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Performance of the coupling of the flat plate collector and a heat pump system associated with a vertical heat exchanger for heating of the two types of greenhouses system

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ABSTRACT

The renewable energy resources appear to be the most effective solution to energy increasing demand. In particular the consumption of energy in greenhouses in Tunisia country has gained an increasing interest. The objective of this work is the heating of the two types of greenhouses (with surface area 100 m^2) by using the different installations. The heat pump (water/air) system is coupled with a flat plate collector (with surface area 2 m^2) and a vertical heat exchanger in order to obtain a comfortable climate in the winter in the greenhouses. The system is subdivides into three parts; (i) the conversion of the solar energy on the thermal energy in the level of the flat plate collector; (ii) increasing this energy at the level of the heat pumps system; (iii) heating the greenhouses by using this abundant and universal source of energy. Here, we present a mathematical description of the heat pump as well as the numerical results of the simulation of the system, such as the coefficient of performance, the outlet temperature in the level of the flat plate collector and in the heat pump system, the temperature and the energy indoor the greenhouse, finally a good results are obtained comparing with others similar results in research area.

1. Introduction

Heating of the greenhouses is one of the most energy consuming fields during the cold climates conditions. Geothermal and solar sources in Tunisia (the water of surfaces, the water of the wells, the solar energy, etc.) are used for heating and cooling of greenhouses, by using geothermic heat pumps and solar collectors. Previous research in the aims; (i) 'heating and cooling a greenhouse and a residential building using a geothermal heat pump' [1]; (ii) 'solar energy assisted with heat pump system [2] are utile in our study'.

The coefficient of performance and the efficiency of the coupling of the heat pump and a vertical/horizontal heat exchanger are determined in experimental study established in Ref. [2]. In Ref. [3], the author's studied the analytical comparison of the performance of air-source and horizontal ground source air-conditioners. The Experimental study on solar assisted with heat pump in term of ameliorating the performance of the system and decreasing the consumed electric power was developed [4]. Attar et al. [5] simulated the performance of the heating system with water as working fluid in related to the storage tank and a capillary polypropylene heat exchanger; this simulation was performed for tomato greenhouses. Bouadila et al. in Ref. [6] improved the greenhouse inside climate by solar air heater coupled with latent storage energy; the storage system was a packed bed of spherical capsules with phase change materials [7]. In the sum field, the demand of thermal energy in Mediterranean region presented the obligation of the numerical research in Ref. [8] in the aim 'performance of the heat pump coupled with the vertical/horizontal heat exchangers'. The thermal solar collector was used for the production of hot water and the performing refrigerant R-22 was included in the heat pump system in order to ameliorate the output power of this component [9]. The solar energy assisted with heat pump system and associated with a greenhouses model was investigated in experimental and numerical study realized in Ref. [10]. The heat pump and the coupling heat pump/flat plat collector have been studied in separates works with the experimental research one by one. The good results have been obtained if the coupling of the heat pump/flat plat collector was assured in term of energy gain and efficiency values. The consumed electric power increased if this coupling was not assured [10]. This investigation has been improved by Chargui et al., in Ref. [11]. The coupling of the pump and the greenhouse has been also ameliorated in the

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Nomenclature

A	total collector array aperture or gross area (m^2)
A_p	the cross-sectional area (m^2)
C	volumetric heat capacity($J\,m^{-3}\,K^{-1}$)
COP	coefficient of performance (–)
COP_{sys}	the overall system (–)
$\cos\varphi$	the power factor (–)
Cp_{air}	pressure specific heat of air ($kJ\,kg^{-1}\,K^{-1}$)
C_{pf}	specific heat of collector fluid ($kJ\,kg^{-1}\,K^{-1}$)
C_{p_w}	pressure specific heat of water ($kJ\,kg^{-1}\,K^{-1}$)
F_R	overall collector heat removal efficiency factor (–)
$F_r(i,j)$	the radial heat flow in cell i, j (W)
I_{com}	the current of the compressor (A)
I_p	the current of the water pump (A)
I_T	global radiation incident on the solar collector ($kJ\,h^{-1}\,m^{-2}$)
q	heat injection rate (W)
q_l	this heat source term ($J\,m^{-3}$)
q_{sf}	the heat source term for a global cell ($J\,m^{-3}$)
Q_{comp}	the useful heat of the compressor ($kJ\,h^{-1}$)
Q_{eva}	the useful heat of the evaporator ($kJ\,h^{-1}$)
Q_u	the useful heat that is received from the collector ($kJ\,h^{-1}$)
$K_r(i,j)$	the heat conductance between cell $i-1$; j and i; j ($W\,K^{-1}$)
m_{air}	the flow rate of the air ($kg\,h^{-1}$)
m_w	the flow rate of the water ($kg\,h^{-1}$)
R_b	total thermal resistance ($K\,W^{-1}$)
r_1	outer radius of the region (m)
r_b	the outer pipe radius (m)
$T_{air\ in}$	condenser air inlet temperature (°C)
$T_{evap,in}$	evaporator air inlet temperature (°C)
$T_m(t)$	the mean temperature (°C)
$T_f(t)$	the temperature in the fluid (°C)
T_a	ambient air temperature (°C)
T_i	inlet temperature of fluid to collector (°C)
$T(i,j)$	temperature in cell i, j (°C)
V_{com}	the voltage of the compressor (V)
V_{pump}	the voltage of the pump (V)
W_{com}	the power of the compressor (W)
W_{pump}	the power input to a circulating pump (W)
λ	thermal conductivity ($W\,cm^{-1}\,K^{-1}$)
α	thermal diffusivity ($cm^2\,s^{-1}$)
$(\tau\alpha)_n$	at normal incidence (–)

