PERFORMANCE IMPROVEMENT OF GROUND SOURCE HEAT PUMP SYSTEMS BY APPLYING MULTI-SPLIT HEAT PUMPS AND LOW FLOW CIRCULATION SYSTEM

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Abstract: In order to promote installation of the ground source heat pump (GSHP) system to the medium-scale building in moderate climate region, the authors have developed a low flow circulation (LF) GSHP multi-split system. This system applies low flow and large temperature difference circulation system in primary side and multi-split system in secondary side and can reduce energy consumption for circulating the thermal medium. The authors have been conducted field experiment of the LF-GSHP multi-split system since June 2006. Until present, the result of cooling operation demonstrated that the output and COP with the highest output in this field test were almost equal to the one in laboratory experiment. This was similar to the result of heating operation. Result of cooling operation with the output of around 7 kW provided the largest COP of 6~8.

Key Words: ***Ground Source Heat Pump, Multi-split Heat Pump, Low Flow Circulation, Field Test***

1 INTRODUCTION

The Ground Source Heat Pump (GSHP) system can generally operate with higher efficiency than the Air Source Heat Pump (ASHP) system. The number of the GSHP systems installed in Japan has been increasing from a viewpoint of energy saving and reduction of CO_2 emission. However, very few of the GSHP systems are installed in the medium-scale buildings in the moderate climate region, whose area occupies approximately two-third of the total area of the whole buildings in Japan. The reason is that combined efficiency of the GSHP system is decreased due to electric power consumption of the circulation pumps. Also, cooling demand is larger than heating demand in almost of the medium-scale buildings in the moderate climate region. Therefore, it is predicted that the ground temperature is increased and efficiency of the heat pump unit becomes worth by excessive heat injection compared to heat extraction.

In order to promote installation of the GSHP system to the building, the authors have developed the Low Flow Circulation Ground Source Heat Pump (LF-GSHP) multi-split system, which can operate with lower energy consumption of circulation pumps. Additionally, the authors investigate utilization of heat of the ground water flow and the combined use of a cooling tower and the ground heat to resolve temperature increase by the excessive heat injection.

In this paper, the authors firstly describe the system configuration and schedule of the development. Next, outlines and results of field tests of the LF-GSHP multi-split system were introduced. The LF-GSHP multi-split system in this field has a water-source multi-split heat pump and steel foundation piles as ground heat exchangers. The authors have measured performance of the heat pump system during heating or cooling operation by changing heat demand and flow rate in the primary side.

2 OUTLINES OF LOW FLOW CIRCULATION GROUND SOURCE HEAT PUMP MULTI-SPLIT SYSTEM

2.1 System concept

Figure 1 shows an example of the conventional GSHP system, which consists of water-water heat pump units, ground heat exchangers, circulation pumps, and fan-coils. In the cooling period, the ground temperature is generally lower than ambient air temperature. Thus it is not difficult to obtain the average heat pump COP of more than 5.0 during cooling period by designing the GSHP system adequately. However, energy consumption of the circulation pumps is relatively large and it is more than 40 % compared to that of the compressor in the heat pump unit. This decreases the system COP (SCOP), which means total performance of the GSHP system including circulation pumps, around 3.6 as shown in Figure 1. On the other hand, ASHP system multi-split system widely installed to medium-scale buildings in moderate climate region of Japan can operate with no energy consumption of circulation pumps. As the result, advantages of the GSHP system compared to the ASHP system, which are e.g. energy saving and reduction of the CO_2 emission, get lower.
Therefore, the LF-GSHP multi-split system has been developed in order to keep the advantage of the GSHP system and prevent decrease of the SCOP. This system adopts low flow and large temperature difference circulation system in the primary side and multi-split system in the secondary side. The SCOP will be achieved around 4.5 by adopting the low flow circulation system and water source multi-split heat pump as shown in Figure 1.

2.2 Schedule of development

As shown in Table 1, development of the LF-GSHP system is scheduled from Apr. 2006 to Mar. 2009. In the first year, prototype ground heat exchangers applying low flow circulation and water source multi-split heat pump unit are developed and tested each other. These are integrated as the LF-GSHP system and the characteristics are investigated in the field test, which is carried out in the second year. However, field test using only the ground heat exchangers is also continued in order to standardize the specification. The result of field test with the ground heat exchangers is reported in the other paper. In the final year, the authors demonstrate that the LF-GSHP system can operate with average SCOP of more than 4.5 throughout the cooling period.
On the other hand, to absorb excessive exhaust heat generated by the cooling operation is also important for keeping higher energy efficiency of the LF-GSHP system as described above. From this reason, effect of the ground water flow to the ground temperature and design method of the LF- GSHP system integrated with the cooling tower are investigated. Finally, a design tool for the LF-GSHP system integrated the calculation method is developed. Other experiments and investigates are also conducted but the detail will be reported in future.

