Performance of a 2 Room Multi-Heat Pump with a Constant Speed Compressor

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ABSTRACT: In order to improve the performance of a 2 room heat pump with a constant speed compressor, the optimum refrigeration circuit of the heat pump with different cooling and heating capacities is developed by applying capillary tubes. The refrigeration circuit is composed of four parts; a heating circuit, a cooling circuit, a by-pass circuit and a balance circuit. The performance of the 2 room heat pump are investigated from a rating experiment and a reliability experiment, using the calorimeter. Results of the rating experiment show that the capacity of heat pump is about 93% of the design value. In particular, the capacity of the cooling single operation is about 13% higher than the design value, and the capacity of the heating multi operation is about 5% higher than the design value. From the reliability experiment, it is found that the lowest driving voltage of the compressor is about 75% of the rating voltage. Also the compressor is reoperated normally under the flood back and the over load.

1. Introduction

To pursuit the improvement of living standards and comfortable office environment, the demand of a HVAC&R system is rapidly increasing. It also raises critical issues of environmental protection and energy problem. Therefore, the importance on the development of a high efficiency energy system is largely emphasized in order to solve the increment of energy consumption and an environmental problem, and to provide more comfortable environment. The high efficiency of HVAC&R system is obtained by improving the performance of the whole system and units such as a heat exchanger, an expansion unit or a compressor. There is a limit to improve the operating efficiency of the HVAC&R by the partial performance improvement of units. Thus, the technical development on the whole operating efficiency of the HVAC&R system is highly demanded. In recent years, the development on the HVAC&R is in progress to improve the whole performance of the system.

Heat pump is able to be a cooling and a heating by controlling the refrigerant flow rate according to the change of cooling and heating loads. To understand the capability and performance on the multi-HVAC&R system with multi-indoor units connected to one outdoor unit, lots of experimental data should be obtained.[1,2] From these, the operating efficiency of the system on the design change can be estimated.

The one of the most important points of the multi-system operation is that the system must be able to control accurately the cooling and heating capacities needed on independent zones. It can be controlled by the optimum control of

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a refrigerant flow. Because the multi-system is connected to several indoor units, the change of a refrigerant flow rate according to the load changes of one indoor unit may affect to the other indoor units.[3]

The studies on the multi-systems have been mainly carried out in Japan all these days. They study various systems using a cooling, a heating, a cooling and heating combined, an ice-storage, etc. Lately, studies on the multi-system in Korea are widely in progress. Nakamura[4] studied the control characteristics of a cooling and heating combined HVAC system. Han[5] established the base on the development of the multi-system by studying the dynamic model of EEV (electronic expansion valve) for the control of overheat degree. Kwon et al.[6,7] studied the performance characteristics of system using the compressor of PWM or inverter method.

Generally, a capillary tube is often used to control the load of the system. Bolstad and Jordan[8] proved the exist of critical flow which the refrigerant flow rate is nearly constant, even though the pressure drop below certain degree in an evaporator may occur. Kuehl and Goldschmidt[9] analyzed the tube flow by hypothesizing that two phase flow of R-22 in a capillary tube is a homogeneous flow. Chang et al.[10] showed the boiling delay in a capillary tube and presented the correlation which could estimate the boiling delay, from flow experiments using HFC refrigerants. Kim et al.[11] presented the numerical model which could estimate the efficiency of a capillary tube considered with surface roughness of a tube.

The aims of the present study are the performance improvement of a 2 room heat pump with the rotary compressor and the investigation on the reliability of the heat pump applying the new refrigeration control circuit. This system has different cooling and heating capacities for each zone.

The performance of the 2 room heat pump is experimented using the multi-calorimeter. From this, we can obtain the optimum design concept on the multi-heat pump through the operating state and the performance evaluation according to system operating conditions.

