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A novel solar multifunctional PV/T/D system for green building roofs

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ABSTRACT

A novel transparent roof which is made of solid CPC (Compound Parabolic Concentrator) PV/T/D (Photovoltaic/Thermal/Day lighting) system is presented. It combines the solar PV/T/D system with green building design. The PV/T/D system can achieve excellent light control at noon and adjust the thermal environment in the building, such that high efficiency utilization of solar energy could be achieved in modern architecture. This kind of roof can increase the visual comfort for building occupants; it can also avoid the building interior from overheating and dazzling at noon which is caused by direct sunlight through transparent roof. Optical simulation software is used to track the light path in different incidence angles. CFD (Computational Fluid Dynamics) simulation and steady state experiment have been taken to investigate the thermal characteristic of PV/T/D device. Finally, the PV/T/D experimental system was built; and the PV efficiency, light transmittance and air heating power of the system are tested under real sky conditions.

1. Introduction

Research on PV/T/D (Photovoltaic/Thermal/Day lighting) system is a promising topic in solar energy applications, and many studies have been done on conventional solar concentrators. Kern [1] proposed the basic idea of PV/T (Photovoltaic/Thermal) utilization of solar energy in 1978, the method was that arranging the flow path at the back of PV cell, the thermal energy can be taken away by the flowing fluid and the collected energy could be used for forward thermal application. This method can not only cool the PV cell and increase the photoelectric efficiency, but also can fulfill the comprehensive utilization of solar energy [2–4]. The solar energy comprehensive use ratio can reach 60–80% for PV/T system [5–7], Li [8], Tan [9] and Ibrahim [10] also tested the performance of PV/T system and taken some optimization design.

Combining the PV/T system with building is the developing tendency of green building in the future; it can increase the usage ratio of solar energy. When the CPV/T (Concentrate Photovoltaic/Thermal) technology was used in building, a higher concentrate ratio is expected in order to generate higher temperature for thermal energy. The high temperature heat source will expand its application field, such as solar heater, solar air-condition and solar dehumidification. It will increase the contribution of solar energy in the field of building energy conservation.

High efficiency solar concentrator has its shortcuts such as it requires high-cost accurate optical material, and the tracking system has many complicated moving parts, so it is difficult to combine it with building. In addition, the performance of normal PV cell cannot improve obviously [11]. On the contrast, the CPC (Compound Parabolic Concentrator) with lower concentration ratio is more feasible to combine with the building. Garg [12] and Brogren [13] reached the CPC-PV/T system with the concentrate ratio of 3 and 4, studies showed that the thermal and electric output of a PV/T system increases with increasing collector length, air mass flow rate and cell density, and decreases with enlarged in duct depth. Adsten et al. [14] evaluated the CPC collector for roof or wall application, Finally, a concentrating solar collector for wall mounting was evaluated with an estimated annual output of 194 MJ/m^2 at operating temperature of 75 °C. Li [15,16] and Pei [17] taken some research about the efficiency of CPC-PV/T with different concentrate ratio, the thermal efficiency of CPC-type solar water heater system can be above 49.0% (attaining 95 °C water temperature). Recently, Li [18] presents a novel static incorporated compound parabolic concentrator with photovoltaic/thermal system, the average value of optical efficiency within the half acceptance angle of 35° can achieve 83.0%.

Modern architecture structure design pays more attention on novel lighting and energy conservation, conventional CPC PV/T

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system will prevent the light into the building when it is used for the solar energy, this defect restricts the application field of the device. If the CPC PV/T system was made by transparent material, it will expand the application field and integrate with building easily. This transparent CPC PV/T system using in building can increase the visual comfort for building occupants. In the summer at noon, the sun light would transmit through the roof directly, transparent roof would cause overheating and dazzling in the building. In order to solve this problem, a novel transparent roof which is made of solid CPC PV/T/D system is presented. It integrates the solar energy PV/T/D system with building design. The PV/T/D system can control lights well at summer noon and adjust the thermal environment in the building; as a result, high efficiency utilization of solar energy is achieved in modern architecture.

