ZERO Heating Power Vending Machine "Hybrid ZERO"

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ABSTRACT

Fuji Electric has adopted the concept of achieving extensive energy savings while reducing peak power consumption to decrease environmental burdens, and based on this, it has developed the ZERO Heating Power Vending Machine "Hybrid ZERO" as a unit that does not utilize an electric heater. Conventionally, a portion of the storehouse has been heated using an electric heater, but the Hybrid ZERO heats all heating chambers using a heat pump. We have achieved this functionality by increasing the efficiency of heat exchangers and compressors while newly developing a refrigerant path switching valve. These enhancements have enabled the Hybrid ZERO to achieve a 15% reduction in yearly power consumption based on estimated actual usage in its operation modes, as well as a maximum power consumption reduction of 55% during winter operation mode.

1. Introduction

Fuji Electric has adopted the concept of achieving extensive energy savings while reducing peak power consumption for its vending machines, and based on this, it has developed the ZERO Heating Power Vending Machine "Hybrid ZERO." The product name Hybrid ZERO is based on the following 2 points:

(a) Application of hybrid heat pump technology

It uses both the waste heat generated when cooling beverages and the heat of the outside air as heat sources for heat pump heating.

(b) Utilization of no electric heater power

Since the heating of all hot beverages is exclusively carried out by the heat of the heat pump, there is no need to mount an auxiliary electric heater.

Hybrid ZERO performs cooling and heating by means of a heat pump for all four seasons, thus enabling it to achieve a 15% reduction in yearly power consumption*1, as well as a maximum power consumption reduction of 55% during winter operation mode compared with previous hybrid heat pump beverage vending machines. This paper describes the challenges and work we undertook in the development of the Hybrid ZERO.

2. Development Background

We have been actively pursuing the development of energy-saving technology for vending machines ever since can-and-bottle type vending machines were designated as special equipment in the "Act on the Rational Use of Energy" (Energy Conservation Act) in 2002. Furthermore, power shortages following the Great East Japan Earthquake in March 2011 created the need for a 25% reduction in peak power consumption, and as a result, energy-saving measures were taken such as lighting control and rotational-based cooling-mode operation stoppages of vending machines. Against this backdrop, the vending machine industry has been working to achieve energy savings to reduce environmental burdens, while also responding to demands for reduced power consumption to improve the supply and demand balance for electric power.

Fuji Electric has developed technology capable of achieving extensive energy savings and power consumption reduction benefits.

3. Development Goals and Challenges

3.1 Challenge of achieving energy savings under actual use conditions

Figure 1 shows the structure of a vending machine. General-purpose vending machines are designed with 3 partitioned compartments (left compartment, center compartment and right compartment) for storing beverages, and depending on the season, these compartments can be configured for use in cooling or heating operation mode. Table 1 shows the settings for 4 operation modes. Operators can configure their vending machines to match the purchasing needs of consumers. For example, it is common to set a vending machine to CCC mode (cooling operation for all 3 compartments) during the summer when cold drinks sell well, to HHC mode (heating operation for 2 compartments and cool-

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*1: Amount of yearly power consumption: Measurement of the amount of yearly power consumption is based on an uniquely defined power measuring method.

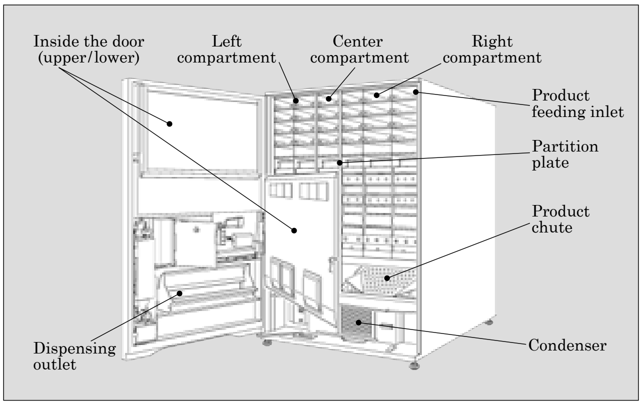

Fig.1 Structure of vending machine

Table 1 Operation modes and cooling/heating settings for each compartment for conventional machines

Operation mode	Left compartment	Center compartment	Right compartment
CCC mode	Cooling	Cooling	Cooling
HCC mode	Heat-pump heating	Cooling	Cooling
CHC mode	Cooling	Electric-heater heating	Cooling
HHC mode	Heat-pump heating	Electric-heater heating	Cooling

ing operation for one compartment) during the winter when hot drinks sell well, and to HCC mode (heating operation for one compartment and cooling operation for 2 compartments) in the spring and fall.

