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# Optimization of performance of Combined Solar Collector-Geothermal Heat Pump Systems to supply thermal load needed for heating greenhouses

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ABSTRACT

In this research, optimum design of the combined solar collector and geothermal heat pump system is studied. The aforementioned system should meet the heat load of a greenhouse as a sample. Our main purpose is analyzing the system from economical and technical points of view simultaneously. In order to optimize the system from technical point of view, operation of the controllers, diverters and mixers are adjusted with some control strategies to preheat the entering fluid into the evaporator of the heat pump and regulation of this temperature up to our ideal temperature was done successfully to increase heat recovery of the ground in maximum heat extraction periods, maximum outlet temperature of the ground source heat exchanger and coefficient of performance of heat pump and to decrease minimum auxiliary energy required for heating the greenhouse and heat recovery during summer season. Furthermore, from economical point of view the optimum condition calculated and the corresponding final optimized design is determined with the aim of balancing between economical and technical issues. Meanwhile, payback time of the system is calculated accordingly. The selected model has mean seasonal coefficient of performance of 4.14, borehole length and number of boreholes of 50 m and 3, correspondingly. Moreover, total collector area of the gained model is 9.42 $m^2$. At the end, a comparison between the final optimized system with an exchanger using the best working fluid for each loop and the same system with one single fluid is done.



## 1. Introduction

Geothermal heat pumps are widely used in greenhouses because of lower operational costs and higher coefficient of performance compared to conventional heat pumps [1]. In [2] it is applied to a gas engine heat pump system for food drying. The first detailed exergetic evaluation of a GSHP system was made by Hepbasli and Akdemir [3].

In applications which are involved with ground, ground water and surface water, Ground source heat pumps can be applied as a heat source and sink, ground coupled (GCHP), ground water (GWHP), and surface water (SWHP) heat pumps are from those types of heat source and sink. [4–8]. The utilization of GSHPs in residential buildings is up-to-date in Turkey, although they have been in use for years in developed countries and the performance of the components is well documented [4]. On the other hand, solar and ground coupled heat pumps can be used for both heating and cooling of the building in most regions of Turkey [5]. Hwang et al. [6] evaluated of estimation method of ground properties for the ground source heat pump system. AL-Sarkhi et al. [7] investigated the performance evaluation of standing column well for potential application of ground source heat pump in Jordon.

Using geothermal heat pumps alone has some disadvantageous like temperature reduction of soil around ground heat exchangers that may cause Coefficient of Performance (COP) decrease of heat pump during years of operation and when higher heating load than normal is required. Other disadvantages are high initial cost of geothermal heat pumps and lower reliability of using a renewable energy system alone. Many of these problems can be solved by coupling geothermal heat pumps with thermal solar collectors.

The GCHP system has been employed as space heating and cooling obtains increasingly [9–12]. Ozgener et al. [9] studied on performance of a solar assisted ground-source heat pump greenhouse heating system. Yumrutas et al. [10] investigated of solar aided heat pump systems with seasonal thermal energy storage in surface

