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Solar integrated energy system for a green building

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Abstract

Shanghai is characteristic of subtropical monsoonal climate with the mean annual temperature of 17.6 °C, and receives annual total radiation above 4470 MJ/m^2 with approximately 2000 h of sunshine. A solar energy system capable of heating, cooling, natural ventilation and hot water supply has been built in Shanghai Research Institute of Building Science. The system mainly contains 150 m^2 solar collector arrays, two adsorption chillers, floor radiation heating pipes, finned tube heat exchangers and a hot water storage tank of 2.5 m^3 in volume. It is used for heating in winter, cooling in summer, natural ventilation in spring and autumn, hot water supply in all the year for 460 m^2 building area. The whole system is controlled by an industrial control computer and operates automatically. Under typical weather condition of Shanghai, it is found that the average heating capacity is up to 25.04 kW in winter, the average refrigerating output reaches 15.31 kW in summer and the solar-enhanced natural ventilation air flow rate doubles in transitional seasons. The experimental investigation validated the practical effective operation of the adsorption cooling-based air-conditioning system. After 1-year operation, it is confirmed that the solar system contributes 70% total energy of the involved space for the weather conditions of Shanghai.

Keywords: Solar energy; Heating; Air-conditioning; Natural ventilation; Green building

1. Introduction

The modern comfort living conditions are achieved at the cost of vast energy resources. Global warming and ozone depletion and the escalating costs of fossil fuels over the last few yeas, have forced governments and engineers to re-examine the whole approach to the design and control of building energy system [1]. Consequently, it is of great importance in the building field to reconsider the building structure and exploit renewable energy systems, which can minimize the energy expenditure and improve thermal comfort. Solar energy is abundant and clean; it is meaningful to substitute solar energy for conventional energy. Solar energy therefore has an important role to play in the building energy system.

The ways solar systems are used in newer buildings usually combine several solar-related technologies. They may be both solar heated/cooled, and solar PV powered, i.e. they are simply "solar buildings" [2]. Recently, solar water collectors have undergone a rapid development; they are installed with the main purpose of preheating domestic hot water and/or to cover a fraction of the space heating demand. However, this application mainly for obtaining hot water through solar energy is not very consistent with the order of nature. In winter, it is convenient to combine hot water system with space heating system just through increasing the collector area. Whereas, for summer with high solar radiant intensity and high ambient air temperature, the demand for air-conditioning and refrigeration is in preference to hot water, this phenomenon is obvious especially in the south of China for example. The prevalence of air-conditioners has brought great pressure upon energy, electricity and environment. Consequently, solar-powered air-conditioning system would be a perfect scheme because it not only makes the best use of solar energy, but also converts low-grade energy (solar energy) into high-grade energy for comfort. In addition, it is meaningful for the energy conservation and environment protection. Solar cooling has been shown to be technically feasible. It is particularly an attractive application for solar energy, because of the near coincidence of peak cooling loads with the available solar power. The future development trend is building integration with solar energy systems.

Solar cooling systems can be classified into three categories: namely, solar sorption cooling, solar-related systems and solar-mechanical systems, thereinto, the former two systems are

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Nomenclature

COP	coefficient of performance
I	solar radiant intensity (W/m^2)
T	temperature (°C)

Greek symbol

η	instantaneous efficiency of solar collector arrays

Subscripts

a	ambient
chill	chilled water
co	cooling water
hp	heat pipe evacuated tubular solar collector array
hw	hot water
in	inlet
o	outlet
U	U-type evacuated tubular solar collector array

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 field efficiency of about 10–15%, depending on the type of cells used, which result in low overall efficiencies for the system [3]. Besides, at otherwise identical refrigerating output, the solar-mechanical systems are 4–5 times more expensive than those powered by solar thermal utilization [4]. Therefore, the majority of solar-powered air-conditioning systems at present are solar sorption and solar-related systems based on solar thermal utilization. In most of the solar cooling systems, hot water driven single-stage lithium bromide absorption chillers 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 several researchers [5,6]. Although a large potential market exists for this technology, existing solar cooling systems are not competitive with electricity-driven or gas-fired air-conditioning systems. The major problems facing solar absorption cooling systems are its high initial cost, low system performance, and solar energy usage for only a short period during 1-day operation [7].

Another potential solar-powered air-conditioning system is solar adsorption cooling system. It is a better choice to use adsorption cooling technology for mini type solar-powered air-conditioning systems [7]. Up to now, the solar-powered adsorption systems have mostly been intermittent and used only for ice making application. For applications such as air-conditioning, when the chilled water temperature requirement is only around 6–8 °C, two or more adsorption beds can be used to produce a cooling effect continuously. Numerical simulations have been done to investigate the performance of a solar powered air-conditioning system driven by simple flat plate solar collectors [8]. As for working pairs, a silica gel/water adsorption refrigerator uses waste heat at below 100 °C, which would be suitable for a wider range of solar thermal collector types [9].

In this paper, an integrated system of heating, air-conditioning, natural ventilation and hot water supply based on solar energy, which was designed for the green building of Shanghai institute of architecture science, was introduced in detail. The design scheme, operation modes as well as experimental results were discussed.

2. Integrated solar energy system and the green building

2.1. Integration of solar collectors and green building

Shanghai is characteristic of subtropical monsoonal climate with the mean annual temperature of 17.6 °C, and receives annual total radiation above 4470 MJ/m^2 with approximately 2000 h of sunshine. The green building of Shanghai Research Institute of Building Science is situated in Xinzhuang, which is a burgeoning town of Shanghai. As a demonstration project, the green building contains multiple green energy technologies, such as solar thermal technology, solar photovoltaic, natural ventilation, natural lighting, indoor virescence, and the like. Here, we designed an integrated solar energy system for heating, air-conditioning, natural ventilation and hot water supply. As the power to drive adsorption chillers and the heat source for the floor heating and natural ventilation, the solar collectors are the most important parts. We installed 150 m^2 solar collectors on the roof of the green building, wherein U-type evacuated tubular solar collectors with CPC of area 90 m^2 were placed on the west side (SCW), and the other 60 m^2 heat pipe evacuated tubular solar collectors on the east side (SCE). For the purpose of efficient utilization of solar energy, the architects designed a steel structure roof, facing due south and tilted at an angle of 40° to the ground surface, on which the solar collectors were mounted and integrated with the building perfectly. Fig. 1 shows the appearance of the green building integrated with solar collectors. All solar collectors of both sides were divided into three parallel rows, as shown in Fig. 2. The collector units in each row were connected in a series arrangement for the purpose of obtaining hot water with relatively high temperature, which plays an important part in improving performance of the solar energy system. Such an arrangement of solar collectors not only guarantees high system performance but also improves the beauty of the building facade. Besides, it provides a feasible idea for integration of solar collectors and civil buildings especially for public buildings.

2.2. Design of solar-powered integrated energy system

An integrated energy system based on solar thermal technologies was designed and set up for building area of 460 m^2. As an office building, the hot water demand is not as significant as that in residential buildings. So, the solar-powered integrated system design of the green building is mainly focused on floor heating in winter and air-conditioning in