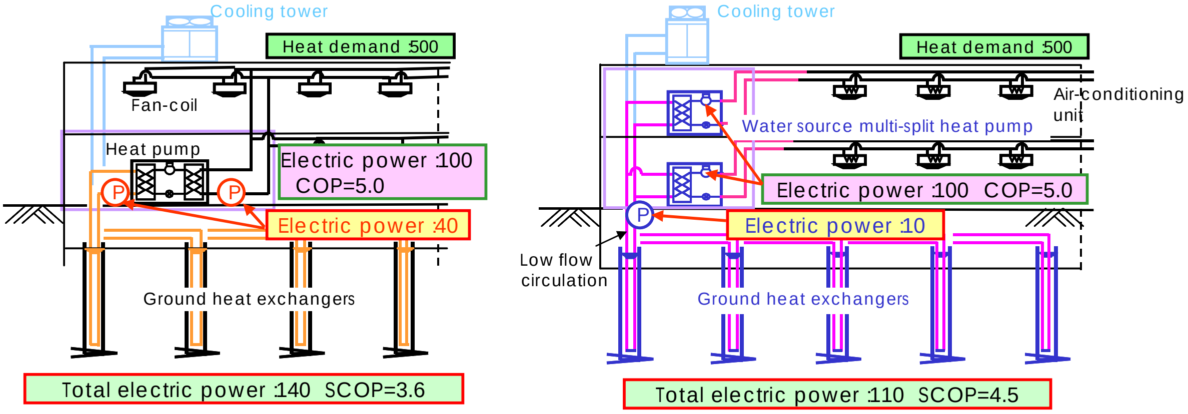


Figure 1: Example of conventional GSHP system (Left) and LF-GSHP multi-split system (Right)

Table 1: Schedule of development

Item	Apr. 2006 – Mar. 2007	Apr. 2007 – Mar. 2008	Apr. 2009 – Mar. 2010
Ground heat exchanger	Field test of heat extraction or injection	Continue	Standardize specification
Heat pump unit	Performance test in laboratory	Field experiment of integrating system (to investigate characteristics)	Field experiment of integrating system (to demonstrate system performance)
Design tool	Investigate calculation method of the ground temperature affected by ground water flow Investigate calculation method of the GSHP system integrated cooling tower		Development of a design tool integrated the calculation method

3 FIELD EXPERIMENT OF LOW FLOW CIRCULATION GROUND SOURCE HEAT PUMP MULTI-SPLIT SYSTEM

3.1 Outlines of field experiment

3.1.1 Experimental set-up

Experimental apparatus of LF-GSHP multi-split system had been constructed in experimental field in Ishikari, Japan and field test has been conducted since June 2007. Figure 2 indicates location of Ishikari. Ishikari city is neighboring Sapporo city, which is the capital city in Hokkaido Island of Japan. Figure 3 and Figure 4 show plane view and appearance of the experimental site. As many as eight piles are buried into the ground. The one is a pre-casting concrete pile with outside diameter of φ500 mm and the others are steel foundation piles. The outside diameters are φ400 mm for the four piles and φ267 mm for the three piles. As shown in Figure 3, the three piles are buried at interval of 0.9 m each other. Each pile is connected to a water source multi-split heat pump unit or control equipment for heat extraction test. At present, the pre-casting concrete pile and three steel foundation piles surrounded by thick line in Figure 3 are used for the experiment with the heat pump unit.

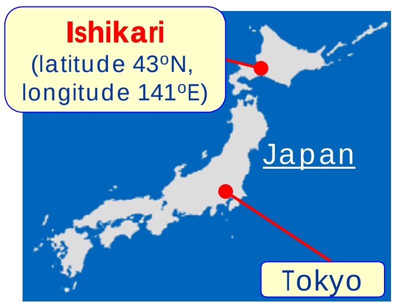


Figure 2: Location of experimental site

Shown in Figure 5 is diagram of the experimental set-up. The multi-split heat pump unit is connected to the foundation piles utilized as ground heat exchangers. This heat pump unit can operate for both of cooling and heating and it conditions the air in the testing room, which has area of 29m^2 × 2 floors. The exhaust heat generated by the cooling operation is injected to the ground via the ground heat exchangers. The heat required to the heating operation is also extracted from the ground.
Two oil boilers are equipped and cooling demand is imitated by using two fan-coils connected to the oil boilers. The reason is that the site is located in cold climate region and cooling demand would not be enough to operate the LF-GSHP system. These boilers can also heat the thermal medium in the primary side of the heat pump unit. It prevents excessive temperature decease and freeze-up of the thermal medium during the heating operation.

