



14<sup>th</sup> IEA Heat Pump Conference  
15-18 May 2023, Chicago, Illinois

# Techno-environmental evaluation of a river-source heat pump system using a hot gas bypass valve

Hyun Ku Cho<sup>a</sup>, Hyun Ho Shin<sup>b</sup>, Se Hyeon Ham<sup>b</sup>, Sun An Jeong<sup>c</sup>,  
Kyoung-Tae Park<sup>c</sup>, Yongchan Kim<sup>b\*</sup>

<sup>a</sup>Department of Smart Convergence, Korea University, 145 Anam-ro, Sungbuk-gu, Seoul 02841, Republic of Korea

<sup>b</sup>Department of Mechanical Engineering, Korea University, 145 Anam-ro, Sungbuk-gu, Seoul 02841, Republic of Korea

<sup>c</sup>Myoung Shin Co., 34 Jayuro Gunsansi, Jeollabukdo, 54006, Republic of Korea

---

## Abstract

River water-source heat pumps show higher energy efficiency than conventional air-source heat pumps because water has better thermal characteristics than air. However, as the river water temperature decreases in winter, there is a risk of freezing in heat exchangers during the heating season. In this study, the performance of a hybrid heat pump system using a hot gas bypass valve (HBHPS) was compared analytically to that of a conventional hybrid heat pump system (CHHPS). In the HBHPS, the refrigerant flow rate can be controlled by the hot gas bypass valve to decrease the heating capacity, hence reducing the temperature difference of the secondary fluid on the evaporator side. Accordingly, it can increase the heat pump operation time in winter. Mechanical components of the HBHPS were modeled analytically. The performances of the two energy conversion systems were compared through transient simulations based on a water temperature measurement in Han River, South Korea. As a result, the HBHPS showed higher life cycle climate performance than the CHHPS owing to the increase in the heat pump operation time.

© HPC2023.

Selection and/or peer-review under the responsibility of the organizers of the 14<sup>th</sup> IEA Heat Pump Conference 2023.

*Keywords: River source heat pump, Heat pump simulation, Hot gas bypass, TRNSYS, Hybrid heat pump system;*

---

## 1. Introduction

Many efforts are being carried out to reduce greenhouse gas emissions around the world. Among these efforts, research related to renewable energy conversion systems is actively being conducted. A heat pump system that uses surface water as a heat source is one of them. The water source heat pump system obtains energy required for heating and cooling loads by using the energy of water sources including river water, lake water, and seawater. The temperature of the water source is higher in winter and lower in summer than that of the air source, which has the advantage of a lower seasonal temperature difference. Therefore, water source heat pumps have the advantage of being able to operate at high efficiency year-round compared to conventional air source heat pumps [1]. However, there is a disadvantage that the use is limited due to the problem of freezing in the heat pump evaporator or source-side heat exchanger when the water temperature is low in winter. For this reason it is difficult for water source heat pumps to be operated alone even though they show high efficiency in summer. To overcome this problem, the conventional water source heat pump system mainly adopted a hybrid configuration in which a gas boiler is installed to satisfy the heating load when the heat pump is not operable. The use of boilers reduces the efficiency of the entire system but allows the system to operate reliably annually. However, the gas boiler is less energy efficient and emits a larger amount of carbon dioxide than the heat pump. Therefore, to reduce the operation time of the gas boiler and increase the operation time of the heat pump, it is essential to control the capacity of the heat pump to broaden the operable water temperature range.

---

\* Corresponding author. Tel.: +82-2-921-5946.  
E-mail address: yongckim@korea.ac.kr.

There are several ways to control the capacity of heat pumps. The first way is to use a variable-speed compressor. It uses energy efficiently by changing the compressor frequency in response to the load and heat source. Nasution and Wan Hassan [2] showed that controlling the compressor through the inverter can save energy consumption more than the compressor on-off control. Jeong et al. [3] compared the hot gas bypass method and the variable-speed compressor method and showed that the COP was higher in the variable-speed compressor control using the inverter during a partial load operation. Generally, most of heat pumps use variable-speed compressors to control the capacity. To continuously operate the heat pump using the low water temperature in winter, it is necessary to reduce the temperature difference of the primary fluid by controlling the capacity of the heat pump. However, in the case of a large heat pump system, limitation exists to control capacity through the compressor owing to the surging problem or degradation of the volumetric efficiency. Therefore, the operation of heat pumps is not available during the winter season when the water temperature is low.