2. Experimental apparatus and method

2.1 Experimental apparatus

The calorimeter used in this study is an air enthalpy calorimeter (Fig. 1). This consists of three cord testers, air conditioner units, a data acquisition system, a sampling unit, controllers for humidity and temperature, refrigerators, a frequency transfer device, etc. All operating

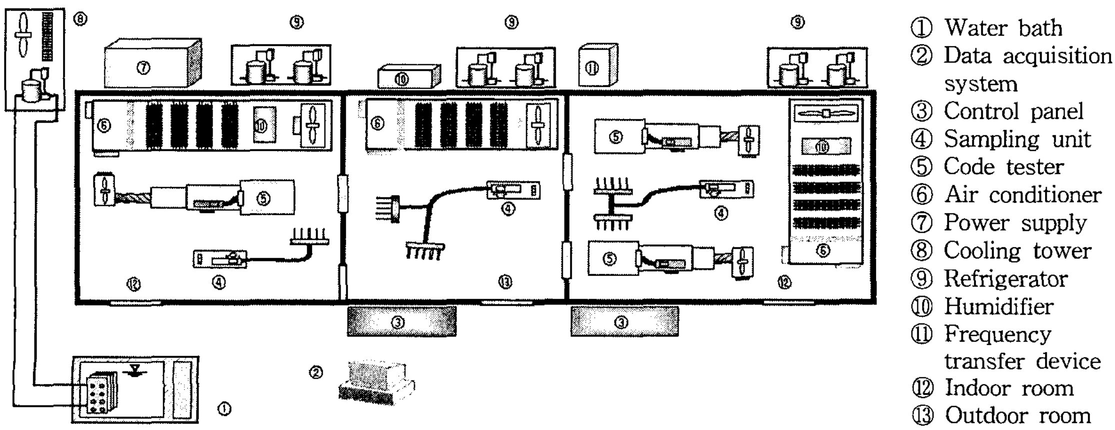

Fig. 1 Schematic diagram of the multi-calorimeter.

Table 1 Specifications of the heat pump

Compressor	Rotary type (50 Hz, 220 V, 1 Ph) 5.9 kW
Heat exchanger	Indoor : 2 row / 2 circuit, ϕ7 mm, slit fin
	Outdoor : 2 row / 2 circuit, ϕ9.52 mm, louver fin
Tube size	Gas : ϕ12.7 mm, liquid : ϕ6.35 mm
Capacity	Outdoor : 6.16 kW, indoor : 2.64 kW, 3.52 kW

states are set to be monitored by real time and adjusted by controllers.

Dry bulb temperatures are controlled by PID controllers, 15~40℃ for an indoor room and −15~60℃ for an outdoor room. The range of humidity ratio is preserved from 30% to 90% by controlling the heat transfer of humidifier heaters.

The reproducibility of the calorimeter is within ±0.5%, the reliability is within ±1.4%, and the precision of dry and wet bulb temperature is within ±0.1℃.[12] The heat pump consists of one outdoor unit with 6,160 W and two indoor units with 2,640 W (A type) and 3,520 W (B type). Table 1 shows the specification of the heat pump.

2.2 Experimental method

After selecting the length and the inside diameter of a capillary tube, the demanded refrigerant flow rate of a system is determined by calculating the pressure drop from a condenser to an evaporator. The performance of the 2 room heat pump using new refrigeration circuit is evaluated according to the KS standard.[13]

After temperature and humidity get to within the programmed stable condition range, the heat pump is continuously operated during about 1 hour. And, when the fluctuation ranges of all measuring data are within setting ranges, the data are obtained as average values every 10 minuets, total 6 times continuously. The heat transfer of the heat pump is calculated by an air enthalpy method with temperature, humidity, and flow rate, which are measured by the method of ANSI/ASHRAE Standard 58-1986 (RA 99).

The performance of the 2 room heat pump with variable cooling and heating is investigated by rating and reliability experiments. Reliability experiment is done under various different conditions, such as temperature, refrigerant flow rate, a tube length, and a power input. Table 2 shows indoor/outdoor temperatures applied rating and reliability experiments.

Table 2 Temperature applied rating and reliability experiments

Condition		Indoor room	Outdoor room
		Dry bulb temp. / Wet bulb temp. [℃]	
Cooling operation	Rating	27.0 / 19.0	35.0 / 24.0
	Over load	32.0±1.0 / 23.0±0.5	43.0±1.0 / 26.0±0.5
	Freeze up	21.0 / 15.0	21.0 / 15.0
	Flood back	19.5 / 14.0	19.5 / 14.0
	Sweat	27.0 / 24.0	27.0 / 24.0
Heating operation	Rating	20.0 / -	7.0 / 6.0
	Over load	27.0±2.0 / -	21.0±1.0 / 15.0±0.5
	Flood back	21.0 / -	−8.0 / −9.0

3. Design of refrigeration circuit

In order to control capacities of the 2 room heat pump, firstly, the size (diameter, length) of the capillary tube is determined by the calculation, which is based on a cooling operation condition. And then it is corrected through the rating experiment.

