Energy and Buildings 43 (2011) 3068–3073

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

A raw water source heat pump air-conditioning system

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ARTICLE INFO

Article history:
Received 26 May 2011
Received in revised form 26 July 2011
Accepted 27 July 2011

Keywords:
Raw-water source
Heat pump
Heating and cooling
Part load performance

ABSTRACT

Raw water source is one of the promising new heat sources that researchers are looking into along with various others water-based sources such as ground, lake, river and sewage water. Generally, the water that is taken from the environment and supplied to a water treatment facility is called raw water. In this study, the heating and cooling performance of a heat pump utilizing the heat energy of raw water supplied to a water treatment facility is investigated. The two heat pumps being investigated have a heating capacity of 65.2 kW and were installed at the site for the heating and cooling of the central control room. A brazed plate heat exchanger was used for obtaining heat energy from the raw water. The raw water source provides a favorable heat source compared to the ambient air source except in spring. In the seasons of spring and autumn, the heating and cooling load are extremely low, this is the main reason for the poor performance of the raw-water heat pump system for those seasons. The average unit COP during the heating season is 3.3, and the average unit COP for the cooling season is 7.2.

1. Introduction

There are various water resources, such as ground, lake, river, sewage and raw water. Raw water is one of the promising heat sources among these. Generally, the water is taken from the environment and supplied to a water treatment facility through large sized pipes for subsequent treatment or purification. This untreated water is called as the raw water. The raw water that is transferred to the multi-regional water supply system is a very large temperature difference resource. In this study, the raw-water is utilized as the heat source for a heat pump system for the heating and cooling of the integrated operation center in a water treatment facility. It is very hard to find the similar systems that use raw-water for the heat sources. Next we will take a brief look at related, existing studies which deal with ground-water source and the ground source heat pump systems.

Nam and Ooka [1] developed the dual-source hybrid heat pump system using groundwater and air. In spring and autumn, the ground water heat pump (GWHP) system is not more efficient than an air source heat pump (ASHP) based on the temperature comparison between the groundwater and the ambient temperature. According to their experiments the developed hybrid system showed an improvement of 2–7% compared to a water cooling system, and 4–18% compared to an air source heat pump. In another study, Nam et al. [2] investigated the performance of a ground water source heat pump. This system depends on the temperature and depth of the water and its efficiency is much higher than that of the air source heat pump. Yu et al. [3] studied a ground source heat pump (GSHP) for an archives building in Shanghi, whose rooms were kept at a constant temperature and relative humidity. It is notable in this study that some of the rejected heat is used to heat the air in the air handling units (AHUs). The coefficient of performance (COP) of the system in spring and autumn is lower than that in summer and winter by 42% and 14%, respectively. However, the operating cost of a GSHP was reduced by 55.8% compared with an ASHP. Chen et al. [4] investigated an underground water-source heat pump system installed in a tall apartment building in Beijing, china. By analyzing this system for 2 years, operation methods and a controlling algorithm for the system were developed. Koo et al. [5] studied the heating performance of a GSHP system in a field test. The average seasonal heating COP of the heat pump was 5.1 at a part load of 46.9%, while the seasonal system COP including the power consumption for the pump and the fans was found to be 4.2.

The objective of this study is to investigate the heating and cooling performance of a heat pump utilizing the heat energy of the raw water supplied to a water treatment facility.

2. Experiment and data reduction

Fig. 1 shows the raw-water heat pump system installed in a water treatment facility located in Chung-ju, South Korea. Raw water from the Daecheong reservoir is the heat source to heat pump system via a plate type heat exchanger with a capacity of 151.2 kW. The heat energy is delivered to the brine water, which circulates

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doi:10.1016/j.enbuild.2011.07.028

Nomenclature

A	area (m^2)
ASHP	air source heat pump
COP	coefficient of performance
c_p	constant pressure specific heat (J/kg K)
WSHP	raw-water source heat pump
h	enthalpy (kJ/kg)
$\dot{m}$	mass flow rate (kg/s)
P	pressure (kPa)
q	rate of heat transfer (W)
T	temperature (°C)
U	overall heat transfer coefficient (W/m^2 K)
W	power consumption (W)

Subscripts

comp	compressor
cond	condenser
evap	evaporator
hp	heat pump
sys	system
w	work

between the heat pump and the plate heat exchanger. The specifications of the heat pump system are provided in Table 1. Two sets of the heat pump were installed in the site as shown in Fig. 1. The cooling and heating capacity of the system is 58 kW, and 65.2 kW, respectively. The system utilized refrigerant R410A, and has three compressors. One is a variable capacity scroll compressor and the others are fixed speed scroll compressors. The indoor units are cassette type and imbedded in the ceiling of the integrated waterworks operation center. Parts of the cassettes are closed when the heating and cooling load are low compared to the nominal capacity of the system. Table 2 shows the measurement instruments and their measurement errors. The RTD sensors are calibrated using the PT-100 Ω simulator and a RTD calibrator, the measurement errors are ±0.1 °C.

$$COP_{unit} = \frac{q}{W_{hp}}, \quad COP_{sys} = \frac{q}{W_{sys}} \tag{1}$$

Table 1
Specifications of the heat pump system.

