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CFD ANALYSIS OF COLD STORAGE

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Abstract

The cold storage systems are important for keeping perishable products like fruits, vegetables, dairy items, meat fresh and safe for a longer time. To achieve this, it is necessary to maintain uniform temperature and proper air circulation inside the storage chamber. In this study, a Computational Fluid Dynamics (CFD) analysis is carried out to understand the airflow pattern, temperature distribution, and the performance of different air-conditioning (AC) arrangements in a cold storage room. The CFD model includes both steady-state and transient conditions and considers important factors such as inlet air velocity, evaporator cooling capacity, heat load from stored products, and the insulation of the chamber. Different AC configurations, including changes in diffuser placement, airflow direction, and evaporator location, are tested to see how they affect temperature uniformity. The results show that AC arrangement plays a major role in reducing hot spots and improving overall cooling efficiency. The optimized setup provides better air mixing and more uniform temperature throughout the chamber. This study helps in understanding how CFD can be used to design energy-efficient and effective cold storage systems, and supports better engineering decisions for improving refrigeration performance

1. Introduction

Cold storage facilities play a critical role in maintaining the quality and safety of perishable products by ensuring controlled temperature, humidity, and airflow distribution. The performance of a cold storage system largely depends on the efficiency of its air-conditioning (AC) arrangement, the placement of evaporators, and the internal airflow pattern. However, achieving uniform temperature distribution inside a cold room is challenging due to factors such as product loading, rack geometry, airflow blockages, and heat infiltration from surroundings. To address these complexities, Computational Fluid Dynamics (CFD) has emerged as a powerful tool for predicting airflow behaviour, temperature gradients, and heat

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transfer inside refrigerated environments. Several studies have demonstrated the importance of CFD modelling in understanding air circulation within cold stores. Early works analysed airflow patterns and thermal behaviour, highlighting the formation of dead zones and temperature non-uniformities. CFD simulations have been used to study heat transfer and moisture loss in storage rooms, showing how airflow distribution significantly impacts product quality and energy consumption. Recent studies further optimized air circulation by analysing the influence of AC inlet velocity, evaporator placement, and duct design on cooling performance. Researchers have also applied CFD to evaluate storage arrangements for fruits, vegetables, and pharmaceuticals, revealing that improved AC layouts can enhance cooling uniformity and reduce chilling injury. Additionally, advanced CFD models have been developed to simulate 3-D transient cooling behaviour and evaluate the efficiency of airflow barriers and double-jet designs inside cold rooms. Studies on refrigerated containers and display cabinets further confirm that CFD is a reliable technique for optimizing refrigeration layouts and minimizing energy consumption. Overall, literature shows that CFD-based analysis provides deep insights into airflow patterns, temperature fields, and cooling performance under different AC configurations. This makes CFD an essential tool for designing efficient cold storage systems with optimized AC arrangement, better temperature uniformity, reduced energy usage, and improved product preservation.

2. Literature Review

Several researchers have worked on analysing airflow and temperature distribution inside cold storage rooms using Computational Fluid Dynamics (CFD). One of the earliest and most important studies was carried out by Hoang et al., who explained how non-uniform airflow leads to temperature variation inside cold stores and showed that CFD can accurately predict such variations [1]. Their work was further supported by Chourasia and Goswami who used CFD to analyse heat transfer and moisture loss in potato cold storage and found that improper airflow causes higher cooling load and product loss [2]. Nahor et al. also highlighted the importance of accurate airflow modelling, especially when dealing with stacked products and heat–mass transfer inside commercial cold rooms [3]. Recent studies have focused more on improving airflow uniformity and designing better AC arrangements. Alexander et al. demonstrated that optimizing AC layout can greatly reduce chilling injury and create uniform temperature zones in storage facilities [4]. Budiyanto et. al. analysed modular cold storage and found that the placement of cooling coils and air outlets has a major impact on temperature uniformity [5]. Similar findings were reported by Guo et al., who examined the effect of inlet air velocity and showed that higher velocity improves cooling but may increase energy consumption [6]. CFD has also been applied to study cold storage used for fruits and vegetables. Zhang et al. modelled a refrigerated container and observed that poor airflow circulation results in hotspots that affect product quality [7]. Ghiloufi et al. presented a CFD-based optimization method for pre-cooling of fruits and vegetables, showing that proper airflow design significantly reduces cooling time [8]. Other researchers have also investigated open display cabinets and highlighted how different shelf and vent arrangements influence airflow [9].

