

AN OVERVIEW OF ENERGY-SAVING HEAT PUMP TEST FACILITY "HEAT PUMP LAB"

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Abstract: "Heat pump lab (HPL)" is a heat pump test facility of Chubu Electric Power Co., Inc. to develop and to evaluate the energy efficiency of heat pumps, which are used for the air conditioning of buildings and for cooling and heating during manufacturing process. HPL consists of two facilities (Heat pump lab East and West). "Heat pump lab-East (HPLE)" is possible to test the large heat pump unit (ex. heat pump chilling unit) with cooling capacity from 150kW to 700kW, which is the largest possible test facility of heat pump in Japan. In the case of test for an air-cooled heat pump chilling unit, cold or hot water from the test unit can be utilized as a part of air conditioning of the test room. Therefore, the air conditional energy of the facility can be drastically reduced compare to that of normal facility without exhaust heat utilization. On the other hand, "Heat pump lab-West (HPLW)" is possible to test the small heat pump unit (ex. multi-type air-conditioner) with cooling capacity from about 10kW to 170kW. In this paper, an overview of HPL and the examples of energy efficiency evaluation for the heat pump using HPL are introduced.

Key Words: heat pumps, test facility, energy saving, efficiency

1 INTRODUCTION

The consideration to the global warming and energy saving is rising every year, and the heat pumps have been focused to one of the most effective among the technologies for carbon dioxide reduction and the energy problems. Chubu Electric Power Co., Inc. has activated the development and the promotion of heat pump unit with high efficiency because of a viewpoint of the efficient utilization of energy. In this paper, an overview of test facility "Heat pump lab (HPL)" and the examples of energy efficiency evaluation for the heat pump using HPL are introduced.

2 OVERVIEW OF HPL

2.1 Purpose of Use

There are three purposes of use for HPL. The first is the development of high efficiency heat pump units. This contributes for the reduction of CO₂ and energy saving. In many cases, the development of the heat pump unit is collaborated with the manufacture companies. The second is energy efficiency evaluation of heat pumps. Evaluating the performance of heat pumps at various conditions corresponding to the actual customer's use contributes to effective energy saving of our customers. Mostly, the heat pump performances described in catalog are the value at the rated condition only. Therefore, we have examined heat pump performance at various temperature conditions and various partial load conditions. The third is funded research and testing. These contribute for efficient uses of HPL.

2.2 Characteristics of Test Facility

Picture 1 shows an exterior view. HPL consists of two facilities. Heat pump lab-East (HPLE) is possible to test of the large heat pump unit (ex. air cooled heat pump chilling unit) and Heat pump lab-West (HPLW) is possible to test of the small heat pump unit (ex. package type air conditioner and multi-type air conditioners).



Picture 1: Exterior View of HPL

2.2.1 Heat pump lab-East (HPLE)

Table 1 shows main specification of HPLE. Figure 1 and Figure 2 show a plan view and a sectional view of HPLE in detail, respectively. Four air-conditioners at the corner of the room and a heat storage tank are installed, and a tested heat pump unit is located in the center of the room. We can examine an air-cooled heat pump chilling unit with cooling capacity up to about 700kW. This is the largest possible as the test facility of heat pump in Japan. The air inlet port of the air-conditioners is located above the air-conditioner, and the air outlet port is located below as shown Figure 2. As the result, since airflow around the test unit moves not only in the horizontal direction but also in the vertical direction, stabilization of the environment around the tested unit is attained.

Generally, examining a large-sized air-cooled heat pump unit inside the facility consumes a large amount of air-conditioning energy due to the process of the exhaust heat. Therefore, in HPLE, the air-conditioning energy is drastically reduced by using the cold (or hot) water generated with a tested unit as shown in Figure 2. According to the calculation, it is expected that the air-conditioning energy of HPL can expect 71% reduction for cooling or 70% reduction for heating as compared with that of an air conditioner which does not use exhaust heat.

