

Dynamic characteristics modeling of a hybrid photovoltaic–thermal solar collector with active cooling in buildings



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ABSTRACT

Building integrated photovoltaic (BIPV), a new concept in solar power generation field, refers to integrating the photovoltaic array into the retaining structure surface of buildings to provide electric power. Photovoltaic (PV) is the key technology in the applications of BIPV, and how to improve the photovoltaic conversion efficiency has obtained more and more attention. In this paper, a brief review on the photovoltaic–thermal (PVT) solar collector and system using various working fluid was presented. Via dynamic simulation, the performance of a hybrid PVT collector using refrigerant as working fluid was evaluated and analyzed for the typical weather condition in Nanjing, China. The simulation results show the influence of the meteorological parameters and the evaporating temperature on the photovoltaic and thermal performance of the hybrid photovoltaic–thermal collector.

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1. Introduction

Nowadays, with the rapid development of the global economy, the energy crisis has become one of the most important issues. The building energy consumption approximately occupies 1/4 of the total energy consumption in China. With the increase of residential buildings amounts in China, the energy issue has been more and more serious. Meanwhile, the environment issue brought by the unreasonable energy consumption structure (coal mainly) and the high building energy consumption will certainly limit economic development in the near future. The heating energy consumption for residential buildings in the North of China occupies a large proportion of the total building energy consumption. The energy-saving and cost-reducing residential building will be the mainstream direction of house design. As a kind of new energy resources, solar energy has two prominent characteristics of inexhaustibility and environmental friendliness, the solar technology owns a broad application prospect and has obtained the increasingly significant development in recent years. The resource of solar energy in China is abundant, and the annual sunshine hours are more than 2000 h. The solar energy is particularly abundant in most heating region in the North of China, which makes the solar buildings possible.

Photovoltaic, a direct conversion of solar energy to electric energy by the photovoltaic principle of semiconductor, is one of the most promising utilization technologies of solar energy. The key component of the photovoltaic technology is the photovoltaic module, which is formed in the way that one or more solar cells are first connected in series and then packed. The photovoltaic technology was rarely restricted by region because the solar energy that reaches the earth is spread out over a large area. Moreover, photovoltaic is a noiseless, pollution-free safe and reliable technology. The photovoltaic technology has obtained significant development over recent years, typically in building integrated photovoltaic (BIPV).

However, the photovoltaic efficiency of common solar cells is between 4% and 17%, which is sensitively affected by working temperature. In practical applications, a large portion of solar energy will be stored by solar cells in the form of heat. This part of heat energy is extremely difficult to be removed from solar cells by natural convection and the resulting rising working temperature of solar cells leads to a declining photovoltaic efficiency consequently. On the other hand, solar thermal is also a common application of solar energy. Via heat collectors, the solar thermal energy can be used for heating working fluid. If water is used as the working fluid, the hot water can be produced for domestic use.

The hybrid photovoltaic/thermal (PVT) is a combination of solar photovoltaic and solar thermal technology. The basic principle of a hybrid PVT system is to collect and take away needless heat energy from the PV module by working fluid, and drop the working temperature of PV module. Finally, this kind of hybrid PVT system

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Nomenclature

A	surface area of PV module (m^2)
C	specific heat capacity ($\text{J/kg } ^\circ\text{C}$)
S	cross-sectional area of pipe (m^2)
h	convective heat transfer coefficient ($\text{W/m}^2\text{ } ^\circ\text{C}$)
I	solar radiation intensity (W/m^2)
k	heat transfer coefficient ($\text{W/m}^2\text{ } ^\circ\text{C}$)
P	power (W)
t	time
T	temperature ($^\circ\text{C}$)

Greek letters

α	absorption coefficient
β	packing factor
δ	thickness (m)
η	photovoltaic efficiency
τ	transmission coefficient

Subscripts

a	ambient
b	backplane
c	solar cell
e	EVA
g	glass
P	photovoltaic

simultaneously produces the electricity and the heat, which are necessary energy forms in residential buildings. Therefore, a reasonable and high-performance hybrid PVT system should be taken into account in modern solar residential buildings.

The brief structure of a typical hybrid PVT collector is shown in Fig. 1 [1]. The PVT collector commonly consists of a PV module and an attached pipe for working fluid flowing.

The hybrid PVT collectors can be generally classified into two types, the PVT air heating collectors and the PVT water heating collectors. Air and water are the most common kind of working fluid applied to the hybrid PVT collectors. The theoretical and experimental researches on these two types of PVT collectors have been conducted in recent years.