3.1.2 Water source multi-split heat pump unit

Figure 6 shows appearance and specification of the multi-split heat pump unit. This unit has an inverter driven compressor with 10 horsepower and can vary the heating or cooling output according to the heat demand. The unit is similar to the one that is available for consumer but it is modified to operate for heating with the lower thermal medium temperature and lower flow rate in the primary side. By the modifying, it is confirmed that the unit can operate on conditions of T_{1in} = 10 ^{o}C and G_f = 30 L/min in the laboratory test shown in Figure 7.

3.1.3 Measurement point

Measurement points are indicated in Table 2. Pt-100 sensors are installed at inlet and outlet in primary side of the heat pump unit. Inlet and outlet of the ground heat exchangers have temperature measurement point with Pt-100 sensors each other. Water temperature in each pile is measured by T-type thermo couples at 13.5 m deep. Internal surface temperature external surface temperature of U-tube is also observed at 13.5 m deep for each pile.
As shown in Figure 8, temperature and relative humidity sensors are placed at inlet and outlet of air-conditioning units in 1st and 2nd floor, respectively. Room temperature and relative humidity in 1st and 2nd are also measured by the ones.
Electromagnetic flow meters are equipped in each line that leads to the pile. Power meters set at the compressor of the heat pump unit and circulation pump in primary side measures the electric power. Additionally, temperature sensors and presser sensors are previously installed in the heat pump unit.

3.1.4 Test procedure and experimental conditions

As indicated in Table 1, the authors conduct field experiment to investigate characteristics of the LF-GSHP system integrated the water source multi-split heat pump unit and ground heat exchangers applying low flow circulation from Jun. 2007 to Mar. 2008. The LF-GSHP system is operated for cooling from Jun. 2007 to Sep. 2007 and for heating from Nov. 2007 to Mar. 2008, respectively.
Performance of the LF-GSHP system is evaluated by using test results of two types of operation. In the first one, the flow rate G_f and heating output O_{hph} or cooling output O_{hpc} are kept constant as far as possible. The example is demonstrated in Figure 9 and this is called 'constant output operation'. The other is 'continuous operation' in which we let the LF-GSHP system run its course as shown in Figure 10.
Figure 11 shows experimental conditions during cooling period, which are variations of system operating time, flow rate G_f, and cooling demand imitated by the oil boiler system. The oil boiler system can change the heating output. Thus the heating output is changed at 1:00 pm like Figure 10 in order to carry out experiment with the different condition. Figure 12 is experimental conditions during heating period, which are variations of system operating time, flow rate G_f, and set temperature of T_{1in}. In the heating operation, since the temperature T_{1in} can be kept constant by the oil boiler system, the temperature is set at 10 ^{o}C.

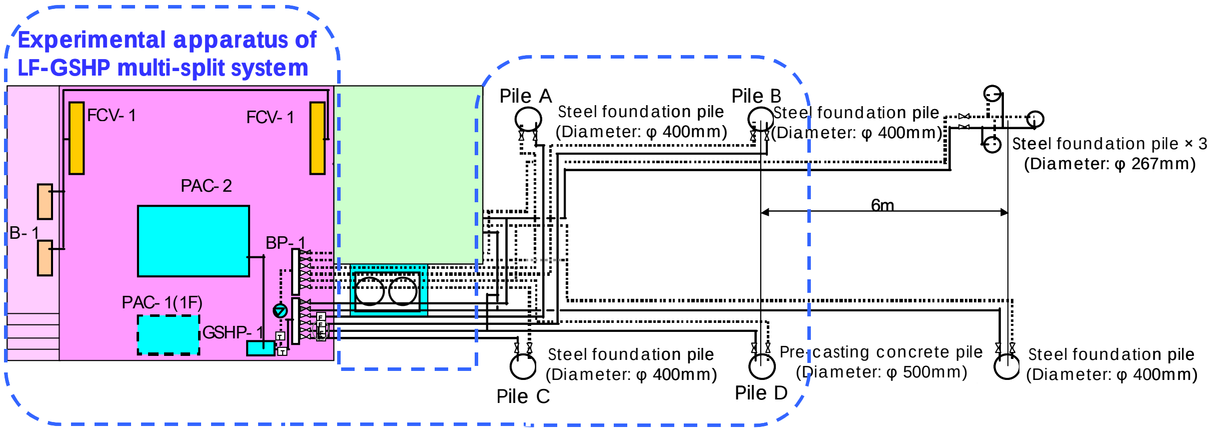
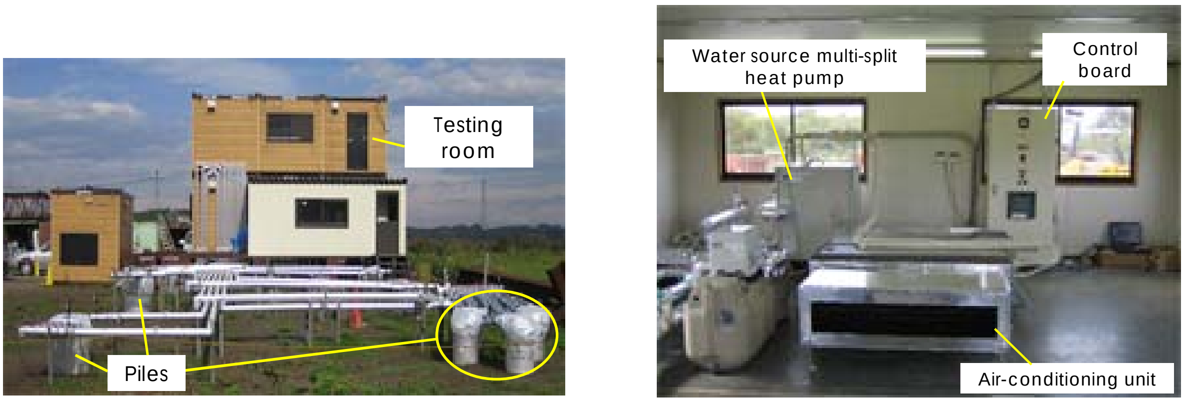