Table 1: Main Specification of HPLE

Type of tested heat pump	Heat pump chilling unit	
Test range	Cooling capacity	150~700kW
	Heating capacity	130~600kW
Range of temperature and humidity	-20~50°C, 40~90%RH	
Dimension	16.8m(L)x16.4m(W)x11.7m(H)	

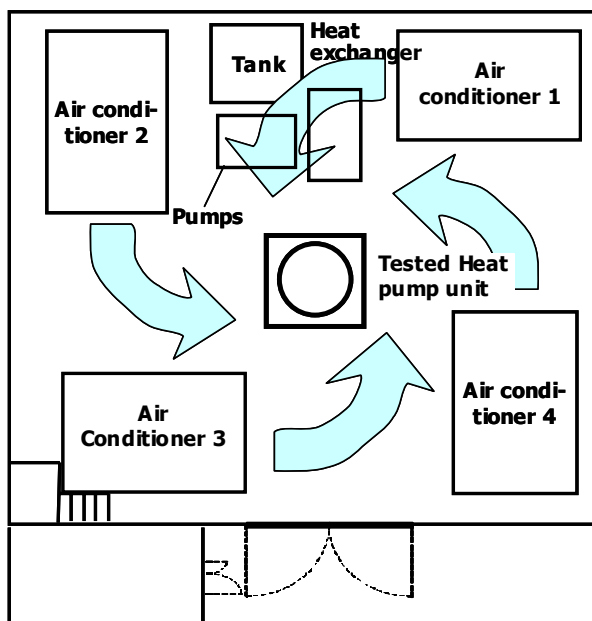


Figure 1: Plain view of HPLE

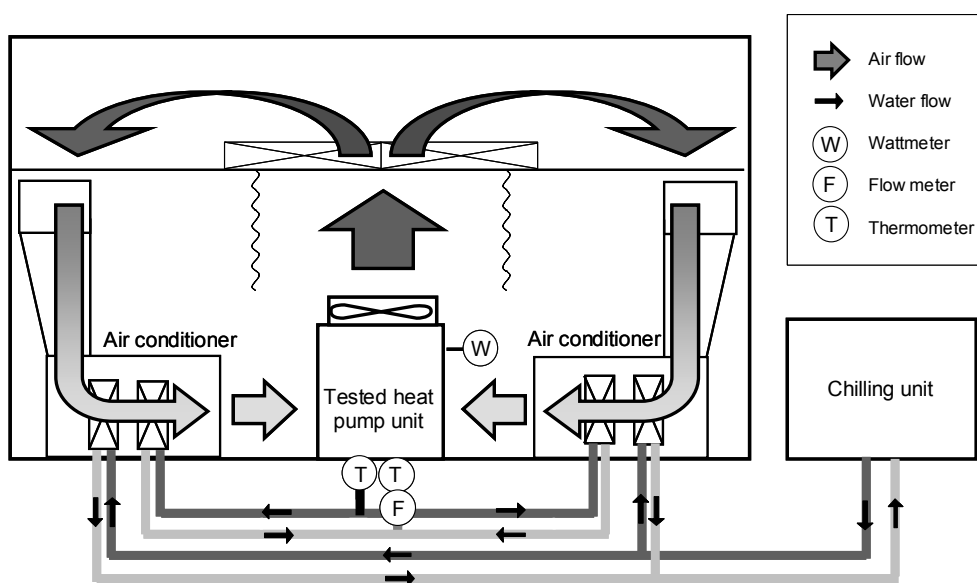


Figure 2: Sectional view of HPLE

2.2.2 Heat pump lab-West (HPLW)

Table 2 and Figure 3 show main specification and a plain view of HPLW, respectively. HPLW consists of two test rooms. An outdoor unit is set in the Room 2 and indoor units-cassette type mounted on the ceiling is set in the Room 1. We can install a maximum of six sets of the ceiling cassette side interior units in the Room 1 or Room 2. Using air enthalpy test method, the cooling of the tested air-conditioners can be obtained up to about 170kW. The air temperature and humidity in the Room2 can be controlled independently of the thermal load in the Room1; the former can be changed from -20 °C to 50 °C, and the latter 40 % - 90 % in RH. Thus one can evaluate the performance of the air-conditioner operated under the partial thermal load conditions at various outdoor air temperatures. It should be noted that HPLW was authorized for having accuracy equivalent to the testing laboratory of Japan Refrigeration and Air Conditioning Industry Association (JRAIA), which acquired certification to ISO 17025.

