AN ANALYSIS OF COLD STORE BY CFD SIMULATION

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ABSTRACT

This paper deals with the numerical analysis of 3d model of a cold store of dimensions 4.5 m (L) x 3.3 m (W) x 2.5 m (H), which is developed to study the effects of design parameters on flow and temperature fields within the cold store. The variation in number of inlets, position of inlets and stacking methodology affect flow and temperature fields within the cold store. Results of CFD simulation indicated the optimum position of the inlets, number of inlets and stacking methodology required to have uniform flow and temperature field within the cold store. It also proved that CFD is a convenient tool for designing and optimizing the flow field in the cold store.

Keywords: Computational fluid dynamics; Cold store; Frozen food; Numerical simulation;

INTRODUCTION

A cold store is a place where the perishable items such as fruits, vegetables, drugs, flowers are stored to minimize spoiling and thereby extending their shelf life. It retains the characteristics of food product, nutritive value and freshness of perishable items for the longer duration of time. Within the cold store, if there exists uneven distribution of temperature and air, it results in hot spots over food products stored, dull appearance on surface and loses its freshness and nutritive value. These problems could be overcome by proper design of the cold stores.

A short discussion of the previous studies of authors who attempted to focus on how the flow and temperature fields within a cold store affected by design parameters are presented here. Enhai Liu et.al [1] carried out theoretical and experimental analysis on an industrial cold storage. CFD was used for analysis of flow field inside the cold storage; the study confirmed the optimum forced air supply was 2 m/sec. Jing Xie et.al [2] studied the influence of design parameters (corner baffle, food storage) of cold store on airflow and temperature fields .S A Tassou et.al [3] proposed a model for wet-air cooled stores based on CFD analysis, in which they considered buoyancy effects also. Model identified design area problems and helped in investigating the effect of design parameters on the wet-air cooled store performance. Tanaka et.al 4] examined the cooling performance of a partially loaded cold store with large solid objects without porous media using a transient three dimensional CFD model. The effect of different loading patterns on the cooling effectiveness was studied by this author.

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Yongfu Xu et.al [5] considered a transient 3d CFD model of heat and mass transfer in porous bulks of particulate foodstuffs. Moisture diffusion and heat transfer was considered within the spherical shaped solids and the heat of respiration as an empirically derived function of temperature. They predicted moisture and temperature changes in potatoes during cooling.

The main objective of this project is to carry out the numerical simulation of the cold store in order to achieve a uniform flow and temperature field within the cold store, resulting in proper cooling of perishable goods, thus increasing their shelf life, to analyse the effect of multiple inlets (position and number of the inlets) and stacking methodology on the flow and temperature fields within the cold store.

II MATHEMATICAL FORMULATION

2.1 The physical model and coordinate system

A 3D model of a cold store is created in ICEM CFD (Ver. 14.5). In view of the geometry, the Cartesian co-ordinate system is chosen to describe the geometry, where X, Y and Z axes represent the length, height and breadth of the cold store respectively.

Table 2.1 Dimensions of various parts of cold store shown in Fig 2.1

Dimensions of cold store	4.5m (l) x 3.3m (h) x 2.5m (b)
Dimensions of inlet duct and outlet duct	1 m x 0.150 m x 0.3 m
Dimensions of the crates of the racks	0.5m (l) x 1.8m (b) x 0.3m (h)
Air gap between the crates of racks	0.3 m
Cold room wall thickness	0.15 m

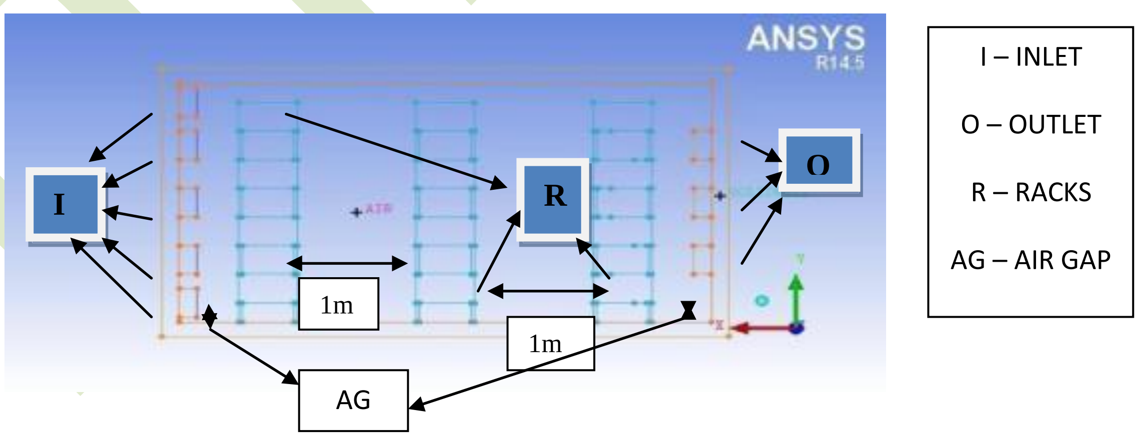

Fig.2.1 Typical dimensions of a cold store

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III MESHING

- ✓ The model is created using ICEM CFD software.
- ✓ The whole model is divided into different parts namely inlet, outlet, inner wall, racks and outer wall.
- ✓ Global Mesh parameters are defined which gives information regarding type of mesh. The global element seed size, part parameters are setup and mesh is computed which gives the mesh information regarding total number of elements.
- ✓ An unstructured tetra mesh is generated in order to perform computations with the Octree approach. The global element seed size is fixed to 200 based on grid independent study. After setting up part parameters for various parts, a mesh is generated with nearly 5 to 6 lakh elements.

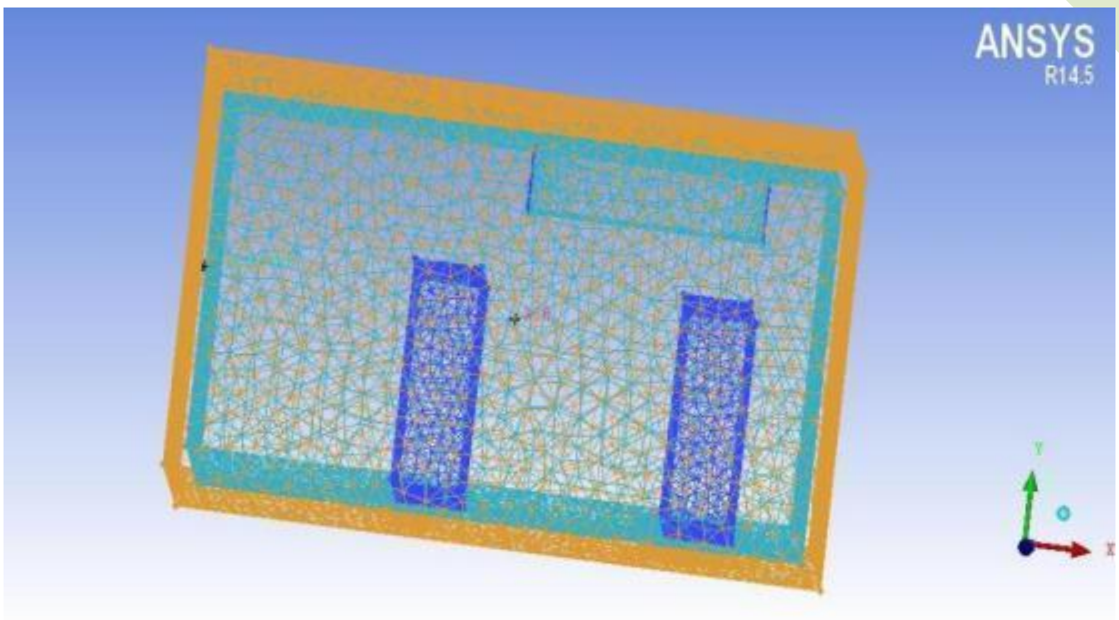

Fig.3.1 Meshed model of a loaded cold store

IV GOVERNING EQUATIONS

The 2D incompressible, turbulent flow is described using a constant-property Boussinesq fluid.

