Whole Number 278, ISSN 0429-8284

FUJI ELECTRIC REVIEW

2022
Vol.68 No. 3

Fuji Electric's Food Distribution Creating New Value

Fuji Electric

Innovating Energy Technology

FUJI ELECTRIC
REVIEW

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Fuji Electric's Food Distribution Creating New Value

Vending machines have evolved to the point where they are now playing a role in the sales growth of beverage manufacturers. Furthermore, our products for store distribution installed on sales floors have help save energy and improve operational efficiency in stores. Recent trends to protect the environment in order to achieve SDGs and carbon neutrality, as well as changing social environment that affects how people live and work due to declining populations and COVID-19 restrictions, have had a significant impact on the way business is conducted. Fuji Electric will respond to these changes and provide products and technologies that create new values by staying one step ahead of market needs. In addition to vending machines and equipment for store distribution, this special issue introduces their core technologies, such as IoT and heating and cooling technology, to create new value.

The archives from the first issue, including articles in this issue, are available from the URLs below.

FUJI ELECTRIC REVIEW (English)
https://www.fujielectric.com/company/tech/contents3.html

FUJI ELECTRIC JOURNAL (Japanese)
https://www.fujielectric.co.jp/about/company/contents_02_03.html
FUJI ELECTRIC JOURNAL (Chinese)
http://www.fujielectric.com.cn/jtkw.html

Cover Photo:

(1) "Thickened Beverage Vending Machine" in-cup mixing automatic tea server
(2) Refrigerated showcase
(3) Can and bottle beverage vending machine
(4) "Frozen Station" frozen food vending machine

FUJI ELECTRIC REVIEW vol.68 no.3 2022
date of issue: February 28, 2023

editor-in-chief and publisher **NAKAYAMA, Kazuya**
Corporate R&D Headquarters
Fuji Electric Co., Ltd.
Gate City Ohsaki, East Tower,
11-2, Osaki 1-chome, Shinagawa-ku,
Tokyo 141-0032, Japan

editorial office Fuji Electric Journal Editorial Office
c/o Fuji Office & Life Service Co., Ltd.
1, Fujimachi, Hino-shi, Tokyo 191-8502,
Japan

The original Japanese version of this journal is "FUJI ELECTRIC JOURNAL" vol.95 no.3

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Preface

Toward the Digital Transformation of Heat

SAITO, Kiyoshi*

Currently, the entire country is promoting the development of the "Society 5.0" as "a society that balances economic growth with the resolution of social issues with a system that effectively integrates physical space (real space) and cyberspace (virtual space)." One of the technologies required for realizing such a society is digital transformation (DX), which uses the Internet of Things (IoT) to transform products, services, and business models by connecting objects, as well as computers, to the Internet to transform business operations themselves and even corporate cultures and climates.

I have been conducting research specialized in the field of "thermal system dynamics and control." Specifically, I have worked on system modeling, optimal design and control, and developing simulators development for heat pump-related technologies, including refrigeration and air-conditioning systems.

Heat utilization technology includes many analog elements, and in Japan, technological development has mainly focused on device technologies based on combustion and heat transfer, including rotating equipment such as compressors. As these technologies require long-term gradual basic research and development, Japan, which excels in this field, has strong technological capabilities and is expected to maintain high competitiveness in the global market.

Recently, studies on heat utilization technologies have been gradually advancing toward DX, with the introduction of increasingly sophisticated learning control, motion sensors, and automated driving. Energy management systems (EMSs), a key technology in DX, have been increasingly introduced in various applications, from residential to industrial. In addition, artificial intelligence (AI) has been used for predicting loads, weather, and even human behavior, and the results of related analyses are now being put to practical use.

In the future, for example, refrigerant charge management will become easier in the field of refrigeration and air-conditioning if early detection of refrigerant leakage becomes possible. As EMSs become more sophisticated, this will promote the consolidation of heat pump-related equipment, which is currently installed in multiple locations, and expand the use of renewable energy sources, enabling more efficient operation with lower CO_2 emissions. In the cold chain, adding evidence related to energy and refrigerants to digital information distribution will lead to reduced CO_2 emissions, lower global warming effect of refrigerants, and even reduced food losses throughout the supply chain.

On the other hand, I feel a sense of crisis when I look around the house and recognize DX hardly progressing. While the IoT is slowly moving forward, as an electronics-consumer enthusiast, I have as many as five remote controls around me, which I use to operate devices. In addition, I have been involved in many audits of energy management services, and, although energy saving and profitability are proclaimed, there are no means to verify the effectiveness of these services. Too often, energy management systems, if introduced, produce little effect. If nothing is changed, Japan will eventually fail to realize the energy management services that are truly needed and eventually lose its global competitiveness.

In the future, the key to realizing a sustainable decarbonized society will be the system integration technology, which Japan has not excelled in. If Japan, which leads the market in many fundamental technologies for heat utilization, can lead the world in heat DX, it will be possible to continue to make heat utilization technologies internationally competitive. One can only hope that Japan will not repeat the footsteps taken in the smartphone industry, which focused only on fundamental hardware technologies and found itself far behind the times.

Waseda University, together with more than 30 organizations including Fuji Electric, has launched a project entitled "Construction and Social Implementation of an Ambient Energy Platform" as a theme promoted by the Council on Competitiveness-Nippon (COCN). The project is investigating the creation of a common platform to quickly realize a thermal EMS by linking various heat utilization devices from various manufacturers with IoT.

The project is also scheduled to grow into a large-scale national project from fiscal 2023. I sincerely hope that the DX will continue to be a driving force for the

* Director, Sustainable Energy & Environmental Society Open Innovation Research Organization Professor, Department of Applied Mechanics and Aerospace Engineering, School of Fundamental Science and Engineering, Waseda University

heat utilization technology in Japan and push the development of a series of globally competitive technologies.

Fuji Electric's Food Distribution Creating New Value: Current Status and Future Outlook

ISHIBASHI, Masanobu*

1. Introduction

The history of vending machines in Japan is said to have begun with a stamp and postcard vending machine that appeared in 1904. Nearly 60 years later, in 1962, a foreign beverage manufacturer entered the Japanese market. Fuji Electric started producing and selling milk vendors in 1965, and a cup-type coffee vending machine was installed at the Osaka Expo in 1970. Since then, vending machines have been developing in tandem with Japan's rapid economic growth as products that play a role in expanding sales for beverage manufacturers. Since open showcases were first sold in 1973, they have supported sales growth for retail stores as products that form a part of the sales floor.

With the global trend toward environmental protection aimed at achieving the Sustainable Development Goals (SDGs) and realizing carbon neutrality, as well as changes in the social environment such as the declining population and the COVID-19 pandemic, companies are being urged to protect the environment and contribute to society.

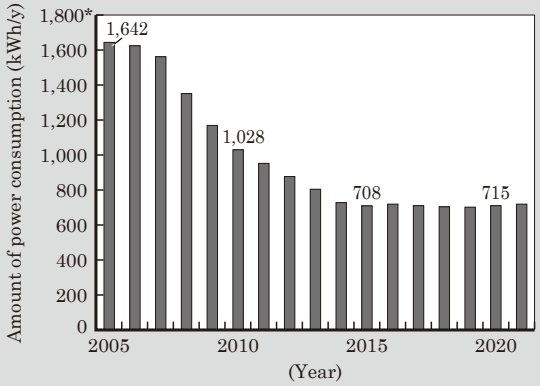
Fuji Electric is working to acquire technologies capable of addressing market changes in order to contribute to customer sales growth and environmental protection. This paper describes the current status and future outlook of Fuji Electric's food distribution business, which creates new value in the form of new technologies and products such as these.

2. Contribution to Global Environmental Protection

To achieve the government's declared goal of realizing carbon neutrality by 2050, Fuji Electric's customers are also working to expand their use of renewable energy and conserve resources by setting their own environmental targets. Among these targets, energy saving has become a top priority because it has the effect of curbing the rise in running costs associated with the recent rise in electricity prices.

2.1 Heat pump*1 technology for beverage vending machines

Figure 1 shows the trend in the annual amount of power consumption per beverage vending ma-



*Values are weighted averages.
Source: Japan Vending System Manufacturers Association

Fig.1 Trend in annual amount of power consumption per beverage vending machine

***1: Heat pump**
A heat pump pumps heat from a low temperature area to a high temperature area. This makes the temperature of the low temperature area even lower and of the high temperature area even higher. This principle is also used in refrigerators and air conditioners. A refrigerant transfers heat between indoor and outdoor units to cool or warm the air. Heat pumps, which can transfer more heat than the workload of a compressor, are gaining attention as an effective means of saving energy.

* Food & Beverage Distribution Business Group, Fuji Electric Co., Ltd.

chine. The amount of power consumption, which tended to decline year by year, has become stagnant since 2015, prompting calls for further energy saving. Beverage vending machines use a heat pump to simultaneously heat and cool the interior. Fuji Electric has been striving to achieve energy saving in the operation of the heat pump.

Figure 2 shows the heat pump mechanism of beverage vending machines. In beverage vending machines installed in a variety of locations both indoors and outdoors, the heat pump load fluctuates depending on a variety of factors, including the outside air temperature, the number of items stored and their sales. In addition, when the seasons change, some of the chambers in the machine are switched from cooling to heating. We have developed a control technology capable of adjusting the heat pump operating method to maximize efficiency under these conditions and maximize energy savings throughout the year.

Heat pumps operate most efficiently under a balance between heating and cooling. When the load on the heating side grows due to external factors, the evaporation and condensation temperatures of the refrigerant in the heat exchanger of the heat pump are adjusted so that the performance against the load is equal on the heating and cooling sides.

By applying this heat pump synchronization control as the highest priority in operation, we have eliminated the need for the heat pump between the interior and exterior, as shown in Fig. 2(b), thereby achieving energy saving (refer to "Technology for Applying Heat Pumps to Beverage Vending Machines" on page 119).

2.2 Showcase energy-saving technology

Among the equipment used in supermarkets and convenience stores, showcases that keep products cooled at suitable temperatures are easily affected by outside air because the product display area is open. For this reason, they consume more energy than refrigerators, which cool the interiors of enclosed chambers. Accordingly, energy saving of showcases is an important challenge.

Showcases are generally classified into two types based on the location of the cooling unit. Known as a built-in showcase, the first type is equipped with a cooling unit inside the showcase that cools the displayed items. The other type, called a separately installed showcase, has a cooling unit outside of the store, which is connected to multiple showcases in the store, as shown in Fig. 3.

For separately installed showcases, piping work is carried out on site, and the lengths and bends of the pipes vary from store to store, which often causes the amount of refrigerant contained in the pipes to vary, making them difficult to optimize. To address this, we have developed and are offering a tool that can be easily used on site to calculate the optimal amount of refrigerant to fill according to the piping capacity. It has been shown to optimize the amount of refrigerant filled at the time of installation, increasing energy savings for the entire store.

We have also developed a control system using an electronic expansion valve capable of optimizing operating conditions, which was difficult with conventional mechanical expansion valves (refer to "Energy-Saving Technology for Showcases" on page

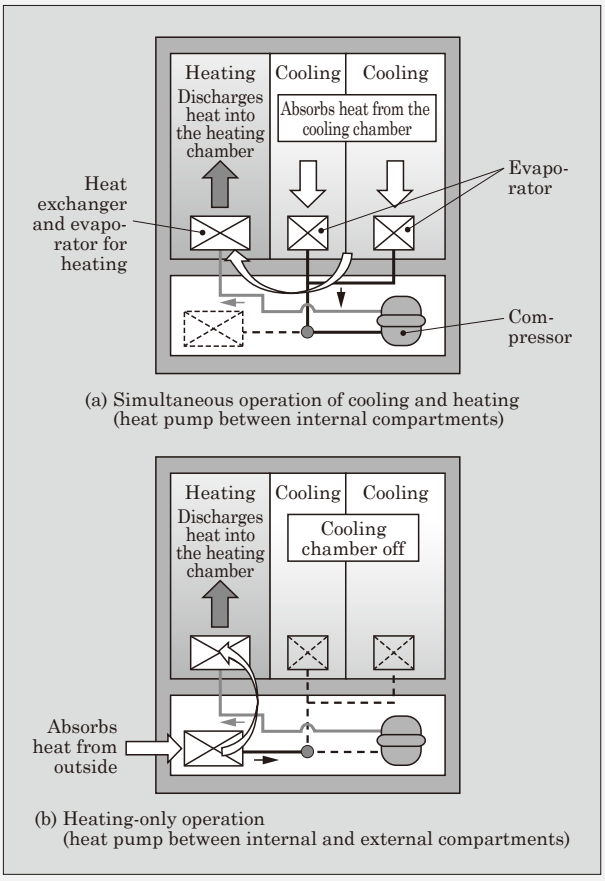


Fig.2 Heat pump mechanism of beverage vending machines

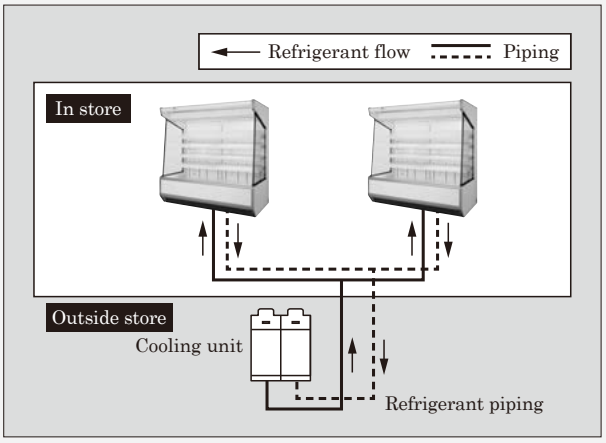


Fig.3 Separately installed showcase

140).

2.3 Energy saving system for stores

As mentioned in Section 2.2, showcases are susceptible to outside air, and the equipment units within a store affect each other. For this reason, it is important to operate the showcases in such a way that saves energy for the entire store, rather than simply improving the efficiency of individual units. In addition, it is necessary to ensure that visitors to the store feel comfortable. For example, while it is generally recognized that raising the temperature setting on the air conditioning during summer is an effective way to save energy, it may have a negative effect on the level of comfort experienced by visitors, which can affect sales. For this reason, it is not easy to save energy and ensure comfort at the same time. To address this, we identified the factors affecting energy saving in actual stores and analyzed their relationship with comfort. Using an index called the predicted mean vote (PMV) to quantify comfort, we studied not only the use of refrigeration equipment and air conditioning, but also the introduction of outdoor air, aiming to achieve both energy saving and comfort (refer to "Energy-Saving Measures for Stores" on page 144).

3. Addressing Changes in the Japanese Market

Under the trend of declining birthrates, an aging society, and a shrinking population, ensuring sales and saving manpower and labor are important challenges in the retail industry. On top of this, while the COVID-19 pandemic has upended the market environment and dealt a major blow to existing businesses, it has also created new needs, such as the need for non-face-to-face sales. In this period of change, there is a demand for the discovery of new opportunities.

3.1 New value-added services of vending machines

Fuji Electric has already been offering vending machine services for businesses that operate vending machines to help improve their operational efficiency. In response to the recent accelerating trend toward greater demand for contributions to the SDGs, operator companies are also stepping up efforts to improve their working environment and reduce food loss and waste. One by one since 2020, we have been offering new and expanded services that address these issues while increasing sales at the same time.

As a platform for providing these services, we have equipped our vending machines with a multi communication unit (MCU) (see Fig. 4). New services using the MCU include dynamic pricing, which enables automatic updates of the sales price display;

Fig.4 Multi communication unit

a smartphone remote controller, which enables operators to use a smartphone app to perform operations such as configuring the vending machine; and New QR Code* Payment, which enables the introduction of cashless payment at a low cost. These features reduce the need to perform tasks that were previously performed by workers, such as making rounds to vending machine locations to replenish items, collecting money, and changing price display when replacing items. In addition, these features make it easier to sell off products at a discount when they are approaching their best-before dates (refer to "Expansion of Vending Machine Operation Services" on page 114).

3.2 Networking in convenience stores

There is a need for convenience stores and other establishments to save energy while introducing new products and equipment to keep up with changes in the market. In addition, responding to the labor shortage caused by the declining birthrate and aging population has become a major issue, and there is a need to save energy as well as manpower and labor in operations. Fuji Electric provides a system to support store operations through the use of networked store equipment.

Figure 5 shows an example of the configuration of a system that uses a store controller. By monitoring and analyzing the operating status of showcase main units and the cooling unit through this system, not only can energy-saving control of the cooling unit be achieved, but predictive maintenance can also be performed through the detection of signs of equipment malfunction (refer to "Network Services for Stores" on page 137).

3.3 "Thickened beverage vending machine"

In Japan, where the population is aging, the number of care receivers is increasing, and at the

* QR code is a trademark or registered trademark of DENSO WAVE INCORPORATED

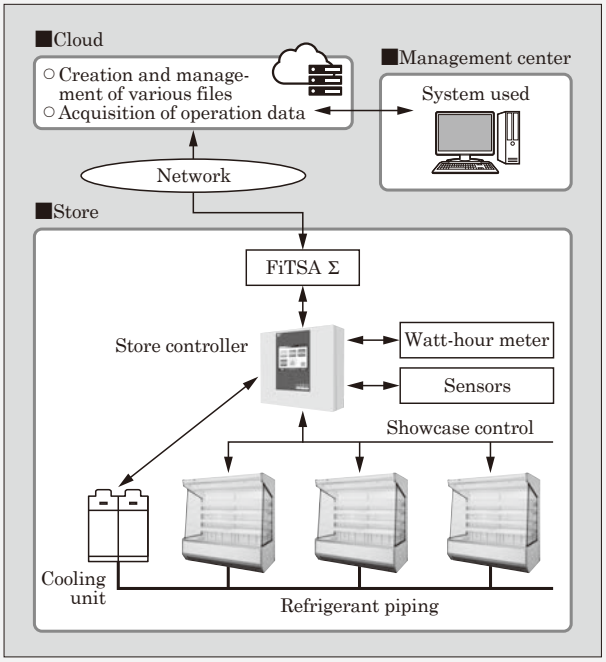


Fig.5 System configuration for store controller

same time, the shortage of labor required to provide nursing care services is becoming increasingly severe. Since people in need of nursing care are prone to aspiration when eating, for example, measures have been taken to thicken their beverages and make them easier to swallow. Because these thickened drinks need to be prepared according to the condition of the care receiver, preparing them required a lot of effort.

To address this, Fuji Electric has applied the technology it cultivated in the development of cup vending machines to develop an automatic tea dispenser with an in-cup mixing system, which prepares thickened drinks (see Fig. 6). It enables thickened drinks tailored to the condition of each user to be prepared with simple operations, and is also designed to operate with minimal maintenance, thus reducing the workload of caregivers who serve thickened drinks (refer to "'Thickened Beverage Vending Machine' In-Cup Mixing Automatic Tea Server" on page 128).

3.4 Frozen food vending machine

Lifestyle changes due to the COVID-19 pandemic have led to rapid growth in the ready-made meal market. Among such products, frozen foods are attracting attention from the perspective of the SDGs as a means to address food loss and waste because of their long shelf life as well as improved quality due to developments in freezing technology.

In the restaurant industry, which has experienced a decline in sales during the COVID-19 pandemic due to stay-at-home policies, shortened business hours, and the general trend toward non-face-to-face communication, vending machines are seen as a promising new sales method to recover from the decline.

With this in mind, Fuji Electric has developed the "Frozen Station," a new frozen food vending machine (see Fig. 7). It is equipped with a spiral rack that can be used to sell a wide variety of products, and the space inside is effectively utilized to accommodate large items and increase the number of items that can be stored. We also used simulations to analyze the movement of conveyed items and develop a conveyance mechanism that ensures that items can be delivered without issue. In addition, we also provide operation support services to enable those who are unfamiliar with operation of vending machines to use them without trouble. This service is geared toward customers who have never operated vending machines before and is expected to expand the market for frozen food sold in vending machines (refer to "'Frozen Station' Frozen Food Vending Machine" on page 123).

Fig.6 "Thickened Beverage Vending Machine"

Fig.7 "Frozen Station" frozen food vending machine

4. Taking on Challenges for Further Growth

This section describes other solutions for the Japanese and international markets. We conduct research and development to create new value by addressing issues in society and improving convenience for customers.

4.1 General-purpose goods vending machines

In Southeast Asia (including Thailand, Malaysia, Singapore and Indonesia), more than 10,000 food vending machines have already been installed. In recent years, convenience store chains have entered the vending machine business, and demand for the sale of a variety of beverages and foods has been on the rise. The variety of the shapes of cans and plastic bottles sold in this region is incomparably greater than in Japan and cannot be handled using beverage vending machines for the domestic market. In Taiwan, the use of vending machines for dispensing pharmaceuticals at hospitals is being considered. This is because vending machines are expected to be useful for preventing human error by pharmacists and for storing pharmaceuticals at constant temperatures.

Fig.8 "FGG160DCY"

Accordingly, Fuji Electric has developed a vending machine equipped with a product conveyance mechanism that can store many items of various shapes and dispense even soft items without damaging the shape of the contents (see Fig. 8) (refer to "'FGG160DCY' General-Purpose Goods Vending Machine" on page 132).

4.2 Edge devices

As the demand increases for real-time performance to provide further benefits, the increasingly popular Internet of Things (IoT) systems are changing from traditional cloud-centric configurations to more sophisticated configurations that enable processing to be performed on edge devices.

Accordingly, in order to meet diverse needs, Fuji Electric has defined the requirements and pursued software to achieve a new IoT platform. We have thus developed the edge computing device that forms the fundamental technology for edge devices.

We have leveraged open-source software (OSS) to provide flexibility for meeting diverse needs and reduce the time required for application development. The hardware is configured with enhanced connectivity and is capable of both wired and wireless connection. The configuration of function modules has been innovated to facilitate future updates. Security software is provided as standard, ensuring secure use (refer to "Fundamental Development and Application of the Next Generation Edge Devices" on page 154).

4.3 Frost-free technology for heat exchangers

Heat exchangers are used not only in showcases and vending machines, but also in refrigerators and other equipment used to cool objects. The evaporative latent heat of the refrigerant circulating inside the heat exchanger is used to cool the interior of

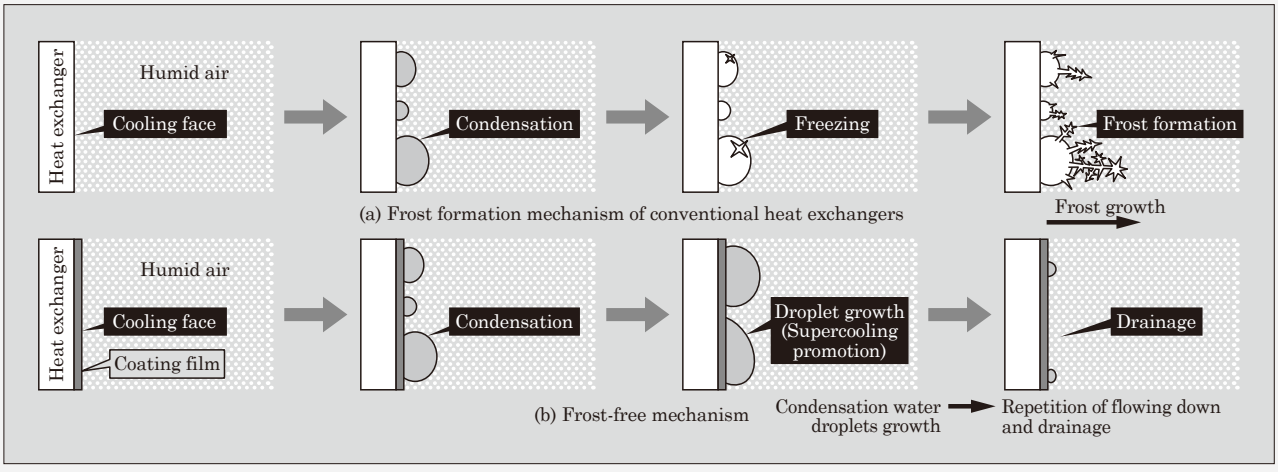


Fig.9 Mechanism of frost-free technology

the equipment. Water in the air condenses on the surfaces of heat exchangers that become cold during operation, which, if cooled below 0 °C, freezes and develops into frost, reducing the efficiency of heat exchange. In the past, defrosting was performed, for example, by heating the heat exchanger surface with a heater, which required extra energy.

Figure 9 shows the mechanism of frost formation prevention. Application of a specific material to the surface of the heat exchanger functions to accelerate supercooling (which hinders the action of ice nuclei, which are the starting points for freezing) and the condensed moisture grows without freezing and runs off under its own weight, preventing frost from forming. We are working on the research and development of technologies that eliminate the need for energy used for defrosting, which has been necessary to date, to further improve the energy-efficiency of showcases and vending machines (refer to "Frost-Free Technology for Heat Exchangers Using Functional Coating" on page 149).

5. Postscript

This paper has presented the current status and future outlook of Fuji Electric's effort to create new value in the food distribution field. The market environment will continue to change at a faster pace, and emphasis will be placed globally on environmentally friendly management.

We will continue to improve the core technologies for food distribution—thermal technology, mechatronics and IoT—to respond quickly to these market changes and provide new value.

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(1) Katayama, S. et al. Vending Machine Operation Service Using IoT and AI to Increase Operational Efficiency. FUJI ELECTRIC REVIEW. 2021, vol.67, no.3, p.149-154.

Expansion of Vending Machine Operation Services

TANAKA, Seiichi* YANAGAWA, Hiroyuki* MIZUNO, Kenta*

ABSTRACT

In the vending machine business, there are calls for efforts to contribute to the SDGs, such as by improving the working environment and reducing food loss and waste. Having been rolling out its Vending Machine Operation Services to improve the efficiency of vending machine operation, Fuji Electric has now developed new functions. These functions are dynamic pricing, which changes product selling prices according to set rules; a smartphone remote controller, which simplifies vending machine remote operation; and New QR Code Payment, which enables the introduction of QR code payments at a low cost. These functions are expected to reduce operating hours by 20%, create an easy operating environment, and increase sales of vending machines.