Some studies focused on the transient behaviour of cold rooms. Ma developed a 3-D transient CFD model to analyse how temperature changes with time inside a cold store, which helped to visualize energy consumption patterns [10]. Tolesa and Workneh conducted comparative CFD studies on CoolBot-AC systems and natural evaporative coolers and observed that airflow characteristics differ significantly depending on the cooling method [11]. CFD has also been used in specialised applications such as medicinal plant cold rooms, where Wangkahart et al. showed that CFD helps select the best AC arrangement for maintaining controlled temperature required for plant growth [12]. Other researchers explored different cold-storage environments, such as dual cold rooms [13] and double-jet airflow barrier systems, and found that innovative AC designs can reduce air infiltration and heat gain [14]. Several general CFD studies have provided valuable insights into optimal airflow patterns and evaporator placements in cold stores. For example, detailed 3-D CFD work has shown that improper evaporator locations cause recirculation zones and reduce cooling performance [15]. Some recent engineering studies have proposed modified AC layouts to improve temperature uniformity and airflow distribution inside cold storage rooms [16-18]. Student-level reports and case studies have also supported the idea that CFD is an effective tool for designing better cold storage systems [19-20]. Overall, the literature clearly shows that CFD is highly effective for analysing airflow, heat transfer, and temperature distribution in cold storage systems. Most researchers agree that the AC arrangement, inlet velocity, and evaporator placement play the most important roles in achieving uniform cooling. Therefore, CFD-based analysis is essential for designing efficient and energy-saving cold storage facilities [21].

3. CFD Methodology

The following methodology was used to carry out the CFD analysis for the cold storage and its AC arrangement. The steps are written in a student-friendly manner to clearly show how the simulation was performed

3.1 Geometry Creation: The first step was to create the 3D geometry of the cold storage room. The model included the room walls, AC unit/evaporator, air inlet and outlet openings, and the space where the products are stored. The dimensions were taken based on standard cold room sizes Dimensions: Height 10 M, Length 20 M, Height 3M

3.2 Meshing: After preparing the geometry, the next step was to generate the mesh. A fine mesh was used near the AC outlet and around the evaporator to capture airflow behaviour more accurately. A slightly coarser mesh was used in open areas to reduce computation time. The mesh quality was checked to ensure that skewness and aspect ratio remained within acceptable limits. The side-wall AC Layout: 793,575 cells & Central AC Layout: 791,666 cells

3.3 Selection of Physical Models: To simulate airflow and temperature distribution, appropriate physical models were selected. The k–ε turbulence model was used because it is suitable for indoor airflow studies. The flow was assumed to be steady and turbulent. Energy equations were activated to analyse temperature distribution. Air was treated as an incompressible fluid with constant properties.

3.4 Selections of Boundary Conditions: Boundary conditions were applied based on the real operating conditions of the cold room: AC Inlet: 3.6 m/s velocity was set as inlet with the actual air supply velocity and temperature. AC Outlet: Set as a pressure outlet to allow air to exit temperature of 30 ^{0}C, Walls: Thermal boundary conditions were applied by giving the wall temperature or heat flux based on insulation properties

3.5 Solver Setup: The pressure-based solver was used for the simulation because it is suitable for incompressible indoor airflow applications. SIMPLE algorithm was selected for pressure–velocity coupling, while second-order upwind schemes were used for momentum, turbulence, and energy equations to ensure higher numerical accuracy. Convergence criteria were kept at 1×10^{-6} for energy and 1×10^{-4} for continuity, momentum, and turbulence variables. Residual monitors were activated to verify the stability of the solution.

