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Simulation Study of a Ground Source Heat Pump Heating System with Air Seasonal Heat Storage in Severe Cold Area

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Abstract

A novel ground source heat pump heating system with air seasonal heat storage (GSHPASHS) is described. This is followed by reporting the development of a simplified mathematical model for the system. The operational performances of the GSHPASHS system applied in a house of 120m^2 building area in Harbin (N45.75°, E126.77°) have been investigated by simulation. The results show that the system can meet the heating space needs of the building. The air seasonal thermal storage can raise the soil temperature around the ground heat exchanger to a higher level, which is favorable for increasing the coefficient of performance of the heat pump.

Key words: Seasonal heat storage; Ground source heat pump; Thermal balance; Simulation

1. Introduction

In severe cold area, if ground source heat pump (GSHP) system is used for heating space, the soil temperature will decrease gradually around the ground heat exchanger (GHE) due to the much large heating load in winter, which can lead to the drop of the heat pump performance year by year. Therefore, the GSHP heating system must be integrated with other heat source to operate in severe cold area. The solar energy as the heat source of the seasonal heat storage has attracted much attention [1-4]. Despite that solar is a kind of pollution-free and renewable energy, whose collection and storage are still limited by location, climate and collector installation. Because there is a three-month heat wave from June to

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August in severe cold area, the energy of the outdoor air could be instead of solar as the heat source.

Nomenclature

d	U-tube diameter(m)
l	side length of square tube (m)
C	heat capacity per unit volume(W/m^3)
h	convection heat transfer coefficient (W/(m^2.k))
q	heat transfer rate of GHE per unit buried depth (W/m)
T	temperature (℃)
u	velocity (m/s)
x1	grid length at first floor (m)
V	volume flow rate (m^3/s)
R	rate between minimum and maximum heat capacity
Q_L	transient heat load of room (W)
Q	heat exchange rate (W)
ϕ	heat exchange (GJ)
P	electricity consumption (W)
W	electricity consumption (GJ)
c_p	specific heat [J/(kg K)]
H	depth of GHE (m)

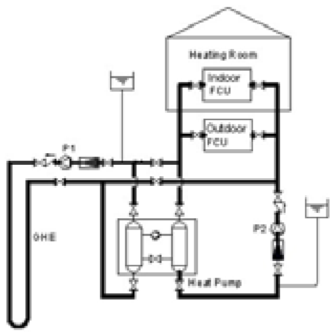
Greek symbols

δ	wall thickness of U-tube (m)
λ	thermal conductivity (W/(m.k))
τ	time (s)
ρ	density(kg/m^3)

Subscripts

w	outside
n	inside
b	tube wall
a	air
f	heat-transfer fluid
s	soil
sr1	node at first floor
o	initial
fan	fan coil
co	outlet fluid temperature of condenser
eo	outlet fluid temperature of evaporator
in	inlet
r	room
hp	heat pump
si	injecting into soil
se	extracting from soil
a_1, a_2, a_3, b_1, b_2, b_3	curve-fit coefficients

Therefore, a novel ground source heat pump heating system with air seasonal heat storage (GSHPASHS) is presented in this paper. The schematic diagram of GSHPASHS system is shown in Fig.1. In summer, outdoor air heat is transferred to the soil by the heat transfer fluid in the GHE. If the indoor FCU runs, the redundant heat of the room could be moved into the soil for space cooling, too. In winter, heat pump extracted the heat from the soil for heating space.



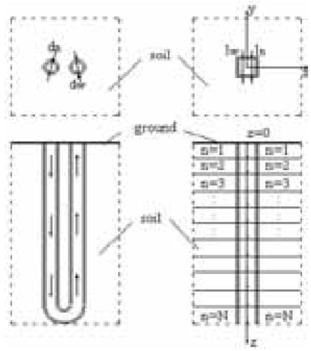


Fig. 1. Schematic diagram of the GSHPASHS heating system, Fig. 2. Schematic diagram of the GHE model

2. Mathematical model of the system

In this paper, the underground quasi three-dimensional heat transfer model was developed using equivalent single pipe with square cross section instead of U-tube, as shown in Fig.2. The size of the square tube can be calculated by

$$l_n = d_n\sqrt{\frac{\pi}{2}}\,, \qquad l_w = l_n + 2\delta \tag{1}$$