Energy and Buildings 68 (2014) 321–328

Contents lists available at ScienceDirect

Energy and Buildings

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

Raw-water source heat pump for a vertical water treatment building

Sunhee Oh[a], Yong Cho[b], Rin Yun[a,*]

[a] Department of Mechanical Engineering, Hanbat National University, Duckmyung-Dong, San 16-1, Daejeon 305-719, Republic of Korea
[b] K-Water Institute, Korea Water Resources Corporation, 462-1 Jeonmin-dong, Daejeon 305-730, Republic of Korea

ARTICLE INFO

Article history:
Received 11 June 2013
Received in revised form 30 August 2013
Accepted 7 September 2013

Keywords:
Raw-water source
Heat pump
Vertical water treatment building
Thermal storage tank
TRNSYS

ABSTRACT

A raw-water source heat pump for a thermal storage tank in a vertical water treatment building was dynamically simulated by TRNSYS. Two different configurations of a heat pump system with either one or two heat pumps were investigated by considering different heating zones in the building. The average COPs of the single heat pump system were 4.79 and 3.76 for cooling and heating, respectively. When the size of the thermal storage tank was changed from 5 m^3 to 15 m^3, the highest COP was found at 10 m^3. The electric power consumption of the heat pump was significantly affected by weather conditions. The average COPs of the two-heat-pump system were 4.92 and 3.68 for cooling and heating, respectively. Except April and October the monthly average COP of the two-heat-pump system was higher than that of the single-heat-pump system.

1. Introduction

Compared to a conventional large-sized water treatment plant, which supplies tap-water to multiple big cities, small and decentralized water treatment facilities are considered as promising for new planned cities. Such systems have been designed and constructed in South Korea for new cities. These small and decentralized systems are located near end users such as city residents or industrial complexes. The small facility areas must be located near to the city, and the energy efficiency for water treatment should be higher or similar to that of existing large sized water treatment plant. Because there are not enough available sites near cities, vertical-configuration water treatment facilities, which are designed as buildings, are generally accepted. The merits of such systems are their lack of contamination during transport through networked pipes, and the minimization of the effects from the suspension of the water supply which is a significant problem in existing large-sized systems. However, because the construction and the operation cost of these systems are much higher than those of existing systems, the improvement of energy efficiency is a main issue. One possible way to solve this problem is to utilize renewable energy technologies in system operation, such as solar cells, small-scale hydropower, and raw-water source heat pump systems.

Raw water is untreated water supplied directly from the water reservoir of a dam to a water treatment plant. Raw water as a heat source is promising for saving energy. The temperature of raw-water is similar to that of the ground, and is higher than the ambient temperature in winter, and lower in summer. Raw water is plentiful in water treatment facilities, and has a large temperature difference. Recently, the use of thermal energy from raw water as a heat source for heat pumps for heating and cooling the building has been tested in Cheongju and Seongnam water treatment plant in South Korea.

Until now, studies on raw-water source heat pumps have been very limited. Cho and Yun [1] investigated the heating and cooling performance of a raw water source heat pump installed in a water treatment plant in Cheongju, South Korea. In spring and autumn, the COP of the raw-water source heat pump was much lower than that in summer and winter. In spring, the heating and cooling loads were extremely low, and the heat pump was operated under a significant part load conditions. The average heating and cooling COPs were 3.3 and 7.2, respectively. There have been more studies on other water sources, such as sea water, ground water, waste water, sewage water, and river water. Park et al. [2] developed a simulator that analyzed the system characteristics of a river water heat pump. The heating COP was predicted to be in the range of 3–4, and the cooling COP was estimated to be 4–6. Lee [3] investigated a sewage water heat pump system. A two-stage screw-type heat pump with a capacity of 100 RT was installed at a site and was tested for proof of operation. The cooling COP ranged from 4.0 to 5.0, and the heating COP was varied from 2.6 to 3.5. When the heating COPs were 2.6 and 3.5, the hot water temperature was 50 °C and 70 °C, respectively. Baik et al. [4] investigated the performance of a sea water source heat pump by changing the compressor capacity with R717. Kim et al. [5] conducted field tests with a sea water cascade heat pump system installed in a building with an air conditioning space of 890 m^2. The tests showed that the average heating and cooling COPs were 4.0 and 5.0, respectively. Jeon et al. [6] investigated

* Corresponding author. Tel.: +82 42 821 1732; fax: +82 42 821 1587.
E-mail address: yunrin@hanbat.ac.kr (R. Yun).

0378-7788/$ – see front matter
http://dx.doi.org/10.1016/j.enbuild.2013.09.011

Nomenclature

COP coefficient of performance
Q heating or cooling capacity (kW)
W_{hp} power consumption of heat pump (kW)

a hybrid cooling system combining a screw water chiller with a ground source heat pump for a building with an area of 484 m^2. For hybrid cooling operation, the COP of the screw water chiller was lower than when only the chiller was used, due to the effect of the part-load conditions in the hybrid operation. Haiwen et al. [7] suggested that energy-saving calculations should be conducted for the electric-driven seawater source heat pump throughout the whole heating season. In a case study, it was found that the energy-saving potential of the heat pump district heating system was significantly underestimated by 20.6% when the conventional static method was utilized. Ally et al. [8] analyzed the exergy and energy of a ground-source heat pump for domestic water heating. The COP of the water heater varied from a low value of 2.64 in February to a high value of 3.67 in September. The performance of the water heater was significantly dependent on the entering water temperature from the ground loop. The main sources of systemic inefficiency came from the compressor and the expansion valve.

