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Research Paper

Comparison of independent and synchronous opening control strategies of two air-dampers in three-temperature frost-free refrigerator

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HIGHLIGHTS

- Supply-air into VC and RC through air-dampers controlled by their temperature sensors.
- Longer air-damper opening time resulted greater refrigerator energy consumption.
- Independent and synchronous opening control strategies were compared experimentally.
- Synchronous opening control shorten the total air-damper opening time by 16.7%.
- Refrigerator energy consumption reduced by 3.1%.

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ABSTRACT

The three-temperature frost-free refrigerator has a variable-temperature (5 °C to −18 °C) compartment (VC) besides regular refrigerating compartment (RC) and freezing compartment (FC). The air cooled by the evaporator always flows into FC during compressor-on period, but into RC and VC through their respective air-damper controlled by their temperature sensors. The effect of RC and VC air-damper control strategy on the refrigerator performance was studied experimentally in this paper. Experimental results show that the FC average temperature could not decrease during air-damper opening period. The main reason was that the evaporator supply-air temperature increased due to higher RC and VC return-air temperature, and up to higher than the FC average temperature. Then, the compressor-on time ratio during on/off cycle was increased. Meanwhile, the compressor input power would be also increased with higher evaporating temperature. The independent and synchronous opening control strategies for RC and VC air damper were compared experimentally. The synchronous opening control shortened the overall time of air-damper opening by 16.7% compared with the independent control since the RC and VC opening time overlapped with each other. Finally, the refrigerator energy consumption decreased by 3.1% while average temperatures of RC, VC and FC stayed almost unchanged, attributed to the decrease in the compressor-on time ratio and the average compressor input power of the refrigerator.

1. Introduction

The household refrigerator is a major appliance to keep food fresh or preserve groceries. Compared with the direct-cooling refrigerator, the frost-free refrigerator utilizes a fan to draw air through the evaporator, and the air cooled by the evaporator is transported into food compartments through air-ducts. Hence the frost-free refrigerator has bigger inner volume and more uniform air temperature field. Especially, three-temperature frost-free refrigerator is much popular because it has a variable temperature compartment (VC) besides regular refrigerating compartment (RC) and freezing compartment (FC). The VC average temperature can be adjusted within the range of 5 °C to −18 °C according to actual needs, and thus it provides a lot of convenience for users.

In the three-temperature frost-free refrigerator, the supply-air flowing out of evaporator is always directed into FC during compressor-on period, but that into RC and VC must flow through their respective air-damper and air-duct. The opening/closing of the air-damper is controlled by the RC and VC temperature sensors. Generally, the refrigerator has just one evaporator and it is important to distribute and offer the proper cooled-air flowrate into RC and VC respectively to maintain the setting temperature of each compartment. Hence, the air-damper control strategy optimization

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Table 1
Main technical specifications of the tested frost-free refrigerator.

Items	Parameters	Items	Parameters
Refrigerator Model	BCD-260WDCN	Compressor	EmbracoVEMB11C
FC volume (L)	76	RC volume (L)	144
VC volume (L)	40	Weight (kg)	71
Throttle device	Capillary Tube	Blowing Agent	Pentamethylene
Climate class	ST	Refrigerant Charge (g)	52
Refrigerant	R600a	Defrost system	Auto defrost

is of great significance to improve the performance of a three-temperature frost-free refrigerator with one evaporator.

Currently, the performance research of frost-free refrigerator in the open literatures are mainly focused on the refrigeration system of the refrigerator [1–4], evaporator frosting/defrosting performance [5–9], various operational factors (such as door opening, load and ambient temperature) in actual conditions [10–13], air circulation in air ducts and compartments [14–21], and so on. Meanwhile, supply-air velocity and temperature distribution inside compartments were investigated. According to previous research, increasing the gap between the back wall and the shelf in compartments [16,17], incorporating the air duct design with appropriate locations of the supply-air openings [18,19] and optimizing geometric configuration in compartments [20] contributed to improving the uniformity of temperature distribution inside compartments, and thus reducing the energy consumption of the frost-free refrigerator. In addition, the short circuit of airflow, which is the airflow reaches the return-air opening directly from the supply-air opening without cooling food, should be avoided [19]. However, no research on the air-damper control strategy of a three-temperature frost-free refrigerator was found from the limited literatures the authors can get.

