Quantification of Air Flow Heat and Mass Transfer in Cold Store CFD Model

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***Abstract*—** The understanding of the flow field inside the cold store is very important to food storage at low temperatures. Transport phenomena, comprising air flow, hit and mass transfer are key processes in refrigerated storage. Temperature homogeneity in most food refrigeration systems is directly governed by the airflow patterns in the system. Numerical modeling of airflow provides an opportunity to develop improved understanding of the underlying phenomena influencing system performance, which can lead to reduced temperature heterogeneity and increased effectiveness and efficiency of refrigeration systems. With the rapid advances in computational power of recent years, the use of Computational Fluid Dynamics (CFD) techniques in this application has become popular. This the application of CFD and other numerical modeling techniques to the prediction of airflow in refrigerated food applications including cool stores and reduce bad food ratio and reduce heat and mass transfer in food.

***IndexTerms*—** **Cold Store, Modeling, CFD, Heat Transfer, Mass Transfer, Speed, Air Temperature,**

I. Introduction

In chilled and frozen food applications, temperature (and often humidity) control during cooling, storage, transportation and display is essential to the maintenance of product quality. In the majority of food refrigeration systems, heat is transferred primarily by convection; therefore, the temperature and its homogeneity are directly governed by the patterns of airflow. Recent studies have shown a significant level of spatial temperature variability in some food refrigeration systems, with non-uniform airflow implicated as a major cause of this variability. For sensitive products, this level of temperature variability may have significant food quality and safety implications.

One of the main aims in designing storage enclosures is to ensure a uniform targeted temperature and humidity in the stored bulk products. The intricate transport mechanics and the complex geometry of a fully loaded cool store make it difficult to determine the optimal configuration and operation parameters of the store in an empirical way. A model-based approach can prove to be advantageous for design purposes with small added cost. With the increasing availability and power of computers together with efficient solution algorithms and processing facilities, the technique of Computational Fluid Dynamics (CFD) can be used to solve the governing fluid flow equations numerically.

1.1. Space Air Diffusion:

Space air diffusion distributes the conditioned air containing outdoor air to the occupied zone (or a given enclosure) in a conditioned space according to the occupant's requirements. Satisfactory space air diffusion evenly distributes the conditioned and outdoor air to provide a healthful, and comfortable indoor environment for the occupants, or the appropriate environment for a specific manufacturing process, at optimum cost.

The objective of air distribution is to achieve the acceptable levels of temperature, humidity, cleanliness and air motion in the occupied zone of conditioned area. All this is done in such a manner that the occupant does not experience any draft.

The performance of space air diffusion mainly depends on air flow pattern in the occupied zone of commercial buildings or in the working area of a factory. The optimum air flow pattern for an occupied zone depends mainly on:

- Indoor temperature
- Relative humidity
- Indoor air quality requirements
- Outdoor air supply
- Characteristics of the building

1.2. Storage guideline for fruits and vegetables

Cold storage of fruits and vegetables was used extensively by our ancestors to keep food after the harvest season. In modern times, the year round availability of fresh produce in the supermarket has reduced the use of home storage.

When harvesting your own produce for storage, or buying it locally in season, there are certain guidelines to follow which assure maximum quality and minimum spoilage of your stored food.

1. Harvest fruits and vegetables at peak maturity or as near as possible.
2. Only use produce that is free from all visible evidence of disease.
3. Do not pick any fruit or vegetable that has severe insect damage.

4. Handle food carefully after harvest so that it is not cut or bruised.
5. Leave an inch or more of stem on most vegetables to reduce water loss and prevent infection.
6. Use late-maturing varieties better suited to storage.

These conditions can be classified into four groups:

1. Vegetables which require cold & moist conditions
2. Vegetables which require cool & moist conditions
3. Vegetables which require cold & dry conditions
4. Vegetables which require warm & dry conditions

A methodology for obtaining reduced order models for temperature distribution in air conditioned rooms was developed and analysed by Sempey et al. [4]. The focus of the work was to test the feasibility of the approach. A two-dimensional configuration was considered here, as the dimension is not a crucial point concerning the application of the proper orthogonal decomposition (POD). As the studied flow is a mixed convection, a limited number of air flow patterns (four) are retained in order to have negligible changes of the buoyancy forces as a function of the boundary conditions. Although this model can be simulated in a few minutes on personal computer, its order is then reduced by using the POD with snapshot method.

An airflow pattern sensor was developed to measure the trajectory of a non-isothermal air jet in a building with a single or multiple air inlet(s) by Ozcan and Vranken [7]. The experimental conditions covered the whole year characteristics to come up with a general conclusion in an experimental room of 8 m×4 m×4 m. The principle of the airflow pattern sensor is to predict the trajectory of a non-isothermal air jet from the temperature distribution measured near to the air inlet.