1. Introduction

Fuji Electric has long been offering the "Vending Machine Operation Service" for businesses that operate vending machines to help improve their operational efficiency. In response to the recent rise in calls for contributions to the Sustainable Development Goals (SDGs), operator companies are stepping up efforts to take on challenges such as improving working environments and reducing food loss and waste. Since 2020, we have been gradually offering new and expanded services that address these issues and increase sales. This paper describes our expanded Vending Machine Operation Service.

2. Challenges in Operation of Vending Machines

The vending machine market is saturated in Japan. In addition, the expansion of retail channels, such as supermarkets and convenience stores, has intensified sales competition, which poses challenges for vending machine operators in terms of how to increase sales per vending machine.

Furthermore, with the decline in the working-age population due to the declining birthrate and aging population, and with the need to review and improve working environment in response to work-style reform, operators are looking for ways to improve efficiency in sales and inventory management operations. For example, workers who make their rounds of vending machines, having to go around multiple locations in a day, cannot increase the number of rounds any further because their jobs are very time-consuming, such as product replenishment and product replacement along with price changes. New measures are also required to address the issue of having to dispose of items that have not sell before the best-before date.

* Food & Beverage Distribution Business Group, Fuji Electric Co., Ltd.

3. Foundation for the Vending Machine Operation Service

To date, Fuji Electric has built a system that quickly transmit information to operators and other staff on sales, items sold out, failures, and operation of the vending machines. The information is aggregated on a cloud server in real time via a multi communication unit (MCU) integrated in vending machines. Figure 1 shows the system configuration of vending machine operation services. These existing services provide inventory management, which associates information about replenishment of products in vending machines with that about sales at vending machines, enabling remote management of product inventory and best-before dates, as well as route management, which provides suggestions for the best route to take based on the inventory information and route information.

The vending machines are connected to cloud servers via the Internet, and information is encrypted and sent back and forth. Cloud servers also ensure security by restricting access through operator user authentication and vending machine device authentication.

4. New Management Service Options

Fuji Electric has developed the following the Vending Machine Operation Services as listed in Table 1: dynamic pricing, which changes product sales prices remotely according to set rules; a smartphone remote controller that simplifies the operation of vending machine remote controls, which would otherwise require

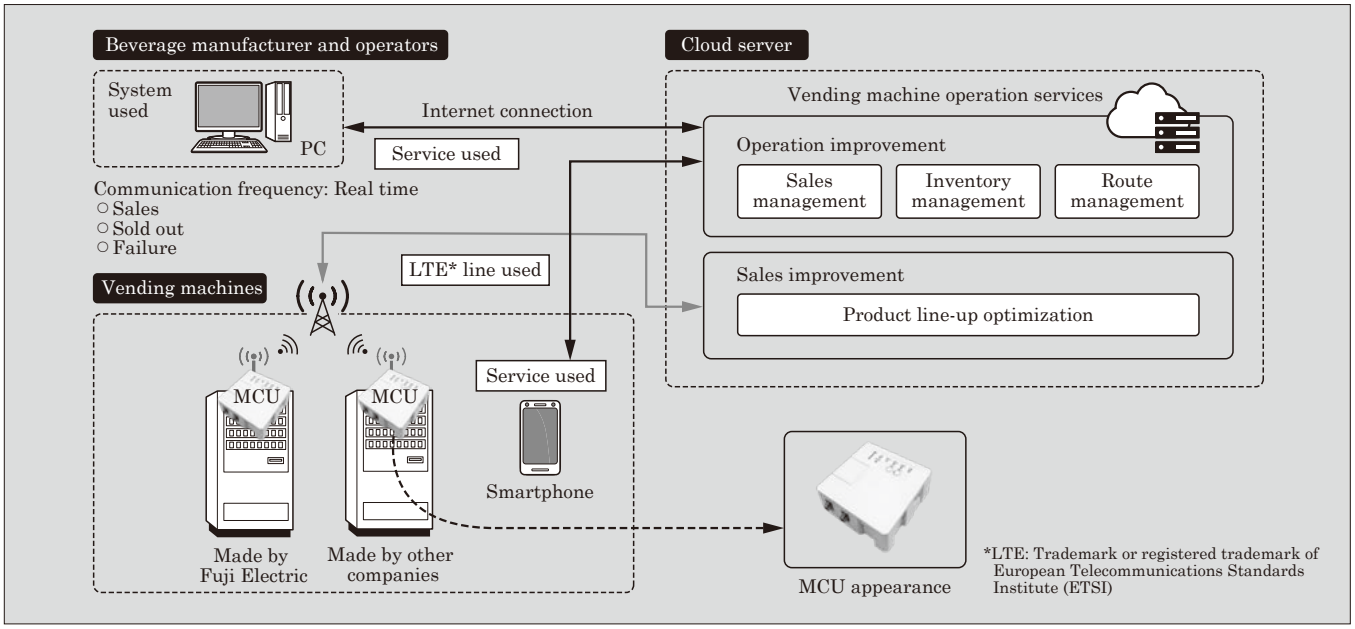

Fig.1 System configuration of the Vending Machine Operation Services[1]

Table 1 Examples of the Vending Machine Operation Services

Effect of introduction	Service
Operation efficiency improvement	Sales management
	Inventory management (sold out products, best-before dates of products, etc.)
	Route management (rounds and replenishment plan)
	Dynamic pricing
	Smartphone remote controller
Sales improvement	Product line-up optimization
	New QR Code Payment

: Services described in this paper

proficiency to operate; and New QR Code*1 Payment, which enables the introduction of QR code payment at a low cost.

Table 1 shows the new service options developed to improve the efficiency of vending machine operation, along with the conventional options. Details of the features of these new services and their effects are described as follows:

4.1 Dynamic pricing service

Product discounts have long been used to sell off products in order to promote new products or replace products. Recently, unmanned sales without face-to-face interaction have attracted attention due to the COVID-19 pandemic, and food vending machines are also becoming more widespread. There is also a need to reduce food loss caused by a failure to sell products before the best-before dates.

Price changes for discounted sales currently require the use of the remote controller come with the vending machine to change the pricing for each item. Furthermore, vending machines that do not have an automatic price display function to display changed prices need manually changing the price labels in the product display. These tasks require operators to go to the locations of vending machines and are a major burden for vending machine operations.

To improve the efficiency of such operations, we have developed a new dynamic pricing service capable of changing the prices of items in vending machines remotely and automatically. Figure 2 provides an overview of this service.

With this service, operators can access the cloud server provided by Fuji Electric from their company devices and change the settings of the respective vending machines to which rounds are made. The changed

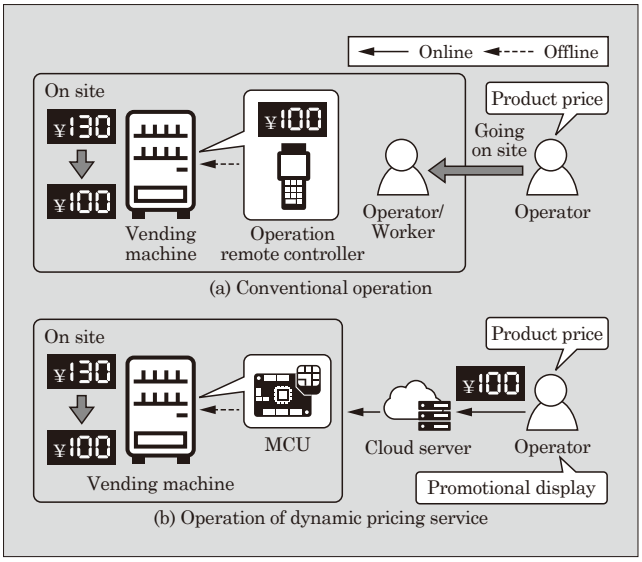

Fig.2 Dynamic pricing service overview

*1: QR code: Trademark or registered trademark of DENSO WAVE INCORPORATED

settings are sent from the cloud server to the vending machines via the vending machine MCU to reflect the new settings. This eliminates the need for operators to make rounds for pricing changes. In addition, the service allows operators to make changes based on the set rules according to their use cases. For example, available functions include a function to change the specified date/time/period for limited sales (timed sales) for events and prior to seasonal product changes, as well as a function to change the equipment and inventory condition specifications, which takes into account equipment conditions such as installation location, as well as inventory conditions such as sales and expiration dates.

In conjunction with this, we have also developed a new price display button that can maximize the effect of the dynamic pricing service. Figure 3 shows a conceptual image of the new price display button. The new features enabled by this new price display button are described as follows:

(1) "Recommended!" indication

Operators can show the text "Recommended!" on buttons assigned to items they especially want to sell. With conventional vending machines, operators used their own POP signs to make such promotional indications. This product accomplishes this using the indicators inside the buttons. In addition, the indication can be made to flash in order to highlight products.

(2) "Discount" indication

The text "Discount" can be shown on buttons assigned to items to be sold at discounted prices. With conventional vending machines, only the discounted sales prices are displayed when discounts have been applied, and the preparation of separate POP signs was required to tell purchasers that the products were discounted. As with the "Recommended!" indication, the "Discount" indication can be made to flash to highlight products, allowing easy solicitation to purchasers.

(3) Temperature indication

The temperature range (hot or cold) of the products can be shown on assigned buttons. While this was conventionally shown by using POP signs inside the product display, this button is equipped with temperature indicator lamps (orange, blue and purple) and temperature indicators (hot, cold, and room temperature), which can be linked to indicate the temperature of a product. In addition, on conventional vending machines, room-temperature products needed to be indicated using POP signs, but with these buttons, room-temperature products can be indicated using the purple setting of the temperature indicator lamp and the room temperature setting of the temperature indicator.

Fig.3 Conceptual view of new price display button

(4) Use of four digits for display prices

With our sights set on non-beverage products such as food and goods, which are expected to expand in the future, this service supports four-digit price indication. Conventionally, the price indications only had three digits and, to handle any product worth 1,000 yen or more, the use of price labels was necessary, even if the buttons had a price display function.

Use of this service eliminates the need for operators to make rounds of vending machine locations to change the settings, reducing the work time of making rounds by 20% compared with conventional operations.

In addition, by conducting flexible promotions tailored to sales conditions and the surrounding environment, operators can increase sales without missing out on sales opportunities, and reduce the risk of having to dispose of products that were left unsold. Furthermore, four-digit price indication can be used to increase sales opportunities for a variety of products, including food and other goods besides beverages.

4.2 Smartphone remote controller

With conventional vending machines, operational settings were changed using the remote controller come with each vending machine, but this operation is not straightforward, which is assumed to have made new customers hesitant to introduce vending machines.

Conventional remote controllers for vending machines use a system in which users enter designated code numbers specified for individual purposes. Table 2 shows examples of inputs of the operation remote controller, and Fig. 4 shows an example of operation of the conventional operation remote controller. Operators are required to memorize these code numbers or read the instruction manual. Multiple buttons on the remote controller must be used to enter the desired code number, and multiple button operations are also required on the menu screen corresponding to the code number. In this way, with a conventional remote controller, it takes time to change and check the settings, which results in long work hours for operators.

We have developed a remote control system that can use a smartphone as the remote controller.

Table 2 Examples of operation remote controller input

Operation	Input
Sales management	Sales aggregation key: TC
Lighting conditions	Mode key: 2-09
Item dispensing action	Test key: T5T1
Sales price change	Pricing key: Price input

[Example] Item dispensing action confirmation
(1) Press “Test” key
(2) Use “Up” and “Down” keys to enter code number “T5T1”
(3) Use “Up” and “Down” keys to enter column number for the item to be dispensed
(4) Use “Start/Stop” key to execute

<Problem>
○ The code number for executing the item dispensing action must be known.
○ Entering numbers takes time and effort.
○ Users need to memorize the column arrangement (column number) of the desired product.

Fig.4 Example of operation of conventional operation remote controller

[Example]
Item dispensing action confirmation
(1) Tap “Confirm item dispensing action”
(2) Tap the item to dispense

<Effect>
○ Intuitive identification enabled by text and pictorial depictions
○ The number of steps is significantly reduced

Fig.5 Smartphone remote controller

This system connects the MCU to a smartphone via Bluetooth*2 and allows the user to set up a vending machine and check information using an application installed in the smartphone in advance. Unlike the code number input operation of conventional remote controllers, the new controller clearly indicates the operation procedure with pictures and letters, which are guided through screen displays for intuitive operation. In addition, with the smartphone remote controller, the settings stored on a cloud server can be changed in advance, greatly reducing on-site work time and preventing configuration mistakes.

4.3 Easy-to-introduce New QR code payment

Electronic money using near-field communication (NFC) has been the dominant form of cashless payment at vending machines, but with the rapid increase in the number of purchasers using QR code payment in Japan, the introduction and operation of payment devices that support QR code payment for vending machines has also been expanding. In order to make these QR code payments, either the QR code displayed on the mobile device must be read by the payment device (consumer-presented mode: CPM) or the QR code must be displayed on the payment device and read by the mobile device (merchant-presented mode: MPM), as shown in Fig. 6. CPM requires a scanner or a camera, and MPM requires a liquid crystal display or another display device, making payment devices expensive. Many customers have given up introducing cashless payments because of this initial cost.

To solve this problem, we have constructed a new QR code payment system (New QR Code Payment) that can be introduced inexpensively by simply posting a single printout of a QR code. Figure 7 shows the conventional QR code payment flow (MPM system) and Fig. 8, the New QR Code Payment flow (MPM system). The New QR Code Payment system uses the MCU installed in a vending machine. The printed QR code is read by a mobile device and connected via Bluetooth, and the same QR code information for payment used for conventional QR code payments is sent to the MCU. The MCU of the vending machine sells an item by receiving the result of a payment made by

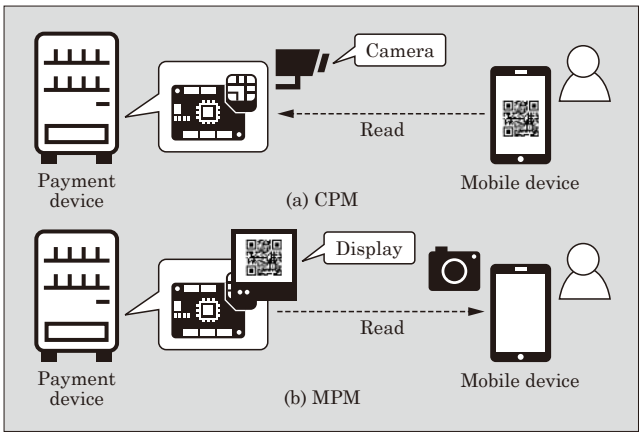

Fig.6 QR code payment system

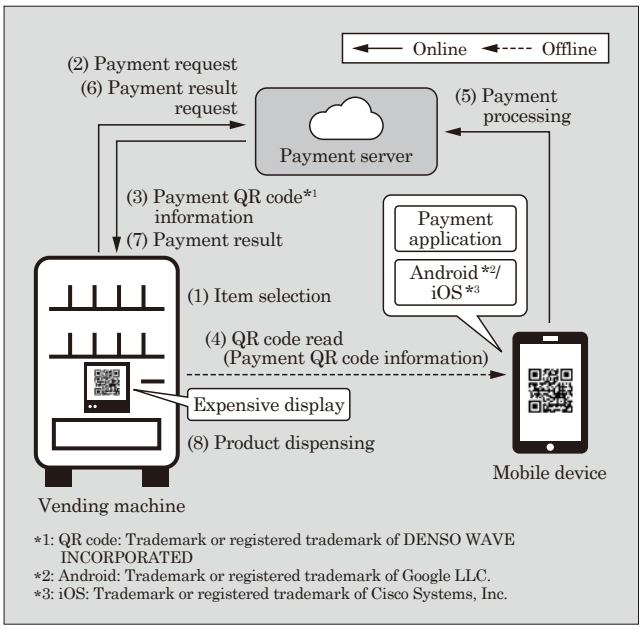

Fig.7 Conventional QR code payment flow (MPM system)

*2: Bluetooth: Trademark or registered trademark of Bluetooth SIG, Inc.

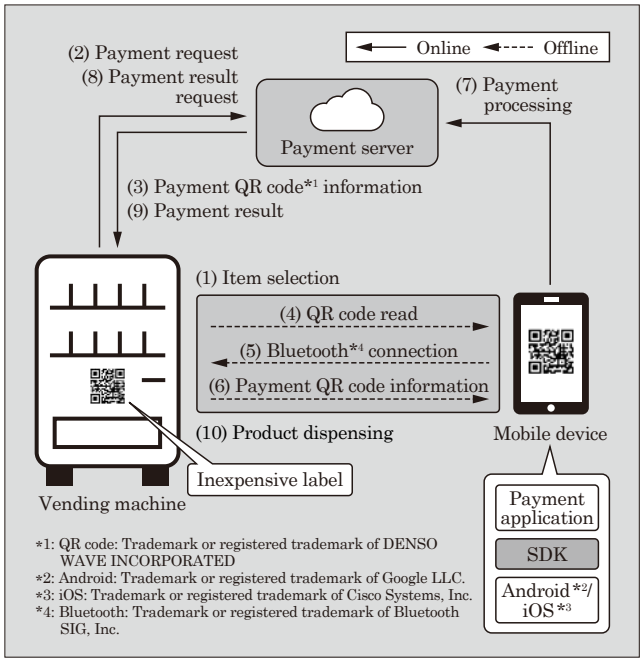

Fig.8 New QR code payment flow (MPM system)

operating a mobile device from the payment server. From the purchaser's viewpoint, the payment flow is compatible with the QR code reading system (MPM) that uses the camera of a mobile device. Under this system, the MCU of a vending machine protects and secures payment information from spoofing, data forgery, and other incidents through three-party legitimacy verification of the transaction with the mobile device and the payment server. Building this system will need to develop a mobile device payment application. To this end, Fuji Electric has prepared a software development kit (SDK) to facilitate this process, which is provided upon customer request.

The New QR Code Payment, which is less costly to build than the conventional system, can be introduced even by customers who had given up installing cashless payment devices because of the initial cost. Support for QR code payment allows linking with discounts and loyalty programs by payment service providers, and its user-friendliness can be expected to increase the number of purchasers and boost vending machine sales.

5. Postscript

This paper has presented developments in the Vending Machine Operation Services. Developed as new services to solve customer problems, we believe that these services can improve the efficiency of vending machine operations and increase sales.

In the future, we will aim to contribute to the business of vending machine operator companies through further value enhancement of vending machines by continuously creating services that cater to market needs, such as by developing electronic key systems that improve operators' key management, as well as vending machine security and electronic receipt services, for which demand is increasing for vending machines due to the digitization of expense reimbursement processes.

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Technology for Applying Heat Pumps to Beverage Vending Machines

WATANABE, Tadao* KONO, Amane*

ABSTRACT

Beverage vending machines, widely used for their convenience, are required to improve their energy efficiency. Fuji Electric has developed a technology for beverage vending machines to expand the use of heat pumps between internal compartments and improve energy efficiency. An electronic expansion valve is used to precisely control the amount of refrigerant expansion to maintain the target evaporation. This load adjustment operation based on the evaporation temperature allows the adjustable operating range of the heat pumps to be expanded. PID control keeps the condensation temperature to match the target value. This technology was able to run vending machines only on heat pumps between internal compartments, thereby saving approximately 4% of energy.

1. Introduction

Beverage vending machines are highly convenient products that readily provide beverages at ready-to-drink temperatures 24 hours a day. There are approximately 2.25 million vending machines in use in Japan. Since beverage vending machines consume energy, they were designated as special equipment in the Act on the Rational Use of Energy (Energy Conservation Act) in 2002 and are required to achieve a higher level of energy efficiency. Fuji Electric has been involved in the development of various technologies, including heat pumps. In this paper, we will describe a heat pump application technology for beverage vending machines that sell both canned and bottled beverages.

2. Heating and Cooling Mechanisms in Beverage Vending Machines

2.1 Internal structure and operation of beverage vending machines

Figure 1 shows the internal structure of a beverage vending machine. A typical beverage vending machine has three product storage chambers (left, middle, and right) inside the storage compartment and a machine room outside the storage compartment. In terms of product storage racks, in addition to the standard racks, which mainly hold small-capacity canned beverages of 350 ml or less, plastic bottle racks are used to hold large-capacity beverages in 500 ml plastic bottles. There are also a wide variety of width and depth dimensions for beverage vending machines, depending on the type of product to be stored.

Beverage vending machines have built-in heat pumps to cool and heat drinks. Each storage chamber can be divided into a cooling chamber or heating chamber depending on the type of product. In typical vending machines, the left and middle chambers serve as both cooling and heating chambers, while the right chamber is dedicated to cooling.

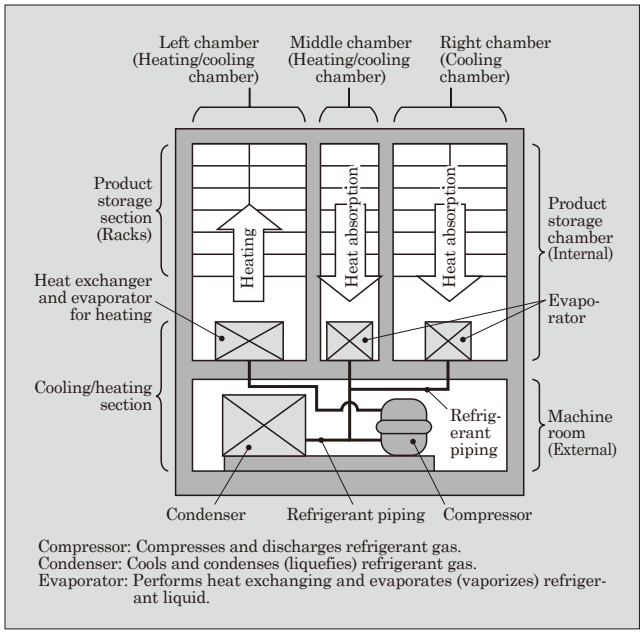

Fig.1 Internal structure of a beverage vending machine

Table 1 shows the different uses (operation modes) of the cooling and heating chambers for beverage vending machines. There are four operation modes, and most of the time, during the summer season, all three chambers are operated in the CCC mode for cooling. During other seasons, cooling and heating operations are switched depending on sales trends and other factors, but in actual operation, the HCC mode shown in Fig. 2 is used for most of the year. Therefore, a reduc-

* Food & Beverage Distribution Business Group, Fuji Electric Co., Ltd.

Table 1 Operation modes of beverage vending machines

Operation mode*	Left chamber (Heating/cooling chamber)	Middle chamber (Heating/cooling chamber)	Right chamber (Cooling chamber)	Main operating seasons
CCC	Cooling	Cooling	Cooling	Summer
HCC	Heating	Cooling	Cooling	Spring and Autumn
CHC	Cooling	Heating	Cooling	Spring and Autumn
HHC	Heating	Heating	Cooling	Winter

*C: Cold; H: Hot

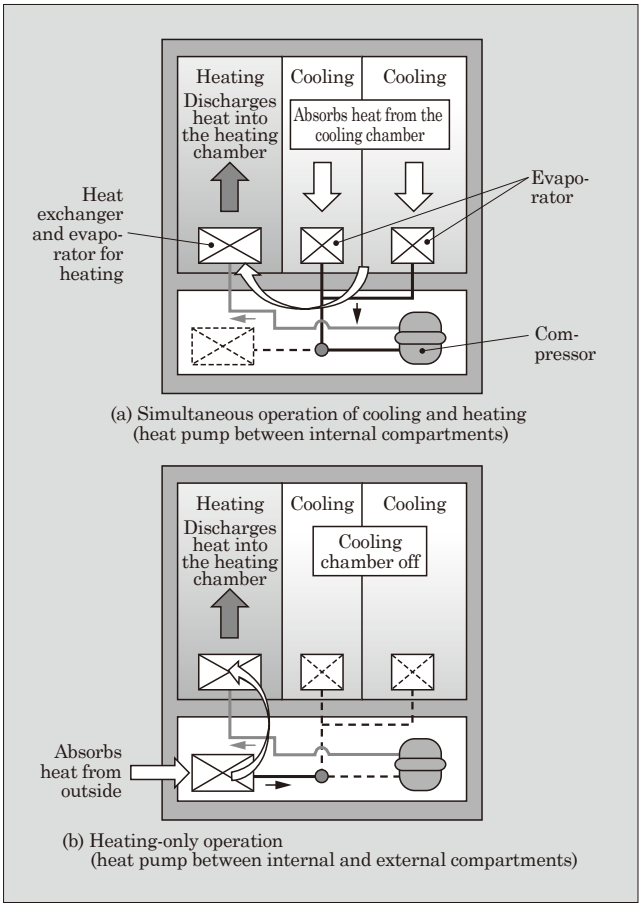

Fig.2 Heat pump mechanism of beverage vending machines (HCC operation mode)

tion in power consumption in this operation mode can be expected to have a significant energy-saving effect.

2.2 Heating and cooling mechanisms of heat pumps

Heat pumps are called heat transfer pumps and are used, for example, in residential air conditioners for cooling and heating. In the case of heating, air conditioners are used to heat indoor rooms by collecting heat from the outdoor air with very little electrical energy. In the case of cooling, air conditioners are used to cool indoor rooms by collecting heat from the indoor air and releasing hot air outside. In contrast to air conditioners, which switch between cooling and heating, beverage vending machines simultaneously perform cooling and heating by drawing heat from cooling chambers so that it can be used in the heating chamber.

