

**Performance Characteristics of a Simultaneous Heating and Cooling Heat Pump System in the Cooling-only and Cooling-main Operation Mode with the Variation of Indoor Air Temperature**

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**ABSTRACT**

The cooling load in winter season is significant in many commercial buildings and hotels because of the usage of office equipments and the high efficiency of wall insulation. Therefore, the development of a multi-heat pump which can cover heating and cooling simultaneously for each indoor unit is required. In this study, the characteristics and performance of a simultaneous heating and cooling heat pump in the cooling-only and cooling-main operating mode were investigated experimentally with the variation of indoor air temperature. The results in the two operation modes were analyzed. The comparison of performance variation due to the mode change and the indoor temperature change was carried out.

**NOMENCLATURE**

COP : coefficient of performance  
IDU : indoor unit  
ODU : outdoor unit  
DB : dry bulb  
WB : wet bulb  
CR : compression ratio  
CO : cooling-only operation mode  
CM : cooling-main operation mode  
c : cooling  
h : heating  
t : total

**INTRODUCTION**

The cooling load in winter season is significant in many commercial buildings and hotels because of the usage of office equipments and the high efficiency of wall insulation. Though the demand of a multi heat

pump increases on account of saving energy and space, a normal multi heat pump cannot supply heating and cooling capacities simultaneously and the various demands of consumers are hardly satisfied. Therefore, the development of a multi-heat pump, which can cover heating and cooling simultaneously for each indoor unit, is required to expand the market of a multi heat pump.

In this study, the characteristics and performance of a simultaneous heating and cooling heat pump in the cooling-only and cooling-main operating modes were investigated experimentally with the variation of indoor air temperature. The comparison of performance variation due to the mode change and the indoor temperature change was suggested to improve cooling and heating performances due to the various loads as a preliminary data.

**EXPERIMENTAL SETUP AND TEST PROCEDURE**

Figure 1 shows the schematic diagram of experimental setup. It was designed to obtain cooling capacity of 8.0 kW and COP of 3.2 in the cooling-only operation mode. R-410A was used as the refrigerant in the system. A hermetic rotary compressor having a brushless direct current (BLDC) motor was adopted for the optimum control of compressor speed. An EEV, consisting of a stepping motor and a needle valve, was adopted for the optimum control of refrigerant flow rate with control resolution of 500 steps. The heat exchangers for the indoor and outdoor units consisted of micro-fin tubes and slit-fins. Heating, cooling capacity and air flow rate were calculated based on ASHRAE Standard 37 [1]. The

