IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 13, Issue 2 Ver. III (Mar- Apr. 2016), PP 81-92
www.iosrjournals.org

Flow Patterns and Thermal Behaviour in a Large Refrigerated Store

Amr Kaood*, Essam E. Khalil** andGamal M. El-Hariry
Faculty of Engineering, Cairo University, Egypt

Abstract: *Refrigeration for the cold storage of perishable foods has been utilized for more than a century. The need for refrigerated storage grows with hot weather. The frozen food industry expanded many times in freezer storage in a few decades after World War II. Cold storage facilities are also significant energy consumers that call for attention to thermal behavior as it greatly influences the cost. Proper design to improve thermal behavior of a refrigerated space requires the knowledge of air distribution and thermal conditions within the space. The frozen food quality is sensitive to both storage temperature and fluctuation in temperature. The present work made use of a computational fluid dynamics technique to adequately predict the cold storage airflow pattern variations within the cold room under variousevaporator'sarrangements of sizes, numbers and positions. Design parameters included local temperatures and velocity distributions inside a large cold store using standard k-e model with mesh element 5,400,000 tetrahedral cells.*
Different optional designs utilizing different number of evaporators were investigated as well as the locations of these evaporators according to load estimation of the cold store.
Key Words: *Cold store, Products, Air flow distribution, Pallets, Numerical simulation, CFD*

I. Introduction

Cold stores play a main rule in our life, its increase due to population growth and global warming. Maintenance of even temperature throughout the cold store is essential in order to preserve the quality, safety and shelf life of perishable food within the refrigerated enclosure, the temperature level and its homogeneity are directly governed by airflow patterns. The design of the air-distribution system should allow these airflows to compensate heat fluxes exchanged through the insulated walls or generated by the products. This process is essential in order to decrease temperature differences throughout the refrigerated room. The temperature field, which is closely related to the airflow field in storage rooms, affects the quality of stacked agricultural products. There are many factors affecting the cold store performance such as refrigeration system, frosting characteristics, air supply mode, airflow field distribution, heat insulation performance. Among these factors, air distribution is an important factor, which saves initial investigation and operating consumption [1]. The most important factor that affects quality loss is the temperature related to respiration and microbial activity; therefore, rapid and uniform cooling is required to avoid the quality loss. Proper methods of cooling may ensure the temperature uniformity of products stacked in a cold store. The cooling rate and quality of food in the cold store are highly dependent on the temperature field and velocity field, which are closely related to flow field. The flow field in the cold store is related with its volume, structure, air temperature, air supply method, refrigerator quantity, its location in the cold store [2].

II. Literature Review

2.1 Airflow pattern and temperature distribution in a typicalRefrigerated truck configuration loaded with pallets

Moureh and Flick, [3][4] in his research activity aiming to improve and to optimize air-distribution systems in refrigerated vehicles in order to decrease the temperature differences throughout palletized cargos. This condition is essential in order to preserve the quality, safety and shelf life of perishable products. The present study reports on the numerical and experimental characterization of airflow within a semi-trailer enclosure loaded with pallets. The experiments were carried out on a reduced scale (1:3.3) model of a refrigerated-vehicle trailer. The performance of ventilation and temperature homogeneity were characterized with and without supply air duct systems. Both configurations are extensively used in refrigerated transport. The numerical modeling of airflow was performed using the Computational Fluid Dynamics (CFD) code Fluent and a second moment closure, the Reynolds stress model (RSM). The results obtained using the RSM model showed good agreement with the experimental data. Numerical and experimental results clearly show the importance of air ducts in decreasing temperature differences throughout the cargo.

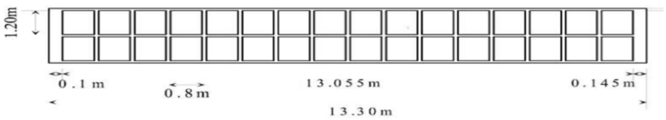


Figure 1: Top-view of cargo

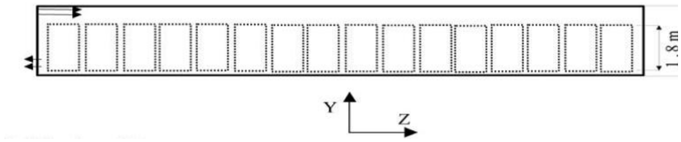


Figure 2: Side-view of cargo

2.2 Numerical simulation of temperature and velocity in a refrigerated warehouse

Ho, Rosario and Rahman, [5] this research presents air velocity and temperature distribution in a refrigerated warehouse. The refrigerated space under study has a set of ceiling-type cooling units installed in front of the arrays of stacks of palletized product packages as shown in figure .3. Numerical solutions of the steady- state airflow and heat transfer were done using a complete 3-D model and an equivalent two-dimensional model. The results obtained from both models were found to be in good agreement with each other. A parametric analysis was performed using the equivalent model with various values of blowing air velocity and locations of the cooling units. It was found that a better cooling effectiveness and uniformity of temperature in the refrigerated space could be achieved by using higher blowing air velocity and/or locating the cooling units lower and closer toward the arrays of product packages.

2.3 Computational Fluid Dynamics Simulation about Comparison of Different Forms of Return Air in a Small Cold Store

Yi, Jing, Jin-feng, , Chen, and Yi, [6] analyzed two forms of return air in the cold store as in figure 4 using the Finite Volume Methods and the SIMPLE Revised. As a result, Combined with the non-equilibrium wall function, it is found that taking the way of return air on both sides of the fan is more reasonable and the cooling consumption of the empty cold store can be saved before the products enter the cold store. Furthermore, the numerical simulation results can provide reference for choosing fans in the small cold store.

