Research on Performance and Optimization of PV-Thermoelectric (PV-TE) Building Integrated System Based on Full Spectrum Utilization of Solar Energy

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Abstract. After China's reform and opening up, China's economy is booming, the real estate once was an important pillar industry of China's economy, but with the progress of China's economy and construction engineering industry, the problem of energy consumption is becoming increasingly serious. Solar energy is a new type of automatic and resource-saving renewable energy. The application of solar energy technology is of great significance to building energy saving, but the application conditions are still not mature. Therefore, in order to make efficient use of solar energy, the project focuses on combining photovoltaic power generation technology, photothermal conversion technology and thermoelectric generator to design an efficient and low-cost PV-thermoelectric (PV-TE) building integrated system that can cope with a variety of harsh environments.

Keywords: Photovoltaic technology, Thermoelectric technology, New energy sources, Building energy saving.

1. Introduction

Since China's reform and opening up, China's economy has made another vigorous growth, gross domestic product (GDP) is rising and rising, the housing once is an important pillar industry of our country's social and economic, but along with our country market economy and the progress and development of construction industry, the problem of the energy consumption is more and more serious, also brings to the environment certain challenges. At the same time, in recent years, China has further accelerated the pace of new-type urbanization construction, in the process of new-type urbanization, basic buildings will still have large market demand. According to a number of data, China's housing market demand for construction still has a huge space and potential. But the practical application of high energy, high material and low efficiency still hinders the development of our green building materials and energy saving. In the current of the new type of urbanization process is accelerating in China at the same time, China's demand for housing and construction are also constantly expanding, and building energy consumption problems gradually exposed, so the development of housing construction resource conservation and green building and has put forward this is closely related to the problem of the industrialization of the housing and construction, it is more and more important.
At the present stage, China's energy demand and utilization is quite large, and its energy utilization and comprehensive management efficiency is quite low. In recent years, the number of building energy consumption in China is more and more, all aspects of energy consumption in the construction industry accounts for about 33% of the total energy of the whole social life at the same time in the process of building process need to use the building more than 10% of the total energy consumption and raw material consumption, it also makes the construction of number is close to the current per capita energy consumption of the nation's energy consumption by 50%. China's building area is gradually increasing, and many buildings are considered to be high energy consumption, the huge consumption of resources and capacity has become a major burden on the entire national economy of our country. Therefore, it is of great significance to strengthen the basic research and practical application of science and technology of building environmental protection and energy saving for reducing energy consumption and promoting the healthy and harmonious development of the whole society in our country.

Heating energy consumption of the building mainly refers to according to indoor building in calculating the temperature of the heating period outside right under the condition of average temperature values, in order to be able to keep the indoor heating design meet the requirements of a certain temperature range, the consumption of unit building area in unit time to the indoor heating equipment supply heat, specific analysis, as a case in Beijing area to provide data to our project.

| Part name            | Heat transfer coefficient W/m^2K | Heat loss |
|----------------------|----------------------------------|-----------|
| Exterior wall        | 1.58                             | 25.5      |
| Outside the window   | 6.4                              | 23.6      |
| The roof             | 1.27                             | 8.5       |
| Staircase wall       | 1.82                             | 10.7      |
| A door               | 2.9                              | 2.7       |
| The ground           | 0.3                              | 2.2       |
| The balcony door     | 6.41                             | 2.9       |
| The air permeability | 23.1                             |           |

Table 1. The proportion of heat consumption of foundation building and heat transfer coefficient of each component

In China, the research on building energy saving started relatively late, and the technology is not mature enough. Many concepts about building energy saving are only limited to the early stage of
technology. Because of the limited technology, it is not possible to combine their concepts with the 
practice of modern society perfectly, which directly affects the progress and development of building 
energy saving in China. At present, there is still a gap between China's building energy saving and 
developed countries. At present, from the perspective of national level, the problem of building energy 
efficiency has been received sufficient attention, although many urban construction projects in the aspect 
of engineering, energy conservation has been basically can meet the national standard, but from the level 
of house decoration and supporting design point of view, will still have larger architectural energy saving 
space. From the situation of comprehensive utilization of solar energy resources we can clearly see that 
the current solar building mainly is widely used in the field of municipal public buildings and a few 
residents residents, some provinces and cities and remote areas have begun to introduce below 12 layer 
residential buildings and public buildings been forced to introduce the use of solar energy hot water 
system, but these are only confined to the coastal developed area, and some are solar energy resources 
are widely used in municipal public facilities, these all indicate that the our country in the field of 
ariculture in the application of solar energy, they also have very big development space and potential. 
And in the world people strongly support and praise energy-saving low carbon environmental protection 
technology background, the use of solar energy has made long-term progress. However, due to the 
immature solar energy technology, the utilization of solar energy has not been introduced and opened 
by the whole industry, and the conditions are still not mature to really apply it to buildings. 

