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SCIENCE DIRECT®
Solar Energy 78 (2005) 427–440
SOLAR ENERGY
www.elsevier.com/locate/solener

A study on the design and analysis of a heat pump heating system using wastewater as a heat source

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Received 10 December 2003; received in revised form 3 March 2004; accepted 21 July 2004
Available online 11 September 2004

Communicated by: Associate Editor Joseph Khedari

Abstract

In this study, the compression heat pump system using wastewater, as a heat source, from hotel with sauna was designed and analyzed. This study was performed to investigate the feasibility of the wastewater use for heat pump as a heat source and to obtain engineering data for system design. This heat pump system uses off-peak electricity that is a cheap energy compared to fossil fuel in Korea. For this, the charging process of heat into the hot water storage tank is achieved only at night time (22:00–08:00). TRNSYS was used for the system simulation with some new components like the heat pump, which we create ourselves.

As a result, it was forecasted that the yearly mean COP of heat pump is about 4.8 and heat pump can supply 100% of hot water load except weekend of winter season. The important thing that should be considered for the system design is to decrease the temperature difference between condenser and evaporator working fluids during the heat charging process by the heat pump. This heat pump system using wastewater from sauna, public bath, building, etc. can therefore be effectively applied not only for water heating but also space heating and cooling in regions like as Korea.

Keywords: Heat pump; Hot water heating; Wastewater; Off-peak electricity; TRNSYS

1. Introduction

Wastewater discharged from saunas and public baths is relatively adequate in quantity and temperature and thus can be used as an efficient heat source for a heat pump (KEPRI, 1998). A heat pump system using wastewater as a heat source allows to use low-cost off-peak electricity, has no outdoor unit to make noise or spoil the appearance of the building where it is installed, and combines cooling/heating and hot water heating in a single unit. In addition, it has outstanding energy saving effect since it is operated at high COP without air pollution. Several types of heat pump systems are widespread in northern developed countries (Stuij and Stene, 1994). In Japan (Baek et al., 2001), a simulation study of district cooling/heating systems using sewage water as an energy source shows that, compared with conventional air-source heat pumps, wastewater source heat pumps

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0038-092X/$ - see front matter
doi:10.1016/j.solener.2004.07.009

Nomenclature

M_{day}	water consumption during day (peak time) (m^3)
T	temperature (K)
V	storage tank volume (m^3)

Greek symbols

η	rate of the thermal storage to daily heating load
γ_i	control function
Δ	dead band

Subscripts

co	condensing
ev	evaporating
hw	hot water
i	inlet
o	outlet
set	setting value
sto	storage
wst	wastewater

could help reducing energy consumption by 34%, lowering the emission of carbon dioxide (CO_2) by 68% and controlling the generation of nitrogen oxides (NO_x) by 75%.

The purposes of this study are to evaluate the efficiency and design of a heat pump hot water system that operates during night time hours and uses as a heat source, wastewater discharged from saunas and public baths, to investigate the properties and potential amount of wastewater discharged from hot spring and accommodation facilities in Yuseong area (KIER, 2001), and to perform design and analysis of a heat pump water heating system based on the investigation.

2. System design

A heat pump system using off-peak electricity is a water heating system designed to heat low-temperature (about 301 K) hot spring water during night time hours (22:00–08:00) and use, as a heat source, its wastewater stored in a wastewater storage tank (hereinafter abbreviated as WST). Heated spring water is stored in a hot water storage tank (hereinafter abbreviated as HWST) and supplied when needed.

2.1. Hot water heating load and wastewater amount

In this study we used the heat pump system of the Hotel "K" that uses hot spring wastewater as a heat source (hereinafter abbreviated as HPSW). Hotel "K" is a large hotel with a total area of 19,977 m^2, 2 basements, 10 floors, 144 rooms, and sauna facilities. The hotel's cooling/heating facilities include two 450RT double effect absorption chillers, three 4 ton/h steam boilers, and a single 425 ton wastewater tank. The hotel's basements contain two sets of a 0.424 m^3 WST and a 0.115 m^3 HWST for the hotel's own uses and for use of sauna, respectively.

The hotel supplies both low (301 K) and high (319 K) hot spring water temperature, 62.5% of which is low-temperature. The system's water heating load is the amount of energy needed to heat low-temperature hot spring water to a higher level of temperature.

Table 1 shows the mean consumption of low-temperature spring water used for every 2 h each day of the week during winter (November–February). There is a notable difference between the mean consumption of hot water used on week days (282 m^3) and on weekends (366 m^3). It was found that the hot water consumption during spring (March–May) and during fall (September–December) was respectively 75% and 50% of the consumption during winter as a result of investigation. The pattern of thermal water use by time of the day was nearly identical to that seen in winter. Critical to determining the capacity of the storage tank for this system is the hourly distribution and the ratio of hot water consumption during peak-off time (22:00–08:00) and peak time (08:00–22:00), which was founded to be 22%:78%, as shown in Table 1.

As described above, the system hot water heating load is the amount of energy needed to heat low-temperature thermal water to a higher level of temperature. Table 2 shows the daily hot water heating loads needed to supply hot water for the Hotel "K". The temperature of hot water supplied is set to be 323 K.

2.2. Design of a heat pump system (KOPEC, 1996)

Existing water heating system with HWST, where an oil or electric heater is used to heat water, minimizes the capacity of the storage tank by storing high-temperature hot water. However, the heat pump is not capable of producing hot water at a temperature of over 328–333 K. Like this system, systems that require an instant supply of hot water exceeding the heating capacity require a storage tank to play the role of a buffer tank. In case there is an adequate amount of thermal water, it is desirable that the storage temperature should be set at a temperature to allow supply of hot water without mixing with cold water (city water).