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## Nomenclature

| | |
|---|---|
| $A$ | area, $m^2$ |
| A.F | annualization factor, year |
| Aux | auxiliary energy required, kW h |
| AUX-percent-total | percentage of auxiliary energy required divided by total energy, kW h |
| Aux-required-max | maximum auxiliary energy required, kW h |
| $C$ | volumetric heat capacity, kJ/kg k $m^3$ |
| $C_{ghp}$ | total cost of geothermal heat pump including exchangers, heat pump and drilling costs, $ |
| $C_{pump}$ | pump cost, $ |
| $C_{sc}$ | total cost of solar collectors including solar panels, pump and tank costs, $ |
| $C_{scp}$ | solar collector price, $ |
| $C_{storage}$ | storage tank price, $ |
| $C_{pump}$ | pump price, $ |
| $C_{el}$ | electricity price, $ |
| $Cap_{heating}$ | heat pump capacity, kW |
| COP | coefficient of performance |
| COPmean-max | maximum mean coefficient of performance |
| COout | output signal of control function that is 0 or 1 |
| $EL_{com}$ | electricity consumption of compressor, kW h |
| $F_{R,j}$ | overall collector heat removal efficiency factor |
| $I_T$ | global radiation incident on solar collector, kJ/h $m^2$ |
| $L_{ghex}$ | length of ground heat exchanger, m |
| $L_p$ | total pipe length in section k, m |
| lt | TRNSYS function |
| $n$ | year |
| $N$ | number |
| $N_s$ | number of identical collectors in series |
| $P_{tot}$ | total power consumption of pumps, kW h |
| $\dot{P}_{heating}$ | power drawn by the heat pump in heating mode, kJ/h |
| $Q_{abs}$ | heat absorbed from ground heat exchanger, kW |
| $Q_L$ | the instantaneous heat loss from the structure minus internal gains, kW |
| $Q_T$ | rate at which energy is transferred into the space across the load heat exchanger, kW |
| Qu | useful energy gain of collector, kW |
| $T$ | temperature, °C |
| $T_{fin}$ | the inlet fluid temperature, °C |
| $T_{fout}$ | the outlet fluid temperature, °C |
| $T_a$ | the ambient temperature, °C |
| $T_{i,j}$ | inlet temperature of fluid to collector j, °C |
| Tout-mean | outlet ground heat exchanger temperature, °C |
| Toutlet, ghx-increase | outlet temperature increase of ground heat exchanger, °C |
| Tset | set temperature of the fluid entering the evaporator, °C |
| $U_{L,j}$ | Overall thermal loss coefficient of the collector per unit area, kJ/h $m^2$ k |
| $T_{k,global}$ | the mean global temperature in subregion, k |
| $T_{k,local-j}$ | the average temperature of local cell (j) immediately outside the pipe |
| $\tau\alpha$ | product of cover transmittance and the absorber absorptance |
| $\alpha_p$ | heat transfer coefficient between the fluid in the pipe and the first cell outside the pipe, W/$m^2$ k |
| $\beta_k$ | damping factor |
| $A, B, k, j, i$ | constants |

tanks. Badescu [11] evaluated model of a thermal energy storage device integrated into a SAHPS for space heating and energy analysis and exergy analysis of this system. He found that both the coefficient of performance of heat pump and exergy efficiency decreased when increasing the thermal energy storage unit length. Bi et al. [12] studied a solar-assisted GCHP system. The heating mode of the system could be switched between a solar energy-source heat-pump and a GCHP. The results showed that the application of a solar-assisted GCHP system is reasonable. Many studies have been done about coupling geothermal heat pumps and thermal solar collectors. Kjellson [13] proposed a model in which the heated fluid from the collector will be directed to the boreholes after passing through the evaporator of the heat pump. Recharging of boreholes results in higher temperature of the soil and lower length of tubes, heat passing through the evaporator would increase COP of the heat pump and decrease electricity usage of the compressor and also operation periods. Trillat [14] presented different combinations of solar collectors and geothermal heat pump and chose the best model from economical and technical point of view by numerical simulations using TRNSYS software. Using the combination of solar collectors and geothermal heat pumps helps to reduce operating costs in comparison with conventional systems using fossil fuels. Jun [15] presented a mathematical model considering in situ results for a combined thermal solar collector-geothermal heat pump system and after solving the equation considering economical and technical constraints, optimized length of boreholes and total area of collectors are presented. Fang [16] used 3d dynamic and numerical simulation of the ground and ground heat exchangers in a combined solar collector-geothermal heat pump system and optimized model is presented after considering temperature change and heat recovery of the ground. The results indicate that heat recovery of the ground will increase reliability of the system and will also help us to improve system economics. The temperature of the ground will increase 3° after one year working of the system that will cause long term operation of the combined system. Zhai [17] compared different systems that can be installed with geothermal heat pumps in a combined system. The results show that coefficient of performance of different combinations would be between 3 and 5 and the system combining geothermal heat pump with thermal solar collectors is mostly suitable for heating. Xi [18] studied a combined geothermal heat pump-solar collector model which is used with a heat storage system to supply heat load and domestic hot water required. Results show that mean annual efficiency for environmental heating will increase up to 26% because solar collectors are used to increase heat stored in the ground and environmental heating is supplied using this energy. Eslami-nejad [19] studied constant heat transfer in single u-shaped exchangers with two independent circuits which one of them is connected to the heat pump for heating and the other to solar collectors for heat recovery. Heat recovery of the ground will decrease heat extraction from the boreholes, borehole length up to 18% and energy consumed in heat pump up to 3.5% in comparison with system without heat recovery. Using system with two independent circuits will also decrease borehole length up to 33% and energy consumption of the heat pump up to 6.5% in comparison with a single circuit system. Bakirci [20] studied COP of a combined solar collector-geothermal heat pump system installed in Erzurum, a city of turkey, in different hours of day. The conclusion is that COP of the overall system is 10% lower than that of heat pump itself in the studied model and considering the advantageous of the combined system, it is suitable from both economical and technical points of view and can be used instead of conventional systems in