Catalina Tiberiu et al.[13] reported a full-scale experimental campaign and a computational fluid dynamics (CFD) study of a radiant cooling ceiling installed in a test room, under controlled conditions and aims to use the results obtained from the two studies to analyze the indoor thermal comfort using the predicted mean vote (PMV). The results of the simulations were first validated with the data from the experiments and then the air velocity fields were investigated. It was found that in the ankle/feet zone the air velocity could pass 0.2 m/s but for the rest of the zones it took values less than 0.1 m/s. The obtained experimental results for different chilled ceiling temperatures showed that with a cooling ceiling the vertical temperature gradient is less than 10C/m. PMV plots showed that the thermal comfort is achieved and is uniformly distributed within the test room. Myhren Jonn Are et al. studied [14] thermal comfort aspects, different heating systems and their position effect on the indoor climate in an exhaust-ventilated office under Swedish winter conditions. Computational fluid dynamics (CFD) simulations were used to investigate possible cold draught problems, differences in vertical temperature gradients, air speed levels and energy consumption.

II. TESTING FACILITY AND EXPERIMENTATION

The objective of this study is to carry out characterization of the test chamber air flow with respect to temperature and velocity, experimentally and the quantification of the thermal comfort. An in house test facility is created to measure the test chamber's air velocity and temperature. Experiments were conducted in different- different test chambers of different shape and size under different conditions. A hot wire anemometer is employed to measure the room air velocity.

2.1 Identification of Room for Experimentation

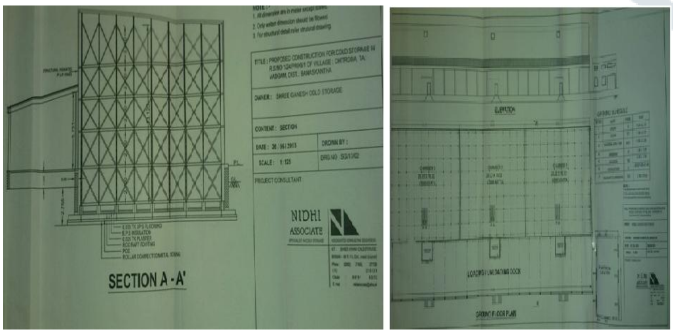


Fig -1: **Floor plan of company and Ground Floor plan**

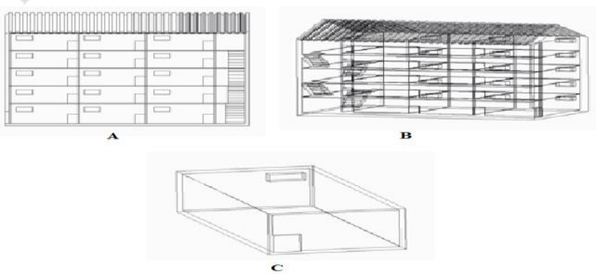


Fig -2: **(A) Geometry of the cool storage, (B) Isometric view of the cool storage and (C) Experimental setup room geometry**

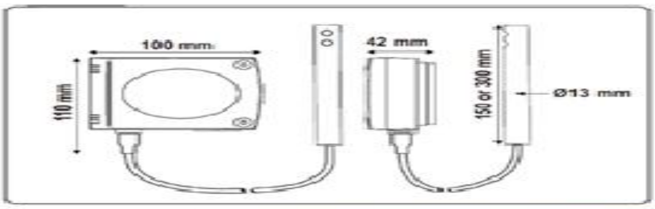
2.2 Experimental test facility

CTV100 hot wire anemometer used for the measurement of velocity and temperature in the experiment of the following specifications: 0-30 m/sec, accuracy = +/- 3% of the reading with response time of 2 sec, temperature range 0 - 500C , +/- 0.5 %

of reading accuracy, 5 sec response time. The detailed view of the anemometer has shown in Figure. Temperature measuring facility is created as shown in Fig.

A

B



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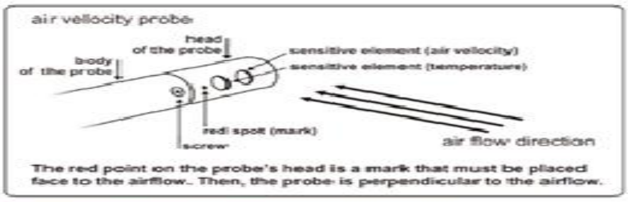


D

E

Fig -3: **Various instruments used for measurements**

A rigid plastic pipe of the 3 meter is selected with the facility to attach the anemometer probe at the required position (at equal interval) on the pipe. The pipe is rested on the iron stand with the heavy base to keep the pipe at vertical position. Care was taken to keep the probe position at all the locations on the entire height of the pole at same orientation to maintain the uniformity.

