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Field measurement and energy efficiency enhancement potential of a seawater source heat pump district heating system

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ABSTRACT

As a renewable energy utilization system, seawater source heat pump district heating system can eliminate the local air pollution compared with the direct combustion of fuel in the conventional boiler house district heating system in northern cold climate area. A field measurement with an emphasis on the energy efficiency of an actual seawater source heat pump district heating system was conducted and analyzed. The field measurement showed that the heat pump units consumed the largest part of energy consumption of the whole system (as high as 78.9% in the project). However, the coefficient of heating performance (COP) of the seawater source heat pump unit was as low as 2.43. Then the energy efficiency enhancement potential of the heat pump unit was carefully analyzed and calculated in the light of the index of Thermodynamic Perfectibility for the heat pump unit. And the results showed that there is about an average of 24.2% energy efficiency enhancement potential of the heat pump units in the project. In the end, a verification case study indicated that the COP of the heat pump units in the project will increase 34.6% if they are substituted by the ones made by another manufacturer.

1. Introduction

Seawater source heat pump system is a renewable energy utilization system as it can utilize the seawater temperature difference energy. When the seawater source heat pump heating system is adopted to heat the buildings instead of the boiler house heating system in north cold climate seaside area, the local air pollution introduced by the fuel burning will be greatly alleviated. So under the severe environmental pollution condition, the research on the seawater source heat pump heating system attracts more attention from the researchers. North European countries take a lead in the engineering application of the seawater source heat pump heating and cooling system. Especially in Norway and Sweden, there are large scale application of the system for buildings [1,2]. Meanwhile, more research and applications of the system have been developed in the United States, Canada, China and Japan [2–9]. These available researches on the seawater source heat pump heating system include such aspects as the advantages of the system over conventional ones, system types that can be applied, heat transfer characteristics between different parts of the system, and energy saving effects or energy efficiency evaluation of the system. However, very few literatures are found on the evaluation of energy efficiency enhancement potential for a running seawater source heat pump heating system. Here, a field measurement was conducted for a running seawater source heat pump district heating system on an island in north China. It was found that the seawater source heat pump units dominated the overall system energy consumption whose energy consumption ratio to the overall system accounted to nearly 80%. And the average heating coefficient of performance of a typical heat pump unit (COP) during the measurement period was only 2.43. So the heating performance of the heat pump units becomes the key in raising the energy efficiency of the whole system. Then the energy efficiency enhancement potential of the heat pump units is evaluated in light of the concept of *Thermodynamic Perfectibility*. In the end, the evaluation result is verified by a joint venture brand heat pump unit.

2. Brief introduction of the project

The seawater source heat pump district heating system is located on an island of Dalian, a northeast seaside city of China. In fact, the original heating system is coal-fired boiler house district heating system. However, not only the transportation of coal was relatively high as the island is far away from the mainland, but also the coal-fired boiler house became the main pollution source of the island that seriously deteriorated the local air quality. The

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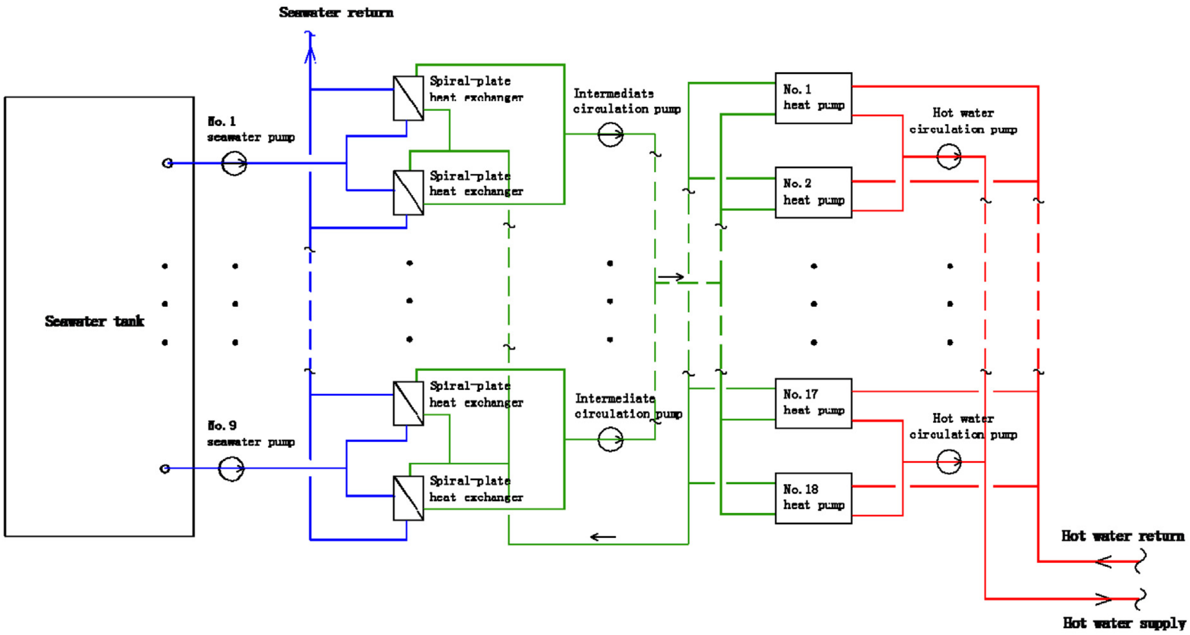