Table 2: Main Specification of HPLW

Type of tested heat pump	Multi-split system, Packaged type	
Test range	Cooling capacity	14~168kW
	Heating capacity	16~200kW
	Air flow	10~510m ³ /h
Range of temperature and humidity	Room1	0~50°C, 40~90%RH
	Room2	-20~50°C, 40~90%RH
Dimension	Room1	10.6m(L)x7.4m(W)x4.8m(H)
	Room2	10.6m(L)x6.9m(W)x4.8m(H)

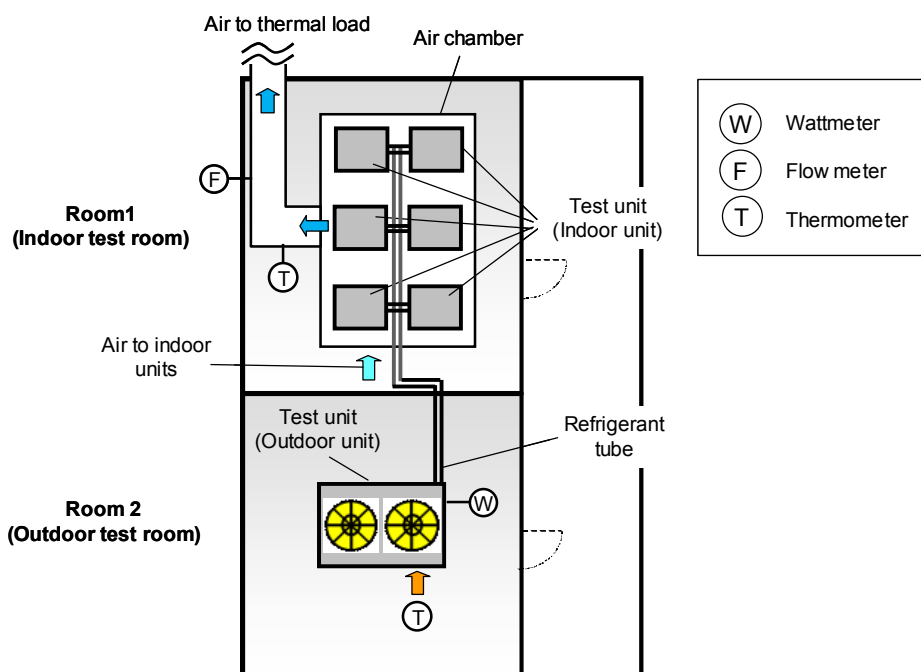


Figure 3: Plain view of HPLW

3 RESEARCH ACTIVITIES USING HPL

In this chapter, the examples of the energy efficiency evaluation of the heat pumps, which is one of the purposes of use for HPL, are introduced.

3.1 High Efficiency Air-Cooled Heat Pump Chiller

In 1980~1990s, low efficient absorption water chilling units have been widely used for middle-scale buildings in Japan because heat source of both cold and hot water are generally necessary. Therefore, In order to satisfy the renewal demand of such absorption water chilling units, the compact and highly efficient heat pump chillers have been developed. In this section, we show the result of the performance tests of an air-cooled heat pump chilling unit with high efficiency were conducted by using the HPLE.

