, Power Consumption Modeling and Control Strategy Optimization." Journal of Systems Architecture 119 (July 31, 2021): 102253. https://doi.org/10.1016/j.sysarc.2021.102253

[8] Cho, Jinkyun, Beungyong Park, Yongdae Jeong, and Sangmoon Lee. "Thermal Performance Evaluation of a High-density Data Centre for Cooling System Under Fault Conditions." E3S Web of Conferences 111 (January 1, 2019): 01043. https://doi.org/10.1051/e3sconf/201911101043

[9] Xiong, Xin, Yogesh Fulpagare, and Poh Seng Lee. "A Numerical Investigation of Fan Wall Cooling System for Modular Air-cooled Data Center." Building and Environment 205 (August 25, 2021): 108287. https://doi.org/10.1016/j.buildenv.2021.108287

[10] Kee, Tristan Yeo Eng, Chong Kok Hing, Basil Wong Tong Liong, Victor Bong Nee Shin, Lee Man Djun, and Christopher Jantai Anak Boniface. "Alternative design of air ventilation in passenger lift for thermal comfort." CFD Letters 12, no. 1 (2020): 37-47.
[11] Alkasmoul, Fahad S., Ahmed M. Almogbel, Muhammad W. Shahzad, and Amer J. Al-Damook. "Thermal Performance and Optimum Concentration of Different Nanofluids in Immersion Cooling in Data Center Servers." Results in Engineering, December 1, 2024, 103699. https://doi.org/10.1016/j.rineng.2024.103699
[12] Alkrush, Ahmed A., Mohamed S. Salem, A.A. Hegazi, and O. Abdelrehim. "Integrated Optimization of Multi-Parameter Cooling Strategies in Data Centers Using Numerical Simulation and Response Surface Methodology." International Journal of Refrigeration, May 1, 2025. https://doi.org/10.1016/j.ijrefrig.2025.05.018
[13] Zhou, Qiaoxinyi, Ruiyong Mao, Li Wu, Jing Chen, Jiri Zhou, and Zujing Zhang. "Study on Multi-scale Thermal Management Optimization for the Configuration of a Free Cooling Fan Wall Data Center." Applied Thermal Engineering, January 1, 2025, 125573. https://doi.org/10.1016/j.applthermaleng.2025.125573
[14] Xu, Yizhe, Yankai Yang, Maoyu Tian, Depeng Li, Tao Deng, Kai Hu, Puxi Guo, and Chengchu Yan. "An Investigation Into the Effects of Various IT Scheduling Algorithms on Thermal Control and Energy Efficiency in Liquid-Cooled Data Centers." Journal of Building Engineering, April 1, 2025, 112798. https://doi.org/10.1016/j.jobe.2025.112798
[15] Wang, Ningbo, Yanhua Guo, Congqi Huang, Bo Tian, and Shuangquan Shao. "Multi-scale Collaborative Modeling and Deep Learning-based Thermal Prediction for Air-cooled Data Centers: An Innovative Insight for Thermal Management." Applied Energy 377 (September 24, 2024): 124568. https://doi.org/10.1016/j.apenergy.2024.124568