If the size of the capillary tube is decided, then a discharge pressure and a mass flow rate can be considered. The 2 room heat pump developing in this study is designed to be adaptable to different cooling and heating loads using a new refrigeration circuit applying the capillary tube. On the other hand, the accumulator is equipped in the front of a compressor to avoid liquid compression by load fluctuations. To control system capacity effectively, the circulating refrigerant flow rate flowing each circuit must be estimated accurately. First, the mass flow rate under saturation pressure and the demanded mass flow rate of the system are calculated. And the inside diameter of the capillary tube is calculated through Hopkinss data and Whitesels modified data.[14] Also, the length is calculated by the pressure drop of the capillary tube. The size of the capillary tube obtained from a series of the calculation is corrected by experiments, until the performance of the system with the new refrigeration circuit applying capillary tubes can be satisfied under various load conditions (Table 3).

The refrigeration circuit (Fig. 2) consists of 4 parts; a heating circuit (A), a cooling circuit (B), a bypass circuit (C), and a balance circuit (D). The heat pump developed from the present study satisfies various loads; a cooling operation, a heating operation, a 2 room simultaneous operation, and a single operation, because the circulating refrigerant flow rate flowing each circuit is controled suitably by opening or closing the various valves.

Table 3 Capillary tube size of heat pump

	Indoor				Outdoor
	A type		B type		Comp. bypass
	Heating	Cooling	Heating	Cooling	
Design spec. (mm)	Inner dia. : 1.8 Length : 500	Inner dia. : 1.6 Length : 1,000	Inner dia. : 2.0 Length : 500	Inner dia. : 1.6 Length : 500	Inner dia. : 2.0 Length : 1,000
Final spec. (mm)	Inner dia. : 1.2 Length : 850	Inner dia. : 1.4 Length : 1,150	Inner dia. : 1.4 Length : 850	Inner dia. : 1.4 Length : 400	Inner dia. : 1.6 Length : 1,000

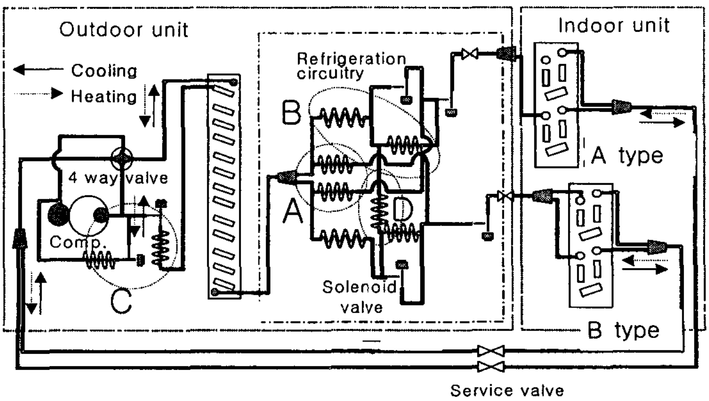

Fig. 2 Schematic diagram of refrigeration circuit of heat pump.

As equipping the bypass circuit at the exit of the compressor, the refrigerant flow rate is controlled accurately when the system is the simultaneous operation or the single operation. Also, the balance circuit is provided between A and B refrigeration circuits, to avoid the unbalance state of the refrigerant flow.

The performance of the refrigeration circuit developed by the capillary tube method is certificated by the rating experiment and the reliability experiment. In order to verify the actual capacity in contrast to the designed capacity of the heat pump developed in the present study, the rating experiment is performed. Problems revealed from the first rating experiment are solved through the repeated experiments.

4. Experimental results

4.1 Rating experiment

Figure 3 shows the results of the first and second rating experiments. As a result of the first rating experiment, the cooling or the heating capacities under the cooling operation or the heating operation are about 80% of designed value. Also, the low evaporator temperature and the low condenser temperature are measured at the cooling operation and the heating operation, respectively. To solve these problems, the refrigerant flow rate and the size of capillary tube are readjusted. When only type A operates under the cooling operation, the refrigerator cycle is optimized through the on/off control of a fan according to the temperature change of the outdoor heat exchanger.