Fig -4: **(A) Cooling Fan (B) Compressor (C) Chiller plant (D) Compressor Pressure gauge**

III. METHODOLOGY

3.1 Mathematical formulation

We are use three method to Short out the problem and identify the problem,

1) Model Formulation : A transient two-phase model of heat and mass transfer in a cool store was proposed. The governing equation expressed in Cartesian coordinates xi (i=1, 2, 3) for the air phase.

2) Model Parameters : The heat of respiration, the heat and mass transfer coefficients, the saturated partial vapor pressure and the latent heat of evaporation as a function of temperature were calculated with the equations and correlations proposed

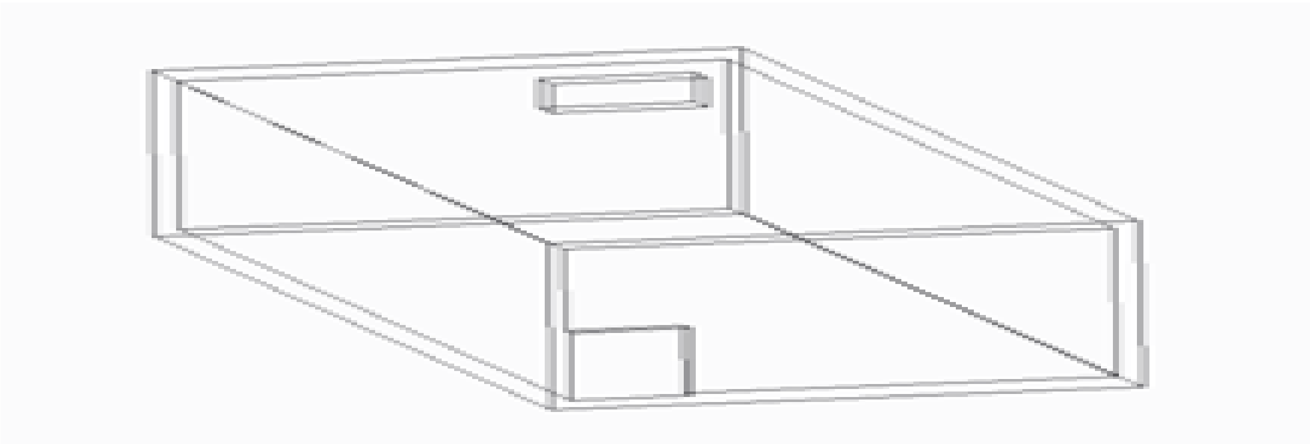
3) Validation Methods: a) Velocity measurements,
b) Temperature measurements,
c) Weight loss measurements.

Sr No.	**Description**	**Specifications**
1	Room dimension	14.35ft (L) x 7.35ft (B)x 10ft(H)
2	Room temperature	+ 4^0 C (± 2^0 C)
3	Humidity	85 - 90% RH
4	Ambience Temperature	35^0 C
5	Material to be stored	Fresh vegetables and fruits
6	Product quantity	10 MT
7	Product Incoming Rate	33% (3300 kg per day)
8	Product entry Temperature	28-35^0 C
9	Pull down time	24 hrs / Batch
10	Insulation	60mm PUF with 0.5mm pre painted CRCA Sheet as external finish and internal finish
11	Floor	60mm thick PUF slab over kota and PCC
12	Hinge door	34”x 78” – 1No.
13	Refrigeration unit capacity	30000 Btu/hr @ 4^0C Room temperature & 43^0C Ambient temperatures
14	No of units	15000 Btu / hr x 2 nos.
15	Refrigerant	R-22 / R404A
16	Compressor	Reciprocating

Table -1: Dimensions of Various parts of Cold storage

3.2 Physical model and coordinate system

A 3D model of a cold store is created in CREO (Ver.3.0). In view of the geometry, the Cartesian co-ordinate system is chosen to describe the geometry, where X, Y and Z axes.



3.3 Meshing

The model is created using Ansys work bench 17 software. The whole model is divided into different parts namely inlet, outlet, inner wall, 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 Hex dominate method. 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 nodes 109081 and 102605 elements.

3.3 Temperature distribution

3.3.1 Empty cold storage

Fig. shows the measured time–temperature profiles at two different positions in the cool store during the cooling period representing the coldest and hottest points. The coldest point was located right in front of the cooler, while the hottest point was in the middle of the cool store.

