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Building-integrated photovoltaics (BIPV) in architectural design in China

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ABSTRACT

Building-Integrated Photovoltaics (BIPV) are one of the best ways to harness solar power, which is the most abundant, inexhaustible and clean of all the available energy resources. This paper discusses issues concerning BIPV in architectural design in China, including how to choose between BIPV and building-attached photovoltaics (BAPV), whether it is necessary for photovoltaic components to last as long as buildings and how to design BIPV structures. The paper shows that we should consider the function, cost, technology and aesthetics of BIPV, rather than solely the high integrations. According to developments in technology and markets, photovoltaic structures and design should be focused on the maintenance and replacement of photovoltaic cell modules, rather than simply prolonging their lives. To solve problems associated with the existing photovoltaic structures in China, we design a building photovoltaic structure that allows convenient maintenance and replacement of photovoltaic components.

1. Introduction

Global environmental concerns and escalating demands for energy, coupled with steady progress in renewable energy technologies, are creating new opportunities to utilize renewable energy resources. To date, solar energy is the most abundant, inexhaustible and clean of all the renewable energy resources. The sun's power reaching the earth is approximately 1.8×10^{11} MW, which is many times greater than the present energy consumption. Photovoltaic technology is one of the best ways to harness this solar power [1,2]. Photovoltaics generate electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect [3]. Photovoltaic power generation employs solar panels composed of a number of cells containing photovoltaic material. Materials presently used for photovoltaics include monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium selenide/sulfide [4]. Due to the growing demand for renewable energy sources, the manufacturing of solar cells and photovoltaic arrays has advanced considerably in recent years [5–8].

BIPV are photovoltaic materials that are used to replace conventional building materials in parts of the building envelopes, such as the roofs, skylights or facades. They are increasingly incorporated into the construction of new buildings as a principal or ancillary source of electrical power, although existing buildings may be retrofitted with BIPV modules as well [9]. The advantage of integrated photovoltaics over more common non-integrated systems is that the initial cost can be offset by reducing normal construction costs of building materials and labor for parts of the building replaced by BIPV modules. These advantages make BIPV one of the fastest growing segments of the photovoltaic industry [10].

For BIPV systems to achieve multifunctional roles, various factors must be taken into account, such as the photovoltaic module temperature, shading, installation angle and orientation. Among these factors, the irradiance and photovoltaic module temperature should be regarded as the most important factors because they affect both the electrical efficiency of the BIPV system and the energy performance of buildings where BIPV systems are installed. The results of basic studies on irradiance and energy output of photovoltaic systems have been reported by some researchers [11–13], while there have been other studies on the temperature and generation performance of photovoltaic modules [14–16].

Based on this background, this paper aims to discuss some issues associated with the following: how to choose between BIPV and BAPV, whether it is necessary for photovoltaic components to last as long as buildings and how to design BIPV structures. To resolve problems associated with the existing photovoltaic structures in China, the paper describes a building photovoltaic construction that

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Fig. 1. An example of BIPV in which photovoltaic arrays are combined with the roof.

allows convenient maintenance and replacement of photovoltaic components.

2. BIPV or BAPV?

2.1. What are BIPV and BAPV?

Two principal classifications can be defined for building photovoltaic array mounting systems: BIPV and BAPV [17]. BIPV are considered a functional part of the building structure, or they are architecturally integrated into the building's design. This category includes designs that replace the conventional roofing materials, such as shingles, tiles, slate and metal roofing. These types of products can be indistinguishable from their non-photovoltaic counterparts. Aesthetically, this can be attractive if there is a desire to maintain architectural continuity and not to attract attention to the array. BIPV modules can also be architectural elements that enhance the building's appearance and create very desirable visual effects. These types of arrays include custom-made module sizes and shapes with opaque or transparent spaces between the cells and can be used for curtain walls, awnings, windows and skylights [17,18]. Thus, BIPV are multifunctional solar products that generate electricity while also serving as construction materials. Fig. 1 shows an example of BIPV, in which photovoltaic arrays are combined with the roof.

BAPV are considered an add-on to the building, not directly related to the structure's functional aspects [17]. They rely on a superstructure that supports conventional framed modules. Standoff and rack-mounted arrays are the two subcategories for BAPV systems. Standoff arrays are mounted above the roof surface and parallel to the slope of a pitched roof. Rack-mounted arrays are typically installed on flat roofs and are fashioned so that the modules are at an optimum orientation and tilt for the application. The superstructure is typically attached to the roof through a series of brackets or "feet" that are mechanically fastened to a structure segment of the roof system. BAPV arrays can also "float" over the original roof without any mechanical connection to the roof. In these cases, the array must be ballasted or designed to remain in place when subjected to wind or other loads that would cause the array to slide, move or overturn [17]. The aim of BAPV is simply to generate electricity. Fig. 2 shows an example of BAPV, in which photovoltaic arrays are attached to the rooftop.

However, sometimes these two classifications cannot be clearly defined in practice. From the above definition, the main difference between BIPV and BAPV is the extent of tightness in the integration of photovoltaic systems and buildings. For example, BAPV becomes BIPV when the photovoltaic arrays are integrated tightly with buildings. The rapid development of photovoltaic technology makes the integration of photovoltaic arrays and buildings easy and diversified. Fig. 3 shows the effect of amorphous silicon thin-film photovoltaic modules. The characteristics of thin-film photovoltaic systems make them closely integrated with buildings so that the level of integration has reached the requirements of BIPV. Therefore, transparent curtain–wall constructions with thin-film solar modules are typical of BIPV. Yet, this classification is consistent with the definition of BAPV.

Fig. 2. An example of BAPV in which photovoltaic arrays are attached to the rooftop.

2.2. How to choose between BIPV and BAPV

Based on the previous descriptions, we know that the purpose of both BIPV and BAPV is to generate electricity with solar energy. The differences between them are that BIPV's level of integration is so high that photovoltaic arrays can act as building envelopes, such as curtain walls, awnings, windows and skylights. The advantages of this form are that it is architecturally clean and attractive and offsets the cost of roofing, façade or glazing materials. However, the total cost of BIPV is much higher than BAPV in China because of BIPV's complicated structures and difficult mounting and maintenance technologies. Conventional building materials and envelope constructions have solved many problems easily, such as those associated with building loads, water drainage and thermal properties. Further, their costs are far lower than those of photovoltaic arrays. In particular, damaged BIPV components directly affect the use of buildings' internal functions. For example, when the waterproof structures of a photovoltaic component are destroyed, the room mounted with this photovoltaic array cannot serve its occupants any more.

While BAPV simply cause photovoltaic components to overlap with the envelopes, their structures are simple to mount and maintain and, even without photovoltaic modules, these types of buildings can function normally. Moreover, BAPV can create a space between photovoltaic arrays and the buildings' skins. This gap is very important for the performance of photovoltaic

Fig. 3. Effect of amorphous silicon thin-film photovoltaic modules.