The second way to control the capacity of heat pumps is to apply a hot gas bypass valve. It controls the evaporator inlet enthalpy by bypassing a part of the high-temperature and high-pressure refrigerant gas at the compressor discharge to the evaporator inlet or controlling the mass flow rate of refrigerant by bypassing a part of the high-temperature and high-pressure refrigerant gas at the compressor discharge to the compressor inlet. Yaqub et al. [4] suggested three methods of capacity control in refrigeration and air conditioning systems through the hot gas bypass method and analyzed the performance characteristics of each method through experiments and analysis. Baek et al. [5–6] analyzed the performance characteristics of the three methods proposed by Yaqub et al. according to changes in load and operating conditions. Ahn et al. [7] experimentally compared the hot gas bypass method in which a part of the refrigerant gas at the compressor outlet bypassing to the compressor inlet and the method in which a part of the liquid refrigerant at the discharge of the condenser bypassing to the suction of the compressor. It was shown that the hot gas bypass method was advantageous during the heating period, the pressure of the condenser was lowered, and the COP was also lowered as the bypass ratio increased.

In this study, the heating performance of a hybrid heat pump system using hot gas bypass (HBHPS) was analyzed analytically. The river water was used as a heat source. The heat pump system using hot gas bypass was simulated by using Python. In the simulation, the characteristics of controlling the capacity of the heat pump by the hot gas bypass valve in the low water temperature condition were simulated. Through the heat pump simulation, performance map data were obtained according to the conditions of the heat source and the load side. The transient simulation program, TRNSYS, was used for the simulation, and the performance change was analyzed compared to the conventional boiler hybrid heat pump system (CHHPS).

## 2. Simulation method

### 2.1. Heat pump simulation method

The heat pump simulation was performed with the algorithm shown in Figure 1, based on the ORNL method [8] proposed by Fischer and Rice. The algorithm started by assuming an initial condensing pressure and an evaporation pressure. Then, the state of each component was calculated. The calculation proceeded until the energy balance converged, and when the convergence was reached. The efficiency model was used for the compressor modeling. The heat transfer occurring in the evaporator and the condenser was calculated using the  $\epsilon$ -NTU method. To simplify the simulation, the effectiveness ( $\epsilon$ ) was fixed at 0.7. In addition, the heat transfer was calculated by dividing the section according to the phase of the refrigerant. Accordingly, energy balance convergence conditions in the evaporator and condenser were set considering the degree of subcooling and superheating. The hot gas bypass method was applied in which some refrigerant was bypassed from the compressor outlet to the inlet. The opening ratio of the hot gas bypass valve ( $x$ ) was set as an input value. However, the mass flow rate that can be bypassed is limited because the high bypassed mass flow rate can cause the compressor to overheat severely. The maximum ratio of bypassed flow rate can be expressed as  $y$ , which is the point where heating capacity can be controlled down to 73% of design capacity [7]. The bypass opening ratio ( $x$ ) became 1 when the ratio of actual bypassed mass flow rate ( $y'$ ) is that of the maximum bypassed mass flow rate ( $y$ ). R-134a was used as the refrigerant, and the physical properties at each point were obtained through CoolProp [9], which is a Python module. The schematic of the hot gas bypass heat pump is shown in Figure 2. The process of from points 2 to 6 is assumed to be the isenthalpic process because the hot gas bypass valve is an expansion valve for reducing the pressure. The operating characteristics of the hot gas bypass method were obtained by Equations (1)–(4).