2.4 Improvement of Loaded Cold StorePerformance

Tanaka and Konishi, [7] investigated the cooling performance of a partially loaded cold store in cooling process using transient three-dimensional computational fluid dynamics model. The model accounted for turbulence by means of the standard k-e model with standard wall profiles. The model validated successfully in cooling experiments with a mean error of 0.36 m/s and 1.4^{o}C for the air velocity in a refrigerated room and the temperature of the product, respectively. Based on the model, we studied the effect of different loading patterns of corrugated fiberboard containers filled with products in a cold store on cooling effectiveness. As a result, flat loading with air gapswas the optimal configuration to achieve high uniformity of temperature and rapid cooling.

The findings of this study can help to elucidate and improve the cooling performance of refrigerated rooms for storing agricultural products.

2.5 Optimizing the Air Distribution of Large Space Cold Store Based on Numerical Methods.

Haixia, Jun& Kunfeng, [8] in his research employs numerical methods to simulate 3-D numerical flow field of large-scale low-temperature cold store.

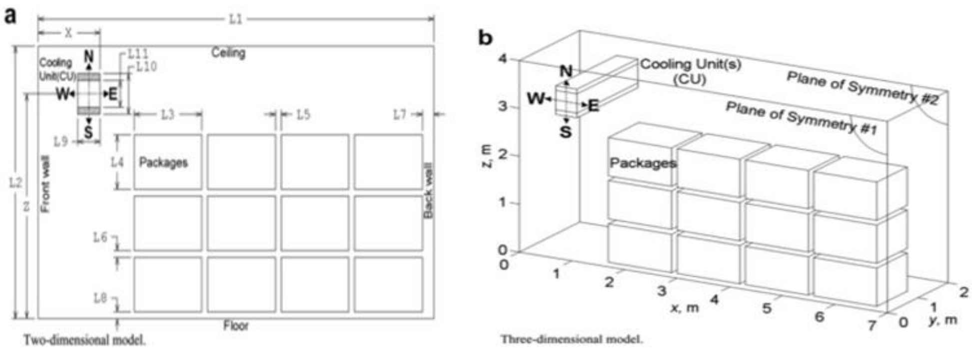


Figure 3: Two- and three-dimensional models of a refrigerated warehouse.

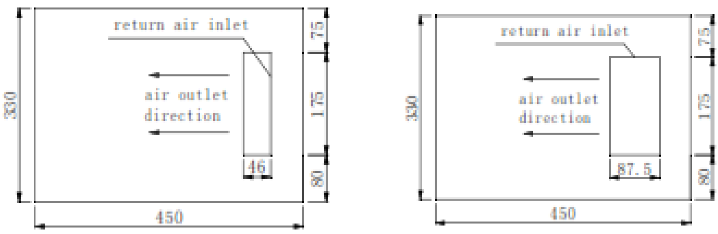


Figure 4: Different forms of return air styles at different arrangement of fan

With help of analysis on different cooler layouts as shown in the figure 6, the research shows that Staggered layout for coolers shall be adopted, under which the air flow has low velocity and even distribution in most of the space. The research method of numerical simulation is simple and convenient in comparison with experimental method which could provide conductive advice to optimization of the design of large space low-temperature cold storage.

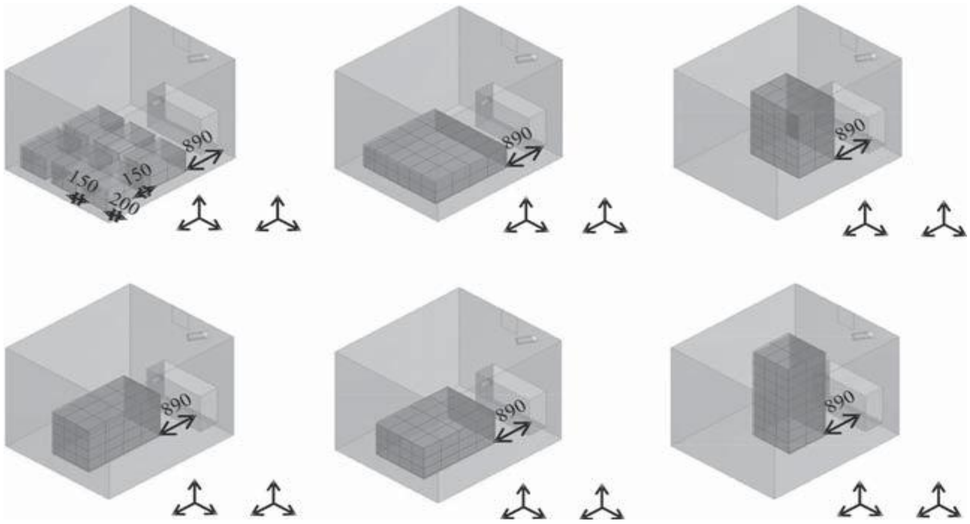


Figure 5: Sixloadingpatternsofcorrugated containersstacked in a cold store

III. Present Work

The present work is part of a research activity aiming to improve and to optimize air-distribution systems in refrigerated rooms in order to decrease the temperature differences throughout palletized cold stores. We study in the present work effect of changing of evaporator's numbers and positions on temperature and velocity distribution inside a large cold store using standard k-e model. The unstructured mesh was chosen in this work, it has been widely used in the simulation of the cold store [9] [10] [11] [12] [13] with mesh element 4,500,000 tetrahedral. Studying of different numbers of evaporators 2, 3 and set on (8) different positions is carried out inside a large cold store according to load estimation of the cold store according to ASHRAE [14][15].

