Applied Thermal Engineering 102 (2016) 904–921

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Exergoenvironmental and exergoeconomic analyses of a vertical type ground source heat pump integrated wall cooling system

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HIGHLIGHTS

- Vertical type of ground source heat pump wall cooling system working has been studied experimentally.
- Analyses were done by using real data obtained from a prototype structure.
- Examination includes energy, exergy, exergoenvironmental and exergoeconomic analyses.
- Exergoenvironmental impact values of all system are detected as 42.60%.
- Exergoeconomic factor values of all system are calculated as 77.68%.

ARTICLE INFO

Article history:
Received 19 September 2015
Accepted 25 March 2016
Available online 11 April 2016

Keywords:
Cooling
Energy
Exergy
Heat pump
Èxergoenvironmental
Exergoeconomic
Wall cooling

ABSTRACT

In this study, exergoenvironmental, and exergoeconomic analyses of wall cooling systems fed by a vertical type of ground source heat pump integrated wall cooling system for cooling were examined experimentally and theoretically in Yıldız Renewable Energy House at Davutpaşa Campus of Yıldız Technical University. The examination includes energy, exergy, exergoenvironmental and exergoeconomic analyses, between the dates of 1 July and 30 September 2013. The main aim of this objective is to minimize energy usage in Residential Sector as low as possible. Therefore, a particular system working with low temperature regime was chosen. According to the outcomes; energy and exergy efficiency of all the system have been found as 74.85% and 29.90%. Part-based environmental factor values are calculated. The compressor and underground heat exchanger have the highest values calculated as 0.040 mPts/s, 0.026 mPts/s respectively. The exergoenvironmental impact values of all system are detected as 42.60%. On the other hand; the exergoeconomic factor values of all system are calculated as 77.68%. The value of exergoeconomic factor changes depending on some particular components: accumulator tank, undersoil heat exchanger, evaporator and condenser calculated respectively as 69.43%, 62.59%, 62.53% and 29.15%. As a result; it is found that in order to determine economic and environmental impacts of irreversibilities occurring in the system and its components, economic and environmental analyses of thermal system as well as wall cooling systems, should be done based on exergy concept.

1. Introduction

The energy systems involve a large number and various types of interactions with the world outside their physical boundaries. Therefore, designers must address many broad issues, especially energy, economy and the environment. The world energy crisis and increasing environmental awareness globally have made many countries reconsider the equipment used in energy conversion, particularly in the building sector for the last forty years. As a consequence, the concept of sustainability has entered the engineering world, and it appears to be connected with every aspect of an engineer's profession. In the building sector, building sustainability is a means to provide a safe, healthy, comfortable indoor environment while simultaneously limiting the impact on the Earth's natural resources [1]. In other words, Heating Ventilation and Air Condition (HVAC) design engineers' concern must not only be the reduction of the energy use by HVAC systems, but also the mitigation of the related environmental impacts. The Vertical Ground

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http://dx.doi.org/10.1016/j.applthermaleng.2016.03.178

Nomenclature

A	area (m^2)
B_F	environmental impact depend on exergy (mPts/s)
b_F	Environmental impact per unit of exergy ratio (mPts/kJ)
c_p	specific heat (kJ/kg °C)
CRF	first investment improvement factor
CELF	Constant escalation leveling factor
D	diameter (m)
E	energy (kJ)
$\dot{E}$	energy ratio (kW)
Ex	exergy (kJ)
$\dot{E}x$	exergy ratio (kW)
$f_{B,k}$	exergoenvironmental factor
f_c	exergoeconomic factor
g	acceleration of gravity (m^2/s)
h	convective heat transfer coefficient (W/m^2 K), enthalpy (kJ/kg)
m	mass (kg)
$\dot{m}$	mass flow (kg/s)
Q	heat energy (kJ)
$\dot{Q}$	heat ratio (kW)
P	pressure (kPa, Bar)
R	thermal resistance (W/m^2 K)
r_i	interest rate
S	entropy (kJ/K)
s	entropy for per mass (kJ/kg K)
T, t	temperature (K, °C)
U	conduction heat transfer coefficient (W/m^2 K), internal energy (kJ)
u	internal energy, for per mass (kJ/kg)
V	volume (m^3)
W	work (kJ)
$\dot{W}$	power (kW)
$\dot{Y}_k$	environmental impact based on part (mPts/s)
Z	total cost (€/h)
$\dot{Z}^{IC}$	investment cost (€/h)
$\dot{Z}^{OM}$	operation cost (€/h)

Subcripts

0	references state
ave	average
C	cooling
c	component
comp	compressor
cond	condenser
dest	destruction
e	electricity
eva	evaporator
k	each system part
L	land
in	input
j	process flow point/each flow
p	pipe/pump
p_1	pump 1
p_2	pump 2
p_3	pump 3
sys	system
th	thermal
tr	reversibility
out	output
W	wall

Superscripts

IC	investment cost
n	specified lifetime of systems or components (year)
ope	operation
OC	operation cost
prod	production
wst	waste
sys	system

Greeks

Δ	differences
η	efficiency (%)
ρ	density (kg/m^3)
υ	Specific volume (m^3/kg)
ϕ	exergy change for per mass at closed system (kW)
ψ	exergy change for per mass at open system (kW)

Abbreviations

ACU	accumulator
ANU	annual working hour
CV	control volume
CExC	cumulative exergy consumption
COP	coefficient of performance
COMP	compressor
COND	condenser
ELEC	electricity
EVA	evaporator
FIC	first investment cost
GSHP	ground source heat pumps
HP	heat pump
HHV	high heating value
KE	kinetic energy
LHV	low heating value
MC	maintenance cost
MTEP	million tons equivalents petroleum
PE	potential energy
TV	throtling valve
SL	system life
UGC	underground circuit
UHE	underground heat exchanger
WCS	wall cooling systems
WCSP	wall cooling system panels

Source Heat Pumps (VGSHPs) form an ideal system that can meet the energy needs of heating and cooling systems that work with particularly low-temperature energy sources and can provide comfort conditions such as radiant systems, specifically Wall Heating and Cooling Systems [2]. Due to their environmental friendliness and the ever-increasing prices of fossil fuels, GSHP systems will only increase in popularity [3]. During the past few decades, there are a lot of studies about VGSHP that have been examined in terms of optimization and simulation, performance, experimental and modeling analysis, testing and others. In this concept, an updated method for the dynamic simulation of ground coupled heap pump system was proposed by Yang et al. [4]. The method developed an analytical heat transfer model for the borehole heat exchanger (BHE) with considering the variation of fluid temperature along borehole length and thermal interference between two adjacent legs of U-tube. Based on the BHE model, the borehole heat exchange effectiveness (BHEE) was put forward and defined, and then the influences of borehole thermal resistance, fluid thermal capacity and borehole depth on the BHEE were investigated. A methodology was brought forward to optimize the operating