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Design and performance of a solar-powered air-conditioning system in a green building

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Abstract

A solar-powered adsorption air-conditioning system was designed and installed in the green building of Shanghai Research Institute of Building Science. The system contained 150 m^2 solar collectors and two adsorption chillers with nominal refrigeration capacity of 8.5 kW. Based on performance characteristics of the adsorption chiller, the operation mode of the solar-powered air-conditioning system was optimized by maintaining a phase shift of 540 s between the two adsorption chillers. Thereafter, the whole system realized stable operation by the balance of heat consumption and refrigeration output. From June to August of 2005, the solar-powered air-conditioning system continuously ran between 9:00 and 17:00. The operation performance of the system under representative working condition showed that the average refrigeration output of the solar-powered air-conditioning system was 15.3 kW during an 8 h operation and the maximum value exceeded 20 kW. Solar fraction for the system in summer was 71.7%, which corresponded to the designed cooling load (15 kW). Compared with the ambient temperature, it was deduced that solar radiant intensity had a more distinct influence on the performance of solar-powered air-conditioning system.

Keywords: Solar energy; Adsorption chiller; Optimization; Operation performance

1. Introduction

Global warming, ozone depletion and energy shortage have triggered widespread research on renewable energy technologies. Solar energy, which is abundant and clean, has received much attention in energy system design of buildings.

Recently, solar water collectors have undergone a rapid development; they were installed with the main purpose of preheating domestic hot water and/or to cover a fraction of the space heating demand. Another attractive application for solar energy is solar cooling because of near coincidence of peak cooling loads with the available solar power. Considering the problem of peak load of electricity consumption in summer due to electric chillers, solar-powered air-conditioning system could be an effective solution because it not only makes

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Nomenclature

A	area (m^2)
COP	coefficient of performance
c_p	specific heat of water (J/kg °C)
i	calculation node
I	solar radiant intensity (W/m^2)
N	number of nodes involved in the calculation
Q	heat quantity (W)
$\overline{Q}$	dimensionless heat quantity (heat consumption/refrigeration capacity)
S^2	variance of dimensionless heat quantity (heat consumption/refrigeration capacity)
T	temperature (°C)
V	volume of the heat storage water tank (m^3)

Greek symbols

η	solar collecting efficiency
ρ	density of water (kg/m^3)
τ	time (s)
Δi	phase shift (s)

Subscripts

a	ambient
chill	chilled water/refrigeration
co	cooling water
hp	heat pipe solar collector
hw	hot water
in	inlet
loss	heat loss from the heat storage water tank
m	mean value
o	outlet
solar	solar
ta	heat storage water tank
u	useful energy of solar collectors
U	U-type solar collector

the best use of solar energy, but also converts low-grade energy (solar energy) into high-grade energy. In addition, it is meaningful for the energy conservation and environment protection.

Solar cooling systems can be classified into two categories: (i) solar sorption cooling; and (ii) solar-mechanical systems. The former system is based upon solar thermal utilization and the latter one utilizes a solar-powered prime mover to drive a conventional air-conditioning system. The solar-powered prime mover can be either a Rankine engine or an electric motor based on solar photovoltaic principle. It is reported that the photovoltaic panels have a low conversion efficiency, which is about 10–15%, depending on the type of cells used [1]. Moreover, considering an identical refrigeration output, the solar-mechanical systems are four to five times more expensive than those powered by solar thermal utilization [2]. Therefore, the majority of solar-powered air-conditioning systems at present are solar absorption or adsorption systems based on solar thermal utilization. In most of the solar cooling systems, single-stage lithium bromide absorption chillers driven by hot water were commonly used. Evacuated tubes or other high-grade solar collectors were adopted to provide a hot water temperature of 88–90 °C as a heat source to drive the chiller. Experimental data on the performance of such systems were reported by Bong et al. [3] and Li et al. [4], among others. Although a large potential market exists for this technology, the existing solar cooling systems are not competitive with electricity-driven