IV. Mathematical Model

Large constructional cold room was chosen as a case study. Its exterior dimensions are 15 m (L) x 7.5 m (W) x 6 m (H). The thickness of the wall of cold room is 152 mm, which is made of polyurethane insolation.

The large coldstore contains 108 standard product's pallets [14] its dimensions are 1200 mm (L) x 1000 (W). Layout of the present model of the cold store is shown in figure 7 and figure 8. Evaporators were arranged inside the cold stores as shown from figure 9 to figure 12.

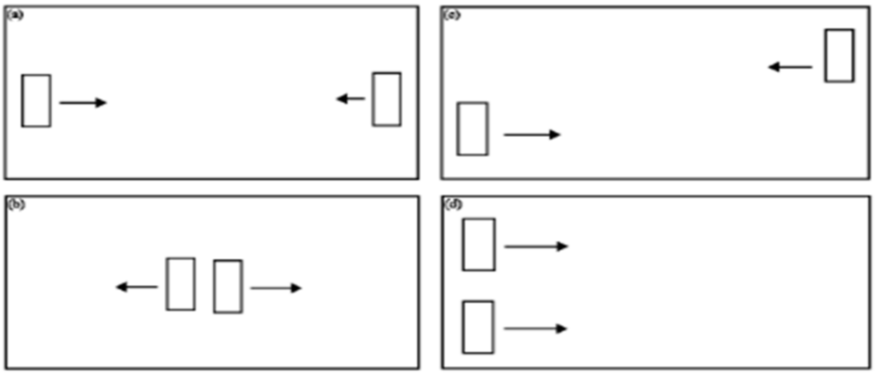


Figure 6: (a) Face to face blowing layout, (b) Back to back blowing layout, (c) Staggered layout and (d) Parallel blowing layout

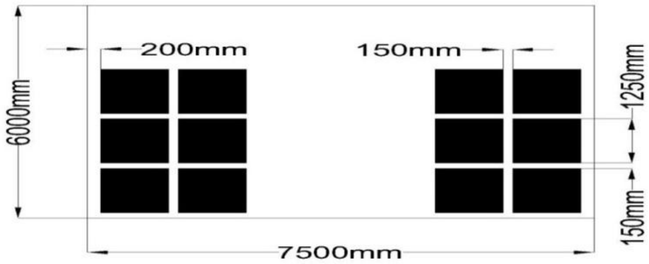


Figure 7: Layout of side-view of cold sore

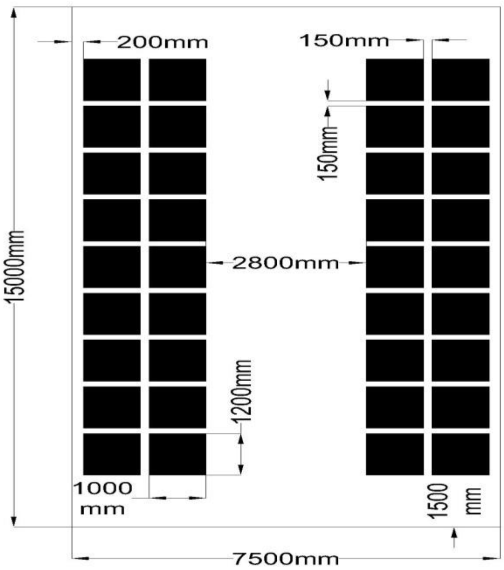


Figure 8: Layout of top-view of cold store

V. CFD Simulation

The cold store model was built in Design Modeller then a meshing was done in mesher and the steady airflow computation was finished in ANSYS Fluent 14.5. Since the unstructured mesh was more suitable to the complicated model than structured mesh, so the unstructured mesh was selected in this study [11]. In the numerical investigation, double precision was employed to increase the accuracy. The convergence criterion is achieved by solving the energy equation to residuals of 10^{-7} using segregated solver algorithm. The continuity equation was solved to a residual below of 10^{-3}. The momentum and k-ε turbulence equations were solved to residuals below of 10^{-3}. Further details of the modeling can be found in reference [16].

VI. Results And Discussion

The following figures presents the solutions of temperature for the whole pallets of products, Streamlines around pallets and Iso-Clips of temperature more than 252 k are indicated to show near zeroflow regimes.

6.1 Overview of (2- Evaporators) cases

As shown in the previous contours it is a comparison for the four cases of two Evaporators .This investigation show that the two – evaporators design is poor for good velocity and temperature distribution and it will be large dead zones with low velocity and high temperature at the outside and far pallets as in case 2-1 and case 2-2. However, the staggered arrangement of the cooling units give acceptable velocity distribution and has good uniformity index for temperature and standard deviation So that numerically case 2-4 is better than the other three cases as shown in Figure 18 which has good temperature and velocity distribution with less dead zones.

