Showcase Using HFO Refrigerant with Built-In Cooling Unit to Render Installation Work Unnecessary

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ABSTRACT

Fuji Electric has developed an environmentally friendly showcase for the convenience store industry. It is designed to be installed in stores that have imposed restrictions on installation work, such as those inside buildings, helping locate a store in excellent property and further improve consumer convenience. The showcase comes with a built-in cooling unit system to simplify installation work and maintenance. Equipped with ducts below the product showcase shelves and airflow guides at the edge of the shelves, it optimizes the amount of airflow to reduce invading heat by about 30%. Moreover, it is the industry-first showcase in the Japanese market to use HFO-1234yf refrigerant, which has a proven track record of use in vending machines, to significantly reduce the environmental burden.

1. Introduction

In recent years, the convenience store industry has seen stagnated growth in the number of stores. Therefore, to facilitate store openings in profitable excellent properties and to further improve the convenience, the businesses in the industry have been studying ways of easily locating a store in a property that has imposed restrictions on the installation work of store facilities. Furthermore, they are working on measures to reduce greenhouse gas emissions to prevent global warming.

It is against this backdrop that Fuji Electric has developed a showcase with a built-in cooling unit that does not require installation work and uses hydrofluoroolefin (HFO) refrigerant with a low global warming impact (see Fig. 1). This showcase was awarded the Outstanding Performance Award of the “21st Ozone Layer Protection and Global Warming Prevention Awards” sponsored by the Nikkan Kogyo Shimbun, Ltd*1.

Fig.1 “USFTL22D1-038AMD”

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2. Background of Development

2.1 Need for eliminating installation work and simplifying maintenance

Showcase installation work requires human resources with specialized knowledge and skills related to refrigerant pipe brazing, drainage pipe laying and electrical work. However, in recent years, these technicians have been becoming more difficult to secure. Moreover, stores are often opened in existing buildings in which the cooling unit has to be installed outside of the store using long pipes or the drainage pipe cannot be laid in the floor of the store. Furthermore, restoration work needs to be considered in advance for the time of tenant lease termination.

Securing human resources for maintenance work are also required to maintain the service systems after installation. In addition, a failure in the refrigerant piping would have to be repaired on-site because it will be difficult to remove or install the cooling unit, including the evaporator. Therefore, it is necessary to streamline maintenance work.

2.2 Environmental support

Showcases and other cooling unit systems that use refrigerants are regulated by the “Act on Rational Use

*1 Showcase using HFO refrigerant with built-in cooling unit was awarded the “21st Ozone Layer Protection and Global Warming Prevention Awards” sponsored by the Nikkan Kogyo Shimbun, Ltd.
https://biz.nikkan.co.jp/sanken/ozon/number21.html

and Proper Management of Fluorocarbons" enacted in April 2015. This act stipulates that existing cooling unit systems must be replaced with new ones using a low global warming potential (GWP) refrigerant, and proper measures must be taken to prevent refrigerant leakage not only when using the system, but also during the life cycle from manufacture to disposal.

In a separate type showcase, the cooling unit system (consisting of a compressor, condenser and control equipment) and the cases for displaying products are installed separately. The cooling unit system and the cases are connected by long refrigerant pipes. This structure requires a larger amount of refrigerant filling, making it more susceptible to large amounts of refrigerant leakage if the piping is damaged. Separate type showcases occupied as high as 26.9% the total emissions from all items of equipment that use fluorocarbons in 2012. It is believed that one of the reasons for the refrigerant leakage was unstable work quality due to the on-site work for flare connection and brazing connection of refrigerant pipes, refrigerant filling, and leakage inspection.

3. Aims and Challenges of Development

The aims of development were to eliminate the installation work, streamline maintenance and reduce the environmental load through a completely-sealed cycle that uses an HFO refrigerant with a low GWP. To achieve these goals, we faced the following challenges:

(a) The load on the cooling unit and the amount of drain water must be lowered by the reduction of the amount of invading heat derived from drawn-in outside air.
(b) The drain water generated by the evaporator must be evaporated in the showcase.
(c) A cooling unit system that uses an HFO refrigerant with a low GWP must be offered and the amount of refrigerant filling must be reduced.
(d) The compact built-in cooling unit must be able to be incorporated in a showcase and easily mounted and removed while delivering high refrigerating capacity.

4. Features

4.1 New air curtain system with distributed airflow

As shown in Fig. 2, conventional units blocked invading outside air by forming an air curtain with airflow from the outtake at the top of the showcase to the intake at the bottom. To form this air curtain, an extremely large amount of airflow was required at the front of the showcase, which induced non-negligible invading heat caused by drawn-in outside air.