Conventional machines have used heat pump operation for beverages in the left compartment as a means of providing more effective heating compared with an electric heater. Using a heat pump instead of an electric heater to heat the center compartment could produce energy savings, but the actualization of this has been difficult for the following reasons.

(a) Since there is insufficient space in the center compartment, it has not been possible to install an appropriately sized heat exchanger for heating.

(b) The size of refrigeration units has been increasing due to the greater complexity of refrigerant circuits and the increasing number of switching valves.

3.2 Points regarding the reduction of the amount of yearly power consumption

Figure 2 shows the percentage of power consumption for conventional machines which commonly use the 3 main operation modes. The percentages are the largest for the compressor used in CCC mode and HCC mode, and for the electric heater used in HHC mode. It is possible to reduce the electric energy pertaining to the compressor by increasing the efficiency of compression, and the electric energy pertaining to the electric heater by using a heat pump instead. In other words, the following 2 points contribute to reducing the amount of yearly power consumption.

(a) Higher efficiency for the compressor

(b) Simultaneous heat-pump based heating for heating compartments in HHC mode (left compartment and center compartment)

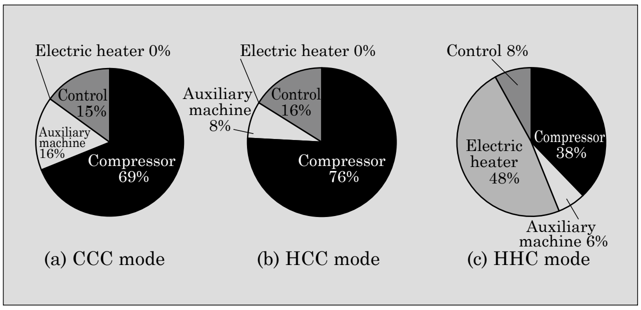

Fig.2 Percentage of power consumption in main operating modes of conventional machines

However, the use of heat-pump based heating for the center compartment faces several problems as described in Section 3.1 above. These include the need for a larger installation space due to the complexity of the circuit structure of the refrigeration unit, as well as the problem of excessive discharge pressure resulting from the insufficient capacity of a heat exchanger being installed in the narrow center compartment. Furthermore, there also exists the problem of not being able to secure the capacity needed to use a heat pump to heat both the left compartment and center compartment simultaneously. Summarizing these challenges, we are confronted with the following 3 tasks.

(a) Streamlining the devices that make up the refrigeration circuit

(b) Securing heating capacity by simultaneously heating 2 compartments with a heat pump

(c) Suppressing excessive discharge pressure generated in heating the center compartment with a heat pump

4. "Hybrid ZERO" Refrigeration Unit Structure and Technology

4.1 Streamlining the devices that make up the refrigeration circuit

In order to reduce the amount of power consumed when using an electric heater, we have constructed a refrigeration circuit for heating the center compartment with a heat pump.

Figure 3 shows the switching of the discharge piping for the compressor in the refrigeration circuit of a conventional machine. In a conventional machine, the refrigerant was only able to flow through one of 2 paths, that is, either through the path of the condenser used for the cooling operation, or through the path of the left-compartment heat exchanger used for heating with a heat pump.