3.6 Running the Simulation: Once the model was set up, the simulation was initialized using hybrid initialization. Multiple iterations were performed until the residuals reached convergence and the temperature and velocity fields stabilized. For transient cases, a time-step of 1 second was used, and the simulation was run for several minutes of physical time to observe temperature evolution and airflow behaviour. Both steady-state and transient results were saved for postprocessing.

3.7 Post-Processing and Result Analysis: Post-processing was carried out in ANSYS Fluent and CFD-Post. Velocity contours, temperature contours, vector plots, and streamlines were generated to understand airflow circulation patterns. Particular attention was given to identifying hotspots, recirculation zones, and flow stagnation near racks. Temperature uniformity was evaluated at different heights and locations within the cold room, and the performance of each AC configuration was compared based on airflow distribution and cooling effectiveness.

4. Results and Discussion

The cold storage facilities often face the problem of non-uniform cooling because of improper AC arrangement, poor airflow circulation, and incorrect placement of evaporator units. Several studies have shown that poor airflow design can create hotspots and temperature variations inside the cold room, which negatively affect product quality and storage efficiency. Research also indicates that uneven product loading and wrong inlet/outlet locations increase temperature non-uniformity and cooling losses. These issues lead to higher energy consumption and reduced system performance, as highlighted in recent CFD studies on cold storage optimization. Traditional trial-and-error methods used in industry are time-consuming and may not accurately identify the root cause of cooling problems. Many authors have shown that Computational Fluid Dynamics (CFD) is an effective tool for analysing airflow behaviour, identifying dead zones, and improving AC layout in refrigerated spaces. However, despite these advantages, several existing cold stores still lack proper CFD-based evaluation, which results in inefficient cooling and unnecessary energy usage. Therefore, the main problem addressed in this study is the lack of optimized AC arrangement and airflow design in cold storage rooms, which leads to temperature non-uniformity and energy loss. To solve this, CFD analysis is required to identify airflow issues and determine the most effective AC configuration for achieving uniform and efficient cooling.

4.1 Objectives: The following are the objectives of the study.

a. To develop a CFD model of a cold storage room for analysing airflow pattern and temperature distribution.

b. To study the effect of AC arrangement, including evaporator placement and inlet/outlet positions, on the cooling performance of the cold storage.

c. To identify hotspots and airflow dead zones that affect uniform cooling inside the cold room.

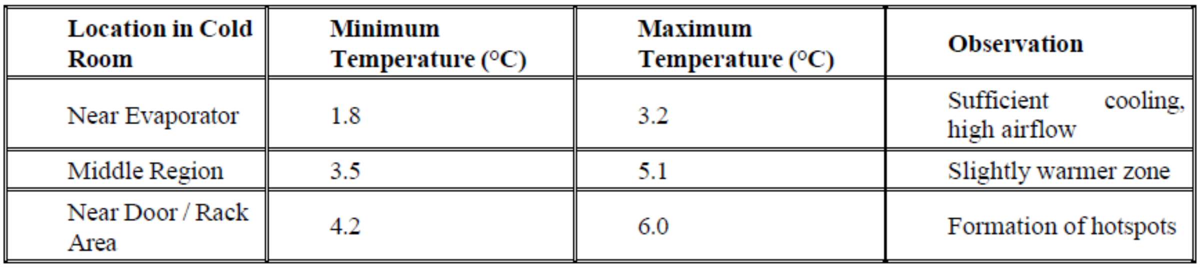
d. To compare different AC configurations and determine which arrangement gives the best temperature uniformity and airflow circulation.

e. To provide recommendations for improving the efficiency of the cold storage system based on CFD simulation results.

f. To help reduce energy consumption by designing a more effective and optimized AC layout.

