2010

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ABSTRACT

Recently, residences with high heat insulation have been increasing in number. Air conditioners in these residences are therefore often operated with comparatively small air conditioning load. And the energy saving guideline index for air conditioners has been changed from the coefficient of performance (COP) measured during rated operation to the annual performance factor (APF) in Japan. In response to these changes, we have developed a new Dual compressor adopting variable cylinder system, which can stop one of two cylinders. Additionally to improve efficiency we adopted (1) an optimized suction piping structure, (2) crank-pin diameter reduction, and (3) high-density winding. These new technologies realize high efficient operation in wide range and an air-conditioner in which this new compressor was installed could be reduced by 44 % at power consumption compared with a twin-rotary in low load. Addition, the seasonal power consumption used in “actual" air-conditioner operating environments can be decreased by 22 % to 85 % during the cooling load and by 7 % to 38 % during the heating load by effect of intermittent operation.

1. INTRODUCTION

With the growing need for CO_2 emission restrictions, an important issue is how to reduce the power consumption of home air conditioners, because they account for about 25 % of the total in standard houses in Japan[1). In response to this need, the energy saving guideline for home air conditioners in Japan has been changed from the coefficient of performance (COP), calculated based on cooling or heating operation at rated load, to the annual performance factor (APF), calculated taking account of annual air-conditioning load and operation time, and this new index is beginning to take root in general. On the other hand, recent houses have been getting more highly insulated than the standard houses used to calculate the air conditioner performance index; we estimate such high-insulated houses account for about 60 % of all houses in Japan.

When an air conditioner is used in a house with high heat insulation, it operates for a high proportion of the time in a low load range near the set temperature and, even though being inverter-controlled, sometimes goes below the low-limit of the compressor load, thus leading to ON/OFF intermittent operation. Such intermittent operation may not only decrease the compressor efficiency but may also cause the indoor temperature to fluctuate, possibly reducing the comfort in the living space.

In view of this situation, we have been engaged in Dual compressor development for the purpose of enhancing the efficiency in low load operation accounting for a high proportion of the actual operating time, while maintained the high efficiency in high load operation contributing to the feeling of sufficient warmth, quick-heating performance, and so forth. This paper presents an overview and effect of the new Dual compressor.

2. MECHANISM OF DUAL COMPRESSOR

In order for an air conditioner to have the capability of achieving not only satisfactory heating/cooling properties during high-load operation but also reduced power consumption during low-load operation, ideally a large-displacement compressor (large-capacity compressor) should be used for high-load operation and a small-displacement compressor (small-capacity compressor) should be used for low-load operation, in addition to inverter load control. Based on technology for embodying this concept into a product, we have developed a Dual compressor using a twin-rotary compressor structure for the first time in the world[2)].

Two-cylinder operation using two compression chambers is performed during high-load operation, such as when the air conditioner begins to operate, and the rotation speed is decreased by inverter control during low-load operation. Also, single-cylinder operation, in which just one cylinder is involved in the compression process, begins when the load becomes much lower, such as near the set temperature. Figure 1 shows the circuit diagram of a Dual compressor modulation. A case inside of this compressor is discharge (high) pressure.

The single-cylinder operation starts with the switching operation of a switching valve (a 3-way valve) located at the suction piping system of the compressor and connecting with discharge pressure gas. As a result of this switching operation, high-pressure refrigerant gas is introduced into the lower compression chamber to balance the pressure in the casing and the pressure in the lower compression chamber. At the same time, the vane, which has been pushed by pressure difference between the high-pressure space and the low pressure space, is relieved of this pressure difference and is then held by magnetic attraction on a compact magnet located near the rear of the vane. Through this operation, the lower compression chamber races idle, and only the single-cylinder of the upper compression chamber performs compression work. And then, when high power is required, these switching steps are reversed. We have established a control method for performing a series of these operating steps without stopping the compressor.

