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Experimental investigation on a vertical display cabinet with central air supply

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ABSTRACT

The frosting and defrosting of air cooler in a display cabinet usually lead to a large temperature fluctuation, thus increase the energy consumption of the display cabinet. In this paper, a vertical display cabinet with central air supply (VDCCAS) is established, experimented and compared with a conventional vertical display cabinet (CVDC). The refrigeration system of the VDCCAS consisting of a compressor, a condenser, a thermostatic expansion valve (TEV) and an evaporator is independent of the cabinet in a VDCCAS, and the cold air cooled by the evaporator is supplied through the air duct to the cabinet to realize refrigeration. Comparing to the CVDC, the VDCCAS can easily control the air curtain velocity, decrease the frost magnitude, increase the defrost cycle from 6 h to 9 h, and reduce the maximum product temperature rise in the defrost cycle from 3.0 °C to 2.0 °C. To reach the lowest temperature distribution in the cabinet, the optimum velocity of the air curtain is 0.7–0.8 m/s and the optimum Reynolds number is 4350–5000. When two cabinets work together, the airflow ratio of the two cabinets should be 1.1–1.2 in order to keep the temperature balance between the two cabinets.

1. Introduction

Vertical display cabinets are widely used in supermarkets. They can not only store various foods, but also have the advantages of good display and easy getting of products stored. There are two important problems in application of vertical display cabinets. Firstly, the steady temperature cannot be guarantied, which may result in serious damage of the quality of the freezing food [1]. The temperature fluctuation is caused by the frosting and defrosting of the evaporator in the vertical display cabinet. The studies showed that cooling load of display cabinet [2–4], compressor power [2,3], product temperature [2–8], discharge air curtain temperature [2,3,8,9] and return air curtain temperature [8,9] periodically fluctuate according to the defrosting cycle. Secondly, the energy consumption of a vertical display cabinet is very high. In a vertical open display cabinet, the only barriers between the refrigerated food inside the cabinet and the ambient air in the store are one or more forced-air curtains. However, these air curtains are easily disturbed by the ambient air, and then a more or less amount of ambient air is entrained into the display cabinet, which results in more power consumption than that for a horizontal display cabinet [10]. It is reported that 50% of energy consumption in a supermarket is consumed by display cabinets in it [8,11].

In recent years, people try all best to solve the two problems mentioned above. Experiments of Tahir and Bansal show that cabinets have less frost, more uniform frost patterns, thus less temperature fluctuation when an electronic expansion valve substitutes for a thermostatic expansion valve [8]. However, an electronic expansion valve is normally much expensive than a thermostatic expansion valve [12]. In order to decrease the temperature fluctuation of a display cabinet, the evaporator with wider pin pitch and smaller windward velocity can be used in the display cabinet, thus lessening the frost magnitude and extending the frost cycle [13]. However, the evaporator is usually located at the bottom or the back of a conventional vertical display cabinet (CVDC). There is no space to install such an evaporator in the CVDC, and so the temperature fluctuation of the CVDC cannot be effectively solved owing to the inherent structure disadvantage of the CVDC.

As the infiltration heat through air curtain constitutes the largest cooling load component of a CVDC [3], air curtain has been studied by many researchers. CFD simulation shows air curtain velocity plays a key role in the entrainment by the ambient air [5,14–17]. Air curtain may lose its sealing ability when a very small air curtain velocity is adopted, thus increasing the infiltration heat from the ambient [18]. However, a very large air curtain velocity may increase the entrainment heat from the ambient [17,19]. Therefore, air curtain may have an optimum velocity or Reynolds number to minimize the energy consumption of a CVDC. In the application of a CVDC, the air curtain velocity needs to be adjusted to the optimum value in order to decrease the compressor power. Unfortunately, as the cold air circulates inside the CVDC, it is not easy to adjust the air curtain velocity. Therefore, the high energy consumption of a CVDC cannot be effectively decreased owing to the inherent structure disadvantage of the CVDC.

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Nomenclature

Aco	air curtain outlet	Re	Reynolds number
AV	air stop valve	RV	refrigerant stop valve
CCU	compressor-condensing unit	S	shelf
CVDC	conventional vertical display cabinet	Te	test environment
Iaci	inner air curtain inlet	TEV	thermostatic expansion valve
Oaci	outer air curtain inlet	VDCCAS	vertical display cabinet with central air supply

In order to avoid the limitation caused by the inherent structure disadvantage of a CVDC, a vertical display cabinet with central air supply (VDCCAS) is developed based on a CVDC in this paper. In the VDCCAS, the evaporator is removed from the display cabinet. The removed evaporator and a new fan constitute a cold air processor, in which the cold air is cooled and supplied to the display cabinet through the air duct. There are no restrictions for the evaporator to adopt a wider pin pitch, thus decreasing the frost magnitude and lowering the temperature fluctuation inside the display cabinet. In addition, the air valve installed in the air supply duct can be used to adjust the air curtain velocity easily.

