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CFD Modelling of Two Different Cold Stores Ambient Factors

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Abstract

Objective of the research was to determine ambient temperature and relative humidity distributions of two different cold stores which have two different cooling systems. One of the cold store which is called as Cold store-I, has classical cooling system such as compressor, condenser and evaporator. Second called Cold store-II, has air conditioning system for cooling, cold air ventilation and aspiration systems, and humidification system. Computational fluid dynamics was used for modelling of distribution of temperature and relative humidity of cold store walls. Storage temperature and relative humidity were assumed 2°C and 90%, respectively. Boundary conditions were set as; Inlet-Surface of fluid inlet, Outlet-Surface of fluid outlet, and walls-solid, proof against flow of fluid. A tetrahedral mesh was created by using ANSYS 14.0 and calculation finished when accessing a solution. Turbulence was modelled using the k-ε (k-epsilon). Spatial distribution in two cold stores for two different cooling systems were modelled and evaluated in this research. Data determined from CFD models were compared for both cold stores. Cold store-II was better than Cold store-I because it has air distribution holes located on ceiling.

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Key words: Temperature, relative humidity cold storage, computational fluid dynamics, modelling

1. Introduction

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Computational fluid dynamics (CFD) uses powerful computer and applied mathematics to model fluid flow. It is only in recent years that CFD has been applied in the food processing industry (Xia, Da-Wen Su, 2002. Numerical modelling of airflow and temperature distribution in a cold store was performed using the Computational Fluid Dynamics (CFD). The aspects which were investigated include the influence of wind velocity outside the building and possible addition of a hallway outside one of the cold store entrance. Both steady and unsteady computations were carried out (Margeirsson and Sigurjon Arason, 2008). A mono-scale three-dimensional Computational Fluid Dynamic model was developed for estimating of airflow, heat and mass transfer (Sajadiye et al., 2012). CFD modelling can predict the temperature during power loss and the results show a acceptable match with experimental results of a domestic freezer. The modelling was extended to predict the temperature changes in a large cold store and the results also indicate that PCM can limit the rise in air temperature (Gin et al., 2010). A computational Fluid Dynamics model was developed to estimate distribution of temperature and relative humidity in greenhouses. The model was validated with data from a fog-cooling experiment in a single-span greenhouse (Kim et al, 2007). Computational fluid dynamics (CFD) has been used in many fields which is related with fluid flow. The cooling rate and quality of food stuffs in a cold store are highly dependent on the temperature field which is closely related to flow field (Xhie et al., 2006).

Objective of this research was to investigate temperature and relative humidity distributions of two different cold stores have two different cooling systems. Computational fluid dynamics was used for modelling of temperature and relative humidity distribution on cold store walls. Storage temperature and relative humidity were assumed 2^{o}C and 90%, respectively. Boundary conditions were set as; Inlet-Surface of fluid inlet, Outlet-Surface of fluid outlet, and walls-solid, proof against flow of fluid. Spatial distribution in two cold stores for two different cooling systems were modelled and evaluated. Data determined from CFD models were compared for both cold stores.

2. Materials and Methods

2.1. Material

2.1.1. Cold store-I

The cold store which is called as Cold store-I, has classical cooling system such as compressor, condenser and evaporator. Sizes of cold store-I were 4.60X 4.35X 3.41 m (in length, width and height) and its volume was 68.3 m^3 (Fig.1)

Fig. 1. Cold store-I dimensions and general view

Type and power of Compressor were hermetic and 7BG, respectively. Condenser has axial fan and its capacity was 15 kW.

2.1.2. Cold store-II

Sizes of the cold store were 4 x 5 x 3 m(in length, width and height) (Fig. 2.). Cold store volume was 60 m^3. Cooling capacity was 15kW and cold air ventilated into cold store by inlet air channels. Consequently, homogeny distribution of cold air establish in cold store Working temperature and relative humidity varied between 0°C /+30 °C and 55-95 %, respectively. Tolerance of relative humidity was ± % 5 and ± 0,5 °C. The system consists of water cooling unit, air conditioning unit and control unit.

Fig. 2. General view of experimental cold storage

Walls, ceiling and base of the cold store established with prefabricated sandwich panel of polyurethane. Heat transfer coefficient of polyurethane was 0,025 $Wm^{-1}K^{-1}$ due to DIN 4108. In addition, surface of the wall and ceiling panels were covered with galvanised steel sheet painted polyester based paint in 0.5 mm thickness. Ground panels were produced from 9 mm plywood with filled polyurethane and covered one side with 0.5 mm stainless steel and another side with 0.5 mm galvanised steel plate. Panel thickness was 80 mm. Air conditioning system includes an axial type ventilator which its flow rate was 8 000 m^3h^{-1}. Air flow rate can be arranged by inverter. Cooling system capacity was 10 kW, heating system capacity was 5 kW. An automatic control system used to change ambient temperature and relative humidity of the cold store. Cold air is distributed in the cold storage by the inlet (pressure) air channels and is aspirated by the outlet (suction) air channels to be released outside. This process is materialized by the central climate of the system. There are 3 inlets for distribution of the cold air and 3 outlets for suction of the exhausted air. The cooling system was also facilitated with a vapour humidification unit. Its capacity was 2 kgh^{-1} and it was used to keep relative humidity of the cold storage at the desired level.