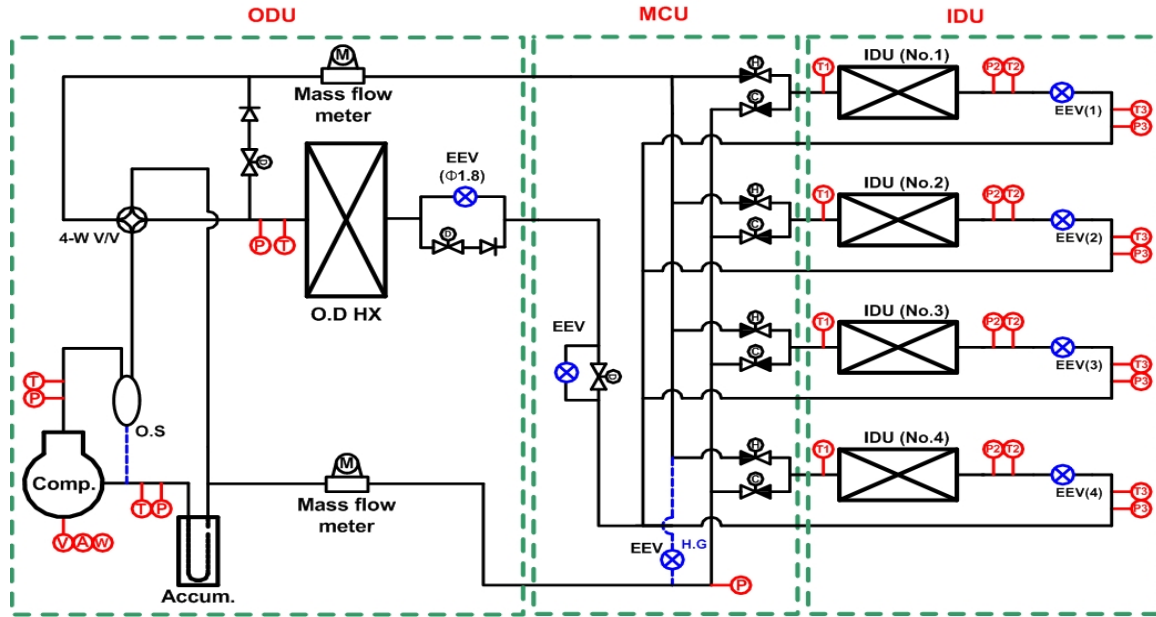


Figure 1 Schematic diagram of the experimental setup.

performance of the system was expressed as

$$COP = \frac{Q_{total\ cooling} + Q_{total\ heating}}{W}$$

Table 1 shows indoor and outdoor temperature conditions in the cooling-only and the cooling-main operation modes.

## RESULTS AND DISCUSSION

**Experimental results in the cooling-only operation mode:** When an indoor temperature changed in the cooling-only operation mode, the characteristics of the system were studied. Experiments on the optimum refrigerant charge were carried out and COP was the maximum at 3900g in the experiments. The compressor operated at the

Table 1  
IDU and ODU Temperature Conditions

| Operation mode              | IDU for cooling (DB/WB) | ODU (DB/WB)     |
|-----------------------------|-------------------------|-----------------|
| Cooling-only & Cooling-main | 21.0°C / 15.0°C         | 35.0°C / 24.0°C |
|                             | 24.0°C / 17.0°C         |                 |
|                             | 27.0°C / 19.0°C         |                 |
|                             | 30.0°C / 21.0°C         |                 |
|                             | 32.0°C / 23.0°C         |                 |
| Cooling-main                | 35.0°C / 24.0°C         |                 |
|                             | 20.0°C / 15.0°C         |                 |

rotating speed of 3500 rpm. The indoor temperature changed as to Table 1. Experiments on the optimum EEV opening in indoor units were executed and COP was the maximum at the EEV opening of 22% (110 steps) at the indoor temperature of DB 27°C/ WB 19°C.

When the indoor temperature rose from 21°C to 35°C, suction and discharge pressures increased due to the increase of evaporation capacity. It caused compression ratio to decrease. Though evaporation capacity increased and the superheated degree became larger, the density of the suction side increased due to the rise of suction pressure. Therefore, the total mass flow rate in the system increased.

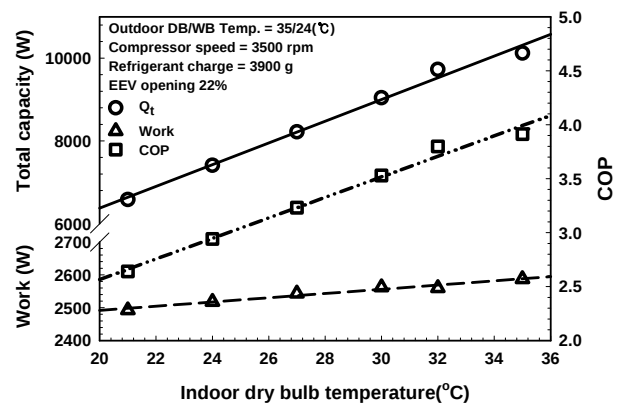


Figure 2 Variations of total capacity, work and COP with indoor temperature in the cooling-only mode

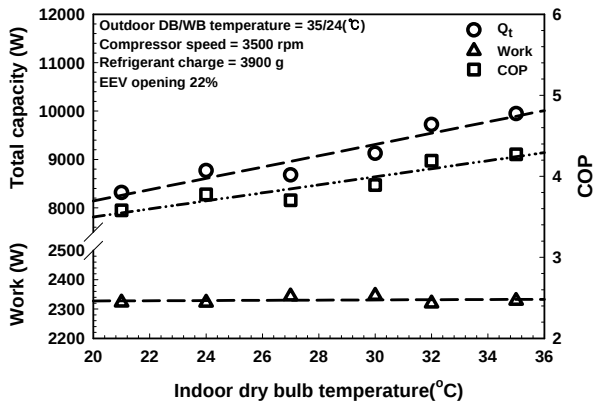


Figure 3 Variations total capacity, work and COP with indoor temperature at the EEV opening of 22% in the cooling-main mode