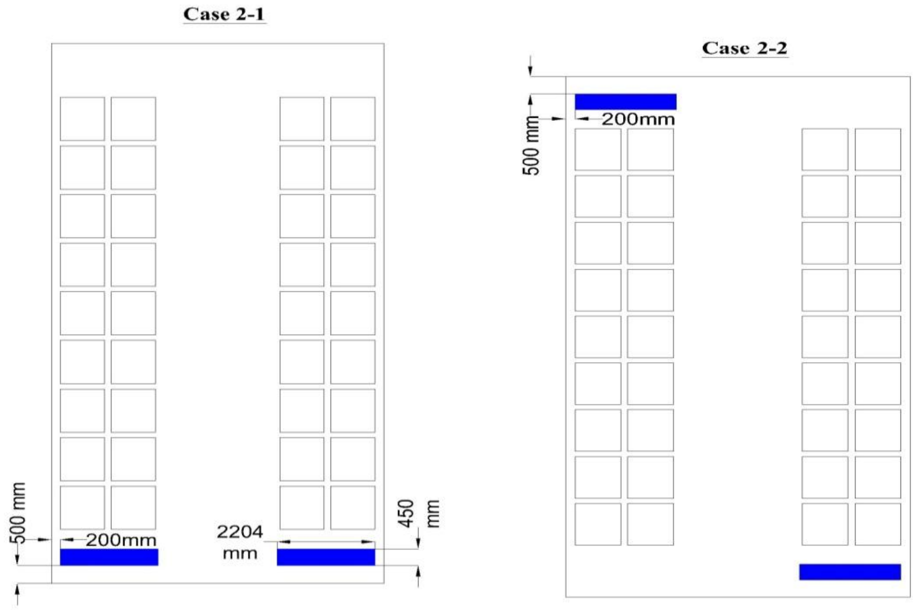


Figure 9: Layout of evaporators inside the cold store Case 2-1 and Case 2-2

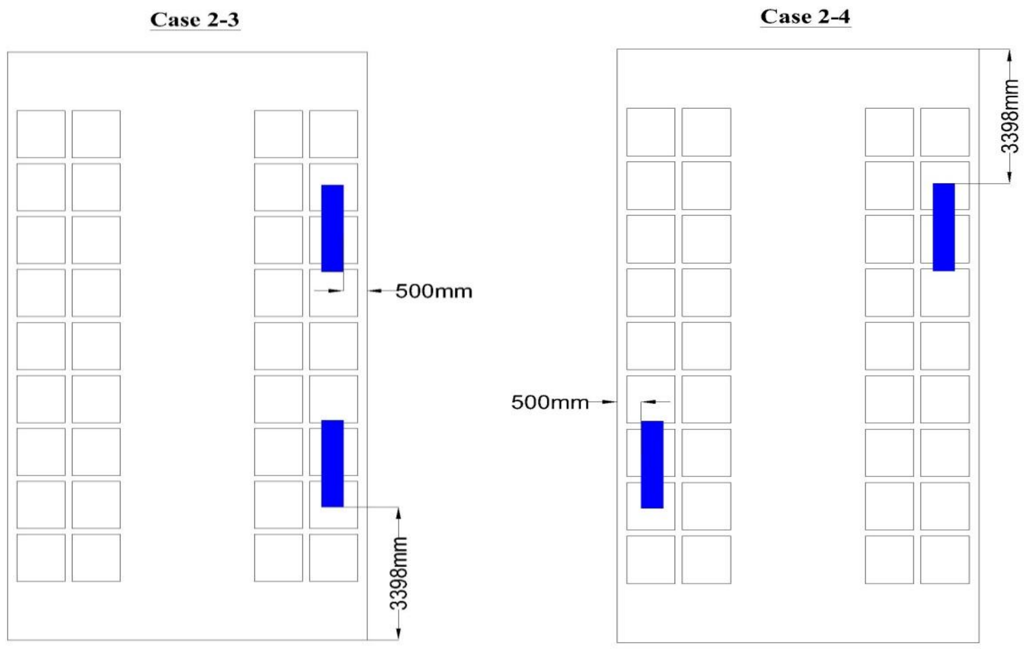


Figure 10: Layout of evaporators inside the cold store Case 2-3 and Case 2-4

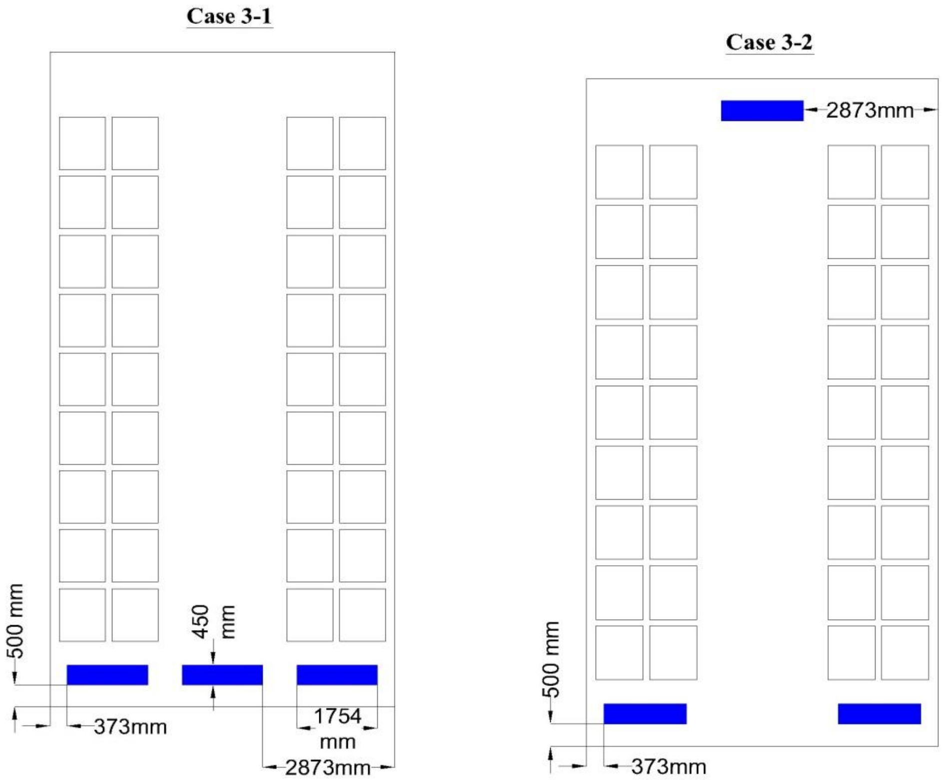


Figure 11: Layout of evaporators inside the cold store Case 3-1 and Case 3-2

