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A study on modeling and performance assessment of a heat pump system for utilizing low temperature geothermal resources in buildings

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Abstract

Low and moderate geothermal resources are found in most areas of the world. A very efficient way to heat and air-condition homes and buildings is the utilization of ground source heat pumps (GSHPs), also known as geothermal heat pump (GHPs), to obtain heat energy from low temperature geothermal resources.

The present study deals with the modeling and performance evaluation of a heat pump system utilizing a low temperature geothermal resource, which is approximated to a geothermal reservoir. The system was designed, constructed and tested in Nigde University, Nigde, Turkey and has been successfully operated since 2005. Energy and exergy analysis methods were used to assess the system performance based on the experimental data. Exergy destructions (or irreversibilities) as well as energy and exergy efficiency relations were presented for each component of the heat pump unit and the whole system, while some thermodynamic parameters, such as fuel depletion ratio, relative irreversibility, productivity lack, exergetic factor and improvement potential, were investigated for the system.

Energy and exergy efficiency values on a product/fuel basis were found to range from 73.9% to 73.3% and 63.3% to 51.7% at dead (reference) state temperatures varying from 0 to 25 °C for the heat pump unit and entire system, respectively. It is expected that the model presented here would be beneficial to the researchers, government administration, and engineers working in the area of heat pump systems for residential applications.

Keywords: Building; Energy analysis; Exergy analysis; Geothermal energy; Geothermal heat pump; Ground-source heat pump; Heat pump; Renewable energy

1. Introduction

Fossil fuels and low-efficiency electrical equipment are still being used for heating during the winter season. However, efficient energy utilization is getting very important due to environmental and energy problems such as global warming and the depletion of fossil fuels. In this context, a high thermal efficiency heat pump has been proposed as a new heating apparatus. Especially after the oil shock of the early 1970s, there has been more research and technical development for smaller, quieter, and higher efficiency heat pump systems [1].

A significant portion of world energy consumption is attributable to domestic heating and cooling. Heat pumps are preferred and widely used in many applications due to their high utilization efficiencies compared to conventional heating and cooling systems. There are two common types of heat pumps: air-source heat pumps and ground-source heat pumps (GSHPs), also known as geothermal heat pumps (GHPs).

GSHPs or GHPs have several advantages over air-source heat pumps as: (a) They consume less energy to operate. (b) They tap the earth or groundwater, a more stable energy source than air. (c) They do not require supplemental heat during extreme low outside temperature. (d) They use less refrigerant. (e) They have a simpler design

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Nomenclature

C	specific heat (kJ/kg K)
COP	heating coefficient of performance of heat pump (dimensionless)
$\dot{E}$	energy rate (kW)
$\dot{E}x$	exergy rate (kW)
f	exergetic factor (dimensionless)
$\dot{F}$	exergy rate of the fuel (kW)
h	specific enthalpy (kJ/kg)
$\dot{IP}$	improvement potential rate (kW)
$\dot{m}$	mass flow rate (kg/s)
P	pressure (kPa)
$\dot{P}$	exergy rate of the product (kW)
$\dot{Q}$	heat transfer rate (kW)
s	specific entropy (kJ/kg K)
T	temperature (K or °C)
$\dot{V}$	volumetric flow rate (m^3/s)
$\dot{W}$	work rate or power (kW)

Greek letters

ψ	specific exergy (kJ/kg)
η	efficiency (dimensionless)
δ	fuel depletion rate (dimensionless)
ε	exergy (second law) efficiency (dimensionless)
ξ	productivity lack (dimensionless)
χ	relative irreversibility (dimensionless)

Indices

a	actual
comp	compressor
cond	condenser
cs	condenser side
dest	destroyed (destruction)
elec	electric
es	evaporator side
evap	evaporator
exp	expansion valve
HE	heat exchanger
HP	heat pump
in	inlet
int	internal
k	location
mech	mechanical
out	outlet
p	constant pressure
r	refrigerant
rad	radiator
res	reservoir tank
s	isentropic
sys	system
Tot	total
w	water
0	dead (reference) state
·	rate

Abbreviations

GHP	geothermal heat pump
GSHP	ground-source heat pump
HP	heat pump

and consequently less maintenance. (f) They do not require the unit to be located where it is exposed to weathering. Their main disadvantage is the higher initial capital cost, being about 30–50% more expensive than air source units. This is due to the extra expense and effort to bury heat exchangers in the earth or providing a well for the energy sources. However, once installed, the annual cost is less over the life of the system, resulting in a net savings [2].

Geothermal energy is a domestic resource which contributes to energy security and decreases the trade deficit by displacing imported fuels. It is also environmentally advantageous energy source which produces far less air pollution than fossil-fuel sources. The life of a geothermal resource may be prolonged by re-injecting the waste fluid which is the most common method of disposal [3,4].

Geothermal energy can be used directly or indirectly, depending on the temperature of the geothermal resource. Geothermal resources are classified as low temperature (less than 90 °C), moderate temperature (90–150 °C), and high temperature (greater than 150 °C). The highest temperature resources are generally used only for electric power generation and found in volcanic regions. Low and moderate geothermal resources are found in most areas of the world. Geothermal energy can be used directly in temperatures ranging from about 35 to 150 °C to heat buildings, greenhouses, aquaculture facilities and to provide industrial process heat. Indirectly, high temperature geothermal steam can be used to drive a turbine and create electricity or in heat pumps [5].

In a comprehensive study conducted by Lund et al. [6], it is reported that GSHPs have the largest energy use and installed capacity according to the 2005 data. The distribution of thermal energy used by category is approximately 32% for GSHPs, 30% for bathing and swimming (including balneology), 20% for space heating (of which 83% is for district heating), 7.5% for greenhouse and open-ground heating, 4% for industrial process heat, 4% for aquaculture pond and raceway heating, <1% for agricultural drying, <1% for snow melting and cooling, and <0.5% for other uses. The equivalent annual savings in fuel oil amounts to 25.4 and 24 million tonnes in carbon emissions to the atmosphere. The equivalent number of installed 12-kW GSHP units (typical of US and Western