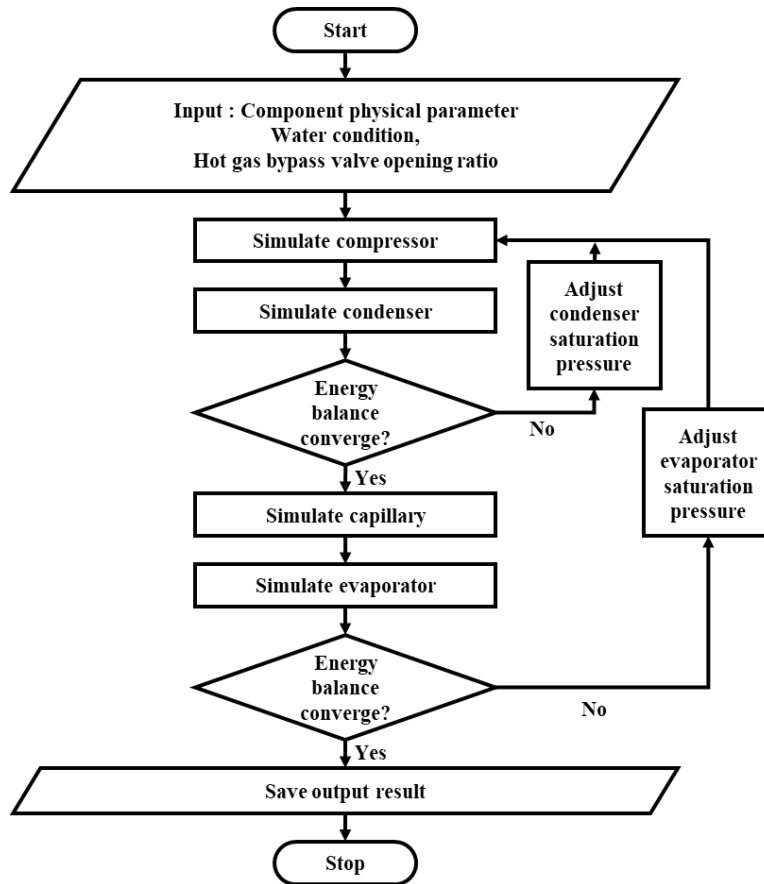


Fig. 1. Flow chart of heat pump simulation.

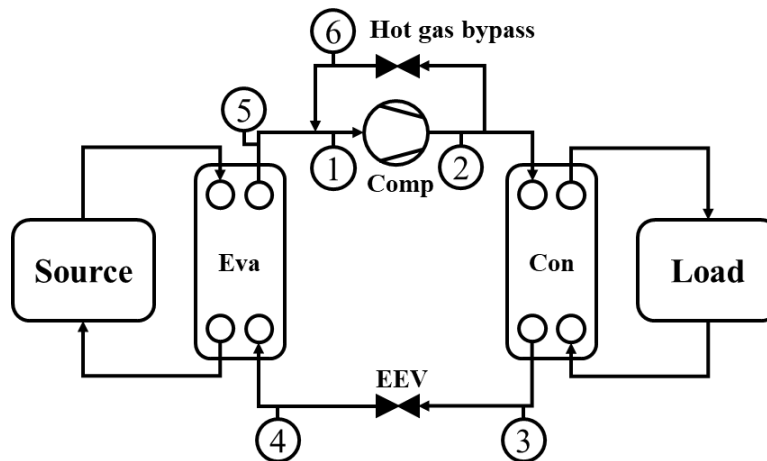


Fig. 2. Schematic of hot gas bypass water source heat pump.

