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Analysis of thermal and electrical performance of semi-transparent photovoltaic (PV) module

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ABSTRACT

Building-integrated PhotoVoltaic (BIPV) is one of the most fascinating PV application technologies these days. To apply PV modules in buildings, various factors should be considered, such as the installation angle and orientation of PV module, shading, and temperature. The temperature of PV modules that are attached to building surfaces especially is one of the most important factors, as it affects both the electrical efficiency of a PV module and the energy load in a building. This study investigates the electrical and thermal performance of a semi-transparent PV module that was designed as a glazing component. The study evaluates the effects of the PV module's thermal characteristics on its electrical generation performance. The experiment was performed under both Standard Test Condition (STC) and outdoor conditions. The results showed that the power decreased about 0.48% (in STC with the exception of the temperature condition) and 0.52%(in outdoor conditions, under 500 W/m^2) per the 1 °C increase of the PV module temperature. It was also found that the property of the glass used for the module affected the PV module temperature followed by its electrical performance.

1. Introduction

Ever since the PhotoVoltaic (PV) industry started boom, the PV system has been advancing both in technological aspects and in economical aspects. Because of this trend, the installation capacity of various application types has been expanding worldwide. BIPV especially is becoming a popular option among the various PV application technologies. Recently, various PV modules are starting to be used in buildings. In particular, semi-transparent PV modules play multifunctional roles as electricity producers, building envelope components, and glazing components.

In order for the BIPV systems to achieve multifunctional roles, various factors need to be taken into account, such as the PV's module temperature, shading, installation angle, and orientation. Among these factors, the irradiance and PV module temperature should be regarded as one of the most important factors, since it affects both the electrical efficiency of the BIPV system and the energy performance of buildings where BIPV systems are installed. The results of basic studies regarding irradiance and energy output of PV system have been reported by some researchers [1–3], while there have been other studies regarding the temperature and generation performance of PV modules [4–6]. Some studies focused on the semi-transparent PV module that maintains space between the PV cells in order to transmit light. In particular, recent studies performed by Wong [7], Fung [8] and Boer [9] dealt with BIPV modules and their performance modelling using the measured data of the PV module. They also analyzed the total building energy consumption, which included heating, cooling, and artificial lighting loads. Li [10] also carried out the economical analysis on the application of PV modules in buildings.

As the application potential of PV modules as building façade components has been increasing, there have been other studies about PV building façades. Vartiainen [11], Infield [12], Khedari [13] and Alzoubi [14] have studied ventilated PV façades, or PV sunscreens, as blinds. Most of the studies about BIPV modules considered the PV module as building envelope material that has typical module configuration. It is necessary to develop more diverse BIPV modules, like semi-transparent ones, with various configurations and designs. These developments will provide more options for architects and building industries on how to apply PVs in buildings.

Based on this background, this paper aims to analyze the electrical characteristics of semi-transparent PV modules in relation to their temperature variations. The study analyzed the effects of solar radiation, ambient temperature, and glass used for the PV laminate

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Nomenclature

I sc	Short Circuit Current(A)
Imp	Current at Maximum Power(A)
Voc	Open Circuit Voltage(V)
Vmp	Voltage at Maximum Power(V)
Pmax	Maximum Power(W)
FF	Fill Factor(%)

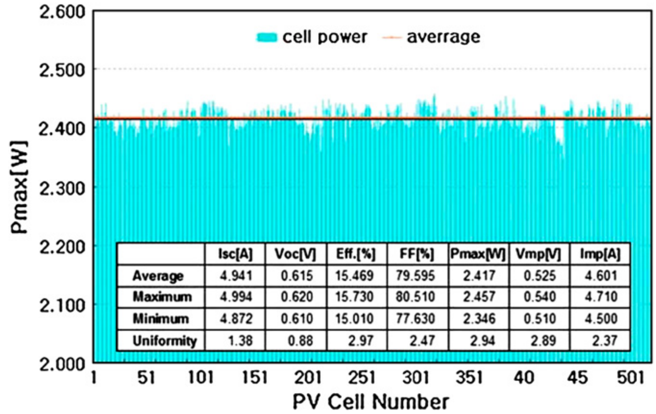
on the temperature of the semi-transparent PV modules and their electrical performance. The experiment was conducted under the standard test conditions and in outdoor settings. Monitoring began in May 2007 and continued November 2008.