2.2. Methods

Modelling of spatial distribution of temperature and relative humidity in these two cold stores were realised by using computional fluid dynamic (CFD). Software was Ansys Fluent 14.0.

Computational analysis includes stages of geometrical modelling, creating numerical mesh, analysis and evaluating of results. This process requires powerful computer system. In this research, this methodology was used to analyse the cold stores. For this purpose, boundary condition of the cold storages were determined. Boundary conditions are;

Inlet; Surface of fluid inlet, Outlet; Surface of fluid outlet, Walls; Solid, proof against flow of fluid

A tetrahedral mesh was created and calculation finished when accessing a solution. Turbulence was modelled using the k-ε (k-e). Heat transition from boundaries and lightening system were taken into account for modelling. Base of cold stores were accepted as isolated surface. As a boundary condition, constant heat transition were used for walls and ceiling.

Storage temperature and relative humidity were assumed 2^{o}C and 90%, respectively.

CFD model were used to determine data to compare two cold stores. Data were determined from 18 different points and evaluated by using descriptive statistics for each cold storage. Walls of Cold stores were named as given in Fig. 3 and Fig.4.

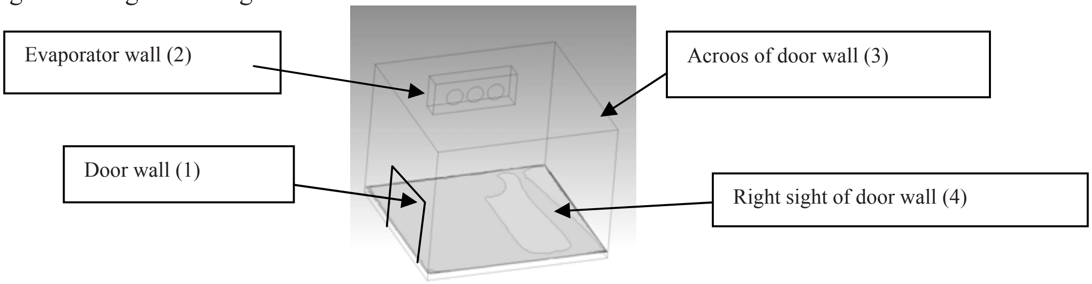


Fig. 3. Wall numbers and name of the cold storage-I

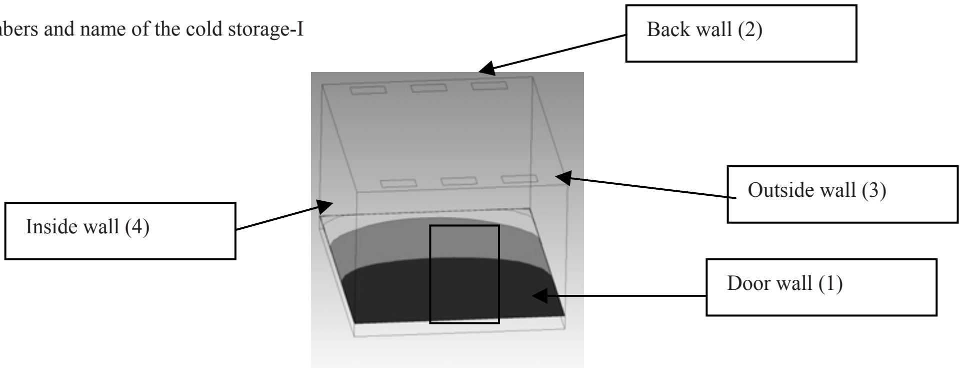
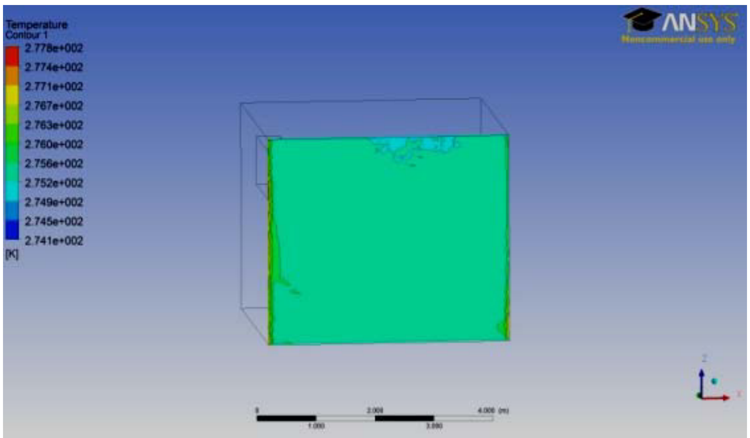


Fig.4. Wall numbers and name of the cold storage-II

3.Results And Discussion

3.1. Cold storage-I

Results of CFD Models for walls of cold storage-I which cooled by convetional cooling system are given in Fig. 5, Fig. 6., Fig. 7 and Fig. 8.



