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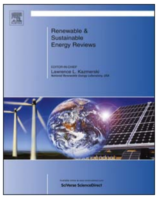

Thermo-economic modeling and GIS-based spatial data analysis of ground source heat pump systems for regional shallow geothermal mapping

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ABSTRACT

The increasing interest in ground source heat pump system (GSHP) as well as its high initial investment cost accentuate the necessity for an assessment tool which supports policy makers with decisions regarding technology development and subsidization. Since the performance of a geothermal heat pump system depends strongly on parameters such as geological and climate conditions, a regional-scale energy-economic mapping by spatial analysis was accomplished for priority assessment of each region which is to be subsidized. The procedure includes numerical modeling and optimization of GSHP systems by Genetic Algorithm (GA), regional heating/cooling design load estimation and spatial data analysis to achieve an economic-based map for 234 cities in Iran. Moreover, spatial interpolation was carried out in order to achieve a statistical surface map for the entire country. For the first time, Iran's regional shallow geothermal map was accurately presented along with other geographical maps including air and earth surface's mean temperature, heating/cooling loads, GSHP required operating hours and Iran's climatology. Total Annual Cost (TAC) values were categorized into five equal ranges from C_A (the highest priority class) to C_E (the lowest priority class) which highlight the convenient regions for shallow geothermal energy use. Finally, Iran's provinces were sorted according to TAC weighted average values.

1. Introduction

When fossil fuels are burned, they emit greenhouse gases (GHG) including CO_2 that are now recognized as being responsible for climate change. The gas like CO_2 allows the suns ray in but stop the heat radiation form re-emerging, much as happens with glass in greenhouse. The result is that the greenhouse gas heats up the whole world. [1]. Fossil fuel depletion, GHG emission and global warming are the major factors which have motivated efforts to reduce society's dependence on fossil fuels, by reducing demand and substituting them with alternative renewable energy sources [2,3]. Geothermal energy as an environmental friendly source of energy with much lower emission than conventional fossil fueled systems have three main applications including: electricity generation, direct heating and indirect heating/cooling via GSHP systems [4]. Providing many advantages over other heating, cooling and ventilation systems, interest in geothermal heat pump systems for meeting the growing demand of energy consumption in buildings has significantly increased in many countries during the last decades. however, the diffusion of GSHP systems is still in its infancy [5]. The advantages of this systems are as follows [6,7]:

- Highly efficient with low energy consumption
- Clean, almost with no pollution, and sustainable
- Not suffering from the intermittency issue
- Simple design and low maintenance cost
- No need for huge, noisy and intelligent systems outside the building

The main disadvantage of GSHP systems which limits their market spread is the high initial investment. The payback time for the investment cost may vary between five to ten years depending on the design specification and building thermal need [7]. One way to overcome this barrier and increase the technology diffusion is to subsidize the GSHP installation, similar to what many other countries or states governments have done [8–10]. If GSHP systems are to be installed in large numbers in the future, a question arises as to whether all building types built in every kind of climate and soil properties show equal benefits and thus should be considered with the same priority level for subsidy allocation. Since the performance of a GSHP system depends strongly on parameters such as geological and climate conditions [11,12], a regional-scale energy-economic mapping by spatial analysis seems necessary for priority level assessment of each region which is to