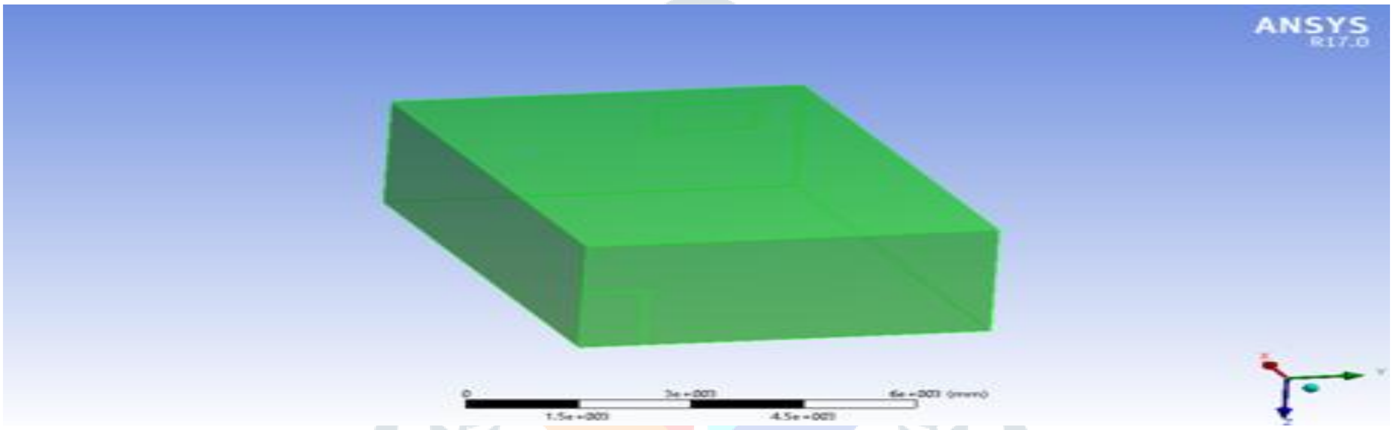


Fig -5 import geometry in Ansys

It is clear that the cooling rates at these two positions were considerably different as a result of the airflow. The increase near time 1800 s is due to the defrosting which was set every 4 h. The fluctuation of the temperature at steady state condition is attributed to the PID control actions for regulation of the room air temperature. It is shown that the model is capable of predicting the temperature during the cooling phase. The hot spot position was found to be the same in the measurement and simulation.

