Energy-Saving Technology for Showcases

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ABSTRACT

The retail industry, including supermarkets and convenience stores, is increasingly demanding further energy saving of showcases, which keep products in adequate cold temperatures. To save showcase power consumption, Fuji Electric has developed a precise valve opening control system using an electronic expansion valve to optimally control the flow rate of refrigerant. This system is also designed to optimize the amount of refrigerant contained in the refrigerant piping and equally allocate the amount of refrigerant to each showcase, ensuring uniform cooling. This control system reduces power consumption by approximately 20% compared to conventional control methods.

1. Introduction

In recent years, the introduction of refrigerated showcases has been increasing in the retail industry, typified by supermarkets and convenience stores, as the need for frozen foods and fresh, hygienic foods has increased due to lifestyle changes. At the same time, energy saving in showcases has become increasingly important, as stores are being required to save even more energy. This paper describes the development status of Fuji Electric on the energy-saving technology for showcases.

2. Basic Configuration and Types of Showcases

Showcases in supermarkets and convenience stores have the function of displaying products while cooling the showcase inside to keep the products at the proper temperature.

Figure 1 shows the basic configuration of the showcase cooling system. The air blown inside the storage compartment is cooled by circulating low-temperature, low-pressure refrigerant through an evaporator installed inside the showcase. At this time, the refrigerant passing through the evaporator draws heat from the air so that it can be evaporated, becoming vapor (gas) at the outlet of the evaporator. An expansion valve installed upstream of the evaporator controls the operating temperature of the evaporator by adjusting the refrigerant flow rate. Therefore, the expansion valve is an important device that determines the cooling efficiency of showcases. The cooling unit consists of a compressor that compresses and discharges refrigerant gas and a condenser that cools and condenses (liquefies) refrigerant gas.

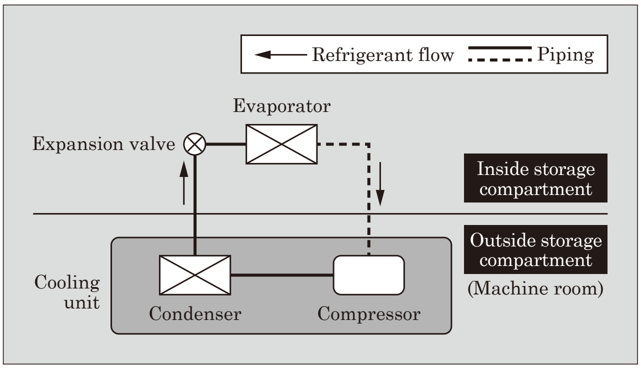

Fig.1 Basic configuration of showcase cooling systems

Showcase component configurations can be broadly classified into two types based on differences in the location of the cooling unit. One type, which is difficult to distinguish by its appearance, is called a built-in showcase and, as shown in Fig. 2, has a cooling unit mounted inside the showcase. Since the mounted

Fig.2 Built-in showcase

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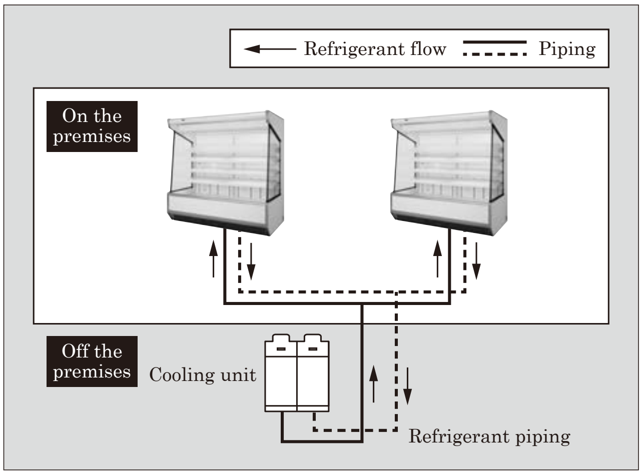

Fig.3 Separately installed showcase

cooling unit and evaporator are connected one-to-one, there is no need for connection work between the showcase and the cooling unit, and the system is often used for stand-alone installation in the center of the store. The other type is called a separately installed showcase, in which a cooling unit is installed outside the store and connected to multiple showcases inside the store, as shown in Fig. 3. In this case, the piping connecting the showcase to the cooling unit is installed on-site. This configuration is often used to arrange multiple showcases along the walls of a store because it is possible to keep costs low by allowing multiple showcases to be operated with a single cooling unit, and because it reduces the impact on the store environment by not releasing the waste heat from the cooling unit inside the store.