As shown in Fig. 3, most of the invading heat is due to latent and sensible heat in the air penetrating through the air curtain. As a result, it became necessary to reduce the airflow velocity while maintaining the air curtain for blocking the outside air.

As shown in Fig. 4, our recently developed showcase forms an air curtain with low velocity airflow for each shelf by mounting a duct below each product showcase shelve and airflow guide at the edge of each

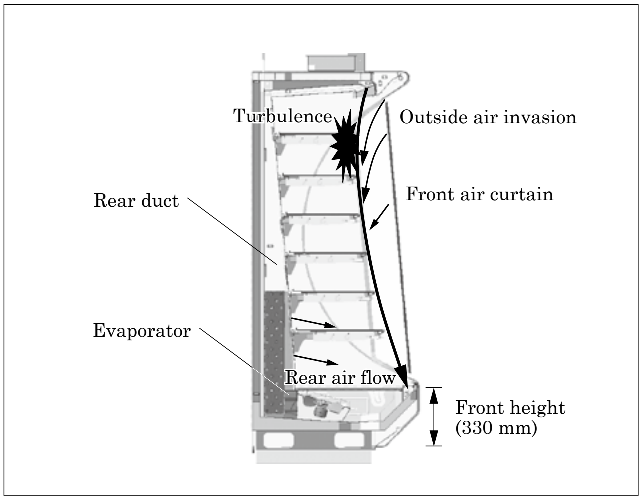

Fig.2 Conventional air curtain system

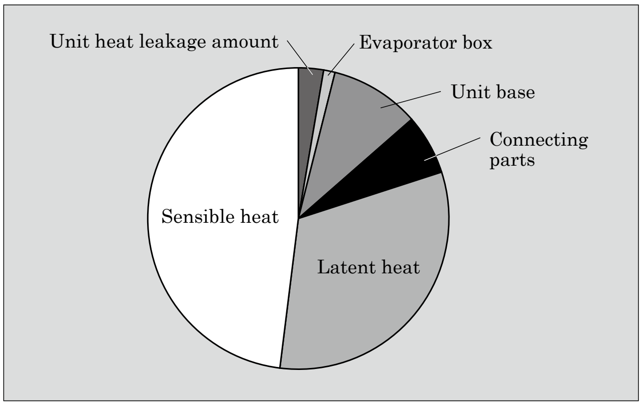

Fig.3 Proportion of showcase invading heat

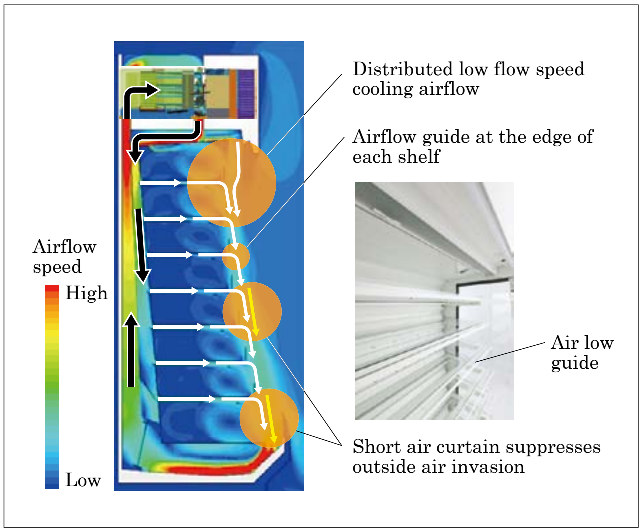

Fig.4 Developed air curtain system

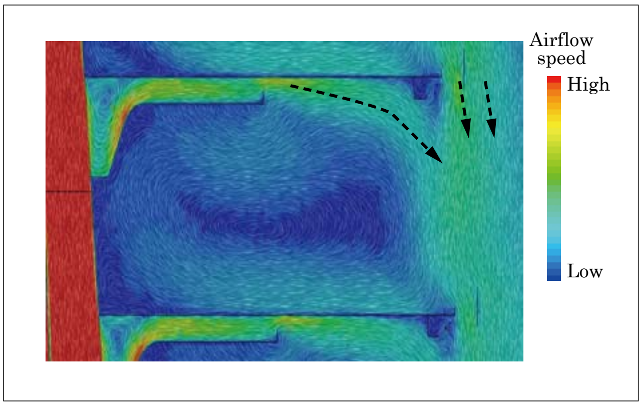

Fig.5 Below-shelf simulation analysis

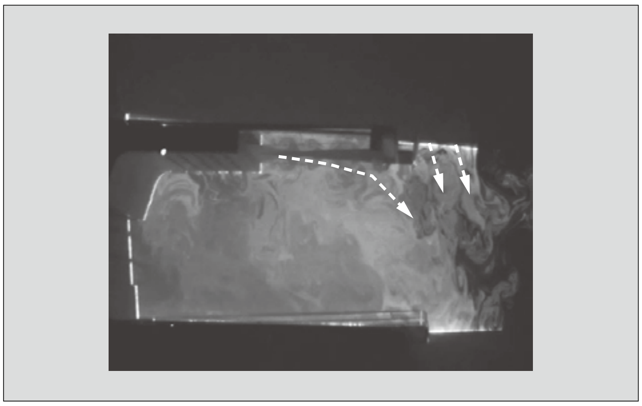

Fig.6 PIV based visualization

shelf. While suppressing turbulence, this air curtain system combines the air that has blown from the duct below each shelf and flowed under the shelf with the air that has blown from the top and flowed along the front face by making these airs flow along the airflow guides at the edge of the shelves.

We analyzed the airflow using a hot air simulation (see Fig. 5) and particle image velocimetry (PIV) that visualizes airflows during an actual operation (see Fig. 6). As a result, we smoothed the airflow at the confluence of air blown from underneath each shelf and the front-face air curtain to optimize the flow rate underneath each shelf and that of the air curtain, reducing invading heat by approximately 30%.

4.2 Drain water evaporation system that uses exhaust heat

