Energy Conversion and Management 109 (2016) 19–39

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Experimental analysis and dynamic simulation of a novel high-temperature solar cooling system

Annamaria Buonomano [a], Francesco Calise [a,*], Massimo Dentice d'Accadia [a], Gabriele Ferruzzi [b], Sabrina Frascogna [b], Adolfo Palombo [a], Roberto Russo [c,1], Marco Scarpellino [c]

[a] DII – University of Naples Federico II, Naples, Italy
[b] DI – University of Naples Parthenope, Naples, Italy
[c] TVP Solar SA, Geneva, Switzerland

ARTICLE INFO

Article history:
Received 2 September 2015
Accepted 21 November 2015
Available online 10 December 2015

Keywords:
Solar cooling
Evacuated solar thermal collectors
Dynamic simulation
Experimental

ABSTRACT

This paper presents experimental and numerical analyses of a novel high-temperature solar cooling system based on innovative flat-plate evacuated solar thermal collectors (SC). This is the first solar cooling system, including a double-effect absorption chiller, which is based on non-concentrating solar thermal collectors. The aim of the paper is prove the technical and economic feasibility of the system, also presenting a comparison with a conventional technology, based on concentrating solar thermal collectors. To this scope, an experimental setup has been installed in Saudi Arabia. Here, several measurement devices are installed in order to monitor and control all the thermodynamic parameters of the system. The paper presents some of the main results of this experimental campaign, showing temperatures, powers, energies and efficiencies for a selected period. Experimental results showed that collector peak efficiency is higher than 60%, whereas daily average efficiency is around 40%. This prototypal solar cooling system has been numerically analysed, developing a dynamic simulation model aiming at predicting system performance. For a representative operating period, numerical data were compared with the experimental one, showing an excellent accuracy of the model. A similar system, equipped with Parabolic Trough solar thermal collectors (PTC) was also simulated in order to compare the novel solar collectors with such reference technology. For both systems a detailed thermo-economic model has been implemented in order to perform such comparison also from the economic point of view. Results showed that the rated energy performance of the prototypal solar cooling system featuring new collectors is better than that of the reference system. In particular, the difference between the novel and the reference solar cooling system becomes more and more significant, when considering the effects of dust and defocusing related to the tracking mechanism of concentrating collectors in harsh environments. Finally, from the economic point of view, results showed that the novel prototype was able to achieve a good profitability.
© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

Solar heating and cooling (SHC) systems are considered as one of the most promising renewable technologies, mainly because in summer the availability of solar energy is simultaneous with cooling demand [1]. In fact, SHC systems are basically equipped with solar thermal collectors and a thermally-driven chiller, which can convert solar thermal energy into cooling energy. When cooling energy is not demanded, solar thermal energy may be used for different purposes (space heating, domestic hot water, etc.) [2].

This basic principle is applied for a plurality of configurations, including absorption chillers, adsorption chillers, desiccant coolers and many other machines [3]. The most common is based on the integration of solar thermal collectors with absorption chillers (ACH), due to their higher efficiency, good commercial availability and lower capital cost [4]. The appropriate combination of solar thermal collector with absorption chiller is crucial in order to achieve high efficiency and good economic profitability [5]. Half-effect, single-effect and double-effect systems are commonly available and selected basing on the solar field available temperature [4]. In particular, when non-concentrating solar thermal collectors (e.g. evacuated tubes) [6] are used, single-effect absorption chillers

* Corresponding author at: DII – University of Naples Federico II, P.le Tecchio, 80125 Naples, Italy. Tel.: +39 0817682301; fax: +39 0812390364.
E-mail address: frcalise@unina.it (F. Calise).
[1] Present address: Consiglio Nazionale delle Ricerche, Istituto per la Microelettronica e i Microsistemi, 80131 Napoli, Italy.

http://dx.doi.org/10.1016/j.enconman.2015.11.047
0196-8904/© 2015 Elsevier Ltd. All rights reserved.