3.1.1 Test method and conditions

Table 3 and Table 4 show the specifications of the tested heat pump chilling unit and test conditions, respectively. In the cooling operation test, the outdoor air temperature t_j (dry-bulb temperature) was changes at 20 °C, 30°C and 35°C and the thermal loads were changed from 25 % to 100 % of the rating cooling capacity. The leaving water temperature was controlled at 7°C. In the heating operation test, t_j was changed from 2°C to 12°C, and the thermal loads were changed from 25 % to 100 % of the rating heating capacity. The leaving water temperature was controlled at 45°C. COPs of the unit were calculated based on the data obtained under the steady-state condition. In heating condition of 2°C, however, intermittent operations of the compressors were observed. In this case, we confirmed that a periodicity appeared in the operations of the compressors and COP was calculated based on the average in one cycle.

Table 3: Specification of Tested Heat Pump Chilling Unit

Items	Specifications
Cooling capacity ^{*1)}	180kW(50USRT)
Heating capacity ^{*2)}	160kW
Refrigerant	R410A

*1) Rated cooling conditions are entering water temperature 12°C, leaving water temperature 7°C, and outdoor temperature 35°CDB/24°CWB

*2) Rated heating conditions are entering water temperature 40oC, leaving water temperature 45°C, and outdoor temperature 7°CDB/6°CWB

Table 4: Conditions of Partial Load Tests

Type of Test	Outdoor Air Temperature DB / WB	Thermal Load Ratio (%)
Cooling	20 °C / -	25, 50, 75, 100
	30 °C / -	25, 50, 75, 100
	35 °C / -	25, 50, 75, 100
Heating	2 °C / 1 °C	25, 50, 75, 100
	7 °C / 6 °C	25, 50, 75, 100
	12 °C / 11 °C	25, 50, 75, 100

3.1.2 Test results

Figure 4(a) shows the results of COP obtained in the partial thermal load performance tests for the cooling operation. The parameter t_j is the dry-bulb temperature of outdoor air. COPs measured under the conditions in Table 4 are normalized by that obtained under the

condition of $t_j = 35\text{ }^\circ\text{C}$ and thermal load 100 %. In all the thermal load ratios, COP decreases as the outdoor air temperature rises. This decrease of COP is caused because the pressure of the refrigerant in the condenser becomes higher to keep enough temperature difference between the refrigerant and outdoor air for heat exchange. Under the constant outdoor air temperature, on the other hand, COP increases gradually as the thermal load is decreased and attains the maximum at 50 % or 25 %. In general, the operation at the low and medium load is very long compared to that at high load all the year round. Hence efficiency at low and medium loads is very important from an energy conservation standpoint. In this unit, a highly effective driving at the partial load was achieved by controlling the number of the compressor driving, the frequency of the compressor, and the rotational speed of the fan. The results of COP obtained in the heating operation tests are shown in Figure 4(b). In this figure, COP is normalized by that measured under the condition of $t_j = 2\text{ }^\circ\text{C}$ and thermal load 100 %. COPs were calculated involving the electricity consumed in the defrosting operation. COP increases as the outdoor air temperature rises. Under constant t_j , differ from the results of the cooling performance test, COP is almost constant as the thermal load is decreased. To evaluate the performance of the tested unit, we calculated the running cost and the CO₂ emission on a trial basis, when the replacing to tested unit from the absorption chilling unit. It compared by having assumed an office building in the Nagoya district of 50USRT x 6unit. Figure 5 shows comparison of running cost and CO₂ emission. Compared to the absorption chilling unit, running cost can be reduced 54% and CO₂ emission can be reduced 56%. It is confirmed the tested unit is an effective product to reduce the running cost and CO₂ emission by means of the replacement from the absorption chilling unit.

