Renewable and Sustainable Energy Reviews 46 (2015) 210–217

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Modeling of driveway as a solar collector for improving efficiency of solar assisted geothermal heat pump system: a case study

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ARTICLE INFO

Article history:
Received 24 June 2014
Received in revised form
27 January 2015
Accepted 23 February 2015
Available online 17 March 2015

Keywords:
Energy efficiency
Energy saving
Geothermal energy
Heat pump
Renewable energy

ABSTRACT

It is well known that rooftop solar thermal panels increase both power rates of circulation pumps and initial investment cost of solar assisted ground source (geothermal) systems. To avoid both of them it means that the unnecessary energy consumption rates of circulation pump(s) and their initial capital cost, rather than installing rooftop solar thermal panels, driveways can be used as solar collectors for improving efficiency of geothermal heat pump systems (GSHP) and declining initial capital cost of SAGSHPs. Mainly this idea was first put in the middle by Jefferson W. Tester. In this paper, we will examine modeling of driveway as solar thermal panel to enhance efficiency of solar assisted geothermal heat pump system (SAGSHP) depends on its different operating types; yet we will give only a case that is investigated theoretically for solar assisted geothermal heat pump systems.

Contents

1. Introduction

GSHP applications have been increased all over the world, since they have huge energy savings in air conditioning of buildings and these systems make it possible to evaluate both shallow geothermal resources and shallow soils as energy resources. Moreover, they have indirect benefits on reduction in NO_x, CO_2, SO_2, etc emissions. These are well known environmental air pollutants.

Typical SAGSHP systems consist of solar thermal panels, heat pump coupled with horizontal or vertical ground heat exchangers. For SAGSHP applications in heating and cooling of buildings, the containment of solar thermal panels becomes an integral part of the projects, yet they can be problematic, since they require storage tanks and special attention to the design of

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http://dx.doi.org/10.1016/j.rser.2015.02.043
1364-0321/

Nomenclature

A_c collector surface area (m^2)
A_0 amplitude of the daily mean air temperatures (°C)
A_z amplitude of the temperature wave at depth z (°C)
$C_{p,wa}$ specific heat of the water–antifreeze solution (kJ/kgK)
COP_{HP} heating coefficient of performance of heat pump (dimensionless)
COP_{sys} heating coefficient of performance of the overall system (dimensionless)
D pipe diameter (m)
$\dot{Ex}$ exergy rate (kW)
$\dot{Ex}_{dest}$ exergy destruction rate of heat exchanger (kW)
$\dot{Ex}_{dest,grh}$ exergy destruction rate of ground heat exchanger (kW)
$\dot{Ex}_{dest,pump}$ exergy destruction rate of pump (kW)
$\dot{Ex}_{dest,col}$ exergy destruction rate of collector (kW)
$\dot{Ex}_{dest,valve}$ exergy destruction rate of expansion valve (kW)
f friction losses (dimensionless)
F_R collector heat removal factor (dimensionless)
h specific enthalpy (kJ/kg)
H monthly average daily radiation on a horizontal surface (MJ/m^2)
H_0 monthly average daily extraterrestrial radiation (MJ/m^2)
I_b direct solar radiation arriving on a horizontal surface (MJ/m^2)
I_d instantaneous diffuse solar radiation on a horizontal surface (MJ/m^2)
I instantaneous total radiation on a horizontal surface (MJ/m^2)
I_T rate of incidence of total radiation on a unit area of surface (MJ/m^2)
K_T monthly average clearness index (dimensionless)
k thermal conductivity (W/m K)
L length, ground heat exchanger layout zone (m)
$\dot{m}$ mass flow rate of refrigerant (kg/s)
$\dot{m}_{wa}$ mass flow rate of water (kg/s)
P period (h),
ΔP Pressure, pressure loss (kPa)
R_{soil} conduction resistance of soil per unit length (Km/W)
R ratio of the total radiation on a tilted surface to that on a horizontal surface
R_b ratio of the instantaneous direct solar radiation on a tilted surface to the instantaneous direct solar radiation on a horizontal surface
S entropy (kJ/kg-K)
q heat flux of density (W/m^2)
$\dot{Q}_U$ rate of useful heat transfer to water in the solar collector (kW)
$\dot{Q}_{cond}$ heat rejection rate in the condenser (kW)
$\dot{Q}_e$ ground heat exchanger or extracted heat load (kW)
$\dot{Q}_{evap}$ heat transfer rate in the evaporator (kW)
T_a ambient temperature (K, °C)
T_i fluid inlet temperature, greenhouse inside design temperature (K, °C)
T_o fluid outlet temperature, greenhouse outside design temperature (K, °C)
U_L overall loss coefficient of the collector (W/m^2K)
U velocity (m/s)
V volumetric flow rate (m^3/s)
T temperature (°C)
T_m annual mean air temperature (°C)
T_s surface temperature (°C)
$T_{z,t}$ soil temperature at depth z, at time t (°C)
t time, a day in year expressed in hours (h)
t_0 time, zero point (h)
$\dot{W}_{comp}$ power input to the compressor (kW)
$\dot{W}_{pump}$ total power input to the brine and water circulating pumps (kW)
$\dot{W}_{fc}$ power input to the fans of the fan-coil unit (kW)
x depth below the ground surface (m)
z soil depth (cm, m)

Greek letters

α thermal diffusivity (cm^2/h), absorptance (dimensionless)
η energy efficiency (dimensionless)
η_c collector energy efficiency (dimensionless)
β tilt angle of drive way (collector) from the horizontal (dimensionless)
γ Inverse of damping depth (cm^{-1})
δ declination angle (dimensionless)
ρ reflectance (dimensionless); density (kg/m^3)
τ transmittance (dimensionless)
ω hour angle at sunrise (dimensionless)
ζ the particular resistance losses (kPa, Pa)
ϕ latitude angle (dimensionless)
ψ specific exergy (kJ/kg)

Abbreviations

AC asphalt cover thickens
BH borehole depth
BZT Bethe–Zeldovich–Thompson
EWT entering water temperature
FC fan coil
GSHP geothermal (ground source) heat pump
HP heat pump
HE heat exchanger
VGHE vertical ground heat exchanger
HGHE horizontal ground heat exchanger
in inlet
out outlet
NIST The National Institute of Standards and Technology
SAGSHP solar assisted geothermal heat pump
SAGSHPS solar assisted geothermal (ground-source) heat pump system
SGR shallow geothermal resources
Sys system
TES thermal energy storage
x,y,z directions
1,2,… successive numbers
0 reference state

ground and solar heat exchangers for charging and discharging, other considerations include possible water leakages bad effects to building roof, cost, short and long term cycling stability, space requirements, sometimes solar thermal panels and their storage tanks can be exposed wind that occurs the heat losses etc. Hence, shallow soils could be an alternative solution instead of solar thermal panels. In this paper, we will examine modeling of driveway as solar thermal panel to enhance efficiency of solar