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Efficiency evaluation of a solar water heating system applied to the greenhouse climate

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Abstract

Tunisia has a sunny climate; therefore, the use of solar energy to heat greenhouses can be a solution to reduce the heating cost. A thermal model has been developed to investigate the potential of using a solar water system for greenhouse heating. This system is mainly based on capillary heat exchangers integrated in the greenhouse and ensuring the ground heat storing. A numerical study is conducted using Trnsys16 in order to estimate the exchanger length and the water flow rate allowing the best performance of the system. The inputs of Trnsys16 software were evaluated by experimental tests. The cost and the efficiency of the system were estimated for different greenhouses size. It was concluded that the heating cost of a 1000 m^3 greenhouse was reduced by 51.8% in April and the system can alone satisfy the heating needs for a 10 m^3 greenhouse. The good efficiency of the studied system was validated by an experimental study. The simulated and experimental results were compared and error did not exceed 6% which makes Trnsys16 simulation program an efficient tool to reproduce the real behavior of the ground solar water heating system.

Keywords: Economic greenhouse; Numerical simulation (Trnsys16); Ground solar heating system; Solar energy; Storage tank; Flat plate collector

1. Introduction

The Tunisian state invests more and more in scientific research specifically in the exploitation of solar energy. Actuality, Tunisia can meet its energy requirements by using the most of these natural resources. Solar thermal energy has been well investigated in the last decade by Tunisian researchers. Therefore, solar energy is used in different domains in Tunisia such as; the sanitary water heating (Hazami et al., 2013), air conditioning of building (Naili et al., 2015) and recently in agriculture (Attar et al., 2014). The main issue for the greenhouse is to provide an appropriate heating system which can ensure the good temperature condition and save energy outside the cultivation season (Joudi and Farhan, 2014). The heating system affects strongly the time of cultivation, quality and quantity of the products (Sethi and Sharma, 2008). Due to the relatively high cost of energy and big greenhouses surfaces, the auxiliary systems cannot meet alone the heating needs (Vadiee and Martin, 2013). Therefore, the use of an appropriate heating system, at low cost, is crucial to provide optimum indoor conditions during cold months. Rather than fossil fuels, different renewable energy sources can be used in a greenhouse heating systems such as; geothermal (Ghosal and Tiwari, 2004), solar, and biomass energy (Chau et al., 2009). The solar energy receives the most serious consideration for greenhouse heating. Two types of solar greenhouse systems are provided; it depends on using water or air as a transfer medium of energy

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Nomenclature

A_s	Ground surface (m^2)
A	Total collector array aperture or gross area (m^2)
C_{pf}	Specific heat of the tank fluid (kJ kg^{-1} K^{-1})
Cp	Specific heat of water at constant pressure (kJ kg^{-1} °C^{-1})
e	Polycarbonate cover thickness, tube thickness (m)
F_R	Overall collector heat removal efficiency factor (–)
h	Heat exchange coefficient (W m^{-2})
K_s	Thermal diffusivity (m^2 s^{-1})
L	Latent heat of water vaporization (J kg^{-1})
M	Mass flux (kg s^{-1})
$\dot{m}$	Water flow inside tube (kg s^{-1})
N	Number of sections (–)
Ns	Number of identical collectors in series (–)
q	Mass exchanges in the soil (liquid, water) (kg m^{-3})
Q	Rate of heat by the capillary heat exchanger (W)
Q_e	Heat exchange rate (W)
QC	Sensible convective heat flux (W)
QR	Net rate of heat loss by thermal radiation (W)
QS	Absorbed solar radiation (W)
QL	Latent heat flux (W)
Q_U	Useful thermal energy (W)
Q_{load}	Greenhouse heating load (kJ)
$Q_{delivered}$	Supply of energy from solar power (kJ)
S	Heat exchanger surface (m^2)
S_1	Source term (W s^{-1})
T_i	Fluid temperature in a ith tank level (°C)
T_a	Ambient (air) temperature (°C)
T_w	Water temperature (°C)
T_o	Outside temperature (°C)
U	Overall heat transfer coefficient (W m^{-2} °C^{-1})
UA	Overall heat transfer coefficient of exchanger (W m^{-2})
U_L	Overall thermal loss coefficient of the collector per unit area (kJ h^{-1} m^{-2} K^{-1})
V	Volume (m^3)
W	Specific humidity (kg kg^{-1} dry air)

Greek letters

ρ	Reflectance (–)
λ_s	Thermal conductivity of the ground (W/m K)
ε	Exchanger energy efficiency (%)

Subscripts

in	Inlet (–)
o	Outlet (–)
f	Fluid (–)
g	Ground (–)
a	Interior air (–)
p	Plant, crop (–)
s	Soil (–)
V	Ventilation (–)
h	Heat exchanger (–)
c	Cover (–)
oc	Outside cover face (–)
ic	Inner cover face (–)
ap	Interior air plant (–)
co	Cover external air (–)
ca	Cover interior air (–)
as	Interior air and interior soil (–)
o	External air, outside, outlet (–)
w	Water (–)
Trnsys16	The Trnsys16 computer simulation program is one of the most widely used simulation programs for solar thermal systems (–)
SWHS	Solar water heater system (–)
GSWHS	Ground solar water heater system (–)
L.E.P.T	Laboratory of Energetic and Thermal Processes (–)

(Jakhar et al., 2015). The solar heating technologies applied to the greenhouses include: hybrid solar heating (Kıyan et al., 2013), hybrid solar photovoltaic (Agrawal and Tiwari, 2015), photovoltaic heating (Cossu et al., 2014), north wall (Gupta and Tiwari, 2005), earth-to-air-heat exchanger system (EAHES) Nayak and Tiwari, 2010; Ozgener and Ozgener, 2010; Ozgener et al., 2011, integrated photovoltaic-geothermal heat pump (Nayak and Tiwari, 2010) and phase change material (**PCM**) storage (Kooli et al., 2015; Benlia and Durmuş, 2009).

The ground heat storage systems using solar energy could be very promising (Attar et al., 2013). However, the performance of a greenhouse coupled with any heating system is influenced by the greenhouse size and energy collected by the heating system. It is important to evaluate the heating needs and the system contribution to predict the effectiveness of the considered solar system. Therefore, different parameters must be taken into account like the greenhouse cover material (Tiwari and Dhiman, 1986), the type of cultivation, the greenhouse location, the weather conditions (Santamouris et al., 1994; Sethi et al., 2013), and the heat loses.

In this paper, we study the storing performance of a ground solar water heating system (GSWHS). A parametric study is conducted using Trnsys16 in order to estimate the effect of the exchanger length and the water flow rate