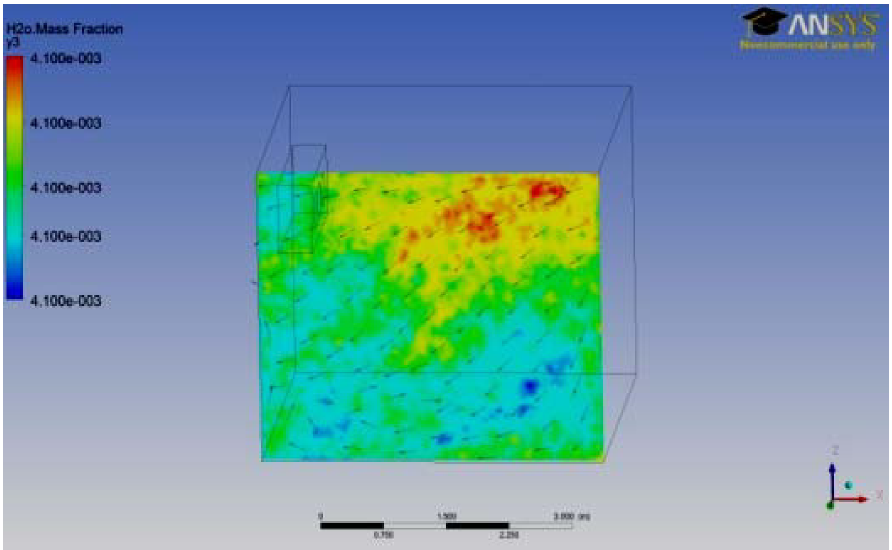
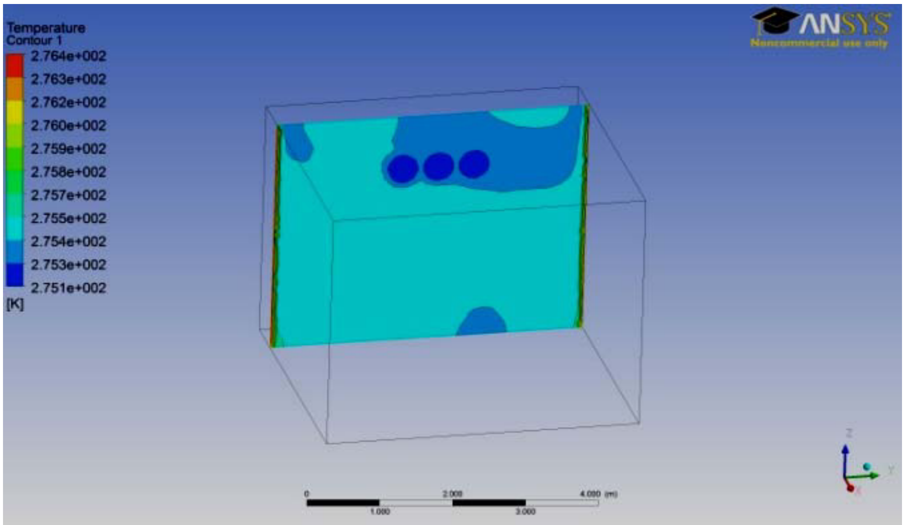