However, with the development of technology, thermal-electric generators (TEGs), which have no 
moving parts, no chemical reactions, no environmental pollution, are friendly, quiet and reliable, and 
are emerging as a promising alternative method to generate electricity from solar energy, which has 
rekindled people's enthusiasm for the field of solar energy. This project focuses on the combination of 
photovoltaic power generation technology, photothermal conversion technology and thermoelectric 
generator, and designs an efficient and low-cost PV-thermoelectric (PV-TE) building integrated system 
that can cope with a variety of harsh environments.

2. Research content

2.1. Research Content

Using various software simulation and various experimental analysis, we designed a set of efficient and 
low-cost solar photovoltaic cogeneration device that can cope with a variety of changing environments, 
and solved the problem of low efficiency caused by energy loss in single photovoltaic power generation 
or photothermal conversion. By consulting information and consulting teachers, the team designed a 
new electricity generation system by studying photovoltaic power generation technology, photothermal 
conversion technology and combining them with thermoelectric generator model analysis, and applied 
it to buildings. Specific contents include:

2.1.1. Innovative overall system design

(1) Heat distribution structure design

This project focuses on taking the form of heat diversion to design an innovative structure that is 
easy to transfer heat to TEG (thermoelectric module), which is easy to concentrate heat at the hot end 
of the hot module. On the one hand, it reduces the heat of the photovoltaic panel and improves the 
service life of the photovoltaic panel. On the other hand, the temperature of the hot end of the TEG 
thermoelectric module is increased, and the heating efficiency of the TEG hot spot module is improved.

(2) Solar thermal power generation system design

The system will concentrate the heat energy through the transverse heat conduction absorption 
substrate inside the high thermal conductivity material, and then absorb and transfer this part of heat 
energy to the thermoelectric generator through the thermal conductivity components. In addition, the 
photothermal effect produced by the infrared light when it is irradiated can also be used as energy. The 
residual heat generated by the radiation in the solar energy can be recycled and utilized through a 
thermoelectric recovery equipment.
2.1.2. Selection of photothermal control bonding coating materials (new graphene). This device adopts a new type of graphene sheet photothermal, which is applied under the photovoltaic plate to facilitate the transfer of heat from the photovoltaic plate to the next layer, so as to realize the effective use of heat transfer and comprehensively improve the working efficiency of the equipment. It is a very important link in this device.

2.1.3. Power and heat transfer system applicable to high-rise buildings. Due to the limited space on the top floor of high-rise buildings, it is inconvenient to use traditional solar water heaters or install photovoltaic panels, so we will mainly use wall-mounted cogeneration devices to effectively save space and improve energy efficiency. In addition, due to the advantages of high efficiency and good stability of the cogeneration device, we can innovatively apply it to the building glass and external walls of the room, maximize the use of solar and thermal energy, and realize the integration of photovoltaic thermoelectric building.

Cogeneration plant design and building equipment of electric power and heat transfer system, the electricity and hot water (cold end-use cold water for cooling, again through the cold end temperature rise, water can be used) to architecture, the system can supply power for the corridor lighting systems, elevators, etc,. And can also provide residents with suitable for hot water, and solar thermal power construction integration reduces the outdoor temperature, reducing the wall body heat. All of these have greatly improved the quality of life of residents and played a role in building energy conservation.

3. Technical route, problems to be solved and expected results:

3.1. Research methods and technical route:
The main purpose of this project is to combine thermoelectric generator with photovoltaic panel to design an efficient system of cogeneration. Firstly, according to the characteristics of photovoltaic panels and the principle of TE thermoelectric generator, the overall structure of PV-TE photovoltaic cogeneration device is designed. Secondly, for the thermoelectric generator part, a high performance thermoelectric TE module matching with the high optimal working temperature of the photovoltaic cell is designed, so that the TE module can produce the highest efficiency within the optimal working temperature range. Then, according to the characteristics of photovoltaic panels, the photothermal absorption layer selectively absorbs infrared bands and conducts and concentrates the heat in the power generation process through the innovatively designed high thermal conductivity absorption substrate to reduce the temperature of photovoltaic panels and improve the heat utilization rate. Electric energy and hot water will be channelled into the interior of the building to complete the complete design of the system.
3.2. Implementation Method

