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Research Paper

Numerical investigation on the buoyancy-driven infiltration airflow through the opening of the cold store

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HIGHLIGHTS

- The infiltration airflow through the door of the cold store is numerically studied.
- The effects of cooling fans on are considered in the simulation.
- The prediction performance of the unsteady RANS model is validated by experiments.
- The inner flow area of the infiltration is analyzed by the CFD model.

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ABSTRACT

With the rapid growth of the total gross of the cold store, the energy consumption problem of the cold store is attracting increasing attentions. Infiltration through the door, which accounts for a very large part of the total heat load, has been highlighted in the previous simulation studies. However, the transient simulation of the infiltration in the cold store is not sufficient and the complex condition such as infiltration coupled with the cooling fans on is not covered. In this paper, a transient infiltration simulation model is established based on the unsteady RANS model. The model is validated by the experimental data of a cold store under conditions with different temperature differences, opening sizes and operation mode of the cooling fans. The results show that the predicted value and change trend of the infiltration air volume, local wind speed and temperature by the established model agree well with the experimental data. By using this model, the characteristics of the infiltration is analyzed. The results show that the position of the velocity boundary around the doorway plane and the tendency of the velocity distribution are almost invariable and are not affected by the door opening sizes and the temperature differences of the cold store.

1. Introduction

With the promotion of the global cold chain commodity market, fresh food industry and the Internet economy, the gross amount of cold stores for perishable food storage increases rapidly in recent years. According to statistics, the current gross amount of cold stores is 118 million m^3 in the US [1], 60–70 million m^3 in Europe [2] and 160 million m^3 in China. However, the rapid expansion of the cold stores also brings some energy consumption problems. Firstly, there is a large difference between the energy use degrees of different cold stores. The specific energy consumptions ranges from 26 to 379 kW h m^{-3} $year^{-1}$ are found by literatures [2,3]. Secondly, researches on the energy assessment and energy audit lag behind in the increasing construction of the cold store. There are any standards for the energy use and energy conservation of the cold store. Finally, the energy consumption of the cold store is affected by a variety of complex and coupling factors (such as weather, refrigeration equipment and different kinds of heat load), which may need to be further studied to be better understanding and optimizing the energy use of the cold store.

The infiltration airflow through the opening of the cold store, which is a natural convection caused by the large difference of air density around the doorway, can lead to a strong and transient air exchange of the warm and the cold air. Chen et al. [4] pointed out that the heat load added by the infiltration airflow into the cold store can even account for more than half of the total heat load.

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Nomenclature

A	area (m^2)
C	gas concentration (ppm)
L	specific length of the doorway (m)
N	initial number of the grid
Q	infiltration flow rate ($m^3\ s^{-1}$)
T	temperature (°C)
U	velocity ($m\ s^{-1}$)
V	volume (m^3)
t	time (s)

Greek symbols

ΔT	temperature difference (°C)
β	coefficient of thermal expansion (K^{-1})

Subscripts and superscripts

c	cold store
e	environment
f	final
i	initial

Lafaye de Micheaux et al. [5] stated that the infiltration through the doorway of the cold store can introduce the sensible and latent heat load into the cold store. The heat load introduced by the infiltration is directly related to the infiltration rate. Therefore, many researchers have carried out the experiments and simulation studies on the characteristics and the prediction of the infiltration airflow. Foster et al. [6,7] have compared some analytical models for predicting infiltration proposed by some early researchers and a CFD model against the measurement of the infiltration with different opening sizes and temperature differences on a specific cold store. The results showed that all the analytical models were steady-state models to over-predict the infiltration flow rate and the largest predict error was over 20%. The CFD model, although could provide a transient infiltration flow rate, was less accurate

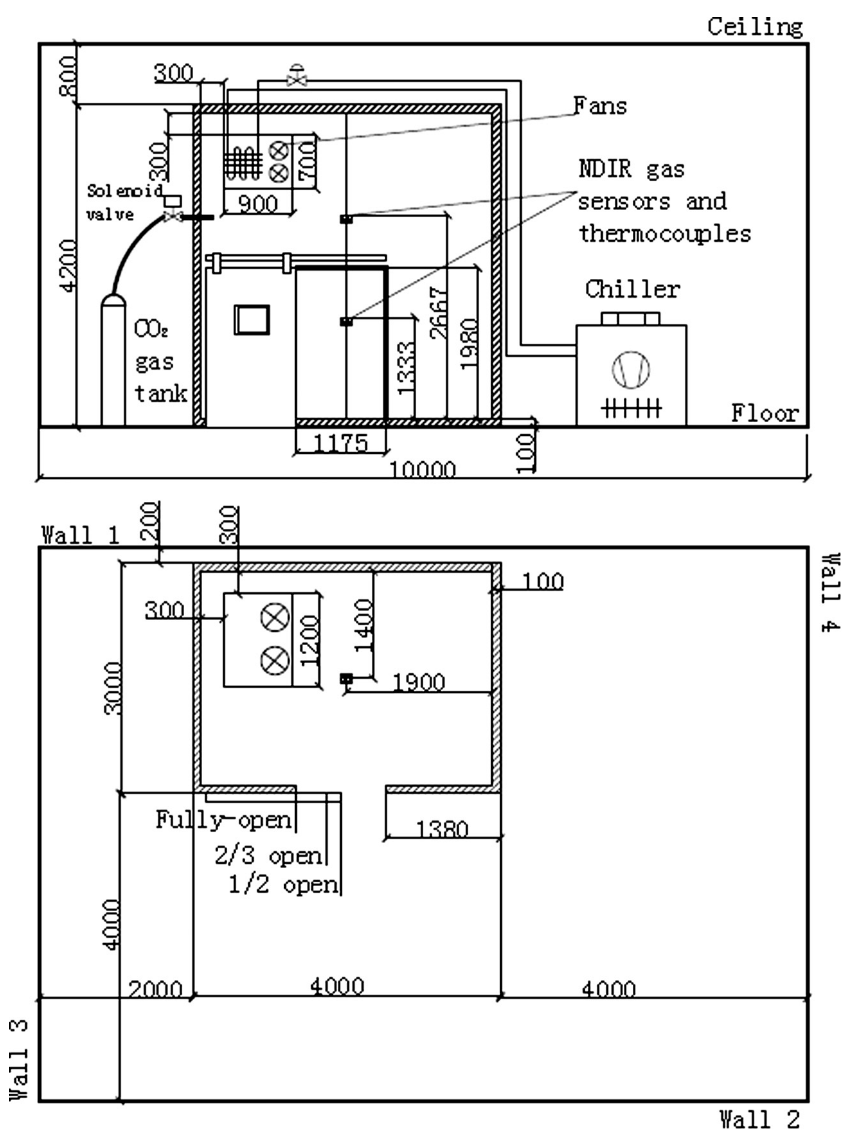

Fig. 1. The physical dimensions of the experimental cold store.