Fig. 5. CFD Models for temperature and relative humidity of door wall



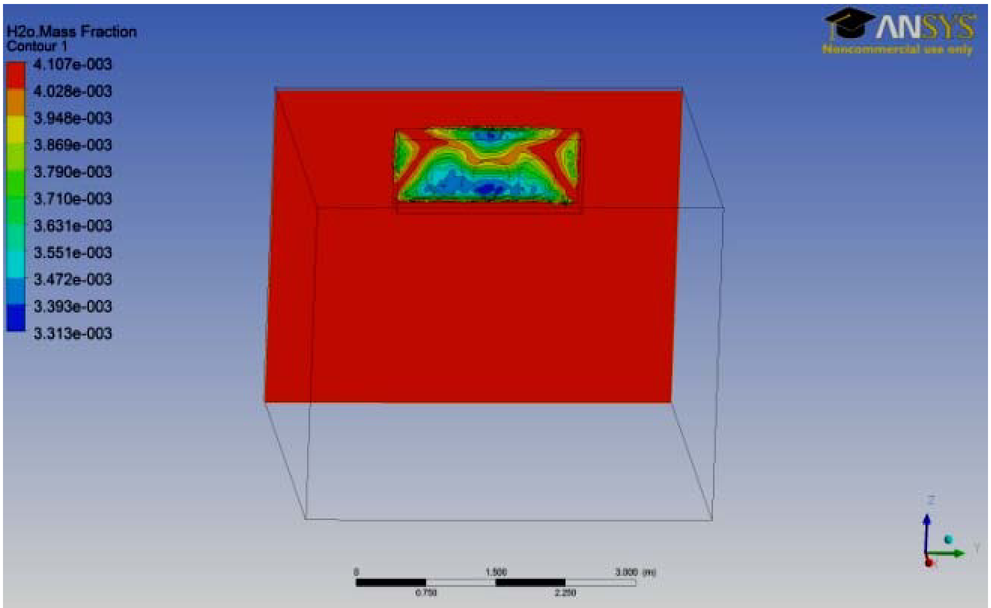
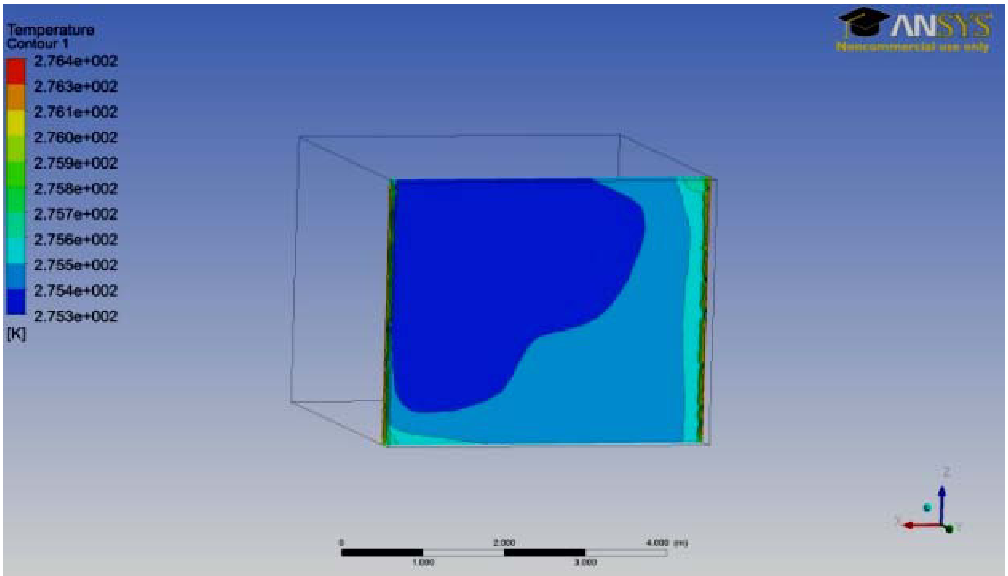


Fig. 6. CFD Models for temperature and relative humidity of evaporator wall



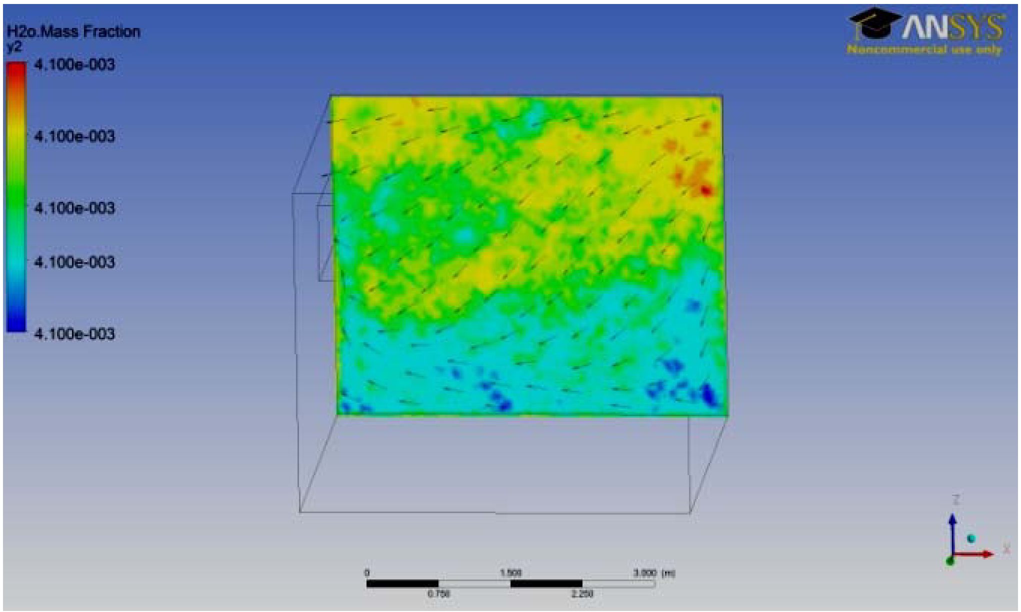
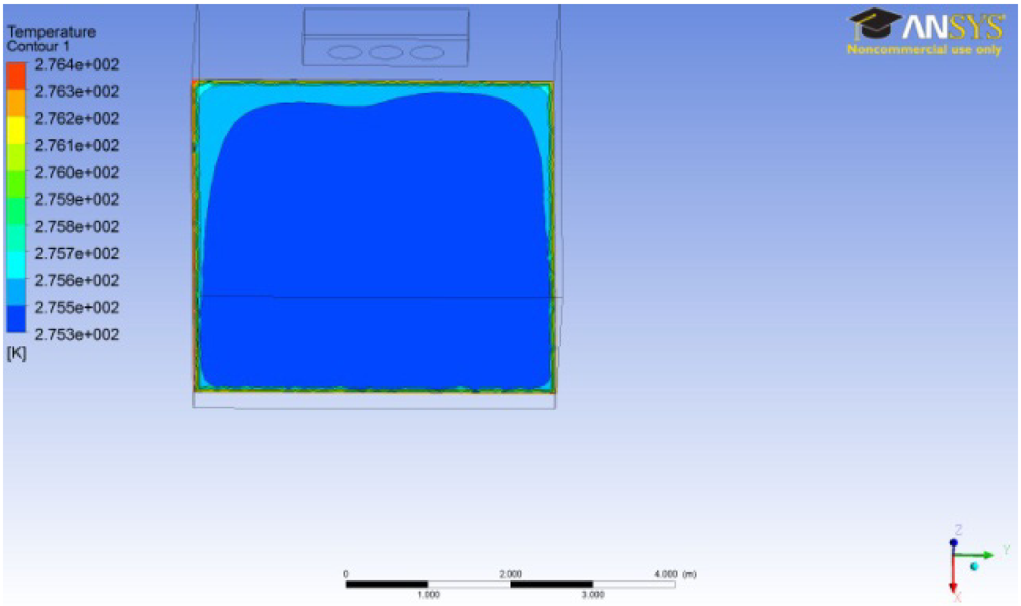