$$x = y'/y \quad (0 \leq y' \leq y) \quad (1)$$

$$y' = \dot{m}_6/\dot{m}_1 \quad (2)$$

$$y' = (h_1 - h_5)/(h_2 - h_5) \quad (3)$$

$$COP = [(1 - y')(h_5 - h_4)]/(h_2 - h_1) \quad (4)$$

2.2. TRNSYS simulation method

Based on the heat pump simulation, the performance map data was obtained according to the temperature and flow rate of the heat source and load, and the ratio of bypass valve opening. The schematic of the TRNSYS model is shown in Figure 3, and the simulation conditions are shown in Table 1. The load for simulation was based on the actual measured data of a commercial building in Gwacheon in 2020. The actual measured temperature of the Paldang Dam basin in 2018 was used for the river water temperature. The average water temperature in winter was 5.3 °C and the range of temperature was 1.3–13.5 °C. Simulations were performed during the heating period in Korea, January–March, and November–December. A 500 RT heat pump system was used based on the maximum heating and cooling load, and water was used for both the heat and load side secondary fluid. When water is used as the secondary fluid, freezing can occur at the outlet of the heat pump evaporator when the river water temperature is low in winter, which makes the entire heat pump system inoperable. Therefore, when the heat pump is not operable, a gas boiler was mainly used for heating. To prevent freezing in the evaporator, the flow rate of source-side water can be increased or the capacity of the heat pump decreased to reduce the water-side temperature change in the evaporator.

As shown in Figure 4, the performance comparison was analyzed by TRNSYS modeling of two cases according to the control method of the heat pump system. The first case was a conventional hybrid heat pump system (CHHPS) which conventional water source heat pump applied. When the low water temperature condition was reached, the temperature change between the inlet and outlet of the primary and secondary fluids can be reduced by increasing the pump flow rate of the heat source. It is possible to increase the flow rate up to 2.0 times for P0 and 1.2 times for P1. Accordingly, the operation time of the heat pump can be extended. However, the power consumption can increase.

In the second case, the hot gas bypass heat pump was used in the hybrid heat pump system (HBHPS). The temperature change between the inlet and outlet of the evaporator of the heat pump can be further reduced by lowering the heat pump capacity through the hot gas bypass method in the low water temperature condition that even CHHPS cannot operate. However, the capacity in the condenser is also reduced, so to maintain the temperature difference on the load side, the flow rate of P2 must be reduced by 0.7 times. The coefficient of performance decreases as the opening of the hot gas bypass valve increases.

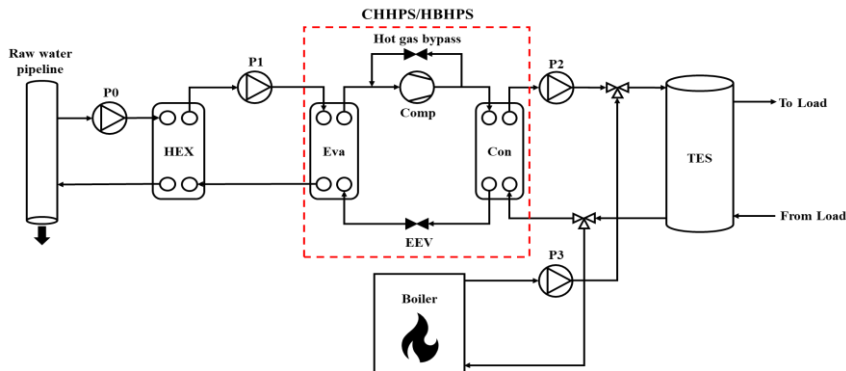


Fig. 3. Configuration of the hybrid heat pump system applying CHHPS and HBHPS.

Table 1. Main simulation condition for the TRNSYS model

| Description                               | Units  | Value    |
|---|--------|----------|
| Water source temperature                  | °C     | Measured |
| Load                                      | kWh    | Measured |
| Heat pump capacity                        | RT     | 500      |
| Evaporator design capacity                | RT     | 391      |
| Evaporator minimum leaving temperature    | °C     | 1        |
| Pump design flow rate (P0, P1)            | LPM    | 6533     |
| Pump design flow rate (P2, P3)            | LPM    | 5040     |
| TES load side minimum leaving temperature | °C     | 45       |
| Gas boiler combustion efficiency          | %      | 80       |
| Electricity bill                          | \$/kWh | [10]     |
| Gas bill                                  | \$/kWh | [11]     |