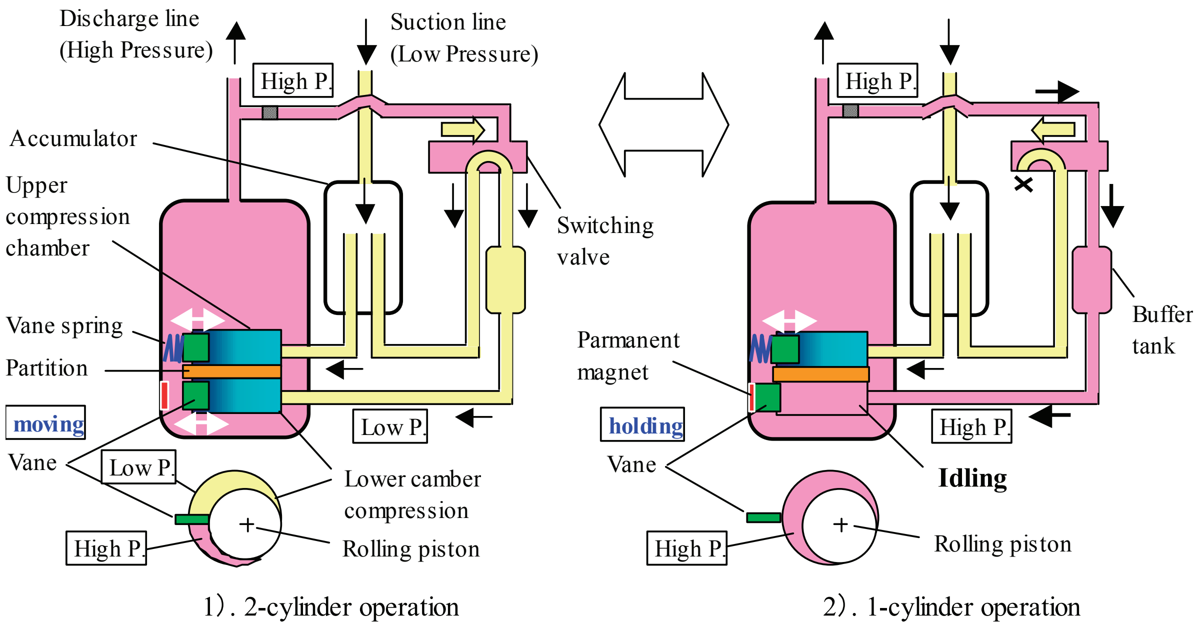

Fig.1 Circuit diagram of a Dual compressor modulation

3. STRUCTURE AND OVERVIEW OF NEW DUAL COMPRESSOR

Figure 2 shows a cross-sectional view of the new Dual compressor, Fig. 3 shows a cross-sectional view of the compression unit. The new Dual compressor is also a twin-rotary compressor with an inverter motor. The lower compression chamber is made to race idle in the single-cylinder operating mode by the variable compression-capacity mechanism. The magnet that attracts the vane is provided on the rear face of the vane. In addition, the suction pipe is connected to the lower compression chamber through the switching valve for introducing high-pressure refrigerant gas. A buffer tank for preventing supercharging in the two-cylinder operating mode is provided between the switching valve and the lower compression chamber.

The high-efficiency technologies adopting in the new Dual compressor are as follows.

(1) Optimizing the switching valve connection piping structure.
(2) Reducing frictional loss by decreasing the diameter of the crank pin.
(3) Developing a new motor.