On the other hand, the Hybrid ZERO, which is ca-

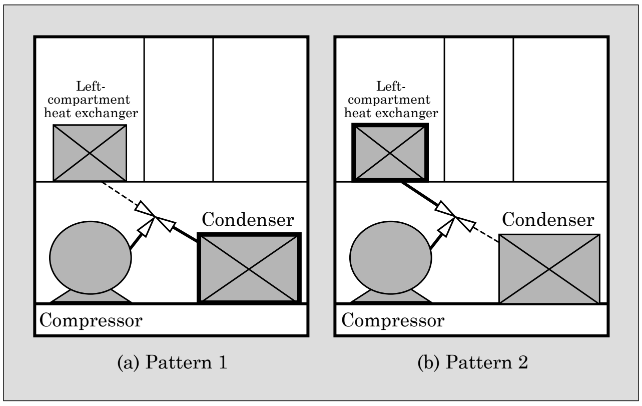

Fig.3 Switching of discharge piping for the compressor in refrigeration circuit of a conventional machine

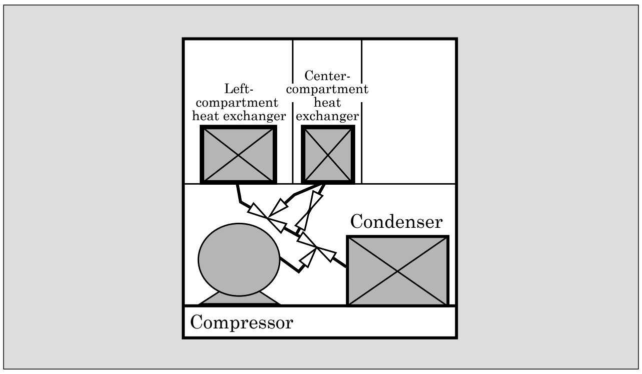

Fig.4 Discharge piping for achieving simultaneous heating of 2 compartments using conventional switching valves

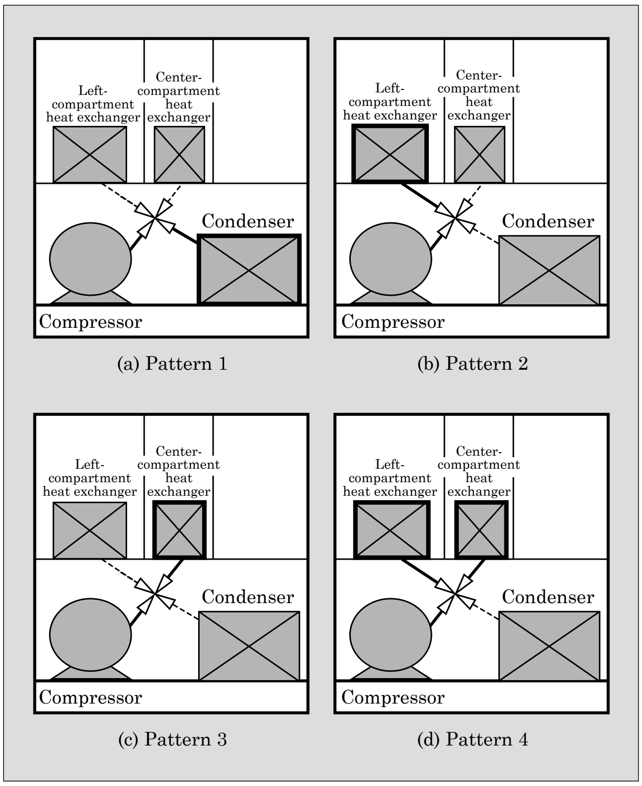

Fig.5 Switching of discharge piping in "Hybrid ZERO"

pable of using a heat pump to heat both the left compartment and center compartment simultaneously, has been designed with 3 connection destinations for the compressor discharge piping, which include the conventional destinations for the condenser and left-compartment heat exchanger, while also now including the center-compartment heat exchanger. In order to enable heating with a heat pump for the center-compartment heat exchanger, there are now twice as many switching paths.

Configuring the refrigeration circuit with the conventional switching valve created the problem of an increased size for the refrigeration unit, resulting from an increase of 2 switching valves compared with conventional machines as shown in Fig. 4.