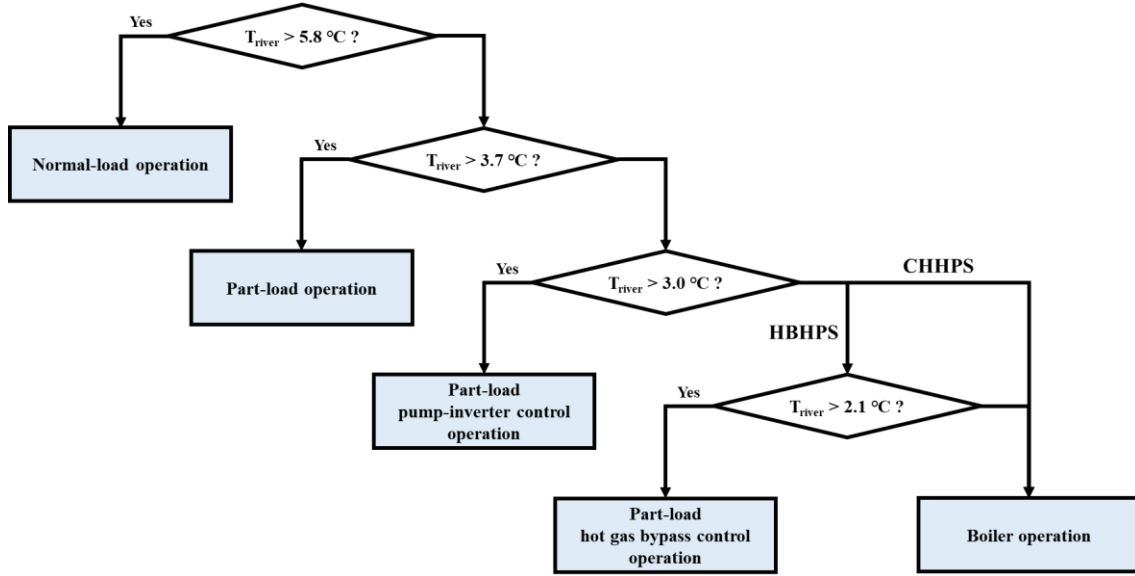


Fig. 4. Control strategy for HBHPS and CHHPS.

### 2.3. Performance indices

For the above two cases, the performance change was analyzed with various evaluation indices. Performance change was compared with seasonal performance factor (SPF), operation time, greenhouse gas emissions (GHGE), and operation costs. The formulas of each evaluation index are as follows. The SPF is the factor of efficiency for the whole heat pump operation period. The SPF is expressed as the heat supplied by the heat pump system ( $E_{th,HP}$ ) divided by whole energy consumption ( $E_{p,tot,P} + E_{p,tot,HP}$ ) for the operation period. The greenhouse gas emission factors for electric power and gas were 0.4594 ( $EF_e$ ) and 0.2016 ( $EF_g$ ), respectively, which are based on the Korean standard. Each emission factor was multiplied by the annual energy consumption of electricity and gas (AEC). In addition, for the annular operation costs of electricity and gas (AOC), rate tables based on Korean standards [10–12] were used. The exchange rate of the dollar was as of November 1, 2022. Greenhouse gas emissions and operating costs were compared under the assumption that the heat pump was operated for 16 years, which is the life cycle of the heat pump ( $L$ ), under the same water temperature and load conditions. Inflation rate ( $i$ ) and discount rate ( $d$ ) were both set as 0.1.

$$SPF = \frac{E_{th,HP}}{E_{p,tot,P} + E_{p,tot,HP}} \quad (5)$$

$$GHGE = L * (AEC_e * EF_e + AEC_g * EF_g) \quad (6)$$

$$Operation\ cost = \sum_n \left\{ \frac{1+i}{1+d} \right\}^{n-1} (AOC_e + AOC_g) \quad (7)$$

## 3. Simulation results

### 3.1. Heat pump simulation results

Figure 5 shows the change in the P-h diagram when the condenser water inlet temperature was 40 °C, the evaporator water inlet temperature was 12 °C, and the  $x$  was 0.5. As a part of the refrigerant gas at the compressor outlet passed through the hot gas bypass valve and flowed into the compressor inlet, the condensing pressure was lowered. However, the evaporating pressure was slightly increased because a part of the high-temperature and high-pressure refrigerant gas flows into the outlet of the evaporator. Additionally, the compression ratio and compressor work were reduced, but the heat pump capacity reduction was larger. Accordingly, the COP was lowered.

