Energy Conversion and Management 147 (2017) 40–54

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Determining of the optimal design of a closed loop solar dual source heat pump system coupled with a residential building application

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ARTICLE INFO

Article history:
Received 12 January 2017
Received in revised form 5 May 2017
Accepted 10 May 2017

Keywords:
Flat plate collector
Dual source heat pump
Building
Heating mode
TRNSYS

ABSTRACT

This work highlights the results on the coupling of a flat plate collector coupled with a dual source heat pump system and a heat exchanger for building application. The novelty point of this work is to integrate a heat exchanger in the floor and in the interstitial space of the residential house roof in order to minimize the consumed electric power. This technology defining the operational state of the system has been developed and adapted in the present investigation by adopting the Tunisian climate. The dimensioning of this installation for different component makes it possible to operate the hot water heating systems ecologically. Hence, our objective is to ameliorate the performance of the system using the solar radiation converted to the thermal energy in the level of the flat plate collector and the heat pump. A several experimental data have been added for realizing a numerical model based on TRNSYS software. From this point of view, a numerical model was improved in building application using a 150 m^2 as surface area of the building which consists of two floor zones. The dual source heat pump was coupled with a ground heat exchanger (GHE) with 0.2 m of depth. The distance between two consecutive tubes is 0.3 m and the surface area of the solar collector is 8 m^2. The simulation results have been obtained for 48 h operation in January and all inputs data of the system have been predicted during 48 h and 6 months of heating in Tunisia. It was demonstrated that the COP of the dual source heat pump was enhanced with the increase of the solar radiation during the typical sunny day in the heating season. In addition, the COP strengthened in proportion to the solar collector area, as well. Meanwhile, the numerical model predicts a gain of energy which exceeds 50% compared with a conventional heating system for 25 years as viewing time.

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1. Introduction

Considering energy use in the building sector is an aspect that requires conceptual thinking and dedicating far more attention thanks to its importance than in previous years. Especially nowadays, there is a growing call for energy efficiency and environmental friendly heating systems. This is in conjunction with the trend for well-insulated constructions with low thermal requirements. The coupling of the flat plat collector and the heat pump system have become increasingly common in residential and commercial buildings and can be used in district heating systems. The installation of the heat pump with and without the solar collector in building or in agricultural application has been investigated by several studies. Hence, a comparison between the performance of the heat pump with and without the solar collector in the same conditions was demonstrated in the some of the recent published papers. Consequently, the contribution and energy advantage was evaluated.

Feng and Ziwen [1] used a heat pump with a high temperature for heating the residential building. The R134a was considered as refrigerant fluid. They noticed a sharp decline in heating capacity when the condensation temperature exceeds 70 °C. The experimental study of the geothermal heat pump (GSHP) (Geothermal System Heat Pump) coupled with a horizontal heat exchanger buried in the ground and an under floor heating inside the test room has been studied in [2,3]. The experience was realized in the research center of energy technology in Tunisia, the considered test room was a surface area equal to 12 m^2 oriented in the north direction. The authors claimed that Tunisia has a great geothermal potential for a good exploitation of geothermal heat pump. In fact, they demonstrated that the outlet temperature of the horizontal exchanger in the ground reaches a maximum value of 55 °C. The heat was transferred to soil, when the compressor starts reaching a maximum value that equals 9 kW. The average values of the COP_{hp} and COP_{sys} are equal to 4.25 and 2.88 respectively. In order to ameliorate the performance of the heating system, several authors discussed the

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http://dx.doi.org/10.1016/j.enconman.2017.05.025
0196-8904/Published by Elsevier Ltd.

Nomenclature

A	collector area (m^2)
C_{pf}	specific heat of water at constant pressure ($kJ\ kg^{-1}\ K^{-1}$)
COP	coefficient of performance (–)
F_R	overall collector heat removal efficiency factor (–)
F′	product of the collector efficiency (–)
I_T	total incident radiation per unit area
I_d	horizontal diffuse radiation per unit area ($kJ\ h^{-1}\ m^{-2}$)
I_{bT}	beam radiation per unit area ($kJ\ h^{-1}\ m^{-2}$)
L	length (m)
$\dot{m}$	flow rate ($kg\ h^{-1}$)
N_s	number of identical collectors in series (–)
$\dot{Q}_{abs}$	rate of energy adsorbed by the heat pump evaporator ($kJ\ h^{-1}$)
$\dot{Q}_{exp}$	the experimental heat exchanger rate (W)
$\dot{Q}_{e_{exp}}$	the experimental heat exchanger rate per unit length ($W\ m^{-1}$)
$Q(MAX)$	the theoretically possible of maximum heat exchanger rate (W)
$\dot{Q}_{dh}$	rate of energy delivery to the room by direct liquid source heating ($kJ\ h^{-1}$)
$\dot{Q}_{ei}$	rate of electrical energy required by heat pump ($kJ\ h^{-1}$)
$\dot{Q}_{hp}$	rate of energy delivery by the heat pump ($kJ\ h^{-1}$)
$\dot{Q}_u$	the useful heat that is received from the collector ($kJ\ h^{-1}$)
T_{dh}	minimum fluid source temperature necessary for direct liquid source heating (°C)
T_a	ambient temperature (°C)
$T_{min,\ a}$	minimum ambient temperature necessary for ambient source heat pump operation (°C)
T_0	temperature of fluid returning to liquid source (°C)
U_L	overall thermal loss coefficient of the collector per unit area ($kJ\ h^{-1}\ m^{-2}\ K^{-1}$)

