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Comparison on the transient cooling performances of hybrid ground-source heat pumps with various flow loop configurations

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ABSTRACT

A HGSHP (hybrid ground-source heat pump) is proposed to solve the performance degradation of the GSHP (ground-source heat pump) under imbalanced load conditions. The HGSHP is composed of three flow loops: a refrigerant flow loop, a GFL (ground flow loop), and a SFL (supplemental flow loop). In this study, the transient performance characteristics of the HGSHP were measured and analyzed in the cooling mode at various flow loop configurations, including the $HGSHP_S$ (HGSHP with the serial configuration) and $HGSHP_P$ (HGSHP with the parallel configuration), and GSHP. During the hybrid operation, the $HGSHP_S$ showed relatively higher COP (coefficient of performance) than the $HGSHP_P$ due to the lower heat accumulation in the ground under the degraded ground thermal condition. In addition, under the steady state condition, the COPs in the $HGSHP_S$ and $HGSHP_P$ were 15% and 7% higher, respectively, than that in the GSHP.

1. Introduction

An ASHP (air-source heat pump) has been applied in a conventional space cooling and heating system [1–5]. However, the performance of the ASHP can be degraded under extreme ambient conditions. A GSHP (ground-source heat pump) has been adopted for effective cooling and heating in commercial and residential buildings because of its energy saving potential under extreme ambient conditions [6]. Lohani and Schmidt [7], Yu et al. [8], Michopoulos et al. [9], Martin [10], and Catan and Baxter [11] reported that the GSHP consumed less energy compared to the conventional heating and cooling systems. Since the GSHP uses the ground as a heat source or sink, its performance is not strongly dependent on the ambient temperature [12]. However, the performance of the GSHP is affected by various design methods and operation parameters, such as the hydrogeological condition [13,14] and the configuration and operation of GHEs (ground heat exchangers) [15,16] governing the thermal environment into the ground. Especially, for buildings located in a hot climate region, the ground temperature can increase over time because of a load imbalance between heating and cooling from larger cooling demands, resulting in performance degradation [17–21]. This problem can be delayed by increasing the total length of the GHE and increasing distance between adjacent boreholes [22]. However, due to significant effects of the number of boreholes and their depth on the installation cost of the GSHP [23], this solution will incur a higher initial cost and make short-term economics unattractive. Therefore, a HGSHP (hybrid ground-source heat pump) has been proposed to solve the performance degradation of the GSHP under the imbalanced load conditions by decreasing the heat rejection into the ground and adopting supplemental equipment for auxiliary heat rejection or extraction. Furthermore, the HGSHP can allow a lower initial cost because the SHR (supplemental heat rejecter) is less expensive than the GHE [24].

Basically, a HGSHP is composed of three flow loops: a refrigerant flow loop, a GFL (ground flow loop), and a SFL (supplemental flow loop). The performance of the HGSHP is strongly dependent on the flow loop configurations [19] that are determined by the flow loop combination, flow direction, and SHR type. Especially, an effective arrangement between the GFL and SFL is crucial to improve the system performance with the balanced ground thermal condition. As shown in Fig. 1(a) and (b), serial and parallel configurations of the HGSHP have been considered. In a $HGSHP_S$ (HGSHP with the serial configuration), a GHE is connected serially with an OHE_S (outdoor heat exchanger in the supplementary side) (outdoor heat exchanger in the supplementary side). The $HGSHP_S$ can be classified as an up-stream and down-stream flow configuration according to the flow direction of the secondary fluid in the GFL. For the

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Nomenclature

ASHP	air-source heat pump
C	specific heat at constant pressure (kJ kg^{-1} K^{-1})
COP	coefficient of performance
EEV	electronic expansion valve
GFL	ground flow loop
GHE	ground heat exchanger
GSHP	ground-source heat pump
h	enthalpy (kJ kg^{-1})
HGSHP	hybrid ground-source heat pump
$HGSHP_P$	hybrid ground-source heat pump with parallel configuration
$HGSHP_S$	hybrid ground-source heat pump with serial configuration
IHE	indoor heat exchanger
$\dot{m}$	mass flow rate (kg min^{-1})
OHE_G	outdoor heat exchanger in the ground side
OHE_S	outdoor heat exchanger in the supplementary side
P	pressure (kPa)
Q	heat quantity (kJ)
$\dot{Q}$	heat transfer rate (W)
SFL	supplemental flow loop
SHR	supplemental heat rejecter
ST	set-point temperature (°C)
T	temperature (°C)
TSB	thermal storage bath
V	volume (m^3)
$\dot{W}$	power (W)