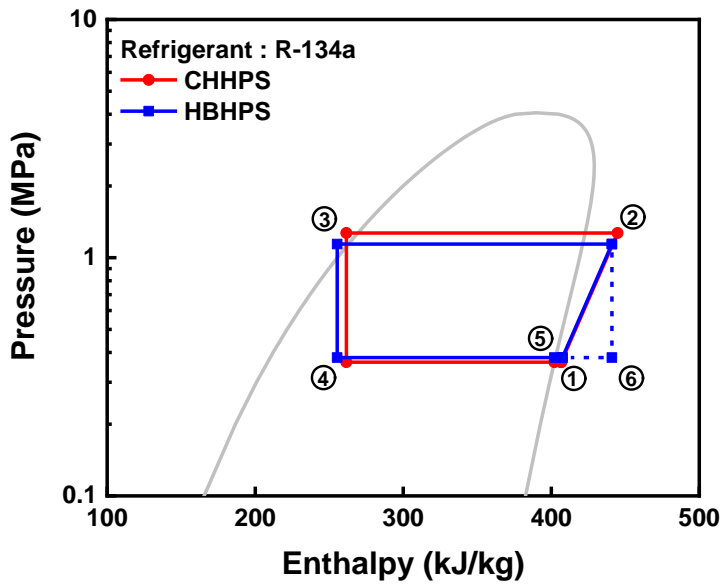


Fig. 5. P-h diagram of the heat pump applied in CHHPS and HBHPS of bypass opening ratio 0.5.

### 3.2. TRNSYS simulation result

Figure 6 shows the load supply period by the heat pump of CHHPS and HBHPS. The operating time of the HBHPS was 97 hours longer than that of the CHHPS. This corresponded to 2.68% of the total heating period. This was because the capacity of the heat pump was lowered by the hot gas bypass valve and can operate until the water source temperature was 2.38 °C compared to CHHPS which can operate until 3.03 °C. Both cases cannot cover the heat load by heat pump operation alone during the coldest season in winter because the river water temperature was below than 2.38 °C.

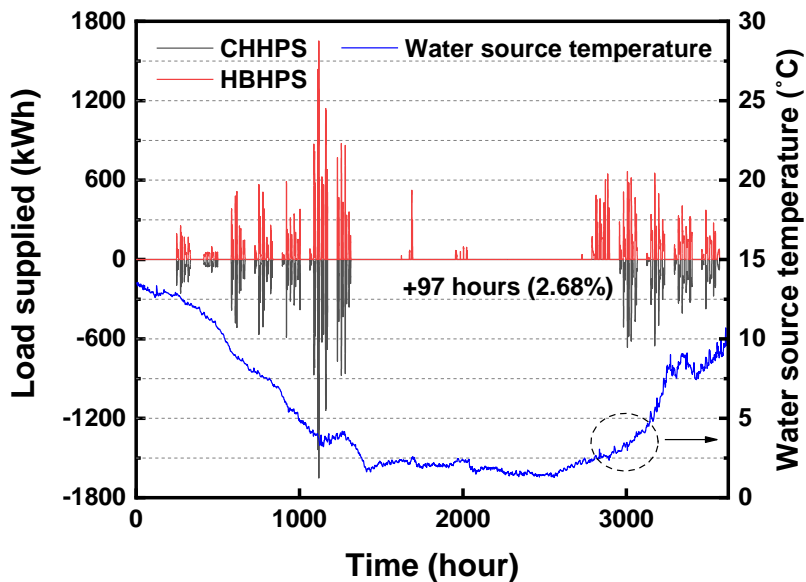


Fig. 6. Operation time of CHHPS and HBHPS and winter season river water source temperature.

Figure 7 shows the energy consumption, heat supply, and SPF for the heat pump operation period by the heat pump systems of CHHPS and HBHPS. Since HBHPS had a longer operating time compared to CHHPS,

the energy consumption was 28.30% higher and heat supply was 16.43% higher. The increase in energy consumption was larger than the amount of heat supplied, resulting in a lower SPF of 9.26%.

