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Experimental study of a photovoltaic solar-assisted heat-pump/heat-pipe system

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ABSTRACT

A practical design for a heat pump with heat-pipe photovoltaic/thermal (PV/T) collectors is presented. The hybrid system is called the photovoltaic solar-assisted heat-pump/heat-pipe (PV-SAHP/HP) system. To focus on both actual demand and energy savings, the PV-SAHP/HP system was designed to be capable of operating in three different modes, namely, the heat-pipe, solar-assisted heat pump, and air-source heat-pump modes. Based on solar radiation, the system operates in an optimal mode. A series of experiments were conducted in Hong Kong to study the performance of the system when operating in the heat-pipe and the solar-assisted heat-pump modes. Moreover, energy and exergy analyses were used to investigate the total PV/T performance of the system.

1. Introduction

Heat pumps that consume conventional energy can possibly output two to six times thermal energy through absorption from renewable and "free" energy sources, such as air, water, and solar radiation. Therefore, these heat pumps are a significant energy-saving technology widely used in domestic hot water production and space heating.

A solar-assisted heat pump (SAHP), which is an integration of a heat pump and solar collectors, uses solar energy as an evaporating heat source and can achieve high coefficient of performance (COP). The concept of SAHP was first proposed by Sporn and Ambrose in 1955 [1]. Since then, a large number of theoretical and experimental investigations on SAHP systems have been reported. MacArthur et al. [2] presented a quasi-dynamic computer model that predicts the performance of an SAHP system when it is used for space heating and domestic hot water production, and discussed an economic analysis of the system. Chaturvedi [3,4] showed that the evaporating temperature of SAHP can range from 0 °C to 10 °C higher than the ambient temperature when R12 was used, and presented the factors that affect SAHP performance, including refrigerant type and compressor frequency. Ito [5] used the SAHP system for water heating, and presented results showing that the system can reach a COP of 5.3 at noon on a sunny day during winter. Kaygusuza and Ayhan [6] developed a solar heat-pump system with energy storage in an encapsulated phase-change material packing for residential heating, and experimentally and theoretically studied the performance of the system. Huang and Chyng [7] developed an integral type solar-assisted heat-pump water heater in which both solar and ambient air energies can be absorbed at the collector/evaporator. Cervantes et al. [8] performed an exergy analysis of a solar-assisted heat-pump system. Kuang et al. [9] integrated a number of flat solar collectors, a storage water tank, and a water source to the heat pump to form an indirect-expansion solar-assisted heat-pump system for space heating. Finally, Li et al. [10] experimentally studied the direct-expansion solar-assisted heat-pump water heater and suggested a number of methods to optimize system performance with the use of thermodynamics analysis. Furthermore, various other studies on the SAHP system have been reported in recent years [11–16].

The hybrid photovoltaic/thermal (PV/T) technology is another significant and practical technology that uses solar energy. The hybrid PV/T technology refers to the integration of a PV module and a solar thermal collector, which can simultaneously generate electrical and thermal energies. Compared with separately installed PV module and solar thermal collector, the PV/T collector can reduce the required space and initial costs because a common frame and bracket are used in the setup [17]. In addition, the collecting area of the effective rate of solar energy utilization per unit can also be increased. Wolf [18] first reported work on a PV/T system in 1976. Other studies have been subsequently conducted on PV/T collector/systems. Raghuraman [19] presented two separate one-dimensional mathematical models to predict the performance of water and air PV/T flat plate collectors, and compared the

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