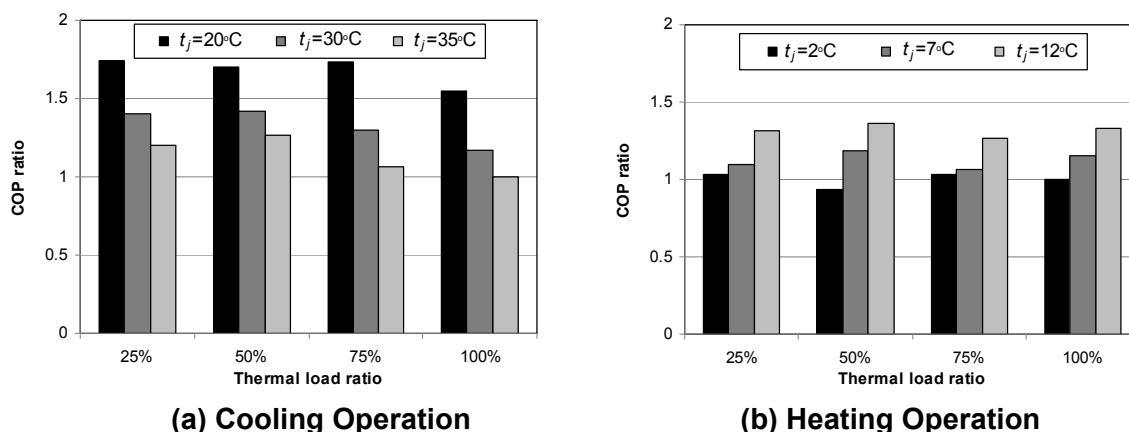


Figure 4: Coefficients of Performance obtained in the partial thermal load tests

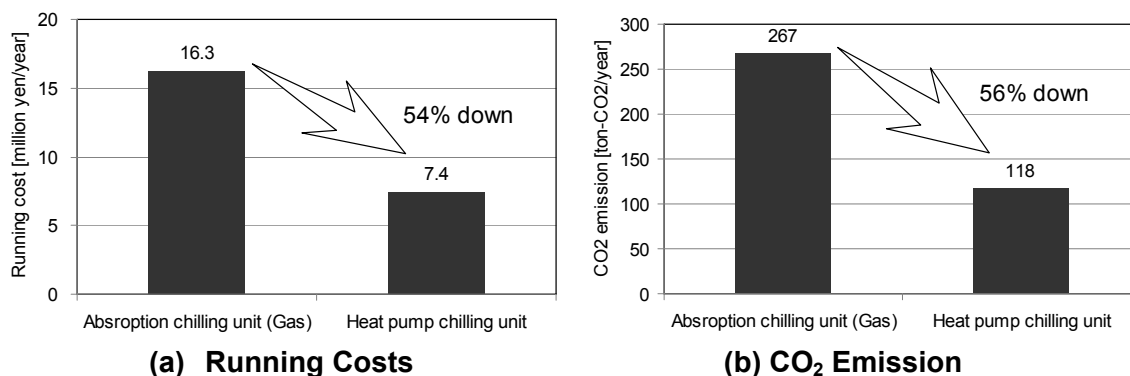


Figure 5: Comparison of Running Cost and CO₂ Emission

3.2 Multiple Air-Conditioning System Providing Simultaneous Cooling and Heating

In the office buildings of Japan, installation of the multiple air-conditioning system providing simultaneous cooling and heating (MAC-SIM) which allows freely selectable cooling and heating from each indoor unit on a single refrigerant piping system is increasing recently. In addition, it is expected that MAC-SIM have the high energy-saving effect as compared with the conventional multiple air-conditioning system (MAC), because the exhaust heat can be utilized. However, in the situation where the cooling and the heating load are intermingled, the performance characteristics of MAC-SIM are not clarified. Therefore, in order to make clear the performance characteristics of MAC-SIM, we carried out by using both HPLW and HPLE.

3.2.1 Test method and conditions

Table 5 shows the detailed specifications (nominal values listed in catalog) of the tested MAC-SIM. The air-conditioner powered by electric motors (EHPs) have a rating cooling capacity of 56 kW and a rating heating capacity of 63 kW. An inverter is used to control the revolutions of the compressors. This MAC-SIM has two outdoor units and four indoor units of ceiling-mounted cassette type. In the case of cooling individual operation (or heating individual operation) and the simultaneous operation which use one interior unit or two interior units at each room, we carried out the test in the arrangement A as shown in Fig.6(a). On the other hand, in the case of simultaneous operations which use three interior units at a room, we carried out the test in the arrangement B as shown in Fig.6(b).