Figure 2 shows the variations of total capacity, compressor work and COP with an indoor temperature. As the indoor temperature increased, the mass flow rate increased. So, the work increased. The superheat became larger with the increase of evaporating capacity. However, as the difference between suction and discharge pressures decreased, the enthalpy difference between the suction and the discharge sides hardly changed. The total capacity increased by 53.8% due to the increase of the total mass flow rate and the increase of the subcooled degree and the superheated degree. As the increase of total capacity was larger than that of the work, COP increased by 48.1%.

#### Experimental results in the cooling-main operation mode:

When an indoor temperature in the cooling mode was changed in the cooling-main operation mode, the characteristics of the system were studied. When the indoor unit in the cooling mode was operated at DB 27°C/ WB 19°C and the EEV opening at MCU which controls the bypassed mass flow rate to the indoor unit for heating was 40% (200 steps), the average cooling and heating capacities per an indoor unit were 2,804 W and 2,002 W. They were higher than the designed capacity, 2,000 W. [2] The charge of refrigerant was 3,900g and the compressor rotation speed was 3,500 rpm. The EEV opening at MCU was fixed at 40%. In accordance with temperature conditions in Table 1, the system was operated in the cooling-main mode at the EEV opening of 22%, the optimum EEV opening in the cooling-only mode, and at the EEV opening of 34%, the optimum EEV opening in the cooling-main mode.

The experiments at EEV opening of 22%: As the indoor temperature went up from 21°C to 35°C, suction and discharge pressures rose. As the compression ratio became larger, the total mass flow

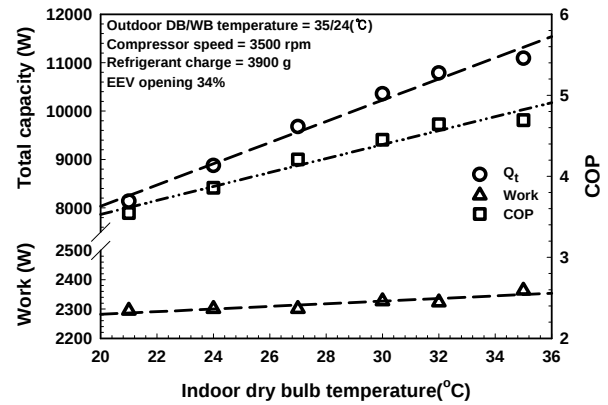


Figure 4 Variations total capacity, work and COP with indoor temperature at the EEV opening of 34% in the cooling-main mode

rate increased and the bypassed mass flow rate also increased. Due to the increase of evaporation capacity and mass flow rate, the average cooling capacity per an indoor unit increased. Since condensing capacity increased due to the rise of condensing temperature and the bypassed mass flow rate increased, heating capacity increased.

Figure 3 shows the variations of total capacity, compressor work and COP with indoor temperature at the EEV opening of 22%. As an indoor temperature went up from 21°C to 35°C, compressor work hardly changed. The reason of the little change was that the effects of the increase of mass flow rate and the decreased enthalpy difference of the compressor counterbalanced each other because the enthalpy difference between at the suction side and at the discharge side decreased. The superheat increased due to the rise of indoor temperature. But, the increase of suction pressure and the difference of suction pressure and discharge pressure caused the enthalpy difference between at the suction side and at the discharge side to decrease. Total capacity increased by 19.6% and COP increased by 19.3% due to the increase of mass flow rate and the increase of the average cooling and heating capacities per an indoor unit.

The experiments at EEV opening of 34%: Figure 4 shows the variations of total capacity, compressor work and COP with indoor temperature at the EEV opening of 34%. Like those at the EEV opening of 22%, suction pressure and discharge pressure rose. The total mass flow rate and the bypassed mass flow rate increased. As the indoor temperature went up from 21°C to 35°C, compressor work increased by 3.0%. Total capacity increased by 36.3% and COP increased by 32.4% due to the increase of the total mass flow rate and the increase of the subcooling degree and the superheat.