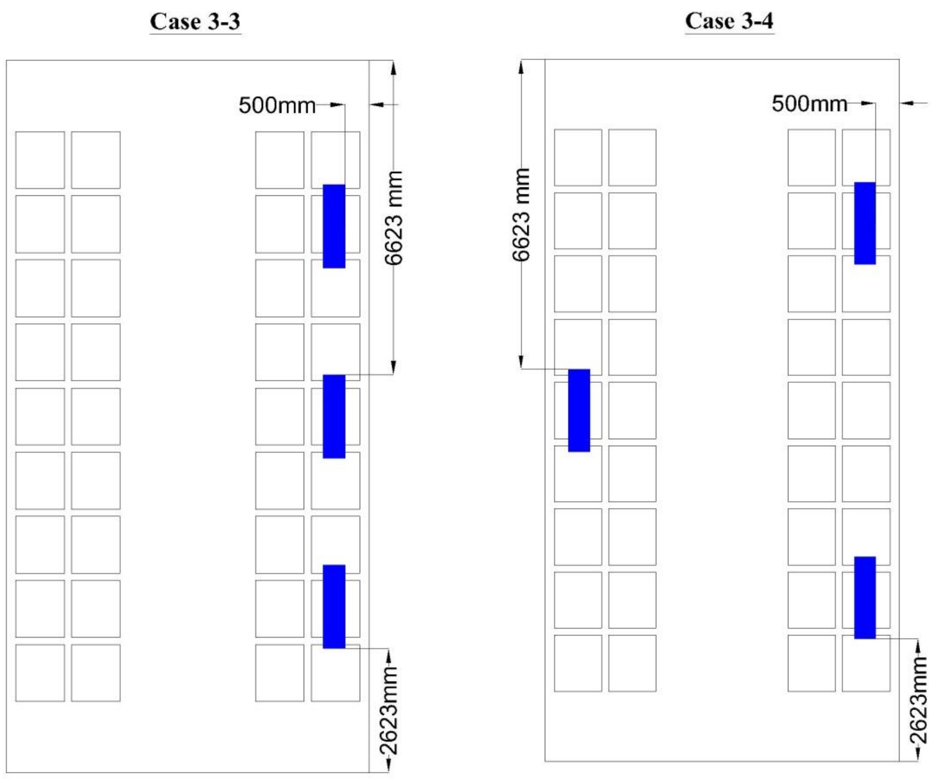
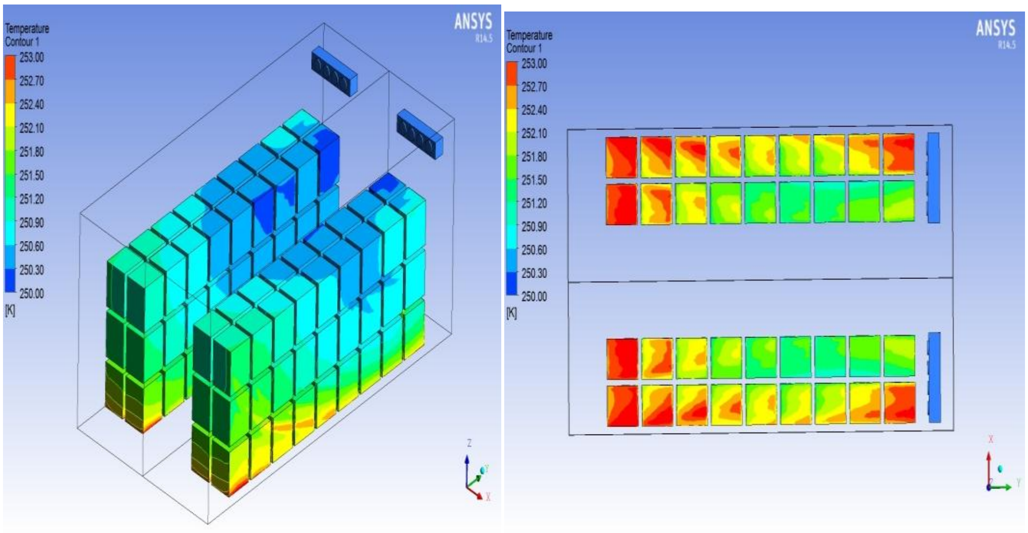


Figure 12: Layout of evaporators inside the cold store Case 3-3 and Case 3-4

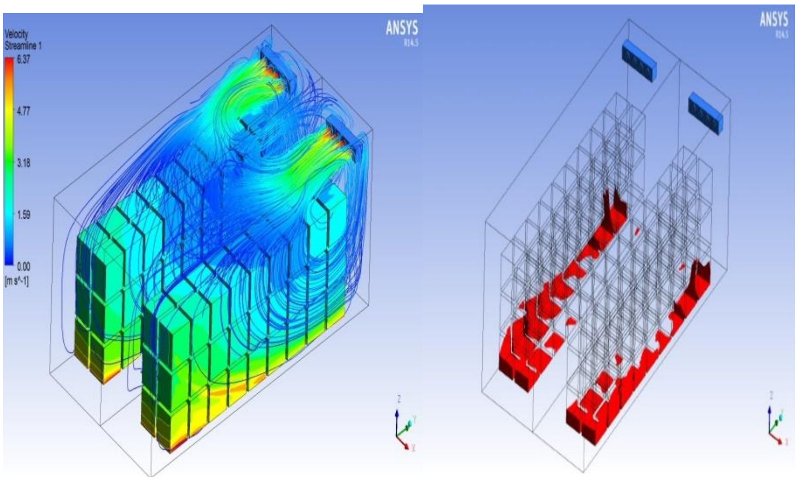
Case 2-1



a) **b)**

Figure 13: (a) Contours of temperature of Pallets in case 2-1 ,
(b) Contours of temperature of Pallets (Bottom – view) in case 2-1