The test conditions in the case of cooling individual operation (or heating individual operation) only are shown in Table 6. In this study, in addition to the partial thermal load performance, we measured the rating performance of these air-conditioners based on the method prescribed in JIS B 8615-1:1999. In this test, the performance of the air-conditioner was measured keeping the revolutions of the compressors at a rating value. The indoor thermal loads were changed at 15 %, 50%, 100 % of the rating capacity for each outdoor temperature (SHF = 0.85). In the cooling operation test, the temperature in the indoor test room was controlled at 27 °C by the air-conditioner itself to simulate its actual operating situation. In the heating operation test, the temperature in the indoor test room was controlled at 20 °C by the air-conditioner.

The test conditions in the case of simultaneous cooling and heating operation are shown in Table 7. The outdoor air temperature was fixed at 7°CDB / 6°CWB. The indoor air temperature for cooling operation was controlled at 27°CDB/19°CWB and that for heating operation was controlled at 20°CDB.

Table 5: Specifications of Tested Air-Conditioners

Type	Multiple Air-Conditioning System Providing Simultaneous Cooling and Heating
Cooling Capacity ^{*1)}	56 kW
Heating Capacity ^{*2)}	63 kW
Refrigerant	R 410A
Type of Indoor Unit	Ceiling-mounted Cassette
Compressor Control	Variable Speed by Inverter or Variable Speed by Inverter + Constant Speed

*1) Rated cooling conditions are indoor temperature 27°CDB/19°CWB and outdoor temperature 35°CDB.

*2) Rated heating conditions are indoor temperature 20°CDB and outdoor temperature 7°CDB/6°CWB

