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Study on the design method of integration of roof and photovoltaic based on aesthetics, technology and energy-saving characteristic

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ABSTRACT

The development and utilization of new energy has been concerned due to the traditional energy is increasingly scarce. In recent years, solar building has developed rapidly in the construction industry which is a major energy consuming component. As an organic part of the building, the combination of roof and solar energy has become the focus of attention because of its large size, less shielding and other characteristics. Based on the works of recent years' Solar Decathlon, this paper analysed the design and implementation of the integration of solar building's roof and photovoltaic. Meanwhile, taking an office building in Xinjiang, China as an example, the paper analysed the design points and energy-saving situation of the roof photovoltaic building and prospected the application prospect of integrated design method of building's solar roof.

KEYWORDS

Roof, Photovoltaic, Integrated design, Energy-saving

INTRODUCTION

As an organic part of the building, roof is usually used to obstruct the unfavorable weather of outside (Li Baofeng and Li Gang, 2010), protect the bearing and maintain the basic function such as indoor micro climate environment. With the development of building energy-saving concept and the photovoltaic technology, it brings more green connotations into the design of roof (Tao Chengqian, 2004). In the whole life cycle of photovoltaic, it is hard to reduce energy consumption of the upper-middle without big manufacturing technology break through which has reached the limit. But on the other hand, the design quality of photovoltaic power generation system which can be optimized greatly affects the length of the payback period, and it can be achieved to improve efficiency and reduce building energy consumption through the optimal design of the building and photovoltaic. There are still some problems in the design of the integration of roof and photovoltaic, especially many traditional buildings do not reserve enough operation space for developing photovoltaic which makes a high cost of installation of photovoltaic power generation system but the effect is not ideal, such as roof space is not enough, the bearing capacity is insufficient, PV systems cannot select reasonable angle and direction because of the shape of building, components of pollution, severe hot spot effect and so on. At the same time, when designing the photovoltaic array, due to the limit of design method, it is unable to simulate accurately the shadow effect on the components and the component can't be designed toward the matching of peak power generation and peak power consumption, which make the power generation efficiency and profit are reduced greatly.

Up to now, developed countries have accumulated rich experience in the area of integrated design of photovoltaic and photothermal. In 1996, Friedrich Sick showed how to combine photovoltaic and building maximization and summed up the design guideline at the earliest. (Friedrich Sick and Thomas Erge, 1996). Peter Gevorkian put forward a series of main points of solar building design from basic theory to project planning, cost estimation and implementation methods (Peter Gevorkian, 2007). Bernhard Weller discussed the relation between integration of solar building and architectural design, and introduced the detailed design of several typical cases in detail (Bernhard Weller, 2010). Peder Vejsig Pedersen described the application of photovoltaic technology in the renovation of the new buildings in Copenhagen and the old buildings with low energy consumption (Peder Vejsig Pedersen et al, 2015). Hai Tao introduced the combination method of integration of roof and photovoltaic, and analysed design and energy saving effect of solar energy building (Hai Tao and He Jiang, 2015).

In summary, the scholars in various countries have a lot of theoretical research achievements in the field of integrated design of photovoltaic system and building. However, there are few researches on the application of photovoltaic technology in roof. Particularly, there are less researches discuss that how to combine photovoltaic systems better with roof from the perspective of architectural design.

Based on the current situation, it is important to summary and refine the current technical strategy and problems of integration of roof and photovoltaic, which aims to form the design idea of aesthetic, technology and energy-saving, through analysing the existing integrated design methods of different forms of roof, the paper put forward an integrated design method of roof and photovoltaic based on energy saving and increasing power generation efficiency.

METHODS

Through investigation and survey, the paper summarized the integrated design of roof and photovoltaic, classified design methods and analysed their characteristic based on the Solar Decathlon competition in recent years. In this paper, the integrated design method of photovoltaic and roof is divided into traditional design method and special design method, and the paper illustrated each design method by analysing concrete cases.