Greek letters

β	solar incidence angle (–)
$(\tau\alpha)$	product of the cover transmittance and the absorber absorptance (–)
ε_{exp}	exchanger energy efficiency (–)
γ_{htr}	control function for heat pump (0, 1)

coupling of the heat pump with others components [4–17]. In the studies [4,5,8,9], a heat pump assisted with a solar energy was developed. The results demonstrate that the COP of the heat pump strengthens with increasing the solar radiation. In [8], the overall system performance and its main components have been tested in northern China. The efficiency of solar cells was obtained and the obtained average value was found to be 67.2%. The coupling of the heat pump and the flat plate solar collector for air conditioning and a production of a hot water was introduced in [9]. This system was installed in a private residence of 180 m^2 in 2004 and the coefficient of performance of the heat pump was ranged between 2 and 3.13. In [7,13,14], an experimental study for a coupling of a horizontal heat exchanger buried in the ground and a heat pump system was realized. The experiments were conducted in a test chamber of 16.24 m^2 [7]; they noticed that the COP_{sys} increases with increasing the depth of the horizontal exchanger. The effects of various parameters such as the depth, the flow rate of water flowing in the pipes on the thermal performance of the heat pump have been validated in [13,14]. The coupling of a heat pump with solar collectors for heating a single zone and residential buildings was realized by [10–12,15]. Ozgener and Ozgener [10], have developed a heating system of an agricultural greenhouse, this heating system can operate in monovalent (heat pump only), or bivalent (heat pump coupled with solar collectors). The experimental results show that the coupling of the heat pump with heat exchangers and solar collectors is a better solution in the Mediterranean climate. In [11], the energy efficiency of the system varies between 30.8% and 65.6%, the energy efficiency of the compressor is 42.1%, and the energy losses of the solar collector are 1.92 kW. The economization of energy by introducing the horizontal heat exchanger in this coupling was the subject of the study developed by Mehmet Esen in [12]. Chargui et al. in [16–18] have ameliorated the numerical study based on TRNSYS software. In [12], the modeling and simulation of a dual source heat pump coupled with a single zone was realized and the COP of this simulation was varied between 3.5 and 5. In [17] a numerical model was implemented to predict the heating of a residential building by using the heat pump and a horizontal heat exchanger. The flat plate solar collector assisted with a storage tank and a heat pump system was realized in [18] for heating a building. Multiple simulations were adopted having same objectives; i, heating a building system by using the renewable energy, ii; also ameliorating the performance of the system by including the control function in the level of the heat pump. The experimental study of a coupling of a heat pump with two types of solar collectors was presented in [16]. The thermal efficiency of the heat exchanger in building application was discussed in [19–22]. In [21,23,24–28], the numerical models using TRNSYS software have been developed in the aim; i, 'thermal performance of a building coupled with a heat pump system' [21,23,24,27], ii, 'feasibility of a solar technology absorption with cooling fed to the Tunisian climate' [25], iii, 'comparing the numerical and the experimental results for the coupling of a heat exchanger and a zone of heating' [27,28]. The coupling of a dual-source heat pump with solar collectors was carried out in [29], this new dual source multifunctional heat pump system (DMHP) uses the air source and solar energy for heating a residential building. They showed that the annual performance of the system varies between 2.5 and 4; moreover, they showed that the rate of exergy loss in each component is very low. Chow et al. in [30] carried out a numerical study of a centralized system of solar water heating in a high-rise residence in Hong Kong. They found that the annual efficiency of vertical solar collectors could reach an average of 38.4%, and they estimated that the heating system heat gain is about 904 GJ. In Ref [30–33], the authors carried out the coupling of a water-to-air heat pump with heat exchanger and a flat solar collector. In [31] the vertical heat exchanger of depth 50 m was used for heating greenhouses in Tunisia, the COP obtained have shown a good accordance with this in Ref [33]. A better performance of heat pump combined with heat exchangers and solar collectors in heating mode was demonstrated in [32]. They analyzed the influence of solar energy on improving the performance of heat pumps. The overall coefficients of performance (COPsys) range from 4.4 to 5.8, the results show that solar collectors is of great importance by improving the performance of a heat pump. In [33–35], the authors have carried out heating applications using solar energy and heat pumps; their economic analysis shows that heat pumps assisted by solar energy are also effective ways of reducing primary energy consumption. A computer code was used in [36] to calculate the performance parameters of a heating system that consists of a heat pump, solar collectors and an underground storage tank. The results indicate that the system studied has better performances (COP varies between 4 and 8) and the physical and thermal