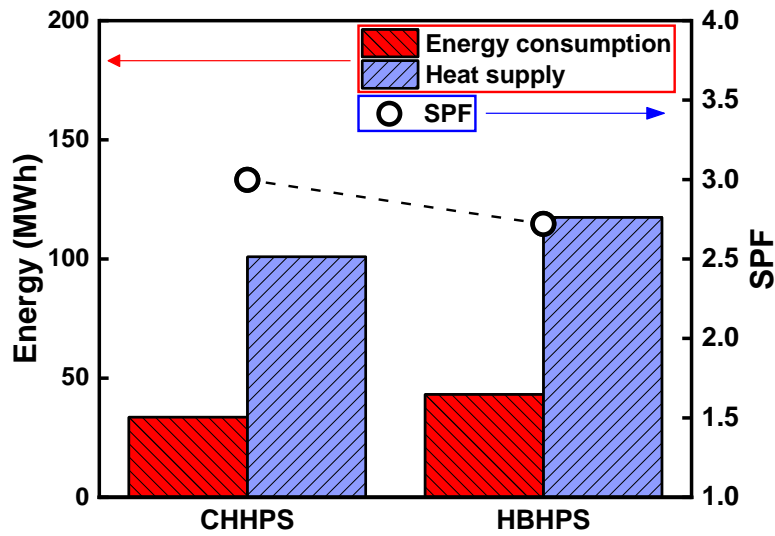


Fig. 7. Energy consumption, heat supply and SPF for CHHPS and HBHPS.

Figure 8 shows the greenhouse gas emissions of CHHPS and HBHPS, and Figure 9 shows the operating costs of CHHPS and HBHPS. As the heat pump operation time in HBHPS increased, the boiler operation time decreased. The decrease in gas usage was larger than the increase in electric energy usage. Accordingly, GHGE was reduced by 2.23%, and winter season operating cost was reduced by 5.88% in HBHPS compared to CHHPS.

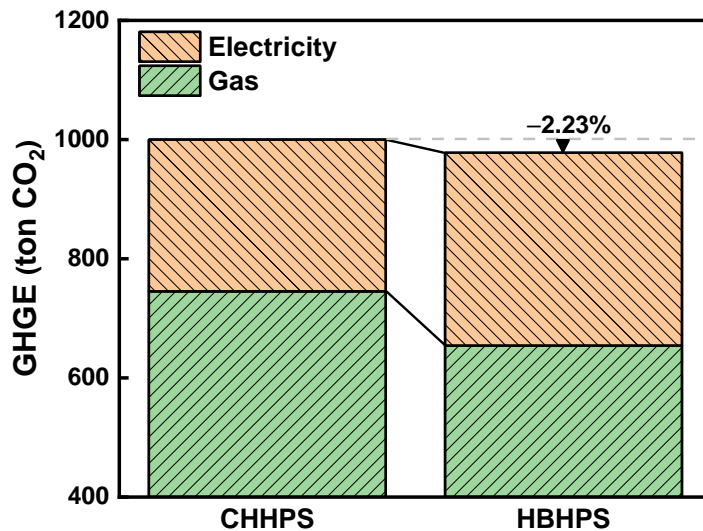


Fig. 8. GHGE of CHHPS and HBHPS for life cycle.

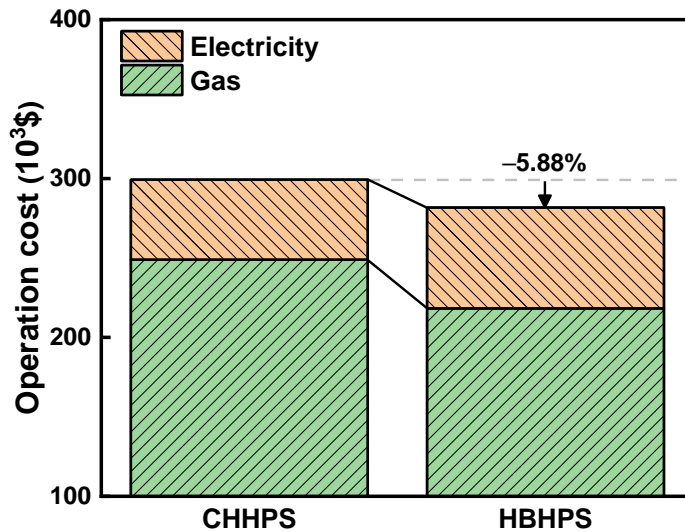


Fig. 9. Operation costs of CHHPS and HBHPS for the life cycle.