Nomenclature

A	collector area [m^2]
a_0	zero loss efficiency of the collector at normal incidence angle for the solar radiation
a_1	heat loss coefficient at $(T_m - T_a) = 0$ [W/m^{2}K]
a_2	temperature dependence of the heat losses [W/m^{2}K^2]
a_3	wind speed dependence of the heat losses [J/m^{3}K]
a_4	long-wave irradiance dependence of the heat losses [–]
a_5	effective thermal capacitance [J/m^{2}K]
a_6	wind dependence of the zero loss efficiency, a collector constant [s/m]
c	concentration ratio [–]
$\dot{C}$	heating capacity
C	cost [€]
E_L	long wavelength radiation [W/m^2]
F	fraction [–]
I	global solar radiation [W/m^2]
J	capital cost [€]
$\dot{m}$	mass flow [l/h]
η	efficiency [–]
Q	energy [W]
T	temperature [°C]
u	wind speed parallel to collector plane [m/s]

Subscripts

a	referred to ambient
aux	referred to auxiliary
clean	referred to cleaning system
diesel	referred to diesel
ext	referred to external
in	referred to input
M	referred to maintenance
m	referred to mean
out	referred to output
ref	referred to reference system
sol	referred to solar system
T	referred to total
w	referred to water

Abbreviation

ACH	absorption chiller
CHW	chilled water
CW	cooling water
BOS	balance of system
DHW	domestic hot water
EE	electrical energy
DB	diesel burner
HE	heat exchanger
HW	hot water
NPV	net present value
PI	Profit Index
PTC	Parabolic Trough Collector
SC	solar collector
SHC	solar heating and cooling
TK	Tank

are often selected, because of their lower driving temperature (>80 °C) [7]. However, the combination of evacuated tubes solar thermal collectors and single-stage absorption chiller often provides poor economic profitability and power density. In fact, the coefficient of performance (COP) of single-effect absorption chillers is just about 0.6 and as a consequence, large solar fields are required to cover the cooling demand [8]. System economic profitability and power density may be improved using double-effect absorption chiller (COP about 1.2). However, the driving temperature of the double-effect absorption chiller is much higher (>140 °C) [9]. As a consequence, high-temperature solar thermal collectors must be included in solar cooling systems equipped with double-effect absorption chillers. According to the findings available in literature, the high operating temperature, required to drive the double-effect absorption chiller, have so far been achieved only by concentrating solar thermal collectors [1].

In fact, many papers are available in literature investigating, from both numerical and experimental points of view, several layouts of solar cooling system, including concentrating solar collectors and double-effect absorption chiller.

As an example, Qu et al. [10] presented a comprehensive analysis of a small scale high temperature solar cooling system. This system consists of 52 m^2 PTC and 16 kW double effect LiBr–H_2O absorption chiller. Authors performed several sensitivity analyses aiming at determining the optimal configuration. In such circumstance, winter and summer solar fraction are respectively around 39% and 20%. A similar work was presented by Yang et al. [11], experimentally investigating a solar cooling system, based on a 54 m^2 solar field, including compound parabolic concentrator (XCPC) and a 23 kW double-effect absorption chiller. The daily average efficiency of the solar collector was around 36–39%, whereas the COP of the absorption chiller was about 1.0. In this case, an annual solar fraction of 55–68% is predicted. Another experimental study is presented by Izquierdo et al. [12], investigating the performance of air cooled both single-effect and double-effect absorption chillers. This study only focused on the novel absorption chiller, being the inlet thermal source simulated. Authors obtained good results when operating in single-effect mode. However, in double-effect mode the system was activated when the driving temperature was 175 °C. Xu et al. [13] investigates a variable effect LiBr–H_2O absorption chiller, specifically designed for the high-efficient utilization of solar power at variable inlet temperature. Results showed that the COP increased from 0.69 to 1.08 under generation temperature from 95 °C to 120 °C. A non-tracking high temperature solar cooling system was experimentally investigated by Winston et al. [14]. Authors employed non-tracking External Compound Parabolic Concentrators (XCPC) coupled with a 23 kW double-effect LiBr–H_2O absorption chiller. The collector operating temperatures ranged between 160 and 200 °C. The average daily efficiency was 36.7% whereas the instantaneous maximum efficiency was 40%. The daily average solar COP was 0.363.

Similarly, a number of papers are available investigating high temperature solar heating and cooling systems from a numerical point of view. In particular, Tierney [15] investigated several high and low temperature solar heating and cooling systems for different climates, showing that the highest savings (86%) were achieved by systems integrating PTC and double-effect absorption chillers. Lokurlu and Richarts [16] presented a prototype of a novel Concentrating Solar Heating and Cooling (CSHC) integrating both PTC and double-effect absorption chiller technologies. The system was supposed to supply space heating and cooling, domestic hot water and laundry steam for a Hotel in Turkey. Li et al. [17] investigated a solar cooling system equipped with compound parabolic concentrator (CPC) and double-effect LiBr–H_2O absorption chiller, aiming at evaluating the optimal collector operating temperature for a subtropical Chinese climate. They found that the optimum inlet temperature of collectors increases as a function of: the increase

Download English Version:

https://daneshyari.com/en/article/760428

Download Persian Version:

https://daneshyari.com/article/760428

Daneshyari.com