In conventional showcases, drain water was drained outside of the store through the embedded piping.

To eliminate the need for piping installation, we have developed a drain water evaporation system that uses the exhaust heat generated when the cooling unit condenses the refrigerant. Figure 7 shows the configuration of the drain water evaporation system. When air at normal temperature and humidity in a store passes through the condenser, the temperature will rise and the relative humidity decrease, resulting in high-temperature dried air. The evaporation sheet is

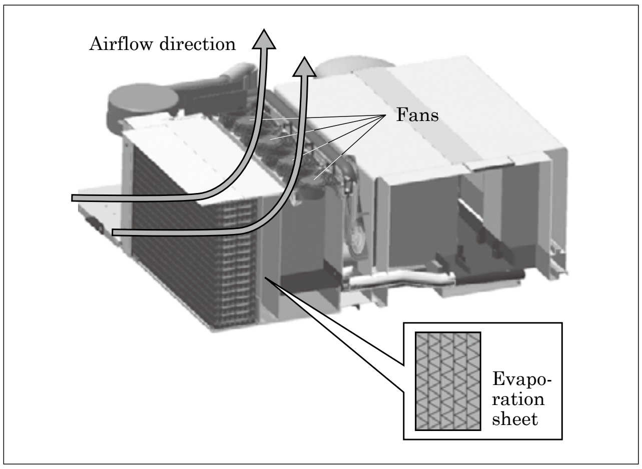

Fig.7 Configuration of drain water evaporation system

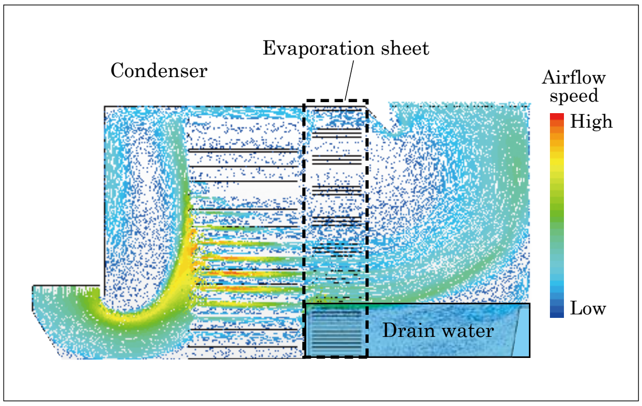

Fig.8 Simulation analysis (evaporation sheet)

placed downstream from the condenser to use the high-temperature dried air, facilitating evaporation.

The drain water that accumulates in the evaporation pan is absorbed from the bottom of the evaporation sheet and moved upwards then evaporated. The surface area in contact with the water surface is increased by using smooth evaporation sheets to enclose both sides of the bellows-shaped evaporation sheet. This increases the water absorption rate and the surface area in contact with the airflow that passes through the evaporation sheet. As a result, we sufficiently increased a water absorption rate that exceeded the amount of generated drain water. Figure 8 shows the simulation analysis results. By utilizing simulation to analyze the air blown to the condenser and evaporation sheet, we increased the proportion of air flowing to the bottom of the evaporation sheet to immediately evaporate a sufficient amount of drain water absorbed by the evaporation sheet.