2. Semi-transparent PV module

Modern buildings are constructed in various ways and finished with various materials, PV modules can be used as one of the special finishing materials for old buildings, as well as new ones. It is not difficult to find buildings where the whole envelope is covered with glass. A semi-transparent PV module, which is the subject of this paper, is suitable for those buildings. For this research, opaque crystalline PV cells were used for the semi-transparent PV module that had a transparent area to allow for light penetration. This section will describe the module in detail.

2.1. Structure of semi-transparent PV module

The semi-transparent PV module used in this study had a PV laminate with polycrystalline Silicon (p-Si) PV cells that were spaced so that some portion of light passed through the glass area. The PV module consisted of several layers: glass, encapsulation material (Ethylene Vinyl Acetate (EAV) Sheet), PV cells, encapsulation material (EVA Sheet), glass, air gap with spacer and glass. Fig. 1 shows the layers of the PV module. In order to apply a semi-transparent PV module as glazing material for buildings, it should have a certain level of thermal resistance. For this reason, one more glass was used to form the air gap for the PV laminate.



	Isc[A]	Voc[V]	Eff.[%]	FF[%]	Pmax[W]	Vmp[V]	Imp[A]
Average	4.941	0.615	15.469	79.595	2.417	0.525	4.601
Maximum	4.994	0.620	15.730	80.510	2.457	0.540	4.710
Minimum	4.872	0.610	15.010	77.630	2.346	0.510	4.500
Uniformity	1.38	0.88	2.97	2.47	2.94	2.89	2.37

Fig. 2. Results of the PV cell tests.

2.2. PV cell

Before manufacturing the PV module for the experiment, PV cell tests were performed. Fig. 2 shows the test results. The 5 × 5 inch polycrystalline Silicon (p-Si) PV cells had the electrical generation performance from the maximum power of 2.5 W to the minimum power of 2.3 W. The 500 cells also had the average output power of 2.4 W and a uniformity of 2.9%. They were sorted into categories based on the test results and were used for manufacturing the semi-transparent PV laminates.

2.3. Glass

Three glass sheets were used for this PV module as Fig. 1 shows. A low-iron tempered glass was used for the front cover and various glasses were used for the supporting back cover. The types of glass used included clear, coloured, and reflected. The last glass was also low iron tempered which was similar to the first glass.

2.4. Arrangement and connection of PV cells

The prototype PV module used in this study consisted of 32 p-Si cells that were connected serially. This PV module includes bypass diodes that protected the PV module from the hot spot caused by

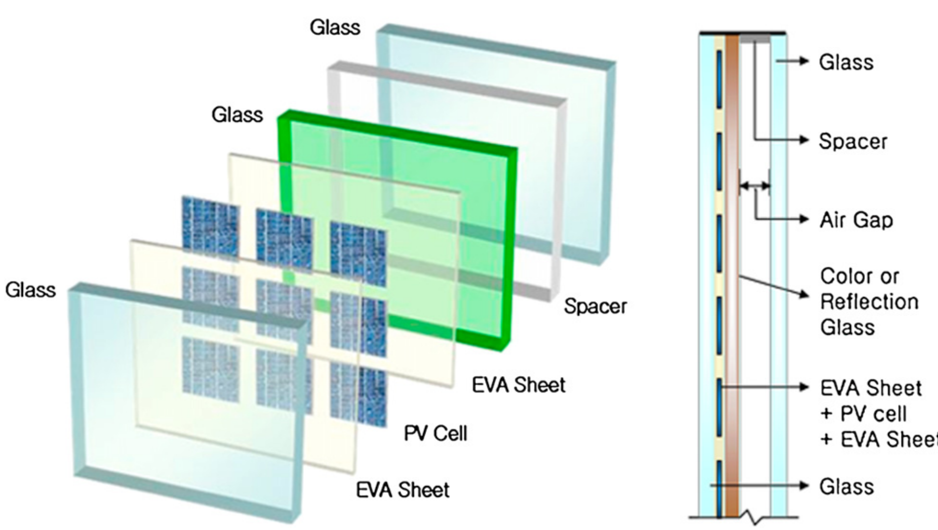


Fig. 1. Layer structure of the PV module.