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Design of a novel geothermal heating and cooling system: Energy and economic analysis

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ABSTRACT

A dynamic simulation study in TRNSYS environment has been carried out to evaluate energy and economic performance of a novel heating and cooling system based on the coupling between a low or medium-enthalpy geothermal source and an Air Handling Unit, including a Desiccant Wheel.

During summer season, a Downhole Heat Exchanger supplies heat to regenerate the desiccant material, while a certain amount of geothermal fluid is continuously extracted by the well in order to maintain high operating temperatures. Simultaneously, the extracted geothermal fluid drives an absorption chiller, producing chilled water to the cooling coil of the Air Handling Unit. Conversely, during the winter season, geothermal energy is used to cover a certain amount of the space heating demand. In both summer and winter operation modes, a geothermal energy is also used to supply Domestic Hot Water. A case study was analyzed, in which an existing low-enthalpy geothermal well (96 °C), located in Ischia (an island close to Naples, Southern Italy), is used to drive the geothermal system. Results showed that the performance of the proposed system is significantly affected by the utilization factor of Domestic Hot Water. In fact, considering a range of variation of such parameter between 5% and 100%, Primary Energy Saving increase from 77% to 95% and Pay-Back Period decreases from 14 years to 1.2 years, respectively. The simulations proved the technical and economic viability of the proposed system. In fact, a comparison with similar systems available in literature pointed out that the layout proposed in this work is characterized by better energy and economic performance, especially in the best scenario. Finally, a sensitivity analysis showed that the system performance is mainly affected by the nominal geothermal flow rate and by natural gas cost.

1. Introduction

Geothermal heat can be used for different purposes, depending on the operating temperature of the source. Usually, in case of low and medium-enthalpy sources, geothermal energy is used directly, for space heating, domestic hot water, agricultural uses, etc. [1]. Conversely, in case of high-enthalpy geothermal resources, heat is more profitably converted into electricity [2,3] or in more complex cascade cycles [4]. Low or medium temperature geothermal energy can be converted into electric power only when innovative and expensive system layouts are considered [3,5]. Unfortunately, at a reasonable depths only low-enthalpy geothermal energy is usually available; only in some specific locations in the world, high-enthalpy geothermal resources are available even using low-depth wells [6].

1.1. Conventional geothermal heating and cooling systems

For the above mentioned reasons, the majority of the studies regarding space heating and cooling systems driven by geothermal energy focus on Geothermal Heat Pumps (GHPs), able to exploit low-enthalpy geothermal resources, available all over the world. Such systems are going to become more and more profitable in the next future, also due to a favorable regulatory framework [7]. For example, an experimental study, investigating a greenhouse heated by biogas, GHPs and solar energy, was recently presented by Esen and Yuksel [8]. This study shows that GHPs play a leading role for the modern greenhouses in Turkey. In Ref. [9], Esen et al. experimented a GHP in Turkey. They found COP values varying from 3.13 to 3.32. The system was also found to be economically feasible when compared with all the reference systems considered,