4.3 Cooling unit system with low GWP refrigerant

(1) Use of low GWP refrigerant

Our recently developed showcase is the first in the industry to use the refrigerant HFO-1234yf, which has a good track record in vending machines.

Table 1 shows the physical properties of this re-

Table 1 Comparison of refrigerant properties

Items	HFO-1234yf	HFC-134a	HFC-404A	HFC-410A
Boiling point	−29.0°C	−26.0°C	−46.2°C	−51.4°C
Critical temperature	95.0 °C	102.0°C	72.0°C	71.4°C
Steam pressure (25 °C)	0.677 MPa	0.665 MPa	1.250 MPa	1.660 MPa
GWP*	1 or less	1,300	3,940	1,920
Ozone depletion potential	0	0	0	0

* Intergovernmental Panel on Climate Change (IPCC) 5th Report using 100-year values

frigerant, along with other refrigerants used in conventional showcases. This refrigerant has an ozone depletion potential of zero and an extremely low GWP of 1 or less. Moreover, it allows cooling unit systems to provide high efficiency in a temperature zone of 10 °C or less, in which refrigerated products are stored. However, HFO-1234yf refrigerant, having a low density, decreases in refrigeration capacity at low pressures due to pressure loss. We must overcome the properties.

(2) Inverter compressor for high-speed rotation

The conventional model used a three-phase 200-V power supply because it mounted a high output compressor to cool multiple showcases. The developed showcase uses a commonly-available single-phase 100-V power supply to be installed in wide range of locations with fewer restrictions. It is required to provide sufficient refrigeration capacity with limited power of 100 V/15 A. Therefore, it employs a compact reciprocating inverter compressor. To circulate refrigerant in a sufficient amount for cooling capacity, the motor of the compressor needs to rotate at a high speed. Figure 9 shows the configuration of the control system for the cooling unit. To obtain stable current from the AC power supply, the control system improves power factor by adjusting the reactor even when the input current of the compressor increases due to environmental changes, such as high ambient temperatures in the summer and low supply voltages. The converter has a current transformer for detecting the

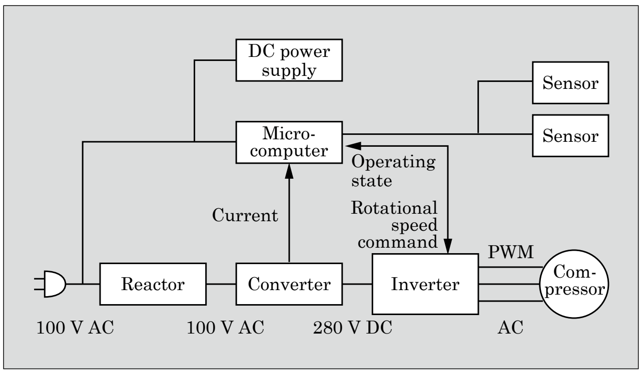

Fig.9 Configuration of cooling unit control system

current so that the current can be increased to its upper limit. Furthermore, the control system maintains a high rotation speed of the compressor by combining the current detection with proportional-integral-differential (PID) control for the temperature inside a showcase to provide required refrigeration capacity.

(3) High efficiency all-aluminum heat exchanger (condenser, evaporator)

In conventional systems, the evaporator that combines copper piping for refrigerant circulation with aluminum fins was installed inside the rear ducts, and the condenser was mounted in the cooling unit outdoors. This structure led high thermal resistance because the fins are only in contact with piping by pipe expansion. It therefore needed a large heat exchanger.

The developed showcase uses an all-aluminum heat exchanger, which is used in vending machines We have integrated the piping and fins into one metal part and used perforated pipes, which have fine holes, for the piping. This structure change allows the heat exchanger to approximately double the heat exchange amount per unit volume and reduce the size. The cooling unit system, including a condenser and evaporator, can be thereby housed in a removable enclosure and mounted on the top of the showcase. Even if a malfunction occurs, the cooling unit system can be removed and replaced very quickly without stopping the operation of the store. Furthermore, the amount of enclosed refrigerant has been greatly reduced by 83% when compared with our conventional separate type showcases. This reduction is due to the miniaturized evaporator, reduced volume inside pipes using perforated piping, and elimination of piping that connects to outside equipment.