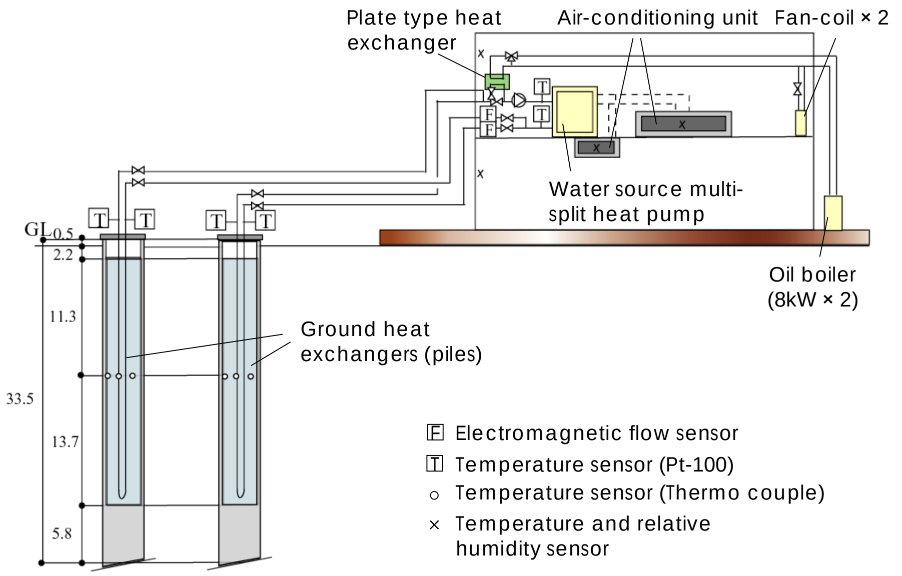
Figure 3: Plane view of field experiment



Exterior

Inside of testing room

Figure 4: Appearance of field experiment



Pile A Steel foundation pile External diameter : 400mm Internal diameter : 380 mm Spec.: 16A U-tube × 5
Pile B Steel foundation pile External diameter : 400mm Internal diameter : 380 mm Spec.: 16A U-tube × 4
Pile C Steel foundation pile External diameter : 400mm Internal diameter : 380 mm Spec.: 25A U-tube × 2
Pile D Pre-casting concrete pile External diameter : 500mm Internal diameter : 300 mm Spec.: 16A U-tube × 5

Figure 5: Schematic diagram of experimental set-up

Dimensions	Height: 1000 mm × Width: 780mm × Length: 550 mm
Refrigerant	R410A
Compressor	Scroll type, inverter driven Electric power : 4.2kW(10HP)
Heat exchanger	Plate type
Standard flow rate	96 L/min
Rated capacity	Cooling : 22.4kW(T_{WB}=19 °C 、 T_{1in}=30 °C) Heating : 25.0kW(T_{DB}=20 °C 、 T_{1in}=20 °C)
Air-conditioning unit (1st floor)	Cooling : 5.6kW(T_{WB}=19 °C) Heating : 6.2kW(T_{DB}=20 °C)
Air-conditioning unit (2nd floor)	Cooling : 22.4kW(T_{WB}=19 °C) Heating : 25.0kW(T_{DB}=20 °C)

Figure 6: Appearance and specification of water source multi-split heat pump unit