Fig. 7. CFD Models for temperature and relative humidity of across of door- wall



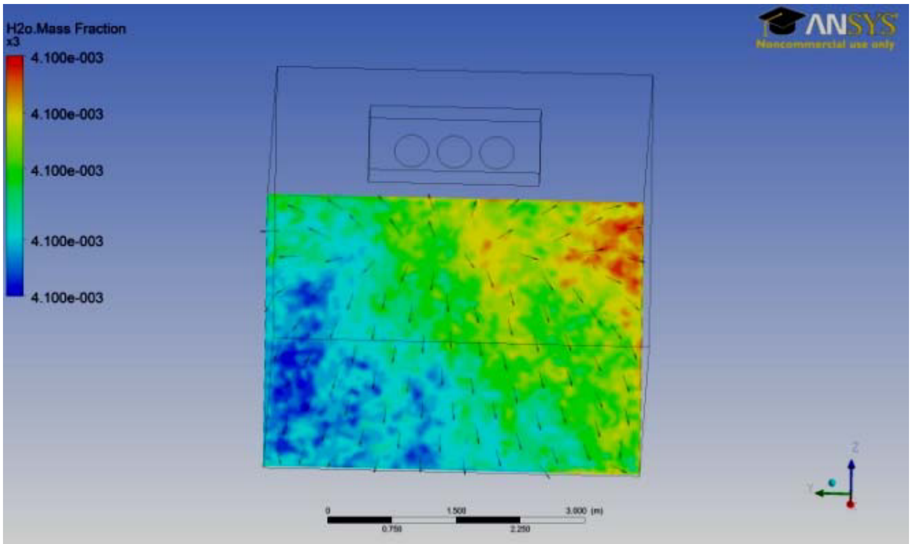
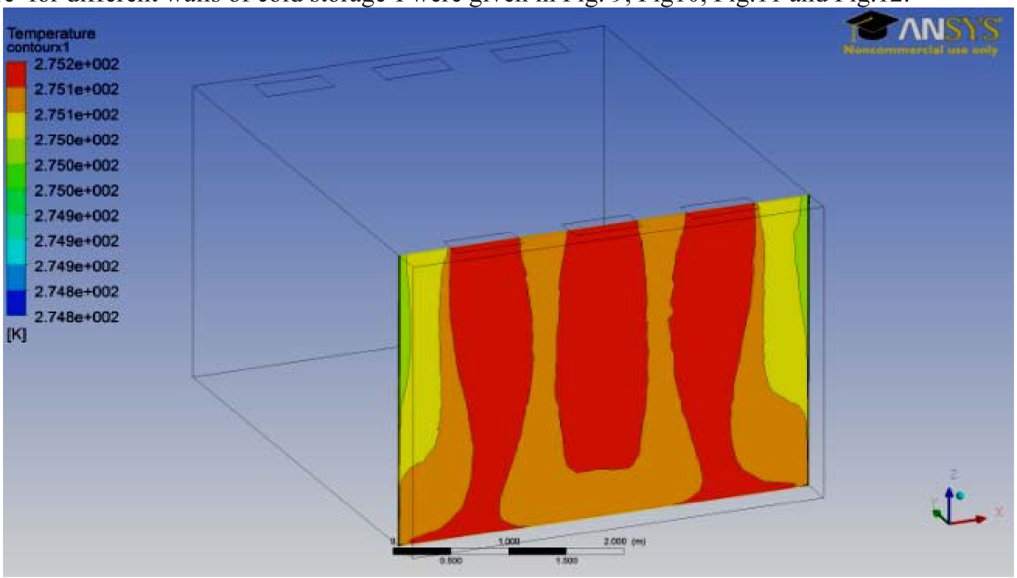


Fig. 8. CFD Models for temperature and relative humidity of across of evaporator wall

3.2. Cold storage-II

Spatial distirbution of temperature (^{o}C) and relative humiditiy (RH) which were determined Ansys Fluent Software for different walls of cold storage-I were given in Fig. 9, Fig10, Fig.11 and Fig.12.