Products in the heating and cooling chambers are required to be kept within an appropriate temperature range. In principle, heat pumps cannot perform cooling and heating separately. Therefore, they need to cool the cooling chambers and heat the heating chambers in sync. In conventional beverage vending machines, the heat pump between internal compartments [see Fig. 2(a)] is controlled primarily for the cooling chamber and secondarily for the heating chamber. For example, if the ambient temperature is 15°C, the temperature difference between the cooling chamber temperature of 5°C and the heating chamber temperature of 55°C will be 10 K and 40 K respectively. Since the load for heating is higher, an insufficient amount of heat will be provided to the heating chamber. To compensate for this, an external heat pump [see Fig. 2(b)] is installed between internal and external compartments to draw heat from the air outside the chamber. Figure 3 shows the operation of the heat pump. When the temperature in the cooling chamber rises to the set temperature, the heat pump between internal compartments begins operating, cooling the cooling chamber and heating the heating chamber. When the temperature in the cooling chamber drops to the set temperature, the heat pump between internal compartments stops. At this point, however, the heating of the heating chamber is insufficient. Therefore, the heat pump between internal and external compartments is immediately started to continue heating the heating chamber. When the temperature in the heating chamber reaches the set temperature, the heat pump between internal and external compartments stops. After this, the process is repeated when the

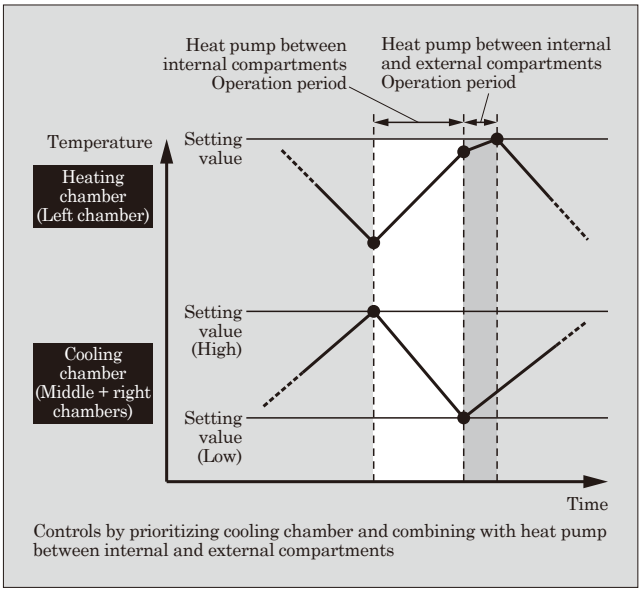

Fig.3 Operational behavior of a heat pump (conventional machine)

temperature in the cooling chamber rises again.

The heat pump between internal and external compartments is used only for heating by drawing heat from outside the chamber. It is less efficient than the heat pump between internal compartments that performs heating and cooling at the same time. In order to save energy, it is necessary to reduce the usage of the heat pump between internal and external compartments.

3. Improving the Operating Efficiency of Heat Pumps

To solve the issues described in Section 2.2, we developed a technology that performs heating and cooling using only the heat pump between internal compartments, eliminating the need of the low-efficient operation of the heat pump between internal and external compartments.

3.1 Balancing heating and cooling capacity by controlling evaporation temperature

Conventional heat pumps between internal compartments have insufficient heating capacity relative to cooling capacity. However, by changing the temperature at which the refrigerant in the evaporator evaporates (evaporation temperature), it is possible to change the ratio of cooling capacity to heating capacity. Figure 4 shows the relationship between the refrigerant evaporation temperature and the ratio of cooling capacity to heating capacity in our newly developed vending machine. The ratio of heating capacity to cooling capacity increases as the evaporation temperature increases. By controlling the evaporation temperature by changing the flow rate of refrigerant at the expansion valve, cooling can be delayed and the heat pump can be controlled so that the temperatures in the cooling and heating chambers reach their respective setting values at the same time. Conventional machines can only operate at a pre-set evaporation temperature, but our newly developed machine can expand the operating range of the heat pump between internal components by adjusting its capacity based on the evaporation temperature as needed.

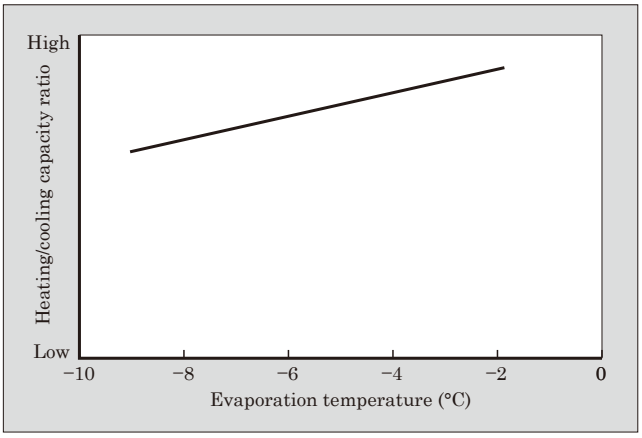

Fig.4 Relationship between the refrigerant evaporation temperature and heating/cooling capacity ratio in our newly developed vending machine

3.2 Improving heating efficiency by controlling condensation temperature

The temperature at which the refrigerant condenses in the condenser (i.e., the condensation temperature) involves conditions that maximize the heating efficiency of the heat pump. By controlling the speed of the compressor, this condensation temperature can be maintained to maximize heating efficiency. By controlling the compressor speed with an inverter using proportional-integral-differential (PID) control, the condensation temperature of the heat exchanger in the heating chamber can be maintained at the target value. Figure 5 shows the block diagram for PID control.

3.3 Effect

Figure 6 shows the operational behavior of the heat pump with the control described in Section 3.1 applied. In this case, the heat pump is controlled primarily

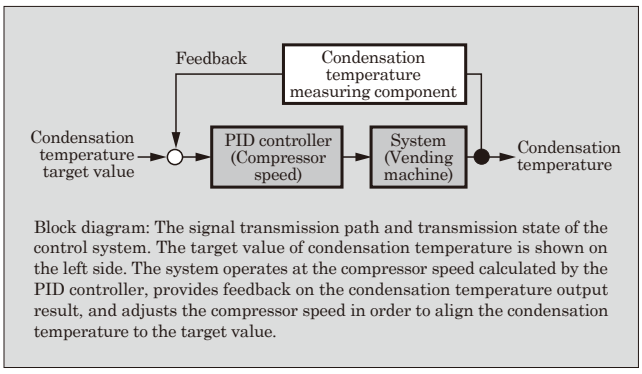

Fig.5 Block diagram for PID control

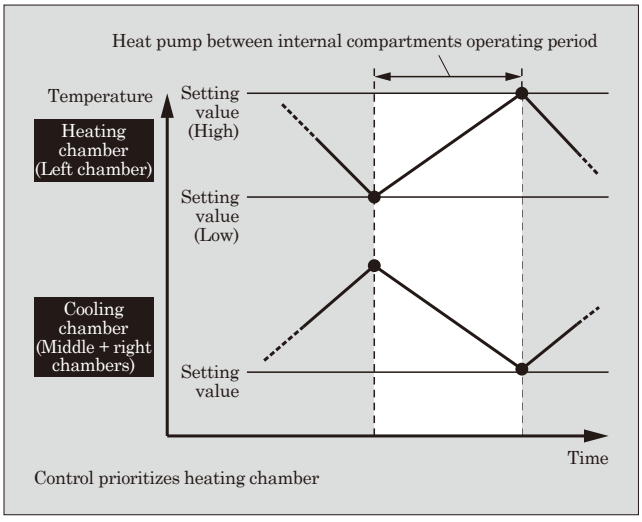

Fig.6 Operational behavior of heat pump (newly developed machine)

for the heating chamber and secondarily for the cooling chamber. When the temperature in the heating chamber drops to the set temperature, the heat pump between internal compartments starts operating to begin heating the heating chamber and cooling the cooling chamber. When the temperature in the heating chamber rises to the set temperature, the heat pump between internal compartments stops. By controlling the evaporation temperature of the refrigerant in the evaporator, the temperatures in the heating and cooling chambers can reach their respective setting values at the same time.

Figure 7 shows the transition of condensation temperature during heat pump operation. Our newly developed machine operates at the target condensation temperature by using PID control. The target condensation temperature is the minimum temperature required to heat the applicable products.

Figure 8 shows the transition of energy efficiency from the start to the end of heat pump operation. Our newly developed machine has an approximately 18% higher ratio of heating capacity to cooling capacity

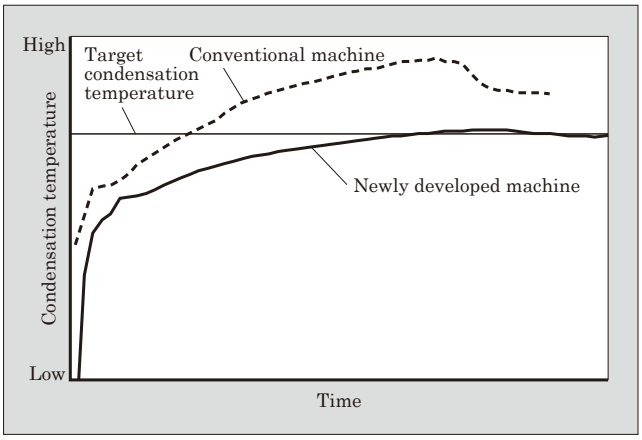

Fig.7 Transition of condensation temperature during heat pump operation

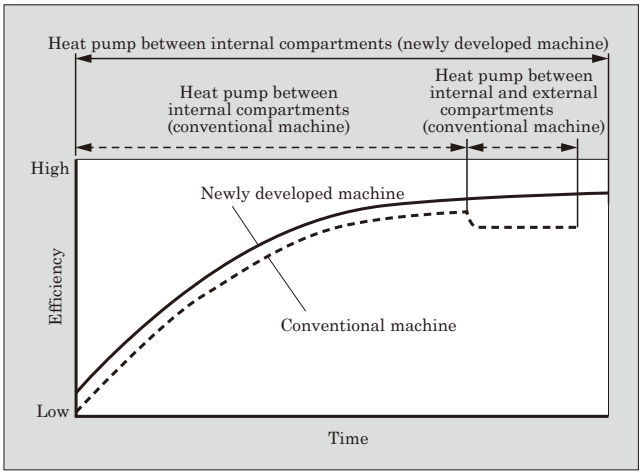

Fig.8 Energy efficiency during heat pump operation

than a conventional machine, and is more energy efficient than a conventional machine from start to finish. The effect of using only the heat pump between internal compartments instead of combining it with a heat pump between internal and external compartments is significant, achieving a 4% energy savings in the example shown in Fig. 8.

4. Postscript

In this paper, we described a heat pump application technology for beverage vending machines. This research has enabled us to expand the operation and improve the efficiency of heat pumps between internal compartments. In the future, there will continue to be a need for optimal energy-saving operation suited to the installation environments of beverage vending machines. We will continue to promote technological development aimed at improving the circuit technology of heat pumps and increasing the sophistication and precision of control to achieve to higher efficiency.

“Frozen Station” Frozen Food Vending Machine

FUKUDA, Katsuhiko* IWAKO, Tsutomu* NAKANISHI, Toshikazu*

ABSTRACT

The market for home meal replacements has been growing rapidly due to changes in lifestyles, and in particular, frozen foods are increasingly in demand for their improved flavor provided by freezing technology advancement and as promising means of solving the problem of food loss. Fuji Electric has developed the“ Frozen Station” frozen food vending machine, which can sell products in stores at various locations 24 hours a day without face-to-face interaction. While achieving the industry’s largest storage capacity capable of stocking 70 large-sized products, the storage structure and conveyance technology for various forms of frozen products stabilize the posture of the products by controlling the posture during dropping. In addition, by optimizing the shape of the conveyance chute, the conveyance resistance is reduced, enabling stable conveyance of goods.

1. Introduction

The impact of COVID-19 has changed lifestyles and increased the demand for ready-to-eat meals. In particular, domestic factory shipments of frozen foods for household use reached a record high in 2021.(1) The frozen food market is expected to grow 8.37% annually until 2030. The reason for this is that consumers are attracted to frozen foods because of their deliciousness achieved through improvements in freezing technology, as well as their ability to reduce food loss and waste, contributing to one of the sustainable development goals (SDGs). Against this backdrop, there is a growing need for restaurants, which have played a key role in the food service industry, to sell dishes previously served in their restaurants in the form of frozen foods as a countermeasure against the decline in sales and shortened business hours caused by COVID-19 restrictions. In response to this change in consumer preferences, Fuji Electric has developed a vending machine that can sell frozen foods at various locations such as stores, 24 hours a day, without face-to-face interaction. In this paper, we will introduce the “Frozen Station” frozen food vending machine.

2. Challenges Facing Frozen Food Vending Machines for Restaurants

This newly developed frozen food vending machine is expected to be used by restaurants to sell frozen foods (dishes) as a new sales channel for the products they have conventionally offered in their stores. Since theses frozen foods will be prepared by the restaurants themselves, they will come in a wide variety of shapes, sizes, and weights. Furthermore, it is assumed that products will often be wrapped in a food pack shown in Fig. 1. Therefore, this new frozen food vending machine needed to have a storage structure and conveyance mechanism capable of handling a variety of products types. Moreover, it was important for the frozen food vending machine to be able to store as many products as possible at one time. This reduces the loss of sales opportunities due to sold-out products and decreases the frequency of product replenishment.

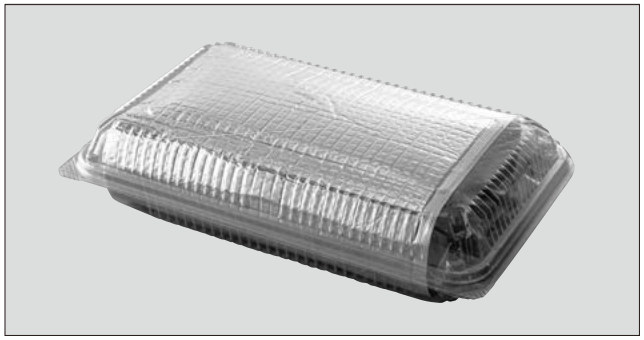

Fig.1 Food pack

It is also assumed that this frozen food vending machine will be operated directly by the restaurant that installed it. Another important issue is to ensure that the vending machine could be operated smoothly even by users who are not familiar with its operations.

3. Features of the “Frozen Station” Frozen Food Vending Machine

3.1 Overview

Figure 2 shows the appearance of the Frozen Station, and Table 1 lists its specifications. The dimensions of the Frozen Station are the same standard size as our ice cream vending machines. This allows it to

* Food & Beverage Distribution Business Group, Fuji Electric Co., Ltd.

Fig.2 “Frozen Station”

Table 1 “Frozen Station” specifications

Item	Specification
Type name	FFS107WFXU1
Dimensions	W1,161 × D836 × H1,830 (mm)
Type of sales	7 selections with 10 selection buttons
Mass of products that can be stored	500 g or less
Product mass	330 kg
Lighting	LED
Installation environment	Installable indoors and outdoors
Product storage temperature	−23°C to −19°C
Power consumption	2,500 kWh/y

be installed in general locations while maintaining sufficient internal volume.

3.2 Storage structure for various products

In designing the storage structure, we first surveyed food packs and commercially available frozen foods, and determined that the product sizes should be able to accommodate a width of 150 to 230 mm, depth of 100 to 155 mm, and height of 41 to 51 mm. Table 2 shows the specifications.

Assuming the sale of large products such as pasta and ramen noodles, we designed the rack structure with an emphasis on efficient storage in order to ensure a sufficient number of product types and capacity. Figure 3 shows the rack structure of its vertical single spiral system. As a system capable of efficiently storing large-sized frozen foods, based on a rack structure that has a proven track record in our ice cream vending machines, we placed a large-diameter spiral of 110 mm at the back of the racks to create a slim structure without spiral fixing parts on either side of the racks, delivering a capacity of 10 products in a rack.

Table 2 Specification of products sold

Item	Specification
Maximum capacity per column	10
Width	150 to 230 mm
Depth	100 to 155 mm
Height	41 to 51 mm
Maximum diagonal length	250 mm or less
Mass	Single rack total 4,000 g or less, 500 g or less per product

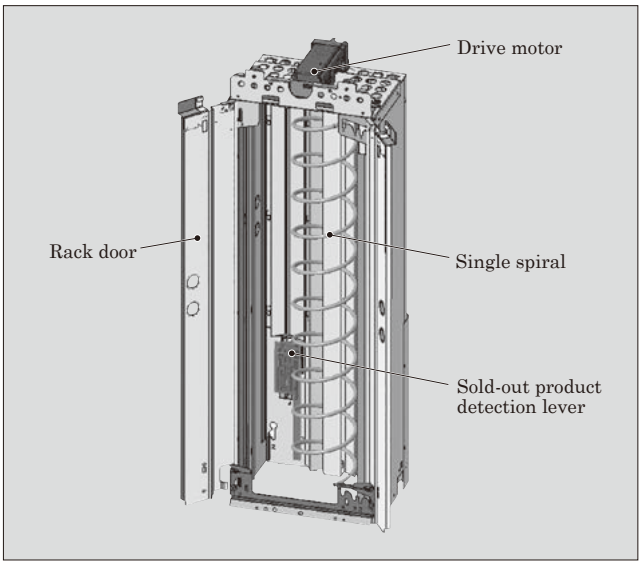

Fig.3 Rack structure of the vertical single spiral system

Figure 4 shows the rack arrangement. By slimming down the rack in the width direction, we arranges four columns in the horizontal direction, giving a total of seven columns suitable for large products. This enabled it to achieve the industry’s largest storage capacity of 70 large-sized products, such as frozen pasta and side dishes.

We also provided it with movable partition plates (adjusters) that can adjust the rack width. This prevents products from falling out of a rack due to the variety of container sizes and types and also stabilizes conveyance for all product sizes. Figure 5 shows an example of the partition plate adjustment. To hold products of various sizes stably in the racks, operators can adjust the inner width of the racks in six levels according to the width of the products. It utilizes an ad-

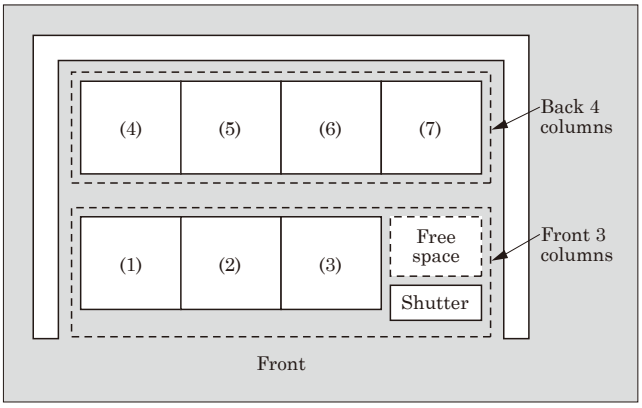

Fig.4 Rack arrangement (top view)

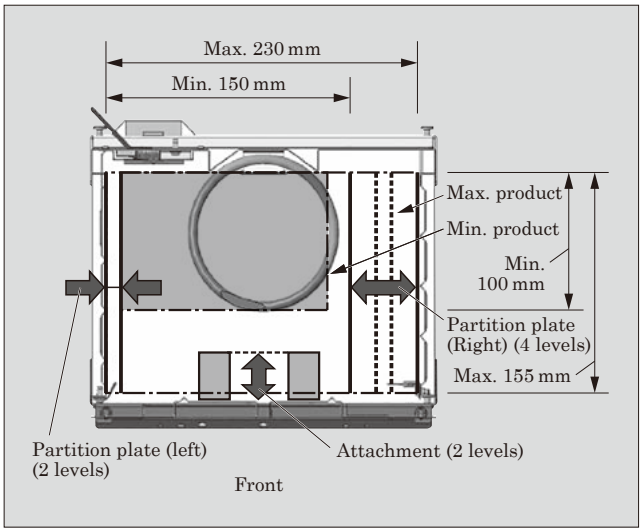

Fig.5 Example of the partition plate adjustment

juster structure that can be easily adjusted with a sliding motion that eliminates the need for troublesome operations such as reattaching the partition plate. To accommodate the depth of different products, it has a lightweight attachment that can be attached to or detached from the door side, allowing for two levels of adjustment. These features allow food packs of different dimensions to be stably stored.

In terms of product height, the Frozen Station comes standard with spirals that can accommodate products within the dimensional range specified in the specifications. To accommodate products with heights outside this range, spirals with spacing appropriate to the height of the products are available as an option.

This design contributes to the mechanism that can store products of various sizes.

3.3 Mechanisms to ensure the dispensing of products

(1) Spiral rack mechanism

As mentioned previously, the rack structure for storing products uses a vertical spiral system that facilitates product replenishment. In a vertical spiral system, the spiral of the conveyance unit rotates to push products downward. It is available as a single spiral system [see Fig. 6(a)] or a twin spiral system [see Fig. 6(b)]. In a twin spiral system, as shown in Fig. 6(b), both ends of the product are inserted into the left and right spirals to hold the product horizontally, making it easier to control the falling posture of the product when dispensing it. The use of two spirals however causes the rack width to be larger than that of the product. In a single spiral system, the rack width is reduced to enable products to be loaded diagonally along the spiral, and the storage efficiency can be increased relative to the floor level of the vending machine. In light of these features, we uses the single spiral system for the Frozen Station.

However, with this system, if the product is rectangular-shaped, it could fall upright in the longitudinal

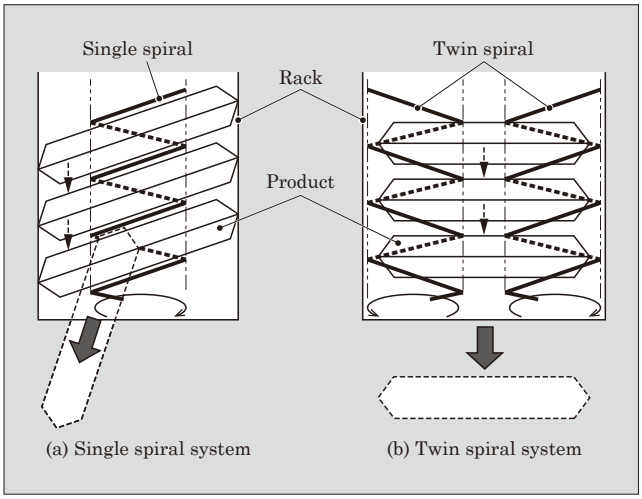

Fig.6 Rack and product dispensing behavior (front view)

direction when it is dispensed, potentially causing it to be jammed in the upright position. As a preventive measure, it has a function to control the posture of products by installing two layers of posture control guides under the racks, a primary guide to control the fall of products in the longitudinal direction, and a secondary guide to adjust the posture of products falling in the lateral direction. Figure 7 shows the posture control in dispensing products. In this way, we achieve a highly reliable dispensing mechanism that prevents product jamming by controlling the posture of products when they land on the conveyance chute and using a single spiral system with high storage efficiency for large products.

(2) Conveyance chute

Figure 8 shows the conveyance chute. Products that fall from the rack mechanism are received by the conveyance chute. The conveyance chute has a function for drawing the products dispensed from the racks on the left, right, front and rear sides to the center and conveying them along the slope to the outlet . The structure is integrally molded with a plastic designed for low temperatures and constructed with a low-

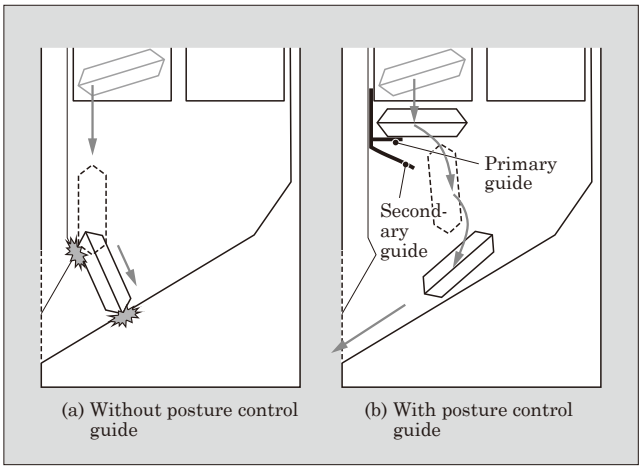

Fig.7 Posture control in dispensing products

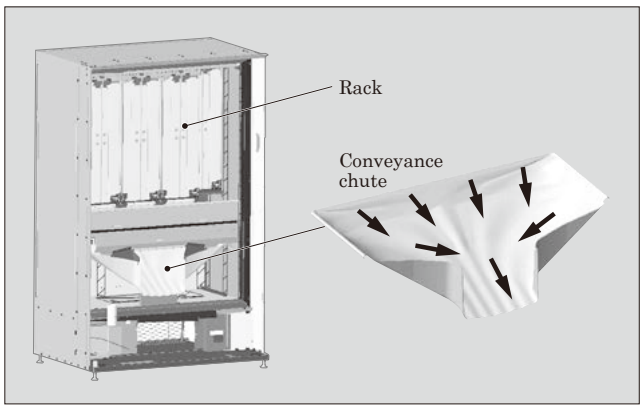

Fig.8 Conveyance chute

friction, seamless, three-dimensional curved surface structure to prevent product jamming due to snagging. However, products are becoming larger, the passage of the conveyance chute needs enlarged, which leads the center area with loose curvature become wider, raising concerns that the products would not slide down and instead get stuck. Using textured surface for the conveyance chute can reduce the contact area with the product and decrease the frictional force, allowing products to slide even on gentle slopes. We experimentally determined the relationship between the weight of the products and the contact area where the products can slide without stagnation, and reflected this in the design of the textured surface.

It is also necessary to consider the direction in which the textured surface shapes should be arranged. If textured surface shapes are arranged so that steps are formed in the conveyance direction of products, it may result in products becoming snagged. Therefore, we investigated the trajectory of products flowing against the base surface of the conveyance chute, arranged the textured surface shapes along the trajectory so as not to interfere with the movement of products sliding down, and determined the pitch of the textured surface shapes so that the contact area ratios would consist of gently curved surfaces. Figure 9 shows the arrangement of the textured surface shapes we designed for the conveyance chute. This arrangement allows a conveyance chute shape that even lightweight bagged items can slide. The contact area of the conveyance chute has been reduced to one-tenth of that of conventional products, providing stable product conveyance even under adverse conditions, such as when condensation hinders slippage.

Figure 10 shows the falling behavior of products after rack dispensing.