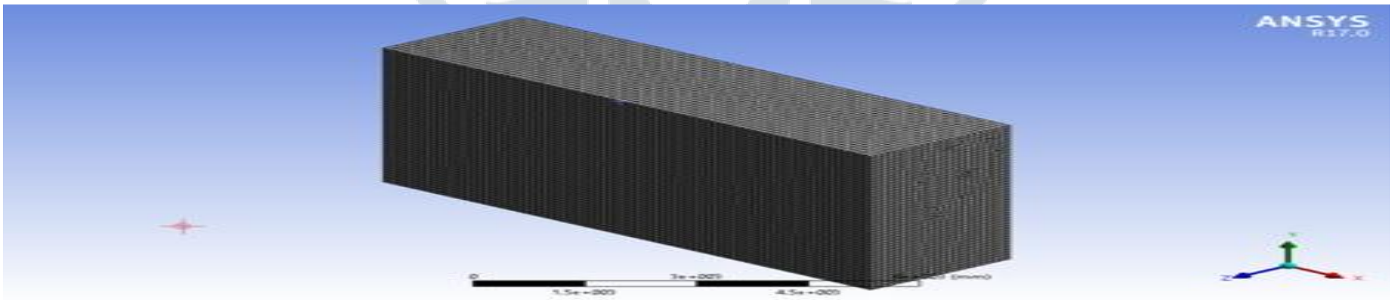


Fig -6 Meshing generation

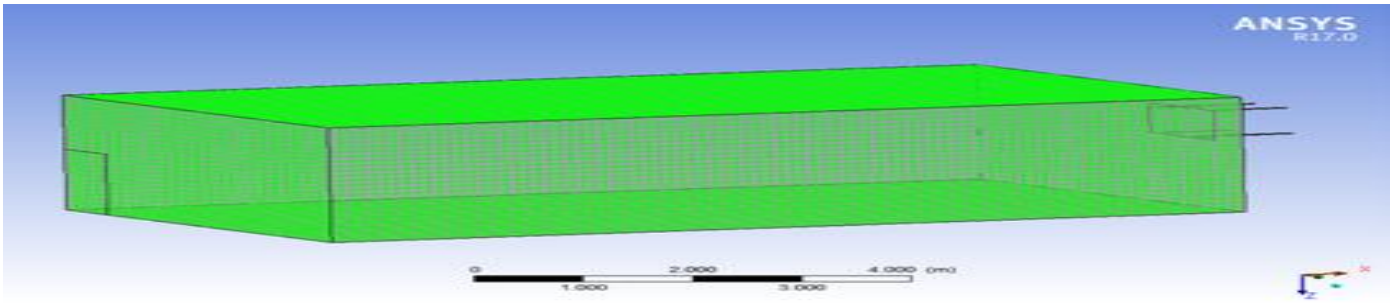


Fig -7 Domain setting

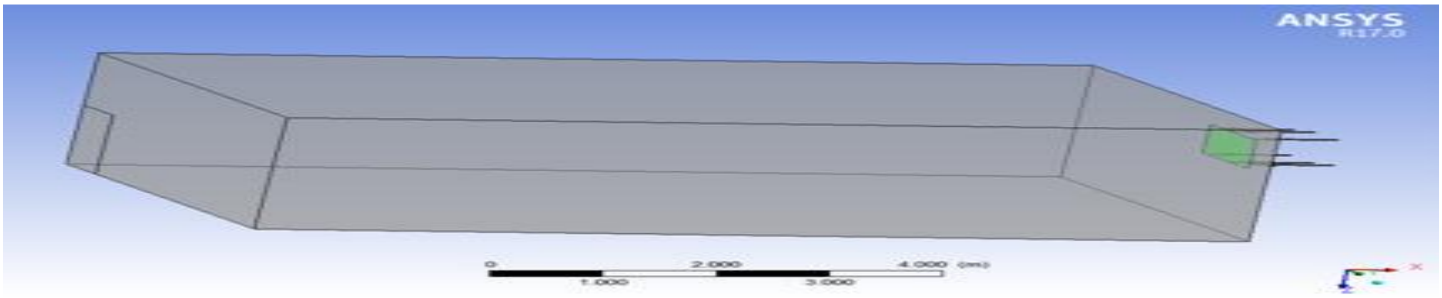


Fig -8 Inlet boundary condition

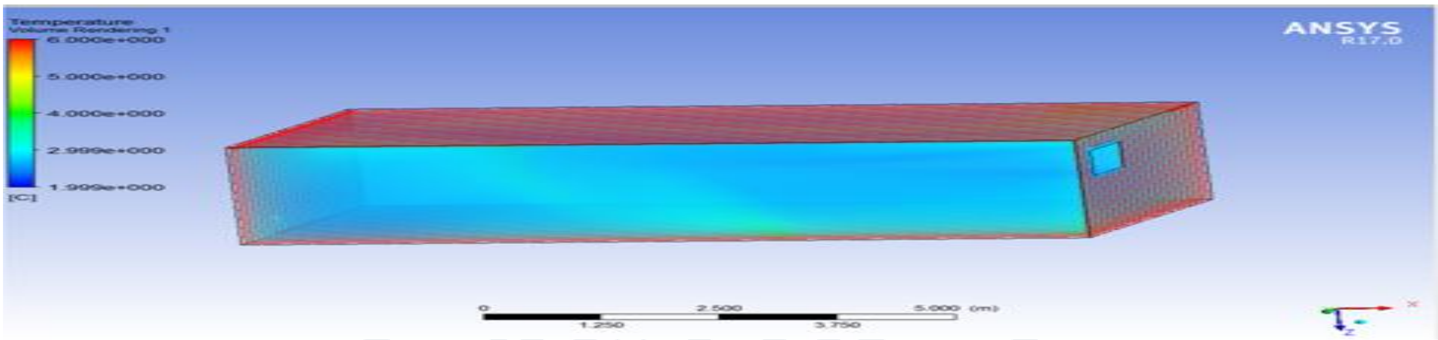


Fig -9 Temperature distribution

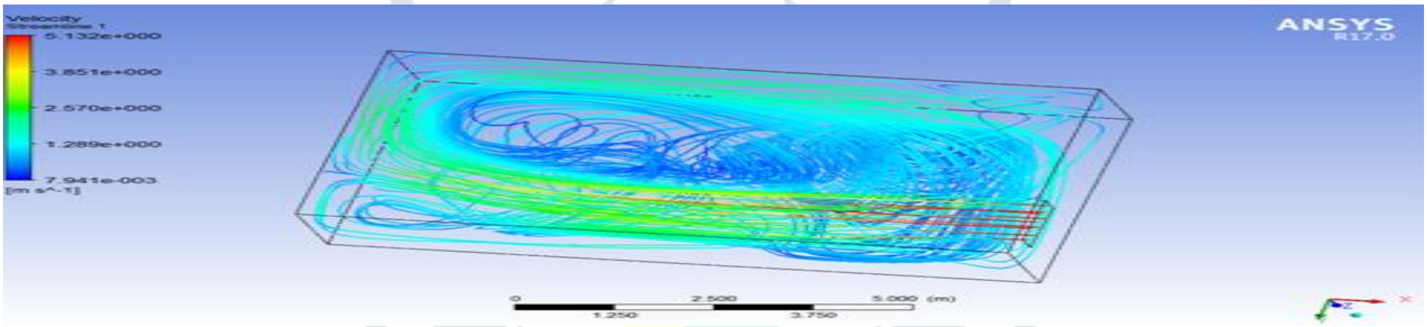


Fig -10 Air flow pattern in cold storage

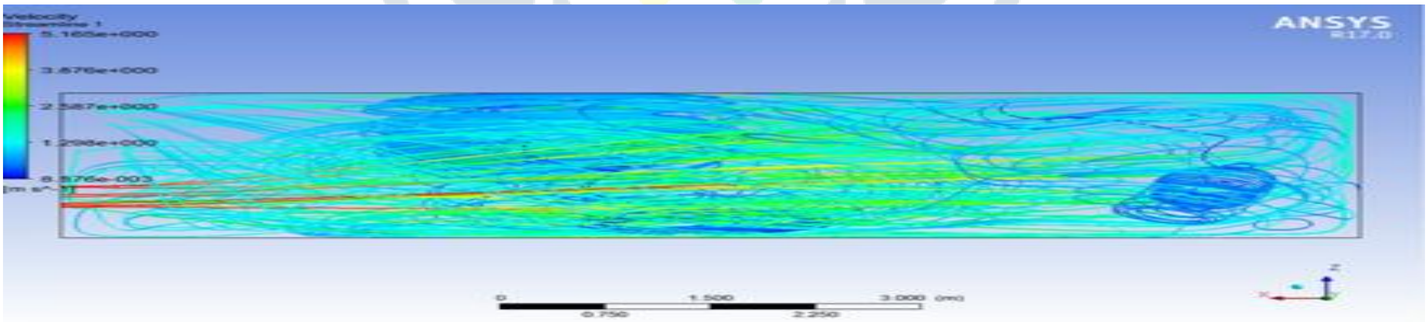


Fig -11 increase Air Velocity

Airflow pattern on the symmetry plane in an unloaded refrigerated comparisons between experimental and numerical results achieved with two alternative turbulence models.

3.3.2 Loaded cold storage

Fig. shows the measured and predicted air temperature inside the vegetable at the bottom and the top of the stack, and at the front and at the back of each bin. It can be observed from the measurement that the defrosting cycle was set every 4 h. The air temperature at the front position reached the steady state condition after 12 h of cooling while it took about 40 h for the air at the back of the bin to reach steady state. This clearly affected the cooling rate of the product at these two positions. It can be observed from Fig. 8 that the model predicted the air temperature for the bins close to the floor quite well (Fig.) The temperature difference between the measurement and prediction was in the range of the accuracy of the temperature measurement for the front.