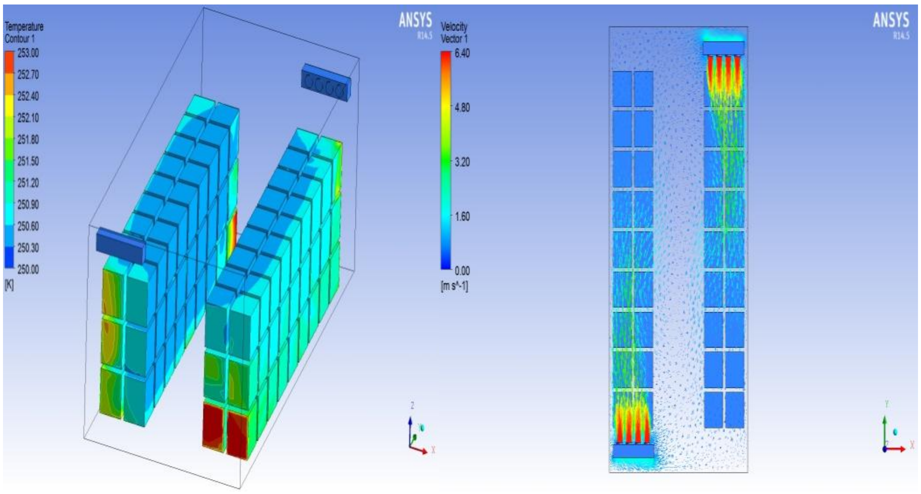
Case 2-1



a)b)

Figure 14: (a) Temperature Contours on pallets and streamlines case 2-1,
(b) Iso-Clip for temperature of pallets more than 252 K for case 2-1

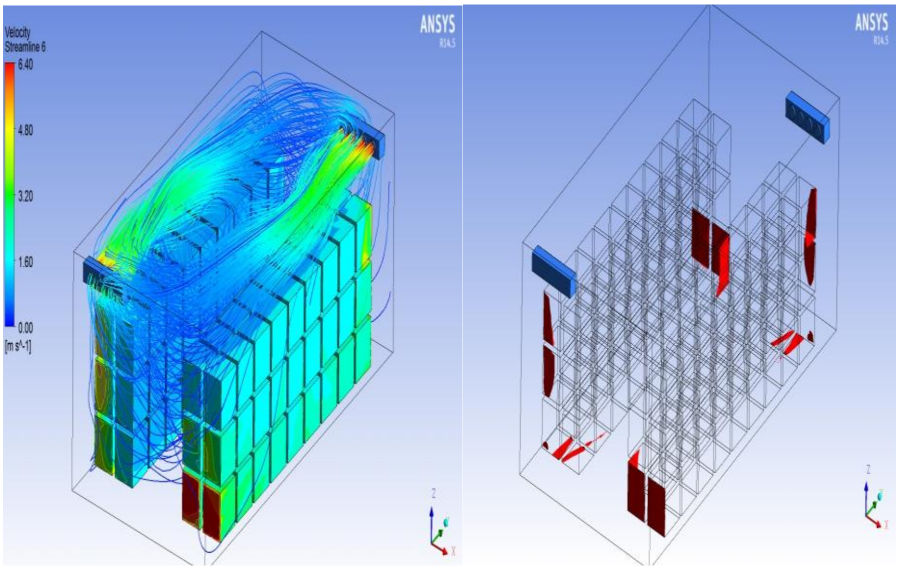
Case 2-2



a) b)

Figure 15: (a) Temperature Contours on pallets case 2-2, (b) Contours of velocity vectors at plane of height (Z = 5.36 m) case 2-2

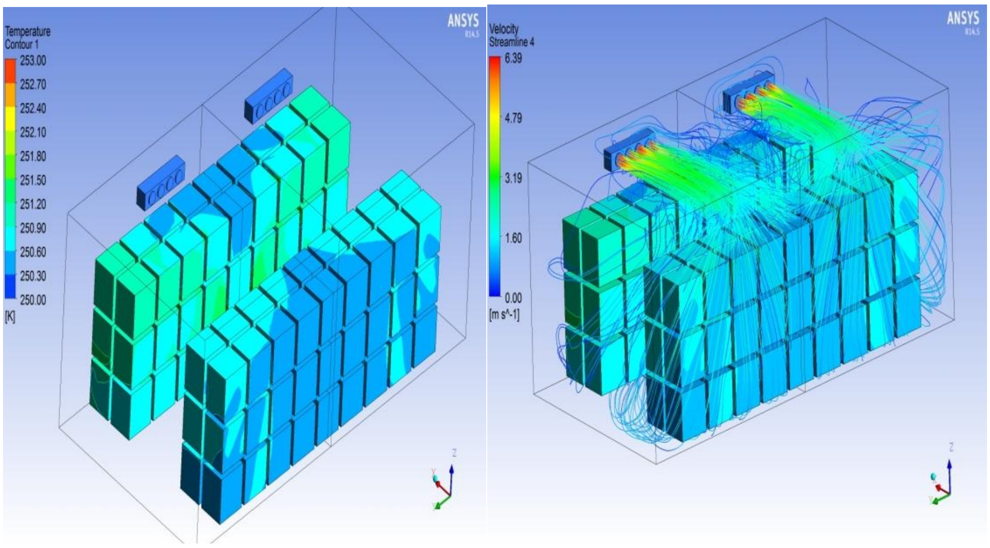
Case 2-2



a) b)

