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Energy and parametric analysis of solar absorption cooling systems in various Moroccan climates

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ABSTRACT

The aim of this work is to investigate the energetic performance of a solar cooling system using absorption technology under Moroccan climate. The solar fraction and the coefficient of performance of the solar cooling system were evaluated for various climatic conditions. It is found that the system operating in Errachidia shows the best average annual solar fraction (of 30%) and COP (of 0.33) owing to the high solar capabilities of this region. Solar fraction values in other regions varied between 19% and 23%. Moreover, the coefficient of performance values shows in the same regions a significant variation from 0.12 to 0.33 all over the year. A detailed parametric study was as well carried out to evidence the effect of the operating and design parameters on the solar air conditioner performance.

1. Introduction

The energy use in buildings is exponentially growing [1]. Vapor compression air-conditioning systems used in building cause a significant consumption of electrical energy in many parts of the world. Currently, the cooling demand is expected to increase because of increased comfort standards and worldwide warming issues. For instance, 40% of electricity production during summer is entirely used by US commercial buildings for air-conditioning purposes [2]. In Egypt, 32% of the electricity is consumed by air-conditioning in the domestic sector [3].

Vapor compression chillers use different types of refrigerants such as Chloro-Flouro-Carbon and Hydro-Chloro-Flouro-Carbo with high negative impact on the environment. Therefore, it is suitable to decrease or at least prevent the use of these refrigerants [4].

To improve the energy efficiency in buildings, solar air-conditioning seems to be an interesting alternative to reduce electricity consumption, especially during summer, when cooling loads coincide generally with availability of solar irradiation.

The technologies of solar cooling using sorption principle such as absorption or adsorption are commercialized by many companies in different sizes because of their relatively high performances compared to other systems [5]. Pons et al. [6] reported the experimental performances over all seasons and on one single day of six chillers using five different technologies and in five different locations. They found that the performances evaluated on one single day can be over-estimated (+30%) compared to seasonal averages, the difference between the two methods can be theoretically interpreted as a non-linear effect related to the thermal inertia of the solar field.

Abbreviations: CFC, Chloro-Flouro-Carbon; HCFC, Hydro- Chloro-Flouro-Carbon; LiBr, Lithium bromide; DHW, Domestic hot water; ADEREE, Agence Nationale pour le Développement des Energies Renouvelables et de l'Efficacité Energétique; COP, Coefficient of Performance

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Nomenclature

A	Area [m^2]
c_p	Specific heat at constant pressure [J kg^{-1} °C^{-1}]
G	Solar radiation [W m^{-2}]
Q	Heat (J)
T	Temperature [°C]
m	Mass flowrate [kg/h]
F_R	Collector heat removal factor [-]
U_L	Heat loss coefficient [W/m^2 K]
g	g-value[-]

Greek letters

η	Collector efficiency [-]
$\tau\alpha$	Transmittance–absorbance product

Subscripts

avg	Average
amb	Ambient
s	Solar
aux	Auxiliary
c	Collector
evap	Evaporator
gen	Generator

Al-Ugla et al. [7] studied a three alternative design (heat storage, cold storage, and refrigerant storage) of a 24 h operating solar absorption system in Saudi Arabia in order to determine the best suitable alternative, their analysis revealed that alternative design with refrigerant storage of a solar LiBr/H_2O absorption system is the best alternative because of its high coefficient of performance (of 0.77) with a small collector size (22 m^2) compared to other alternatives.

Calise et al. [8] presented a technical and economic feasibility of a novel solar cooling system based on a new and innovative flat-plate evacuated solar thermal collector and using a double-effect absorption chiller. The experiment results show that collector peak efficiency is over 60% and daily average efficiency is around 40% and they indicate that systems equipped with flat-plate evacuated solar collectors reach a higher solar fraction (77%) compared to 66.3% for PTC collectors. In Australia, an energetic, economic and environmental analysis of LiBr-H_2O absorption chiller is conducted by Shirazi et al. [9] simulating four configurations of solar heating and cooling systems. The results show that the second configuration which consisted of an absorption chiller with a mechanical compression chiller working as an auxiliary cooling system, reached a solar fraction of 71.8% and primary energy savings of 54.51%. Tsoutsos et al. [10] conducted a parametric study concerning the economic evaluation of two types of solar cooling systems (absorption and adsorption) in Greece. They compared economically the performance of these two technologies to the traditional air-conditioner taking into account several indicators such as the initial cost of primary energy, carbon taxes and energy inflation.

Vasta et al. [11] presented a dynamic simulation and a performance analysis of an adsorption chiller operating under three different cities in Italy. They concluded that the design parameters have a significant influence on the performance indicators. They found that the solar fraction can reach 81% and 50% for the two types of cooler (Dry and Wet) at a lower number of solar collectors. In addition, it was found that the COP of the adsorption chiller can achieve values of 57% and 35% for the same configuration of collectors.

In UAE, Al-Alili et al. [12] conducted a numerical study of an absorption solar cooling system to evaluate its performance. They studied a novel solar air cooling system which consists of hybrid air conditioner and hybrid photovoltaic/thermal solar collectors. They found that the COP of the investigated system is higher than that of an absorption solar chiller. The related average cooling COPs are found to be 0.68 and 0.29, respectively.

Morocco possesses an important potential of solar energy [13,14]. In fact, the average daily solar radiation is about 5.3 kW h/m^2 with more than 5000 h of sunshine annually. Accordingly, the development of solar-air conditioning in Morocco seems to be of a great importance and is within the new government strategies for the promotion of renewable energy projects [15].

The main objective of this work is to provide useful guidelines about the operation of solar cooling systems under Moroccan climate. In this sense, an energy analysis and performance evaluation of a solar-air conditioning system was carried out. Optimal design of the system is reported as well.

2. Design aspects

2.1. Thermal solar cooling system

The solar cooling plant under investigation can be divided into two subsystems: the solar subsystem and the cooling subsystem. The first one includes solar collectors, a heat exchanger, a thermally insulated hot storage tank, an electrical auxiliary heater, two circulating pumps and a distribution circuit. The second one integrates an absorption chiller, a cooling tower, a cold storage tank, and three pumps connected respectively to the generator, evaporator and condenser. The schematic diagram of the overall solar cooling system is shown in Fig. 1.

A flat-plate collector transfers the energy collected from the solar irradiation to a solar tank through an external exchanger. The primary and secondary pumps coupled respectively, the solar field to the heat exchanger and the storage tank to the solar collectors. The thermal energy stocked in the tank flows to the absorption chiller that produces chilled water, then the chilled water is injected into a water/air exchanger to cool the building.