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Comparison of long-term performance and the initial cost of the horizontal ground source heat pump with the air source heat pump in hot regions

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ABSTRACT: Ground-source heat pumps have received much attention due to their high coefficient of performance. In these systems, the ground is used as a sink/source for the heat pump,¬ and the heat transfer between the ground and the heat pump is performed by the ground heat exchanger. In this study, the long-term performance and initial cost of these systems have been compared with conventional air-source heat pumps in a hot region. Both systems are numerically simulated. The performance of the systems is compared for cooling of a residential building in Bandar-Abbas, Iran. Moreover, the effect of various system operating parameters, i.e., ground heat exchanger length, pipe spacing, depth, and pipe diameter, have been studied. According to results, the five-year coefficient of performance and exergy efficiency of ground-source systems is 19.9% to 24.30% and 5.95% to 6.55%, respectively, more than that of the air-source system. However, 1.2 to 2.5 million Tomans is needed as the installation cost for each kW of maximum building load per year. Also, it is demonstrated that by reducing the length of the ground heat exchanger, the initial cost is reduced, and the system performance improves. The pipe spacing is the most influential factor in the required ground surface, the depth has the most impact on the initial cost and the system performance, and the pipe diameter does not affect the system performance..

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1- Introduction

Ground Source Heat Pump (GSHP) systems are Heating, Ventilation, and Air Conditioning (HVAC) systems that use the ground as a sustainable heat source of the Heat Pump (HP). Due to lower temperature fluctuations in the ground than the ambient air, GSHPs have a higher Coefficient of Performance (COP) than the conventional Air Source Heat Pumps (ASHPs).

Several researchers [1-3] have attempted to model the GSHP with horizontal GHEs or vertical GHEs that were mostly in cold or moderate climates. In hot climates, due to the accumulation of heat in the soil, the performance of these systems gradually decreases, so that, applying the vertical GHE is not applicable without auxiliary cooling equipment [4]. However, the horizontal GHE, due to its proximity to the ground's surface, is able to dissipate a portion of the heat accumulated in the ground to the surrounding ambient environment.

In this study, a three-dimensional CFD model of horizontal GHE is developed to study the feasibility of applying horizontal GHEs in a hot climate. The developed model is used to evaluate the long-term COP and the exergy efficiency of the GSHP, and compare it with the conventional ASHP. Moreover, the initial cost and the required land area of the GSHP system are evaluated. Furthermore, the effect of various geometric parameters of the GHE is investigated.

2- System Description

The schematic diagram of the GSHP system is depicted in Fig. 1. As shown in this figure, the GSHP system consists of two different parts of the HP and the GHE. The difference between the GSHP and ASHP is how the condenser is cooled. In the GSHP system, the condenser is cooled with the GHE, while in the ASHP, it cools with ambient air.

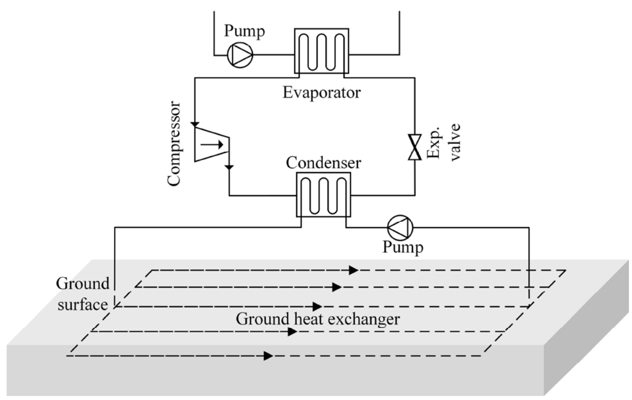

Fig. 1. Schematic diagram of the GSHP system

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3- Governing Equations

In this study, the buried GHE is numerically simulated. The GHE is coupled with the HP through the condenser inlet and outlet. The COP of the GSHP and ASHP system at each time is obtained by Staffell et al. experimental equation [5] as follows:

$$\begin{cases} \mathrm{COP}_{GSHP} = 7.77 - 0.15\Delta T + 0.000734\Delta T^2 \\ \mathrm{COP}_{ASHP} = 5.81 - 0.121\Delta T + 0.00063\Delta T^2 \end{cases} \quad (1)$$

where ΔT represents the temperature difference between the GHE outlet and supplied chilled water. The annual COP of the system is defined as [6]:

$$COP_{annual} = \frac{\sum Q_{Building}}{\sum W_{comp.}} \quad (2)$$

The annual reversible COP of the system is a function of average temperatures of hot and cold sources of HP during system operation [7].