Figure 16 (a) Temperature Contours on pallets and streamlines case2-2, (b)Iso-Clip for temperature of pallets more than 252 K for case 2-2

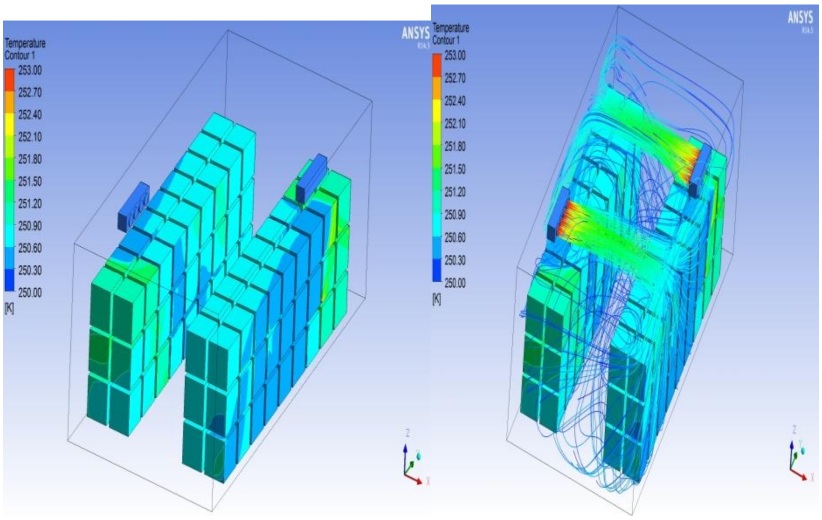
Case 2-3



a) b)

Figure 17: (a) Temperature Contours on pallets case 2-3, (b) Contours of temperatures on pallets and streamlines case 2-3

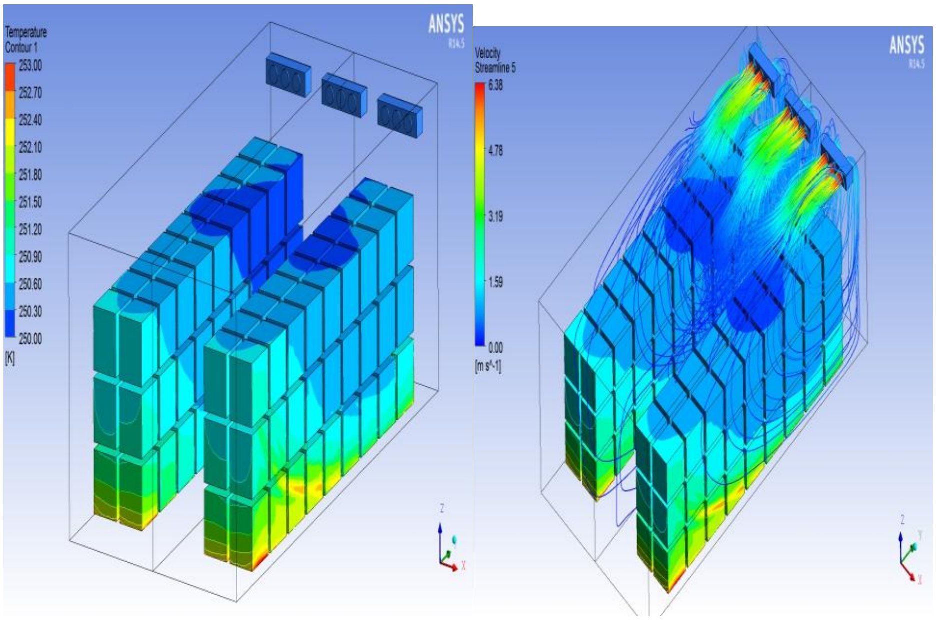
Case 2-4



a) b)

Figure 18: (a) Temperature Contours on pallets case 2-4,
(b) Contours of temperatures on pallets and streamlines case 2-4

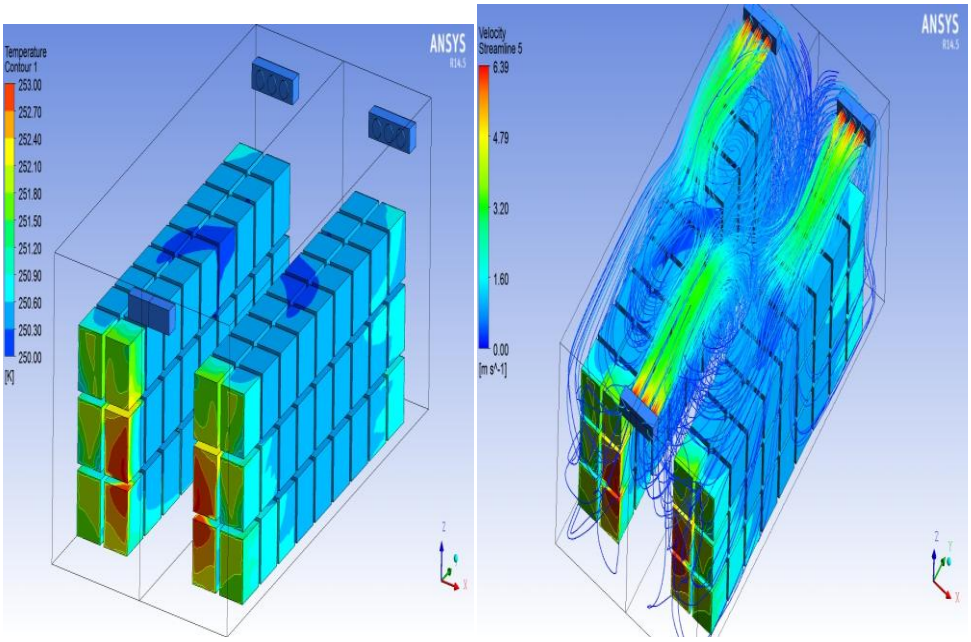
Case 3-1



a) b)