Fig. 1. Schematic diagram of the seawater source heat pump district heating system.

Table 1
Equipment in the seawater source heat pump station.

Equipment	Specifications	Number
Heat pump units	Heating capacity 635 kW; input power 161 kW	18
Hot water circulation pumps	Flow rate 240 m^3/h; water head 46 m H_2O; power 45 kW	9
Intermediate fluid circulation pumps	Flow rate 208 m^3/h; water head 21.5 m H_2O; power 18.5 kW	9
Intermediate fluid make-up pump	Flow rate 30 m^3/h; water head 30 m H_2O; power 1.5 kW	1
Hot water make-up pumps	Flow rate 50 m^3/h; water head 50 m H_2O; power 5.5 kW	2
Seawater pumps	Flow rate 210 m^3/h; water head 25 m H_2O; power 22 kW	9
Spiral-plate heat exchangers	Heat exchange area 150 m^2; operating temperature <50 °C; pressure 0.6 MPa	18

coal-fired boiler house district heating system has been changed to the seawater source heat pump district heating system so as to change the situation. The total building area heated by the seawater source heat pump district heating system is 130,000 m^2. Fig. 1 shows the diagram scheme of this system. And the main equipment within the heat pump station is listed in Table 1.

It has to be pointed out that there are four seawater pumps installed separately in the seawater pumps house (not shown in Fig. 1) to pump the seawater into the seawater tank. The rated performance values of each seawater pump are 45 kW (power), 650 m^3/h (flow rate) and 20 m H_2O (water head).

3. Field measurement of the seawater source heat pump district heating system

The field measurement time was from January 24th to January 27th of 2013. This was nearly the coldest period of Dalian. The lowest outdoor air temperature measured was −11 °C which was lower than the design outdoor air temperature for heating in Dalian (−9.5 °C) [10]. The average outdoor air temperature was −7.0 °C and the outdoor air temperature profile during the measurement period is shown in Fig. 2 (the measurement interval is 10 min).

In the field measurement, a heat user with floor radiant heating system was randomly selected and its indoor air temperature during measurement period is shown in Fig. 3. The average indoor air temperature of the user is 17.4 °C that meets the requirement of China national design standard [11].

The energy efficiencies of the seawater source heat pump unit and the whole system are calculated based on the measurement data.

(1) The actual energy efficiency of the seawater source heat pump unit. Although the outdoor air temperature during the field measurement period was very low, the seawater source heat pump units and the whole system were still in operation. As all the heat pump units were in the same capacity and operated stably, one of the heat pump units was selected as the representative unit and its operational data was collected. The average hot water supply and return temperatures were 39.9 °C and 36.7 °C, and the average inlet and outlet temperatures of the evaporator of the heat pump unit were 0.8 °C and −1.2 °C respectively which are shown in Figs. 4 and 5.

In order to obtain the actual energy efficiency of the heat pump unit, the flow rates of heating and cooling water on the condenser and evaporator side were measured by an ultrasonic flowmeter, and the power consumption of the heat pump unit was acquired by the field monitoring system. According to the national standard "water source heat pump unit" [12], the coefficient of heating performance of a heat pump unit (i.e. COP) is defined as the ratio of the heating capacity to the power consumption of the heat pump unit. That is:

$$COP = \frac{Q_k}{W} \quad (1)$$

In which, Q_k is the heating capacity of the heat pump unit, kW; W is the input power of the heat pump unit, kW. So the actual COP profile of the heat pump unit during measurement period is shown in Fig. 6. The results showed that the COP values of the heat pump unit were relatively stable and fluctuated around 2.43 within the range of 7% (i.e. COP = 2.43 ± 0.18).

(2) Energy efficiency calculation of the overall seawater source heat pump heating system. The energy efficiency of the whole seawater source heat pump district heating system is the ratio of total