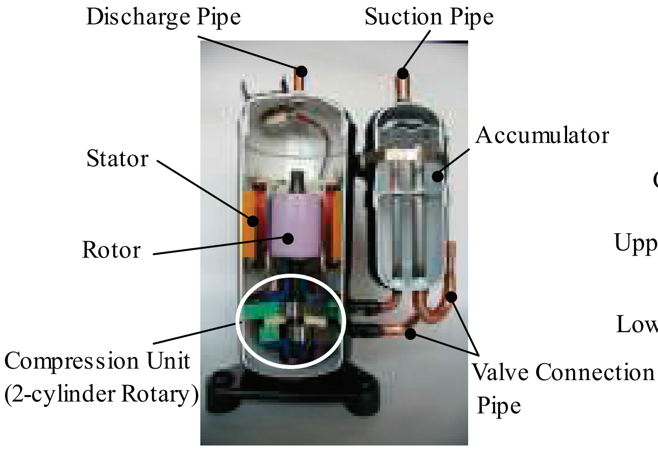

Fig.2 Cross - section of developed Dual Compressor

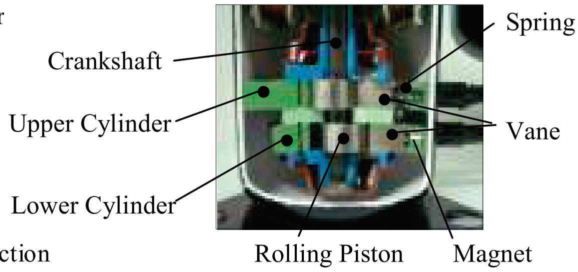

Fig.3 Cross - section of compression unit

4. DESIGN OF HIGH EFFICIENCY DUAL COMPRESSOR

4-1. Optimizing the switching valve connection pipe structure

Figure 4 shows the new Dual compressor and conventional one, and Table 1 lists comparison of the piping structure. Due to repeated periodical suction motion, a rotary compressor causes a pulsating flow to occur in its piping system. The supercharge phenomenon caused by resonance of this pulsating flow increases the suction-gas charge volume in the compression chamber and enhances the volumetric efficiency but, on the other hand, decreases the efficiency due to loss during the suction process. This phenomenon works advantageously in the high-capacity operating mode but is undesirable in rated- to half-capacity operating modes that require the high efficiency. In this point, the conventional dual compressor with the connection pipe had a little disadvantage in the two-cylinder operating mode compared with a normal twin-rotary.

We changed the position of the switching valve close to the compressor by improving connecting pipe design and welding methods. The new Dual compressor has the total length of the connection pipe reduced by 30 % and the enlarged inner pipe on the lower compression chamber connecting from inside the accumulator. Furthermore, in order to avoid the supercharge phenomenon, we optimized a volume of a buffer tank that was provided between the switching valve and the lower compression chamber. As this result, as shown in Fig. 5, efficiency characteristics equivalent to those of a normal twin-rotary can be achieved.

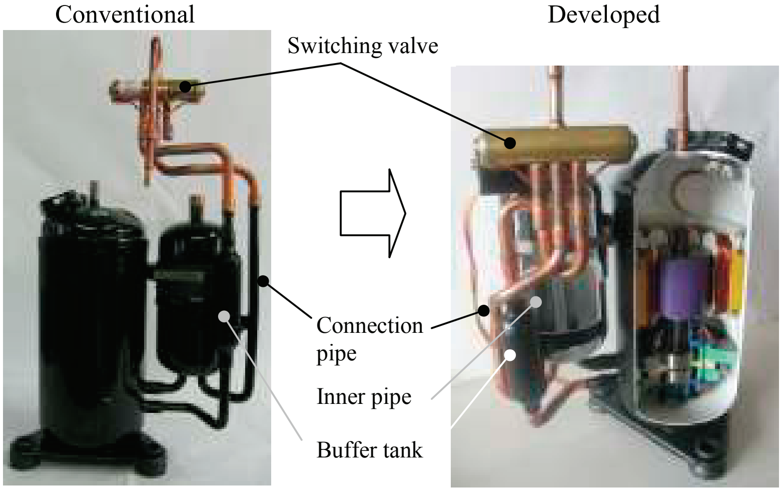

Fig.4 Comparison of Dual compressor

Table.1 Comparison of piping structure

		Developed ／ Conventional
Connection pipe	Diameter ratio	1.40 ／ 1.00
	Length ratio	0.70 ／ 1.00
Buffer Tank	Diameter ratio	1.14 ／ 1.00
	Length ratio	0.78 ／ 1.00
	Volume ratio	0.88 ／ 1.00

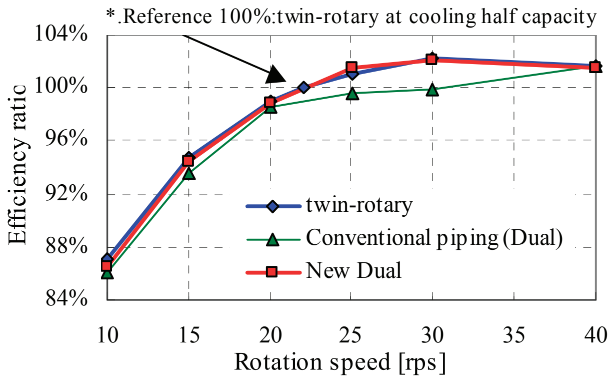

Fig.5 Comparison of compressor efficiency

4-2. Mechanical Efficiency Analysis

We examined reducing friction loss by the same way of thinking from Tominaga et al[3]. Table 2 lists the conditions under which frictional loss was calculated, and Fig. 6 shows the allocation of loss among the sliding sections in the conventional dual compressor. Friction loss was calculated based on:

$$L = \mu \times F \times V = \mu \times F \times \pi \times D \times N \qquad (1)$$