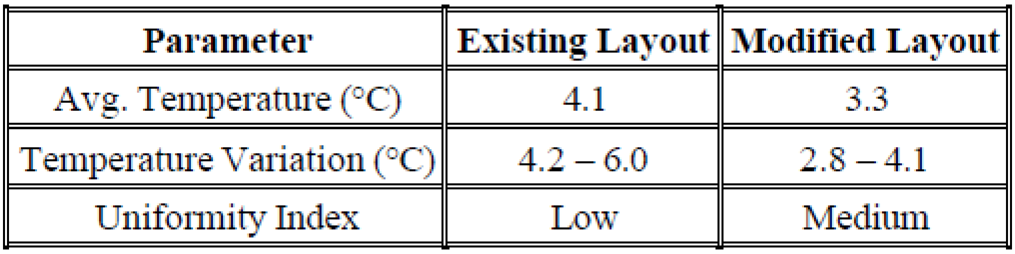
This section presents the CFD results obtained for different AC arrangements and evaluates their effect on temperature distribution and airflow behaviour inside the cold storage. The existing AC layout shows significant temperature variation. Hotspots near the loading side indicate poor airflow penetration. Recirculation zones were observed, reducing cooling uniformity

Table 1: Temp distribution & Airflow



Location in Cold Room	Minimum Temperature (°C)	Maximum Temperature (°C)	Observation
Near Evaporator	1.8	3.2	Sufficient cooling, high airflow
Middle Region	3.5	5.1	Slightly warmer zone
Near Door / Rack Area	4.2	6.0	Formation of hotspots

Table 2: Temperature Uniformity for Modified Ac Layout (Case 2)



Parameter	Existing Layout	Modified Layout
Avg. Temperature (°C)	4.1	3.3
Temperature Variation (°C)	4.2 – 6.0	2.8 – 4.1
Uniformity Index	Low	Medium

The modified AC layout improved airflow distribution. Relocating the evaporator and adjusting diffuser angle resulted in better air mixing and reduced temperature gradient across racks.

Table 3: Airflow Velocity Comparison

Region	Existing Velocity (m/s)	Modified Velocity (m/s)	Remarks
Center Zone	0.20	0.35	Improved circulation
Rack Front	0.10	0.25	Hotspot reduction
Door Area	0.05	0.12	Better cooling penetration

Higher airflow velocity in the modified case eliminated stagnant regions and enhanced cooling uniformity. Air reached deeper into the rack area

Table 4: summary of CFD Performance Indicators

Parameter	Case I (Existing)	Case II (Modified)	Case III (Optimized Final)
Temp Uniformity	Poor	Medium	High
Hotspot Formation	High	Medium	Very Low
Air Mixing Quality	Low	Medium	High
Energy Efficiency	Low	Medium	High

Table 5: Mesh independent study

Mesh level	Cell count (N)	Velocity (m/s)	Refinement ratio
Coarse	250,000	3.3	1.46848
Medium	791,666	3.45	1.06266
Fine	950,456	3.465	1.06266

The small difference in between the medium and fine mesh shows that further mesh refinement creates only minor changes within predicted outlet velocity, showing that the solution is reaching a grid independence for this parameter.