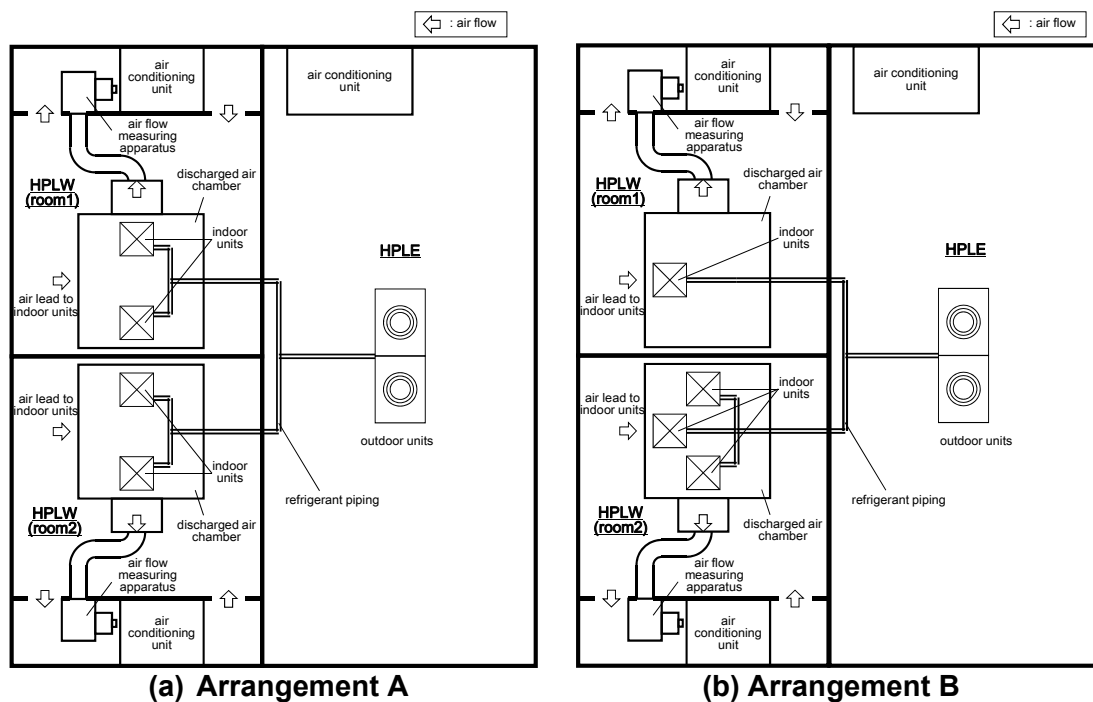


Figure 6: Schematic Diagram of Testing Facility

Table 6: Test Conditions for Cooling/Heating Individual Operation

Type	Outdoor Air Temperature (°C) DB / WB	Partial Load Ratio (%)
Cooling	12/-, 20/-, 30/-, 35/-	15, 50, 100
Heating	2/1, 7/6, 12/11	15, 50, 100

Table 7: Test Conditions for Simultaneous Cooling and Heating Operation

Type	Combination of Indoor Units Number						Indoor Air Temperature (°C) DB / WB
Cooling	3	2	1	1	2	1	27/19
Heating	1	2	3	2	1	1	20/ -

3.2.2 Test results

Figure 7(a) shows the results of COPs obtained in the cooling individual operation. COPs are normalized by that obtained under the rating cooling condition ($t_j = 35^\circ\text{C}$ and partial load ratio 100 %). In all the thermal load ratios, COP decreases as the outdoor air temperature becomes higher. Under the constant outdoor air temperature, COP increases gradually as the thermal load is decreased and attains the maximum at partial load ratio=50 %, but it decreases at partial load ratio=15 %. This deterioration of the performance at the low thermal load is caused by the intermittent on-off operation of the compressors (Watanabe et al. 2007).

Figure 7(b) shows the results of COP obtained in the partial thermal load performance tests for the heating individual operation. COPs are normalized by that obtained under the rated heating condition ($t_j = 7^\circ\text{C}$ and partial load ratio 100 %). Similar to the cooling operation, COP increases gradually as the thermal load is decreased and attains the maximum at partial load ratio=50 %.

Figure 8 shows the results of COPs for simultaneous cooling and heating operation. COPs are defined that summation of the measured cooling capacity and heating capacity is divided by the electric input, and are normalized by COP at the rated heating condition. COP of two cooling operations and two heating operations has 1.8 times larger than that of the rated heating operation (i.e. four heating operations). In the other operation conditions, COPs are 1.1 to 1.2 times larger than that of the rated heating condition.

Figure 9(a),(b) show two typical examples which compared the operational status of the outdoor units. In the case of two cooling operations and two heating operations, one set of an outdoor unit was used as the evaporator, and only a small amount of heat (equivalent to the difference of the cooling capacity and the heating capacity), which could not be exchanged between indoor units, was absorbed from the outdoor air. On the other hand, in the case of three cooling operations and one heating operation, one of two outdoor units was used as the evaporator and another side as the condenser. Though the outdoor unit should dissipate the heat, which could not be exchanged between interior units, the unit was vainly absorbed from the outdoor air, and heat absorption and heat dissipation had occurred simultaneously. This is considered to be control for preventing the frequent change of heat absorption and heat dissipation from the outdoor unit in order to maintain the indoor comfortable nature.