Where L: friction loss, μ: coefficient of friction, F: load, V: velocity, D: diameter, N: rotation speed.
There, we used the coefficient of friction as our empirical value that is affected by the viscosity of the lubricant, the load, the sliding speed, clearance, and so forth. Particularly for the crank section, we have corrected its coefficient through the McKee empirical formula[4], taking into consideration that the crank diameter is larger than its axial length. The results of calculation demonstrate that the loss in the crank section accounts for 50 % of the loss in all sliding sections under any conditions, and it can be presumed that decreasing the loss in this crank section will be effective in reducing the frictional loss. For this, we adopted to decrease the diameter of the crank section, because which reduces the coefficient of friction and the velocity.

Figure 7 shows loss reductions by decreasing. As a result of the calculations, the friction loss in the crank pin was reduced by 15 %, under any conditions with different lubricant viscosities or compression ratios.

Table.2 Calculation and calorimeter test condition

Condition Name	A	B	C	D
Air-conditioner operation mode	Heating rated-capacity	Cooling rated-capacity	Heating half-capacity	Cooling half-capacity
Compression ratio	2.8	2.6	2.2	1.8
Rotation speed [rps]	69	59	28	22

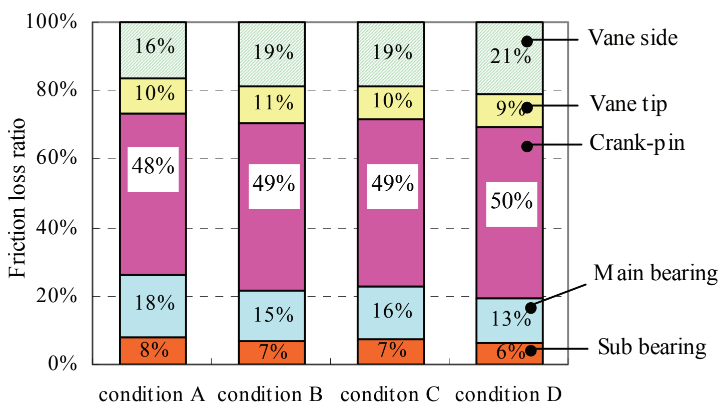

Fig.6 Friction loss ratio of conventional model

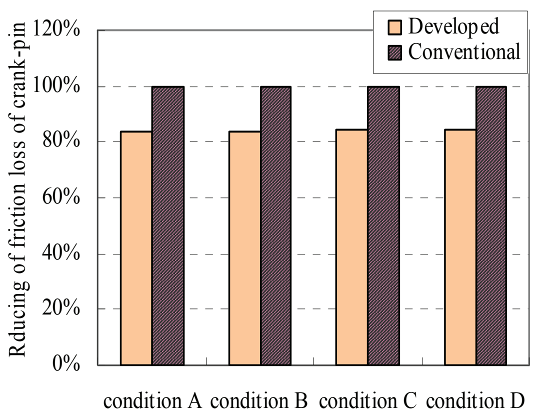

Fig.7 Reducing of mechanical loss (calculated)

4-3. Developing a new motor

For the motor developed in the new Dual compressor, we aimed at enhanced APF performance, compactness and resource saving. Figure 8 shows the core shapes of stators and rotors, and Fig. 9 shows the external appearances of stator assemblies. The new motor features:

(1) Optimizing of winding wire suitable for half-capacity operation

A higher density winding was achieved, and wire selection was made to enhance the total motor efficiency (including the inverter efficiency), enhancing the APF, particularly in half-capacity operation, while high-capacity operation was still possible. The total motor efficiency was enhanced by 0.5 % to 4 %.

(2) Compactness

A rare-earth magnet is shaped and positioned so as to ensure that necessary magnetic force is achieved and a rotor slit is formed in a limited space. The size was reduced by 10 % while still maintaining efficiency.

(3) Resource saving

An insulator made of a thin film is used to insulate between the slot section of the stator core and the coil. As a result, the amount of insulating material used for a resin molding, which is technologically difficult to recycle, was reduced by 24 %.