Through the summary and analysis of the current research results, the paper analysed the design points and energy-saving situation of the roof photovoltaic building and put forward a design method by using SKETCHUP and PVSYSTEM. Based on the characteristics of office buildings, such as large energy consumption, huge electricity supplement, most building load on day time, and higher photovoltaic matching rate, and also, South Xinjiang is endowed with abundant solar energy resources by nature, so we select Turpan, a city in cold area of Xinjiang Province in China, as the research area of office building, which is aimed for a qualitative comparison through the quantitative analysis concluding of the determination of the office building's materials selection and PV component's parameters, and simulating the photovoltaic power generation of the office building.

RESULTS

The implementation of integrated design methods

With the continuous development of roof design ideas, it no longer stay in the passive energy-saving design, but more positive active capacity design appears. In Solar Decathlon competition in recent years, the function of the system which on top of the roof is not overlooked with the limitations of human perspective. Meanwhile, in the architectural design, different roof forms can be used, the integration of solar energy system on the roof is divided into the integrated design of the flat roof, slope roof and curved roof.

Integrated design of flat roof

The solar radiation to the surface of the earth will be at a certain angle to the ground with the change of the longitude, latitude and time. Therefore, the integration of solar energy system and flat roof should generally make the solar angle equipment to adapt to the sun's angle of change, and the system should be set with a certain angle on the flat roof (Zheng Cunyao, 2007). Such as TUC separated the monocrystalline silicon battery array from the roof with the inclination is 2°by using the stent on the flat roof, which ensuring the safety of the system as well as ensuring power generation efficiency by reducing the backside temperature of the battery (As shown in Figure.1). Many new forms of design arised based on the method of installing solar energy system on the flat roof directly which uses no inclination, such as the University of Florida team put the photovoltaic system directly on the top of the building structure system, which can save costs and cover the living room and the bedroom which have different elevations, so as to make the building to form a whole and to acquire a good physical environment and a unified architectural style (As shown in Figure.2).

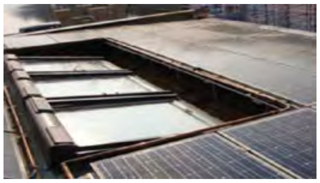

Figure1. Overhead PV panel of TUC

Figure.2. Photovoltaic roof of Florida

With the improvement of the solar energy system integration technology, the design of electro-optical system coupling has developed rapidly. For example, HFT has adopted the electro-optical heat collectors (PVT) on the flat roof. It covered PVT collectors as a building exterior finish on the flat roof surface, which replaced the building materials and reflected the high integration design. At the same time, the radiation boards are set under the dark black monocrystalline silicon cell array, it can not only generated electricity, but also recycled the heat generated by photovoltaic power generation to provide hot water. And the vacuum tube collectors installed on the glass ceiling of the "air gap" between the modules also provide heat, diffuse light and shading for the interior, as well as obtain special beauty as the application of the new material in the building (As shown in Figure.3).

Figure3. PVT collector and vacuum collector of HFT

Integrated design of slope roof

For the slope roof, with the development of integration, the system of solar energy utilization can be directly used as building material for the roof, instead of the additional installation design (Guo Juanli et al. 2012). For example, BER laid the monocrystalline silicon battery assembly directly on the roof of the building, supported by the southward corrugated aluminum and aluminum frames, which is integral with the exterior finish of the building and completed simultaneously with the construction of building, so that reducing the cost and difficulty of repeated construction. At the same time, the building material type's system of solar energy utilization also has the abilities of rain-proof, corrosion resistance, building decorative appearance and strength requirements (As shown in Figure.4).

