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A techno-economic comparison of a direct expansion ground-source and a secondary loop ground-coupled heat pump system for cooling in a residential building

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ABSTRACT

This paper reports a techno-economic comparison between a direct expansion ground-source heat pump system (DX-GSHP) and a secondary loop ground-coupled heat pump system (SL-GCHP). For this purpose, a DX-GSHP and an SL-GCHP system are designed and installed in parallel for same space cooling load in a demonstrating building in Hunan province, China. The structures of the two systems are described. The performances of the two systems were experimentally determined from June to September in cooling season of 2009. The average cooling performance coefficients (PFsys) of the DX-GSHP system was obtained to be 6.03 and that of the SL-GCHP system was determined to be 5.64. The average input power values for the DX-GSHP system and the SL-GCHP system are found to be 1.39 and 1.715 kWh, respectively, which means that DX-GSHP has a 23.8% higher efficiency than SL-GCHP in cooling mode. The paper studied the initial investment, the annual cost (AC) and the present worth (PW) of the two systems. It is concluded that the DX-GSHP is more economic than the SL-GCHP. Further more, the advantage and disadvantage of the DX-GSHP are analyzed. The minimal refrigerant velocity in order to ensure oil return is derived. It is shown that DX-GSHP could be vigorously pushed when oil return problem is solved satisfactorily.

1. Introduction

The worldwide growing energy shortage and increasing energy demand have recently driven a great incentive of the Ground source heat pump (GSHP) applications in heating, cooling and domestic hot water systems in buildings [1–3] because of their higher energy efficiencies. GSHP systems use the ground as a heat source/sink to provide space heating and cooling since heat is extracted from or rejected to the ground via a closed loop, i.e. Ground Heat Exchanger (GHE), through which water or refrigerating fluid circulates. Among the various GSHP systems, the vertical GSHP system has attracted the greatest interest in research field and practical engineering as well, owing to its advantages of less land area requirement and wide range of applicability. Generally, the vertical GSHP system can be divided into two great categories according to the different fluid in the GHE: the Direct Expansion Ground-source Heat Pumps (DX-GSHP) and the Secondary Loop Ground-coupled Heat Pump (SL-GCHP). The DX-GSHP consist of a copper ground heat exchanger, a water-to-water or water-to-air heat pump, and a heat distribution system, in which the refrigerant is circulated in pipes buried in the ground. A typical DX-GSHP with a single U-tube is illustrated in Fig. 1. The most conventional GSHP is the SL-GCHP which circulates pure water or antifreeze fluid through a liquid-to-refrigerant heat exchanger in the ground, with an air-cooled condenser (heat pump) or air-heated evaporator (air conditioner) in the space to be conditioned. The typical schematic with a single U-tube of SL-GCHP is illustrated in Fig. 2. The DX-GSHP systems have certain energy efficiency advantages over conventional ground-coupled heat pump systems. Principal among these advantages are that the secondary heat transfer fluid heat exchanger and circulating pump are eliminated. The installed GSHP systems were basically SL-GCHP systems in the world today. The reasons can be analyzed as follows: the first is that experts and scholars from home and abroad are greatly focusing on the research and development of the SL-GCHP system research and, the technique of DX-GSHP are still at the experimental stage. The other is that the DX-GSHP produces more system design and environmental problems (e.g., compressor starting, oil return, possible

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Nomenclature

a	the oil film thickness [m]
r	radius [m]
u	velocity [m/s]
P	pressure [Pa]
ρ	density [kg/m^3]
g	acceleration of gravity [m/s^2]
Re	Reynolds number
μ	coefficient of kinematic viscosity
U	mean velocity [m/s]
W	power [W]
$\overline{W}$	average power [W]
COP	the coefficient of performance of the unit
PF	the coefficient of performance of the whole system
m	mass flow rate [kg/s]
Q	the heat transfer rate [W]
T	temperature [°C]
Cp	specific heat capacity [kJ/kg·K]
t	time [s]/payback period [year]
Δt	interval time [s]
AC	air conditioning/the annual cost
PW	present worth [yuan]
i	interest rate
x	fuel price escalation rate/dryness fraction
n	number of interest periods.
IC	initial cost [yuan]
AM	annual operating and maintenance paid [yuan]

Subscripts

oil	oil
ref	refrigerant
min	minimum
l	liquid
g	gas
comp	compressor
cond	air conditioning
i	inlet
o	outlet
fan	fan-coil unit
pump	circulating pump
sys	system
w	water
0	starting
add	the additional investment
first	the savings based on the first year
ev	evaporation
con	condensation
outdoor	outdoor

ground pollution, and more refrigerant charging). General design guidelines for DX-GSHP systems are not well documented.