$$COP_{annual,rev} = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{T_{cold}}{T_{hot} - T_{cold}}\right) \quad (3)$$

The annual exergy efficiency can be calculated as follows [7]:

$$\eta_{annual} = \frac{COP_{annual}}{COP_{annual,rev}} \quad (4)$$

4- Results and Discussion

In this study, the COP and the exergy efficiency of the GSHP are compared with the ASHP in a hot climate in five years. For this purpose, a residential house in Bandar Abbas is selected. The building load of the selected house is estimated with the Hourly Analysis Program (HAP). The system is applied to satisfy the building cooling load. Firstly, the COP of the ASHP and the GSHP with the GHE length, pipe spacing, buried depth, and pipe diameter of 30 m, 1 m, 2 m, and 4 cm, respectively, are compared. The results show that the annual COP of the ASHP is 3.033, while, as the ground gradually becomes warmer, the COP of the GSHP decreases from 3.794 in the first year to 3.764 at the fifth year. Moreover, the annual exergy efficiency for the ASHP is 36.46%, while, for the GSHP it decreases from 43.15% in the first year to 42.65% at the fifth year.

In order to investigate the effect of GHE geometric parameters on the performance of the GSHP, various lengths, pipe spacing, buried depth, and pipe diameter are considered. In each case, only the considered parameter of the GHE is changed, and the rest of the parameters have remained constant. The pipe cost and excavation cost are selected as the initial costs of the GSHP. The pipe cost per unit length for pipes with a diameter of 3.2 cm, 4 cm, and 5 cm are 1870 Tomans, 2950 Tomans, and 4530 Tomans, respectively [8]. Furthermore, the excavation cost per each volume is considered to be 13000 Tomans [9]. The calculated COP, exergy efficiency, and initial cost of the GSHP are summarized in Table 1. According to this table, by applying the GSHP instead of the ASHP, the five-year COP and the five-year exergy efficiency of the system can improve from 19.9% to 24.30% and from 5.95% to 6.55%, respectively. However, the initial installation cost increases from 1.213 to 2.5 million Tomans for supplying each kW of maximum building load per year.

Table 1. Details of the required land, pipe, initial cost and five-year performance of the system for each kW of maximum cooling load per year

	Parameter value (m)	Five-year *COP*	Five-year exergy efficiency	Required land area (m^2)	Excavation volume (m^3)	Used pipe length (m)	Initial cost (million Tomans)	*COP* increment (%)	Exergy efficiency increment (%)
Length effect	15	3.710	42.80	64.39	128.78	63.39	1.864	22.32	6.34
	30	3.707	42.77	66.45	132.90	66.45	1.924	22.22	6.31
	45	3.704	42.75	67.38	134.75	67.38	1.951	22.12	6.29
Pipe spacing effect	0.5	3.685	42.67	52.66	105.32	105.32	1.680	21.50	6.21
	1	3.707	42.77	66.45	132.90	66.45	1.924	22.22	6.31
	1.5	3.723	42.84	81.97	163.94	54.65	2.292	22.75	6.38
Depth effect	1	3.770	43.01	76.03	76.03	76.03	1.213	24.30	6.55
	2	3.707	42.77	66.45	132.90	66.45	1.924	22.22	6.31
	3	3.612	42.41	59.60	178.79	59.60	2.500	19.09	5.95
Pipe diameter effect	0.032	3.708	42.78	66.45	132.90	66.45	1.852	22.26	6.32
	0.04	3.707	42.77	66.45	132.90	66.45	1.924	22.22	6.31
	0.05	3.706	42.76	66.45	132.90	66.45	2.029	22.19	6.30

5- Conclusions

In the present study, a three-dimensional CFD model of the horizontal GHE is developed. The model is used to predict the GSHP performance. Moreover, the performance and installation cost of the GHSP with various geometric parameters of the GHE is compared with the conventional ASHP in a hot climate. The results demonstrated, by replacement of the GSHP with the ASHP, the five-year COP and the five-year exergy efficiency of the system can improve up to 24.30% and 6.55%, respectively. However, the initial installation cost can increase from 1.2 to 2.5 million Tomans for supplying each kW of maximum building load per year.

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