Integrated design of curved roof

Considering the characteristics of photoelectric system, it is not suitable for integration on curved roof, but with the continuous development of technology and the improvement of efficiency, some new attempts have been started. For example, in 2013, the works "halo" integrated solar photovoltaic systems on the roof of the building (As shown in Figure.5), it uses a whole new solar technology that make the solar battery as the roof itself rather than fixed on the roof, so as to avoid the limitation of application of the traditional solar battery module brings. The works can get maximum annual energy efficiency gains without summer housing overheating through the angle of roof for precision design. The roof consists of an area of 82m^2 polycarbonate film, and converting 18% of solar radiation to building usable energy through the integrated single crystal silicon solar cells. Meanwhile, there is a transition area under the eaves of the north and south, which provides a comfortable space for outdoor living.

Figure.4. Slope roof of BER

Figure.5. Curved roof of Halo

Special design

Obscure component boundary

In 2015, SURE HOUSE adopted a photovoltaic roof and a movable shading panel integrated with photovoltaic, not only provided the power, but also provided the building shading and natural lighting control. PV panels are not just a power generating device, but are designed to be a part of the roof. In daily weather conditions, the double folding anti-storm baffle is used to provide the function of shading for building, while in stormy weather, it serves as a major barrier to protect the building. Storm baffle is made of a lightweight composite glass fiber and a structural foam core, which can withstand the load required by the design, and can adjust the indoor light environment through manual operation. The panels are equipped with PV panels which can absorb solar energy and provide energy for the building.

Design of double-skin roof

Armadillo Box is designed by GRE. The interior roof of the building is built on an internal load-bearing frame, composite oriented strand board, and filled with thermal insulation material. The exterior roof is made of steel frames, supporting monocrystalline silicon solar cells, photovoltaic modules and low radiation sun curtains, so that a good ventilation corridor is formed between the inside and outside building roofs. (As shown in Figure.6)The low temperature radiation protection layer and the evaporation cooling system for spraying water by using water and rain water on the outside of the inner roof can be used to solve the ventilation problem between the double roofs. The interior of the building is also protected from adverse weather conditions due to the protective effects of the exterior roof. The photovoltaic square itself is controlled by the separation of the double roofs to achieve its own back temperature, while the power generation efficiency is guaranteed. (As shown in Figure.7).

Figure.6. SURE HOUSE

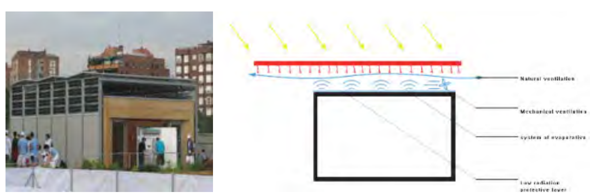

Figure.7. Analysis of double-skin roof of GRE

Analysis of design method of roof and photovoltaic for an office building in Xinjiang

Determination of orientation and dip angle parameters of photovoltaic module

Due to the hot summer in Turpan, the design is mainly aimed on diminishing the heat gain of enclosure, so the glass wall and lighting roof structure should not be considered. The paper built a building model with 1:1 scale that has flat roof and slope roof which laying solar panels (As shown in Figure.8). Due to the angle and slope roof system has fixed, we mainly focus on the best angle and orientation of the flat roof. With the optimizing of PVSYST software, we can conclude that the 39 degrees is the best angle (As shown in Figure.9).

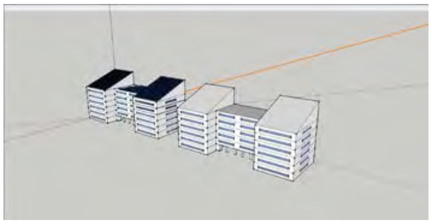

Figure.8. Model for analysis

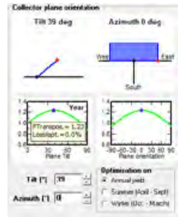

Figure.9. Inclination angle

At the same time, using the solar plugin SKELION to simulate the arrangement and shadow analyze, then choosing 9 to 15 o'clock to simulate without shading, providing the spacing of 3 meters (As shown in Figure.10). There are two kinds of measures to reduce shadow and hot spots loss. The first one is the shadow elimination, which is able to realize the unblocking during the specific time, but it will reduce the use of roof, another is to choose horizontal or vertical arrangement according to the shape of the shadow.