$$\mathbf{div}\ (\rho V\Phi) = \mathbf{div}\ (\tau \mathbf{grad}\Phi)+S$$

Here, Φ is general variable

τ is generalized diffusion coefficient corresponding to Φ

S is generalized source term corresponding to Φ

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Table4.1Relationship between the parameters and different partial differential equations

EQUATION	Φ	τ	S
Momentum Eq in X-direction	u	$\eta + \eta_t$	$-\frac{\partial p}{\partial x}+\frac{\partial}{\partial x}(\eta_{eff}\frac{\partial u}{\partial x})+\frac{\partial}{\partial y}(\eta_{eff}\frac{\partial v}{\partial x})$
Momentum Eq in Y-direction	v	$\eta + \eta_t$	$-\frac{\partial p}{\partial y}+\frac{\partial}{\partial x}(\eta_{eff}\frac{\partial u}{\partial y})+\frac{\partial}{\partial y}(\eta_{eff}\frac{\partial v}{\partial y})$
K- Equation	K	$\eta + \frac{\eta}{\sigma_k}$	$\rho G_k-\rho\varepsilon$
ε-Equation	ε	$\eta + \frac{\eta}{\sigma_\varepsilon}$	$\frac{\varepsilon}{k}(C_1\rho G_k-C_2\rho\varepsilon)$
Energy conservation	T	$\frac{\eta}{p_\tau}+\frac{\eta_t}{\sigma_T}$	0

Here, $G_k = \frac{\eta_t}{\rho}\{ 2 [(\frac{\partial u}{\partial x})^2 + (\frac{\partial v}{\partial y})^2] + (\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x})^2+(\frac{\partial w}{\partial x})^2+(\frac{\partial w}{\partial y})^2 \}$

$\eta_{eff} = \eta + \eta_t$ and $\eta_t = \rho C_\mu k^2/\varepsilon$

Table 4.2The values of coefficients of the k-ε model [6]

C_μ	C_1	C_2	σ_k	σ_ε	σ_T
0.09	1.44	1.92	1.0	1.3	0.9-1.0

V BOUNDARY CONDITIONS

The applicable boundary conditions for the computation of the cold storage are as follows:

- Inlet: In the present analysis the velocity at inlet is varied from 1 m/s to 3 m/s in steps of 1 m/s. The inlet temperature is fixed at278 K.
- Outlet: Relative pressure is set as zero, which facilitates the air flow within the cold storage.
- Racks: Heat flux; i.e. heat generated due to respiration of fruits stored within the racks for different design configurations are considered.
- Wall: The no slip condition and smooth surface conditions are assumed.
- Outer wall: Heat transfer coefficient and outside temperatures are specified as $0.027 Wm^{-2}K^{-1}$ and 298 K respectively.

Two domains were considered for the computation such as air and solid wall, both domains are stationary.

- Air is a fluid domain and K-e model is used for accounting the turbulence. Reference Pressure is assumed to be 1 atm.
- Solid wall is a solid domain which is given the properties of polystyrene foam.

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VI VALIDATION

The problem is solved using ANSYS CFX and the code is validated with the results of a research paper [2] for, it is found that it agrees well with the results of the published work as shown in figures 6.1 and 6.3.

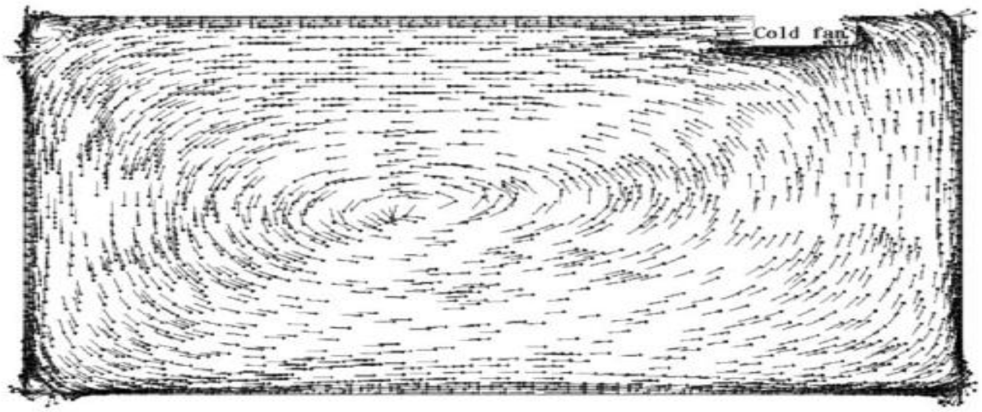

Fig.6.1Previous work model of flow field for 7m/s

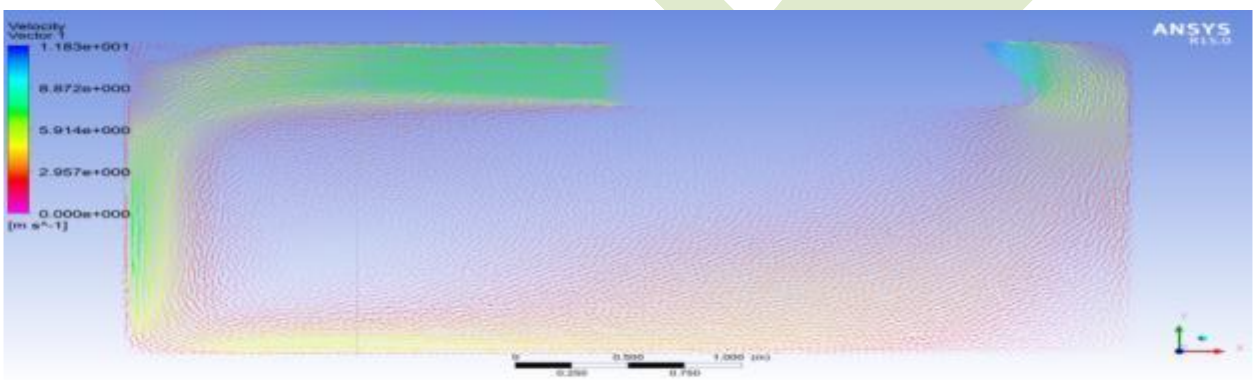

Fig.6.2Present work model of flow field for 7m/s

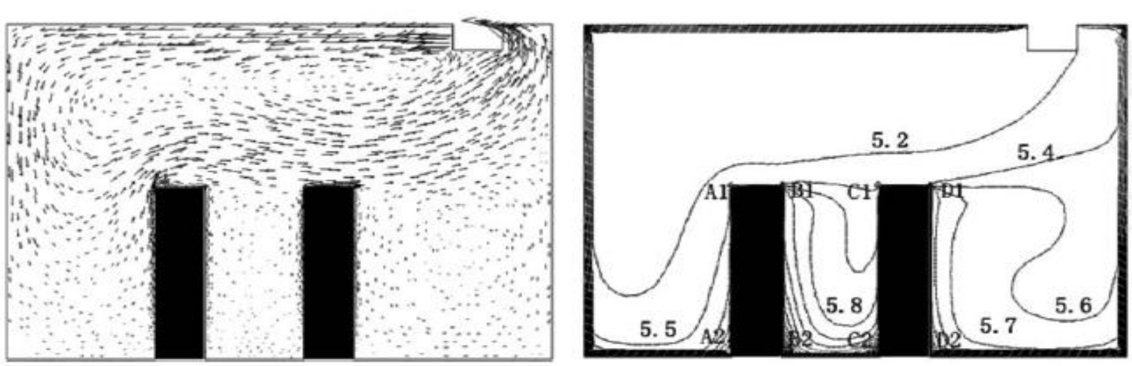

Fig.6.3 Previous work model of flow field and temperature field in the cold store for 6m/s