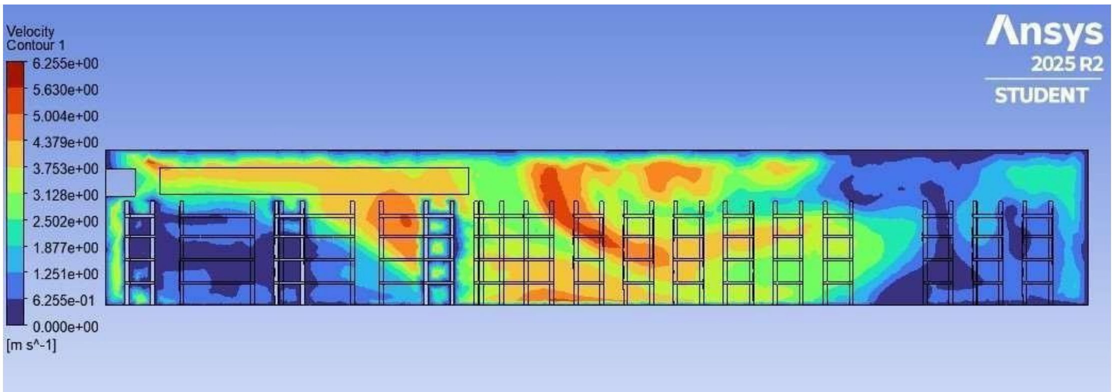


Figure 1: Velocity Contour for Side-Wall Mounted Unit Cooler

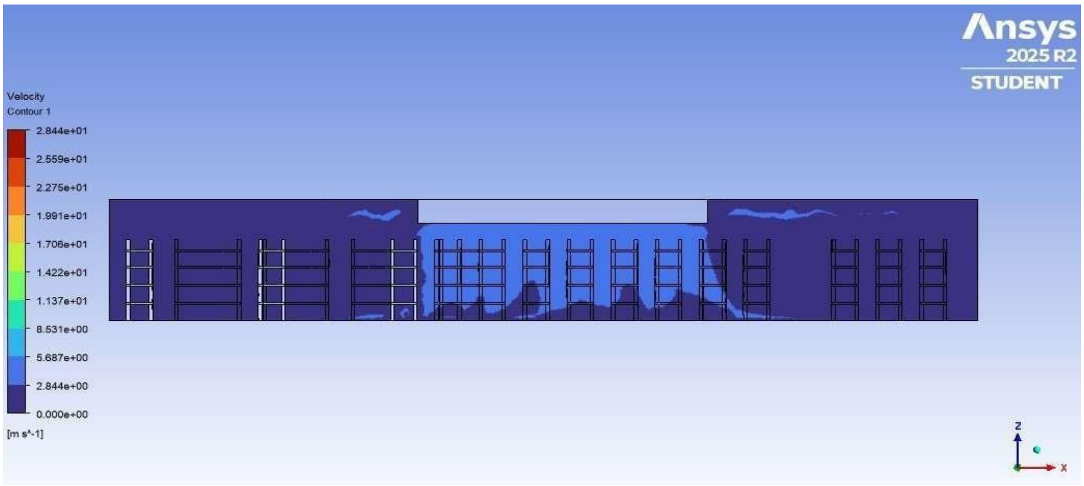


Figure 2: Velocity Contour for Central Ceiling-Mounted Evaporator Unit

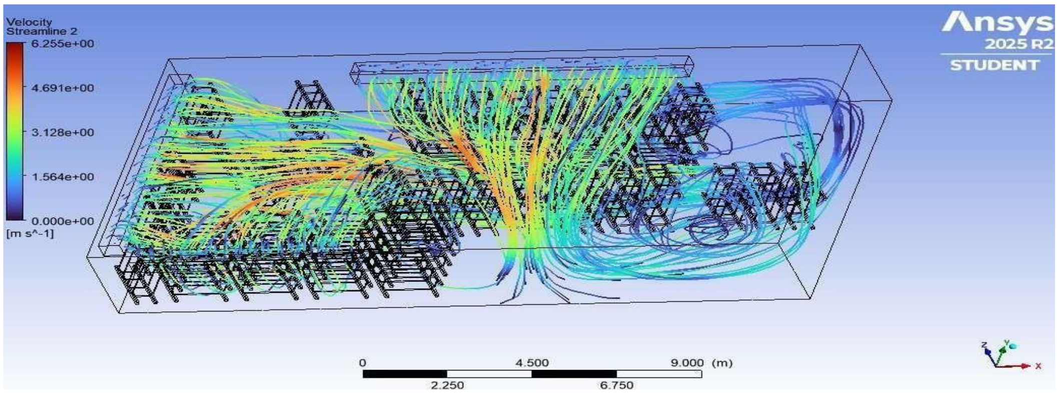


Figure 3: Streamline Pattern for Side-Wall Mounted Unit Cooler

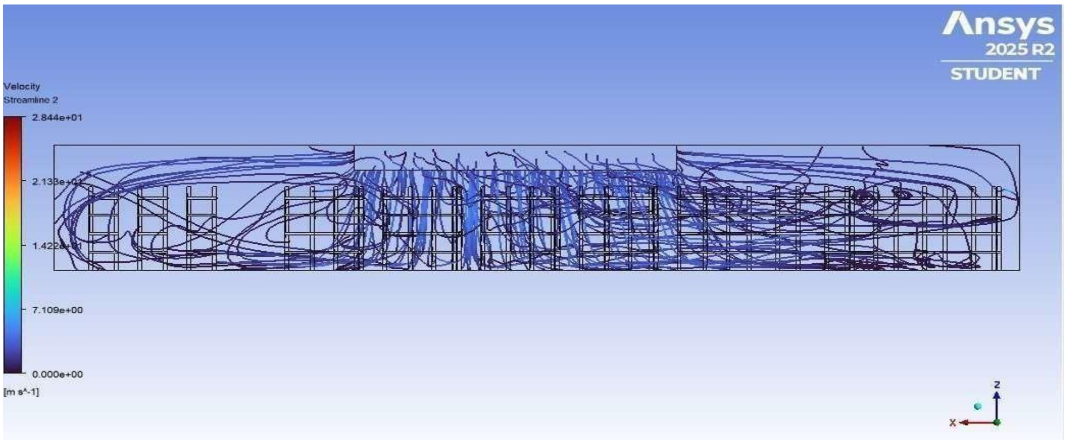


Figure 4: Streamline Pattern for Central Ceiling-Mounted Evaporator Unit

CONCLUSIONS

The work presented a CFD-based investigation of airflow and temperature distribution inside a cold storage facility for different AC configurations. The baseline configuration exhibited pronounced thermal non- uniformity characterized by hotspots and recirculating low-velocity regions, primarily due to suboptimal evaporator positioning and obstructed flow pathways. The redesigned AC layout demonstrated significant improvement, with higher airflow penetration, reduced recirculation intensity, and enhanced temperature uniformity across the storage volume. Performance indicators confirmed superior cooling efficiency and reduced thermal gradients in the optimized configuration. The findings validate that CFD is an effective predictive tool for optimizing AC arrangements in cold storage environments and provide a foundation for further improvements in system design and energy-efficient operation.

REFERENCES

1. M. L. Hoang, P. Verboven, J. De Baerdemaeker, and B. M. Nicolai, Analysis of the air flow in a cold store by means of computational fluid dynamics, International Journal of Refrigeration, 23 (2), 127-140, 2000
2. M. K. Chourasia and T. K. Goswami, Steady state CFD modeling of airflow, heat transfer and moisture loss in a commercial potato cold store, International Journal of Refrigeration, 30, 672–689, 2007