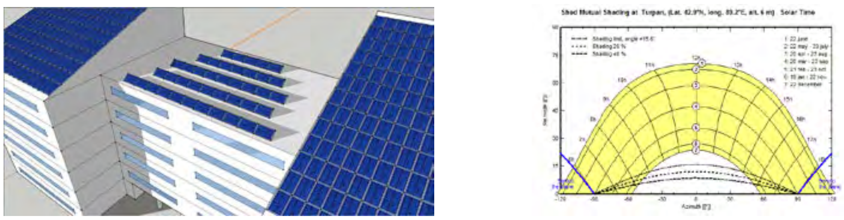

Figure.10. Model component layout in SKETCHUP and the sun time path diagram in Turpan

Calculation of photovoltaic power generation

Using PVSYST software for simulation and calculation, and arranging the number of PV modules by using SKETCHUP. The type of PV modules we choose is monocrystalline silicon component with the size of 1680*990*50, and its power is 240W. There are 468 pieces on the slope roof whose rated power is 120kw and there has an installing area of 750 ㎡. And there are 41 pieces on the flat roof whose rated power is 11.3kw and there has an installing area of 375 ㎡. The total rated power is 131.3kw, and we calculating respectively the power generation of flat roof and slope roof (As shown in Fig.11).

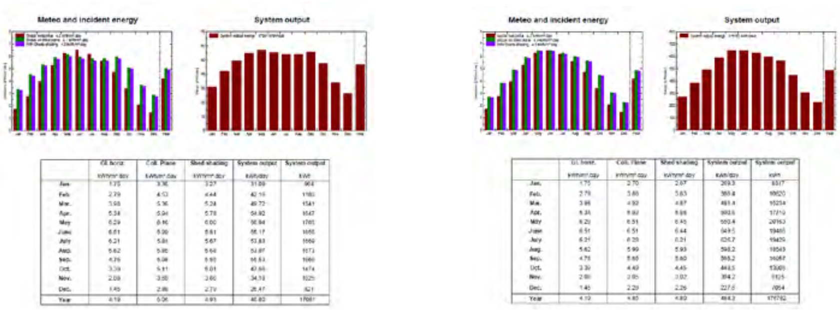

Figure.11. Calculation results of power generation from flat roof and curved roof

The calculation results show that the PV annual power generation of flat roof of the office building is 17081 kWh, and the figure for slope roof is 176782 kWh. Due to the characteristics of office building that most of its power consumption is concentrated during the daytime which matches the high efficiency period of PV power generation. Therefore, the integration of solar building's roof and photovoltaic with optimized design will effectively reduce office building and other buildings' energy consumption (Yang Shanqin. 1997).

DISCUSSIONS

Through the above analysis, we can conclude that the integration of roof and photovoltaic has many forms based on the roof's type and the design concept, but these designs rarely synthetically consider aesthetics, technology and energy saving, which caused many problems such as roof space, hot spot, unreasonable PV panels' angle and direction. The paper put forward a new design method which synthetically used SKETCHUP and PVSYSTEM that can solutes problems which are common in the design of integration of roof and photovoltaic aims to aesthetics, technology and energy saving.

CONCLUSIONS

The integration of roof and photovoltaic not only makes architecture an energy consumer, but also an energy provider. A scientific and appropriate design of integration design will make a great contribution to energy-saving. Meanwhile, besides paying attention to form and style, meeting the elemental functions such as protection and isolation, the design should also be an integrated design based on the building which focusing on the use of environmental advantages, unifying with the whole structure of the building and paying more attention to the roof system's energy-saving design. With the development of the utilization of solar energy and integration of architecture, new design methods of roof integration are derived from many cases that the roof design is not only a traditional addition or a design with covert attitude anymore. This integrated design still should be an exploring direction which should not only ensure efficiency, meet demand and overall consideration of cost, but also truly integrate design with the building to achieve the perfect combination of technology and art.

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