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Nomenclature

A	area (m^2)
A_q	horizontal cross-section of the well (m^2)
AF	annual factor
C_{EE}	unit cost of electric energy (€ kW h^{-1})
$C_{NG,user}$	unit cost of natural gas (€ S m^{-3})
$c_{p,w}$	specific heat capacity of the fluid in the well (kJ kg^{-1} K^{-1})
C_{ACH}	capital cost of absorption machine (k€)
C_{OP}	operative cost (k€ y^{-1})
COP	coefficient of performance (–)
E_{cc}	energy of cooling coil (MW h)
E_{cool}	energy supplied by the geothermal system (MW h)
E_{DHHE}	energy of downhole heat exchanger (MW h)
E_{DHW}	energy for Domestic Hot Water supplied by the geothermal system (MW h)
E_{DHW1}	energy for Domestic Hot Water supplied by the downhole heat exchanger (MW h)
E_{DHW2}	energy for Domestic Hot Water supplied by the geothermal fluid (MW h)
E_{GHWE}	energy of the geothermal fluid (MW h)
E_{heat}	heating energy supplied by the geothermal system (MW h)
E_{HC}	energy of heating coil (MW h)
E_{HE1}	energy of heat exchanger HE1 (MW h)
$E_{el,aux}$	electricity required by auxiliary devices (MW h)
E_p	primary energy (MW h)
F_1	F_1 characteristic potential
F_2	F_2 characteristic potential
h	heat transfer coefficient (W m^{-2} K^{-1})
H	hydraulic head (m)
H_w	well height (m)
J_{HE}	capital cost of heat exchanger (k€)
J_i	capital cost of pump (k€)
J_p	capital cost of component i of proposed system (k€)
J_{tot}	total capital cost of proposed system (k€)
LHV_{NG}	lower heating value of natural gas (kW h S m^{-3})
$\dot{m}$	mass flow rate (kg s^{-1})
$\dot{m}_{dp}$	mass flow rate through the double port p (p = 1…10) (kg h^{-1})
n_{dzk}	number of nodes in zone k with $(UA)_{w,wk}$ = const. (k = 1…4) (–)
n_{hy}	number of nodes occupied by heat exchanger x (x = 1…4) (–)
N	number of tubes (–)
N_{node}	number of nodes (–)
NPV	net present value (k€)
p	pressure (kPa)
PES	primary energy savings (%)
PI	profit index
Q	thermal power (kW)
SPB	simple pay-back (years)
t	temperature (°C)
T	temperature (K)
U	overall heat transfer coefficient (W m^{-2} K^{-1})
$UA_{hy,w}$	constant heat transfer capacity rate between heat exchanger y and the well (kJ h^{-1} K^{-1})
$UA^*_{hy,w}$	temperature-difference and mass flow dependent heat transfer capacity rate between heat exchanger y and the well (kJ h^{-1} K^{-1})
$UA_{w,wk}$	constant heat transfer capacity rate between the well and k wall zone (kJ h^{-1} K^{-1})
$\dot{V}$	volume flow rate (m^3 s^{-1})
V_w	well volume (m^3)
W	production ratio, (kW h kW^{-1})

Greek symbols

α	parameter for variable and constant mass flow rate pump
ΔCO_2	CO_2 equivalent avoided emission (%)
η	efficiency
λ_{con}	effective vertical thermal conductivity in the well (kJ m^{-1} h^{-1} K^{-1})
ξ	logical switch
ρ	density (kg m^{-3})
ρ_w	density of the fluid in the well (kg m^{-3})
ω_i	air humidity ratio (g kg^{-1})

Subscripts

ext	external
F_1	F_1 potential
F_2	F_2 potential
h	hot fluid
i	referred to number of node of well
in	inlet
k	number of a zone with $(UA)_{w,wk}$ = const. (1…4)
out	outlet
p	number of a double port (1…10)
reg	regeneration
t	referred to the value of a parameter in time step
tot	total
w	geothermal well
ww	wall of well
y	number of a heat exchanger (1…4)

Acronyms

ACH	Absorption Chiller Hot water
ACW	Absorption Chilled Water
AHPW	Absorption Heat Pump Water
AHU	Air Handling Unit
CC	Cooling Coil
CHP	Combined Heat and Power
CPVT	Concentrating PhotoVoltaic Thermal collector
CS	Conditioned Space
CSW	Cooling Sea Water
DEC	Direct Evaporative Cooler
DHHE	DownHole Heat Exchanger
DHW	Domestic Hot Water
DW	Desiccant Wheel
EHP	Electric Heat Pump
EV	Evaporative Cooler
GHWE	Geothermal Hot Water Well Extraction
GHPs	Geothermal Heat Pumps
GW	Geothermal Well
HC	Heating Coil
HE	Heat Exchanger
HWA	Hot Water Absorption device
HWHE	Hot Water flowing into downhole Heat Exchanger
HVAC	Heating Ventilation and Air Conditioning
ORC	Organic Rankine Cycle
PS	Proposed System
RS	Reference System