Greek letter

Δ	difference
ρ	density (kg m^{-3})

Subscripts

comp	compressor
cooling	cooling
cur	current
ent	entering
f	fluid
HA	heat accumulation
HR	heat rejection
ini	initial
lea	leaving
p	pressure
pump	pump
tot	total
tsb	thermal storage bath
wb	water bath

up-stream flow configuration, the secondary fluid flows through the GHE, an OHE_G (outdoor heat exchanger in the ground side) (outdoor heat exchanger in the ground side), and an OHE_S, consecutively, while, for the down-stream flow configuration, it passes these components in the reverse direction. A $HGSHP_P$ (HGSHP with the parallel configuration) has two separate flow connections between a GFL and an OHE_G, and between a SFL with an OHE_S.

The control strategy and capacity of supplemental equipment for a $HGSHP_S$ have been optimized by many researchers. Sagia et al. [25] carried out a theoretical analysis on a cooling-dominated HGSHP adopted to cover the energy demand of an office building. Chiasson and Yavuzturk [26] conducted design optimization through an economic assessment of a HGSHP using the solar collector with the variations of climate and insolation. Man et al. [27] compared the initial cost and energy consumption of a HGSHP with those of a GSHP under various control strategies. Man et al. [28] also determined the capacity of a cooling tower as a SHR according to the difference between peak and average value of hourly cooling load in a building. Pamamoorthy et al. [29] determined the optimum size of a shallow heat rejecting pond as a SHR of a HGSHP. Park et al. [18] conducted the performance optimization in a

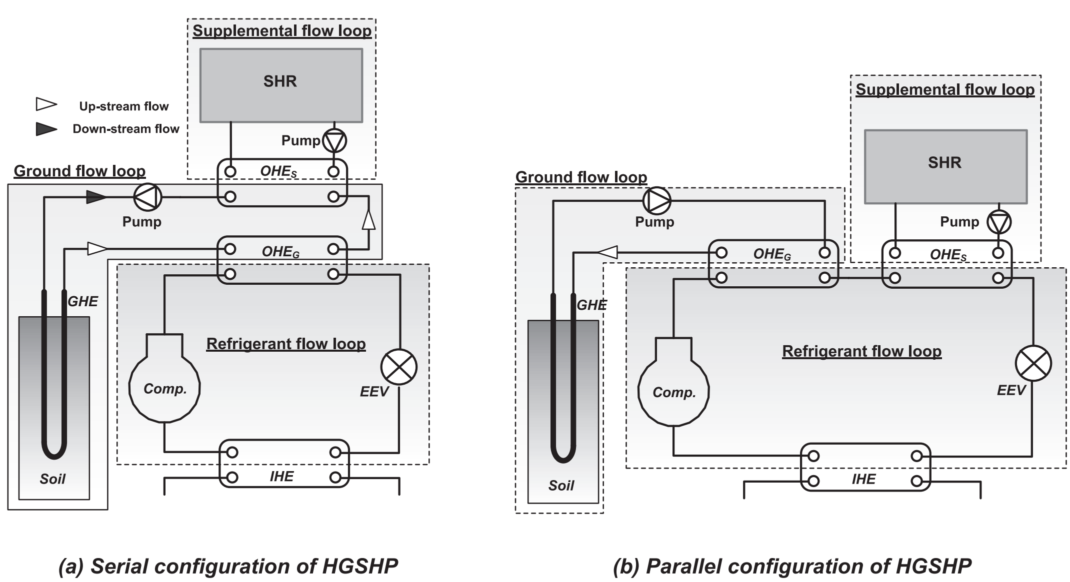

Fig. 1. Schematic diagrams of HGSHPs with the serial and parallel configurations.

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