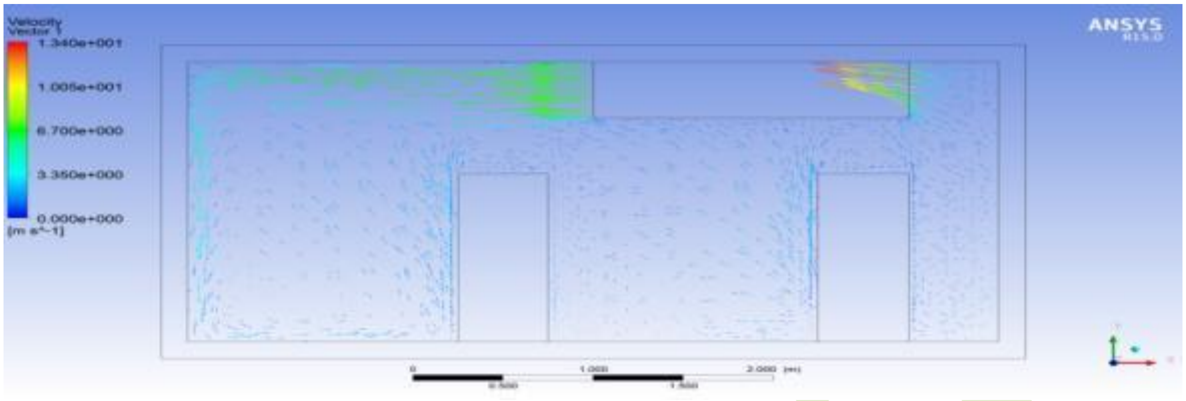

Fig.6.4 Present work model of flow field in the cold store for 6m/s

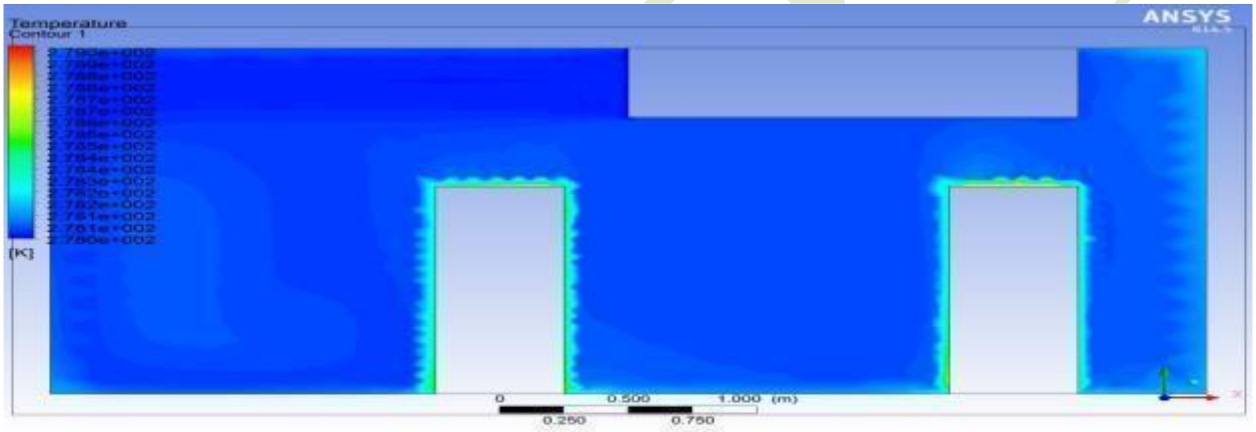

Fig.6.5 Present work model of temperature field in the cold store for 6m/s

It may be seen from fig.6.1 and Fig.6.3 that here is recirculation of air with less velocity, causing hot spots in that region

Comparing the Fig.6.3 with Fig.6.4,it is found that the stacking of foodstuff within the cold store affect the flow field making it to be non uniform and disorder as it creates a large number of eddies.

From the Fig.6.5, it is found that temperature on the i) windward face is lower than leeward face ii) upper side is lower than downside which agrees with the previous work result as shown in Fig.6.3. Thus the empty and loaded cold store models are validated.

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VII PRESENT STUDY

In the present study the design parameters affecting the flow and temperature fields are studied. The design parameters include the position of the inlet, number of the inlets and outlets and the stacking methodology. It aims to have uniform air flow and temperature distribution within the cold store and thus prevent hot spots on the surface of the produce. The following designs are considered for analysis

A) To change the position of the inlet and outlet in case of single inlet type of cold stores

DESIGN 1

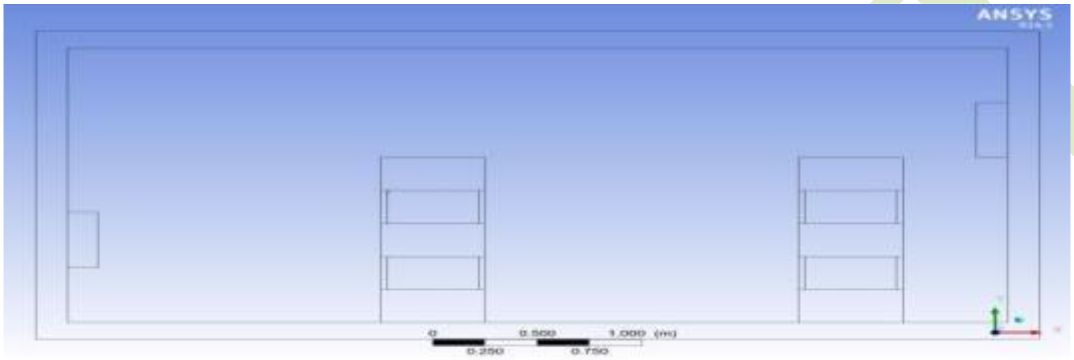

Fig.7.1 A cold store with inlet at 500 mm and outlet at 1500 mm from base

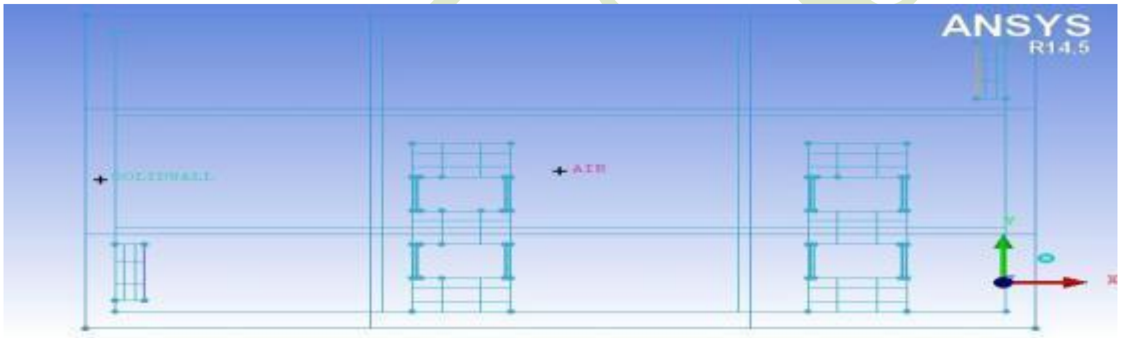

Fig.7.2 A cold store with inlet at 100 mm and outlet at 1900 mm from base

B) To have different configurations of multiple air inlets and outlets instead of single inlet and outlet and changing the stacking methodology.