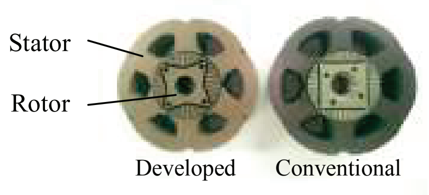

Fig.8 Comparison of motor core

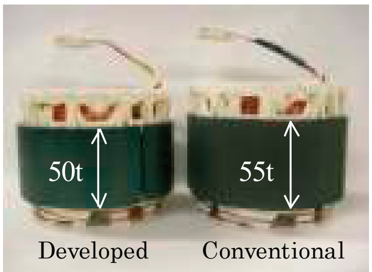

Fig.9 Comparison of motor stator

5. EXPERIMENTAL RESULTS OF NEW DUAL COMPRESSOR

5-1. Efficiency characteristics of the compressor

Figure 10 shows efficiency characteristics of the new Dual compressor under the Condition D in comparison with those of the conventional one. Efficiency was enhanced a 3 % to 5 % in minimum- to rated-capacity operating modes by employing the above-described high-efficiency technology. In addition, a maximum of 4 % improvement in efficiency was achieved in the single-cylinder operating mode, compared with the two-cylinder. The APF in a compressor calculated from these results also showed an increase of 3 % compared with that of the conventional Dual compressor.

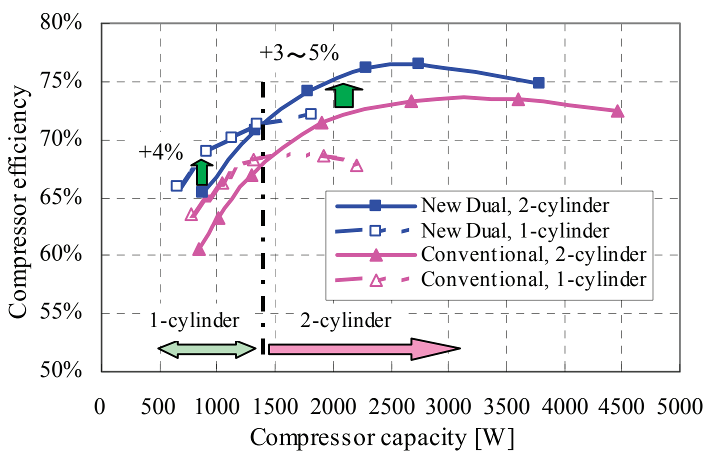

Fig.10 Comparison of compressor efficiency

5-2. Effects of the new Dual compressor as installed in an air conditioner

We investigated effects of the new Dual compressor as installed in an air conditioner[5]. Figure 11 shows the power consumption in an air conditioner with the new Dual compressor and an air conditioner with a twin-rotary compressor without a variable compression-capacity mechanism. We tested these performance in our environmental testing room that is a normal Japanese-style room under standard conditions: an outdoor air temperature of 31 °C, a set temperature of 27 °C, and a cooling capacity of 2.8 kW. In single-cylinder operation with the new Dual compressor, the power consumption at low load (half or lower capacity operating mode) was reduced by 17 % compared with the twin-rotary. The main reason is that it can use high motor efficiency that the rotation speed is doubled. Similarly, Fig. 12 shows the results of power consumption during stable cooling operation at an outdoor temperature of 29 °C. For the air-conditioner with the twin-rotary compressor, when the indoor temperature came closer to the set temperature, for requested capacity the variable (low) capacity range of it was exceeded, and the twin-rotary began intermittent operation in which power was repeatedly turned ON/OFF. This intermittent operation leads to energy loss and causes the indoor temperature to fluctuate, degrading user comfort. On the other hand, for the air-conditioner with the new Dual compressor, when the indoor temperature came closer to the set temperature and the load was decreased, the operating mode was switched from the two-cylinder operating to the single-cylinder in which the displacement of the compressor was halved. Therefore, the product can be operated such that cooling is not interrupted up to half the lower limit level of two-cylinder operation. Average power consumption under this condition could be reduced by 44 % compared with the air-conditioner with the twin-rotary. In addition, this non-intermittent operation can maintain a stable indoor temperature, thereby achieving both enhanced energy-saving benefits and user comfort. Cooling operation can be performed at a minimum power consumption of 45 W, which is as low as that of an electric fan (set to strong wind mode).

