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# Numerical study of air temperature distribution and refrigeration systems coupling for chilled food processing facilities

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**Abstract**

This paper presents an air temperature distribution and refrigeration system dynamic coupling model to assess the performance of air distribution systems used in chilled food processing areas and its energy consumption impact. The coupling consists of a CFD air flow/temperature distribution system model and a compression refrigeration system model developed in EES integrated in the TRNSYS platform. The model was tested and validated using experimental data collected from a scaled air distribution test rig in an environmental chamber showing a good agreement with the measured data (an hourly energy consumption error up to 5.3 %). The CFD/EES coupling model can be used to design energy efficient cooled air distribution systems capable to maintain the required thermal environment in chilled food processing facilities.


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*Keywords:* Air distribution systems; Chilled food factories; Refrigeration; CFD; EES; TRNSYS

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**Nomenclature**

| | |
|---|---|
| q | Heat flow [$W.m^{-2}$] |
| Ui | Overall heat transfer coefficient [$W.m^{-2}.K^{-1}$] |
| ΔT | Temperature difference [K] |
| P | Power consumption (kWh) |

## 1. Introduction

The UK chilled food market is one of the most highly developed in the world. Its growth over the last few years has been massive. According to the UK Chilled Food Association the prepared chilled food marked in the UK has grown from £7357 m in 2005 to its current £12280 m in 2015 [1]. Chilled food chain relies heavily on refrigeration for the maintenance of low temperatures during processing, transportation, and retail of chilled food products. In the UK, refrigeration systems in the cold food chain are estimated to be responsible for 16,100 GWh energy use and 13.7 $MtCO_2e$ Greenhouse Gas Emissions in 2010. This account for approximately 28 % of final energy use and 7 % of GHG emissions of the whole food-chain for 2010 [2]. Chilled food products have short shelf lives and processing takes place in facilities that are normally maintained at temperatures in the range between +4 to +12 ºC depending on the type of product, processing time and the desired minimum shelf time. Chilled food processing takes place in large spaces with high ceilings where cooling is normally provided by ceiling mounted fan coil units, air socks or diffusers. For the system to be effective, large air circulation rates and air velocities are required which, combined with the low temperatures cause high energy consumption and in some cases discomfort for the workers in the space. Therefore, the air distribution is an essential factor that needs to be carefully considered in order to create an environment capable of maintaining food quality without excessive worker discomfort. The air distribution system should create a temperature and humidity homogeneity around the food product to maintain its quality.

Air distribution modelling techniques have been developed to provide a better understanding of air flow patterns and temperature distribution in large spaces including cold rooms. The most powerful of these is the Computational Fluid Dynamics (CFD). Experimental results can be initially used for the CFD model validation. Once the CFD model is validated, it can be used to investigate different air distribution systems under different cooling conditions. This can lead to a better understanding of the air distribution in the space and optimum designs to improve product quality. Gowreesunker et al. [3] investigated numerically the energy performance and indoor environmental control of a displacement diffuser in an airport terminal space. A coupled TRNSYS-FLUENT model was developed and used to predict the performance of the building under two different control strategies. TRNSYS was used to simulate the air conditioning system, while FLUENT was used to simulate the indoor airflow and radiation. Ambaw et al. [4] reviewed the application of CFD for the modelling of post-harvest refrigeration processes. They identified the most common solution method to be the finite volume method with the upwind differencing scheme. In addition, it was reported that the Reynolds Stress Model (RSM) provides more accurate predictions compared to the conventional k-ε model but the k-ε model is more commonly used due to its lower computational requirements. Laguerre et al. [5] and Duret et al. [6], in order to avoid the computational time of a CFD model, created a simplified model using the knowledge obtained from experimental measurements. The model was separated into zones and heat balance equations for each zone were developed. The simplified model was found to predict the product cooling rate and the final product temperature at different positions in the cold room quite well. Delele et al. [7] developed a 3-D model in CFD in order to predict air-flow and heat transfer characteristics of a horticultural produce packaging system. In contrast to previous studies which considered the bulk of the product as a porous media due to limitations in computational power and time, Delele's study considered the detailed geometry and properties of the packaging material. The air flow in the space was solved using the Reynolds averaged Navier Stroke equations (RANS). The authors applied a transient simulation with a time step of 180 s (50 iterations per time step) and the governing equations were discretized using a second order upwind scheme. The SST k-ω was found to produce the most accurate predictions. This paper presents the evaluation of an integrated CFD air distribution and EES refrigeration systems model. The model was tested and validated using experimental data collected from a scaled air distribution test rig in the environmental chamber.