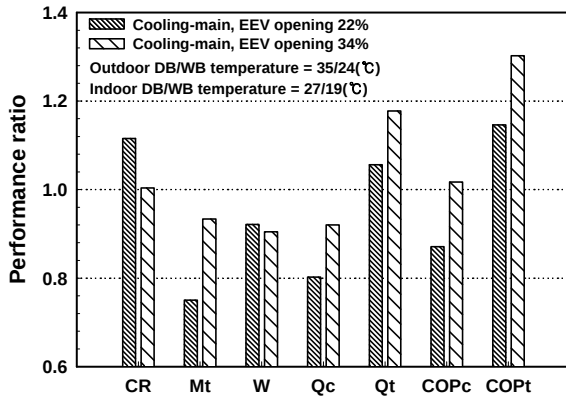


Figure 5 Ratio of performance in the cooling-main operation of EEV opening 22% and 34% to that in cooling-only mode

**Comparison of performances and characteristics in the cooling-only and the cooling-main operation mode :** Figure 5 shows the ratios of the performance in the cooling-main operation of EEV opening 22% (110 steps) and 34% (170 steps) to that in the cooling-only operation. Total cooling capacity,  $Q_c$ , in the cooling-main mode was less than that in the cooling-only mode because the number of indoor units decreased from 4 to 3. However, the average cooling capacity per an indoor unit was 7.0% more at the EEV opening 22% in the cooling-main mode than that in the cooling-only mode and 22.7% more at the EEV opening 34% since lower evaporating temperature in the cooling-main mode caused the higher efficiency of heat transfer per an indoor unit. As the compressor work was less in the cooling-main mode,  $COP_c$  was 1.7% higher at the EEV opening 34% in the cooling-main mode than that in the cooling-only mode even though  $COP_c$  did not include heating capacity. And  $COP_t$ , including heating capacity, was 30.2% more in the cooling-main mode. Figure 6 shows the variation rate of the performance in the cooling-only operation at EEV opening of 22% (110 steps) and in the cooling-main operation at EEV opening of 34% (170 steps) as the indoor temperature in the cooling mode increased from 21°C to 35°C. The compression ratio decreased more in the cooling-only mode than in the cooling-main mode. This is because the increase rate of evaporation capacity was larger in the cooling-only mode and the evaporation pressure became higher. Higher compression ratio causes lower volumetric efficiency, so that the mass flow rate decreased. The heat transfer efficiency in the system was lower in the cooling-main mode than in the cooling-only mode and the increase rate with the increase of the indoor temperature was also lower in the cooling-main mode. Therefore, the increase of the evaporation pressure was larger in the cooling-only

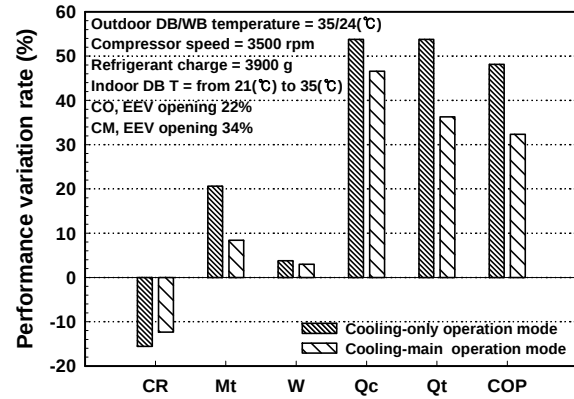


Figure 6 Performance variation rate of total capacity, work and COP from 21°C to 35°C with indoor dry bulb temperature

mode and the compression ratio decreased more. As the decrease of the compression ratio was larger and the increase rate of the density in the suction side of the compressor was also larger, the mass flow rate increased in the cooling-only mode. The compressor work, total capacity and COP increased more in the cooling-only mode with the increase of the indoor temperature. Therefore, the variation of a indoor temperature had more effect on the performance in the cooling-only mode than in the cooling-main mode.