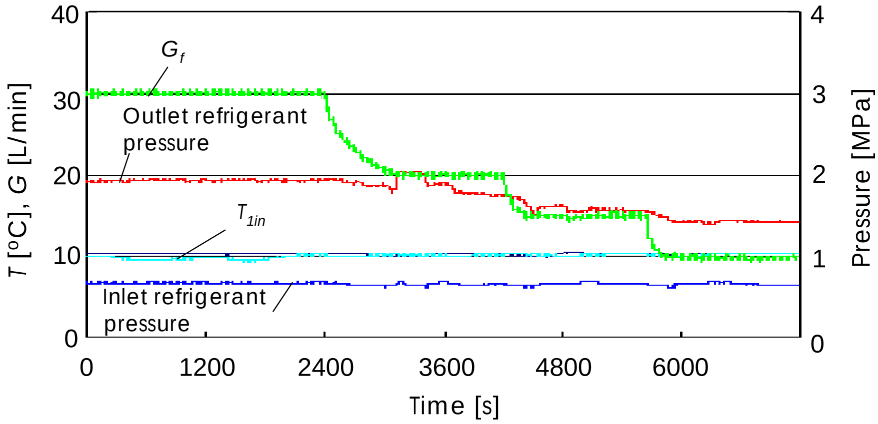


Figure 7: Laboratory test result

Table 2: Measurement point

Temperature (Pt-100)	Inlet of ground heat exchangers × 4 (for each pile) Outlet of ground heat exchangers × 4 (for each pile) Inlet of heat pump unit Outlet of ground heat exchangers
Temperature (Thermo couples)	Water temperature in pile at 13.5 m deep × 4 (for each pile) Internal surface of pile at 13.5 m deep × 4 (for each pile) External surface of U-tube at 13.5 m deep × 4 (for each pile)
Temperature and relative humidity (Sensor)	Inlet of Air-conditioning unit × 2 (1st and 2nd floor) Outlet of Air-conditioning unit × 2 (1st and 2nd floor) Experimental room × 2 (1st and 2nd floor)
Flow rate (Electromagnetic flow meter)	Each line lead to Pile A ~ Pile D (The point indicated in Figure 3)
Electric power (Power meter)	Compressor of heat pump unit Circulation pump
Refrigerant temperature (Sensor)	Internal of compressor × 3, Inlet and outlet of compressor, Inlet and outlet of refrigerant-water heat exchanger Inlet and outlet of air conditioning unit
Refrigerant presser (Sensor)	Inlet of compressor Outlet of compressor