3. Features of the Latest Energy-Saving Technology

3.1 Optimizing control with electronic expansion valves

(1) Challenges

In order for the cooling system to operate properly, the superheat of the refrigerant vapor reaching the outlet of the evaporator must be maintained at a constant level. Superheat refers to the temperature level of the refrigerant vapor relative to the boiling point (saturation temperature) of the refrigerant. When the superheat reaches a negative value, that is, a temperature below the boiling point, the refrigerant does not fully evaporate, causing a phenomenon called "liquid return," in which liquid refrigerant is fed into the downstream compressor. This phenomenon must always be avoided because it risks overloading the compressor and causing it to malfunction. The expansion valve installed on the inlet side of the evaporator is required to have a function for controlling the flow rate of the refrigerant to keep the above-mentioned superheat level constant. To achieve this, the mechanical expansion valve used in conventional cooling systems has a mechanism in which a temperature-sensitive cylinder is attached to the piping at the outlet of the evaporator, the refrigerant sealed inside the cylinder is vaporized to change the pressure inside the cylinder, and the opening of the expansion valve is mechanically adjusted using this pressure. However, this mechanism does not directly control the opening of the expansion valve by the superheat. This can result in many potential error factors. Moreover, due to structural constraints, it is not always possible to properly adjust the control performance.

To use the evaporator efficiently, the superheat should be as close as possible to the ideal value of zero. However, in order to prevent the previously mentioned liquid return, when a mechanical expansion valve is used, it is common practice to set the superheat value to a value greater than the ideal value in consideration of safety factors. For the expansion valve, the valve opening is made smaller than necessary, resulting in a decrease in pressure at the outlet of the evaporator. The downstream compressor must increase the overly reduced refrigerant pressure (low pressure) to the specified pressure (high pressure). In other words, the compression ratio, that is, the ratio of high pressure to low pressure, must become higher than necessary, requiring more compressor power to achieve this. This results in unnecessary energy consumption, thereby increasing the power consumption of showcases.

(2) Countermeasures and effect

In order to reduce the power consumption of a showcase alone, we replaced the mechanical expansion valve, which is not always capable of being properly adjusted, with an electronic expansion valve that can precisely control the valve opening, and developed a control system that provides optimal feedback control for the valve opening of the expansion valve.

Since the electronic expansion valve has a mechanism that can adjust the valve opening using a stepping motor, its valve opening can be adjusted with high precision. The newly developed control system uses thermistors to measure temperatures at both the inlet and outlet of the evaporator and adjusts the valve opening by using the superheat value calculated according to the measurements as the control quantity for proportional-integral-differential (PID) control. In addition, we provided it with liquid return prevention control that sets a liquid return threshold to trigger the current superheat level and time. These controls ensure that the superheat level is always close to the ideal value. This allows for an optimal cooling unit cycle at all times without excessively lowering the pressure, thereby suppressing compressor power. Figure 4 shows a comparison of the compression ratio and compressor power between the conventional showcase and newly developed one, with the value of the conventional device being 1. It shows that the newly developed showcase can suppress the compression ratio and compressor power more than the conventional one. The results of our in-house evaluation of the showcases