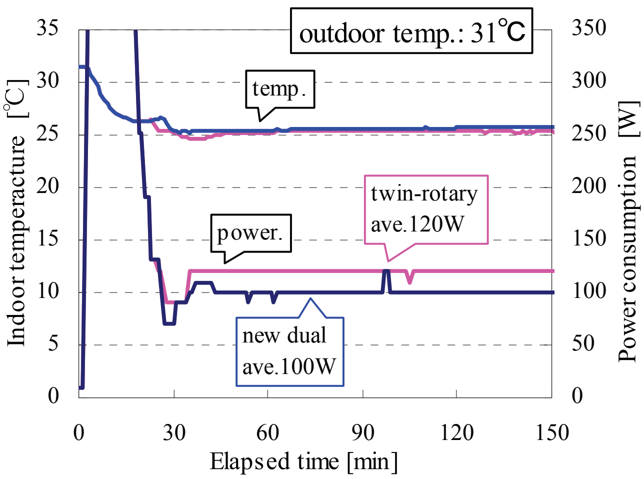

Fig.11 Performance at outdoor temp. 31℃

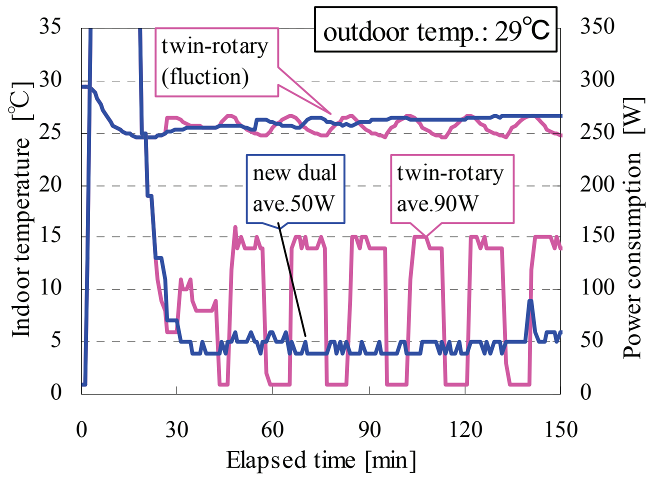

Fig.12 Performance at outdoor temp. 29℃

5-3. Comparison of seasonal power consumption

Next, we examined seasonal power consumption under close to actual air conditioner operating environments. The evaluation conditions show Table 4. For cooling and heating, the air conditioners were operated under three different outdoor conditions to measure the power consumption. We used it to calculate the seasonal power consumption, annual outdoor temperatures (for Tokyo) according to the JRA4046 standards. For outdoor temperatures other than the measuring points, values obtained by proportionally interpolating the measurement results. For comparison, we used a twin-rotary and a scroll compressor having the similar capacity and efficiency (equivalent level of JRA-standard APF) as those of the new Dual compressor had.

Figure 13 shows outdoor temperatures and measurements of air-conditioner power consumption, and Fig. 14 shows a comparison of the seasonal power consumption. The seasonal power consumption of the air conditioner with the Dual compressor was reduced by 22 % during the cooling load and by 7 % during the heating load, compared with the twin-rotary. Furthermore, compared with the scroll, it was reduced by 85 % during the cooling load and by 38 % during the heating load.

These results demonstrate that the new Dual compressor is highly effective in increasing the JRA-standard APF index. This effect is mainly due to appropriate control of intermittent operation occurring in “actual” air conditioner operating environments. In recent houses with higher heat insulating properties, this new Dual compressor will produce even more effective results.

6. CONCLUSIONS

We have developed a unique, a high efficiency Dual compressor that can stop one of two cylinders according to the necessary capacity, enabling highly efficient operation within a wide range of low-capacity to high-capacity operation conditions.

- With the high-efficiency technologies adopted, the new Dual compressor achieved an efficiency increase of 3 % to 5 % compared with a conventional Dual compressor. An air conditioner with this could be reduced by 44 % at average power consumption compared with a twin-rotary.
- It is expected that the seasonal power consumption with the new Dual compressor used in “actual" air conditioner operating environments can be decreased by 22 % to 85 % during the cooling load and by 7 % to 38 % during the heating load, compared with compressors without a variable compression-capacity mechanism.

The variable capacity technology of the Dual compressor is expected to greatly contribute to the development of future air conditioners. We will further contribute to global environment conservation and environmental comfort based on these technologies.