Specifications	Capacity and type
Cooling capacity	58.0 kW @ Indoor dry and wet bulb temperature (27 °C/19.5 °C) @ Water temperature and flow rate (20 °C/190 l/min)
Heating capacity	65.2 kW @ Indoor dry bulb temperature (20 °C) @ Water temperature and flow rate (20 °C/190 l/min)
Compressor	Digital scroll compressor + two fixed speed scroll compressors
Refrigerant	R410A
Heat exchanger type	Brazed plate heat exchanger
Raw water flow rate	190 l/min

Table 2
Specifications for the measurement instruments.

Measurement items	Type	Instrument errors
Temperature	RTD (PT-100 Ω)	±0.1 °C
Flow rate	Electromagnetic flow meter	10.2–741.9 l/min ± 1% of full scale
Power consumption	3Phase-4Wire	Less than 1.0% of reading value

$$W_{hp} = W_{comp} + W_{fan} \tag{2}$$

$$W_{sys} = W_{hp} + W_{pump} \tag{3}$$

$$q_c = \dot{m}c_p\Delta T - W_{hp}, \quad q_h = \dot{m}c_p\Delta T + W_{hp} \tag{4}$$

The performance of the raw-water heat pump system was evaluated using COP. Eq. (1) is the definition of the unit and system COP. The unit COP is defined by the power consumption of only the heat pump system, which includes the compressor and fans for the heat exchangers. The power consumption for a heat pump comes from the compressor and the fans as shown in Eq. (2). For the system COP the power consumption, including the pumping power, is defined in Eq. (3). The cooling and heating capacity of the system is calculated using Eq. (4). Because the capacity is only measured in outdoor units, the heating and cooling capacity was calculated by adding or extracting the compressor power. The uncertainties of the system COP for all seasons were calculated by the RSS method [6]. The average uncertainty is ±16.8%.

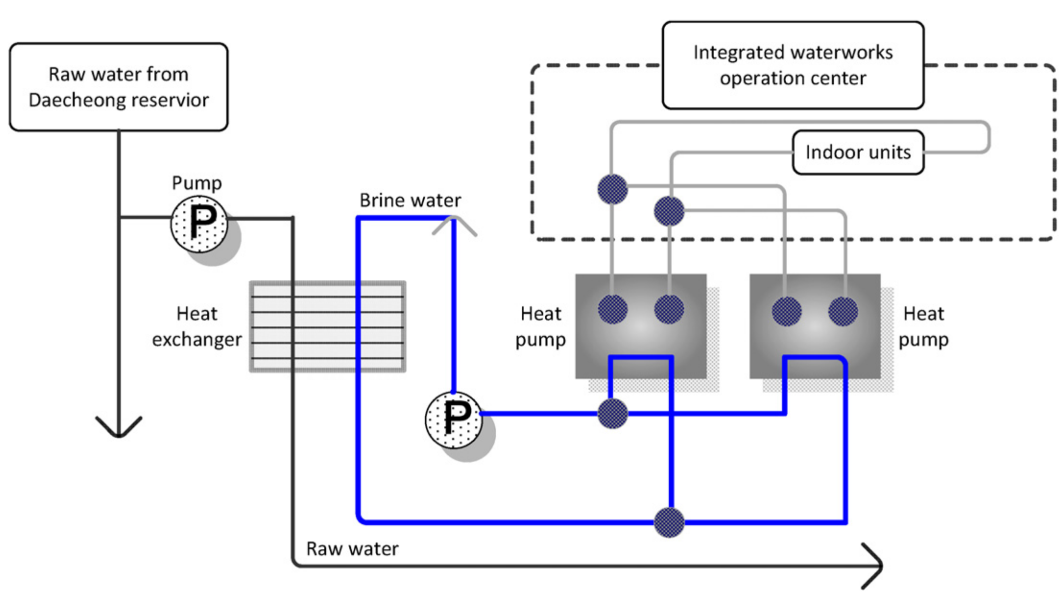

Fig. 1. Schematic of the raw water-source heat pump installed in the site of the water treatment facility.