DESIGN 2

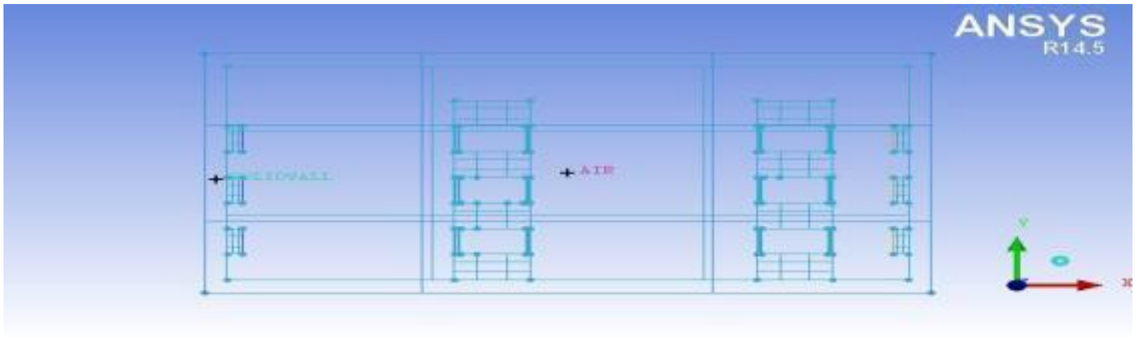

Fig.7.3A cold store with 1500 mm gap between racks

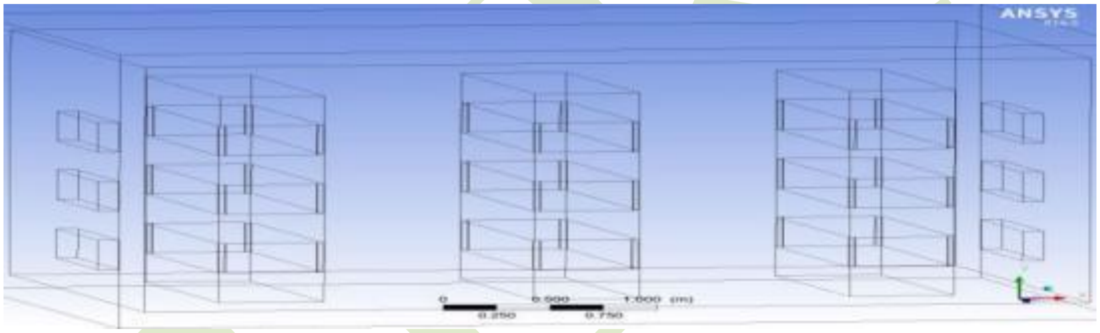

Fig.7.4A cold store with 1000 mm gap between racks

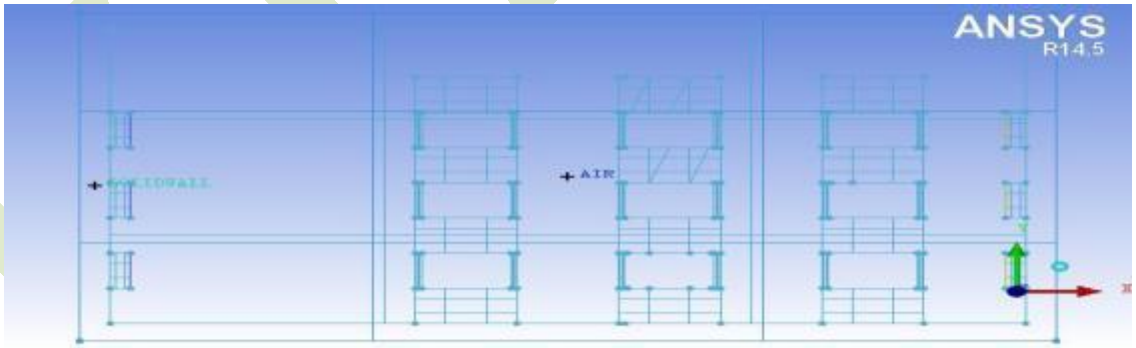

Fig.7.5 A cold store with 500 mm gap between racks

DESIGN 3

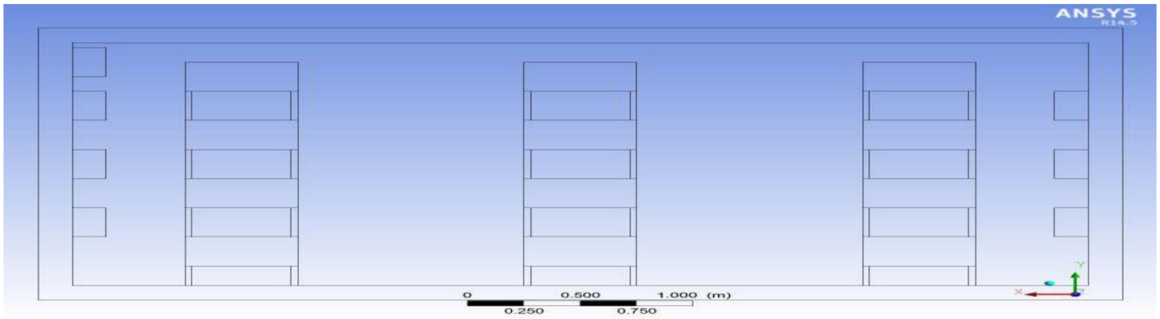

Fig.7.6 A cold store with 1000 mm gap between racks, an inlet at top and air gap of 200 mm at bottom of racks

DESIGN 4

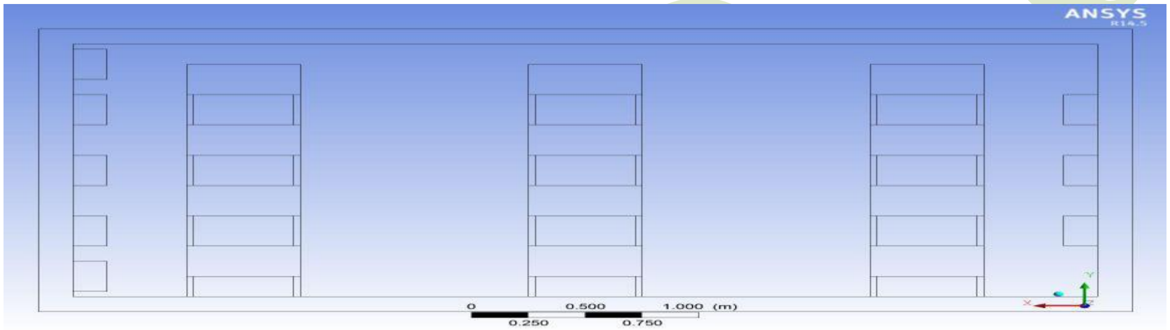

Fig.7.7 A cold store with 1000 mm gap between racks, an inlet at top and bottom of racks and air gap of 200 mm at bottom of racks

