Integrated application of combined cooling, heating and power poly-generation PV radiant panel system of zero energy buildings

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Abstract. A new type of combined cooling, heating and power of photovoltaic radiant panel (PV/R) module was proposed, and applied in the zero energy buildings in this paper. The energy system of this building is composed of PV/R module, low temperature difference terminal, energy storage, multi-source heat pump, energy balance control system. Radiant panel is attached on the backside of the PV module for cooling the PV, which is called PV/R module. During the daytime, the PV module was cooled down with the radiant panel, as the temperature coefficient influence, the power efficiency was increased by 8% to 14%, the radiant panel solar heat collecting efficiency was about 45%. Through the nocturnal radiant cooling, the PV/R cooling capacity could be 50 W/m². For the multifunction energy device, the system shows the versatility during the heating, cooling and power used of building utilization all year round.

1. Introduction

Hybrid photovoltaic/thermal (PV/T) collector is a device that converts solar energy into electricity and heat simultaneously. According to the different type of PV cell, it has a generation efficiency ranging from 5% to 20%. This implies that about 80% or even more of the incident solar radiation would be harvested in the form of heat. While a PV/T collector could collect this part of heat, and by a series of appliances, such as water-tap heating and space heating, this heat would be consumed.

Garg [1] (1994) tested the PV/T system as a thermo syphon water heater. It was found that the generating efficiency and the thermal efficiencies were 3.35% and 33.5% respectively. Huang et al. [2] (2001) suggested using the primary-energy conservation as an evaluation criterion of the performance of the PV/T system. Their PV/T system, composed of polycarbonate thermal collector and polycrystalline silicon photovoltaic cell, is used for domestic heating with a daily average heat efficiency of 38%, and the primary-energy saving was up to 60%. Zondag et al. [3] (2002) found that the presence of the cover-top increased the thermal efficiency while decreased the generating efficiency, and that a better generating efficiency was displayed in an uncovered state but with a heat pump. Agrawal [4] (2011) made an energy efficiency evaluation and analysis of a hybrid micro-channel PV/T module, and an observation showed that an increasing in the overall annual gain of thermal and energy as for the Srinagar climate situation by 70.62% and 60.19% respectively.

Guarracino[5](2016) present a dynamic model of a hybrid photovoltaic/thermal (PVT) collector with a sheet-and-tube thermal absorber, indicate that the use of a dynamic model and of real climate-
data at high resolution is of fundamental importance when evaluating the yearly performance of the system.

Eicker [6] (2011) developed a new type of PV/T system for power generation and cooling. He supposed that this system could be implemented into a residential building with zero energy consumption, and also gathered the test records under the climate condition of Madrid. It showed that the cooling power ranged from 60W/m² to 65W/m², the ratio of cooling energy to power (required for pumping water through the PV/T collector at night) was excellent with values between 17 and 30.

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As an integrated component, PV/R module can provide cooling, heating and power at the same time, as the multi-functional component, it could optimize the building energy system. Based on the PV/R module, the building energy system design, application performance was analyzed in this paper.

2. PV/R description

PV modules and PV/T collectors are normally only used during the daytime, for thermal and power generation. The efficiency of power and thermal are mostly influenced mutually due to the higher temperature of the output. While considering both the cooling load of the building in summer and heating load in winter, the radiation panel is proposed to combine with the PV module in this paper, which is called PV radiant panel (CCHP-PV/R), the structure of the PV/R, See figure 1.

![Figure 1. Schematic diagram of PV/R modules.](image)

3. Multi-functional Energy system of zero energy building

3.1. Description of the energy system

The multi-functional energy system is composed of five components, PV/R modules, energy storage device, multi-source heat pump, low temperature terminal and energy balance control system, see figure 2.

In daytime, the radiant panel of PV/R module cooling the PV to increase the PV generating efficiency and collect the thermal storage in the energy storage device. At night, the radiant panel of PV/R module through space radiation refrigeration to cooling the energy storage device. While in the other project the buried pipe can be used as the thermal energy storage to increase the energy efficiency and adaptability of the system.
3.2. System composition

3.2.1. Low temperature difference radiation terminal
Low temperature difference radiation terminals base on the theory of radiation heat transfer. Its characteristic is the low temperature difference between the heat transfer medium and the indoor air. It is set on inner face of the envelope. In the Sunflower there are two positions for the low temperature difference radiation, the inside envelop, which are 18m² of the ceiling and 22m² of the inner face of the wall, see figure 3.