Therefore, we newly developed a 4-way valve, which is a stepping motor type flow-path switching valve, to implement switching, as shown in Fig. 5. This enhancement has enabled us to suppress the increase in valves. By doing this, we were able to decrease the space of the refrigeration unit by about 15% compared with designs that utilize conventional valves.

4.2 Securing heating capacity by simultaneously heating 2 compartments with a heat pump

In HHC mode, conventionally applying the single compartment heat-pump heating capacity to 2 compartments (left compartment and center compartment) would cause the heating capacity per compartment to be halved. In general, all that is needed to increase the heating capacity is to increase the rotational speed of the compressor. However, an increase in the rotational speed causes degradation in the efficiency of the compressor, so there has been a need to increase the efficiency of the refrigeration unit.

We have solved this problem by switching to a circuit in which the compressor sucks in the refrigerant in a manner that makes more effective use of the waste heat of the compressor. This technique is explained as follows. General reciprocating compressors have 3 ports as shown in Fig. 6. These include the suction port for sucking in the refrigerant, the discharge port for discharging the compressed refrigerant and process port for services.

A suction muffler is mounted to the suction port,

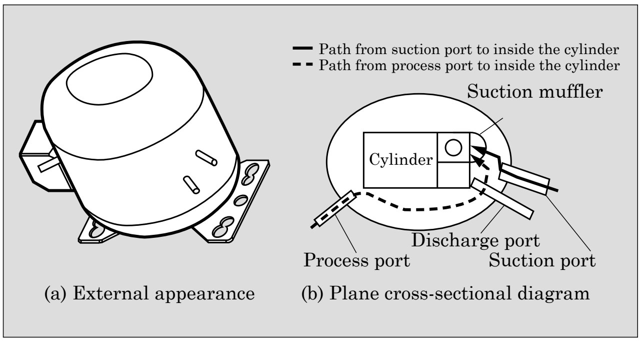

Fig.6 Compressor

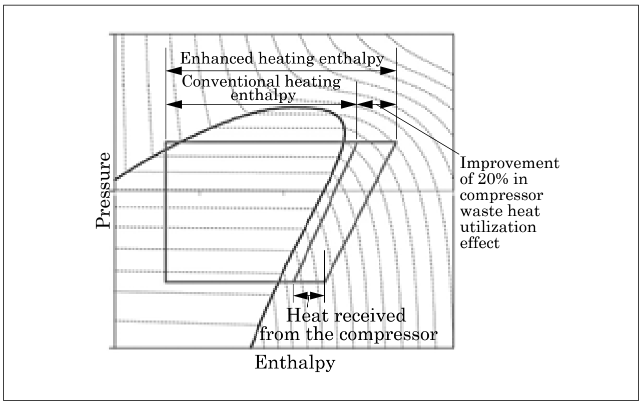

Fig.7 Waste heat utilization effect of compressor

and refrigerant sucked from the suction port into the compressor reaches the inside of the cylinder by following the shortest path as shown in Fig. 6. Therefore, the heat that the refrigerant receives from the high-temperature compressor is minimized, and as a result, there is very little temperature rise compared with the refrigerant temperature before compression. This effect makes it possible to implement a highly efficient cooling operation in which the discharge temperature is not likely to rise since the refrigerant is sucked in from the suction port. On the other hand, when there is no suction muffler on the process port, the path until the refrigerant, which is sucked in from the process port, reaches the inside of the cylinder becomes long, and thus the amount of heat the refrigerant receives from the compressor is large. As a result, the method of sucking in refrigerant from the process port causes a larger discharge temperature, and as such, it is easy to increase the capacity of the heat-pump heating.

However, the adoption of a refrigeration circuit in conventional machines to suck in refrigerant from the suction port during either refrigeration operation or heat pump operation makes it difficult to obtain the heating capacity during heat pump operation. Therefore, the Hybrid ZERO utilizes a refrigeration circuit capable of switching the port that sucks in the refrigerant depending on the operation. During refrigeration operation, it switches the port to the suction port, and during heat pump operation, it switches the port to the process port not equipped with a suction muffler. The result of this is that the waste heat of the compressor can be effectively used as shown in Fig. 7, while also increasing the heating capacity of the heat pump by 20%. By combining this effect with the increase in the rotational speed of the compressor, system efficiency is maintained and it becomes possible to implement simultaneous 2 compartment heating with a heat pump.