DESIGN 5

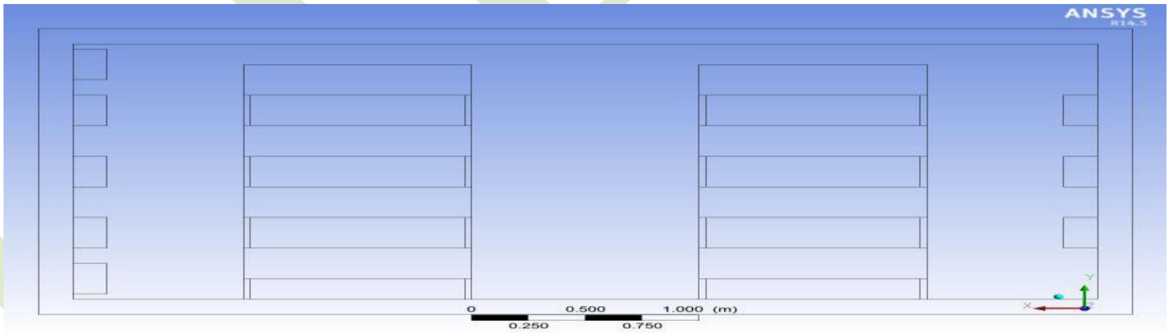

Fig.7.8 A cold store with 1000 mm gap between racks, inlets at top and bottom of racks and air gap of 200 mm at bottom of racks

VIII RESULTS AND DISCUSSION

The results obtained indicate the flow and temperature fields which are obtained for different design configurations in which design parameters namely viz. position of the inlet, number of inlets& outlets are varied. Figures show the results generated by ANSYS CFX. In these figures, velocity vector and temperature contours shown by different colors, which describe the flow and temperature fields characteristics within the cold store for different design configurations.

8.1 Results obtained for single inlet type of cold stores

The figures 8.1.1 and 8.2.1 show velocity vector for different configurations of cold store,which gives the characteristics of flow field in the cold store. These design configuration refers tosingle inlet types of cold store. The vectors show the velocity variation and how flow occurs at different points within the cold store. As we can see from these vector diagram, there exists recirculation of air in between the racks, at the top and sides of the racks, in between the air gap provided between the crates of the racks, near the inlet and outlet and in the empty spaces in cold store.It accounts for the non uniform distribution of the airflow in the cold store, resulting in the non uniform distribution of temperature field within the cold store as shown in figures8.1.2 and 8.2.2. This is easily depicted by temperature variation on the surface of the food product as shown in temperature contours. High temperature could be noticed at the top, bottom, sides of the crates of racks and at the corner of the rooms.Thus, there exists a temperature variation of about 0.5^0C - 0.7^0C on the surface of food products as seen from temperature contour. Therefore, in order to overcome these defeciencies several other multiple inlet configuration are tried.

DESIGN 1

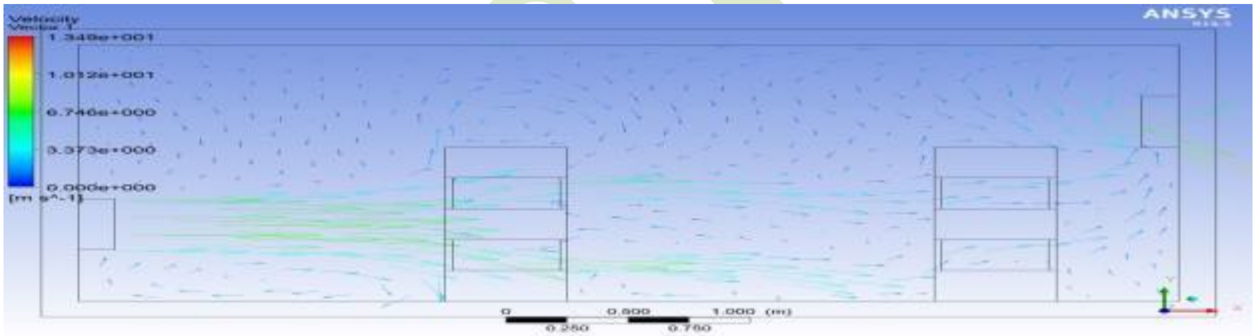

Fig.8.1.1 Flow field of a cold store with inlet at 500 mm and outlet at 1500 mm from base

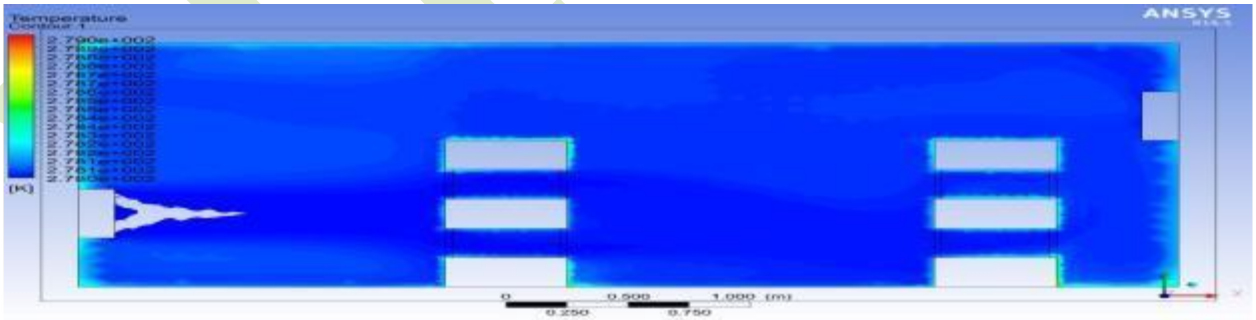

Fig.8.1.2 Temperature field of a cold store with inlet at 500 mm and outlet at 1500 mm from base

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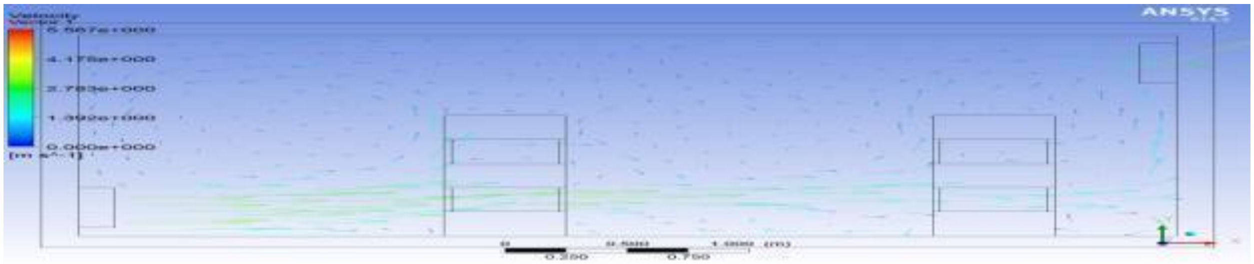

Fig.8.2.1 Flow field of a cold store with inlet at 100 mm and outlet at 1900 mm from base