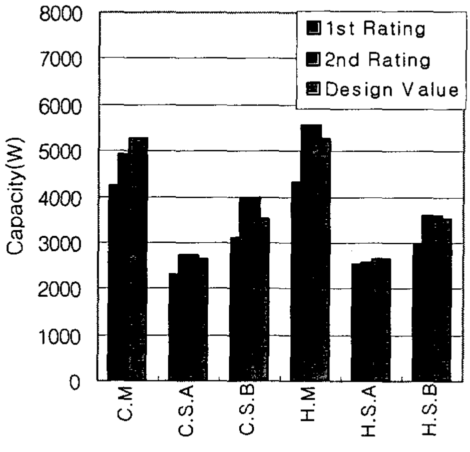

Fig. 3 Rating experiment of heat pump (C: cooling, H: heating, M: multi, S: single, A: A type, B: B type).

The second rating experiment shows that the cooling and the heating capacities are about 93 % of the design value. The capacity of cooling single operation is about 13% higher than the design value, and the capacity of heating multi operation is about 5% higher than the design value. And, the temperature of compressor is within the normal temperature range during the rating experiment. From these, the optimum refrigerant for the 2 room heat pump system applying a 5.9 kW compressor is selected as 2100 g.

4.2. Reliability experiment

To exanimate the influence of the refrigerant over/under charge on the heat pump performance, 130% and 70% charge experiments of standard refrigerant are carried out. In the case of 30% over charge, the capacity of the only heating operation is about 10% higher than the rating capacity. However, the saturated refrigerant inflow at the inlet of the compressor and the decrease in COP due to the increase in the power by over charge are observed. In the case of 70% under charge, the capacity at the heating operation is about 10% lower than the rating capacity. When the refrigerant is insufficient, the high and the low pressures of the system go down. It means the decrease in the circulating refrigerant flow rate of the system. Thus, the system heating capacity is to decrease.

To search the lowest driving voltage which the compressor can be operated stably, the ultimate trip experiment appeared OLP (Over Load Product) trip is carried out. While the heat pump is operating under the heating and the cooling standard conditions, the lowest driving voltage measured as decreasing each 10% voltage from 220 V (rating voltage). Also, the system stability is experimented by checking the real time temperatures of the inlet and outlet of the compressor. From the result, it is found that the lowest driving voltage of the compressor is about 75% of the rating voltage, and then the variation of temperatures at the inlet and outlet of the compressor is very stable.

To investigate the performance of the system applying 15 m extended tube, extension tube experiments on the single and the multi operations are carried out. The standard length of the tube is 5 m. Figure 4 is the result of extension tube experiments under the cooling operation. A type single experiment shows the similar capacity to rating experiment. B type single experiment shows 8% capacity down and multi experiment shows 4% capacity up, compared to that of the rating experiment.

When the outdoor is the low temperature and the heat pump is the heating operation, the flood back experiment is carried out to check the compressor destruction due to the non-vaporization refrigerant of the outdoor heat exchanger. The stabile operation of the experiment is assured when the temperature of the lower part of the compressor must be about 5℃ higher than the saturated temperature of a high pressure side. Also, to assure user safety and the stabile operation of the system under over load, the cooling and the heating over load experiment is carried out. Figures 5 and 6 show the real time temperature transition at 30 points of the system. Figure 5 is the real time result of the flood back experiment according to the time of the compressor stopped during 5 minuets. The oval shape (solid line) shown in the figure indicates the interval time of the compressor stopped

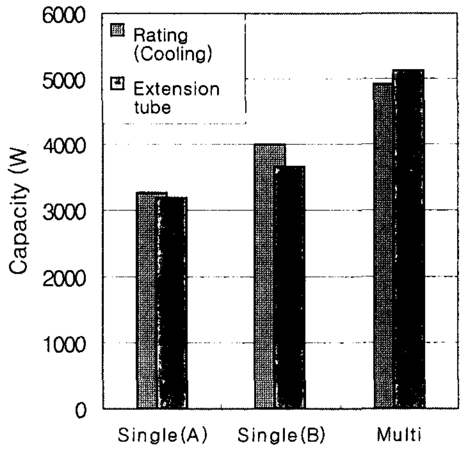

Fig. 4 Extension tube experiment of heat pump for 15 m tube length (A: A type, B: B type).