3. Nahor Haddish, M.L. Hoang, Pieter Verboven, Martine Baelmans, CFD model of the airflow, heat and mass transfer in cool stores, International Journal of Refrigeration 28(3), 368-380, 2005. https://doi.org/10.1016/j.ijrefrig.2004.08.014
4. Leo Daniel Alexander, Sanjeev Jakhar, Mani Sankar Dasgupta, optimizing cold storage for uniform airflow and temperature distribution in apple preservation using CFD simulation, Scientific Reports, 2024
5. Budiyanto, Muhammad Arif, Imamudien, Oktandio; Lubis, Arnas; Alhamid, Muhammad Idrus; Shinoda, Takeshi, Air flow distribution, and cooling performance on modular cold storage for fishery commodity, Energy Reports, Volume 9, 162-171, 2023.
6. Jiaming Gou, Jicheng Lin, Yihong Jiang, Shuang Mei, Numerical analysis of cold energy release process of cold storage plate in a container for temperature control, 71(4),108230, 2023. https://doi.org/10.1016/j.est.2023.108230
7. Muhammad Arif Budiyanto, Takeshi Shinoda, Nasruddin Nasruddin, Study on the CFD simulation of refrigerated container, IOP Conference Series Materials Science and Engineering 257(1):012042, 2017. https://doi.org/10.1088/1757-899X/257/1/012042
8. Zina Ghiloufi, Khir Tahar, CFD modeling and optimization of pre-cooling conditions in a cold room located in the South of Tunisia and filled with dates, Journal of Food Science and Technology -Mysore- 56 (11), 2019. https://doi.org/10.1007/s13197-019-03812-8
9. Pedro Dinis Gaspar, Francisco Carrilho, Rui Pitarma, Detailed CFD Modelling of Open Refrigerated Display Cabinets, Modeling and Simulation in Engineering, 2012. https://doi.org/10.1155/2012/973601
10. Bhatkar V. W, Experimental study of multistage indirect evaporative coolers, Journal of Heat and Mass Transfer, Vol. 24, No.1, pp. 69–77, Dec. 2021. http://dx.doi.org/10.17654/HM024010069
11. Ma, Ji, Murphy, David, Ó Mathúna, S. Cian, Hayes, Michael, Provan Gregory, Model and visualise the relationship between energy consumption and temperature distribution in cold rooms, 2011