3.4 Operation support services for vending machines

This newly developed frozen food vending machine comes with a communication unit that notifies operators of the vending machine's status as a feature that supports its operation.[2] By using this feature, operators can check product sales remotely without having

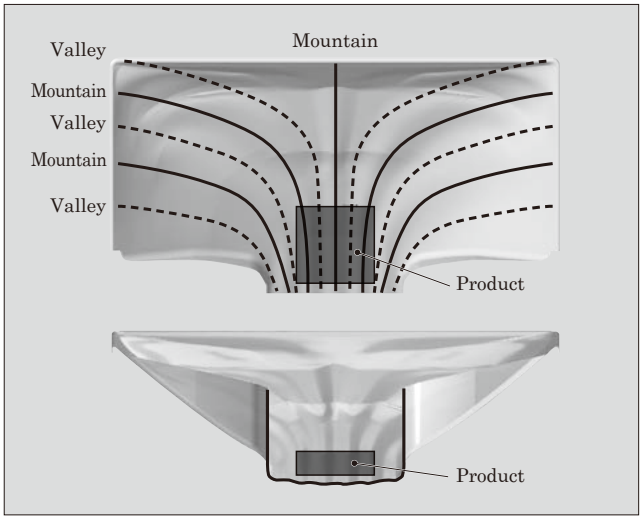

Fig.9 Arrangement of the textured surface shapes designed for the conveyance chute

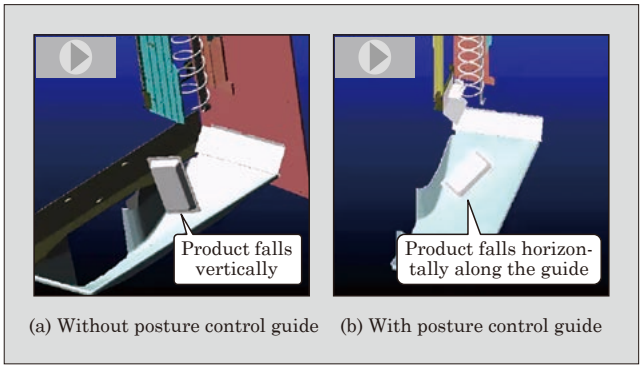

Fig.10 Falling behavior of products after rack dispensing

to visit the installation site. This also means that the vending machine can be replenished with product on a single visit.

In addition, it has a function that immediately notifies operators via email when problems occur, such as sales trouble and running out of changes, due to unskilled workers improperly replenish products or setting configurations. This facilitates prompt countermeasures and minimizes the loss of sales opportunities.

4. Postscript

In this paper, we introduced the "Frozen Station" frozen food vending machine. This frozen food vending machine provides the market with the ability to sell new types of products previously unavailable at stores without face-to-face interaction. Moving forward, we plan to develop technologies that accommodate various container shapes so that we can further contribute to the expansion of the frozen food vending machine market.

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“Thickened Beverage Vending Machine” In-Cup Mixing Automatic Tea Server

KUROYANAGI, Yasuhiko* KIDA, Akira* OZAWA, Tatsunori*

ABSTRACT

As the population of Japan continues to age, there is a need to address labor shortages and improve the working environment in the nursing care field. Fuji Electric has launched the“ Thickened Beverage Vending Machine,” which facilitates the preparation of thickened beverages using the technology it has cultivated in cup vending machines and other products. Thickened beverages have more viscosity than usual to prevent aspiration, that is, accidental entry of food or drink into the trachea. In the medical and nursing care field, the viscosity must be varied depending on the condition of each individual care receiver by hand, placing a burden on the caregivers. Our newly developed Thickened Tea Vending Machine can automatically adjust the beverage temperature and viscosity according to the care receiver.

1. Introduction

The number of people in need of nursing care continues to increase as the birthrate in Japanese society declines and the population ages, making it an urgent social issue to eliminate labor shortages and improve the working environment at nursing care sites. For example, when caring for people with difficulty swallowing, measures need to be taken to thicken meals and drinks to prevent aspiration. This creates a heavy burden on caregivers because the work is cumbersome and requires careful attention. To help solve this problem, Fuji Electric has developed and released the “Thickened Beverage Vending Machine” that can easily serve thickened beverages optimally suited for each person requiring nursing care by utilizing technology cultivated in vending machines.

2. Development Background and Challenges

2.1 Thickened beverages

Thickened beverages have more viscosity than usual. In order to prevent elderly people and other patients with weakened throat functions from aspiration and choking, we are supplying this product to medical institutions, long-term care facilities, senior citizen housing facilities, and nursing homes. Adding a little viscosity to a beverage slows the rate at which it passes down the throat and thus helps prevent aspiration. This viscosity should be changed according to the condition of the person requiring care. In addition, temperature control is also important because thickened beverages take time to pass through the throat and may cause burns if the temperature is too high. Currently, thickened beverages are made by hand by caregivers such as hospital staff. In order to prepare a thickened beverage of the quality (viscosity and temperature) suitable for each person requiring nursing care, careful measuring of ingredients and lengthy stirring are required, placing a heavy burden on caregivers.

* Food & Beverage Distribution Business Group, Fuji Electric Co., Ltd.

2.2 Challenges in developing the “Thickened Beverage Vending Machine”

There are some challenges to developing the Thickened Beverage Vending Machine, as described below. Table 1 shows the challenges and corresponding solutions for the Thickened Beverage Vending

Table 1 “Thickened Beverage Vending Machine” development challenges and corresponding functionalities

User	User needs	Corresponding challenges		Function
Care receivers	Provide suitable beverages for care receivers	Preparation according to the condition of care receivers	Adjustable to a prescribed viscosity	Precise weighing and blending
			Uniform mixing, no residue	In-cup mixing, shaking control
			Adjustable to a prescribed temperature	Controlling the temperature and amount of cold and hot water
Caregivers	Can make drinks easily and reliably	Automation of beverage preparation		Automated preparation using buttons
		Prevents operation errors		Selection guide function
	Easy clean up after preparation	Ensures sanitation		Automatic cleaning (New propeller system)

Machine.

(1) Preparation according to the condition of the person requiring care

Care receivers need thickened beverages that have a suitable viscosity, uniform composition with ingredients completely dissolved, and a suitable temperature.

The Japanese Society of Dysphagia Rehabilitation has established three levels of criteria for thickened beverages, depending on the degree of dysphagia. The Thickened Beverage Vending Machine is also required to comply with this criteria.

Temperature control is also important for preparing properly thickened beverages. Interviews with medical professionals and raw material manufacturers showed that a temperature of approximately 45°C is desirable for hot beverages. At the same time, it is also important to consider how to prepare and control the temperature of cold beverages.

Another need for care receivers is to be able to drink thickened beverages at the right time without waiting. Therefore, another challenge is to reduce the preparation time of the Thickened Beverage Vending machine so that it is faster than preparing beverages by hand.

(2) Ease of use

Caregivers are responsible for operating the Thickened Beverage Vending Machine to serve care receivers thickened beverages. Therefore, another challenge is to improve the ease of use of the Thickened Beverage Vending Machine. Conventional tea vending machines are designed for convenience, offering users a one-touch selection of beverages by just pressing a button. However, in the case of the Thickened Beverage Vending Machine, if the wrong button is pressed, it could dispense a beverage with the wrong viscosity. If this beverage was served to a care receiver, it could lead to aspiration. Therefore, the most important requirement is to be designed so that operators can select the thickening agent being added or not and thickening viscosity without fail.

(3) Ensuring sanitation

Sanitation control is essential for caregivers in hospitals and nursing homes who are responsible for managing the Thickened Beverage Vending Machines, since the thickened beverages are consumed by the elderly and handicapped. Therefore, desirable products can perform stable and easy automatic cleaning without the need of cleaning equipment. To reduce the burden on caregivers, the product needed to be sanitary in daily operations and not time-consuming to maintain.

3. "Thickened Beverage Vending Machine"

3.1 Product overview

Figure 1 shows the external appearance and internal structure of the Thickened Beverage Vending Machine, and Table 2 shows its specifications.

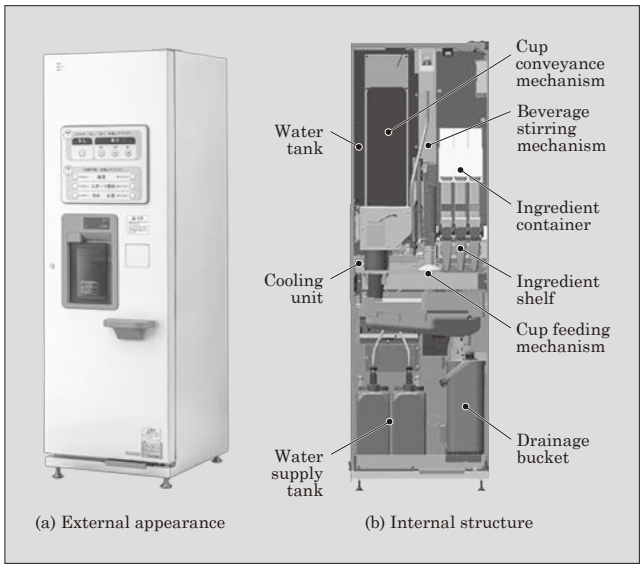

Fig.1 External appearance and internal structure of the "Thickened Beverage Vending Machine"

Table 2 Specifications of the "Thickened Beverage Vending Machine"

Item	Specification
Dimensions	W550 × D605 × H1,700 (mm)
Type of sales	Hot beverages × 3, Cold beverages × 3
Function buttons	4 (3 levels of thickness, None)
Ingredient capacity	2.4 L × 3 (Thickener × 1, Powder × 2)
Ingredient preparation method	In-cup mixing system
Cup mechanism	Yes (9 oz)
Cup capacity	1 type 2 rows (200 or more)
Cup conveyance system	X-axis conveyance system
Heating unit	Capacity 7 L, Heater 550 W
Cooling unit	Water tank 4.5 L (ice bank system)
Water supply system	Direct tap water connection, Cassette tank system
Refrigerant	R1234yf
Power supply	100 V, 50/60 Hz, 15 A

3.2 Features

(1) Control parameters to ensure high quality beverages

We collaborated with raw material manufacturers who are experts in thickening agents and identified control parameters for handling thickening agents. Table 3 shows the characteristics and control parameters of the thickening agents.

Based on our understanding of the characteristics of thickening agents, we identified the conditions necessary to provide thickened beverages with three levels of viscosity by referring to the viscosity criteria established by the Japanese Society of Dysphagia Rehabilitation (see Fig. 2) and reflected the conditions in the thickened beverage vending machine.

(2) Automation of preparation process

Table 3 Characteristics and control parameters of thickening agents

Characteristics of thickening agents	Control parameter
Solubility	Hot and cold water temperature, Stirring time
Viscosity change	Stirring time, Standing time
Viscosity effect	Ingredients, Cold water, Hot water slowing
Temperature dependence	Beverage temperature and standing time
Stickiness	Sanitation (rinse water volume, timing)

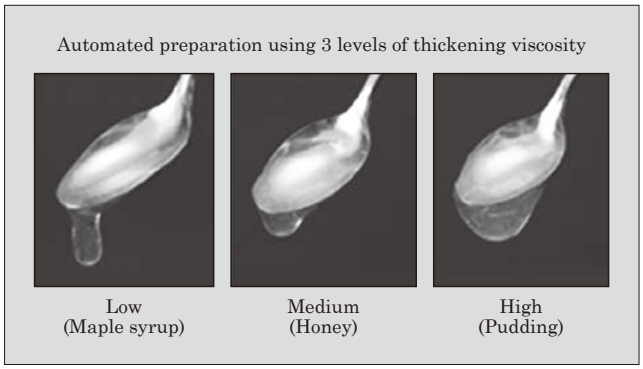

Fig.2 Viscosity criteria[1]

Figure 3 shows the preparation process. This is the first automatic tea server to use the in-cup mixing system utilized by cup-type vending machines. Figure 4 shows the in-cup mixing system. This system prepares beverages by using a propeller to stir the ingredients and hot or cold water inside the cup. This is a cutting-edge technology for preparing beverages that allows the position, number of revolutions, and time to be optimized to the characteristics of the ingredients, such as particle size and viscosity. Furthermore, by adding a side-to-side shaking motion to the cup during stirring to increase stirring efficiency, it can prepare a

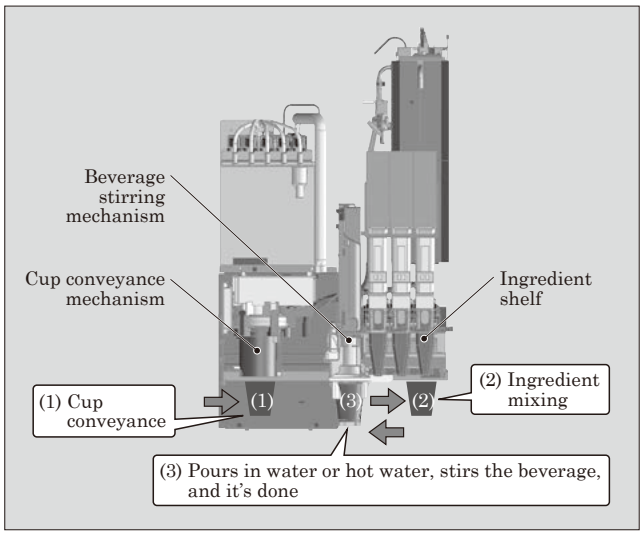

Fig.3 "Thickened Beverage Vending Machine" beverage preparation process

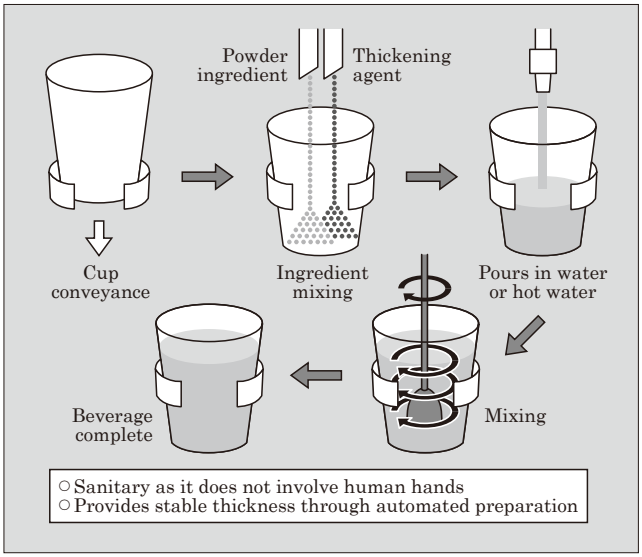

Fig.4 In-cup mixing system

thickened beverage with no residue in approximately 60 seconds. This cuts in half the 120 seconds typically required to prepare thickened beverages by hand (see Fig. 5).

In order to control the temperature of beverages at an optimal level, it uses a system that adjusts the amount of cold water used, instead of relying on ice. Specifically, it utilizes a beverage circuit with a sensor that detects the amount of fluid in automatic tea servers. By precisely controlling the amount of hot and cold water, it stably provides hot beverages at approximately 45°C and cold beverages at approximately 20°C.

(3) Easy-to-use user interface

The Thickened Beverage Vending Machines utilizes an easy-to-use user interface that is designed based on interviews with medical professionals and caregivers who gave us feedback on their experiences

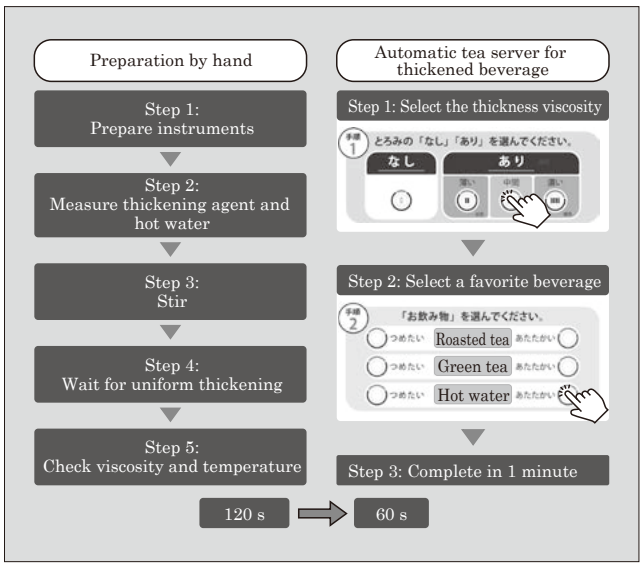

Fig.5 Thickened beverage preparation method

actually using the product (see Fig. 6).

To ensure that no mistakes are made when deciding whether or not to use a thickening agent, it was designed in a way that prevents operation errors and makes it easy to identify buttons at a glance by using a mandatory two-action function, navigation lamp based guide function, and a thickening viscosity display that lights up within a range of LEDs. It also provides the option of selecting non-thickened beverages. This enables it to prepare beverages for both caregivers and care receivers.

(4) Automatic cleaning mechanism to maintain sanitary conditions

Since it uses an in-cup mixing system, the only thing that needs to be cleaned after each beverage preparation is the mixing propeller. Moreover, this newly developed Thickened Beverage Vending Machine uses a new propeller system. Figure 7 shows how the propeller is cleaned. This system has structure that has optimized shape of the nozzle that discharges hot water and the height of the propeller to pour hot water over the entire propeller. The timing of pouring the hot water and the rotational speed of the propeller and duration can be changed to accommodate different beverages.

We evaluated the sanitation of this new cleaning method with the aerobic plate count as criterion, which is adopted in the ATP (adenosine triphosphate) test kit used in medical institutions. We set the target value for a sanitary propeller condition to 10^2 or less, which is the criterion according to the Water Supply Act. This is stricter than the criteria for food products, an aerobic plate count of 10^5 or less, since it will be mainly used in hospitals and nursing homes. We verified that this cleaning method maintained an aerobic plate count of 10 or less, demonstrating that it ensured a sanitary condition.

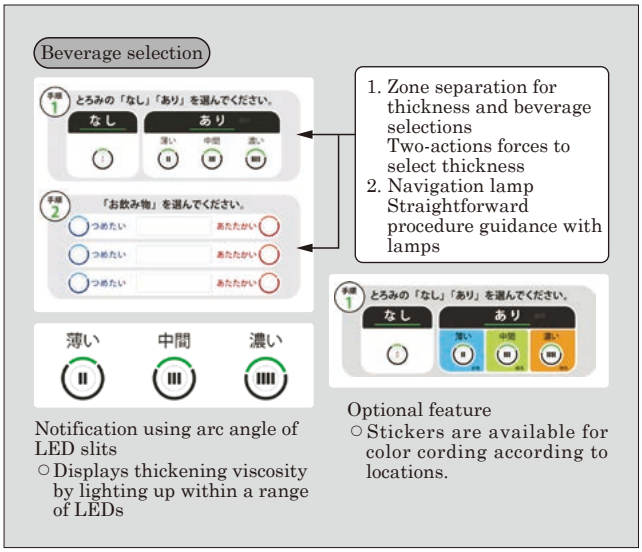

Fig.6 User interface

Fig.7 Propeller cleaning

4. Postscript

In this paper, we introduced the "Thickened Beverage Vending Machine" in-cup mixing automatic tea server. As Japan evolves into an aging society, reducing the burden on those engaged in nursing care will continue to be a challenge in the future. We believe that this product will help meet this challenge. Moving forward, we will continue to address social challenges and develop products that contribute to people around the world.

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"FGG160DCY" General-Purpose Goods Vending Machine

ABE, Junichi*

ABSTRACT

In the retail market that uses vending machines in Southeast Asia, consumer purchasing requirements has become increasingly diversified. In response to this trend, Fuji Electric has developed a new general-purpose goods vending machine, the "FGG160DCY." Equipped with the storage that has been greatly expanded in capacity, its product storage equipment (rack) and elevator mechanism stably dispense large and small, various products, such as food, beverages, and pharmaceuticals. In terms of cooling performance, strengthening the internal insulation structure inside and adopting a blow-down airflow structure have enabled all products to be kept uniformly cool in the temperature range of 1°C to 8°C. In addition, the housing structure has been strengthened to withstand the shocks during transportation outside Japan.

1. Introduction

In recent years, consumers have diversified their purchasing behavior worldwide, and there is a growing need for vending machines to sell products 24 hours a day without face-to-face interaction. Outside Japan, particularly in Southeast Asia, there has been a growing trend to install vending machines for food products such as confectionery and instant noodles, daily necessities, and pharmaceuticals on the premises of offices and commercial facilities. In response to this trend, Fuji Electric has developed a general-purpose goods vending machine, the "FGG160DCY."

2. Needs for Vending Machines in Southeast Asia

2.1 Market trends

The vending machine market in Southeast Asia (Thailand, Malaysia, Singapore, Indonesia, etc.) has conventionally been dominated by small and medium-sized operators mostly selling canned and plastic bottled beverages. In recent years, convenience store chains have also entered this business, and demand has increased for various food products such as snacks, rice, and desserts, in addition to beverages, resulting in the installation of more than 10,000 food vending machines. On the other hand, constant traffic congestion in urban areas makes access to vending machine locations cumbersome. Operators are increasingly demanding larger capacity to reduce the frequency of replenishment of products, as well as a greater variety of products in order to avoid missing out on buying opportunities.

* Food & Beverage Distribution Business Group, Fuji Electric Co., Ltd.

At the same time, hospitals in Taiwan are currently experimenting with new vending machines for non-food uses. In particular, they are studying methods of automatically dispensing pharmaceuticals from vending machines in order to reduce human error of mixing drugs up in dispensing work by pharmacists because this kind of issue occurred.

As described above, in overseas markets mainly in Southeast Asia, demand for vending machines with high capacity is increasing to accommodate a wide variety of products.

2.2 Challenges

Typical food vending machines (general-purpose machines) have had the following features: transparent glass doors, shelf-type product storage racks, an elevator mechanism for product conveyance, and a cooling unit for the entire interior of the storage compartment. This design is advantageous in that users can directly see the products displayed on the shelf, and loading products is as easy as placing them in a columns (sales spaces on the racks). A glass door is also suitable for hospital use, as it is important to visually check the pharmaceuticals that are actually dispensed from the display racks. At the same time, however, this design also has the following challenges.

(1) Ability to store various products

(a) Storage of large products

The capacity of plastic bottled beverages distributed in Japan is usually 500 ml, but many beverages outside of Japan are 600 ml in size and longer in overall length than those distributed in Japan. Therefore, it is necessary not only to expand the capacity of the racks, but also to create a storage structure that allows flexible shelf positioning to adapt to various products, such as large products in overseas markets.

(b) Conveyance of products

Racks of general-purpose machines are equipped with an elevator at the front of the racks to dispense products even from high positions, allowing products to be conveyed vertically to the dispensing outlet. However, conventional elevators sometimes have problems in the process of vertically conveying a wide variety of products. For example, some products might stick out and come into contact with other shelves and products. In addition, when heavy products are loaded on the elevator, its braking force could become ineffective, preventing it from stopping properly at specified positions. In addition, some products can become unsaleable because of content deformation and container damage due to shaking during conveyance or by the action of receiving products at the dispensing outlet. Therefore, the challenge is to ensure reliable and stable conveyance of large, heavy, fragile, and delicate products.

(c) Uniform internal cooling

An internal temperature of less than 8°C is required for pharmaceutical applications in Taiwan. This is the temperature specified by drug manufacturers for storing pharmaceutical products. General-purpose machines are designed to cool the entire interior of the storage compartment by supplying cold air to each shelf position. However, this does not comply with the requirement because their rated internal temperature ranges from 0°C to 10°C. In contrast, our new general-purpose goods vending machine comes standard with a new internal structure that is capable of keeping general foods, beverages, and pharmaceuticals uniformly cool within the same temperature range.

(2) High thermal insulation

Since heat dissipation increases with larger storage capacity, there is concern that larger cooling loads will increase power consumption. In order to improve the cooling performance of the storage compartment, it is necessary to strengthen the heat insulation of its housing and door beyond that of general-purpose machines.

(3) Reinforced structure that supports transportation

This product is designed to be manufactured in Japan and exported overseas. Unlike distribution conditions in Japan, delivering a product overseas can damage the product housing, due to shocks and vibrations during transport by cargo ship or by truck on unpaved roads and during unloading. To prevent this, it is necessary to ensure the strength of the product's housing and packaging. During container transportation, vending machines are subjected to impact forces up to 16 G (gravitational acceleration) and need to have structure to withstand these forces.

3. Features of the General-Purpose Goods Vending Machine

3.1 Overview

Figure 1 shows the external appearance of the "FGG160DCY," Fig. 2 shows the internal structure, and Table 1 shows the specifications compared with the general-purpose machine "FGG136MCY."

It has a bi-parting door, consisting of a dispensing door for the inside of the storage compartment and an operation door for the outside where the payment equipment and other devices are located. The benefit of using the bi-parting door that separate the inside and outside of the storage compartment is that the inside does not need to be opened when performing tasks, such as collecting money or changing sales settings. This reduces cooling loss and intrusion of warm outside air and insects while performing these tasks.

Fig.1 "FGG160DCY"

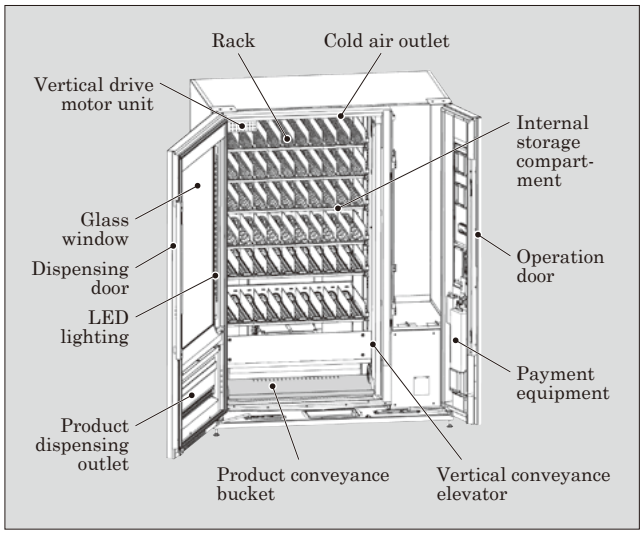

Fig.2 Internal structure of "FGG160DCY"

Table 1 Specifications compared with a general-purpose machine

Item	General-purpose machine	This product
Model	FGG136MCY	FGG160DCY
Dimensions	W882 × D840 × H1,834 (mm)	W1,435 × D890 × H1,934 (mm)
Selection	6 columns × 6 shelves 36 selections	10 columns × 6 shelves 60 selections
Product capacity	Max. 540 products	Max. 900 products
Sales assistance	Vertical conveyance elevator	Vertical conveyance elevator
Cooling system	High cooling (0°C to 10°C)	High cooling (1°C to 8°C)
Door	Single door	Bi-parting door

3.2 Features

The main features of the product are as follows:

(1) Racks for large items

Figure 3 shows the overall structure of the racks. The racks can be pulled out for product replenishment, equipped with sales modules with spiral or belt conveyor mechanisms. The product has 10 columns per shelf and supports up to 6 levels of shelves, allowing for a maximum of 60 selections of products to be stored. This capacity is 1.67 times larger than that of general-purpose machines, which accommodate 36 selections. In addition, in order to accommodate a variety of overseas products, the overall rack height and internal height have been extended by 100 mm compared with general-purpose machines, and the vertical height position of each shelf can be freely set in increments of 20 mm. By supporting a combination of up to 6 levels of shelves, operators can effectively configure the height between shelves from 163 to 258 mm. With this product, even long-length items such as bottles can be sold by adjusting the pitch between the corresponding upper and lower shelves. Moreover, the upper first and second shelves have a sloping drawer structure to facilitate replenishing work even for high-mounted shelves.