There are still several important problems in the application of a VDCCAS. Firstly, when a VDCCAS is adopted, the frost magnitude is decreased. It is necessary for researchers to employ a new defrost cycle and defrost time to attain the minimal temperature fluctuation. Secondly, as mentioned above, the influence of air curtain velocity on the display cabinet temperature is obvious. In a VDCCAS, it is very important to investigate the air distribution by experiments, in an attempt to control the air curtain velocity in the display cabinet. Thirdly, many display cabinets work at the same time in a normal supermarket. However, in a VDCCAS system, one cold air processor supplies the cold air to many display cabinets. The air distribution among these display cabinets plays a very important role in the temperature equilibrium of these display cabinets, therefore experiments on the air distribution among many display cabinets is necessary, and experiments can be done on two cabinets at the beginning.

The purposes of this paper are as follows:

(1) To find the suitable defrost cycle and defrost time for attaining the minimal temperature fluctuation in a VDCCAS.
(2) To investigate the optimal air curtain velocity for small temperature fluctuation in a VDCCAS.
(3) To present the strategy of air distribution for the temperature equilibrium between two cabinets.

2. A vertical display cabinet with central air supply

A typical CVDC is shown in Fig. 1. The refrigerant vapor is sucked into the compressor-condensing unit (CCU), compressed by the compressor, cooled by the condenser and becomes refrigerant liquid with high pressure at the CCU outlet. The refrigerant liquid enters the display cabinet through the liquid pipe, then flows through the thermostatic expansion valve (TEV) with temperature and pressure decreasing, finally passes through the evaporator coil located at the back of display cabinet. The refrigerant absorbs heat and becomes vapor in the evaporator, and then flows back to the CCU.

At the same time, the air is forced to flow through the surface of the evaporator coil to decrease its temperature and humidity. The cold air is blown through two linear diffusers to form two air curtains. The temperatures and humidities of the air curtains are increased due to the mass and heat transfer between the air curtains and the entrained ambient air.

Although CVDCs are widely used, they have some disadvantages, which are listed as below:

- Air curtain velocity is difficult to be adjusted.
- Large air velocity over the evaporator surface accelerates frosting on the fin surface.
- Small fin pitch increases the airflow resistance, reduces the airflows through evaporator surface, thus lessening the air curtain velocity.
- As the evaporator locates at the narrow space inside the cabinet, the inner structure of the display cabinet is complex.

As mentioned above, the small fin pitch of evaporator and large air velocity over the evaporator surface are the key to the disadvantages of a CVDC. However, it is impossible for a CVDC to overcome these difficulties because there are no more space to install an evaporator with wider fin pitch and small windward velocity. A feasible scheme is to remove the evaporator from the display cabinet. The removed evaporator and a new fan constitute a cold air processor, in which the cold air is supplied to the display cabinet through an air supply duct to form the air curtains, and the air at the air curtain outlet can be returned by the air return duct to accomplish the cycle. The new type display cabinet, so-called "vertical display cabinet with central air supply (VDCCAS)" is shown in Fig. 2.

The new display cabinet has some advantages. Firstly, the evaporator can use wider pin pitch and smaller upwind velocity compared with a CVDC, which can reduce frost amount, decease the temperature fluctuation, and lessen the energy consumption. Secondly, the air valve installed in the air supply duct can be used to control the optimum air curtain velocity easily. Lastly, the inner structure of the display cabinet can be simplified, the effective load space can be improved, and the fabrication cost of the display cabinet can be lowered.

3. Experimental setup and procedure of VDCCAS

3.1. Experiment apparatus

The schematic of a VDCCAS experimental rig is shown in Fig. 3. The experimental rig is composed of a CCU, a cold air processor, an air supply duct, an air return duct and two display cabinets. In order to compare the characteristics of the VDCCAS with those of a CVDC, a cabinet (Cabinet 2) must be used as either a CVDC or a VDCCAS. Thus, the refrigerant liquid flows through a TEV, and then enters the evaporator coil inside Cabinet 2. However, the evaporator is completely removed from Cabinet 1, which makes Cabinet 1 be only employed as a VDCCAS. Cabinet 1 and Cabinet 2 are installed in parallel, and connected to the air supply (return) main duct by an air supply (return) branch duct. In order to control the air curtain velocity accurately during the experiments, the air