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Application of an exhaust heat recovery system for domestic hot water

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ABSTRACT

Typically, a great deal of heat is wasted in the drainage systems of large-scale public shower facilities, such as those in schools, barracks, and natatoriums. This paper enhances a heat pump system used in public shower facilities for exhaust heat recovery. The system consists of three sections for exhaust heat recovery: solar energy collection system, drainage collection system, and heat pump system. In the system, the energy from the solar energy collection system is used for the initial heating the shower's tap water. Afterwards, the drainage collection system collects the used shower water. Finally, the electric heat pump recycles the exhaust heat from the collected water to heat the shower's tap water. The operational practice of the system was presented. The drainage temperature and equipment capacity was optimized based on a practical example. The advantages of this heat pump system compared to gas-fired (oil-fired, coal-fired, electric) boilers are lower energy consumption, less pollution, and lower operating costs. Therefore, the system is superior in energy conservation and has a promising application prospect.

1. Introduction

The use of a heat pump to recover and recycle exhaust heat has significant impacts in energy-saving and environmental protection. In addition, heat pump technology has been quickly developing over previous decades, and currently various kinds of heat pump systems are widely used [1]. For example, the heat pump system that recovers heat from urban wastewater has been used with greater frequency [2–5]. Unfortunately, the urban wastewater temperature is relatively low (generally around 10 °C) in winter, causing higher recycling costs [6]. Thus, an alternative method is necessary to adjust the high recycling costs of low temperature urban wastewater in order to prove the sewage source heat pump useful in saving energy. Different from the urban wastewater heat recovery, the wastewater discharge of large-scale public shower facilities, such as those in schools, barracks, and natatoriums has the following characteristics:

(1) The bathroom opens up at a specified time, therefore heat use and heat elimination are concentrated, and hot demand is stable throughout the year;
(2) The time interval from wastewater collection to heat recovery is shorter. The wastewater temperature is higher (up to above 30 °C), and can be used as an efficient heat source for a heat pump [7,8] to easily recover the exhaust heat;
(3) The heated tap water temperature is lower (about 10 °C), and can initially directly carry out the heat exchanger with wastewater so that the capacity of the heat pump can be reduced and its investment can be saved.

Therefore, the key problem is determining a highly efficient exhaust heat recovery and recyclability. A heat pump system using wastewater from a hotel as a heat source was presented [9]. However, the hotel carried no hot features, such as public bathrooms, thus the required heat pump heat recovery system forms are different. Regardless, this study merely evaluates the efficiency of the system which operates during night time hours, but does not analyze its economical efficiency. Therefore, a heat recovery system combined with a solar energy collection system using domestic hot water is discussed, with some economical and environmental analysis.

2. System description

Public shower facilities tend to have a high occupancy rate because they are only opened during specified times. This means the waste heat in the water drain could be a valuable resource. The solar heat pump system, as illustrated in Fig. 1, could be used to recover exhaust heat and reduce energy consumption.

The proposed system consists of three subsystems: solar collection system, drainage collection system, and heat recovery system.

The solar collection system consists of a heat collector (1), a pump for the collector (2), a heat storage tank (3), and an electric

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Nomenclature

A	area of the heat exchanger (m^2)
c_p	specific heat capacity of water (kJ/kg °C)
COP	coefficient of performance
K	heat transfer coefficient between tap water and gray water in the heat exchanger (W/m^2 °C)
m_f	tap water flow rate into heat pump (L/s)
m_p	gray water flow rate into heat pump (L/s)
Q_{EX}	heat provided to tap water by heat exchanger (kW)
Q_{hp}	heat provided to tap water by heat pump (kW)
S	the surface area of the solar collector (m^2)
t_c	condensing temperature (°C)
t_{f1}	inlet tap water temperature of heat exchanger (°C)
t_{f2}	outlet tap water temperature of heat exchanger (°C)
t_{f3}	outlet tap water temperature of heat pump (°C)
$t_{f,m}$	annual average temperature of tap water (°C)
$t_{f,m}$	annual average temperature of tap water (°C)
t_{p1}	inlet gray water temperature of heat exchanger (°C)
t_{p2}	outlet gray water temperature of heat exchanger (°C)
t_{p3}	outlet temperature of heat pump (°C)
t_{supply}	hot water supply temperature (°C)
Δt_{ex}	heat transfer temperature difference between tap water and gray water in the heat exchanger (°C)
V_r	heat storage tank (m^3)
V_p	volume of the gray water pool (m^3)
W	electric power of heat pump (kW)
ρ	water density (kg/m^3)