Figure 19: (a) Temperature Contours on pallets case 3-1 ,
(b) Contours of temperatures on pallets and streamlines case 3-1

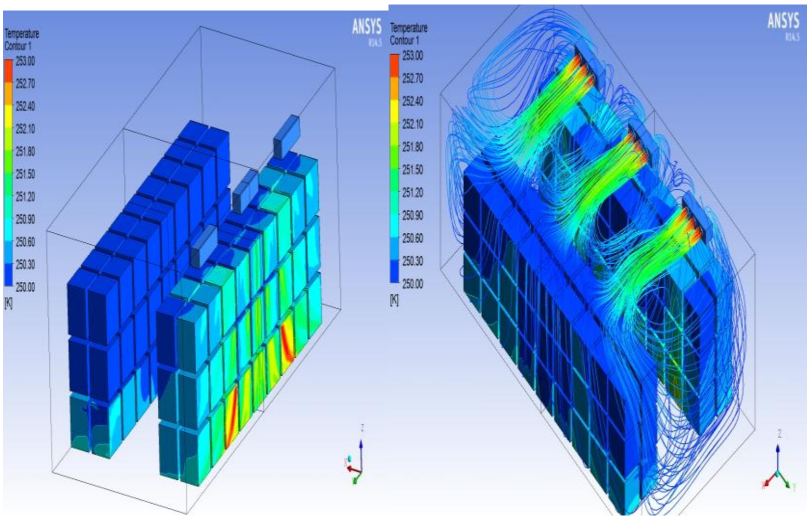
Case 3-2



a) b)

Figure 20: (a) Temperature Contours on pallets case 3-2, (b) Contours of temperatures on pallets and streamlines case 3-2

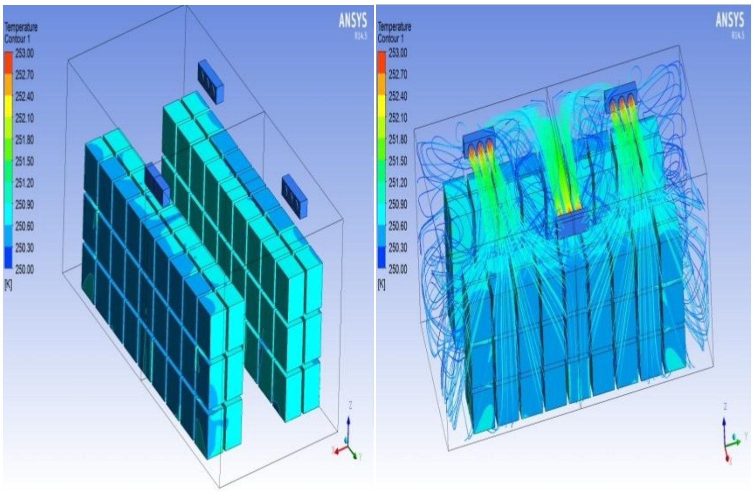
Case 3-3



a) b)

Figure 21: (a) Temperature Contours on pallets case 3-3,
(b) Contours of temperatures on pallets and streamlines case 3-3

Case 3-4



a) b)
Figure 22: (a) Temperature Contours on pallets case 3-4 ,
(b) Contours of temperatures on pallets and streamlines case 3-4

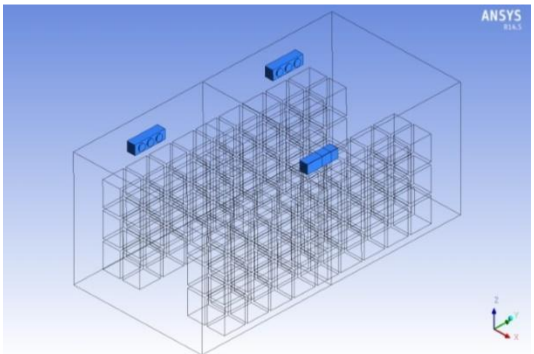


Figure 23: Iso-Clip for temperature of pallets more than 252 K for case 3-4

6.2 Overview of three Evaporatorscases

As shown in the previous contours it is a comparison for the four cases of 3 Evaporators .This investigation show that the three–evaporators design give better velocity and temperature distribution than two evaporators and it will be less dead zones with low velocity and high temperature at the outside and far rows of pallets as in case 3-1 and case 3-2. However, the staggered arrangement of the cooling units give good velocity distribution and has good uniformity index for temperature and standard deviation So that numerically case 3-4 is better than the other three cases as shown in Iso-Clip Figure 23 which indicatedbetter temperature and velocity distributions in the room without dead zones.

VII. Conclusions

In this work, a simulation model of large cold store was constructed. To improve the accuracy of the calculation, the unstructured mesh was used. Equations of (Energy, continuity, momentum and k-e) were solved. As well as Under Relaxation techniques were applied to accurately predict the performance of the airflow patterns in the cold store. It was found that CFD is a powerful tool that can simulate air pattern inside large cold store. Temperatureand velocity gradients were affected by flow field due to the numbers and locations of the cooling units (Evaporators). It was found that using of staggered design gives better flow patterns (velocity and Temperature distributions) and minimizesthe dead zones. It was found that using of large number of evaporators would give better flow field (velocity and Temperature distributions) and would minimize dead zones. It is not recommended to use two evaporators for that large cold store because it will be create large dead zones with high temperature and low air stream velocities.

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