#### 4. Conclusion

In this study, the performance change according to the hot gas bypass heat pump application of the hybrid heat pump system for heating load in winter was analyzed. As a result, when the hot gas bypass heat pump was used, the SPF of the heat pump system was reduced by 9.26%. However, the operating time increased by 2.68%, GHGE was reduced by 2.23%, and operating cost by 5.88%. This study was based on the water temperature in the Paldang Dam basin in 2018, where the average water temperature condition in winter was very low. The hot gas bypass heat pump system is expected to show better performances in areas where the water temperature is relatively higher.

#### Acknowledgments

This work was supported by the Technology Innovation Program (No. 20011094) funded By the Ministry of Trade, Industry & Energy (MOTIE, Korea).

#### References

- [1] Park, C. S., Jung, T. H., Park, H. H., Kim, Y. C., 2009. Performance characteristics and economic assessment of a river water: source heat pump system. *Korean Journal of Air-Conditioning and Refrigeration Engineering*, 21(11), 621-628.
- [2] Nasution, H., Wan Hassan, M. N., 2006. Potential electricity savings by variable speed control of compressor for air conditioning systems. *Clean Technologies and Environmental Policy*, 8(2), 105-111.
- [3] Jeong, S. K., Lee, D. B., Yoon, J. I., 2012. Comparison of system performances of hot-gas bypass and compressor variable speed control of water coolers for machine tools. *Korean Journal of Air-Conditioning and Refrigeration Engineering*, 24(1), 1-8.
- [4] Yaqub, M., Zubair, S. M., 2000. Performance evaluation of hot-gas by-pass capacity control schemes for refrigeration and air-conditioning systems. *Energy*, 25(6), 543-561.
- [5] Baek, S. M., Yoon, J. I., Son, C. H., Heo, J. H., 2014. Performance Comparison of Hot-gas Bypass Types with the Variation of Refrigeration Load. *Journal of Power System Engineering*, 18(5), 48-54.
- [6] Baek, S. M., Son, C. H., Heo, J. H., Choi, I. S., Yoon, J. I., 2014. Performance characteristics of hot-gas bypass refrigerator with the variation of operation conditions. *Journal of Advanced Marine Engineering and Technology*, 38(9), 1021-1026.
- [7] Ahn, J. H., Joo, Y., Yoon, W. J., Kang, H., Kim, Y., 2013. An experimental study on the performance characteristics of hot-gas and liquid bypass heat pump systems for capacity modulation. *Korean Journal of Air-Conditioning and Refrigeration Engineering*, 25(3), 137-142.
- [8] Fischer, S. K., Rice, C. K., 1983. Oak Ridge heat-pump models. I. A steady-state computer design model for air-to-air heat pumps (No. ORNL/CON-80/R1). Oak Ridge National Lab., TN (USA).

- [9] Bell, I. H., Wronski, J., Quoilin, S., Lemort, V., 2014. Pure and pseudo-pure fluid thermophysical property evaluation and the open-source thermophysical property library CoolProp. *Industrial & engineering chemistry research*, 53(6), 2498-2508.
- [10] Korea Electric Power Corporation., Electric Rates Table.  
<https://home.kepco.co.kr/kepco/EN/F/htmlView/ENFBHP00101.do?menuCd=EN060201>; [accessed 1 November 2022].
- [11] Samchully Corporation., City gas rates table.  
<https://www.samchully.co.kr/customer/gas/info/fee/system.do>; [accessed 1 November 2022].
- [12] Korea Ministry of Environment., 2022. Guidelines for Reporting and Certification of Emissions of Greenhouse Gas Emissions Trading System.