Huang et al. [2] made a study to analyze the performance of an integrated PVT solar water heater using a commercial polycrystalline PV module and compare with a conventional solar water heater. Using the concept of primary-energy saving efficiency, the overall performance of the PVT solar water heater was evaluated. The study results showed the performance of this system was improved and the application was economically feasible. Axaopoulos et al. [3] studied the energetic and economic performance of

commercially available PVT systems for electricity and domestic hot water production in three European countries. Ceylan et al. [4] experimentally analyzed different PVT systems to cool the photovoltaic modules by placing a simple pipe on PV module as a spiral heat exchanger in order to provide active cooling. Vera et al. [5] developed a mathematical model for making quantitative and qualitative predictions on the performance of water cooled PVT collectors integrated with a building domestic hot water (DHW) system. Kalogirou et al. [6] designed a hybrid PVT solar system for domestic hot water applications, and the electrical and thermal performance of this system was evaluated via TRNSYS simulation for three locations at different latitudes. The study results showed the PVT system produced a considerable amount of thermal and electrical energy and was economically feasible for the applications in blocks of flats or in small office buildings. To achieve the best energy performance, Chow et al. [7] presented a centralized PV hot water collector wall system and experimentally analyzed the thermal and electrical performance of this water pre-heating system for the climate of Hong Kong. The results showed this system led to substantial saving in energy consumption, and suggestions on further improving the system performance were given consequently. Erdil et al. [8] constructed a hybrid system integrated with a PV module and a solar thermal collector, and experimentally measured the energy performance of this system in Cyprus. The pay-back period was evaluated and the results showed this proposed low-cost hybrid system was economically feasible. Using the theoretical modeling and basic energy balance equations, Dubey et al. [9] evaluated the thermal, exergetic and electrical performance of a PVT flat plate water collector in detail for four weather conditions in five different cities of India. The results indicated the flat plate water collectors partially covered by PV module were preferred for water generation, and collectors fully covered by PV module were preferred for electricity generation. Cost analysis also indicated the PVT flat plate water collector was economically attractive. Santbergen et al. [10] constructed a solar domestic hot water system with one-coversheet-and-tube PVT collectors and evaluated the electrical and thermal performance of the system through numerical simulations. The results indicated the mechanisms determining the electrical and thermal output and the approaches improving the output. The application of anti-reflective coatings and low-emissivity coatings could improve the electrical and thermal performance of the PVT systems. Pei et al. [11] presented a detailed simulation model of a heat-pipe PVT system and analyzed the performance of the systems compared with traditional water-type PVT systems. The annual electrical and thermal performance of two heat-pipe PVT system with and without auxiliary heating equipment were evaluated and analyzed under four different kinds of hot-water heating load for three typical climate of China.

Both water and air have been used as working fluid in hybrid PVT systems, despite the poor thermo-physical properties, air is preferred due to its low operating cost than water. Pantice et al. [12] conducted a theoretical and experimental study of energy performance of three different open loop air heating BIPVT systems. Hegazy et al. [13] presented four popular designs of flat plate PVT solar air collectors with the air flowing over or under the absorber, and on both sides of the absorber in single pass or double-pass, and conducted a comparative study of the thermal, electrical and overall performances of these systems, which provided significant information about the design and operation of PVT solar air collectors. Tiwari et al. [14] conducted the theoretical calculation and experimental validation to analysis of the performance of the PV module with higher efficiency integrated with air duct for composite climate of India, and the theoretical results are in fair agreement with the experimental results. To overcome some inherent defects of the PVT solar air collectors, Tonui et al. [15] presented

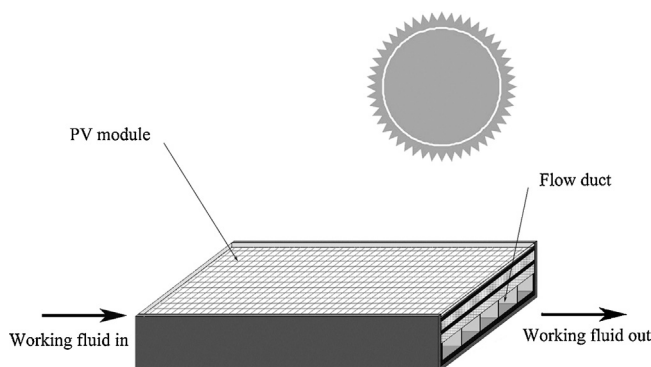


Fig. 1. The brief structure of a typical hybrid PVT collector.

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