2. Structure and working principle of PV/T/D system

The structure of a novel PV/T/D system is shown in Fig. 1. It is consist of upper cover, lower cover and side plate, all of them are made by PMMA (Polymethyl methacrylate). The upper cover is composed by solid CPC. The PV cell was pasted on the undersurface of solid CPC. The light transmittance varies in accordance to the changing light incidence angles. The thickness of lower cover of PV/T/D device is 3 mm, and there are 900 holes in this plate. The length and width of PV/T/D device are all 300 mm, other sizes are marked in Fig. 1, and unit is mm.

The working principle of a novel PV/T/D system is expressed briefly: sun light penetrates into the system from upper cover plate, light will be concentrated to the PV cell when the incidence angle is small; when the incidence angle is large, the light will escapes from the lateral wall of a solid CPC and provides daylighting to the building. The detailed optical principle of solid CPC was expressed by Yu [19]. The PV cell could generates electrical energy as well as sufficient thermal energy, those thermal energy could heat the air between the upper and bottom plate, so the temperature of air is raised up. When the suction pump is working, the air would flow through the PV/T/D device and take away the warmed air for forward thermal application. This method can obtain additional thermal energy and fulfill the combination of PV and thermal energy, which raises the comprehensive utilization ratio of solar energy.

In the current study, the geometrical concentration ratio of solid CPC is 4, the right and left parabola equation of CPC is expressed by formula (1) and (2).

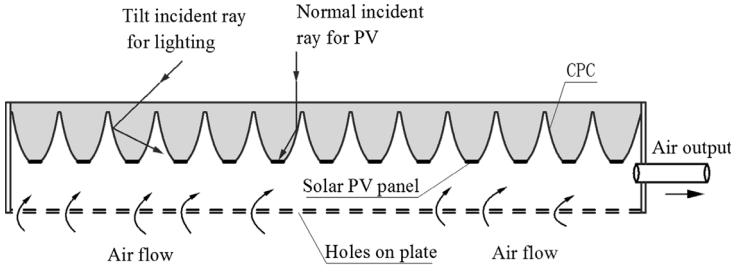
$$0.968y + 0.2504x + 75.1 = \frac{(0.2504y - 0.968x + 72.6)^2}{375} \quad (1)$$

$$0.968y - 0.2504x + 75.1 = \frac{(0.968x + 0.2504y + 72.6)^2}{375} \quad (2)$$

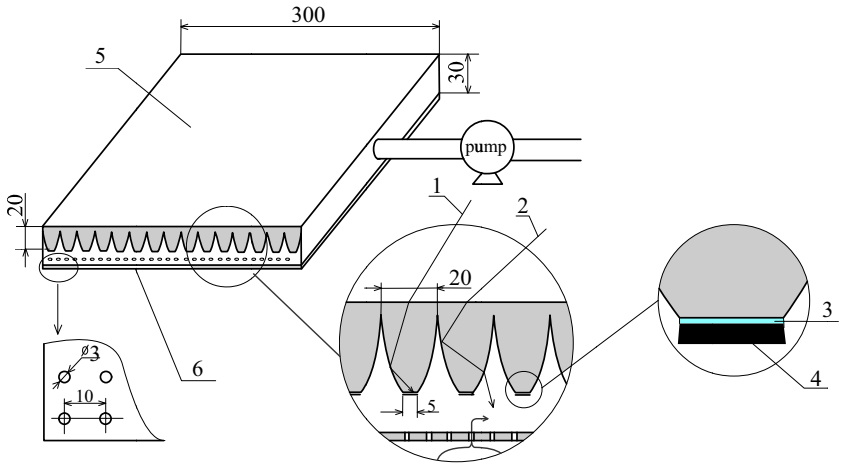
where x and y are coordinate in the Descartes, unit is m.

When the light irradiates the solid CPC in different incidence angles, it will be reflected and refracted by the different surface of solid CPC, the light path is shown in Fig. 2.

Fig. 2 illustrates two representative light paths within a solid CPC. One is effective electricity generating light, like the ray 1; it will be concentrated on the PV cell which is pasted on the base



(a) 2D sketch map



1. Effective generates electricity light; 2.Effective lighting light;
3. Anti-reflection coating; 4.PV cell; 5.Upper cover plate; 6.bottom cover plate

(b) 3D sketch map

Fig. 1. The working principle of the PV/T/D device.