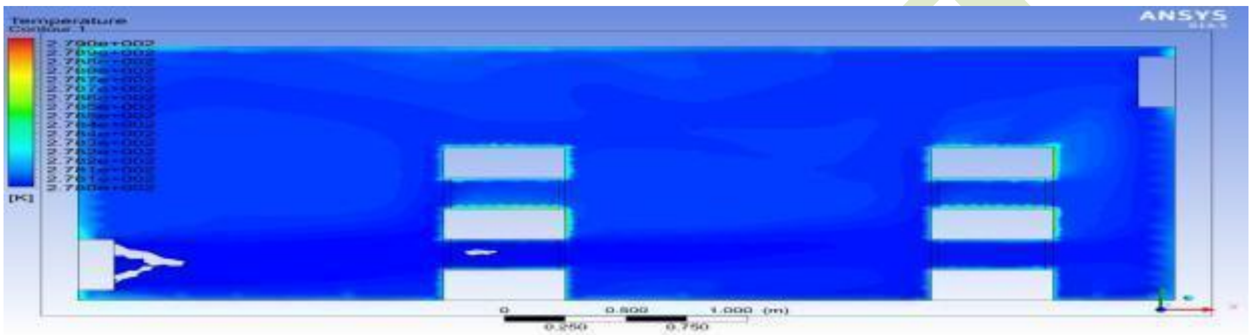

Fig.8.2.2 Temperature field of a cold store with inlet at 100 mm and outlet at 1900 mm from base

8.2 Results obtained for multiple inlet type of cold stores

Cold stores with multiple inlet configurations are shown in Fig. 8.3.1 to Fig.8.5.2, with number of inlets being three.These inlets are such that they are inline with the multiple outlets and air gapprovided in between the crates of the racks. Fromfigures 8.3.1, 8.4.1 and 8.5.1 depicting velocity vector diagrams,it is found that such a modification in the design configuration of the cold store resulted in decreased recirculation of air in between racks and near the inlet and outlet. But still there exists a noticebale amount of recirculation at top and bottom of the racks. It accounts for higher temperature on the surface of produce at the top and sometimes at the bottom and sides, as shown in figures 8.3.2, 8.4.2, 8.5.2. In these cases, the temperature variation on the surface of produce kept in racks vary upto about 0.5^0C - 1^0C.

Thus in order tofully achieve uniform airflow and uniform temperature distribution in the cold store room, an additional inlet is provided at the top and a small air gap is provided at the bottom as shown in Fig. 8.6.1 to Fig.8.6.2. But still it does not give the uniform airlow and temperature distribution, as there exists recirculation of air at the bottom of the racks where the air gap is provided. Also higher temperatures of about 0.5^0C - 0.7^0C at bottom of racks causing a hot spot at that point of the food produce. So a small improvement, i.e providing an additional inlet at the bottom as shown in Fig.8.7.1to Fig.8.7.2 and Fig.8.8.1 to Fig.8.8.2 results in uniform temperature and airflow fields in the cold stores. Here, the temperature variation on the surface of produce kept in racks is about 0.1^0C - 0.3^0 C.

From the above study, it is found that the design configurations 5 and 6 of cold stores as shown in Fig.8.7.1 to Fig.8.7.2 and Fig.8.8.1to Fig.8.8.2 with uniform flow and temperature distribution gives the desired results. The results obtained are for inlet air velocity of 3 m/s and an air gap of300 mm between the crates of racks.

