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Model performance assessment and experimental analysis of a solar assisted cooling system

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ABSTRACT

Due to the economic development and occupancy requests, building thermal comfort reached higher levels during the last years. Energy consumption rates have become excessive and engendered an increasing reliance on fossil-fuel reserves. Hence, the conception of energy-efficient buildings as well as applying solar cooling techniques has become a promising solution. In this context, the current work dealt with the appraisal of a solar system that drives the cooling process in an office building located in the Center of Researches and Energy Technologies in Tunisia. The solar system consisting of linear parabolic trough solar collectors' field coupled to a 16 kW double effect Lithium Bromide absorption chiller, supplies chilled water to a set of fan coils installed in the 126 m^2 laboratory building.

A dynamic model that couples the solar cooling system with the building was developed using the TRNSYS tool and several simulations were performed to assess the case study and improve its performance. The model results were compared to the data collected during the experimental campaign conducted in summer 2015 and showed that the collectors efficiency was at the range of 26–35%, the COP ranged between 0.65 and 1.29, the daily maximum solar COP was approximately at 35%. However, the solar system was unable to cover 32.3% of the cooling requirements, the absorption chiller was switched on only during 53.8% of its total operating time. An improved system configuration was then studied; the integration of an auxiliary heater prior to the chiller as well as the increase of the aperture area guaranteed high driving temperatures and more suitable conditions to the absorption chiller. As a result, the chiller operating time increased to 75.8%, the cooling power increased by 75.6%, the solar COP reaches 57% and the solar fraction averaged 87%. The summer season performances predict that the improved system configuration achieves primary energy savings that reach 82.3% compared to a classic air conditioning system producing the same cooling power, the yearly avoided CO_2 emissions are estimated to 2947 kg.

1. Introduction

During the last years, a significant rise of the number of installed solar assisted systems has been observed all around the world. The application of these systems was either domestic hot water production, space heating or infrequently space cooling. Nevertheless, solar cooling systems appear to be the most promising solar technology able to replace conventional electrical driven cooling units as the incident radiation availability and the cooling requirements are always in concordance seasonally and geo-graphically. For this reason, several analytic studies of these systems have been performed either before or after prototypes installation. Actually, the analytic studies preceding system design generally focus on the feasibility of the solar cooling system, its performance prediction and optimization. After implementation, further experimental and analytical studies are also required to assess the systems functioning and improve the operating conditions in order to develop this technology.

Some reviews studies of solar assisted absorption cooling systems have been realized (e.g. Allouhi et al., 2015; Boopathi and Shanmugam, 2012; Cabrera et al., 2013; Gomri et al., 2010; Henning, 2007; Sarbu and Sebarchievici, 2013, 2015). They affirmed that, based on the coefficient of performance values, the absorption systems are preferred over the adsorption systems. The comparison of the water bromide and the ammonia water absorption systems showed that H_2O/LiBr systems operating at lower pressures and recording higher COP values are more suitable

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Nomenclature

A	aperture area (m^2)
$BEAM$	beam radiation (kW)
COP	coefficient of performance
c_p	specific heat of water (kJ/kg K)
c_{HTF}	specific heat of the heat transfer fluid (kJ/kg K)
DNI	direct normal irradiation (W/m^2)
Err	error (%)
$\dot{m}$	mass flowrate (kg/s)
P_h	high pressure in the absorption process
$\dot{Q}_{Aux}$	auxiliary heating rate (kW)
Q_{coll}	useful collector energy (kW h)
$\dot{Q}_{coll}$	useful collector energy rate (kW)
Q_{chill}	chilled water energy rate (kW)
$\dot{Q}_{chill}$	chilled water energy (kW h)
Q_{in_chill}	heat delivered to the chiller (kW)
$\dot{Q}_{in\_chill}$	HTF energy delivered to the chiller (kW h)
Q_{Load}	cooling load of the existing building (kW h)
Q_{Load_pred}	cooling load of the predicted building model (kW h)
$SCOP$	solar coefficient of performance
SF	solar fraction (%)
TOT	total incident radiation (kW)
T_{coll}	temperature of the HTF exiting the collectors (°C)
T_{chill}	temperature of the chilled water produced by the chiller (°C)
T_{set}	auxiliary setpoint temperature (°C)
η_{Coll}	efficiency of the solar collectors