The objectives of this study are to design and analyze a raw-water source heat pump to be installed in a vertical water treatment building, using TRNSYS, a dynamic simulator. Two system configurations are considered, one with a single heat pump equipped with a thermal storage tank, and one with two heat pumps and two thermal storage tanks. The operation characteristics were compared. The performance of the raw-water source heat pump were investigated by changing regional locations where the vertical water treatment building would be built, and the size of the thermal storage tank was optimized to maximize the COP of the heat pump.

2. Simulation of raw water source heat pump

2.1. Vertical water treatment building

Fig. 1 shows air-conditioning spaces of a vertical water treatment building in Cheongju. There are two water reservoirs and pump-room in the basement. On the second floor, an activated carbon filter, ozone generator, ozone tank, and motor control devices are installed. There are membrane filter units, backwash tank, and pumps on the third floor, and control rooms and offices for the vertical water treatment are located on the fourth floor. The staff resides only on the fourth floor in the building. Fig. 2 shows the details of the main walls and the floor, which are required to estimate the heating and cooling loads of the building. The thermophysical properties of wall materials are summarized in Table 1. Fig. 3 shows the variation of the raw water temperature in the Cheongju water treatment plant from January to December. The heating season was from October to April, and the cooling season was from May to September. The average raw water temperatures in the heating

Table 1
Thermal properties of walls for vertical water treatment building system.

Materials	Thermal conductivity (kJ/m h K)	Specific heat (kJ/kg K)	Density (kg/m^3)
Concrete	5.50	0.90	2300
Board	0.60	100	800
Insulation	0.12	1.47	40
Mortar	5.45	0.80	2000

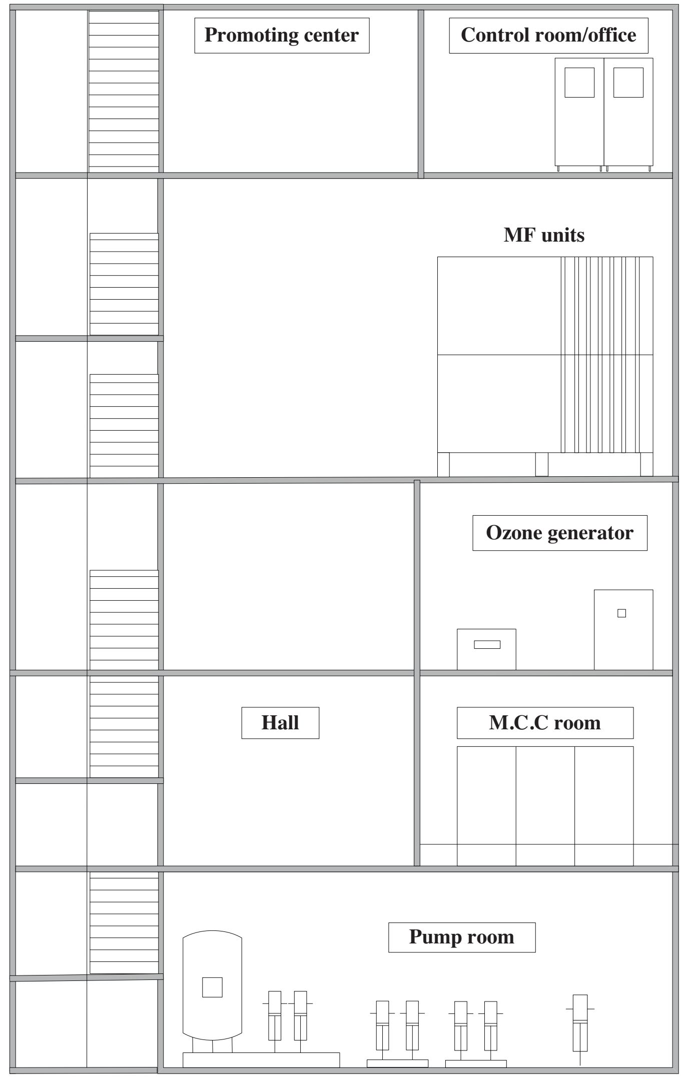

Fig. 1. Air conditioning spaces in Cheongju vertical water treatment building.

and cooling seasons were 9.9 °C and 20.7 °C, respectively. In the heating season, the raw water temperature ranged from 3 °C to 15 °C. Relatively low water temperature was found in February and March.

2.2. Details of simulation

Fig. 4 shows the schematic of the raw-water source heat pump for the vertical water treatment building. The raw-water source heat pump is composed of a heat pump, thermal storage tank, and fan-coil unit. The raw water supplies its heat energy to the secondary fluid through the heat exchanger, and the circulating secondary fluid provides the heat energy to the heat pump. The water in the thermal storage tank is heated or cooled by heat exchange with the heat pump. The fan-coil unit is utilized to supply the conditioned air to the vertical water treatment building. Two different configurations of heat pump were investigated, one with a single heat pump and one thermal storage tank, and the other with two heat pumps and two thermal storage tanks. Because the temperature of the third floor and the non-residential spaces below are to be maintained around 10 °C, high water temperature does not need to be supplied to the fan-coil unit. The objective of heating the space is just to prevent the water treatment equipment from freezing in winter. For the system with two heat pumps and two