DESIGN 2

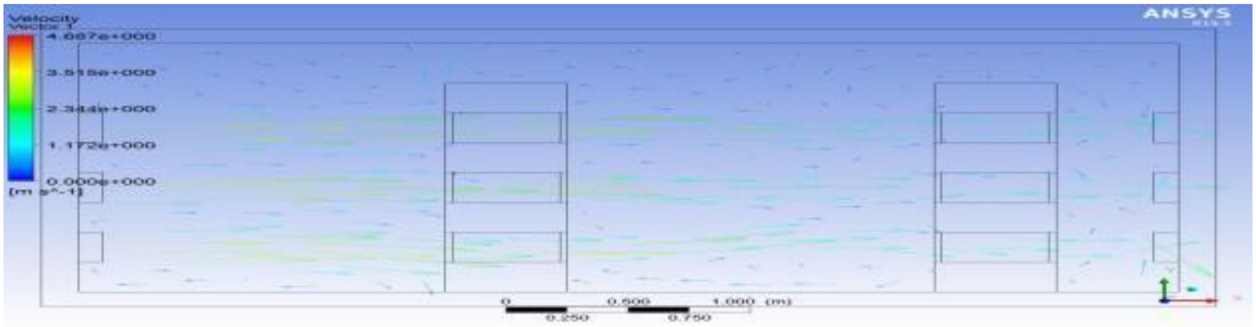

Fig.8.3.1Flow field of a cold store with 1500 mm gap between racks

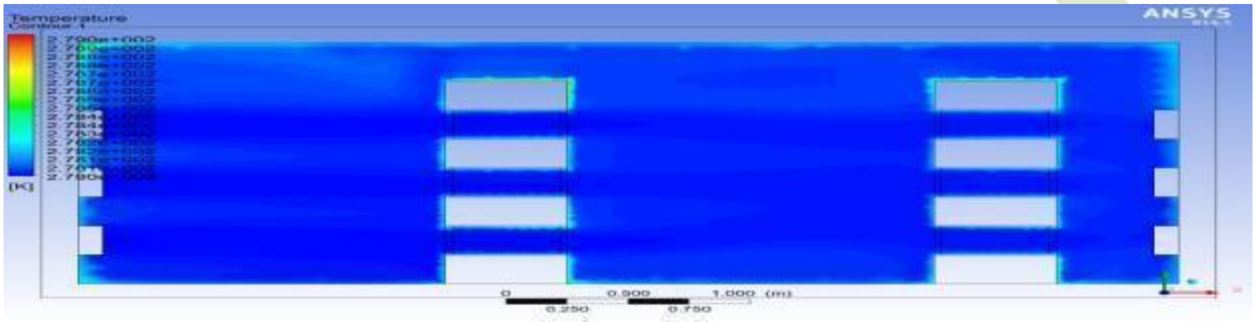

Fig.8.3.2 Temperature field of cold store with 1500 mm gap between racks

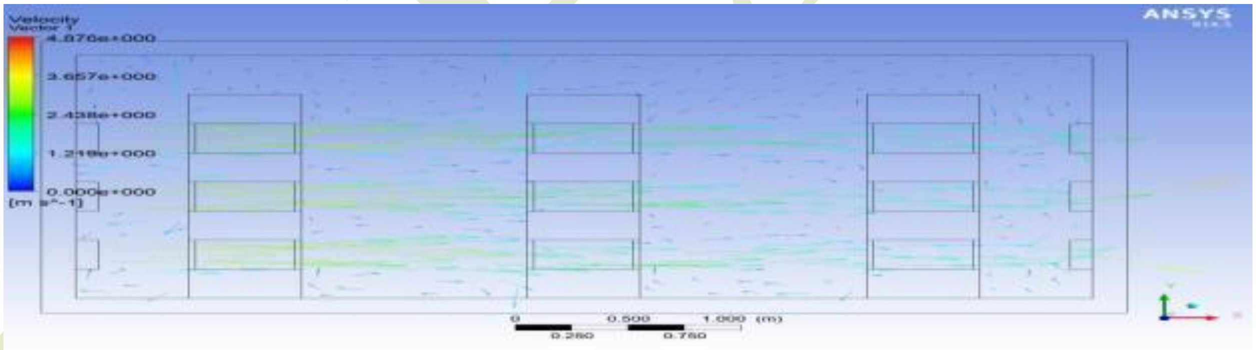

Fig.8.4.1 Flow field of a cold store with 1000 mm gap between racks

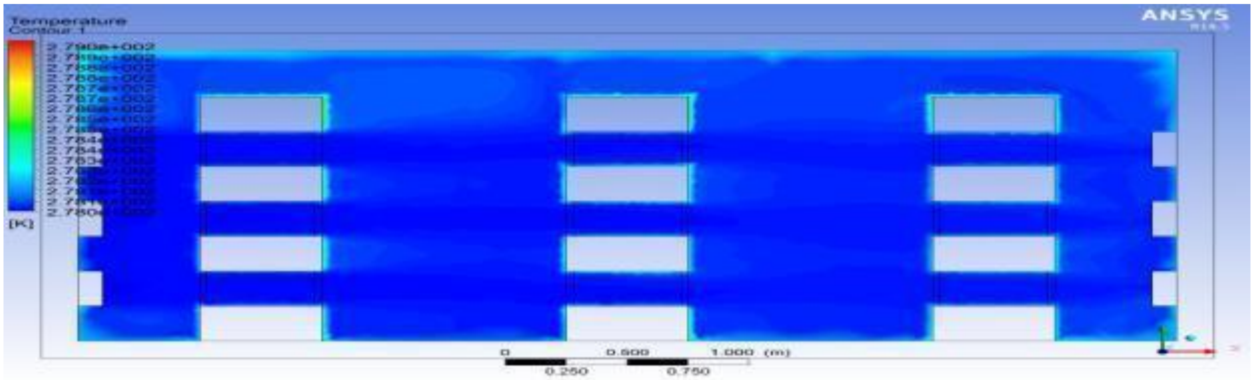

Fig.8.4.2 Temperature field of a cold store with 1000 mm gap between racks

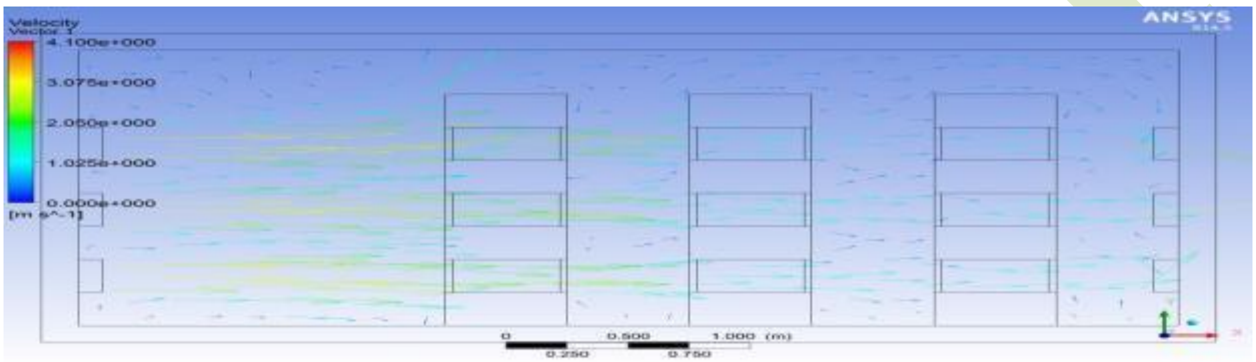

Fig.8.5.1 Flow field of a cold store with 500 mm gap between racks

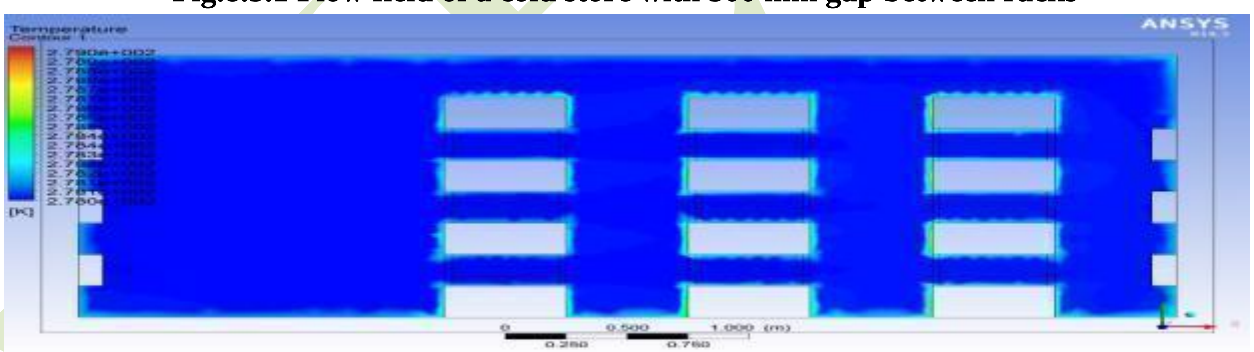

Fig.8.5.2 Temperature field of a cold store with 500 mm gap between racks

DESIGN 3

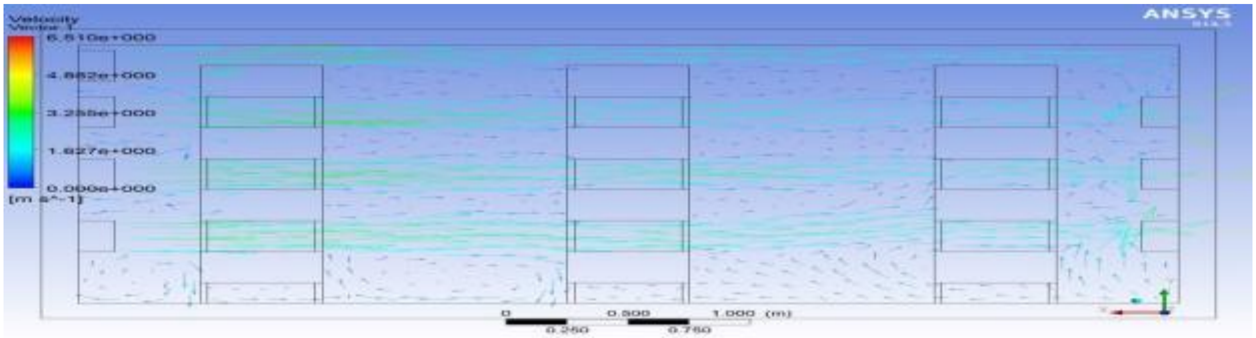

Fig.8.6.1 Flow field of a cold store with 1000 mm gap between racks, an inlet at top and air gap of 200 mm at bottom of racks

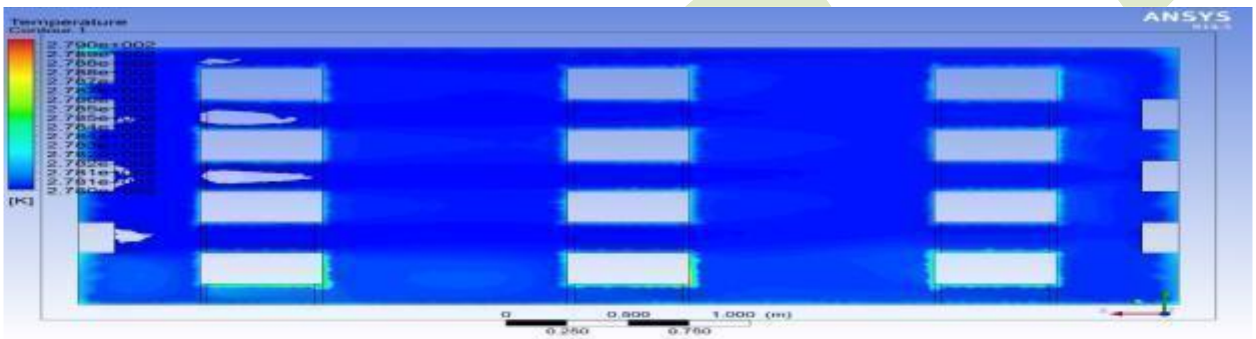

Fig.8.6.2 Temperature field of a cold store with 1000 mm gap between racks, an inlet at top and air gap of 200 mm at bottom of racks