Abbreviations

HTF	heat transfer fluid
HTG	high temperature generator
HTHX	high temperature heat exchanger
LTG	low temperature generator
LTHX	low temperature heat exchanger
PTSC	parabolic trough solar collectors
RAHX	refrigerant/absorbent heat exchanger

Subscripts

Amb	ambient
coll	collector
ch	chiller, chilled water
ex	experimental
G	chiller's generator
h	hot
in, out	inlet, outlet
L	Low
m	measured
me	medium
sim	simulation

Superscripts

e	entering
s	exiting

for air-conditioning, but the use of an anti-crystallization device remains necessary. On the whole, it is important to note that among the multiple solar cooling existing plants, most of the projects feature single effect chillers (e.g. Ahmed Hamza et al., 2008; Agyenim et al., 2010; Lu and Wang, 2014; Marcos et al., 2011) and a few are dedicated to double-effect absorption chillers installations. It was asserted that this is due to the technical operating barriers of efficient double effect absorption chillers that require thermal energy at temperatures of 140–180 °C afforded only by concentrating collectors (e.g. Bermejo et al., 2010; Li et al., 2014; Duff et al.,2004).

Fong et al. (2011) studied the feasibility of a solar hybrid cooling system coupling desiccant dehumidification and absorption refrigeration in the subtropical Hong Kong. The solar system consisted of a field of 100 m^2 flat-plate collectors coupled to a single effect H_2O/LiBr absorption chiller, used to cool a 196 m^2 office building. The analytical results found using the TRNSYS software showed that, compared to the conventional centralized air-conditioning system; the solar system could reach 36.5% of primary energy savings.

Hang et al. (2014) performed an experimental study of a solar cooling system installed in the University of California Merced. The solar system comprised of a solar field of 54 m^2 external compound parabolic concentrator (XCPC) driving a 23 kW double effect absorption chiller was run in August 2012. Experimental data showed that the average efficiency of the collector ranged between 36% and 39%, the average *COP* of the chiller varied from 0.91 to 1.02 and the daily solar *COP* averaged 0.374.

Rosiek and Garrido (2012) proved the great importance of integrating chilled water storage tanks in a solar assisted cooling system installed in the CIESOL building (Campus of the University of Almería). The system included a solar field of 160 m^2 of selective absorption coated flat plate collectors, a 70 kW single effect LiBr-H_2O absorption chiller, two hot water storage tanks, a cooling tower and an auxiliary heater. The results showed that the integration of two chilled water tanks allowed a decrease of about 20% of total energy consumption as well as 30% of water resource consumption and about 1.7 tons of CO_2. The main advantage was the reduction of sudden absorption chiller on/off cycles that deeply improved the efficiency of the cooling system.

Sanjuan et al. (2010) studied a solar system coupled to a bioclimatic building constructed in the Plataforma Solar de Almeria in Spain. The system consisted of an absorption system coupled to a solar field composed by ninety high efficiency flat plate collectors with transparent insulation material of a total aperture area of 170 m^2. As for the absorption heat pump system, it was composed by four heat pumps units that store solar energy in the form of crystallized salts. The heat and cold distribution were guaranteed by a radiant floor and a set of inductors. Each absorption unit featured two separate barrels functioning separately: the first barrel stores energy from the solar collectors and the second delivers the heat or cold produced to the building. The storage capacity was 60 kW h per unit and the total maximum cooling power produced was about 80 kW. The effect of the control strategies as well as different configurations of the four units has been studied. The simulations results using the TRNSYS tool showed that the solar fraction varies from 50% to 90% depending on the control strategy. The interior storage absorption system was also compared to an ordinary absorption unit; it was concluded that the same solar fraction could not have been achieved unless a storage tank of 16 m^3 is employed. The study has also proved the high adaptability and efficiency of interior storage absorption units especially when medium powers are required.

Multiple other studies have also focused on the design and the experimental investigation of solar cooling prototypes installed all over the world (e.g. Beausoleil-Morrisson et al., 2015; Bermejo et al., 2010; Chemisana et al., 2013; Mazloumi et al., 2008;