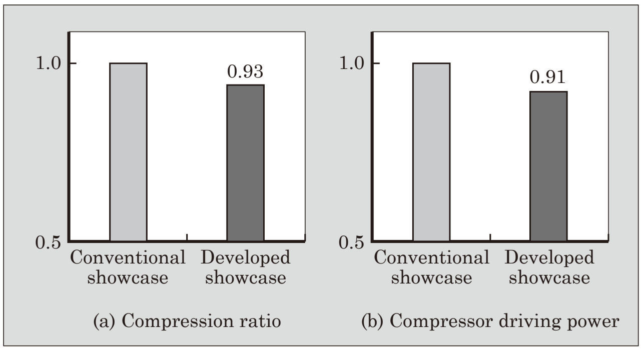

Fig.4 Comparison of compression ratio and compressor driving power

showed that the newly developed device consumes approximately 10% less energy throughout the year than conventional devices.

3.2 Optimization of amount of refrigerant according to on-site installation conditions

(1) Challenges

For built-in showcases, the piping around the cooling unit is pre-installed at the factory, and the amount of refrigerant to be injected can be properly controlled. On the other hand, for separately installed showcases, the piping between the separately installed showcases and the shared cooling unit is done on-site. This means that it is necessary to adjust the amount of refrigerant on-site according to the type and number of showcases and the length of piping required to connect the showcases to the cooling unit.

Conventionally, after completing the piping work on-site, refrigerant is injected until it is completely liquefied in the condenser, while visually monitoring the status with a sight glass on the high-pressure side of the cooling unit. This procedure tends to inject more refrigerant than required due to the influence of the conditions during installation. This means that it has been necessary to optimize the amount of refrigerant.

(2) Countermeasures and effect

To solve the above issue, we introduced a tool that can be easily used on-site to calculate the required amount of refrigerant to be injected based on the piping volume. The amount of refrigerant to be injected is calculated by Equation (1).

$$M = a \times A + b \times B + c \times C + d \quad \cdots\cdots (1)$$

M: Amount of refrigerant to be injected (kg)
a: Refrigerant density in evaporator (kg/m^3)
b: Refrigerant density in high-pressure piping (kg/m^3)
c: Refrigerant density in low-pressure piping (kg/m^3)
d: Amount of refrigerant in the cooling unit (kg)
A: Evaporator internal volume (m^3)
B: High-pressure pipe internal volume (m^3)
C: Low-pressure pipe internal volume (m^3)

In developing this tool, we combined an actual cooling unit with showcases to experimentally determine the optimal amount of refrigerant to be injected when the following four parameters were varied: environmental conditions, piping length, number of showcases (volume in the piping), and amount of refrigerant. Based on the results of this experiment, we determined a through d and completed the development of the calculation tool. We obtained A by inputting the type and number of showcases using the calculation tool, and determined B and C by inputting the outer diameter and length of the piping to be connected on-site. As a result, the optimum amount of refrigerant can be automatically calculated for each store, enabling energy savings of up to 12% in showcase power consumption compared to the conventional technique.

3.3 Equalizing amount of refrigerant in separately installed showcases

(1) Challenges

In separately installed showcases, refrigerant from the cooling unit is distributed to each showcase. Since the length of the piping between the cooling unit and each showcase varies with the location of each showcase, the refrigerant flow rate also varies according to the pressure loss in the piping. As a result, showcases with refrigerant readily flowing or low energy load are overcooled due to excessive refrigerant flow, while showcases with refrigerant insufficiently flowing or high energy load are insufficiently cooled due to lack of refrigerant flow. This causes inconsistent cooling conditions among the showcases.

In addition, conventional stores implement energy-saving controls that monitor the cooling status of all showcases in the store and instruct the cooling unit to reduce its operating frequency when it determines that all showcases have been sufficiently cooled. However, if the cooling status is inconsistent among showcases as described above, the cooling unit is controlled according to the needs of the insufficiently cooled showcase, which may result in higher power consumption. Therefore, it has become necessary to equalize the amount of refrigerant among showcases.

(2) Countermeasures and effect

By using the electronic expansion valve described in Section 3.1, it is easy to achieve a variety of controls according to the application. While the use of electronic expansion valves has been effective in enhancing the energy-saving performance of built-in showcases, we needed to develop a control system for separately installed showcases that adjusts the electronic expansion valve of each showcase so that all showcase are cooled uniformly.