DESIGN 4

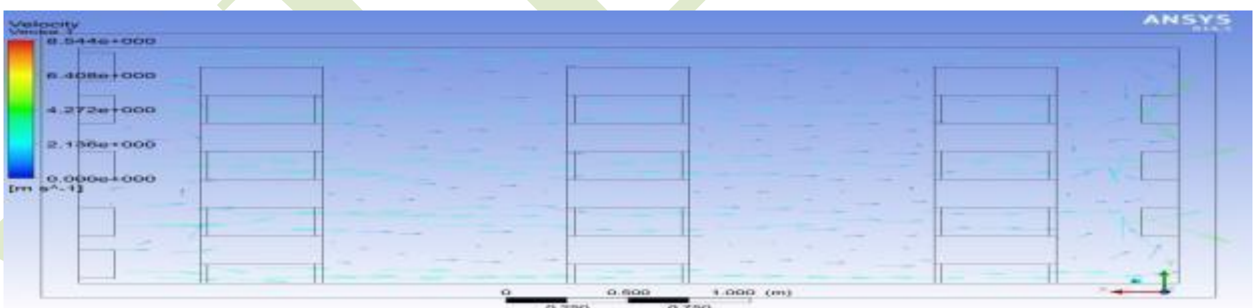

Fig.8.7.1Flow field for design configuration 4 of cold store

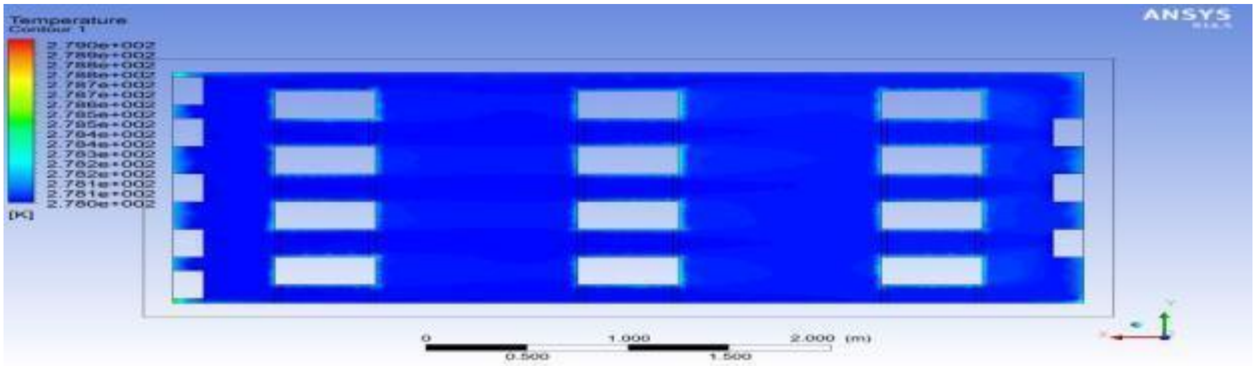

Fig.8.7.2 Temperature field for design configuration 4 of cold store

DESIGN 5

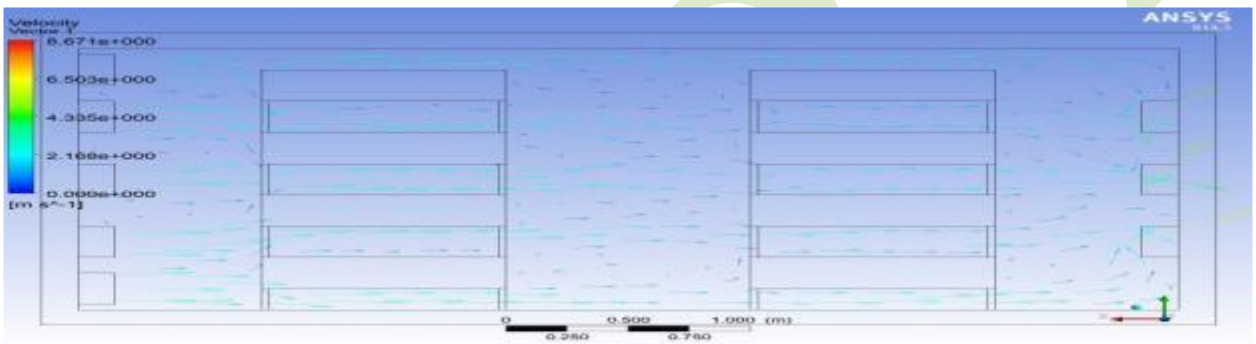

Fig.8.8.1 Flow field for design configuration 5 of a cold store

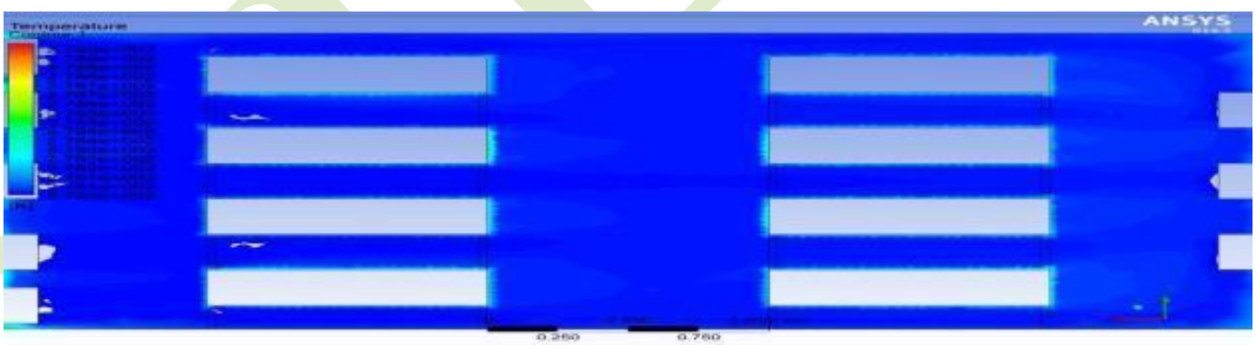

Fig.8.8.2 Temperature field for design configuration 5 of a cold store

VII CONCLUSIONS

A CFD analysis is carried out to investigate the airflow and temperature fields within the cold store. Based on exhaustive study of various design configurations, results and discussions the following conclusions could be made:

1. Providing air gap between the racks reduces the hot spot areas on the surface of the racks when compared with the continuous racks having no air gaps.
2. The optimum position of the inlet is that it should be in line with the air gap between the crates of the racks, and outlet, also inlets should be provided at top and bottom of the racks to facilitate uniform airflow and temperature distribution within the cold store.
3. Multiple inlets as stated in conclusion 2 proved to be beneficial by 11.5% in terms of reduction in variation of temperature over the surface of racks in which food is stored when compared to single inlets. It also resulted in uniform airflow and temperature field within the cold store.
4. Study confirms that the racks with lesser length i.e. 500 mm provides temperature variation of about 0.3^0C to 0.4^0C when compared to that of 1000 mm which provides better results with lesser temperature variation of 0.1^0C over the surface of the racks in which food produce are stored.

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