4.3 Suppressing excessive compressor discharge pressure generated in heating the center compartment with a heat pump

When adopting a refrigeration circuit capable of simultaneous 2 compartment (left compartment and center compartment) heating with a heat pump, it is possible to use stand-alone heat-pump heating for the center compartment. However, this creates the problem of excessive pressure.

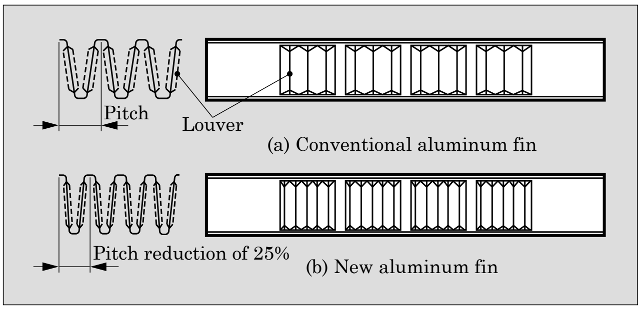

Fig.8 Conventional aluminum fin and new aluminum fin

In general, the center compartment is the smallest among the 3 compartments in a vending machine, and thus, it also provides the smallest amount of space for installing a heat exchanger. As such, excessive pressure is generated without the ability for the heat exchanger to create sufficient heat radiation for the flowing refrigerant. Therefore, we adopted the countermeasure of increasing the efficiency of both the heat exchanger and the compressor.

(1) Higher efficiency for the heat exchanger

In 2012, we developed an aluminum-fin fin pitch for our all-aluminum heat exchanger that is 25% narrower than conventional products as shown in Fig. 8. This has resulted in a 25% increase in the heat transfer area without changing the volume of the heat exchanger. Furthermore, we also optimized the shape of the louver of the fin to accommodate the narrow pitch. We verified in a simulation that this new type of aluminum fin achieves an average thermal conductivity improvement of 32%.

(2) Higher efficiency for the compressor

In order to reduce the amount of refrigerant of the center-compartment heat exchanger when heating the center compartment, the easiest and most effective method is to lower the rotational speed of the compressor. However, the minimum rotational speed for conventional compressors is not enough to suppress the excessive rise. Therefore, it became needful to reduce the minimum rotational speed of the compressor. So, in addition to increasing the efficiency, we worked on technology development with compressor makers and have successfully optimized specifications to match the load of vending machines. As a result, we have reduced the minimum rotational speed of the compressor by 12%, and have also achieved about a 10% improvement in efficiency. By adopting this compressor in the Hybrid ZERO, we have been able to sufficiently reduce rotational speed during stand-alone heating for the center compartment, while also suppressing excessive discharge pressure in the compressor and increasing the efficiency of the refrigeration unit.