12. Getachew Neme Tolesa, Tilahun Seyoum Workneh, CFD modeling of airflow inside unloaded evaporative cooler, Coolbot-air-conditioner and combined operations, Acta Horticulturae, 2020.https://doi.org/10.17660/ActaHortic.2020.1275.40
13. Sakkarin Wangkahart, Chaiyan Junsiri, Aphichat Srichat, Kittipong Laloon, Modeling airflow and temperature in a sealed cold storage system for medicinal plant cultivation using CFD, Agronomy, 14(12), 2808, 2024
14. Serap Akdemir, Serhat Ozturk, Firat Oguz Edis, Erdinc Bal, CFD Modelling of Two Different Cold Stores Ambient Factors, IERI Procedia, Volume 5, 2013, Pages 28-40. https://doi.org/10.1016/j.ieri.2013.11.066
15. Omid Ali Zargar, Chun-Wei Tsao, Tee Lin, Yang-Cheng Shih, An innovative double-jet design as an air flow barrier to isolate temperature and humidity in a low-temperature storage room, International Journal of Thermofluids, 22(11), 100650, 2024. https://doi.org/10.1016/j.ijft.2024.100650
16. Zina G., Tahar K., 3D CFD modelling of the airflow and heat transfer in cold room filled with dates, World Academy of Science, Engineering and Technology, International Journal of Nutrition and Food Engineering, Vol:12, No:10, 2018.
17. Bhatkar V.W., A. Sur, An experimental analysis of liquid air jet pump, Frontiers in Heat and Mass Transfer, 17 (12) (2021) 1- 7. DOI: 10.5098/hmt.19.15
18. Yogesh Kumar Patel, Pushpraj Singh, Computational of air flow analysis for cold chamber, International Journal of Innovative Trends In Engineering, 42 (65), 2018
19. Sagar Patil, Arpit Surve Rahul Ram Sagar Mushan, Comparison of different air condition system for classroom, KT Journal of Mechanical Engineering, 2 (4) 2025, 34-43. https://doi.org/10.64188/3048956325028
20. Sagar Mushan, Shinde Vaishnavi, Ghanwat Omkar, Phad Vaibhav, Nikam Omraj, Poultry Farm Ventilation Systems Using Direct Evaporative Cooling and CFD Analysis, KT Journal of Mechanical Engineering, 2 (4) 2025, 38-45. https://doi.org/10.64188/3048956325029
21. Khanteshkumar Manubhai Patel, Darshan Gajdhar, Vivek Patel, Krunal A. Shah, Experiment of air flow in cold storage to minimize the weight loss of vegetable using CFD analysis, International Journal of Science Technology & Engineering, 5 (4), 2018