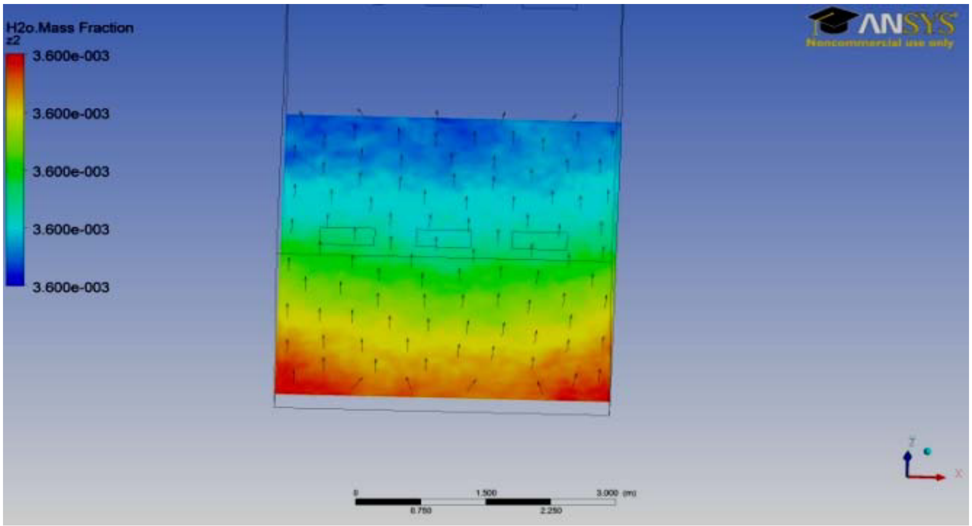
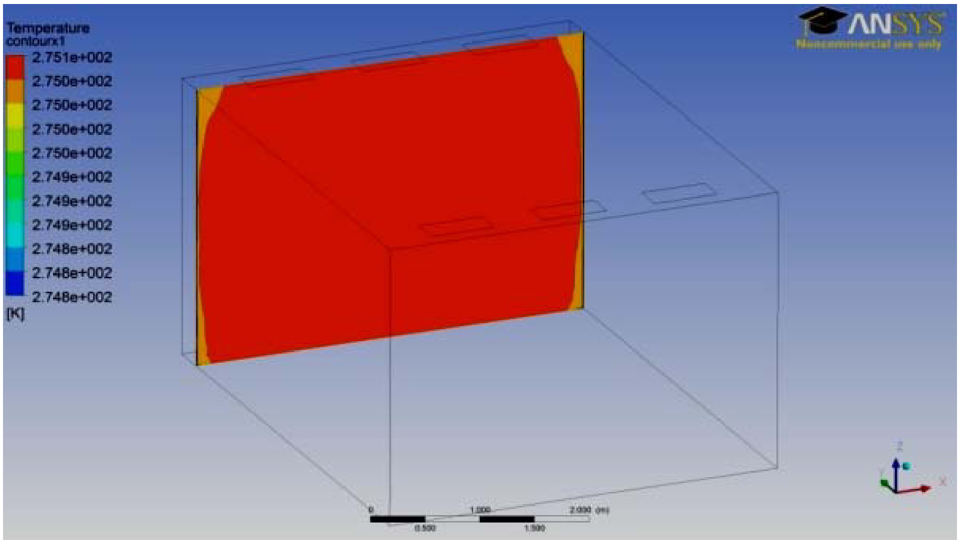