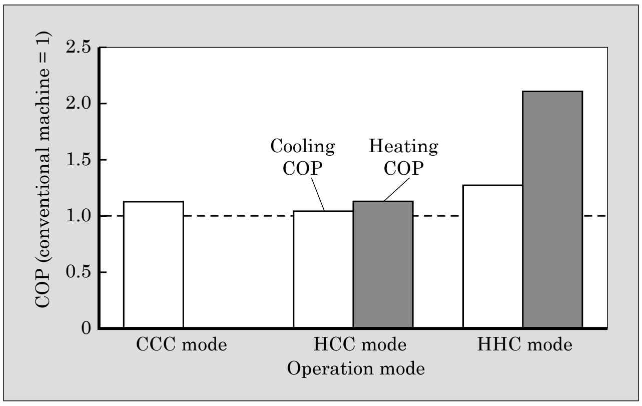

Fig.9 "Hybrid ZERO" COP

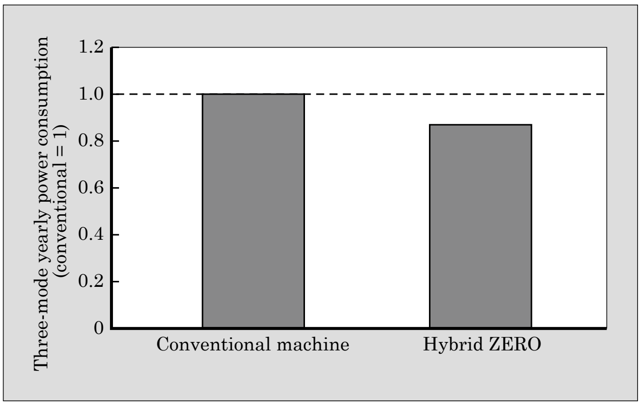

Fig.10 Amount of yearly power consumption in 3 modes for conventional machines and "Hybrid ZERO"

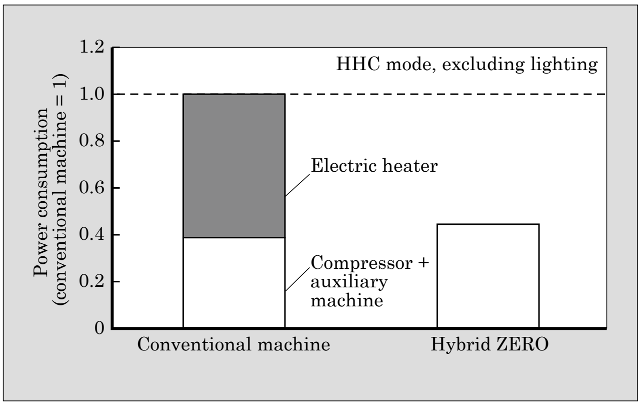

Fig.11 Power consumption for conventional machines and "Hybrid ZERO"

5. "Hybrid ZERO" Performance

5.1 Refrigeration unit performance

We measured the coefficient of performance (COP) to verify the effect of the energy-saving measures that we described above. The COP corresponds to the efficiency of the refrigeration unit mounted on the Hybrid ZERO. The measurement results are shown in Fig. 9. The vertical axis represents the ratio of cooling unit COP compared with conventional machines (conventional machine COP=1). In particular, there was significant improvement in heating efficiency when implementing heat pump operation in HHC mode, and we were able to confirm the considerable effect of using a heat pump for the center compartment.

5.2 Vending machine performance

We calculated the amount of yearly power consumption for the 3 modes to compare its performance with real life conditions (see Fig. 10). Calculation for the amount of yearly power consumption for the 3 modes is based on an assumed operation of 90 days per year for CCC mode (summer), 185 days per year for HCC mode (spring and fall) and 90 days per year for HHC mode (winter). The vertical axis represents the ratio of the amount of yearly power consumption for the 3 modes compared with conventional machines (conventional machine performance=1). The Hybrid ZERO achieves a 15% reduction in the amount of yearly power consumption for the 3 modes compared with conventional machines. In addition, it also achieves a 27% reduction in power consumption according to measurements based on JIS B 8561.

Following this, we measured power consumption in HHC mode to verify the effect of reducing power consumption (see Fig. 11). Similar to the other figures, the vertical axis represents the ratio of power consumption compared with conventional machines (conventional machine power consumption=1). In conventional machines, the power consumption of the electric heater occupied more than 60% of the total unit power consumption, but this source of power consumption has been completely eliminated in the Hybrid ZERO, which suppresses overall power consumption to just 45% of conventional machines. These results have shown that the unit not only achieves yearly power savings, but also is extremely effective in improving the supply and demand balance of power in the winter.

6. Postscript

In this paper, we have introduced the ZERO Heating Power Vending Machine "Hybrid ZERO." The Hybrid ZERO is designed with consideration of the environment, and has achieved considerable energy savings and reduction in power consumption during winter operation mode by adopting a heat pump to heat all heating compartments. It contributes to preventing global warming and also improves the supply and demand balance of energy in Japan.

In the future, we plan on continuing our efforts to achieve energy savings in vending machines while we also strive to develop products that further alleviate environmental burdens.

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