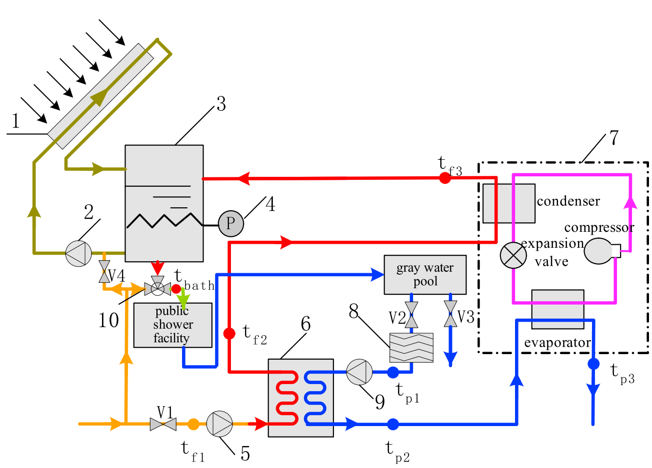
heater (4). The flat-plate solar collector is located on a slanted roof facing south. The heat storage tank is used for heat collection and storage to maintain a balance between the required heat volume and heat collected by the solar collector. The start and stop signals of the pump for the collectors are determined by the temperature difference between the solar collector outlet temperature and the water temperature at the bottom of the heat storage tank. In general, the pump begins when the temperature difference is greater than 3–5 °C and stops at less than −0.5 °C–2 °C. If the water temperature does not meet the requirements, then the electric heater supplements the heat.

The drainage collector system is mainly comprised of a gray water pool. The water is drained through a pipe and stored in the tank.

In the heat recovery procedure of the heat recovery system, the wastewater is filtered and then piped to the heat exchanger to heat the tap water. Afterwards, the water is piped to the evaporator of the heat pump system to for additional heating. Finally, the wastewater is discharged and the tap water is piped to the heat storage tank.

2.1. The operational procedure of the exhaust heat recovery system

The main control and operational processes of the system are as follows:



1-solar collector; 2-pump for collector; 3-heat storage tank; 4-electric heater; 5-water pump;6-water-water heat exchanger; 7-water-water heat pump; 8-filter; 9-wastewater pump; 10-tee joint mixing valve;

Fig. 1. Illustration of the heat recovery system.

◆ The process of filling the storage tank with water and heating it up

When the shower facility first opened, the heat pump system did not work yet, because there was no hot water in the gray water pool to provide evaporating heat. The hot water in use in the public facility at this point was the water in the storage tank, which was heated through a solar collector during the daytime. The heat could be supplemented by electric heaters during bad weather or when the water temperature does not meet the requirements for shower water. If thermal solar energy was quite adequate and the water temperature in the water tank was even higher than the requirement, the tee joint valve would be adjusted to maintain a proper water supply temperature for the public shower facility.

◆ The recovery and recycle process of the exhaust heat

After a period of time, as the wastewater accumulates volume in the gray water pool, the heat pump system could begin the heat recovery and recycling. The starting and stopping of the heat pump could be controlled according to the waterlines in the storage tank and gray water pool as illustrated in Fig. 2. There are three waterlines in the storage tank (F1, F2, and F3) and four lines in the gray water pool (P1, P2, P3, and P4).

If the water in the gray water pool rises above waterline P3, then the heat pump system, water supplying pump, and wastewater pump starts, and valves V1 and V2 open. The gray water is filtered through the filters and then pumped to the heat exchanger to heat the tap water, which consequently drops the temperature of the gray water. After, the gray water is piped to the evaporator of the heat pump to release additional heat. The tap water is heated through the heat exchanger and goes to the condenser of the heat pump to recover additional heat. In this way, the exhaust heat is recycled. If the outlet temperature of the tap water is not high enough to be used for showering, the electric heater is activated to compensate. This operational mode should maintain working if the water level in the gray water pool remains between P1 and P4 and

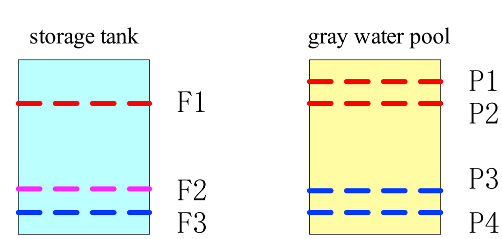


Fig. 2. Controlling waterlines.