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Performance analysis of a solar cooling plant based on a liquid desiccant evaporative cooler

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ABSTRACT

Summer air conditioning represents a growing market in buildings worldwide, with a significant growth rate observed in European commercial and residential buildings. Available heat driven cooling technologies can be used in combination with solar thermal collectors to reduce the load caused by air conditioning on the electric utilities and to reduce the environmental impact. This work reports a performance analysis of an open cycle solar cooling plant. The plant, installed in Northern Italy, is based on a liquid desiccant evaporative cooler coupled with a solar field. Experimental tests run during summer show average primary energy ratio and primary energy saving index of about 1.6 and 30%, respectively. Though this performance is satisfactorily, the regeneration unit always operated near the lower bound of the nominal temperature range. Therefore, optimization of the solar system design could lead to higher performance.
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Analyse de la performance d'un système de refroidissement solaire basé sur un refroidisseur évaporatif à déshydratant

Mots clés : Froid solaire ; Refroidissement évaporatif solaire ; Taux d'énergie primaire ; Économies d'énergie primaire

1. Introduction

The use of air conditioning systems during summer showed considerable growth in the last few years all over the world and mainly in European residential and commercial buildings. Considerations about energy efficiency and environmental impact suggest that available heat driven cooling technologies coupled with solar thermal collectors could perform better than conventional plants based on chillers or heat pumps (Henning, 2004).

Solar cooling is a particularly interesting application of solar energy since the load is matched by the overall solar availability. In temperate climates, these systems guarantee a better utilization of solar collectors, further improving the economic performance of solar thermal systems that provide heating and domestic hot water.

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Nomenclature

Latin symbols

A	solar collectors area, [m^2]
a_1	coefficient ($a_1 = 0.974$ W $m^{-2}K^{-1}$), [W $m^{-2}K^{-1}$]
a_2	coefficient ($a_2 = 0.005$ W $m^{-2}K^{-2}$), [W $m^{-2}K^{-2}$]
c	specific heat at constant pressure, [kJ kg^{-1} K^{-1}]
COP	coefficient of performance (seasonal performance factor)
E	electric energy, [kJ]
F	fractional solar cooling saving
G	solar irradiation, [W m^{-2}]
h	humid air enthalpy referred to the unit mass of dry air, [kJ kg_{da}^{-1}]
h_{lv}	liquid vapor phase transition enthalpy, [kJ kg^{-1}]
H	humid air enthalpy [kJ]
P	primary energy ratio
Q	heat exchanged, [kJ]
S	solar fraction
T	temperature, [°C]
t	time, [s]
$\dot{V}$	volume flow rate, [m^3 s^{-1}]
X	absolute humidity, [kg $kg_{d.a.}^{-1}$]
y	generic function
z	generic independent quantity

Greek symbols

δ	percentage variation referred to the actual value
η	efficiency
ρ	dry air density, [kg m^{-3}]
η_0	solar collector efficiency when the mean liquid temperature is equal to the outdoor temperature ($\eta_0 = 0.718$)

Subscripts

0	reference
a	air
b	backup boilers
c	chiller
d	desiccant evaporative cooler
da	dry air
e	whole plant
f	fuel combustion
g	irradiation
i	supply conditions
in	water inlet
l	latent
m	mean value between inlet and outlet
ma	manufacturer
o	outdoor conditions
out	water outlet
p	heat pump
q	thermal
r	regeneration
s	solar collectors
t	total
v	vapor
w	water

A complete and comprehensive description of solar cooling plant configurations, including sizing criteria according to user and climate data, are available in (Henning, 2004; Wiemken, 2009). Overviews of European research on solar-assisted air conditioning are reported in (Henning, 2004; Kima and Ferreira, 2007; Henning, 2007).

Desiccant cooling systems are thermally driven open cooling cycles based on evaporative cooling and adsorption processes. The most common technology involves rotating desiccant wheels with solid material (for example zeolites), deeply investigated in terms of configurations and performance (Daou et al., 2006; Finocchiaro et al., 2012; Beccali et al., 2012; Eicker et al., 2010; Beccali et al., 2009).

On the other hand, desiccant cooling systems using a liquid solution as sorption material are a more recent development. This technology shows as major advantages:

- the possibility of high energy storage through the concentrated solution, thus allowing operation when solar energy is inadequate or even unavailable;
- low operating temperature of the liquid solution (60 ÷ 90 °C), that makes it suitable for solar energy application (Zeidan et al., 2011; Katejanekarn et al., 2009; Alizadeh, 2008; Gommed and Grossman, 2007; Crofoot and Harrison, 2012; Fong et al., 2010).

Unfortunately, the liquid desiccant technology still presents high investment cost (Henning, 2007). This drawback can be obviously overcome, if better performance and higher energy saving compared to traditional technologies are achieved.

Ricerca sul Settore Energetico S.p.A. (RSE) has been studying solar cooling technologies for some years (Viani et al., 2013; Rossetti et al., 2013a, 2013b). In particular, the work presented in this paper is included in a research activity aimed at monitoring the performance of large scale (>20 kW) solar cooling plants installed in Italy. Actually, systematic test on the performance of small scale systems (<20 kW) is already available (IEA Report). This analysis shows that for such systems the closed loop solution with single effect absorption chiller and low temperature collectors prevails on the other ones. Differently, the plant described in this work represents one of the prototypal plants with lithium chloride – water mixture desiccant evaporative cooling technology installed in Italy. The performance has been evaluated according to a shared monitoring procedure (Napolitano et al.).

2. Experimental plant

The Kloben facility, located near the city of Verona in Italy, is an industrial warehouse (surface 14,000 m^2) with an office

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