Applied Energy 102 (2013) 877–884

Contents lists available at SciVerse ScienceDirect

Applied Energy

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

The cooling seasonal performance factor of a hybrid ground-source heat pump with parallel and serial configurations

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HIGHLIGHTS

- ▶ The performance of a HGSHP with parallel and serial configurations is measured.
- ▶ The CSPFs of the HGSHP and the GSHP are estimated using the weather data.
- ▶ The CSPF of the parallel HGSHP is 6.5% higher than that of the GSHP.

ARTICLE INFO

Article history:
Received 6 May 2012
Received in revised form 19 September 2012
Accepted 20 September 2012
Available online 8 November 2012

Keywords:
Hybrid ground-source heat pump
Cooling seasonal performance factor
Configuration
COP
Heat rejection ratio
Ground thermal degradation

ABSTRACT

A hybrid ground-source heat pump (HGSHP) is proposed to overcome the decrease in the performance of a ground-source heat pump (GSHP) at the degraded ground thermal condition. In this study, a performance comparison between the GSHP and the HGSHP with parallel and serial configurations was conducted by varying the leaving fluid temperature (LFT) of the ground heat exchanger (GHEX), the fluid flow rate of the supplemental loop, the mean outdoor bin temperature, and the switching temperature of the hybrid operation. At the LFT of the GHEX of 40 °C, the coefficient of performances (COPs) for the HGSHP with the parallel and serial configurations were 18% and 6% higher than that of the GSHP, respectively. The cooling seasonal performance factors (CSPFs) of the HGSHPs with the parallel and the serial configurations were 6.5% and 2.0% higher, respectively, than that of the GSHP for Daegu city in South Korea.

1. Introduction

Energy consumption in commercial and residential buildings for space cooling and heating is an important issue [1]. A ground-source heat pump (GSHP) shows higher energy efficiency than the conventional air-source heat pump (ASHP) or air-conditioner (AC) because the ground thermal environment provides lower temperatures for cooling and higher temperatures for heating, and also experiences less temperature fluctuation than ambient air temperature change in extreme weather conditions [2]. Furthermore, the GSHP systems are economically preferable to the ASHP system or conventional heating systems [3–5]. Many theoretical and experimental studies showed that the performance of the GSHP was higher than that of the conventional systems [6–13]. However, during long-term operation, the performance of the GSHP with a vertical closed-loop ground heat exchanger (GHEX) can be degraded because of the thermal imbalance between heat extraction from the ground and heat rejection into the ground [14,15]. A hybrid ground-source heat pump (HGSHP) was proposed to solve the problem of thermal imbalance in the degraded ground thermal condition by combining the GSHP with supplemental heat rejecters and heat extractors in cooling- and heating-dominated buildings, respectively. Sagia et al. [16] used a cooling tower as a supplemental heat rejecter of the HGSHP for a Greek cooling dominated climate, and Man et al. [17] conducted a feasibility study on a novel HGSHP with a cooling radiator for cooling load dominated buildings. Chen and Yang [18] proposed a solar collector as a heat extractor of the HGSHP for the space heating and hot water production. Michopoulos et al. [19] reported that the use of the supplemental cooling or heating devices of the HGSHP might be determined by the heating degree-days.

As shown in Fig. 1a and b, the HGSHP can be classified by the "serial configuration" and "parallel configuration," respectively, based on the arrangement between the GHEX and the supplemental equipment (heat rejecters and heat extractors) [15]. Previous researchers have focused on the optimization and control strategy of the HGSHP with the serial configuration. Zhai et al. [20]

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http://dx.doi.org/10.1016/j.apenergy.2012.09.035

Nomenclature

C	specific heat at constant pressure (kJ kg^{-1} K^{-1})
COP	coefficient of performance
CSPF	cooling seasonal performance factor
EFT	entering fluid temperature (°C)
HSPF	heating seasonal performance factor
LFT	leaving fluid temperature (°C)
$\dot{m}$	mass flow rate (kg min^{-1})
n	bin hours (h)
P	total power consumption (W h)
$\dot{P}$	power (W)
Q	total cooling capacity (W h)
$\dot{Q}$	heat transfer rate or cooling capacity (W)
SPF	seasonal performance factor
T	temperature (°C)
TA	outdoor air bin temperature (°C)