Figure 7 shows the rate of the performance variation at 21°C and 35°C when the operation mode changed from the cooling-only to the cooling-main mode. As the difference of the suction pressure with respect to the mode change was larger at 35°C, compression ratio increased more and the total mass flow rate decreased more at 35°C. Even though the variation of the mass flow rate was less at 21°C, the decrease rate of the compressor work and total cooling capacity did not show a big difference between at 21°C and 35°C, respectively. Since the heating capacity was almost uniform regardless of temperature change and the cooling capacity was larger at a higher temperature. The heating capacity had less effect on the COP than the cooling capacity. Therefore, the COP increased much more at 21°C. When the operation mode of the system changed from the cooling-only mode to the cooling-main mode, the variation of the cooling capacity was larger at a higher temperature and the variations of the total capacity and the COP were larger at a lower temperature.

Figure 8 shows the variation of COP with total capacity in the cooling-only mode and the cooling-main mode when an indoor temperature was as to Table 1 at the EEV opening 20, 22, 24% in the cooling-only mode and the EEV opening 20, 22, 24, 34% in the cooling-main mode. The COP increased uniformly with total capacity in the cooling-only

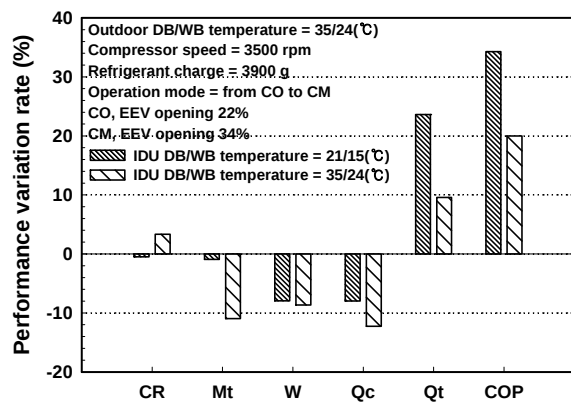


Figure 7 Performance variation rate of total capacity, work and COP from in the cooling-only mode to in the cooling-main mode with indoor dry bulb temperature

mode and the cooling-main mode as the total mass flow rate was controlled with EEV opening and total capacity changed with indoor temperature change. When total capacity became higher with the control of the total mass flow rate and the variation of an indoor temperature, higher COP was obtained. Since the increasing rate of total capacity was higher than that of the compressor work, when there is no change of compressor rotation speed, the higher work had higher COP. And COP was higher with specific total capacity in the cooling-main mode than in the cooling-only mode. As total capacity increased, the difference of COP between the two operation modes increased.

## CONCLUSIONS

The performance of the simultaneous heating and cooling heat pump system in the cooling-only mode and the cooling-main mode were tested with indoor temperature. The variation of the performance in the two modes with indoor temperature was studied and the difference between the performance in the two modes was compared each other.

(1) When the indoor temperature changed from 21°C

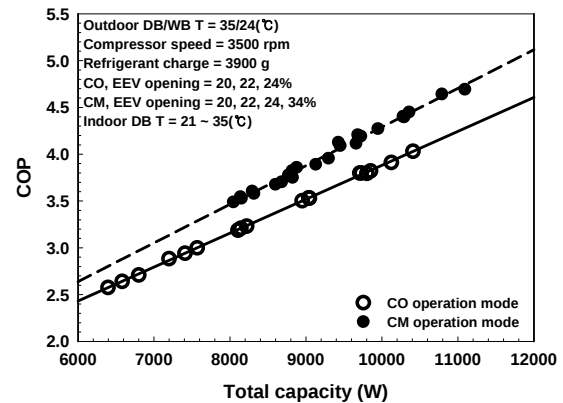


Figure 8 Variations of COP with total capacity in the cooling-only and the cooling-main mode

to 35°C, total capacity, the compressor work and COP increased.

(2) The change of the indoor temperature showed more effects on the performance in the cooling-only mode than that in the cooling-main mode.

(3) The difference between cooling capacities in the cooling-only mode and cooling-main mode was larger at 35°C than at 21°C. But, the difference of total capacity and COP was larger at 21°C than at 35°C.

## ACKNOWLEDGEMENTS

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