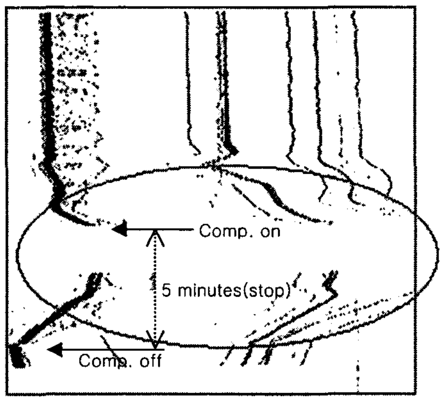

Fig. 5 Flood back experiment of heat pump.

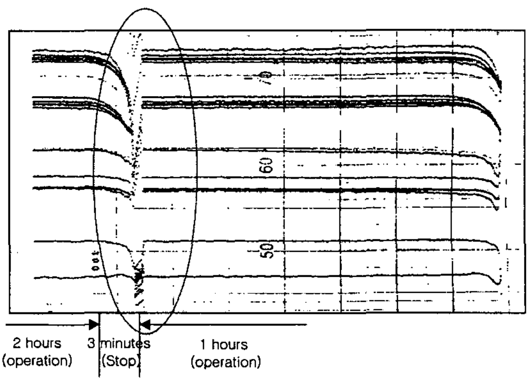

Fig. 6 Overload experiment of heat pump.

during 5 minuets. When the compressor is running, it is observed a flood phenomenon. However, the compressor after 5 minuets is reoperated normally. Figure 6 is the real time result of the over load experiment according to time (vertical line). The overload experiment is carried out at 174 V and 266 V under the rating experiment condition. After 2 hours operation and 3 minuets stop (oval solid line), the compressor is operated normally during 1 hour.

The freeze up experiment is also performed to examine the outflow (toward the indoor zone) of a frost appeared on the fin surface of the indoor heat exchanger, under the cooling operation. Figure 7 shows the frost generated on the evaporator lower part after the freeze up experiment. After 6 hours of normal operation, the system is ventilated during 1 hour. Visualization shows that about 20% surface of the evaporator is covered with the frost, but there is no outflow of ice drop during the operation.

Figure 8 shows the condensation drops on a blower. The sweet experiment examines the outflow (toward the indoor zone) condensation drops appeared on the heat exchanger surface or the blower during the cooling operation. After the indoor unit is separated from a code tester, it is operated the state of the low fan speed during 4 hours. When the air humidity is 80%, liquid drops appear at the outlet and the blower of the indoor unit, however, the outflow of liquid drops isn't observed during the operation.

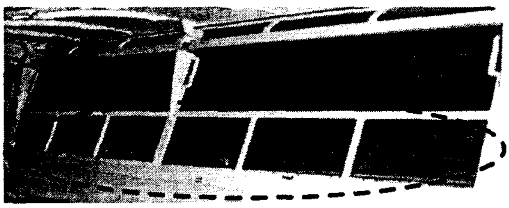

Fig. 7 Freeze up experiment of heat pump.

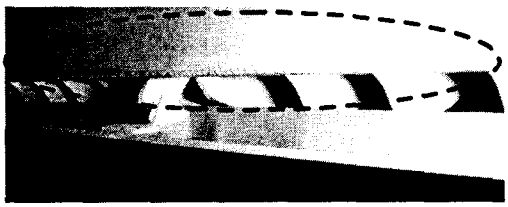

Fig. 8 Sweat experiment of heat pump.

5. Conclusions

In the present study, the 2 room heat pump system with different cooling and heating capacities is developed experimentally by applying capillary tubes and the new refrigeration circuit. The performance of the heat pump is investigated by the rating experiment and the reliability experiment, using the calorimeter. Results of the rating experiment show that the cooling and the heating capacities are satisfied above 93% of the design value. The reliability is verified by various reliability experiments. The over/under charge condition shows that the capacity is about 10% higher than the rating capacity for over charge but is about 10% lower for under charge. The freeze up and the sweet experiments show there is no outflow of ice drops or liquid drops during the operation. The lowest driving voltage of the compressor is about 75% of the rating voltage. The flood back and the over load experiment show the compressor is reoperated normally.

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