3.2.1. Innovative design scheme of integrated heat and power generation system

(1) Overall structure design for heat diversion

The heat generated in the thermoelectric conversion process of photovoltaic cells and the energy conversion of solar infrared band are collected and transmitted to the thermoelectric power generation module by using thermal regulation and thermal management technology. The temperature of photovoltaic cells is reduced and the input heat flux of the thermoelectric power generation module (TE) is increased to improve the power generation efficiency. Adopting the innovative design of high heat concentration, the high thermal conductivity absorption substrate inside the transverse heat conduction is used as the hot end of the thermoelectric device. This method of heat concentration has been used in a variety of thermal systems. In addition, according to Kirchhoff's law of thermal radiation, high temperature causes large radiant heat loss, therefore, can be in the bottom of the absorber has added a aluminium insulation plate in order to reduce the heat loss of the radiation, heat concentration and in economic and effective way to improve its thermal performance, makes into TE hot side heat input to maximize, and transfer the ordinary solar infrared photoelectric device can't use the heat generated, the photovoltaic panels have cooling effect, can make its high-performance, greatly extend the service life of him, and to reduce summer heat pollution excess energy. The utilization direction of solar energy spectrum is shown in Figure 3.

Figure 2. Technology roadmap
Before building the real thing, we build smaller models, experiment, find the right components and power generation mode, and then scale up production. According to this, we put forward a unit device model as shown in Fig. 4. First, small device modules were used for tests to reasonably calculate the feasibility of the device.

(2) Design scheme of solar thermal power generation system

Through the transverse heat conduction absorption substrate inside the high thermal conductivity material, the heat energy is concentrated, and then the heat energy is absorbed and transmitted to the thermoelectric generator through the thermal conduction parts. The thermal effect generated by infrared light can be used as a natural heat source for thermoelectric power generation, and the heat generated in solar energy can be utilized through thermoelectric device (TEG). The power generation principle of TE module is shown in Figure 5:
3.2. Selection of photothermal control bonding coating materials. Our device requires a coating with high heat transfer properties. Since graphene has unique heat transfer properties and is used in many heat transfer devices and systems, it was used in our photothermal control connection coating. The
thermal conductivity of graphene-filled polymer composites can be improved by increasing the load of graphene, so we prepared a new type of composite material. The thermal performance of the composite was verified by infrared thermal imaging technology. The experimental results show that graphene-filled polymer composites are likely to be a good candidate material for high performance thermal interface materials. The application of the new graphene sheet under the photovoltaic plate is convenient for the heat transfer of photovoltaic panels, to realize the effective use of heat transfer, and to comprehensively improve the working efficiency of thermoelectric devices.

3.2.3. Model establishment of power and heat transfer system applicable to high-rise buildings. Since the implementation of "Green Building Evaluation Label" in China in 2008, China's green building has been relatively rapid development. As a green building energy-saving technology with the earliest promotion time and the highest technical maturity in the market, solar water heating system is favored by users. This technology can save electric energy, reduce the consumption of resources, save user expenses, and take into account environmental and economic benefits, but there are also some disadvantages in the application of solar water in buildings, such as the contradiction between the installation of collector and equipment and the overall planning and layout of the building. And for high-rise buildings, there is a large demand for hot water, installation space is insufficient and other problems, so the traditional single solar energy products have been difficult to efficiently use solar energy. The solar photovoltaic cogeneration device proposed in this project solves the disadvantages of a single device because it can use both light and heat energy at the same time. It is not only efficient and low-cost, but also better able to cope with severe weather conditions such as high temperature and maintain stable operation compared with traditional devices. Therefore, we innovatively adopted the wall-mounted type as shown in Figure 6 to solve the original problems of single products and small usable area in solar energy utilization and reduce installation and maintenance costs.

![Figure 6. Wall-Mounted cogeneration device Problems to be solved](image)

(1) Based on the study of the traditional thermoelectric generator and photovoltaic power generation model, a system with the form of heat diversion is established to solve the problem of high temperature damage to photovoltaic panels and improve the utilization efficiency of solar and thermal energy.

(2) According to the power generation performance of thermoelectric generator and photovoltaic panel, design a high-performance structure that can absorb and transfer the heat of photovoltaic panel to solve the problem of heat consumption; New graphene heat transfer materials are selected to improve the heat transfer efficiency and effectively improve the utilization rate of solar energy.
(3) By comparing with the traditional thermoelectric generator, a reasonable and constant heat input structure is designed after research to solve the problem of heat loss of the traditional single device and improve the power generation efficiency of the thermoelectric module of the co-generation device.

(4) Establish the basic model of the cogeneration device in building equipment, and the model reflects the efficiency of the device in the power and hot water supply of high-rise buildings.

![Figure 7. Research implementation plan](image)

4. Conclusion
Combined with the current development of solar photovoltaic industry, this paper puts forward a kind of efficient photovoltaic-themoelectricity suitable for the construction industry. The system, through the use of metal thermal conductivity, reduces the temperature of the photovoltaic panel, while improving the efficiency of the photovoltaic panel, at the same time, prolonged the service life of photovoltaic panels. At the same time, through reasonable thermal control, the combination of thermoelectric power generation technology and photovoltaic technology, to achieve the maximization of power generation efficiency has certain use value and market prospect.

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