(2) Vertical conveyance elevator that reduces product shaking

Figure 4 shows the product receiver mechanism of the vertical conveyance elevator. The product conveyance bucket of the vertical conveyance elevator normally waits at the bottom of the storage compartment. At the time of delivery, it rises to the height of the rack containing the product to be sold and stops. After this, it uses a product detection sensor at the entrance of the product conveyance bucket to detect the passage of the product and confirms that the product has been transferred from the rack to the product conveyance bucket. Finally, it quietly moves the product to the position of the door's product dispensing outlet while maintaining a horizontal posture, and then directly unloads the product on the bucket in a way that ensures the safe dispensing of even fragile products.

The vertical drive motor has a higher torque, enabling it to transport twice the mass of similar machines in Japan. Even though the transport distance of the product conveyance bucket is longer due to the lower standby position and the 100-mm increase in the inner storage compartment height as mentioned above, the time required for the required series of operations (ascending from the standby position and stopping at the uppermost shelf ⇒ receiving the product from the rack ⇒ descending and stopping at the standby position) is the same as that of general-purpose machines. The depth of the product conveyance bucket has been increased by approximately 50 mm in comparison with that of conventional buckets, allowing it to reliably receive various types of products, both large and small. In addition, both ends of the product conveyance bucket are supported in a well-balanced manner by a four-wheel roller and conveying belt. This enables the product to be transported with hardly any shaking, even for larger products. We confirmed that the high-torque drive and stable dispensing operation of

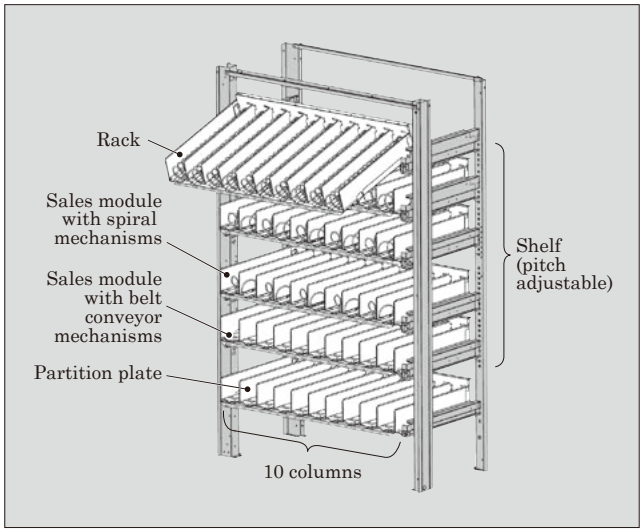

Fig.3 Overall structure of the racks

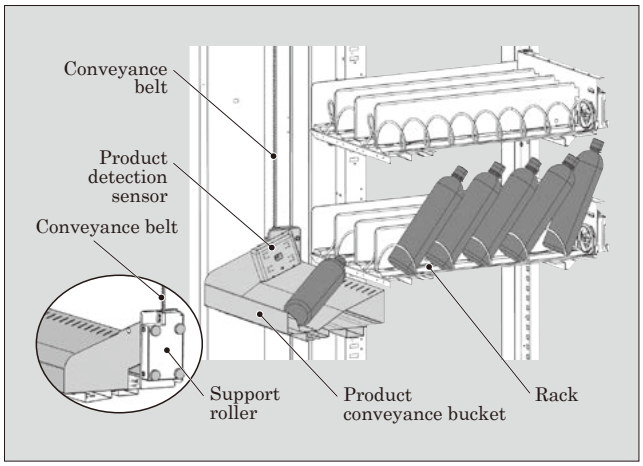

Fig.4 Product receiver mechanism of the vertical conveyance elevator

the product conveyance bucket in a horizontal posture enable conveyance of heavy plastic bottles and glass bottles such as drug ampoules without any problems.

(3) Equalization of internal temperature using a ceiling duct structure

The FGG160DCY incorporates ceiling ducts for the pathway of cold air that cools the inside of the storage compartment. Figure 5 shows the structure. This structure allows for ducts to be connected to the back of the storage compartment and the ceiling to provide ventilation paths and blow cold air down from the front part of the ceiling. The cold air is pushed up through the back ducts by the ventilation fan and down through the ceiling outlet via the ceiling ducts. It provides efficient internal airflow using natural convection and fan-assisted circulation, as well as uniform product cooling, allowing it to achieve a target controlled temperature of 1°C to 8°C. There was some concern that heat loss would occur when circulating cold air to the ceiling, but this was resolved through efforts to improve the cooling performance, as described below.

(4) High insulated structure

Table 2 shows a comparison of the structure and thermal insulation performance between this product and a general-purpose machine. Although the internal volume of the unit is 58% larger than that of a medium-sized general-purpose machine, it utilizes a thicker overall heat insulation material to suppress heat leakage and improve its cooling performance. For the main unit and the door, all walls facing the inner storage compartment are covered with urethane foam, and the volume of the overall insulation material is 1.5 times greater than that of general-purpose machines. In particular, it uses thicker insulation material in the ceiling to reduce heat transmittance. When the performance is compared with that of general-purpose machines, it reduces heat leakage by approximately 10% per real unit volume, resulting in improved thermal insulation. The synergistic effect of the aforementioned cooling structure has also achieved a 13% reduction in power consumption for the inner storage compartment.

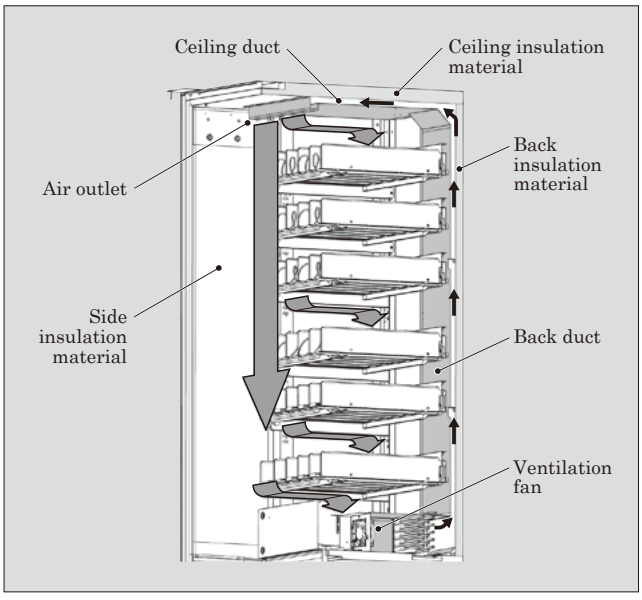

Fig.5 Ceiling duct structure (storage compartment cross-sectional view)

Table 2 Comparison of the structure and thermal insulation performance between this product and a general-purpose machine

Item	General-purpose machine	This product
Internal storage volume (m^3)	0.685	1.08
Internal insulation volume (m^3)	0.17	0.27
Ceiling insulation thickness (mm)	25	45
Ceiling insulation heat transmittance ($W/m^2 \cdot K$)	0.99	0.55
Theoretical heat leakage (W)	184	262
Theoretical heat leak (internal storage volume ratio)(W/m^3)	269	243
Power consumption (internal storage volume ratio) ($kWh/y \cdot m^3$)	2,920	2,530

(5) Highly rigid housing

In order to ensure that products are not damaged when transported outside of Japan, we have established the standards for product drop tests and vibration tests using sine waves and random waves in accordance with the U.S. transportation packaging test standard "ASTM*1 D 4169." The housing, which has been enlarged, is made with thicker sheet metal and beams with higher cross-sectional coefficient. Figure 6 shows the housing rigidity analysis and vibration test using an actual vending machine. Figure 6(a) shows the rigid stress analysis of mounting base of the housing. It has installation legs at the four corners of the mounting base, and even if the load is unevenly distributed to one leg, it exhibits no stress concentration that causes deformation. In addition to the structure

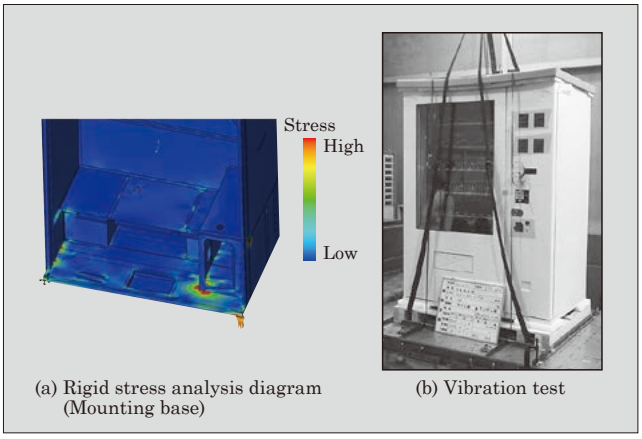

Fig.6 Housing rigidity analysis and vibration test using an actual vending machine

*1: ASTM refers to the international standards for industrial materials and testing methods developed and published by ASTM International of the United States.

of the vending machine, we have examined packaging specifications. A wooden pallet is used for the base of product packaging, and a resin foam cushioning material is incorporated between the pallet and the product body. We selected the cushioning material by calculating the required cushioning capacity based on the product load and assumed impact value and evaluated the vibration in this packaging condition. Figure 6(b) shows an example of the vibration test. During this test, neither the inside or outside was damaged, and we confirmed that the impact absorption of the packaging material was functioning normally.

4. Postscript

In this paper, we described the "FGG160DCY" general-purpose goods vending machine. This development enabled us to create a standard model for products to be exported mainly to Southeast Asia. Its ability to handle large products and certain pharmaceuticals has expanded the range of vending machine applications from general food products to a variety of other goods. However, market needs differ from country to country. For this reason, it includes an electronic payment function, support for communication protocols, signage, and other features.

In the future, we intend to use this product as a platform to meet further market needs by providing flexible customization and a variety of models.

Network Services for Stores

TOKUNAGA, Yuki* MUTO, Kenji‡ ISHIHARA, Yudai*

ABSTRACT

It has recently become an urgent priority for retail industry, including supermarkets and convenience stores, to save energy and solve labor shortages due to the declining birthrate and aging population. To address the challenges, Fuji Electric has developed a network connection system to collect operational information and alarm histories from each store equipment, such as showcases, and to deliver data to the equipment via the cloud. A function that analyzes the operating conditions of equipment and detects signs of abnormality is equipped to allow for preventive maintenance of each piece of equipment. In addition, monitoring trends by store and equipment allows users to reflect them to operation control conditions and maintenance plans, contributing to energy saving and improved efficiency of operational tasks.

1. Introduction

Various industrial sectors are being asked to contribute to achieving the sustainable development goals (SDGs). The retail industry, typified by supermarkets and convenience stores, is currently faced with the urgent task of promoting energy saving to help combat global warming and to solve labor shortages caused by the declining birthrate and aging population in Japan. Fuji Electric has been offering its "Ecomax" Series, a line-up of equipment cooperative control systems that contribute to energy saving in stores, since 2011. In this paper, we will describe the development of a network system for stores with greatly expanded features and performance, as well as information on the availability of services.

2. Circumstances Surrounding Convenience Stores

Convenience stores are creating new sales points by expanding small-volume ready-made meals and frozen foods as well as by expanding the selection of freshly prepared products at sales counters in order to meet new needs, such as the rise in demand for take-out foods and sales without face-to-face interaction due to the impact of COVID-19 restrictions. It is against this backdrop that convenience stores are deploying new types of equipment. At the same time, in order to reduce CO_2 emissions and power consumption, equipment manufacturers are taking initiatives to promote the use of renewable energy sources and achieve energy-saving in store equipment. In addition, labor shortages due to the declining birthrate and aging population in Japan have forced some stores to stop operating 24 hours a day. Even stores that are increasingly employing senior citizens and foreign nationals are looking for ways to save labor in store operations through the use of digital technologies, in order to alleviate the steep learning curve of store equipment.

3. Characteristics of Network Services for Stores

Fuji Electric has been offering convenience stores with a wide variety of equipment, such as refrigeration equipment (showcases and cooling units), counter fixtures (warming and cooking equipment installed next to cash registers) and automatic change dispensers, as well as facility management systems designed to improve energy and maintenance efficiency for equipment. When we first launched our facility management system in 2011, we designed it to save energy and improve maintenance efficiency for individual stores. Today, however, we are faced with the need to solve challenges common to entire convenience store chains, such as reducing CO_2 emissions and saving labor in store operations. In this respect, there is a need to optimize the entire convenience store chain by increasing the number of stores managed by systems.

Next, we will describe the characteristics of our newly developed network services for stores.

3.1 Systems for store controllers

(1) Overview

Figure 1 shows the system configuration for store controllers. Store controllers are connected to showcases, cooling units and watt-hour meters in stores, and also communicate with external servers via the Internet.[1] Conventional systems communicate with the outside world by synchronizing data to the cloud

* Food & Beverage Distribution Business Group, Fuji Electric Co., Ltd.

‡ Corporate R&D Headquarters, Fuji Electric Co., Ltd.

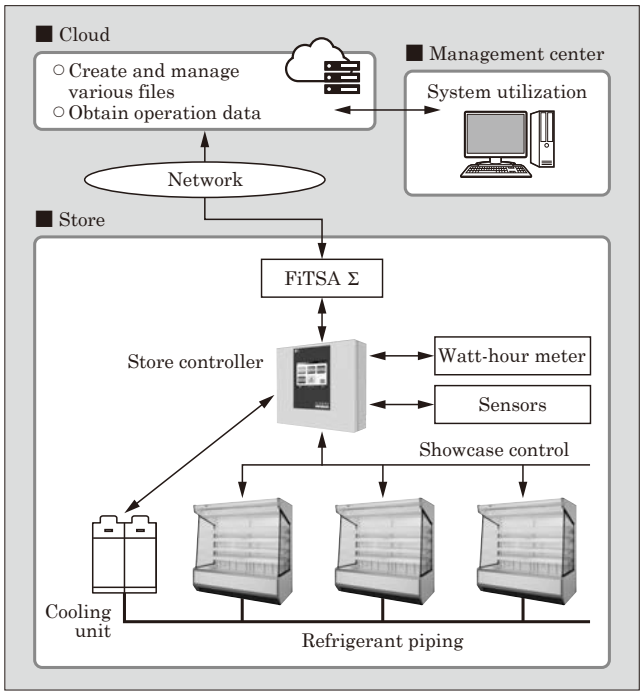

Fig.1 System configuration for store controllers

via virtual private networks (VPNs) and file transfer protocol (FTP) connections. The problem is that introducing this system to thousands or tens of thousands of stores would require an increase in server routers for VPNs and an expansion of server resources due to the increase in data collection time. In contrast, our new system uses message queuing telemetry transport security (MQTTS) as the communication protocol, since it is both large-scale and highly secure. Because MQTTS communication sends data asynchronously, it can send data to servers even in unstable network environments, facilitating expansion to tens of thousands of networks. It also uses Fuji Electric's "FiTSA Σ" IoT/M2M controller instead of a VPN server router to achieve MQTTS communications. The FiTSA Σ is a SIM-integrated product that supports MQTTS communications. The store controller has FTP server and web server functions and can be used to easily transfer and modify various types of files to and from an external cloud.

(2) Operational support for refrigeration equipment

Refrigeration equipment in stores must store products at optimal temperatures at all times and operate continuously 24 hours a day, 365 days a year. Furthermore, because refrigeration equipment consumes a large amount of power, optimizing its operation can significantly contribute to energy saving in stores. Conventional systems have functions to visualize operation data (such as being HACCP compliant), alarm history and power data.

In addition to the functions of conventional systems, our newly developed system also has the ability to analyze the operating status of equipment and detect signs of abnormalities, enabling predictive maintenance of each piece of equipment through the analysis of operating data. It can also track trends by store and by equipment and reflect them in maintenance plans.

These functions can detect failures in advance and shorten repair lead times, and by using power consumption records to compare data not only for each device but also for each store and region, it can distribute setting conditions for operation control that are highly effective in saving energy, thereby achieving energy saving for the whole convenience store chain.

3.2 Counter fixtures

Since a counter fixture is used to prepare and dispense food products in stores, routine maintenance is essential, such as replenishment of ingredients used in sales and periodic cleaning of the fixture.

Figure 2 shows the system configuration of a counter fixture. The newly developed system collects information on the operating status of the counter fixture and alarms. It detects and records the detachment and attachment of parts that need to be cleaned, so that the status of maintenance can always be known. It can inform clerks of areas that need to be cleaned and when to do so, and encourage them to ensure that maintenance is performed.

In addition, a counter fixture is expected to offer products with renewed flavors and aromas in accordance with changes in seasons and tastes in order to attract new customers and retain existing ones. To accomplish this, food preparation methods for the counter fixture need to be adjusted to match the timing of menu changes in the stores. The newly developed system pre-registers the control data of the counter fixture according to the new menu recipes in the cloud. The control data is distributed to the counter fixture via the network, but is not immediately executed. The control data is updated when maintenance work is performed so that new menus can be offered. This ensures that menus can be updated without requiring

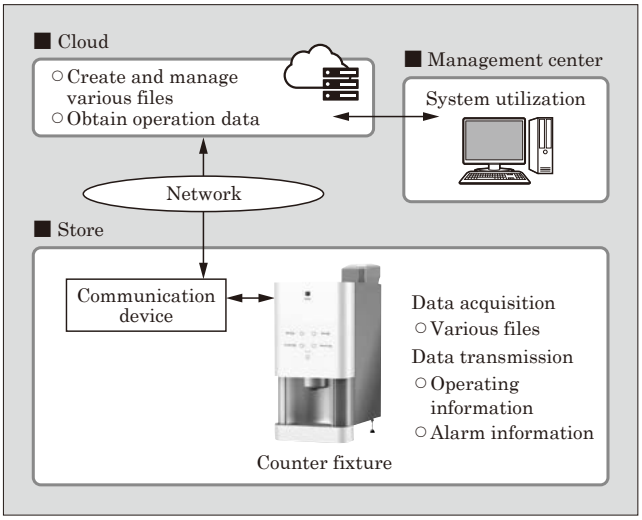

Fig.2 System configuration of counter fixture

cumbersome procedures. This feature also makes it easy to implement sales promotion measures such as area-specific or time-limited product offerings.

3.3 Automatic change dispensers

Automatic change dispensers are devices that interface with point-of-sale (POS) registers to automatically accept and dispense cash at checkouts, and have been increasingly deployed in convenience stores to reduce the labor required for checkout tasks.[2] They are increasingly requiring features that facilitate operations and contribute to labor saving.

Figure 3 shows the system configuration of a change dispenser. The newly developed system records into the interfaced POS system the history of cash transactions, such as the number of deposits and withdrawals of coins and bills into and out of the automatic change dispenser, as well as the history of operations such as deposits, withdrawals and key operations. These records can also be viewed from management centers connected via the network. These functions help reduce the load on stores by allowing management centers to grasp the status of equipment in the store, making it possible for them to perform various tasks, such as restoring equipment in the event of an operational error by an untrained clerk and promptly responding to equipment malfunctions.

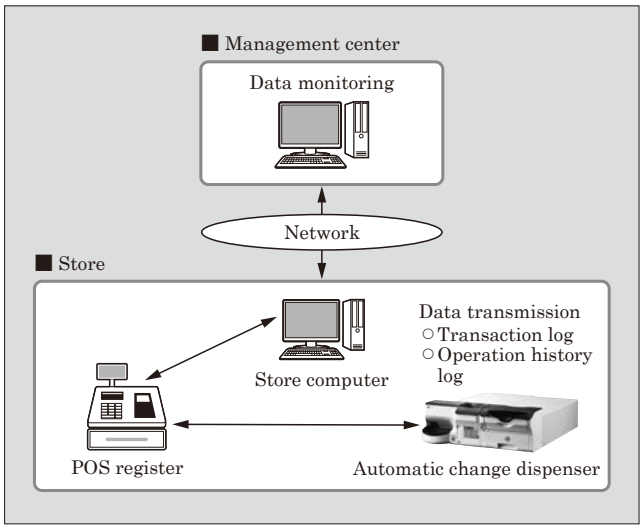

Fig.3 System configuration of a change dispenser

4. Vision for the Future

Currently, energy and labor saving can be achieved by optimizing the operation of refrigeration equipment and air conditioners, since these types of equipment consume large amounts of electricity. In order to further reduce CO_2 emissions, we are planning to develop a new store controller with a built-in energy management system, and envision a system that can expand the use of renewable energy sources for electricity supplied to the stores from the outside. We believe that popularizing such a system in supermarkets and convenience stores throughout Japan will contribute to reducing CO_2 emissions.

5. Postscript

In this paper, we described the latest network services for stores, which contribute to further energy and labor saving in store operations.

In the future, we intend to contribute to the retail industry, typified by supermarkets and convenience stores, by working toward further energy saving and the use of renewable energy sources through connection of in-store and out-of-store systems.

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Energy-Saving Technology for Showcases

KINOSHITA, Suguru*

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.

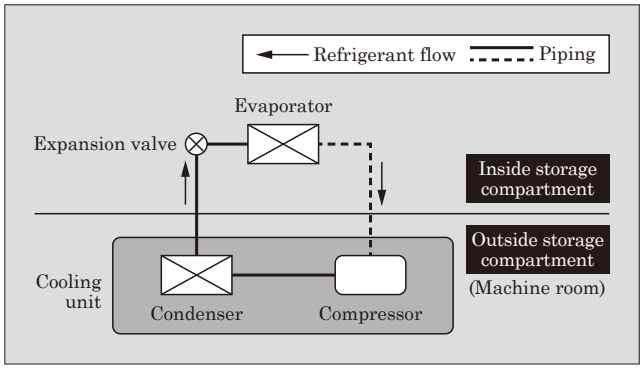

Fig.1 Basic configuration of showcase cooling systems

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

* Food & Beverage Distribution Business Group, Fuji Electric Co., Ltd.

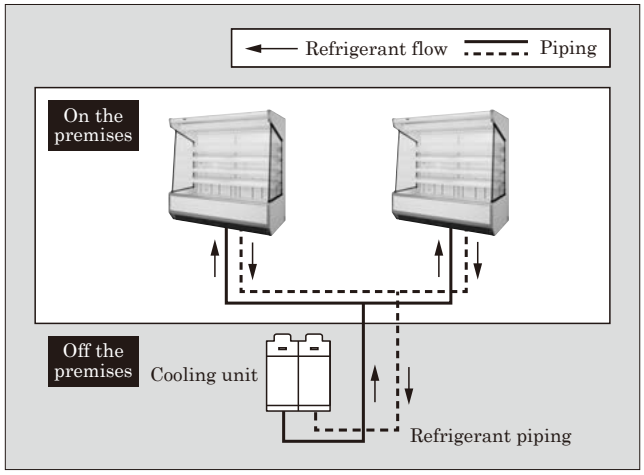

Fig.3 Separately installed showcase

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

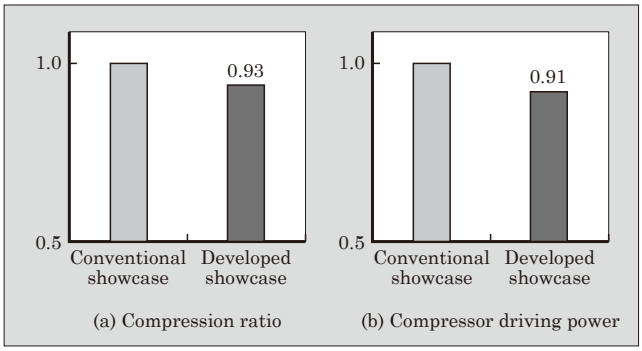

Fig.4 Comparison of compression ratio and compressor driving power

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

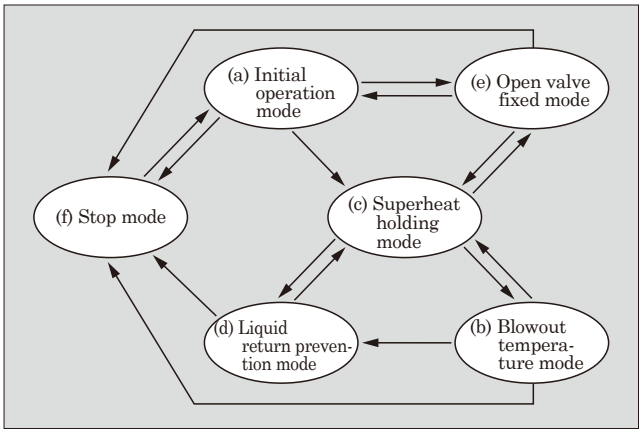

Fig.5 State transition diagram for controlling the expansion valve

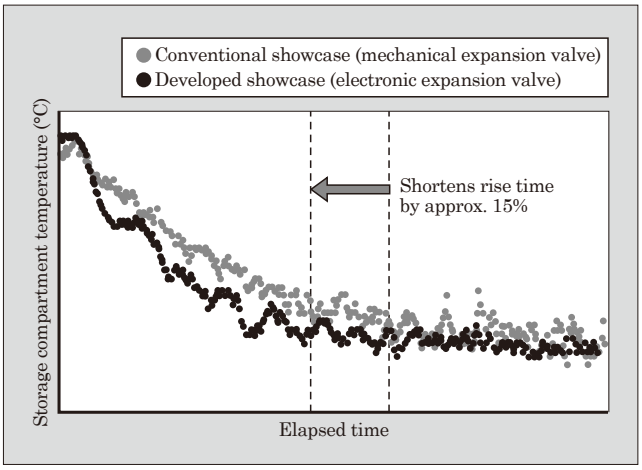

Fig.6 Application example for the initial operation mode

for the inside of the storage compartment to reach the target temperature by approximately 15% compared with the conventional showcase.

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.