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Nomenclature

η_s	isentropic efficiency of compressor (%)
η_{el}	electric efficiency of compressor (%)
η_{pump}	electric efficiency of circulating pump (%)
η_M	efficiency of pump motor (%)
μ	dynamic viscosity (Pa.s)
ΔP	pressure drop of water flow (Pa)
τ	System full capacity operating hours
GA	genetic algorithm optimization technique
$VGHE$	vertical ground heat exchanger
A	heat transfer surface area of exchanger (m^2)
a_1-a_9	constants in computing the equipment cost
c_{AF}	cost of anti-freeze solution (\$/m^3)
C_{El}	annual cost of power consumption (\$/y)
C_{Inv}	initial or investment cost per operating years of the system (\$/y)
c_p	specific heat (KJ/Kg °C)
c_{pipe}	cost of polyethylene pipe (\$/m)
COP	coefficient of performance
CRF	capital recovery factor
$D_{e,EVA}$	equivalent diameter of the evaporator annulus (m)
D_{GHX}	GHX nominal pipe diameter (in)
$D_{i,GHX}$	GHX inner pipe diameter (m)
$D_{o,GHX}$	GHX outer pipe diameter (m)
$D_{I,i,Con}$	inner diameter of condenser's inner pipe (m)
$D_{I,i,Eva}$	inner diameter of evaporator's inner pipe (m)
$D_{I,o,Con}$	outer diameter of condenser's inner pipe (m)
$D_{I,o,Eva}$	outer diameter of evaporator's inner pipe (m)
E	annual power consumption (KW h/y)
F	part-load factor
h	Enthalpy (KJ/Kg)
J	convection heat transfer coefficient (KW/(m^2 K))
H_{Pump}	pump head (m)
i	interest Rate (%)
K_{Con}	thermal conductivity of inner pipe of condenser (KW/(m °C)
K_{Eva}	thermal conductivity of inner pipe of evaporator (KW/(m °C)
$K_{p,GHX}$	thermal conductivity of GHX pipe (KW/(m °C))
K_w	water thermal conductivity (KW/(m °C))
L	length of heat exchanger (m)
$\dot{m}$	mass flow rate (Kg/s)
n	depreciation time (y)
Nu	Nusselt number
Q	thermal load (KW)
R	effective thermal resistance (°C/KW)
RH	relative humidity (%)
t	annual operating hours (h/y)
$\overline{T}_{Air}$	annual average air temperature (°C)
T_{Con}	condensation temperature (°C)
T_{Eva}	evaporation temperature (°C)
T_S	annual average soil temperature (°C)
$\overline{T}_{Surface}$	annual average soil surface temperature (°C)
$T\_superheating$	superheating temperature (°C)
$T\_subcooling$	sub cooling temperature (°C)
$T_{Comfort}$	comfortable temperature (°C)
T_db	Design dry bulb (°C)
T_{wb}	wet bulb temperature (°C)
T_{W1}	water temperature at the inlet of heat pump (°C)
T_{W2}	water temperature at the outlet of heat pump (°C)
T_{Wi1}	building circulating water temperature at the inlet of heat pump (°C)
T_{Wi2}	building circulating water temperature at the inlet of heat pump (°C)
TAC	total annual cost (\$/y)
U	heat transfer coefficient (KW/m^2 K)
$V_{pipe,in}$	pipe inside volume (m^3)
VFA	volume fraction of the anti-freeze in the intermediate fluid (%)
W	power consumption (KW)
AF	anti-freeze
b	borehole of GHX
c	cooling mode
Con	condenser
Com	compressor
Eva	evaporator
GHX	ground heat exchanger
h	heating mode
HP	heat pump
i	inner
M	monthly
Min	minimum
Max	maximum
o	outer
$Pump$	circulating pump
R	refrigerant
S	soil
VFA	volume fraction of anti-freeze
W	water

be subsidized.

Somogyi et al. [13] reviewed the recent scientific literature concerning geothermal heat pumps and the existing regulations and/or technical guidelines in selected European countries stating that Geographic Information System (GIS)-based maps of shallow geothermal potential may be great tools in deciding on investments. Focus was put on the environmental effects caused by open- and closed-loop vertical systems.

Ondreka et al. [12] presented potential maps that offer planning support and marketing tools for shallow geothermal energy use with borehole heat exchangers. They concluded that the potential maps are useful tools for highlighting convenient regions for shallow geothermal energy use. A methodology aimed at generating maps of geo-exchange potential for shallow geothermal systems at regional scale was proposed by Galgaro et al. [14]. The final product was the map of maximum exchangeable ground heat through the unit area, evaluated on the basis of local geological and climatic conditions, energy requirements for a typical reference residential building and energy requirements on heat pump efficiency. Such a quantity was proposed there as geo-exchange potential.

Nam and Ooka [10] suggested a method for developing an energy potential map for GSHP system and conducted its application to a specific area with GIS data. The heat exchange rate and the effect of the system on the underground environment can be predicted by utilizing the tool developed in this research.

Alcaraz et al. [15] proposed a methodology to establish a market of shallow geothermal energy use rights which represents an advance in the management of this resource. The new concept developed to define the basic unit of management is the thermal plot. It is related to the shallow geothermal potential of a registered plot of land. This methodology is based on a GIS framework and is composed of a geospatial database to store the main information required to manage the shallow geothermal energy (SGE) systems, such as groundwater velocity, thermal conductivity or thermal heat capacity, and a set of GIS