(4) Reduction in pressure loss of the cooling unit system

To improve the cooling capacity, the developed showcase increases refrigerant circulation amount through high-speed compressor rotation. However, as shown in Equation 1, cooling capacity decreases due to a significant increase in pressure loss proportional to the square of the flow velocity in the pipe.

Using perforated piping, composed of thin pipes, for the all-aluminum heat exchanger is effective in that it increases the heat transfer area. On the other hand, the small inner diameter of the pipe causes the heat exchanger to increase pressure loss, decrease refrigerant circulation, and reduce cooling capacity.

$$\Delta P = \lambda \cdot \frac{L}{D} \cdot \frac{\gamma v^2}{2} \quad (1)$$

ΔP : Pressure loss (Pa)
λ : Pipe friction coefficient
L : Pipe length (m)
D : Pipe inner diameter (m)
γ : Pipe inner gas density (kg/m^3)
v : Pipe inner flow velocity (m/s)

Therefore, we divided the paths through which the evaporator refrigerant circulates into four parts (top-left, top-right, bottom-left and bottom-right), as shown in Fig. 10, to reduce the pipe length of each path by 75% while maintaining the overall pipe length in the evaporator. Moreover, by shortening the pipe for heat exchange in the internal heat exchanger, we were able to decrease pressure loss by 70% for the entire cooling unit system, as shown in Fig. 11, and secure the target refrigerant circulation amount.

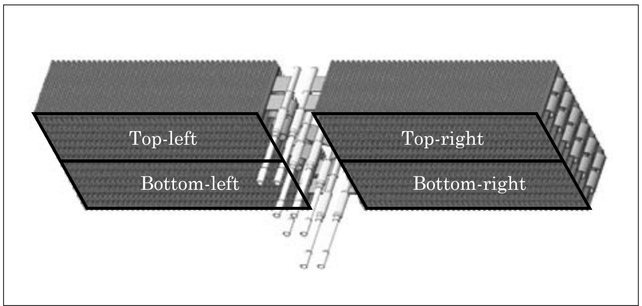

Fig.10 Structure of evaporator path

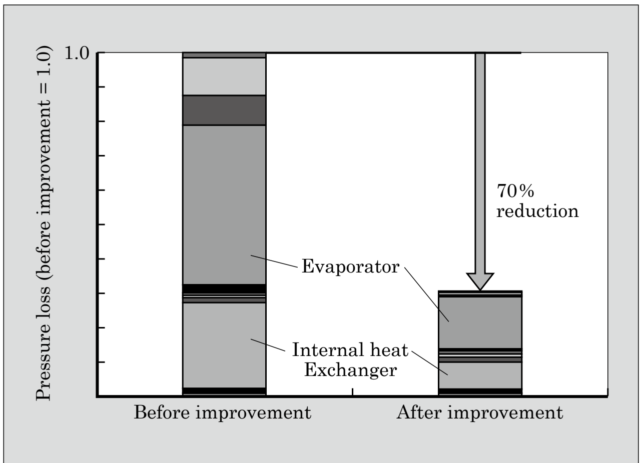

Fig.11 Proportion of cooling unit system pressure loss

(5) High-precision control of refrigerant circulation

The conventional cooling unit was connected to multiple showcases. To control refrigerant circulation for each showcase, It used mechanical automatic temperature expansion valves, which control the amount of valve opening by detecting overheating in the evaporator outlet. However, these valves had difficulty controlling the refrigerant temperature at the evaporator inlet. Therefore, the conventional showcase cooled the refrigerant to approximately −10 °C to increase the difference in temperature with the showcase inside. As a result, the evaporator needed defrosting because frost formed on it and decreased the amount of heat exchange. Furthermore, the cooling unit stopped during defrosting and a large-capacity heat exchanger is needed to restore the temperature rise in the showcase.

The developed showcase utilizes an electronic expansion valve with pulse width modulation (PWM) control, which has been employed in vending machines. The circulating refrigerant can be linearly controlled at very small flow rates according to the duty ratio (proportion of ON/OFF time) of the electronic expansion valve. Since the refrigerant temperature can be controlled with high precision, the refrigerant no longer need cooling below 0 °C, and this makes it possible to eliminate evaporator frost. Therefore, the developed showcase can continuously operate while controlling temperature fluctuation without defrosting.

5. Postscript

In this paper, we described a showcase that uses an HFO refrigerant and does not require installation work because it comes with a built-in cooling unit. We plan to continue to develop products that reduce environmental burdens by constantly expanding our line-up, while also working to improve consumer convenience and preserve the global environment.

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