Energy-Saving Measures for Stores

MIYAKOSHI, Tomoya* MIZUSAWA, Tatsuya*

ABSTRACT

Retail outlets such as convenience stores have been further required to save energy. Meanwhile, store comfortability is also need. Fuji Electric's store environment analysis using an index called predicted mean vote (PMV) suggested the effectiveness of controlling the temperature setting of air conditioners during the summer. We have also developed an outdoor air intake system to reduce the load on showcases by using cold outdoor air during the winter. The results of using thermal fluid analysis software showed that the system can reduce the power consumption of showcases installed in typical stores by 1.84 kWh.

1. Introduction

In order to respond to the growing social demand to combat global warming, the convenience store industry is working on various energy-saving measures. In this regard, individual stores are being required to further reduce power consumption. Although it is conceivable to reduce air conditioning as an energy-saving measure in stores, it is not easy to implement in practice because of concerns that the resulting loss of comfort in the store may affect the number of customers and sales. Fuji Electric has been contributing to reducing power consumption in stores by pursuing higher efficiency in individual pieces of equipment such as showcases and developing positive pressure control systems that improve air conditioning efficiency. In order to further contribute to energy saving, we have begun to work toward comprehensive energy saving that reduces the power consumption of the entire store, taking into account of even comfort, rather than optimizing individual equipment and systems.

In this paper, we will describe measures to achieve both energy saving and comfort from the viewpoint of the entire store, focusing on operational methods for showcases, positive pressure control systems,(1) air conditioners, ventilation systems, and other equipment.

2. Energy-Saving Issues at Stores

Figure 1 shows the percentage of electricity consumed by typical store equipment. More than 70% of the total is occupied by air conditioning, refrigerated and freezer equipment, and heating and warming equipment, where Fuji Electric can contribute to energy saving. We have been improving the efficiency of showcases, which are refrigerated and freezer equipment with high power consumption, reducing their power consumption to the same level as that of heating and warming equipment. Furthermore, we have developed positive pressure control systems that improve the operating efficiency of air conditioning equipment by maintaining the air pressure inside the store at a pressure slightly higher than the air pressure outside the store. As shown in Fig. 1, the difference in the ratio of power consumption at present is 25% for refrigerated and freezer equipment, 26% for heating and warming equipment, and 20% for air conditioning equipment.

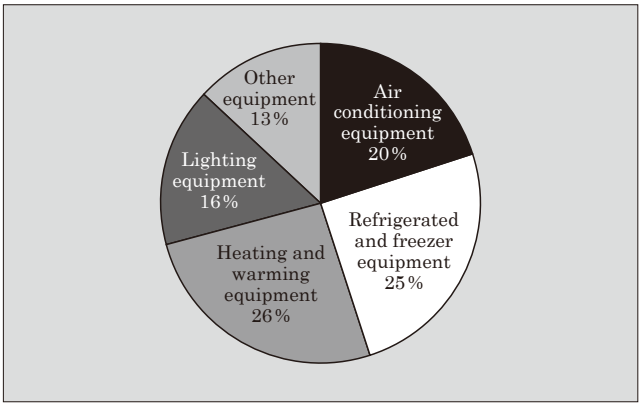

Fig.1 Percentage of power consumption by equipment

Although optimization of individual equipment has been pursued until now as described above, pieces of thermal equipment interact with each other in power consumption. To further save energy, the operating conditions of these equipment and systems thus must be coordinated so that they optimize the entire store.

In order to reduce the power consumption of the entire store, it is necessary to visualize the overall heat balance. We investigated the heat balance of an

* Corporate R&D Headquarters, Fuji Electric Co., Ltd.

Fig.2 Appearance of the simulated experimental store

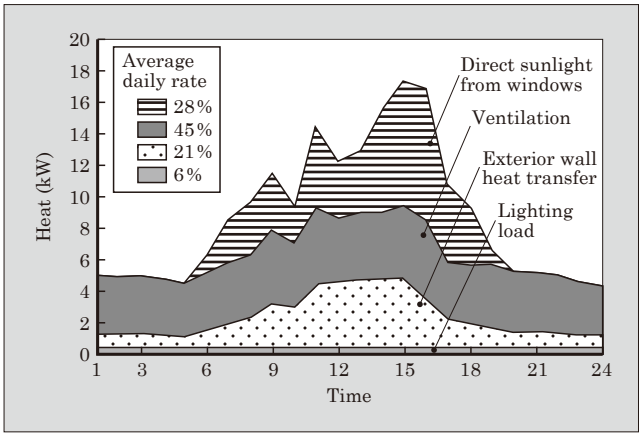

Fig.3 Percentage of heat entering stores

actual store using a simulated experimental store set up on the premises of Fuji Electric's Mie Factory, as shown in Fig. 2. Figure 3 shows a time-series graph of the amount of heat entering the store on a single day in June. We can see that the amount of heat entering the store varies more than threefold between night and day. Furthermore, the amount of heat entering the store varies not only on a daily basis, but also on a seasonal basis. It is necessary to consider energy-saving measures in response to such changes in the external environment.

3. Considerations to Achieve Both Energy Saving and Comfort

3.1 Modeling the entire store

The overall power consumption of the store and the comfort of the inside of the store are greatly affected by the external environment, such as the season and the weather. The simulated store shown in Fig. 2 is located outdoors, its external influences cannot be controlled, making it difficult to systematically demonstrate the effect of the energy-saving measures in the simulated store. Therefore, we decided to model the entire store and utilize simulation. Figure 4 shows the model used for in-store analysis. The model had air conditioning units, showcases, and magazine shelves,

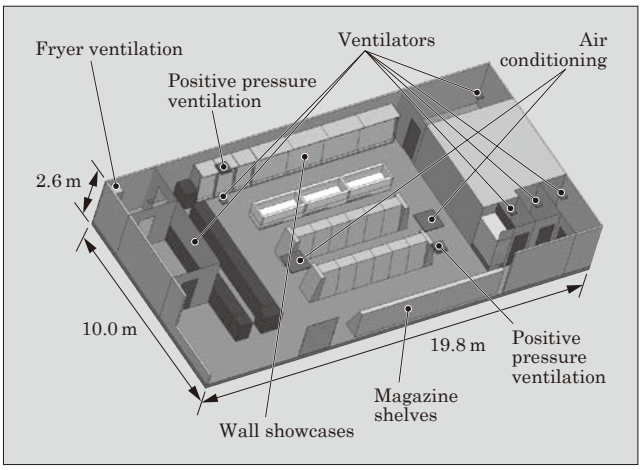

Fig.4 Model used for in-store analysis

which were arranged in the same way as in the simulated store in Fig. 2. The model can be modified in settings, such as air conditioning settings, the amount of ventilation for the positive pressure control system, and even the number of air conditioning units in operation. As for external environmental factors, the outside temperature and solar radiation can be changed and analyzed.

3.2 Comfort evaluation index PMV

In order to study the compatibility of energy saving and comfort, it is necessary to introduce a comfort evaluation index. This study therefore uses an index called the Predicted Mean Vote (PMV). PMV was published based on the comfort equation derived by Fanger[(2)] and became an international standard in 1994. PMV is distinctive in that it uses the thermal sensation, rather than sensible temperature, as the index. It is calculated by adding the four environmental factors that determine the thermal sensation [air temperature (°C), relative humidity (%), wind speed (m/s), and thermal radiation (°C)] to the two human factors [metabolic rate (met) and amount of clothing (clo)]. The PMV rating scale is based on the predicted percentage of dissatisfied (PPD), which indicates the percentage of people who are dissatisfied or uncomfortable with the thermal environment. Table 1 shows PPD and PMV for the thermal sensation. In terms of the PMV index, PMV

Table 1 PPD and PMV for sensation of warmth and coolness

Thermal sensation	Predicted percentage of dissatisfied (PPD) (%)	Predicted mean vote (PMV)
Hot	99	+3
Warm	75	+2
Slightly warm	25	+1
Neutral	5	±0
Slightly cool	25	−1
Cool	75	−2
Cold	99	−3

= 0 is considered neutral, and PMV = ±3 is considered unpleasant by as many as 99% of people.

3.3 Analysis-based correlation evaluation of energy saving and comfort

(1) Analysis conditions

We performed analysis using the model described in Section 3.1 and thermo-fluid analysis software. Factor assignment was performed using the design of experiment method for the analysis conditions to determine the impact of each factor. Table 2 shows the conditions of the analysis parameters. Here, the air conditioning blowout angle is specified as 0° when blowing horizontally with the ceiling, and the number of air conditioners is normally specified as two independently operated air conditioners. Reference values are also listed for control factors. For the human factors of the PMV calculation, the clothing of outdoor visitors was assumed, with 0.6 clo as the amount of clothing representing typical clothing in summer, and 2.0 clo representing clothing in the winter. The metabolic rate was set to 1.4 met, which represents standing posture in both summer and winter. To evaluate energy savings and PMV, we used sensitivity analysis to determine the effect of each factor on total power consumption (energy efficiency), which represents the sum of air conditioning, ventilation, and refrigerated equipment, as well as on PMV (comfort), which represents the average of space in the store. By doing this, we examined how to control energy saving.

Table 2 Conditions of analysis parameters

	Factor	Analysis conditions (criteria)
Control factors	Air conditioning temperature setting (°C)	22, 25, 28 (Reference: 25)
Environmental factors	Air conditioning blowout airflow (m^3/h)	1,200, 1,620, 1,800 (Reference: 1,620)
	Air conditioning blowout angle (°)	20, 40, 60 (Reference: Swing)
	Qty. of air conditioners in operation	1, 2 (Reference: 2)
	Positive pressure ventilation rate (m^3/h)	1,000, 1,400, 1,800 (Reference: Automatic)
	Outdoor air temperature (°C)	Summer: 28, 32, 36 Winter: 0, 5, 10
	Sunlight	Without sunlight; shading; and with sunlight

(2) Analysis results

Figure 5 shows the results of total power consumption and PMV sensitivity analysis under summer conditions, and Fig. 6 shows the results of total power consumption and PMV sensitivity analysis under winter conditions. The left vertical axis and the black plot represent the total power consumption, with smaller values being preferable. The right vertical axis and gray plot is PMV, with values close to zero being pref-

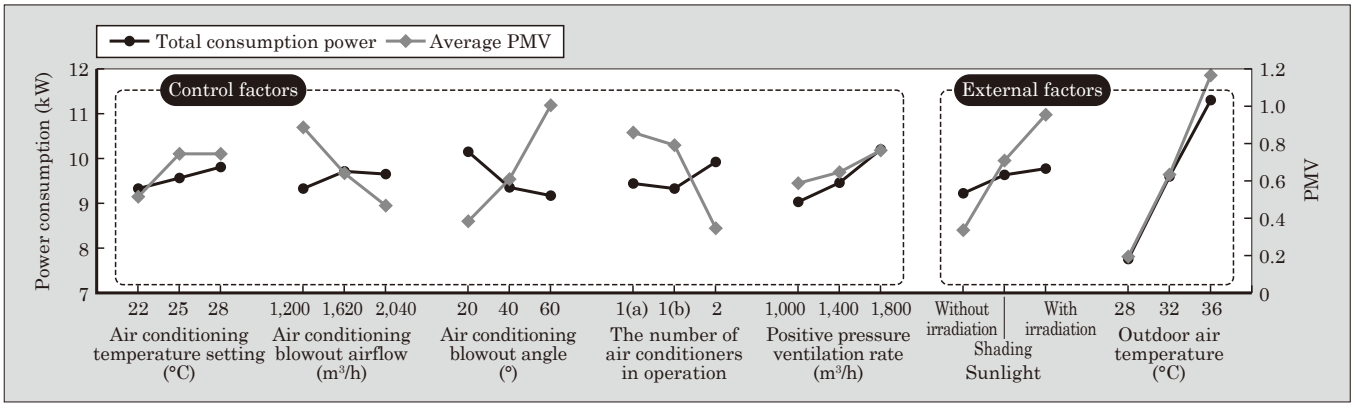

Fig.5 Sensitivity analysis results of summer total power consumption and PMV

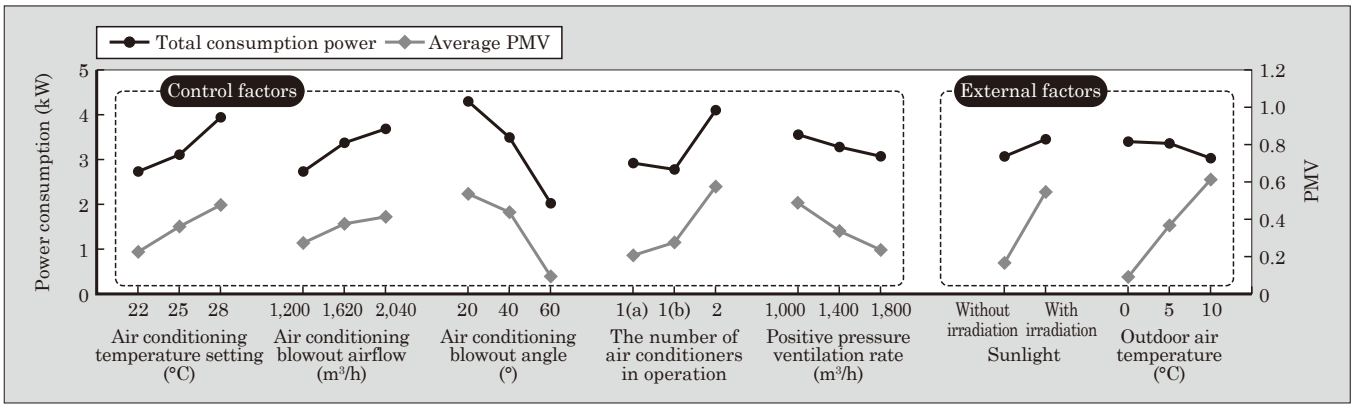

Fig.6 Sensitivity analysis results of winter total power consumption and PMV

erable.

Under summer conditions, by focusing on the air conditioning blowout angle as a control factor, we found that the larger the blowout angle, the smaller the power consumption and larger the PMV, indicating that it is difficult to achieve both energy saving and comfort. Due to the large slope of the PMV, we found that maintaining a small air conditioning blowout angle was effective in improving comfort. We also discovered that trends in power consumption and PMV were the same at the set air conditioning temperature and positive pressure ventilation rate, indicating that both energy saving and comfort can be achieved. Both power consumption and PMV can be reduced by lowering the set air conditioning temperature, in contrast to the generally recognized trend to save energy by raising the set air conditioning temperature. We believe this is because showcases consume more power than air conditioners in stores, and lowering the air conditioning temperature setting improves the power consumption of refrigeratied equipment, resulting in lower overall power consumption.

Under winter conditions, we found that the control factors showed the same trend in power consumption and PMV, indicating that energy saving and comfort are highly compatible. In terms of the positive pressure ventilation rate, the more ventilation is increased, the more energy is saved. We think the reason for this is that, similar to summer, the temperature around the showcases drops due to the outdoor air, reducing the power consumption of refrigerated equipment.

Since this analysis assumes that there will be outdoor visitors, we can expect differences in PMV among store clerks and visitors who use various modes of transportation. We plan to verify this in the future.

3.4 Proposed measures to balance energy saving and comfort in winter

Analysis of summer conditions showed that lowering the temperature around showcases was effective in reducing overall store power consumption. Therefore, as a measure to save energy in winter, we examined the use of an outdoor air intake system as a way to effectively use cold outdoor air through ventilation. Figure 7 shows an overview of the outdoor air intake system. By allowing cold outdoor air to blow downward from above the showcase during the winter months, we expect the air curtains to be less warmed by contact with the air inside the store, resulting in less energy required to cool the air supplied to the air curtains.

The energy saving effect of the outdoor air intake system was calculated using thermo-fluid analysis software. Figure 8 shows the power consumption for a single three-foot-long showcase relative to the airflow rate. We calculated the heat load on the showcase by setting the outdoor air temperature to 5°C and varying the airflow rate of the outdoor air, and then calculated the amount of power consumed for a single showcase. We found that power consumption decreases as the blowout airflow rate of the outdoor air intake increases. Figure 6 shows that a positive pressure ventilation rate of 1,800 m^3/h, which is the maximum airflow rate, can reduce power consumption by 0.23 kWh compared with the rate of 0 m^3/h. Although the configuration of showcases varies depending on the type of store, power consumption can be reduced by 1.84 kWh for a 24-foot-long unit installed in a standard store.

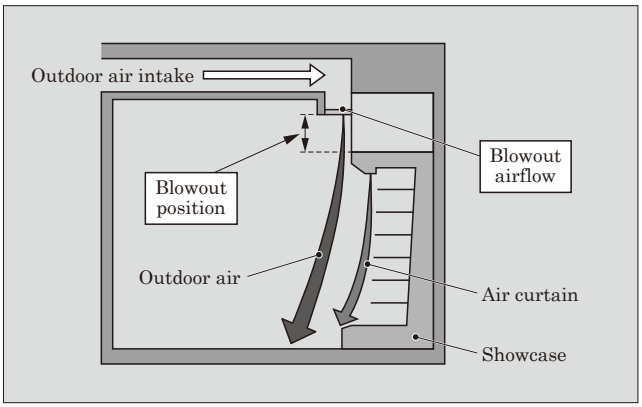

Fig.7 Overview of the outdoor air intake system

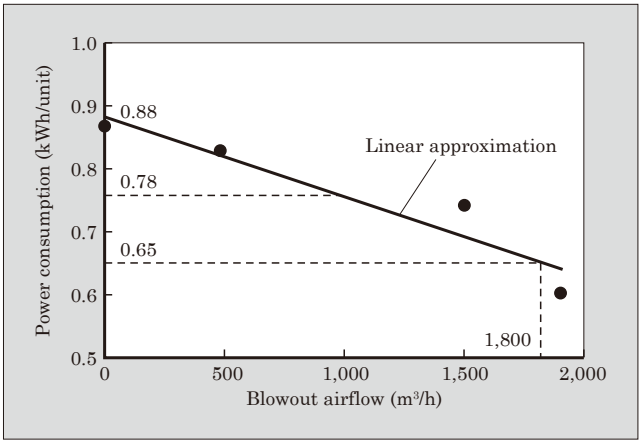

Fig.8 Power consumption for a single three-foot-long showcase relative to the airflow rate

4. Postscript

This paper described energy-saving measures for stores. In addition to clarifying the effect of air conditioning and ventilation on comfort and energy saving, we found that it is possible to achieve both energy saving and comfort by effectively adjusting the air conditioning temperature in the summer and utilizing outdoor air in the winter. In the future, we plan to verify the findings of these analyses through long-term evaluations in a simulated experimental store, and establish energy-saving design guidelines for convenience stores that take comfort into account.

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Frost-Free Technology for Heat Exchangers Using Functional Coating

OGAWA, Riku* MIZUSAWA, Tatsuya* TAKIGUCHI, Koji‡

ABSTRACT

In recent years, as energy saving has become an increasingly important social issue, refrigerated showcases in stores have been required to save energy. In response, Fuji Electric has been developing frost-free technology that uses functional coating to prevent frosting, which is an efficiency lowering factor in the heat exchanger of showcases. The functional coating can promote a state in which water does not freeze even at 0°C or lower (supercooling). We found that a functional coating film promotes supercooling of condensed droplets on small test pieces of aluminum simulating the surface of a heat exchanger.

1. Introduction

In recent years, energy saving has become an even more important social issue to achieve carbon neutrality. In this respect, it is also being required for showcases, or cooling and heating equipment for stores, provided by Fuji Electric. Fuji Electric has so far addressed energy saving of showcases by optimizing the air curtains, which cool the internal storage compartment, and defrosters, which obstruct cooling.(1) Air curtains, in particular, contribute to energy saving. We have optimized the airflow path and airflow volume of them using proprietary computational thermo-fluid simulation technology. On the other hand, defrosting consumes extra energy due to the heating and air blowing required to remove frost from the heat exchanger. In this paper, we will introduce a frost-free technology for heat exchangers using functional coating.

2. Heat Exchanger Issues

Figure 1 shows the basic structure of a showcase. The showcase is connected to a compressor unit, and the refrigerant is circulated by the compressor in the compressor unit. The refrigerant evaporates in the heat exchanger in the showcase, and the heat of vaporization cools the air flowing through the showcase and the interior of the showcase. Since the surface of the heat exchanger is cold, moisture in the air condenses on the surface of the heat exchanger when the moist air comes in contact with it. When the temperature of the heat exchanger surface falls below 0°C, the condensed water droplets freeze and form frost. Open showcases, as shown in Fig. 1, have no door, so the air inside the store, which is hot and humid, intrudes into the air curtain, inevitably resulting in frost on the surface of the heat exchanger. The growth of frost can block the airflow path of the heat exchanger, significantly impairing heat exchange performance. To deal with this issue, heaters and warm store air have been conventionally used to periodically heat the heat exchangers to melt the frost and drain it. Since latent heat of solidification and removal of frosted ice unnecessarily consume extra energy, if frosting of the heat exchanger can be prevented, these energies will no longer be needed, resulting in more energy savings than before.

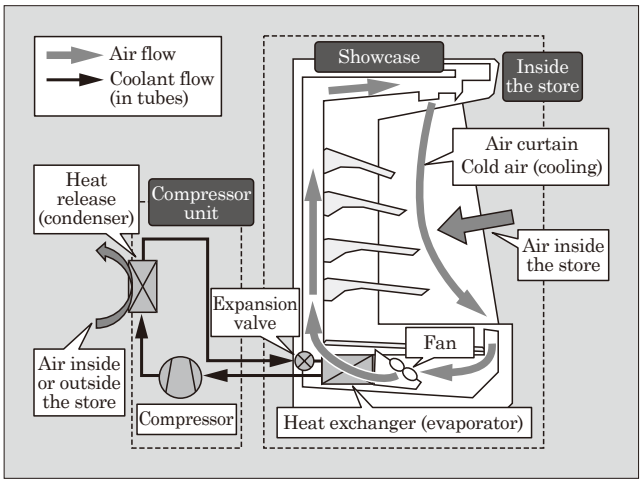


Fig.1 Basic structure of a showcase

2.1 Frosting mechanism in heat exchangers

Frosting on the surface of the heat exchanger starts with the freezing of condensation water drop-

* Corporate R&D Headquarters, Fuji Electric Co., Ltd.
‡ Food & Beverage Distribution Business Group, Fuji Electric Co., Ltd.

lets. In general, there are two possible mechanisms for freezing. One is called homogeneous nucleation, in which a freezing nucleus (ice nucleus) forms and freezes throughout the water without any clear freezing factors such as dust or dirt in the water. When this homogeneous nucleation alone dominates frosting, water is known not to freeze down to around −40°C. This state in which water does not freeze below 0°C is called a supercooling state. The other mechanism is called heterogeneous nucleation, in which dust and other foreign particles in the water form ice nuclei that cause the water to freeze throughout its entirety. Much of the freezing seen in natural phenomena is the latter heterogeneous nucleation.

Figure 2 shows the basic structure of a heat exchanger consisting of fins and tubes, and Fig. 3 shows the freezing mechanism of condensation water droplets in the heat exchanger. Air blown by the fan flows over the surface of the heat exchanger and is cooled. During the cooling, foreign particles contained in the air adheres to the surface of the heat exchanger and condensation water droplets, resulting in freezing due to heterogeneous nucleation. The amount of the adhered foreign particles is affected by the concentration of foreign particles in the air and the amount of air passing through the heat exchanger. Therefore, prevention of foreign particles adhesion is effective in preventing condensation water droplets from freezing. However, adhesion of foreign particles is practically unavoidable, and on the premise of this condition, we have to suppress ice nucleation of foreign particles to prevent frost formation.

3. Newly Developed Frost-Free Technology

3.1 Overview of substances that promote supercooling

Several substances reportedly maintain the supercooling state even when foreign particles adheres to them (supercooling promoting substances).[2] Most of them are supercooling promoting substances to be previously dissolved in water as additives. However, it is difficult to selectively and continuously add supercooling promoting substances to condensation water droplets naturally generated in a heat exchanger. On the other hand, Nagatomo et al. selected an amino acid compound called a tyrosine trimer as a supercooling promoting substance and combined it with a resin to make a coating material. They demonstrated that the application of this coating material to glass substrates promoted supercooling of water droplets on the surface of the coating film. However, this demonstration was conducted using glass substrates and a silver iodide additive (silver iodide is one of the typical ice nuclei materials) under conditions different from those in which heat exchangers are used.