Fig. 9. CFD Models for temperature and relative humidity of door-wall



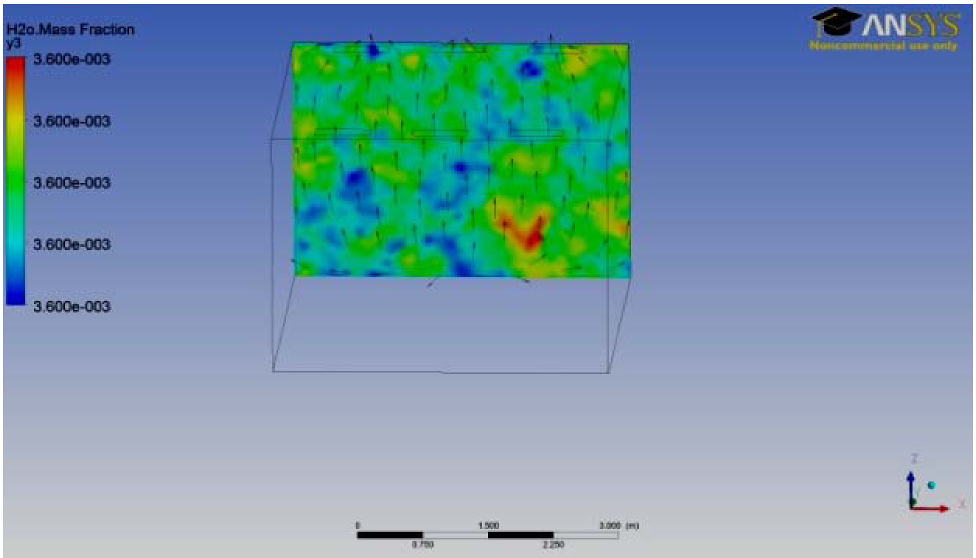
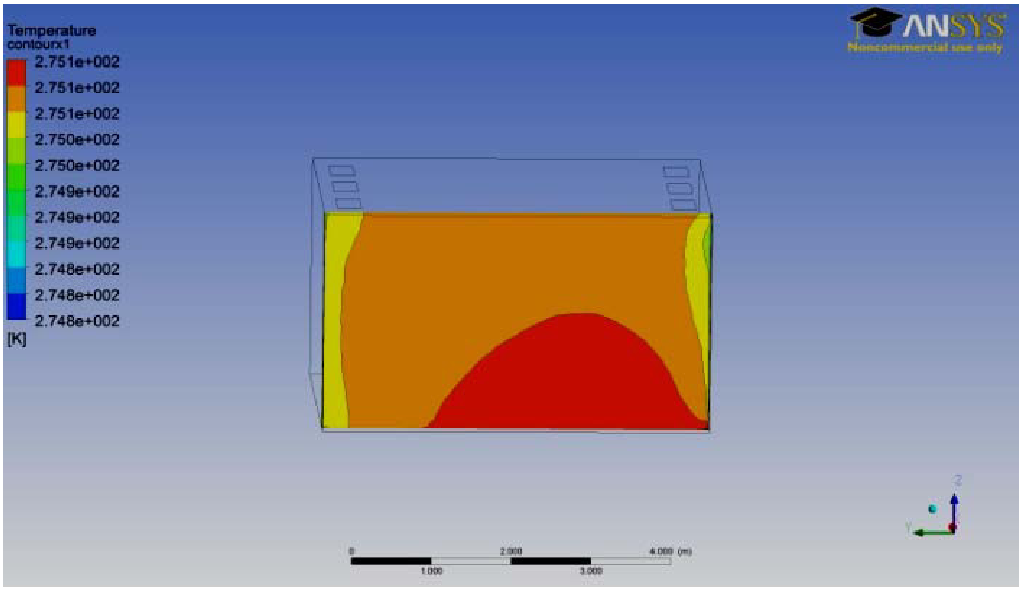


Fig. 10. CFD Models for temperature and relative humidity of across of door-wall



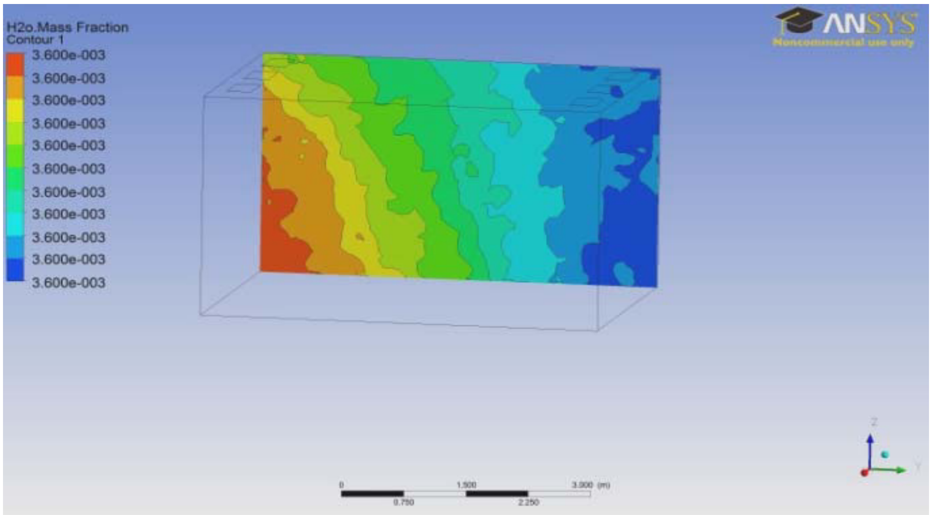
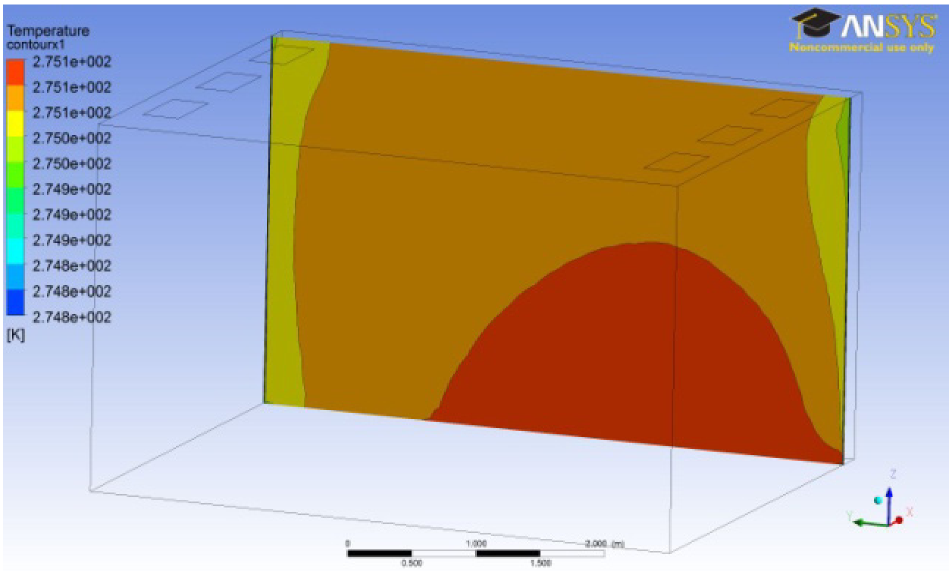