This newly developed control system also measures the cold air blowout temperature to determine the cooling status of each showcase. The cooling status of each showcase is determined from the temperature readings at three locations combined with the temperatures at the inlet and outlet of the evaporator described earlier.

These cooling statuses are then classified into the six modes shown below.

(a) Initial operation mode (start of cooling)
(b) Blowout temperature mode (insufficiently cooled)
(c) Superheat holding mode (stable cooling)
(d) Liquid return prevention control mode (sufficient cooling)
(e) Open valve fixed mode (cooling unit is stopped)
(f) Stop mode (showcase is stopped)

Based on the results of this classification, if there is a showcase that does not have enough refrigerant, it will first aim to equalize the overall cooling conditions by controlling and opening the expansion valve of that showcase more widely. Next, it will implement optimal flow control by fine-tuning the expansion valve opening to stabilize the cooling conditions of the separately installed showcases. Figure 5 shows the state transition diagram for controlling the expansion valve. The expansion valve of each showcase is controlled according to the respective mode. Figure 6 shows an application example for the initial operation mode. It shows the effect of the control of the initial operation mode, shown in Fig. 5(a). It reduces the time it takes for the inside of the storage compartment to reach the target temperature by approximately 15% compared with the conventional showcase.

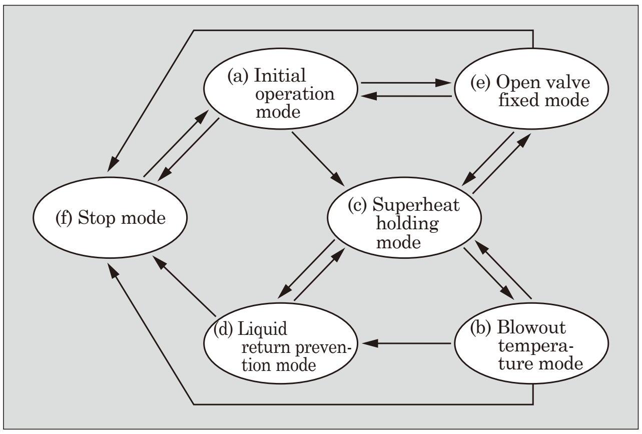

Fig.5 State transition diagram for controlling the expansion valve

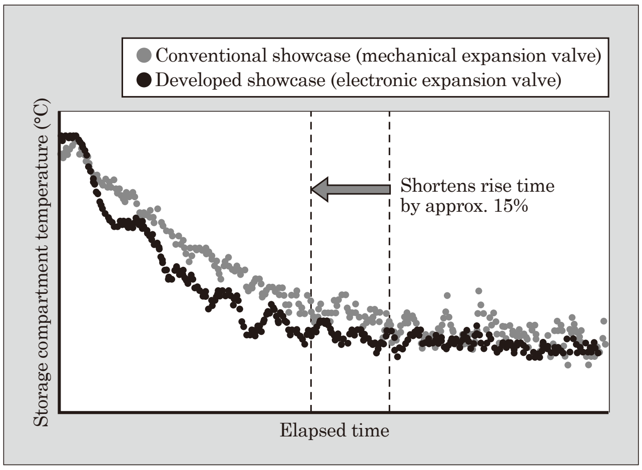

Fig.6 Application example for the initial operation mode

By applying the control system described above, the optimal amount of refrigerant can always be distributed to each showcase. This equalizes the cooling conditions of each separately installed showcase in the system, and reduces power consumption by approximately 20% compared with the conventional control method.

4. Postscript

In this paper, we described an energy-saving technology for showcases.

Fuji Electric offers both built-in and separately installed showcases depending on the market needs of customers. Meeting the challenges of each type according to their corresponding characteristics, we are further committed to developing energy-efficient showcases and energy-saving systems for an entire store to offer eco-friendly products, responding to customer needs.

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