3.2 Application to heat exchangers

To achieve frost-free heat exchangers, it is necessary to form a coating of the supercooling promoting substance on the metal heat exchanger surface. Figure 4 shows the molecular structure for the raw material of the functional coating to be applied to metal sur-

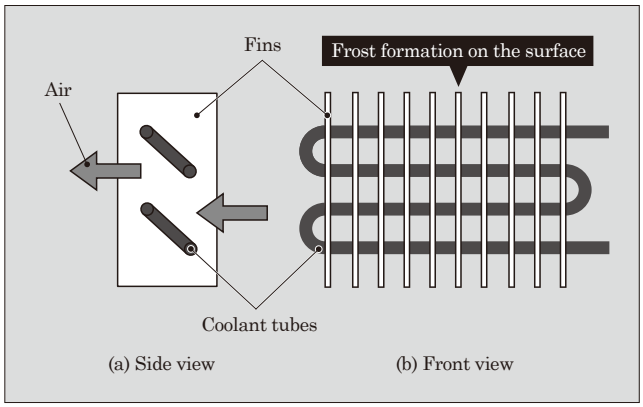


Fig.2 Basic structure of heat exchanger (fins and tubes)

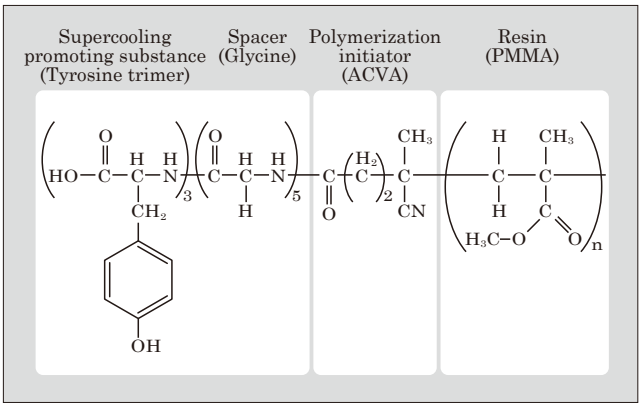


Fig.4 Molecular structure of raw material for functional coating

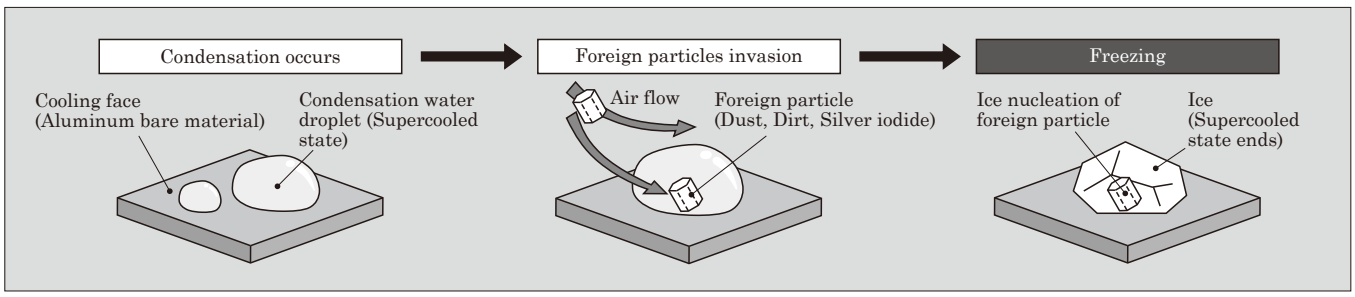


Fig.3 Freezing mechanism of condensation water droplets on heat exchangers

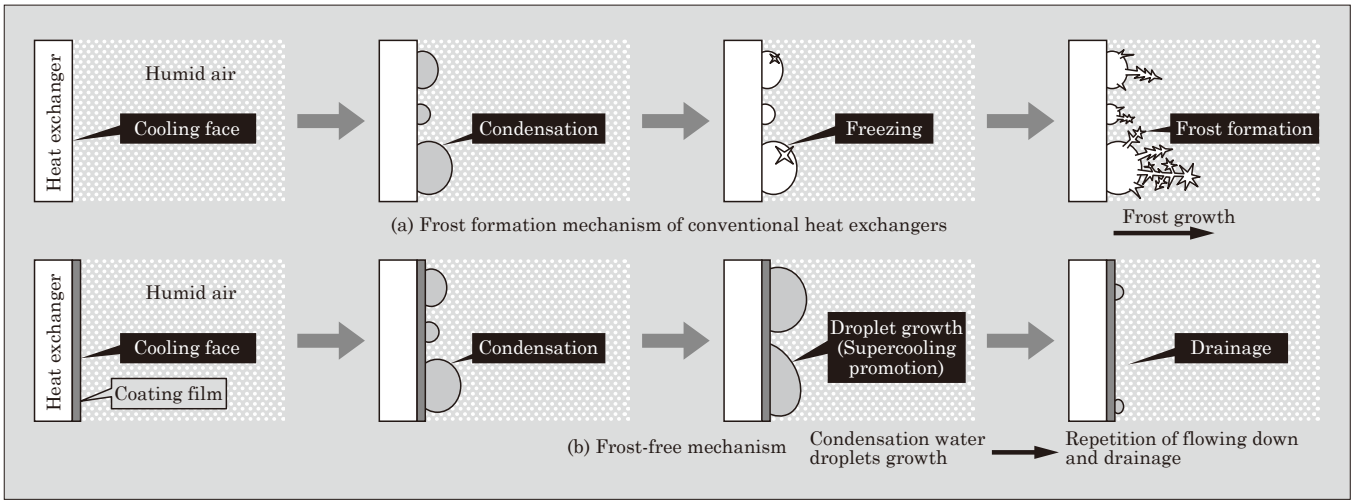


Fig.5 Mechanism of frost-free technology

face. The raw material, made by combining a resin to be physically adsorbs on the metal surface with a supercooling promoting substance, was dissolved in a solvent to form a coating. We have confirmed that this functional coating can be applied to aluminum, which is the surface material of the heat exchanger.

Figure 5 shows the frost-free mechanism using the functional coating. Condensation forms on conventional heat exchangers at low temperatures, and foreign particles in it turns into ice nuclei, causing freezing. On the other hand, the condensation water droplets on a heat exchanger coated with the functional coating remain supercooled even at temperatures below 0°C, thanks to the action of the supercooling promoting substance in the coating. Condensation water droplets in a supercooled state grow and increase in mass over time, and flows down and drains when gravity exceeds its adhesion to the condensation surface. The repetition of condensation and drainage enables continuous cooling and frost-free operation.

3.3 Verification of effects

(1) Evaluation of the supercooling promotion effect

We reproduced the actual conditions of the heat exchanger to evaluate the supercooling promoting effect of the functional coating on the condensation water droplets. We prepared the evaluation sample by applying the functional coating to small pieces of aluminum (D20 mm × W20 mm × t2 mm) that simulated the fins of a heat exchanger. In order to reproduce the naturally occurring condensation water droplets on the surface of the heat exchanger, we used an evaluation stage to simulate the air flow on the heat exchanger with the air maintained at a constant temperature and humidity by a bubbler unit, as shown in the system configuration diagram of the condensation water droplets evaluation in Fig. 6. When cooling the sample, we set the conditions for the cooling surface temperature based on the micro-liquid freezing method to measure the temperature at which the condensation water

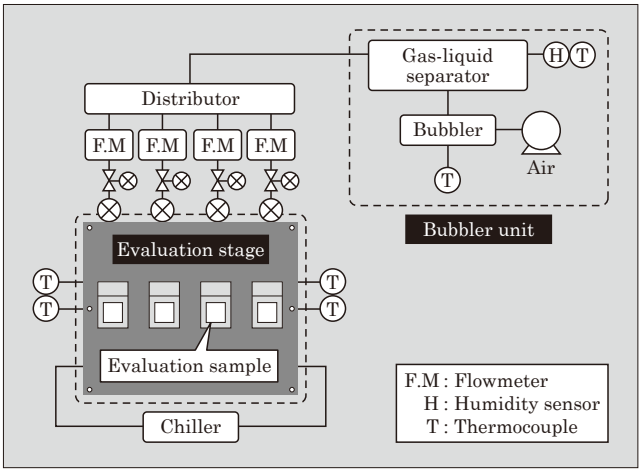


Fig.6 Condensation water droplets evaluation device diagram

droplets freeze. The air temperature and humidity were set to 20°C and 65% respectively based on the actual conditions of the heat exchanger. The evaluation index "anti-ice nuclear activity value" is defined as the freezing temperature of the bare material without coating minus the freezing temperature of the coating sample. We determined the freezing of condensation water droplets when any part of the water droplets on the whole surface was frozen.

Table 1 shows the evaluation conditions under which a heat exchanger was reproduced (condensation water droplets evaluation conditions). As a result of evaluation under the conditions of Table 1, the anti-ice nuclear activity value was 4.2 K. Table 2 shows the results of the principle evaluation (silver iodide additive evaluation) conducted by Okamoto, et al. using drops of easily-freezing water (silver iodide additive), based on previous literature as a reference. As a result of evaluation under the conditions of Table 2, the anti-ice nuclear activity value was 2.3 K. These results showed that the anti-ice nuclear activity value in the condensation water droplets evaluation was on the positive side, similar to the evaluation of the silver iodide addi-

Table 1 Condensation water droplets evaluation for reproducing a heat exchanger

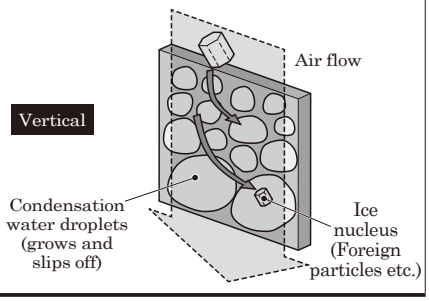
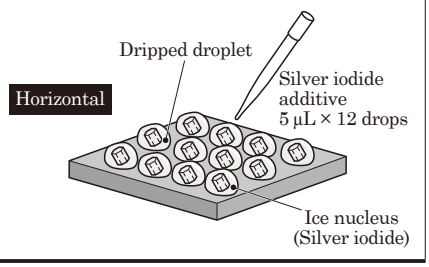
Item	Evaluation conditions
Cooling surface temperature (°C)	−26 to +4
Cooling rate (°C/min)	0.2
Air temperature (°C)	20
Air humidity (% RH)	65
Air velocity	Natural convection
Sample posture	

Table 2 Evaluation of silver iodide additive

Item	Evaluation conditions
Cooling surface temperature (°C)	−18 to 0
Cooling rate (°C/min)	1.0
Air temperature (°C)	25
Air humidity (% RH)	– (Desiccant installation)
Air velocity	Natural convection
Sample posture	

tive, enabling us to confirm the supercooling promotion effect. Based on the results in Table 1, it appears that the film of the functional coating can promote supercooling even with a water quality and cooling method similar to that of the actual operation of a heat exchanger.

In addition, Fig. 7 shows how the condensation water droplets in the supercooled state drain over time. Based on the evaluation conditions in Table 1, in order to observe the time elapse of the cooling process, the cooling temperature needs to be kept constant at a representative temperature of 0°C or lower, and the air velocity needs to be kept constant by forced convection that simulates a real environment. The photographs in the figure show how condensation water droplets grow and drain over time.

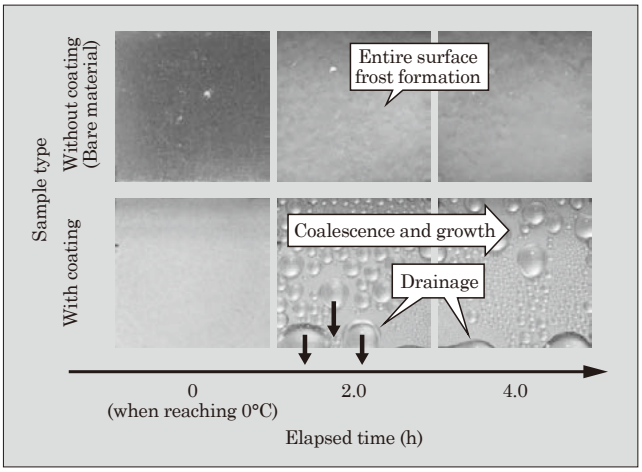


Fig.7 How the condensation water droplets in the supercooled state drain

Based on these results, we demonstrated that the designed functional coating film can promote supercooling of condensation water droplets in the heat exchanger and make it frost-free.

(2) Estimation of energy-saving effects

Frost formation occurs when condensation water droplets freeze, thus involving a phase change. This results in condensation latent heat being consumed during condensation and solidification latent heat being consumed during freezing. These two latent heats are waste energies when a heat exchanger cools air. Heat exchangers that apply frost-free technology can save energy because they no longer require solidification latent heat. Unlike conventional defrosting methods using heater, frost-free technology requires no heater power. In light of the above, we estimated the energy-saving effects of applying the frost-free technology to heat exchangers.

By using our in-house standards as conditions, we estimated the energy consumption of a conventional heater defrosting system and that of the frost-free technology. The calculation suggested that the energy-saving effect of the frost-free technology over the heater defrosting system was 7% per year for a three-foot refrigerated multi-deck showcase.

In addition, since the functional coating of this frost-free technology can be applied to conventional heat exchangers, energy-saving effects can be obtained without changing the size of the heat exchanger or the volume of the internal storage compartment.

4. Postscript

In this paper, we described a frost-free technology for heat exchangers using functional coating. This functional coating is a technology that can be applied not only to showcases but also to many other types of refrigeration equipment that use heat exchangers for cooling. Since the evaluation was conducted using small pieces of aluminum, we plan to confirm the

supercooling promotion effect on the actual scale of a heat exchanger in the future. A challenge in commercialization is to reduce the production cost of the supercooling promoting substance, which is the raw material used in the coating film. In the future, we will work to overcome these challenges and develop a fully-established frost-free technology that contributes to the realization of a carbon-neutral society.

Finally, it should be noted that the supercooling promoting substance used in this development was the result of joint research with Professor Yoshiaki Hirano of Kansai University. We are grateful for his valuable contributions.

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Fundamental Development and Application of the Next Generation Edge Devices

PERERA, Madhura* TAKEUCHI, Shiro* HAMADA, Kosuke*

ABSTRACT

There is a growing need for IoT systems to minimize the use of cloud systems and enable data collection and analysis to be completed in the field. Fuji Electric is developing a platform for "edge devices" that collects data from on-site equipment and relays them to cloud systems. This next-generation device has hardware that delivers enhanced processing power and diverse connectivity in wired and wireless networks, allowing it to be used for a broad range of products. It also includes highly scalable business application frameworks and other convenient software.

1. Introduction

Conventional Internet of Things (IoT) systems were built around cloud systems, but recently, there has been a growing need to minimize the use of cloud systems and complete the process from data collection to analysis on site at factories and other locations where IoT systems are applied. With that comes changing requirements for edge devices that collect data from on-site equipment and relay them to cloud systems.

Fuji Electric is developing an edge device platform aimed at meeting these new requirements. This paper describes the development of this next-generation edge device platform and its application to Fuji Electric's products for the food and beverage distribution field.

2. IoT System Technology Trends

2.1 Expectations for edge computing

Conventional IoT systems are based on a configuration in which various types of information is collected from equipment on site at factories and other locations and stored in a cloud system on the Internet via edge devices. The collected data are analyzed using applications that use artificial intelligence (AI) or other technology on the cloud system.

For some customers, this conventional configuration gave rise to the following concerns, which posed a barrier to the adoption of IoT systems.

(a) Increased communication costs between edge devices and cloud systems
(b) Increased processing time from data collection to completion of data analysis on cloud systems due to communication-related overhead (making real-time analysis difficult)
(c) Concerns about data leaks and other security risks arising from sending data to cloud systems

To address these concerns, the focus is now on "on-site completion" IoT systems that do not involve sending data to cloud systems. For example, these systems feature a configuration in which a server PC is installed in a customer factory in place of a cloud system to collect and analyze data on site. This type of data processing using server PCs installed in the field is called edge computing.

These new IoT systems that use edge computing are expected to utilize edge devices as its computing platform. In particular, edge devices, which are installed in environments close to the on-site equipment, may be capable of realizing real-time data collection and analysis. Because edge devices are so-called embedded devices, they cannot completely replace cloud systems or server PCs, but by sharing the appropriate functions and performance, they may enable a reduction of overall system costs by minimizing the required performance of server PCs or by reducing the number of PCs required.

2.2 Computing technologies for edge devices

Computing technologies available for edge devices have evolved significantly in recent years. This owes largely to the widespread use of smartphones, and the increasing density, multifunctionality and energy saving of computing devices are remarkable. Systems on chips (SoCs) on which the elements necessary for computing (such as the CPU, the GPU, security and multimedia) are integrated have been improving in functionality and performance and have been getting smaller. In addition, systems on modules (SoMs) on which these SoCs are integrated together with memory and wired communications

* Corporate R&D Headquarters, Fuji Electric Co., Ltd.

(such as USB*1and Ethernet*2), wireless communications (such as Wi-Fi*3, Bluetooth*4 and cellular*5) and other components into a single module have also evolved significantly, and their application is becoming more widespread. For these SoMs, international standards have been established for interfaces for these modules, and competition among module vendors has led to lower prices, making them easier to adopt for various embedded devices.

On the other hand, the adoption of SoCs and SoMs has its disadvantages. Because they are multifunctional, the number of man-hours required to develop their firmware (software for controlling hardware) can be enormous. However, it has become common for SoC and SoM vendors themselves to provide firmware samples, which users can leverage to speed up product development. In addition, most of these firmware applications are made into license-free open-source software (OSS) applications, which allows users to easily modify the firmware according to their product designs, and in terms of software development, they have come to be adopted for SoC and SoM embedded devices.

3. Recent Challenges in Retail Businesses

Fuji Electric provides supermarket and convenience store business owners operating brick-and-mortar stores with showcases, counter fixtures and store systems to be installed in their stores. We also provide beverage manufacturers, operators and other clients with vending machines that can sell beverages and various other goods unattended and around the clock. The business environment surrounding these retail businesses has changed significantly in recent years, and new challenges have emerged.

3.1 Strengthening efforts to address social issues

Traditionally, the main challenge in store operations has been to eliminate labor shortages by improving operation efficiency, which in turn increases profits.

Recently, the Sustainable Development Goals (SDGs) have become widely recognized. Moreover, corporate social responsibility (CSR) has become a major pillar of corporate evaluation, and both general consumers and investors are placing importance on corporate CSR initiatives. Consistent with this trend, convenience stores are also working to reduce greenhouse gas emissions and food loss. To realize this initiative, further energy saving in store operations is essential. The systems we have developed in the past, which are self-contained within in a single store fixture or the store, are insufficient. For example, there is a need for lighting and air conditioning that is linked between the inside and outside of the store, optimal control of each fixture and synchronization with demand response, as well as energy management for all of these features.

3.2 Responding to changes in markets and consumption preferences

The main challenges in the vending machine operation business have traditionally been increasing sales per unit and reducing costs. To address these challenges, Fuji Electric has been developing sales promotion functions for stand-alone vending machines by using digital signage and functions for operation efficiency improvement using IoT technology.

While the existing beverage vending machine market was greatly affected by changes in consumer behavior caused by the current COVID-19 pandemic, renewed attention has been paid to the characteristics of vending machines, which allow customers to purchase items 24 hours a day without face-to-face contact, leading to a new need for multipurpose vending machines. It is more important than ever before to quickly materialize new services that take into account these market changes. In order to achieve this, a system that can efficiently conduct a proof of concept (PoC) is required.

4. Features of Next-Generation Edge Devices

As a means of achieving the challenges described in Chapter 3, the introduction of a new IoT system that utilizes edge computing is thought to be effective. We believe that edge devices can be installed in store equipment or vending machines to autonomously collect and analyze the necessary information, perform coordinated control of equipment units in the store, and display the digital signage of the vending machines while adjusting the content as necessary according to certain conditions. These edge devices should have the following features.

(a) Advanced connectivity including wired and wireless connections with easy access to a variety of surrounding facilities and content on the Internet
(b) High processing capacity that enables image data to be captured from cameras to analyze them in real time using AI
(c) Provision of a versatile application development environment that enables quick changes and additions of functions as needed, as well as easy replacement of applications

To provide these features, we redefined the hardware and software requirements to develop a platform

*1 USB is a trademark or registered trademark of USB Implementers Forum
*2 Ethernet is a trademark or registered trademark of FUJIFILM Business Innovation Corp.
*3 Wi-Fi is a trademark or registered trademark of the Wi-Fi Alliance
*4 Bluetooth is a trademark or registered trademark of Bluetooth SIG, Inc.
*5 Refers to cellular communication systems

for next-generation edge devices. The following sections present the details.

4.1 Hardware platform

Next-generation edge devices require flexible hardware that can fulfill various customer needs. Therefore, we considered the functions required for new services to fulfill customer needs and defined the specifications for next-generation edge devices, assuming future technological trends.

Figure 1 shows the appearance of the edge device (prototype), and Table 1, its main specifications.

The following describes the hardware features of the next-generation edge device.

(1) Diverse connectivity

The device is equipped with wired and wireless network communication capabilities for connection to the cloud and enables the construction of IoT systems according to needs. It also has a variety of external communication interfaces and inputs and outputs for video and audio signals to connect to various devices. Regarding wireless communication functions, for which technology is rapidly evolving, the device has been modularized, making future upgrades easy. It has also been configured to allow installation of built-in antennas for Wi-Fi and cellular communications. External antennas can also be mounted depending on the installation environment.

(2) High processing capacity

A high-performance SoC and high-speed, large-capacity memory are installed as standard equipment in order to significantly improve processing capacity as compared with conventional products. In addition, the device uses a hardware architecture that allows SoC upgrades and memory expansion to meet product requirements. For example, AI functions can be achieved by swapping processors for those with AI accelerators. The embedded multimedia card (eMMC) is expandable up to 64 GB and the Low-Power Double Data Rate 4 (LPDDR4) is expandable up to 8 GB for high-capacity applications.

(3) Usability in a variety of applications and environments

The device has been designed to be compact in size, making it easier to mount on a variety of equipment. It also uses industrial-grade parts to enhance its environmental endurance.

- Size: W153 × D30 × H100 (mm)
- Temperature (installation environment): –20°C to +70°C

Fig.1 Edge device (prototype)

Table 1 Main specifications of edge device (base model)

Component		Specification
Processor		Cortex*1-A53 Quad Core + Cortex-M7
Memory		eMMC 32 GB
		LPDDR4 1 GB
Storage		SD card
Clock		RTC
Interface	Ethernet*2	Gigabit Ethernet (GbE)
	Wireless communication	Bluetooth*3 5.0
		Wi-Fi*4 4
		cellular*5 4 G CAT-4
	USB	USB*6 3.0 Host
		USB 2.0 Function
	Serial	RS-232C, RS-485, I2C, SPI
	Video	LVDS, HDMI
	Multimedia	MIC, speaker
	I/O	LED, SW, DIO

*1 Cortex is a trademark or registered trademark of Arm Ltd.
*2 Ethernet is a trademark of FUJIFILM Business Innovation Corp.
*3 Bluetooth is a trademark or registered trademark of Bluetooth SIG, Inc.
*4 Wi-Fi is a trademark or registered trademark of the Wi-Fi Alliance
*5 Cellular refers to a cellular communication system
*6 USB is a trademark or registered trademark of USB Implementers Forum

4.2 Software platform

While cloud computing IoT systems are based on providing standardized services regardless of where they are applied, edge computing IoT systems have the advantage of services that are easily built and optimized for the specific challenges of each site where they are applied. To achieve this, a variety of software applications (business applications) must be built for services that meet the needs of each site, and improving the efficiency of their development is a challenge. The edge device to be developed takes the form of an embedded device, but unlike software development for PCs and the cloud, software development for embedded devices requires expertise such as knowledge of hardware and the know-how to utilize it, making it difficult. In addition, replacement of software is often difficult in that a dedicated tool is required to install the created software in embedded devices, for example.

Figure 2 shows the overall configuration of a software platform to be installed on the next-generation edge device platform intended for facilitating software development. The platform comes standard with firmware that covers the basic functions of edge devices, and on top of it is installed a business application framework for facilitating the development of software, or business applications, to address individual issues. Table 2 shows the components of the software plat-

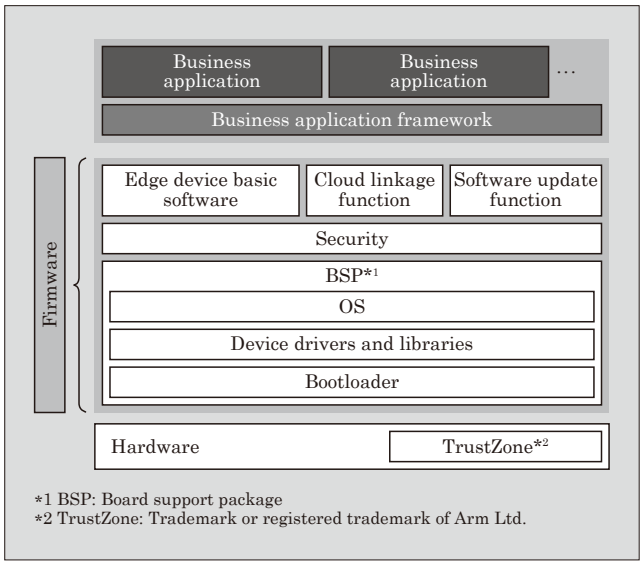

Fig.2 Overall configuration of the software platform

Table 2 Components of the software platform

Component	Overview
Board support package (BSP)	Built-in software suite for running hardware: ○ Bootloader Software that runs immediately after power-up Supports secure startup to prevent malware from running ○ Device drivers and libraries A collection of drivers and libraries to utilize each device on the hardware (platform) ○ OS Linux*1 5.15 installed
Security	Secure software execution environment using TrustZone*2 available on Arm microcomputers
Edge device basic software	Software that integrates basic features of edge devices ○ Data collection function ○ System monitoring function ○ Network management function ○ Clock function, log function ○ System maintenance function and other functions
Cloud linkage	Function for communication and data linkage with edge devices and cloud systems (various clouds provided by various IT vendors)
Software updates	Offline or online software update capabilities
Business application framework	Framework to manage and run business applications

*1 Linux is a trademark or registered trademark of Linus Torvalds in Japan and other countries
*2 TrustZone is a trademark or registered trademark of Arm Ltd.

form. Its features are as follows:

(1) Linux*6 OS installed

As the operating system (OS) of the platform, we have adopted the Linux OS, which is OSS widely used around the world. This makes it easier for software developers to build a development environment and take advantage of their software development know-how for PCs and the cloud, which is expected to improve the efficiency of business application development in particular.

(2) Full support BSP installed

To make all hardware functions included in the hardware platform readily available to software developers, components including device drivers for initializing and using the hardware applications have been put together into one package, and a board support package (BSP) that meets Fuji Electric's quality standards is installed as firmware.

(3) Business application framework that uses container technology

In order to improve the development efficiency of business applications and facilitate their installation, we have adopted a technology called a container to virtually build an operating environment of applications. Figure 3 shows the structure of the business application framework, and Table 3, its components.

Using a typical PC as an example, container technology can be explained as a technology that creates a virtual PC inside the PC and runs applications on the virtual PC, managing the individual virtual PCs in units called containers. This software platform adopts Docker*7 Engine, which is standard for the cloud, as container management software for creating and man-

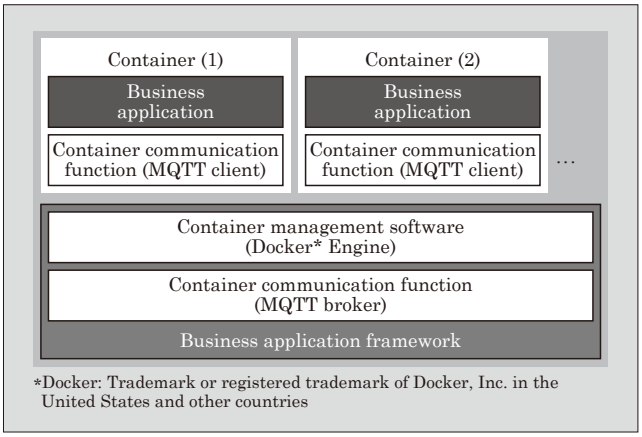

Fig.3 Configuration of business application framework

Table 3 Components of business application framework

Component	Overview
Container	Virtual edge device that runs business applications
Business application	Application that exclusively occupies an edge device and runs alone
Container management software	Management software for managing and running containers (e.g. Docker* Engine)
MQTT brokers and clients	Communication functions and protocols for data communication between business applications and functions outside the container

* Docker is a trademark or registered trademark of Docker, Inc. in the United States and other countries

*6 Linux is a trademark or registered trademark of Linus Torvalds in Japan and other countries

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aging containers. This business application framework allows developers to create business applications without the need for detailed hardware knowledge or consideration for firmware or other business applications. Applications can also be easily updated using the Docker Engine feature.

