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Transient performance characteristics of a hybrid ground-source heat pump in the cooling mode

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HIGHLIGHTS

- The transient characteristics of a hybrid ground-source heat pump were measured.
- A heat storage bath was adopted to simulate the ground thermal condition.
- The hybrid operation improved the performance under degraded ground conditions.
- The optimum set-point temperature was suggested at various cooling conditions.

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ABSTRACT

The objective of this study is to compare the transient performance characteristics between a ground-source heat pump (GSHP) and a hybrid ground-source heat pump (HGSHP), accounting for the degradation of the ground thermal condition during long-term operation. A heat storage bath for the ground heat exchanger (GHE) was adopted to simulate the transient characteristics of the ground thermal condition. In transient state, the performances of the HGSHP and GSHP were measured by changing the fluid flow rate (FFR) through the supplementary plate heat exchanger (SPHE) and the set-point temperature of the hybrid operation. The optimum FFR and the optimum set-point temperature of the HGSHP were determined as 8 kg min^{-1} and 30 °C, respectively. At the optimized conditions, the average COP of the HGSHP increased by 7.2% compared with that of the GSHP.

1. Introduction

The energy consumed during space cooling and heating has become an important issue in the design of commercial and residential buildings [1]. An air-source heat pump (ASHP) has been applied frequently for space cooling and heating. Its performance, however, ultimately degrades during operation at either very low or high ambient air conditions. A ground-source heat pump (GSHP) rejects heat into the ground or extracts heat from the ground via a ground heat exchanger (GHE), such as the vertical type shown in Fig. 1(a). The performance of an ASHP is highly dependent on ambient temperature, while that of the GSHP on the ground temperature. A GSHP provides higher performance than an ASHP because the ground heat source offers more favorable operating conditions [2–5]. Therefore, the GSHP has been widely applied in residential and commercial buildings [6,7].

However, during long-term operation, the thermal condition of the ground around the GHE can be degraded by the thermal imbalance between heat rejection and extraction in the GHE [8,9]. In cold-weather regions such as Beijing, the average ground temperature around the GHE decreased from 14 °C to 10 °C during a 10-year operation of a GSHP [10]. In hot-weather areas such as Hong Kong, the borehole wall temperature of the GHE increased on average from 23 °C to 41 °C during a 10-year operation of a conventional GSHP [11]. Increased ground temperature degrades the heat transfer performance of the GHE and thus, decreases the performance of a GSHP in the cooling mode. Therefore, the performances of the GHE and GSHP during long-term operation must be evaluated in transient state. The transient heat transfer characteristics of a GHE and their effects on the transient system performance of the GSHP have been studied by many researchers [12–19]. Eskilson [12] presented a method to predict the temperature distribution of the ground around a GHE during long-term operation. He introduced a transient temperature response of the borehole, referred to as long time step (LTS) g-functions.

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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
EFT	entering fluid temperature (°C)
FFR	fluid flow rate (kg min^{-1})
FFRS	fluid flow rate through SPHE (kg min^{-1})
GHE	ground heat exchanger
GPHE	ground plate heat exchanger
GSHP	ground-source heat pump
HE	heat exchanger
HGSHP	hybrid ground-source heat pump
HRG	heat rejection rate of GPHE (W)
HRS	heat rejection rate of SPHE (W)
IPHE	indoor plate heat exchanger
LFT	leaving fluid temperature (°C)
$\dot{m}$	mass flow rate (kg min^{-1})
OPHE	outdoor plate heat exchanger
$\dot{P}$	power (W)
PHE	plate heat exchanger
$\dot{Q}$	cooling capacity or heat rejection rate (W)
SPHE	supplementary plate heat exchanger
ST	set-point temperature (°C)
T	temperature (°C)
THR	total heat rejection rate (W)

Greek letter

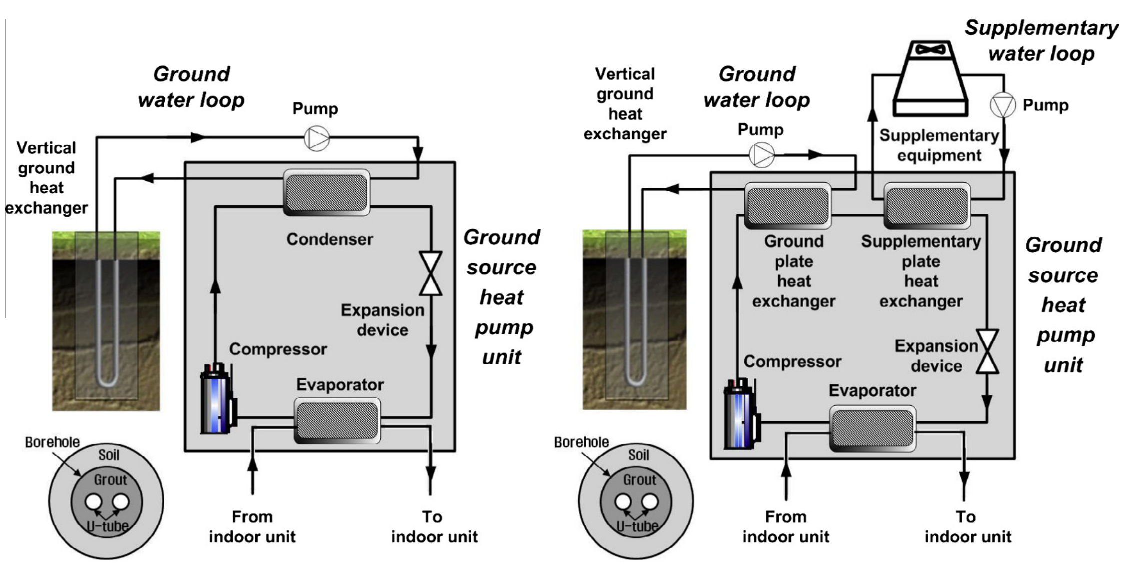
Δ	difference

Subscripts

amb	ambient
c	cooling
comp	compressor
f	fluid
G	ground heat exchanger
heater	heater
hs	heat sink heat exchanger
in	in
out	out
p	pressure
P	parallel
pump	pump
S	serial
tot	total
wb	water bath

In this study, a hybrid ground-source heat pump (HGSHP), as shown in Fig. 1(b), is proposed to overcome thermal imbalance under degraded ground thermal conditions by incorporating the GSHP with supplementary heat rejecters or extractors. The supplementary equipment in the HGSHP controls some portion of the heat rejection or extraction rate of the GHE to reduce the cooling or heating load imposed on the GHE. Therefore, the HGSHP lessens the deterioration of the ground thermal condition, increasing the system performance during long-term operation. However, the HGSHP can be applied when the energy saving potential by the hybrid operation exceeds the additional energy consumption of the supplementary equipment.

Most previous studies on the HGSHP were conducted to determine the optimum capacity and control strategy of the supplementary equipment during long-term operation using simulation methods [8,10,11,19–25]. However, there are hardly any experimental studies on the transient performance improvement of the HGSHP under optimized hybrid operation with consideration of degraded ground thermal conditions. The objective of this study is to compare the transient performance characteristics of the GSHP with those of the HGSHP with consideration of degraded ground thermal conditions during long-term operation. A heat storage bath was adopted to simulate the transient characteristics of ground thermal conditions. The transient performances of the



(a) Ground-source heat pump (b) Hybrid ground-source heat pump

Fig. 1. Schematic diagrams of the GSHP and HGSHP.