Greek letter

Δ	difference

Subscripts

bin	bin method
c	cooling
comp	compressor
f	fluid
j	*j*th bin temperature group
max	maximum
mean	mean
min	minimum
pump	pump
tot	total

Abbreviations

AC	air-conditioner
ASHP	air-source heat pump
BLDC	brushless DC motor
Comp	compressor
EEV	electronic expansion valve
GHEX	ground heat exchanger
GPHEX	ground plate heat exchanger
GSHP	ground-source heat pump
HGSHP	hybrid ground-source heat pump
HRRG	heat rejection ratio of ground heat exchanger
HRRS	heat rejection ratio of supplemental equipment
IPHEX	indoor plate heat exchanger
P	parallel
S	serial
SHEX	supplemental heat exchanger
SPHEX	supplemental plate heat exchanger

reviewed the HGSHP systems using several different types of supplemental sources. Yavuzturk and Spitler [14], Ramamoorthy et al. [21], Chiasson and Yavuzturk [22], Xu [23], Hackel et al. [24], and Man et al. [25] optimized the size of the supplemental equipment based on the life-cycle cost. Chiasson and Yavuzturk [26] optimized the size of the supplemental equipment to balance the cooling and heating loads on the GHEX to limit a long-term temperature increase. The size design of the supplement equipment is highly dependent on the control strategy for the switching temperature from the GSHP to the HGSHP mode. Yavuzturk and Spitler [14] recently introduced the differential temperature control and night-time operation control of a HGSHP with the serial configuration. For a parallel-type HGSHP, in which a GHEX and a cooling tower were connected in parallel with the condenser of a heat pump unit, Kavanaugh [27] presented the revised design procedure to balance the cooling and heating loads on the ground, and Singh and Foster [28] showed the significant first cost savings, which were traded for slightly higher operating and maintenance costs. In addition, Park et al. [15] studied the optimization of a parallel-type HGSHP as shown in Fig. 1b.

In order to estimate the performance degradation of the GSHP under extreme weather conditions, it is necessary to evaluate seasonal performance factors (SPFs), such as the cooling seasonal performance factor (CSPF) for the cooling season and the heating seasonal performance factor (HSPF) for the heating season. The coefficient of performance (COP) at the specified testing condition is estimated by ISO 13256-1 for the water-to-air GSHP [29] and ISO 13256-2 for the water-to-water GSHP [30]. The calculation procedure of the SPF in the ASHP or the AC is defined in ANSI/ASHRAE 116 [31], JIS C 9612 [32], and KS C 9306 [33]. However, there is no such standard defining the calculation procedure of the SPF in the GSHP. The performance of the ASHP strongly depends on outdoor air conditions, while that of the GSHP relies on the ground thermal condition. Nam et al. [1] calculated the SPF of a hybrid system using the ground water and the air source. However, they did not consider the degradation of the ground thermal condition by assuming that

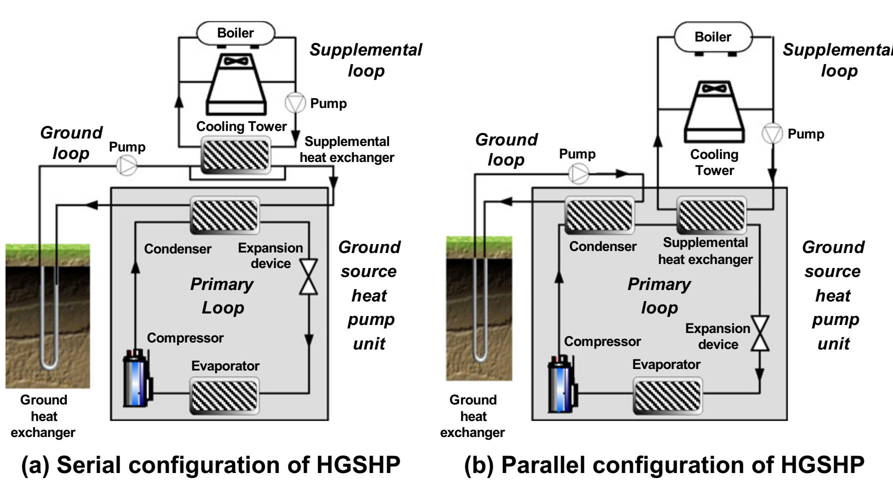

Fig. 1. Schematic diagram of the hybrid ground-source heat pump [15].