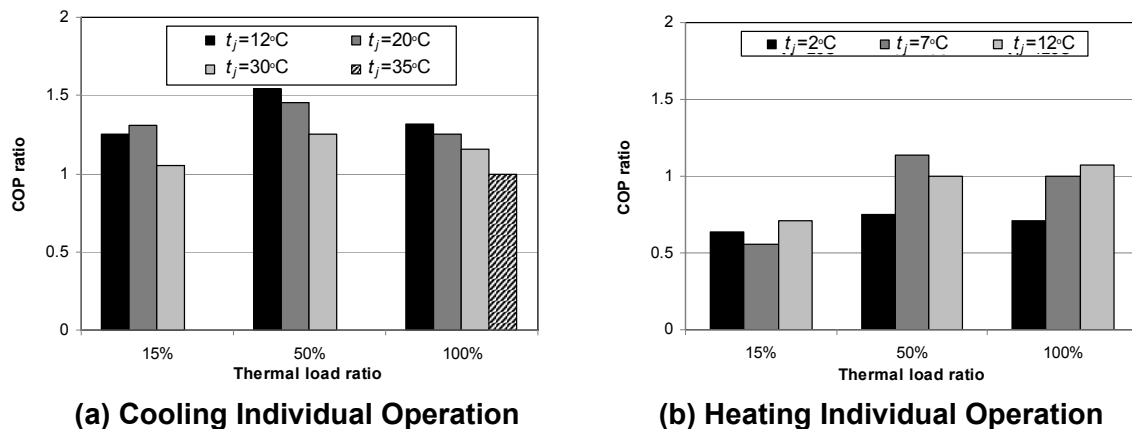


Figure 7: COPs obtained in Cooling/Heating Individual Operation

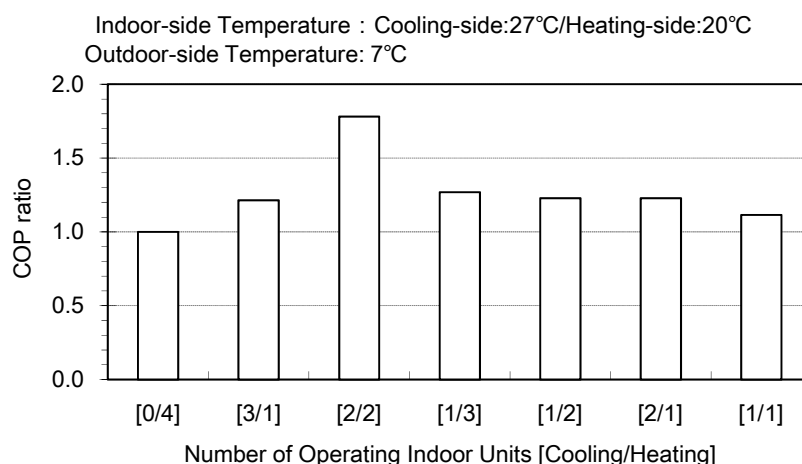


Figure 8: COPs obtained in Simultaneous Cooling and Heating Operation

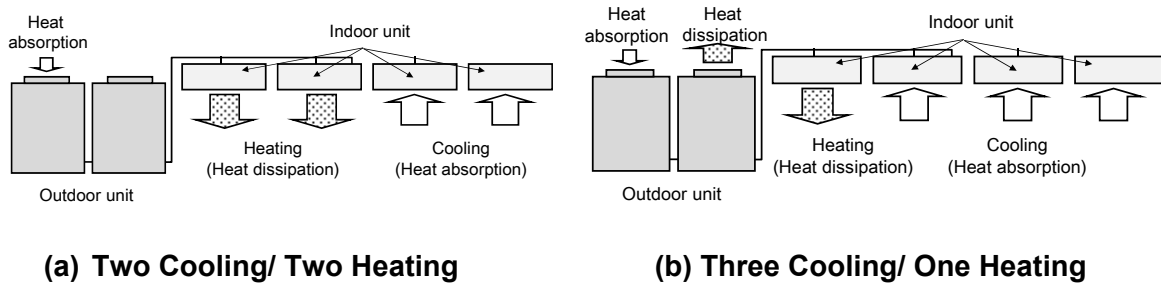


Figure 9: Examples of Status in Simultaneous Cooling and Heating Operation

4 CONCLUSIONS

In this paper, an overview of test facility "Heat pump lab (HPL) " of Chubu Electric Power Co., Inc. and the examples of energy efficiency evaluation for the heat pump using HPL were introduced. Promoting the substitution of cooling/heating and hot water supply with the fossil fuel in a high efficiency heat pump unit can contribute to the reduction of CO₂ emissions, and can contribute greatly as a global warming measures. We utilize the performance data obtained by using HPL for energy saving activities of customers. In addition, we further accelerate the development of heat pumps for the air conditioning of buildings and for cooling or heating in the manufacturing processes cooperation with the manufacture companies.

5 REFERENCES

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