In order to reduce the energy consumption of a three-temperature frost-free refrigerator by optimizing air-damper control strategy, this study was focused on the air-damper control strategy and its effect on corresponding refrigerator performance. The main works are as follows: First, the RC and VC air-dampers were controlled independently, and the dynamic characteristics of the tested refrigerator were studied. Then, the control strategy of two air-dampers was optimized by a synchronous opening control strategy to shorten the overall air-damper opening time. Finally, the refrigerator performance with two different air-damper control strategies was analyzed comparatively.

2. Experimental apparatus and procedure

2.1. Experimental apparatus

The experimental apparatus consisted of two major parts: the tested frost-free refrigerator, and a set of data acquisition system.

The tested frost-free refrigerator has a overall volume of 260 L, divided into 144 L of refrigerating compartment (RC), 40 L of variable temperature (5 °C to −18 °C) compartment (VC) and 76 L of freezing compartment (FC). The detailed specifications of the refrigerator are shown in Table 1.

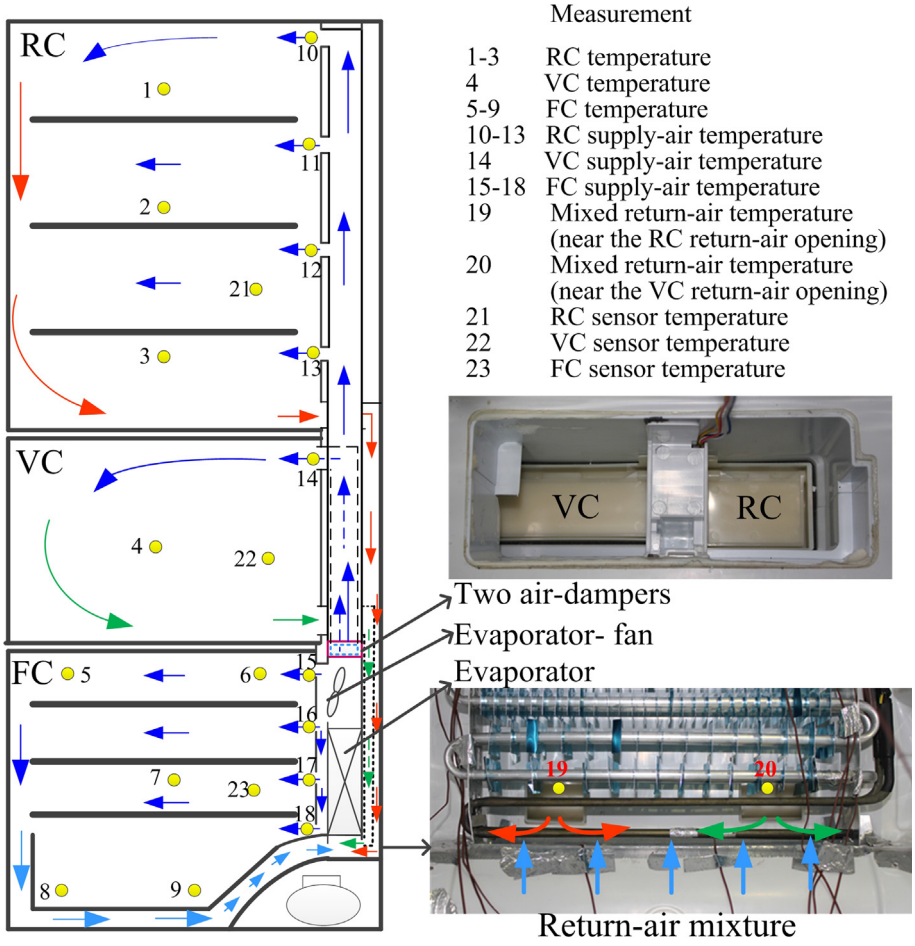

Fig. 1. Air circulation of the three-temperature frost-free refrigerator.