Renewable Energy 65 (2014) 236–244

Contents lists available at ScienceDirect

Renewable Energy

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

Potential to enhance performance of seawater-source heat pump by series operation

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ARTICLE INFO

Article history:
Received 18 February 2013
Accepted 17 September 2013
Available online 14 October 2013

Keywords:
Heat pump
Annual heating performance
Seawater-source

ABSTRACT

In this study, the performance enhancement potential by series operation in seawater-source heat pump system, assumed installed in Gangneung city near the East Sea in Korea, was investigated. An annual heating load for a typical Korean-style apartment house, which has an effective area of about 85 m^2, was modeled by using TRNSYS program. An ambient condition was assumed to be in accordance with the Korean standard meteorological data, while the seawater temperature was calculated from the regression equation based on the measurement. A heat pump performance at full-load was calculated from the regression equation, which involves refrigerant's evaporating and condensing temperatures, based on a commercial screw compressor performance map. A part-load performance was also considered. Simulation results show that an annual heating performance of a seawater-source heat pump system can be improved by 8% or more by series operation under the simulation conditions considered in the present study.

1. Introduction

Similar to geothermal energy, seawater offers outstanding characteristics as a heat source for the heat pump. This is because it has less seasonal temperature variation and lower freezing temperature (about −2 °C) than river water, and also maintains 5–10 °C temperature difference from the atmosphere, which is ideal for heating and cooling. Moreover, since Korea is bordered by seawater on three sides, a huge amount of ocean thermal energy can be utilized.

Northern European countries, such as Sweden and Norway, have been using seawater heat as a heat source for district heating since 1982. Sweden uses seawater between 1.5 and 2.0 °C to operate a number of heat pumps of some MWs of capacity. In Norway, seawater between 4 and 7 °C is used for heat pumps to provide district heating for a region of about 15 km^2. Since 1993, areas in Japan, including Fukuoka Seaside Momochi, Osaka Nanko Cosmosquare Area, and Sunport Takamatsu District have also been using seawater heat source for district heating and cooling. There have been several related research and application cases in Korea. Han et al. [1] introduced a design practice of the seawater source heat pump, which has a capacity of 800 kW, for a Korean Pavillion at EXPO 2012 Yeosu, Korea. Kim et al. [2] investigated the in situ performance of the seawater source R134a/R410A cascade heat pump. Park and Kim [3] carried out an economic evaluation of a cooling system using deep ocean water. Park [4] also introduced an ongoing research on HVAC system using deep ocean water in Korea.

In this study, as part of fundamental research for establishing design and operation strategy for large-scale seawater source heat pump systems, the annual heating performance enhancement potential by series operation of heat pumps was investigated. In order to do this, for a typical Korean-style apartment house, the hourly heating load during a year was calculated by using TRNSYS program. After that, annual heating performances of a single-unit heat pump and 2-, 3-, 4-series-connected heat pumps were simulated.

2. Simulation modeling

2.1. Heating load

The seawater heat pump system discussed in this study is appropriate for supplying heat to relatively large areas. Accordingly, this study discusses using the heat pump system in residential complexes consisting of up to hundreds of households. Specifically, the heat pumps in this study can be understood as conventional district heating substations installed in residential complexes that receive hot water from district heating suppliers and distribute heat to each household. While various ways exist to calculate the

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http://dx.doi.org/10.1016/j.renene.2013.09.021

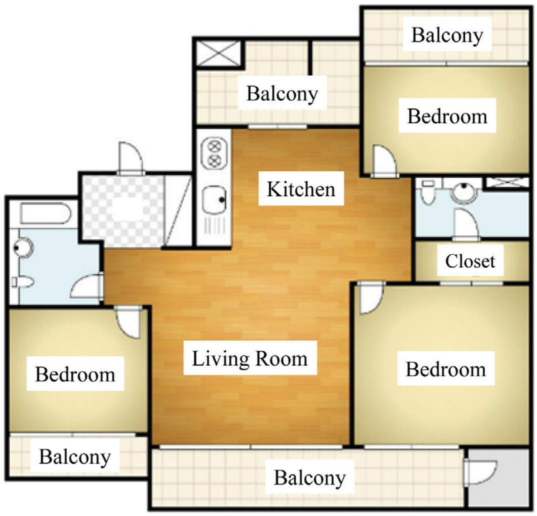

Fig. 1. A plan of a typical Korean-style apartment house (Kyeryong Construction Industrial Co., Ltd).

heating load of a residential complex that uses district heating, the most common method is to multiply the total area by a predefined unit heating load [5,6]. Based on this method, we decided to establish a heat load model for a typical household that is representative of the units in the complex, rather than model hundreds of individual units with various configurations. The representative household (or individual unit) has a dedicated floor space of 85 m^2, faces south, and is not adjacent to building's outer wall. After calculating the heating load for each hour of the year for the typical unit, we assumed that other households had similar characteristics. Because specifying the number of households under these assumptions is not very significant, we used the heating load ratio (HLR, 0–1), a dimensionless index that indicates the ratio between the heating load at each hour and the highest heating load of the year.

