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Experimental investigation and performance analysis of a mini-type solar absorption cooling system

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HIGHLIGHTS

- The energy step utilization improved the performance of a solar cooling system.
- Thermal environment of Class A was achieved by using radiant cooling.
- Solar radiation intensity has prominent impact on the solar cooling system.

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ABSTRACT

A mini-type solar-powered absorption cooling system with a cooling capacity of 8 kW was designed. Lithium bromide-water was used as the working pairs of the chiller. Solar collectors with an area of 96 m^2 were installed. A water storage tank with a volume of 3 m^3 was used to store the hot water from the solar collectors. The experimental results showed that the average values of PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) of the test room were 0.22 and 5.89, respectively. Taking the average value of PMV and PPD into consideration, the solar cooling system could meet the indoor thermal comfort demand with the comfort level of A. The power consumption was reduced by 43.5% after introducing the stepped utilization of energy into the air handling unit. Meanwhile, a theoretical model was established based on Matlab to predict the variations of the system performance with ambient parameters. It is shown that the solar radiation intensity has a greater impact on the performance of the solar powered absorption cooling system compared with the ambient temperature. It is also shown that the indoor air temperature goes down with the increase of the solar radiation intensity as well as the decrease of the ambient temperature.

1. Introduction

There is a rapid increase in the electricity consumption around the world. The global environment has been deteriorating due to the utilization of fossil fuel and the employment of CFCs fluid in conventional refrigeration systems. The use of solar energy in buildings greatly reduces the consumption of fossil fuel and harmful emissions to the environment [1]. As a promising technology, solar cooling systems have been paid more and more attention to. Lithium bromide-water absorption chillers are most commonly used in solar cooling systems, because they are readily available commercial equipments [2].

In recent years, different strategies of cooling technologies powered by renewable energy have been widely presented, particularly in Europe, USA and China [3–5]. Malkamäki et al. [3] analyzed a hybrid solar and hydro (SHE) system that provided continuous electric power and energy supply to its consumers. Besides, the possibility of its implementation in Europe and other areas with the similar climate was also analyzed. The results clearly showed a wide range of implementation of the SHE system. Otanicar et al. [4] described a technical and economic comparison of existing solar cooling approaches including both thermal driven and electrical driven systems. The initial costs of these technologies, including the projections of the future cost of solar electric and solar thermal systems, were compared. The results showed that the cost of the solar electric cooling system was highly dependent on the system COP. The cost of the solar collection only accounted for a small part in the total cost of the solar thermal cooling system, however, the cost of the refrigeration unit often bulked up into a considerable sum if the PV price remained at current level. It could be expected that the solar thermal cooling would be competitive with the solar electric

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Nomenclature

A	area (m^2)
CL	cooling load
COP	coefficient of performance
COP_{system}	COP of the system
C_p	specific heat (J/(kg K))
d	humidity (g/kg)
D	duration of the operation (s)
D'	total humidity (g)
i	enthalpy (kJ/kg)
I	solar radiation intensity (W/m^2)
M	mass flow rate (kg/s)
n	number of people
PPD	predicted percentage dissatisfied
PMV	predicted mean vote
Q	energy (kW)
T	temperature (°C)
U	thermal conductivity (W/m °C)
V	volume (m^3)
ρ	density (kg/m^3)

Greek symbols

η	efficiency
Φ	ratio of latent to total cooling load

Subscripts

a	ambient
c	collector
cap	cooling capacity
cc	cooling ceiling
ch	chiller
co	cooling
d	device
e	envelope
ev	evaporator
f	air infiltration
fa	fresh air
fad	fresh air device
g	generator
hot	hot water
i	inlet
l	cooling load
L	thermal load on the body
latent	latent cooling load
M	metabolic rate
o	outlet
p	people
r	room
s	system
sensible	sensible cooling load
su	supply air
save	energy saving
ta	tank

cooling with respect to the cost, if the cost of the refrigeration unit decreased and the thermal refrigeration COP increased. Zhai et al. [5] reviewed the existing theoretical and experimental investigations of solar single-effect absorption cooling systems as well as some new design options with regard to solar collectors, auxiliary energy systems and cooling modes. Besides, some reviews were found to demonstrate the feasibility of application of solar cooling technologies in buildings [6,7]. There are also some demonstration projects that have been set up to study the operation characteristics of solar cooling systems [8,9]. Bermejo et al. [8] tested a solar/gas cooling plant in Spain during the period 2008–2009. A LiBr/water absorption chiller with 174 kW cooling capacity was powered by a linear concentrating Fresnel collector or a direct-fired natural gas burner. The experimental results showed that the solar fraction was 0.75. Gebreslassie et al. [9] presented a systematic method for reducing the life cycle impact of cooling applications. The method relies on formulating a bi-criteria MINLP (mixed-integer nonlinear programming) problem that accounts for the minimization of the total cost and environmental impact of solar assisted absorption cooling cycles. The results showed that the significant reductions in the environmental impact could be achieved if the decision-maker was willing to invest on a solar collector subsystem. Besides, the reductions could be attained by increasing the number of the collectors installed, which increased the solar fraction of the cooling system. It was also shown that the type of collectors should be selected depended on the particular operating conditions and weather data. Al-Alili [10] studied the feasibility of a solar absorption cooling system under Abu Dhabi's weather conditions. The results showed that solar cooling was attractive because it was capable of saving electricity by 47% compared with vapor-compression cooling systems with the same cooling capacity. Fong [11] showed different styles of solar collectors for use in sub-tropical regions like Hong Kong, and suggested that the use of building-integrated solar collectors in solar cooling systems should be considered depending on the building situations.

It is found that the efficiency of a solar cooling system is generally lower than that of a conventional electric cooling system, which becomes a significant hinder for the popularity of solar cooling systems. Therefore, some new strategies were studied to improve the system performance. Calise [12] simulated different solar cooling systems to seek proper operation parameters for the purpose of maximizing the COP of solar cooling systems. Venegas [13] presented the influence of operational variables on the system performance. The results showed that the most important variable that influenced the daily solar COP was the amount of the collected solar energy.

There are also some researches based on filed investigations [14–18]. Fong [14] reported a solar hybrid cooling system operating in a hot and humid climate. The system consisted of a solar powered absorption chiller system which was used to handle the sensible load, and a desiccant dehumidification wheel system which was employed to remove the latent load. It was shown that the annual primary energy consumption of the solar hybrid cooling system was lower than that of a conventional vapor compression refrigeration system by 36.5%. Ali [15] presented the performance of an integrated cooling plant including both a free cooling system and a solar powered single-effect LiBr/water absorption chiller. The system was in operation during a five years' period from 2002 to 2007 in Germany. It was indicated that the free cooling system in some cooling months could provide cooling consumption up to 70% while it was about 25% during all the five years operation. Besides, the monthly average value of solar heat fraction varied from 31.1% to 100% with the average value during the five years of about 60%. Bermejo [16] tested a