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Table.3 Measurement conditions for environmental test

Environmental test room (Japanese-style room 10jou, about 16.5m^2) in Toshiba Carrier Corp., equivalent to house in compliance with the first energy-saving standards in 1980	
Cooling	Settings: 27℃(cooling), automatic airflow/flow direction Outdoor temperature: 33, 29, 26℃ Internal load: 500W, no solar radiation
Heating	settings: 20, 23℃(heating), automatic airflow/flow direction Outdoor temperature: 12, 7, 2℃ Internal load: 40W, no solar radiation

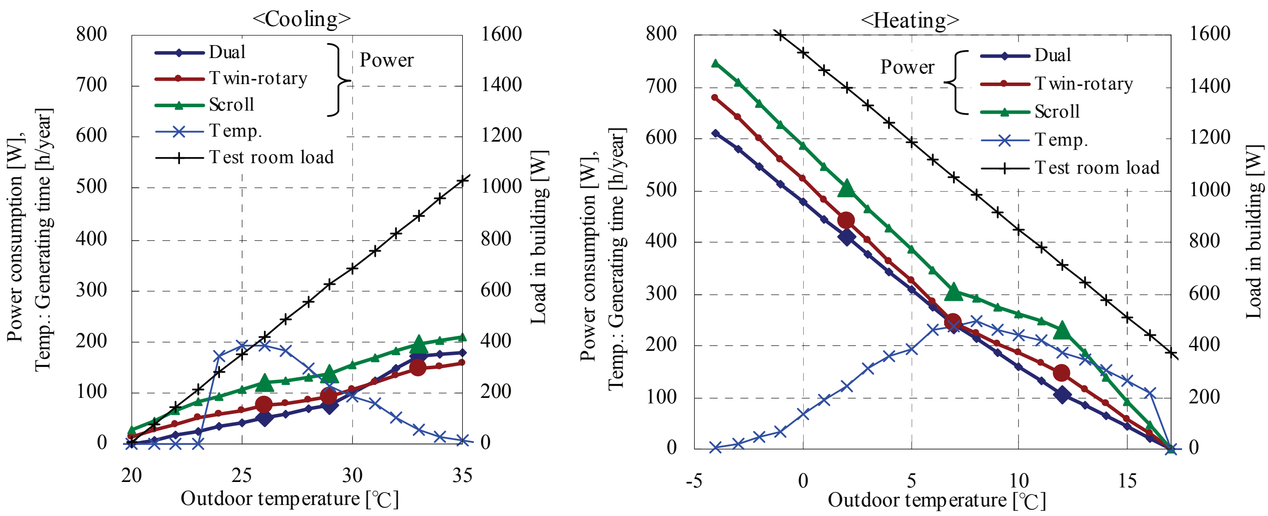

Fig.13 Outdoor temperature and Air-conditioner power consumption

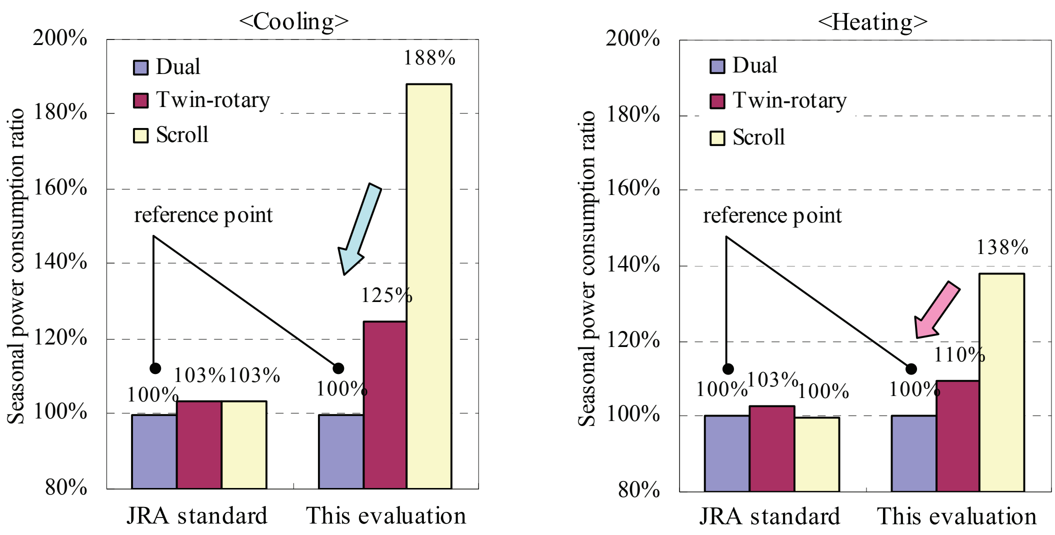

Fig.14 Comparison of seasonal power consumption