Fig. 11. CFD Models for temperature and relative humidity of left sight of door-wall



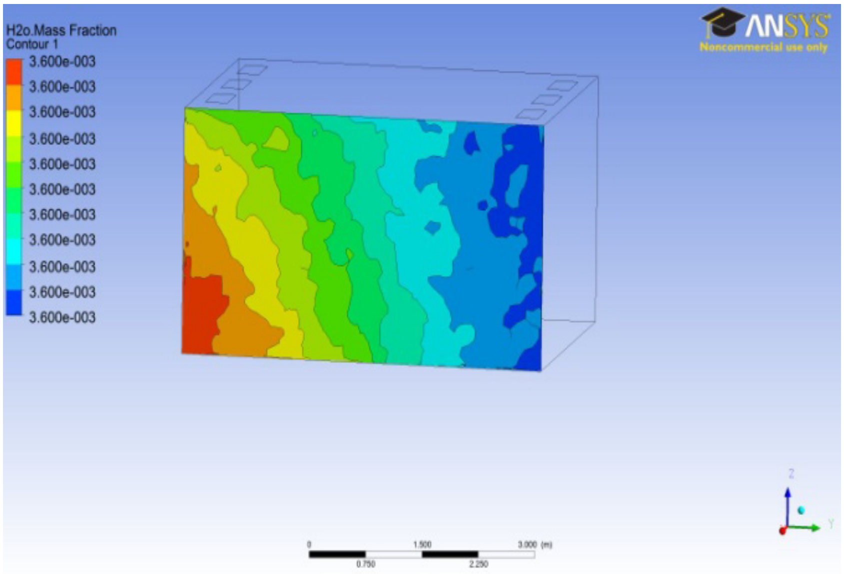


Fig. 12. CFD Models for temperature and relative humidity of right sight of door-wall

Data determined from CFD models and descriptive statistics were given in Table 1 for cold stores.

Table 1. CFD Model data and descriptive statistics for Cols stoeage-I and Cold storage-II

		Cold storage-I		Cold storage-II	
Wall number	**Descriptive statistics**	**t(°C)**	**RH (%)**	**t(°C)**	**RH (%)**
1	Mean	2.54	90.69	2.21	81.85
	Minimum	1.32	80.60	1.54	76.00
	Maximum	3.45	98.20	3.25	85.16
	Standard deviation	0.84	2.06	0.66	3.86
2	Mean	2.88	96.15	2.23	86.72
	Minimum	1.59	94.20	1.60	83.31
	Maximum	3.32	99.18	3.25	95.20
	Standard deviation	0.57	2.06	0.62	3.83
3	Mean	2.87	91.39	2.20	84.70
	Minimum	0.88	80.60	1.56	79.80
	Maximum	3.55	99.18	3.25	94.20
	Standard deviation	0.61	7.19	0.64	3.29
4	Mean	2.78	92.26	2.22	84.26
	Minimum	0.88	76.0	1.54	76.00
	Maximum	3.55	99.18	3.25	95.20
	Standard deviation	0.68	6.96	0.63	3.80

Spatial distribution of the ambient temperature and relative humidity near cold store walls were evaluated. According to the modelling results spatial variability of cold store-II which includes air distribution and suction system was better than cold store-I with conventional cooling system because cold air distributed only from evaporator in cold store-I. In the cold store-II, there were three cold air distribution inlets and the exhaust air suction outlets located different places of ceiling.

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