During the past few decades, a considerable number of studies have been carried out to investigate the development and applications of the conventional GCHP systems. The theoretical researchers have concentrated on numerical methods of simulating ground heat exchanger (GHE) and studying the parametric effect on the system performance [4–17]. For example, Esen et al. [4] have reported a detailed techno-economic analysis of a ground-source heat pump system and six conventional heating systems for the climate conditions of Turkey in heating season of 2002–2003. Bakirci et al. [14] investigated the performance of the solar-ground source heat pump system in the province of Erzurum having cold climate from October to May of 2008–2009. Ozyurt et al. [15] evaluated the experimentally performance and energy analysis of vertical ground source heat pump for winter climatic condition of Erzurum. Wang et al. [16] presented the experimental study of a solar-assisted ground-coupled heat pump system (SAGCHPS) with solar seasonal thermal storage installed in a detached house in Harbin. Inalli et al. [17] validated the effects of the parameters such as the buried depth of earth coupled heat exchanger, mass flow rate of the water-antifreeze solution and sewer water on the performance of a horizontal ground-source heat pump system used for space heating experimentally. There are also a few comparison studies with ground coupled air conditioning systems. The experimental and simulated comparisons of a reversible ground-source heat pump coupled to a municipality water reticulation system to the a conventional air-source heat pump are conducted in both the cooling and the heating cycles by Swardt et al. [18]. Results obtained from measurements and simulations indicate that the

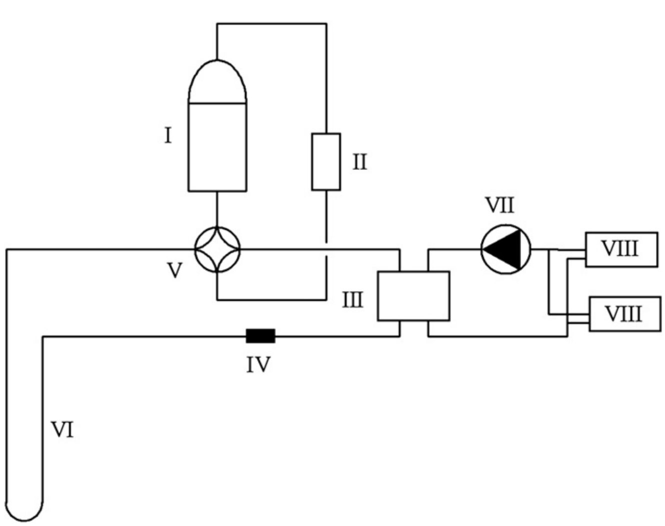

Fig. 1. The main components and schematic of the DX-GSHP system.

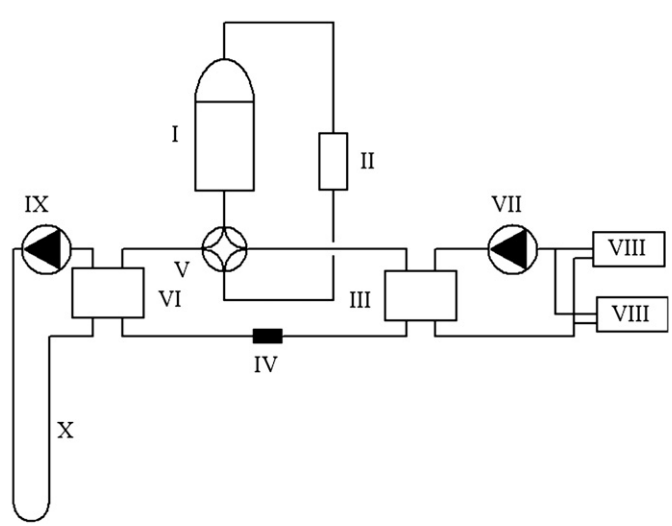

Fig. 2. The main components and schematic of the SL-GCHP system.