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Design and test results of a low-capacity solar cooling system in Alicante (Spain)

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Abstract

Despite its attractiveness, solar cooling technology is still in an early stage of development. Most installations currently in operation show differences in the collector area per kilowatt of cooling capacity that cannot be explained only by project-specific circumstances. The purpose of this paper was twofold. First, to answer some questions that came up during the design process of the plant by using a TRNSYS system model and statistical tools. Second, to gain knowledge about the plant operation and validate the TRNSYS model through measured data. The system was equipped with a flat-plate collector field of 38.4 m^2. A lithium bromide-water single-effect absorption chiller (17.6 kW) was selected in order to provide chilled water to fan-coils. Performance data were registered at the solar plant working with a 1000-l heat storage tank and a required temperature of 80 °C to drive the absorption machine. An average of 29% of the solar energy incident on the solar collectors' surface was transferred to the hot water storage. The registered average COP of the absorption chiller was 0.691. The performance data were compared with the values predicted by the TRNSYS plant model and a high level of agreement was obtained.

Keywords: Solar cooling; Absorption; TRNSYS; Experimental designs; ANOVA

1. Introduction

Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings states that "the residential and tertiary sector, the major part of which is buildings, accounts for more than 40% of final energy consumption in the community and is expanding, a trend which is bound to increase its energy consumption and hence also its carbon dioxide emissions".

Heating and air-conditioning facilities are responsible for most of the energy consumption mentioned above. Application of thermal solar energy to buildings for heating and cooling reduce conventional energy consumption and carbon dioxide emissions, and provide a solution for a sustainable energy supply. Furthermore, the combination of solar heating and cooling applications improves the efficiency of solar thermal systems compared to heating or cooling alone.

Solar cooling is an attractive idea because of the chronological coincidence between cooling load and available solar radiation. However, this technology is still in an early stage of development. Balaras et al. (2007) state "the main obstacles for large scale application, beside the high first cost, are the lack of practical experience and acquaintance among architects, builders and planners with the design, control and operation of these systems". Most installations currently in operation are part of demonstration projects, and show collector areas per kilowatt cooling capacity that range from 0.8 to 8 (DGS, 2005). These differences cannot be caused by project-specific circumstances alone.

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Nomenclature

a_0	optical efficiency	av	average
a_1	lineal loss coefficient (W m^{-2} K^{-1})	col	collector
a_2	quadratic loss coefficient (W m^{-2} K^{-2})	cool	cooling
A	area (m^2)	cw	cooling water
COP	coefficient of performance	chw	chilled water
E	energy	elec	electricity
Eff	effectiveness	eva	evaporator
I	solar radiation incident on the collector (W m^{-2})	exp	experimental
		gen	generator
m	mass flow rate (kg s^{-1})	hw	hot water
SF	solar fraction	hx	heat exchanger
T	temperature (K)	in	inlet
V	volume (m^3)	nom	nominal
X	standardised factor value	out	outlet
		req	required
Greek		sec	secondary loop of the solar circuit
η	efficiency	sim	simulated
		sol	solar
Subscripts		sto	storage
amb	ambient		

A review of the solar air-conditioning technologies and equipment that are commercially available can be found at (Henning, 2004). This reference also shows design approaches, which require different levels of effort and available data (solar collector parameters, nominal operating temperature of the thermally driven cooling machine, meteorological and load data).

Several simplified methods have been developed to evaluate the long-term performance of solar cooling systems in terms of the solar fraction. Klein and Beckman (1979) developed the $\bar{\varphi}$, f-chart method for closed-loop systems with finite storage where the load (thermally-driven cooling machine) is characterised by a minimum useful temperature. Oliveira (2007) presented a method based on the calculation of two utilizability values related to the temperature at which the hot water is delivered to the absorption machine and the temperature at which hot water returns from the chiller. Joudi and Abdul-Ghafour (2003a, 2003b) developed a method that correlated the monthly solar fraction with two non-dimensional parameters (like in the f-chart method). Among other variables, these non-dimensional parameters take into account the characteristics of the thermally-driven cooling machine and the effect of heat storage.

The long-term performance of solar cooling systems can also be evaluated through detailed simulations, which require specific simulation tools and a greater effort to establish the system's model. Maybe the most well-known simulation tool for solar thermal systems is TRNSYS (2004), which is a widely used modular simulation program. The use of detailed simulations for the design of solar-assisted air-conditioning designs is helpful because of the complexity of these systems.

By simulating a solar cooling system, Eicker and Pietruschka (2009) showed that different collector areas (2–4 m^2 kW_{cool}^{-1}) were required to reach a design solar fraction (80%) depending on the characteristics of the building load and on the chosen control strategy. The model of the solar cooling system included a single-effect water-lithium bromide absorption chiller and a commercial evacuated-tube solar collector ($a_0 = 0.775$, $a_1 = 1.476$ W m^{-2} K^{-1}, $a_2 = 0.0075$ W m^{-2} K^{-2}).

Zambrano et al. (2008) developed a dynamic solar cooling plant model. This model was validated with real data from a demonstration plant located in Seville (Spain), which had a flat-plate collector field of 151 m^2 ($a_0 = 0.872$, $a_1 = 5.38$ W m^{-2} K^{-1}) to drive a 35 kW single-effect water-lithium bromide absorption chiller. The specific collector area was therefore 4.3 m^2 kW_{cool}^{-1}. The heat storage ratio was 33 kg m_{col}^{-2} (two 2500-l heat storage tanks connected in parallel).

Several questions arise when designing a solar-assisted heating and cooling system: Which collector technology for which thermally-driven cooling technology should be used? How much collector area and how much heat storage capacity? Some other questions are related to design parameters that do not have either an obvious effect on the performance of the solar-assisted system or a known optimum value.

Since there was a lack of common practices for the design of solar-assisted heating and cooling systems, the first purpose of this work was to answer some of the