For a calculation of the hourly heating load, the TRNSYS program was used for a typical Korean-style apartment house. An actual apartment unit, the floor plan of which is shown in Fig. 1, was modeled by dividing it into heating space and non-heating space (balcony, stairway, and elevator space), as shown in Fig. 2. In order

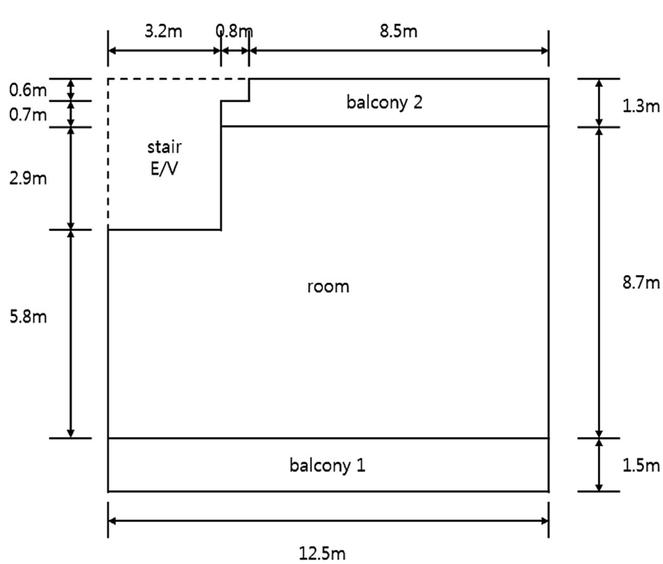

Fig. 2. A simplified simulation model.

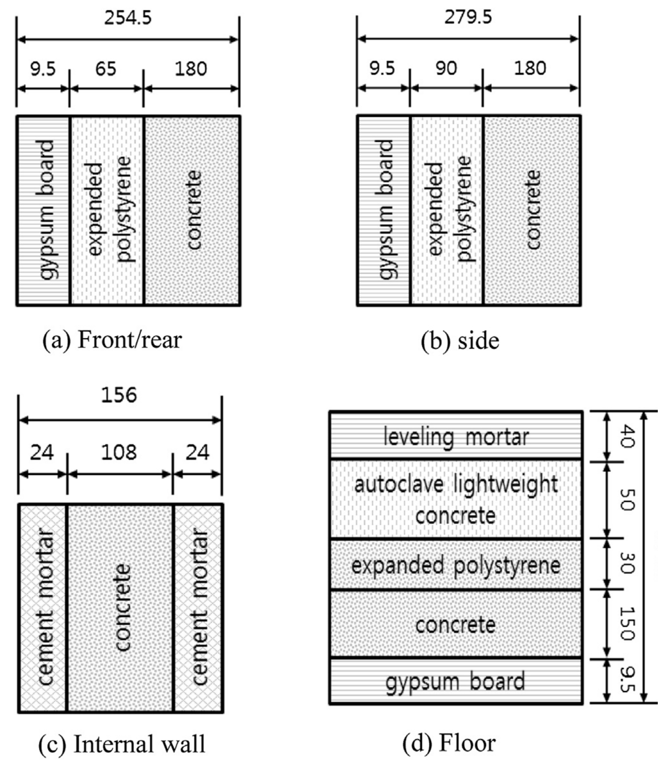

Fig. 3. Details of main walls and floor (unit: mm).

to allow the modeled space to be thermally equivalent to the actual space (in other words, to allow every walls and windows to have an identical area), the perimeter of the walls, rather than the floor area, was made identical [7]. The ceiling height was fixed at 2.3 m.

Although the energy-saving design standards for buildings published by the Korean Ministry of Land, Transport and Maritime Affairs recommend room temperature of 20 °C for heating, 23.5 °C was used in this study for calculating the heating load, based on the actual operating data of the district heating system [8]. When it comes to ventilation rate, a typical apartment unit design in Korea uses 1.5 ACH, the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) recommends 0.5 and 0.7 ACH for new and existing buildings, respectively, and the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan (SHASE) recommends 0.7 ACH or higher. In this study, 0.85 ACH was used [5].

As for the insulation thickness of walls, we adhered to the energy-saving design standards discussed above, which are shown in Fig. 3. The physical properties of wall materials and the window

Table 1
Thermophysical properties of wall materials and window.

Material	Thermal conductivity [W/(m K)]	Specific heat [kJ/(kg K)]	Density [kg/m^3]
Gypsum board	0.21	1.13	910
Expanded polystyrene	0.034	1.25	28
Concrete	1.62	0.79	2400
Autoclave lightweight concrete	0.17	1.09	600
Mortar	1.51	0.79	2000
Leveling mortar	0.37	0.79	2000
Windows *U*-value	Inside(insulating glass): 2.8 W/m^2 °C Outside(double low-e): 1.76 W/m^2 °C		