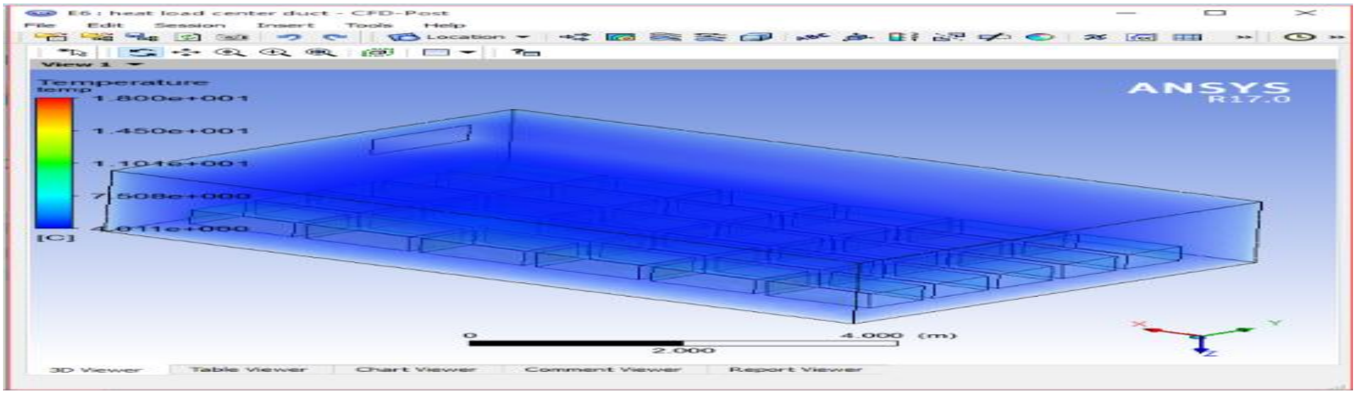


Fig -12 Temp. distribution in loaded condition

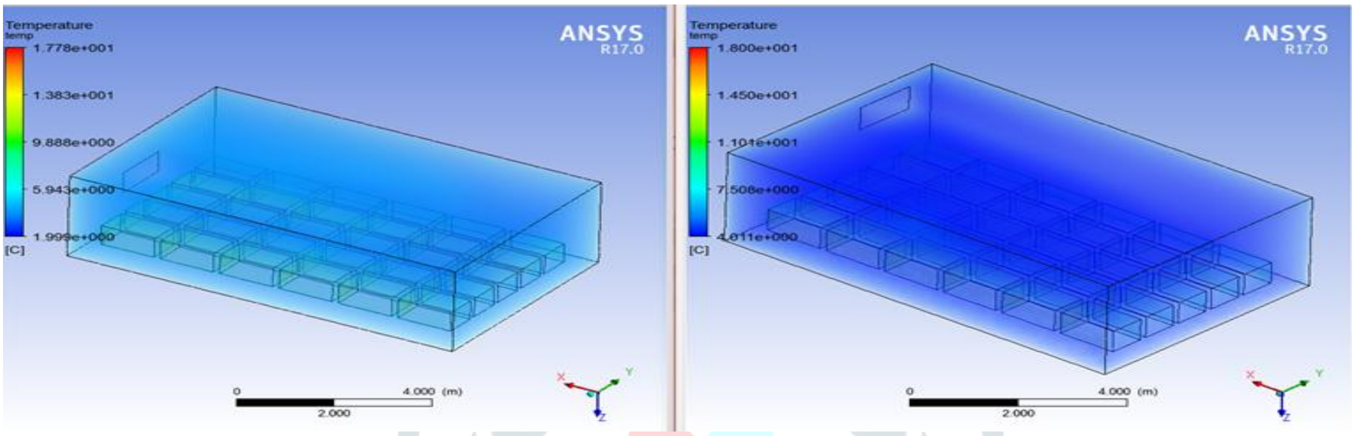


Fig -16 loading condition temperature distribution in room

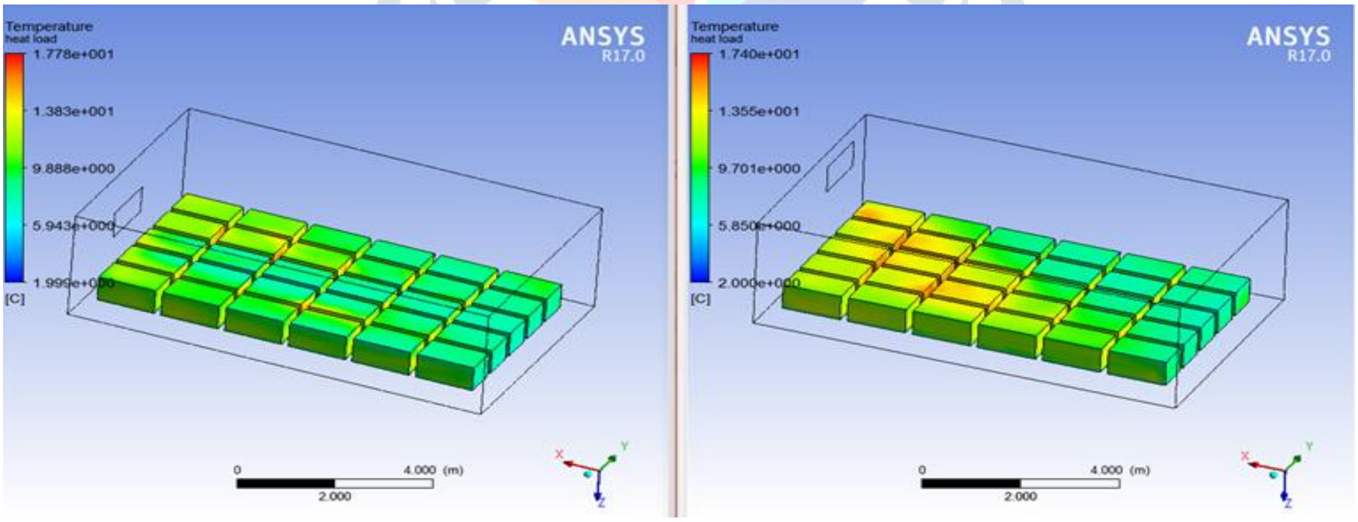
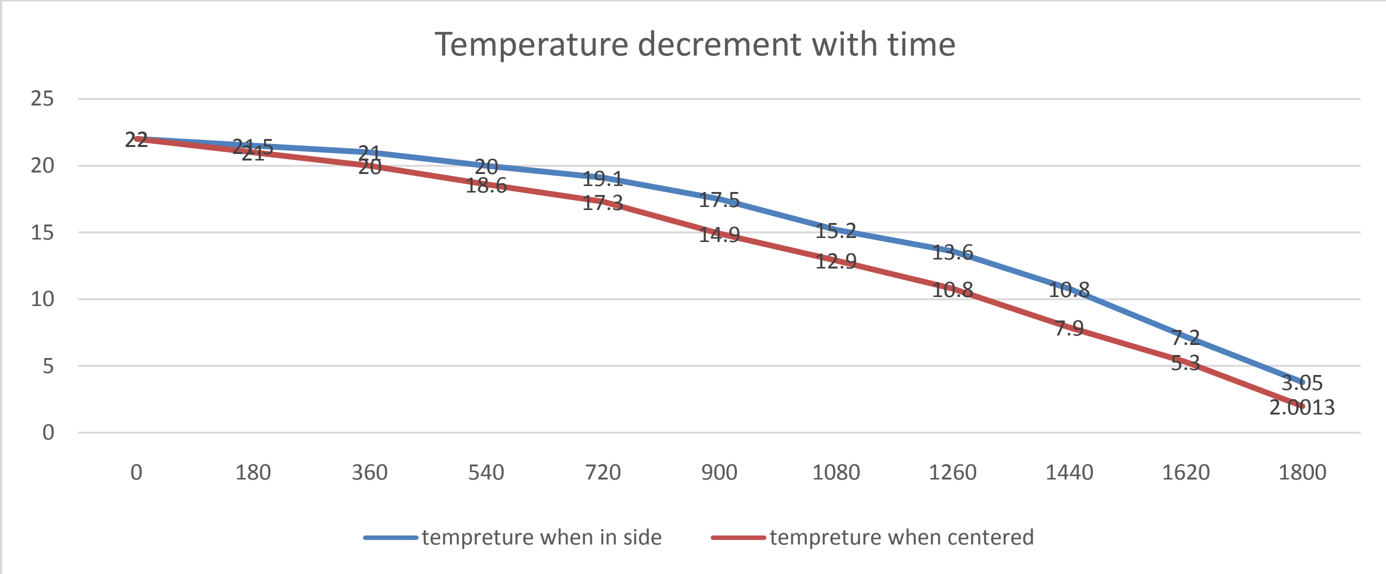