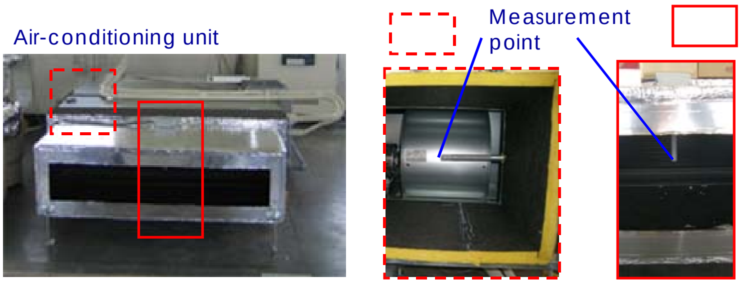


Figure 8: Measurement points in air conditioning unit

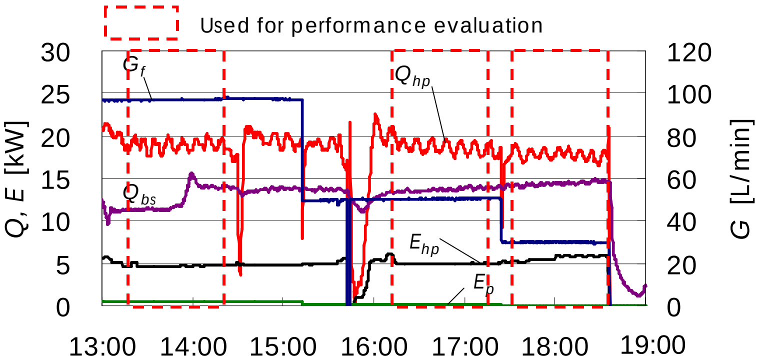


Figure 9: Example of constant output operation

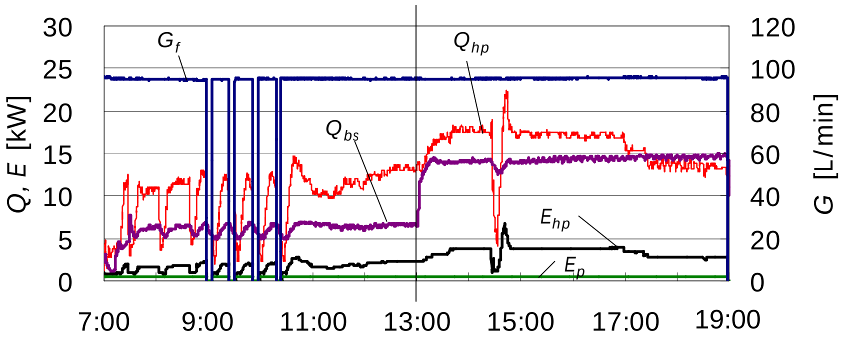


Figure 10: Example of continuous operation

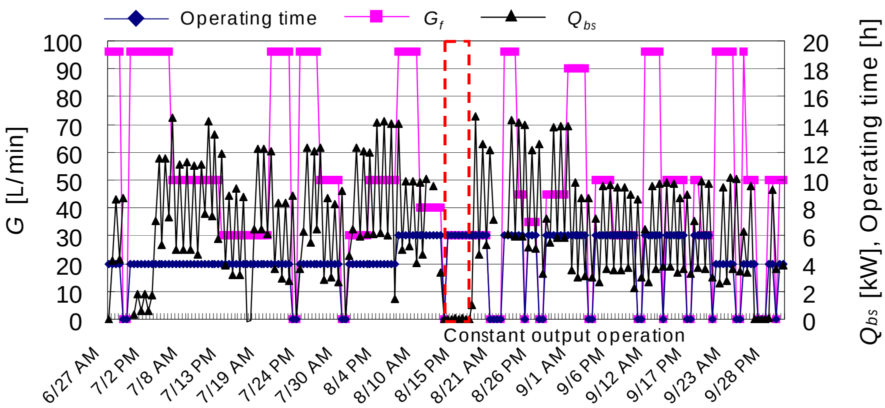


Figure 11: Experimental conditions during cooling period

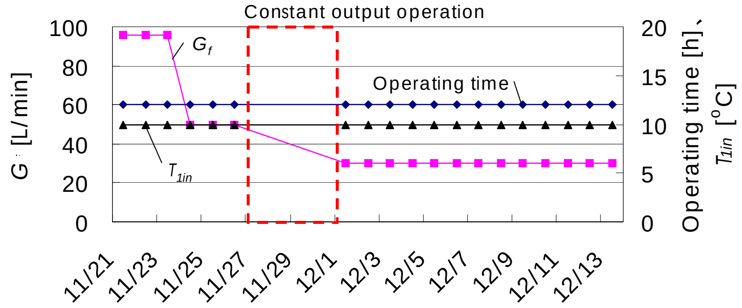


Figure 12: Experimental conditions during heating period

3.2 Results and discussions

3.2.1 Constant output operation

As the experimental result of constant cooling output operation, COP and SCOP according to Q_{hpc} are shown in Figure 13. Figure 13 also indicates COP according to Q_{hpc} obtained by the laboratory experiment. In order to compare with the result of laboratory experiment, the cooling output Q_{hpc} is calculated by the following equation.

$$Q_{hpc} = G_r\ h_{eout}\ \rho_{eout} - G_r\ h_{ein}\ \rho_{ein} \tag{1}$$

Here, each property of refrigerant is evaluated with values of temperature and presser, which are measured by the sensors set at inlet and outlet of evaporator. The flow rate of refrigerant G_r is estimated by using temperature data inside the compressor.
Also, COP and SCOP are given as the following.

$$COP = Q_{hp} / E_{hp} \tag{2}$$

$$SCOP = Q_{hp} / (E_{hp} + E_p) \tag{3}$$

The cooling output and COP with the highest Q_{hpc} obtained by this field test are around 20 kW and 4.0, respectively. The values are almost equal to the one in laboratory experiment. However, the difference of Q_{hpc} and COP with variation of G_f is smaller than the laboratory experiment's one. Reducing electric power of the circulation pump by applying the low flow circulation system improves the system performance, since the difference of COP is small. The highest SCOP of 4.7 is obtained on a condition of G_f = 50 L/min for the largest Q_{hpc}. When the Q_{hpc} becomes smaller, the smallest flow late of G_f = 30 L/min provides the largest SCOP.
Next, Figure 14 gives the experimental result of constant heating output operation, which is COP and SCOP according to Q_{hph}. The heating output Q_{hph} is calculated by the following equation as well as the cooling output.

$$Q_{hph} = G_r\ h_{cout}\ \rho_{cout} - G_r\ h_{ecn}\ \rho_{cin} \tag{4}$$

The values of Q_{hpc} and COP with the highest Q_{hph} of the field test are also almost equal to the laboratory experiment's one. With regard to the SCOP, the values with G_f = 50 L/min and G_f = 30 L/min are larger than the ones with G_f = 96 L/min.