(4) High security

A mechanism has been built to prevent unauthorized software from running by performing security authentication on the bootloader (the first software application started after power-up), the OS and other software applications at startup.

4.3 Examples of application to products for the food distribution sector

(1) Vending machine

We are currently conducting research for next-generation vending machines that apply next-generation edge devices. Figure 4 shows the system configurations of vending machines. We believe that we can create new value by completely renewing the system configuration of conventional vending machines that has been in use for more than 20 years. For example, by using wireless communication functions of next-generation edge devices to connect machines to smartphones owned by operators in charge of tasks such as replenishing vending machines, remote control functions used to input various settings for vending machines can be implemented on smartphones. These remote controllers are much easier to use than the remote controllers for operation included with conventional vending machines. Many other new features can be achieved using next-generation edge devices.

(2) Stores

In order to save further energy in stores in the future, it is necessary not only to link together various facilities and equipment inside stores, but also to link together various systems outside stores to enable energy saving measures that could not be implemented previously. The requirements for the next-generation store controllers, which form the core of this system, include the ability to perform advanced information processing at high speeds, through means such as wired and wireless communication functions for network communications, with external systems, and communication functions for connecting to various facilities and equipment in the store. We believe that the application of next-generation edge devices will satisfy these requirements, which could not be achieved with conventional store controllers.

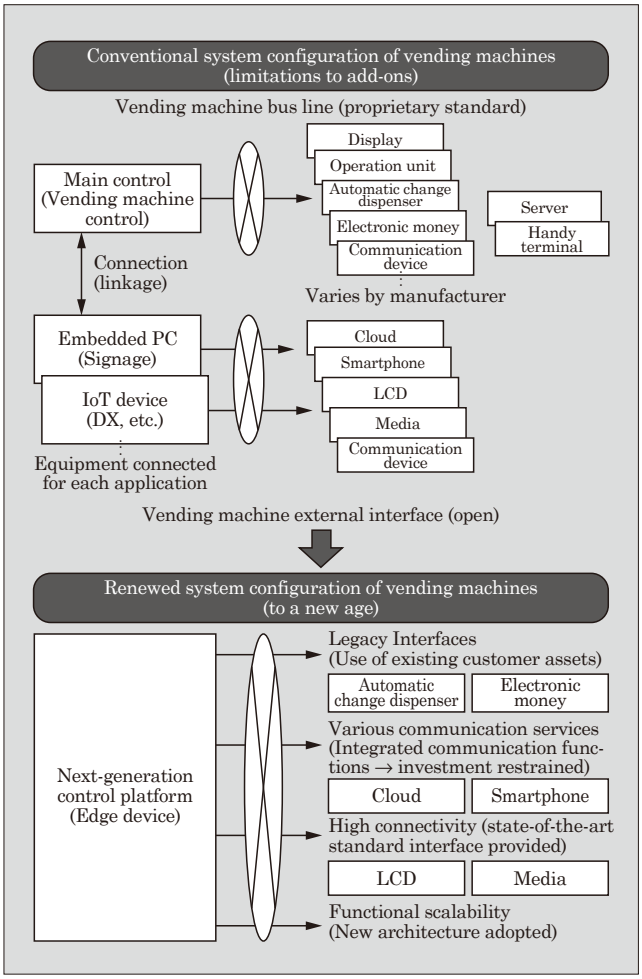


Fig.4 System configurations of vending machines

5. Postscript

This paper has described the development of a next-generation edge device platform and its applications.

In addition to products for vending machines and stores, we are studying its applications for a variety of products, including factory automation applications, and will continue to respond swiftly to the increasingly diverse needs of our customers.

7th-Generation "X Series" 1,700-V/800-A RC-IGBT "Dual XT" Modules for Industrial Applications

YAMANO, Akio* EBUKURO, Yuta* KAKEFU, Mitsuhiro*

In recent years, there has been increasing expectations that power electronics technology will further contribute to efficient energy usage and energy saving, and play an important role in achieving a sustainable society. In particular, the demand is growing for power semiconductors as key devices of power conversion equipment used for various applications, such as the industrial, automotive, and renewable energy applications.

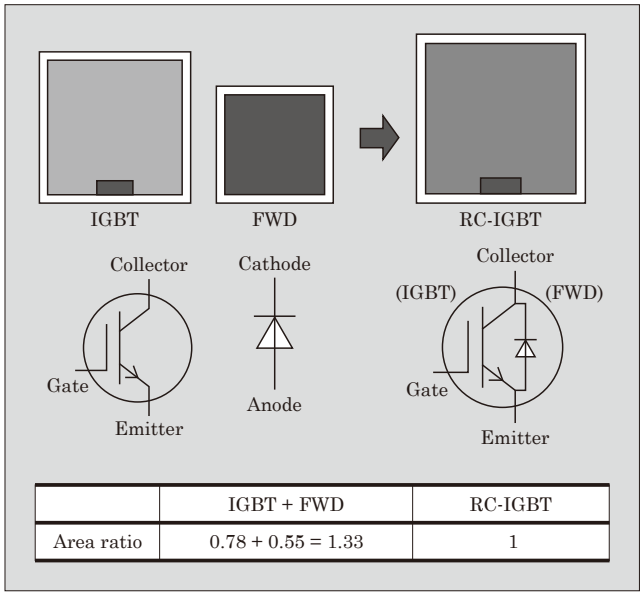
Fuji Electric has made many technological innovations to reduce the size, lower the power dissipation, and improve the reliability of insulated gate bipolar transistor (IGBT) modules, contributing to the miniaturization, cost reduction, and performance of power conversion systems by helping them become smaller, more efficient and reliable. Our latest 7th-generation "X Series" IGBT modules achieve even lower power dissipation, higher reliability, and higher power density, by innovating in chip and packaging technology.

In addition, we have also developed reverse-conducting IGBTs (RC-IGBTs), which combine 7th-generation IGBT and free-wheeling diode (FWD) functions into a single chip to create a line-up of the X Series RC-IGBT module for industrial applications. This line-up has even higher power density and higher reliability than conventional IGBT modules, which combine IGBT and FWD chips. Moreover, the current rating has been increased to 800 A, compared with the previous maximum current rating of 600 A.(1)

1. Characteristics of RC-IGBTs

Figure 1 shows the schematic and equivalent circuit diagrams of the X Series RC-IGBT for industrial applications. In inverters that are used as power conversion equipment, two types of semiconductor chips, IGBT and FWD, are connected in anti parallel (IGBT + FWD system). In contrast, an RC-IGBT integrates the IGBT and FWD functions into a single chip.

Since RC-IGBTs incorporate the functions of an IGBT and FWD into a single chip, the chip area of RC-IGBTs is larger than that of individual IGBTs and FWDs at the same rated current. Therefore, they have better heat dissipation and lower thermal resistance than conventional chips. At the same time, the chip area of an RC-IGBT is smaller than that of the combined chip area of an IGBT and FWD. Therefore, an RC-IGBT can provide a higher rated current for the same chip area. By taking advantage of these features, we have increased the output of IGBT modules while maintaining the same package size.



	IGBT + FWD	RC-IGBT
Area ratio	0.78 + 0.55 = 1.33	1

Fig.1 Schematic and equivalent circuit diagrams of the "X Series" RC-IGBT for industrial applications

2. Product Line-Up

Figure 2 shows the line-up, product appearance,

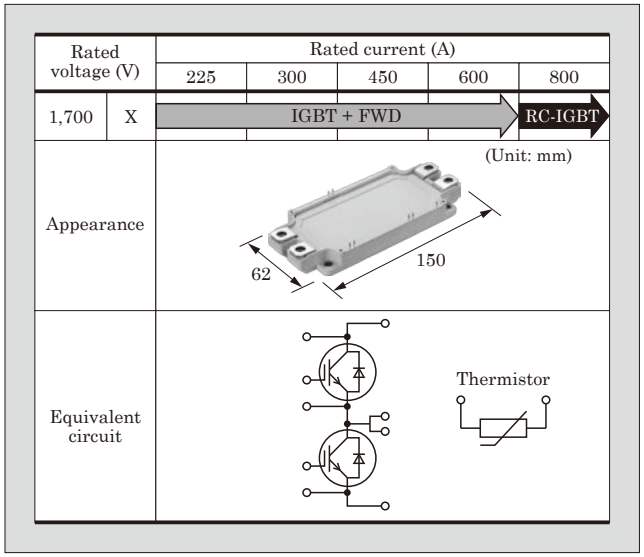


Fig.2 Line-up of the 1,700-V "Dual XT" modules

* Semiconductors Business Group, Fuji Electric Co., Ltd.

and equivalent circuit of the newly added X Series 1,700-V RC-IGBT "Dual XT" modules for industrial applications. Customers can select the most suitable module for their application.

3. Features of the 7th-Generation "X Series" 1,700-V/800-A RC-IGBT "Dual XT" Modules for Industrial Applications

(1) Reduction of ΔT_{vj} chip virtual junction temperature

Wind power conversion systems, which are considered to be one of the most important sources of renewable energy, widely use IGBT modules with a rated voltage of 1,700 V. Figure 3 shows a schematic diagram of a wind power conversion system. The rotation of the wind turbine causes the generator to produce AC power and the generator-side power conversion equipment converts it into DC power. The DC power is reconverted to AC power by the power conversion equipment on the grid side.

During this process, the generator-side power conversion equipment, which converts the rotation of the wind turbine into electrical energy, can have a large temperature time variation ΔT_{vj} during low-frequency operation of 1 to 10 Hz, shortening the lifetime of the RC-IGBT module in the power cycle.

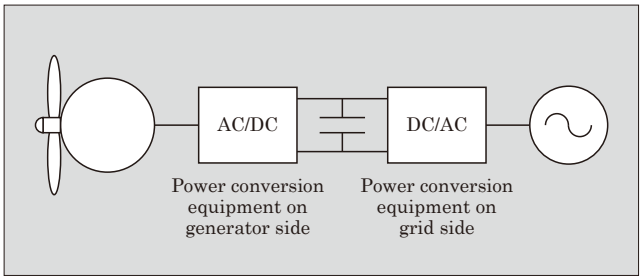


Fig.3 Schematic diagram of wind power conversion system

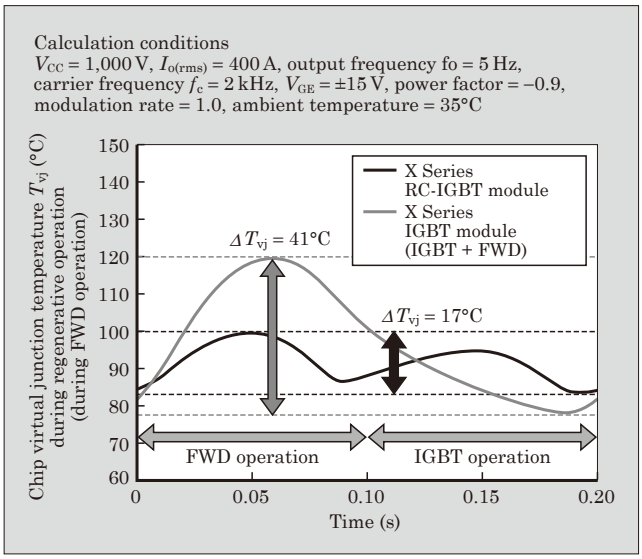


Fig.4 T_{vj} calculation results during low-frequency operation

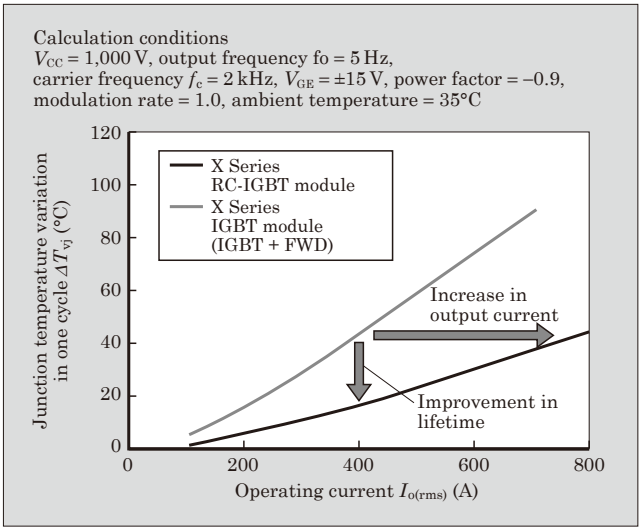


Fig.5 ΔT_{vj}–I_o calculation results during low-frequency operation

Figure 4 shows the calculation result of the chip virtual junction temperature change T_{vj} in one cycle of low-frequency operation during regenerative operation. In conventional IGBT modules with the IGBT + FWD system, the IGBT and FWD chips alternately generate heat, and the ΔT_{vj}, in one cycle, was 41°C. In contrast, the X Series RC-IGBT module has reduced the lower maximum chip virtual junction temperature T_{vjmax} due to the larger RC-IGBT chip area improving heat dissipation. Moreover, the IGBT and FWD regions in an RC-IGBT chip alternately generate heat, increasing the minimum chip virtual junction temperature T_{vjmin}. As a result, the X Series RC-IGBT module has significantly improved ΔT_{vj} to 17°C, which reduces the amount of thermal stress variation applied to the aluminum wire and solder.

(2) Output current and power cycle life improvement

Figure 5 shows the calculation results of ΔT_{vj} and output current I_o at low-frequency operation. The X Series RC-IGBT module for industrial applications can have the significantly lower ΔT_{vj} than the conventional X Series IGBT module with the IGBT + FWD system at the same output current. This means that under the same power conversion conditions, thermal stress variation decreases with reductions in the IGBT module's temperature variation. Moreover, under the same power cycle life time conditions that means same ΔT_{vj} conditions, the X Series RC-IGBT module can output higher current than the conventional IGBT + FWD system, as shown in Fig. 5. In case of ΔT_{vj} is 41°C, the X Series RC-IGBT module for industrial applications can expand 1.8 times output current of power conversion systems compared with using the conventional IGBT + FWD modules.

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(1) Ebukuro, Y. et al. 7th-Generation "X Series" RC-IGBT "Dual XT" Modules for Industrial Applications. FUJI ELECTRIC REVIEW. 2021, vol.67, no.4, p.242-246.

Launch Date

October 2021

Product Inquiries

Sales Department I, Sales Division, Semiconductors Business Group, Fuji Electric Co., Ltd.
Tel: +81-3-5435-7152

2nd-Generation Discrete SiC-SBD 1,200-V Series

HARA, Yukihito* **MIYAMOTO, Shin*** **NAKAMURA, Yuji***

In recent years, the increase in worldwide data traffic has accelerated the installation of data centers and telecommunication base stations. Since data centers require a stable supply of power, they use uninterruptible power systems (UPSs). The power semiconductors used in UPSs are requiring lower loss and higher durability.

Fuji Electric has developed the 2nd-generation discrete SiC-SBD 1,200-V Series as a line-up that achieves lower loss by reducing forward voltage V_F and improves surge forward current I_{FSM} compared with the 1st-generation discrete SiC-SBD Series.(1)

1. Features

Figure 1 shows the package appearance of the 2nd-generation discrete SiC-SBD 1,200-V Series, and Table 1 provides an overview of the product line-up. The main features are as follows.

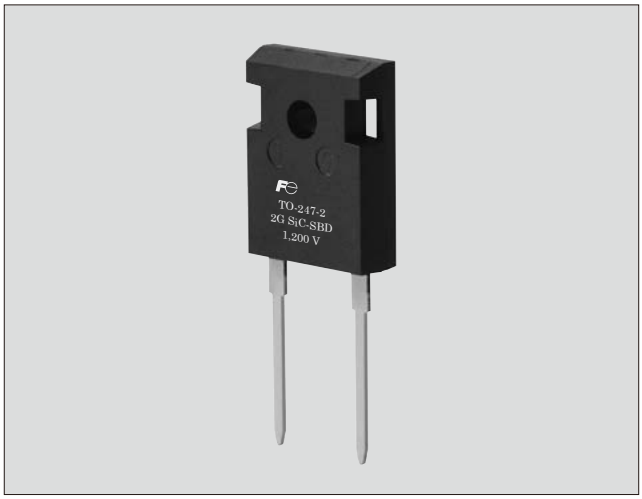

Fig.1 Package appearance

(a) Its low forward voltage (T_{vj} = 25°C, 10% lower than conventional products) contributes to improved efficiency in applicable power supply equipment.
(b) Improved I_{FSM} (surge forward current) (T_{vj} = 25°C, 110% better than conventional models) improves dielectric strength against large instantaneous forward currents (inrush currents).

2. Chip Technology

SIC-SBDs exhibit small switching loss during reverse recovery operation since they are unipolar majority carrier devices that contribute to conduction without any accumulation effect. This mean that in order to reduce device loss, it is necessary to reduce conduction loss by decreasing V_F. In addition, diodes in a power factor correction (PFC) circuit must not be damaged by the inrush current when smoothing capacitors charge at the power supply turned on.

Figure 2 shows the structure of the 1st- and 2nd-

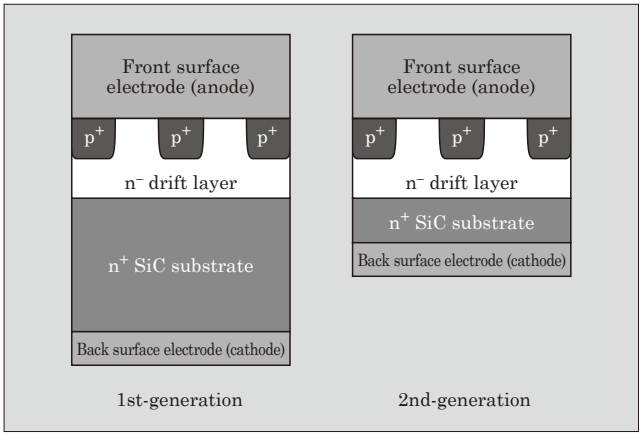

Fig.2 Structure of the 1st- and 2nd-generation SiC-SBD chips

Table 1 Line-up

Type	Package	Maximum ratings			Electrical characteristic	
		V_{RRM}	I_F	I_{FSM}	V_F T_{vj} = 25°C (typ.)	V_F T_{vj} = 150°C (typ.)
		(V)	(A)	(A)	(V)	(V)
FDC2 WT20S120	TO-247-2	1,200	20	190	1.57	2.29
FDC2 WT40S120	TO-247-2	1,200	20	305	1.57	2.29

* Semiconductors Business Group, Fuji Electric Co., Ltd.

generation SiC-SBD chips. Both utilize junction barrier Schottky (JBS) structures with a p^+ layer on their device surface. We have reduced n^+ SiC substrate thickness, reduced barrier height by optimizing the Schottky junction, reduced drift resistance by optimizing the JBS structure and drift layer, and reducing contact resistance by using proprietary wafer process technology, allowing the 2nd-generation SiC-SBD to have reduced V_F and improved I_{FSM}.

Figure 3 shows the temperature characteristics of V_F for 1st- and 2nd-generation products with a 1,200 V/20 A rating when I_F = 20 A. For the entire region between −55°C and +125°C, 2nd-generation products have lower V_F, and when T_{vj} = 25°C, V_F is 10% lower than 1st-generation products.

Figure 4 shows the I_F–V_F characteristics of a 1,200-V/20-A device in the high current range. When the pn junction diode consisting of the p^+ and n^- drift layers in contact with the surface electrode (anode) operates, a large current of 100 A or more flows through

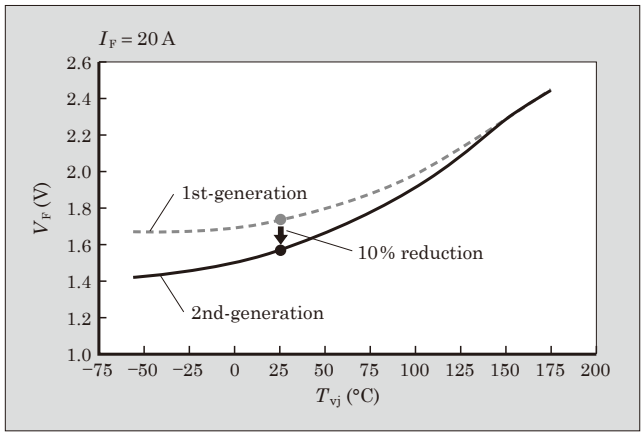

Fig.3 V_F temperature characteristics of 1st- and 2nd-generation 1,200-V, 20-A devices

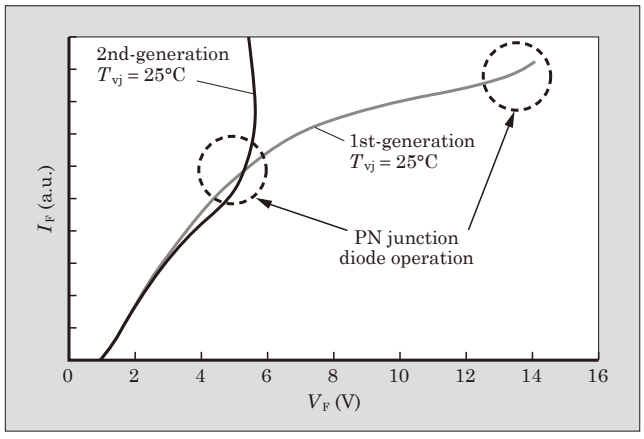

Fig.4 I_F – V_F characteristics in the high-current range of 1st- and 2nd-generation 1,200-V, 20-A devices

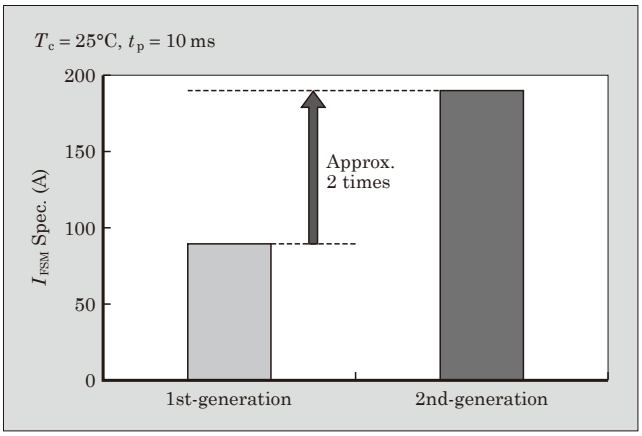

Fig.5 I_{FSM} characteristics of 1st- and 2nd-generation 1,200-V, 20-A devices

the ohmic region of the surface electrode (anode) and the p^+ layer. The 2nd-generation device has an optimized JBS structure that allows current to flow through the pn junction diode more easily than the 1st-generation products. As shown in Fig. 5, the guaranteed I_{FSM} value has been increased twice, 190 A for the 2nd-generation products than 90 A for the 2nd-generation products, due to thermal resistance reduction (improved heat dissipation) through thinner n^+ SiC substrate.

3. Package

This device uses the TO-247-2 package, presenting an industry standard TO-247 outward form, which has two terminals with no center terminal. Since the creepage distance (insulation distance) between terminals is longer than that of 3-terminal products, its insulation performance is higher, and its structure is suitable for applications that need a high dielectric strength. In addition, using lead-free solder for the connections between the chip and lead frame is compliant with the RoHS Directive (EU 2011/65/EC).

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Launch Date

December 2021

Product Inquiries

Sales Department I, Sales Division, Semiconductors Business Group, Fuji Electric Co., Ltd.
Tel: +81-3-5435-7152

Through our pursuit of innovation in electric and
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Design, manufacture, sales, and engineering for drive control systems
Tel +91-129-2274831

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Manufacture of semiconductor devices
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Fuji Furukawa E&C (Malaysia) Sdn. Bhd. *
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Fuji Electric Co.,Ltd. (Middle East Branch Office)
Promotion of electrical products for the electrical utilities and the industrial plants
Tel +973-17 564 569

Fuji Electric Co., Ltd. (Myanmar Branch Office)
Providing research, feasibility studies, Liaison services
Tel +95-1-8382714

Representative office of Fujielectric Co., Ltd. (Cambodia)
Providing research, feasibility studies, Liaison services
Tel +855-(0)23-964-070

■Equity-method Affiliates

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Manufacture and sales of low/high-voltage inverters, temperature controllers, gas analyzers, and UPS
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Fuji Electric (Changshu) Co., Ltd.
Manufacture and sales of electromagnetic contactors and thermal relays
URL http://www.csfe.com.cn/

Fuji Electric (Zhuhai) Co., Ltd.
Manufacture and sales of industrial electric heating devices
URL http://www.fujielectric.com.cn/fez/

Fuji Electric (Shenzhen) Co., Ltd.
Manufacture and sales of photoconductors, semiconductor devices and currency handling equipment
URL http://www.szfujielectric.com.cn/

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Manufacture of low-voltage circuit breakers
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Fuji Electric Motor (Dalian) Co., Ltd.
Manufacture of industrial motors
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Dalian Fuji Bingshan Control Systems Co., Ltd.
Energy management systems, distribution systems, and related system engineering
Tel +86-411-8653-6010

Fuji Electric (Hangzhou) Software Co., Ltd.
Development of vending machine-related control software and development of management software
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Fuji Electric FA (Asia) Co., Ltd.
Sales of electrical distribution and control equipment
Tel +852-2311-8282

Fuji Electric Hong Kong Co., Ltd.
Sales of semiconductor devices and photoconductors
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Hoei Hong Kong Co., Ltd.
Sales of electrical/electronic components
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