Fig -17 Loading condition temperature distribution in vegetable

IV. RESULT AND ANALYSIS

Uniform temperatures throughout the system are essential to preserve the product's quality, safety and shelf life. As convection is the primary mode of heat transfer, the air distribution system must provide sufficient airflows to absorb the energy from heat sources such as walls, doors and often the product itself to avoid unacceptable temperature increases. Solving air distribution problems is extremely complex, partially because of the influence of operational factors such as loading practices and product properties.



Many important factors, act simultaneously, are interdependent and have time constants differing by orders of magnitude. This situation leads to a very complex model with almost unpredictable accuracy. Therefore, simplified models are usually employed for more accurate investigation of single parts of the Room, and the simulation of the airflow pattern is separated from the prediction of the time temperature distribution of the contents. Simulations of the airflow pattern were initially performed by means of codes developed in-house. For example, Corellas et al. used a 2-D finite element code based on the stream function vertices formulation for the simulation of a double air curtain in an open vertical display cabinet for chilled food. The computational domain was subdivided into non-overlapping nine-node parabolic elements, for a total amount of 20,000 grid points, which was the maximum number compatible with a 24 h simulation on the CPU available at that time. Grid dependence was checked, and a 2% variation of the total heat flow rate was experienced with a 30% reduction of the average distance between grid points. A turbulence model similar to a large eddy simulation (LES) procedure was successfully employed. A dynamic simulation was performed, and the radioactive heat transfer over the load was neglected. In fact, by simulating the air curtain alone for a reduced time interval, the load surface can be effectively considered as an isothermal solid surface, whose temperature can be evaluated taking into account the radioactive contributions, if any. The average values of the return air temperature and refrigerating power were found to be in good agreement with experimental values. Higher velocity of the internal jet was found to enhance the air-curtain stability . Other models are available in the literature based on codes developed in-house for the simulation of air curtains. The model aimed to evaluate the temperature, velocity and moisture content in the air curtain. An implicit method was used for the solution of the differential equations, thus leading to an unconditionally stable solution, but possibly affecting the evaluation of turbulence. The results from this method were used to obtain simplified correlations, which allow the estimation of the heat flow rate and return air temperature at different operating conditions.

V. CONCLUSION

A simplified model for 2-phase momentum, heat and mass transfer in an empty as well as loaded cool store with agricultural product was established to predict airflow around bins, air and product temperature as well as product weight loss. The model equations were solved and validated by means of experimental data from a pilot cool room. An error of about 20% for velocity magnitude prediction for both the empty and loaded cool store was achieved. The model was capable of predicting the cooling rate of the air as well as the product. Discrepancies in the temperature prediction are due to local under-prediction of the air velocity caused by the k-3 turbulence model, the assumption of uniform initial temperature distribution inside bins and ignoring gradients inside the individual products. The model shows a rather good trend of cooling rate and weight loss rate of the product and can be used to study the effects of different parameters in the design and operation of industrial cool stores.

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