3.2.2 Continuous operation

Figure 15 shows COP according to average O_{hpc} in the continuous cooling operation. Here, the cooling output O_{hpc} is calculated by the following equation.

$$Q_{hpc} = c_f \rho_f G_f \left(T_{1out} - T_{1in}\right) - E \qquad (5)$$

This result indicates that the highest COP of 6~8 are obtained when O_{hpc} is around 7 kW. However, the COP drops as O_{hpc} decrease on condition of O_{hpc} less than 7 kW. The reason is that the heat pump unit repeats running and stopping because of the small heat demand. Shown in Figure 16 is COP according to T_{1in}. As T_{1in} becomes larger, COP decreases. Furthermore, there is a tendency that the COP with G_f = 96 L/min is little higher than the ones of G_f = 50 L/min and G_f = 30 L/min on the same T_{1in}.
The COP according to average O_{hph} in the continuous heating operation is drawn in Figure 17. Here, the following equation provides the heating output O_{hph}.

$$Q_{hph} = c_f \rho_f G_f \left(T_{1out} - T_{1in}\right) + E \qquad (6)$$

The COP is smaller than the one obtained by the constant output operation. This is due to difference between O_{hph} calculated by equation (4) and (6). The difference is generally larger than difference between O_{hpc} calculated by equation (1) and (5).

3.2.3 Comparison of heat injections via ground heat exchangers

Total amounts of heat injection via each ground heat exchangers during cooling period are compared. The result is shown in Figure 18. The heat injection via Pile B, which is the steel foundation pile and has four U-tubes with outside diameter of 16 mm, is equal to the one via Pile A with five U-tubes. The heat injections via Pile C and Pile D are approximately 5 % smaller than the ones via Pile A and Pile B. Pile C is the steel foundation piles and similar to Pile A and Pile B. Thus, specification of the ground heat exchanger yields the difference of heat injection. Pile D is the pre-casting concrete pile so that specification of the pile results the decrease of heat injection.

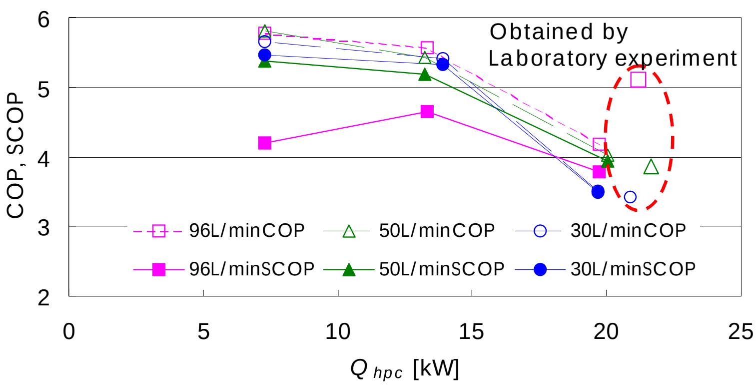


Figure 13: COP and SCOP according to Q_{hpc} in constant cooling output operation

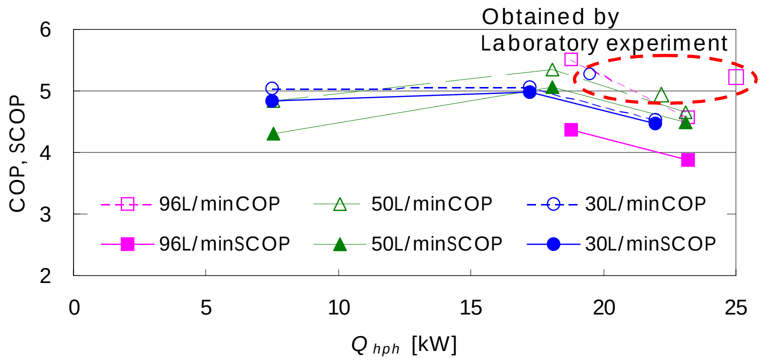


Figure 14: COP and SCOP according to Q_{hph} in constant heating output operation

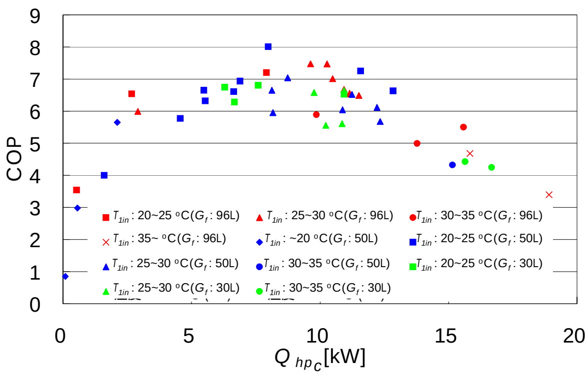


Figure 15: COP and SCOP according to Q_{hpc} in continuous cooling output operation