Subscripts

Min	minimum
TRNSYS	Transient System Simulation program
air	air
com	compressor
eva	evaporator
out	output
int	input
m	average
f	fluid
Max	maximum

numerical study and the performance of all components of the system was determined [12]. The COP of the system, the energy delivered and the research, the highest COP was determined as 15.60 maximum and the average COP was consumed electric power have been investigated in [13]. The energetic and exergetic parameters in the coupling heat pump and heat exchanger have been improved also in [14]. The exergoeconomical analysis of an underground air tunnel system has been enhanced in [15]. In this research, the highest COP was determined as 15.60 maximum and the average COP was 10.10 in the heating mode in [15] (they used the same set up for heating applications in the same region) and between 4.6 and 8.2 for heating a single zone in [12] (COP was found to be 6.20 maximum and 4.79 on averages in heating mode). Several studies have been developed in this field in order to exploit the renewable energy for building system and to explain the experimental method for using the materiel, such as [16]. Hence, several researches have been based on the TRNSYS software for their simulations [17]. In Ref. [17] the numerical study of this author has been based on the thermal performance of the residential house coupled with the geothermal heat pump. For this reason, two types of installation have been realized; the first one installation is based in the heating/cooling using the heat pump system and the second is based for the coupling geothermal heat pump and horizontal heat exchanger. The comparison of the two systems in the same reference shows that the using of the heat pump as indicated in the second condition is mostly economical. This investigation [17] is proposed and improved by the mathematical and numerical description in Ref. [18]. The using of ground-source geothermal heat pumps for heating a greenhouse system was ameliorated in [19]. This investigation was improved an experimental study developed by the sum author's in Ref. [20]. The heating of greenhouse with 400 m^2 for surface area in Melbourne (Australia) is the objectives of the work established in [21]. This research [21] is similar to our study "Performance of the coupling of the flat plate collector and a heat pump system associated with a vertical heat exchanger for heating of the two types of greenhouses system" in the case of modeling, simulation and boundary conditions and the all operating state of the system. In north east of Tunisia [22], the experimental study is based on the forage of the heat exchanger. In Ref. [23], the author's explained the performance of a heat exchanger in different positions; This experimental study have been realized in Elazig (Turkey) for heating an agricultural greenhouse (6 m × 4 m × 2.10 m) by using a heat pump (water/air) system operates with R22 as refrigerant gas and horizontal exchanger associated with a six flat solar collectors. They concluded that the storage of the water with a high temperature in the ground heat exchanger is a better solution for using during the night and for saves the energy. The COP increase with the increasing of the high of a vertical heat exchanger as indicated in Ref. [24]. A experimental study validated by a numerical study (by using a software Fluent) of a heat pump coupled with a three vertical exchangers (30 m, 60 m, 90 m) was examined in Ref. [25].

The present study shows the evolution of the performance of the heat pump (water/air) R134 a system coupled with a vertical heat exchanger and a flat plate solar collector with surface area equal 2 m^2. The forage of the heat exchanger is 50 m as indicated in the experimental study realized in north east of Tunisia and based of bibliography models [22]. The main parameters and inputs of all components are indicated in Tables 1–4. The objective is to heating two types of greenhouses with different style and material as demonstrated in Table 5. The simulation of the numerical model was affected by the software TRNSYS daring the heating period and for two days for January 2013.