3.2.2. Energy storage system
According to the heat/cool load of building, the capacities of the PV/R module, for the energy balance and stability of the system, the water tank energy storage system were designed. At night, the radiant panels on the roof would circulate for gather the radiant nocturnal cool and the cool would be stored into the energy storage device as the cooling source for cooling the PV in daytime, and also for the multi-functional heat pump to cooling.
According to the array arrangement of the PV cells, there set three inverters to connect to the grid. Besides, considering the possibility of island operation mode, there also equipped with storage battery for the access to the main alternating currents by a bi-direction inverter.

3.2.3. Multi-source heat pump
The PV/R module has the ability to collect thermal and cold, but the temperature cannot be high or low enough, and unstable due to the ambient conditions. During the refrigerating work state the water could not be used directly for the fan coil dehumidification, due to

Figure 2. Schematic diagram of PV/R modules.

Figure 3. Sunflower of the SDE 2010.
this situation, the multi-source heat pump is brought out, in order to optimize the system energy configuration, improve the quality of the heat/cool source and enhance the stability of the system, see figure 4.

![Diagram](image)

**Figure 4.** The poly-generation energy system of the Sunflower.

### 3.3. Operational principle
The PV generate efficiency of the PV/R is the most important, the thermal and cooling capability is accessory substance, which is not high or low enough, so the main principle of the heating and cooling system control is with high energy efficiency to collect the heat and cool. For the poly-generation energy system of the Sunflower, the heating and cooling the building is also the most important, so the energy storage bag, the multisource heat pump were set up, at night, the radiant panel with the water bag and the multisource generate the different temperature cooling water with the highest efficiency, and daytime, the high temperature water bag cooling water was used to cool down the PV, and the low temperature water bag was used to cool down the building.

### 4. Results and discussion

#### 4.1. Poly-generation module performance
As the upper side of the radiation panel, the PV module transforms the solar energy into electricity and heat. The circulation in the loop of the radiation panel absorption the heat of PV module in order to cool PV module and let it working in a relatively cool situation (35°C), which can rise up the generating efficiency by 8% to 14% approximately, if it was not cooling down, the PV temperature can be surpass 70°C, decrease the PV generate efficiency 10%, see figure 5.
Figure 5. Temperature of the normal PV module and the PV/R module.

The heat collected by the cooling circulation can be reach at 35°C to 45°C with the efficiency of 45%, which can be storage by the seasonal energy storage used as the heating source in winter. At night, the radiation panel by the radiant nocturnal cool can be used to cooling the building, the it cooling capacity is around 50 W/m², while in spring or winter, the nocturnal cooling is low enough that can be storage for the summer cooling.

4.2. System performance

Improve the PV module generate efficiency is the first, and the principle of the system operation, which means that the system should get the enough cooling source for cooling the PV at daytime, so the energy storage device is necessary, but the capacity is determined not just for the PV cooling, but also for the building cooling, however, the temperature of the nocturnal cooling was not low enough to cooling the building, so the multisource heat pump is necessary, while to increase the energy efficiency of the system, the independent temperature-humidity control air conditioning system was brought in. The system energy efficiency is very important, so the energy balance of the system is the key point. Through the energy balance of generate and consumption, the temperate of the heating and cooling PV/R and the terminal is very important. In the Sunflower house, the nocturnal cooling working temperature is 25°C in the summer, and the PV cooling start temperature is 40°C, and the multisource heat pump was start at the middle with the night off-peak electricity to generate the low temperature cooling water with the highest cooling capacity of the radiant panel of the PV/R module.

4.3. Energy balance

During the testing time, the generating power of the PV system is generally larger the energy consumption of the system. At night, the PV system is in the non-work state of electricity generation but in the work state of night radiation refrigeration. So there is a relatively stable consumption during the night period. During the contest week in Madrid, the energy consumption is 163.2kWh (20.4kWh/d) and the total generated power is 346kWh (43.3kWh/d), see figure 6. This test result is basically same to the simulation result of the electrical output of the PV/R system under the 45°C working temperature.
Figure 6. The power generated and consumed during the contest week.

5. Conclusions
This paper put forward the multi-functional PV/R module, and based on the PV/R modules, set up a multi-functional Energy system which generates cooling, heating and power. This energy system can raise the electricity generating efficiency of the PV module and reduce the generating cost, collect the heat/cool source. In this way, the PV/R module can be coupled with the different energy devices, such as water-source and ground source heat pump, coupled with the radiant panel terminals by an intelligent control system.

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