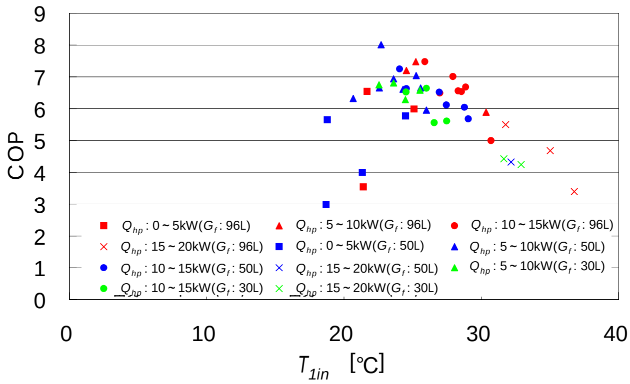


Figure 16: COP and SCOP according to T_{1in} in continuous cooling output operation

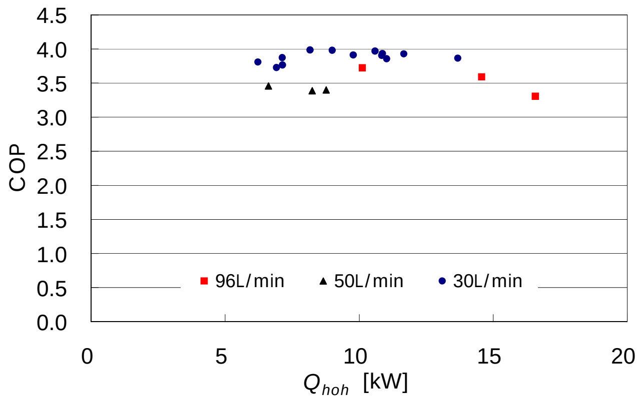


Figure 17: COP and SCOP according to Q_{hph} in continuous heating output operation

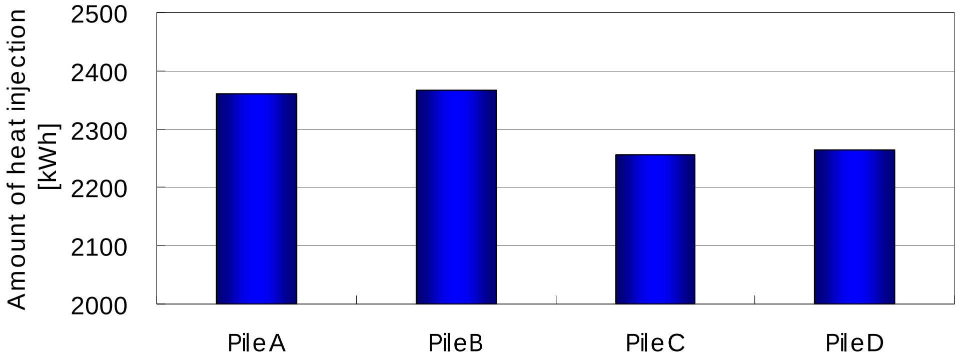


Figure 18: Amount of heat injection via each pile during cooling period

4 SUMMARIES

1) The authors introduced outlines of the LF-GSHP multi-split system, which will operate with average SCOP of more than 4.5 throughout the cooling period.
2) Field experiment of the LF-GSHP multi-split system has been carried out. The following results were obtained until present.

    1. The cooling output and COP with the highest cooling output obtained by this field test were around 20 kW and 4.0, respectively. The values were almost equal to the one in laboratory experiment. The heating output and COP were also equal to the laboratory experiment's one.
    2. Result of continuous cooling operation indicated that COP was the highest with the cooling output of around 7 kW and the values were 6~8.
    3. Amount of heat injection via a steel foundation pile used as ground heat exchanger was 5 % larger than the one via a pre-casting concrete pile when the specifications of the ground heat exchangers were the same.

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NOMENCRATURE

c: Specific thermal capacity [kJ/kg/K], *E*: Electric power [W], *h*: Enthalpy [kJ/kg], *G*: Flow late [m^3/s], *Q*: Heating output [W], *T*: Temperature [^oC], *t*: Time [h], ρ: Density [kg/m^3]

Subscript

bs: Boiler system, *c*: Condenser, *e*: Evaporator, *f*: Thermal medium, *hp*: Heat pump, *hpc*: Heat pump cooling operation, *hph*: Heat pump heating operation, *p*: Pump, *r*: Refrigerant, *in*: Inlet, *out*: Outlet, *1*: Primary side, -*in*: Inside, -*out*: Outside