

Analysis of Thermal and Electrical Performance of Semi-transparent PV Module

Kyung-Eun Park¹, Gi-Hwan Kang², Hyun-Il Kim³, Gwon-Jong Yu⁴, Jun-Tae Kim⁵

¹Dept. of Architecture, Kongju National University (KNU), Kongju, Chungnam, South Korea, kepark@kongju.ac.kr

²Photovoltaic Research Centre / Korea Institute of Energy Research (KIER), Daejeon, South Korea, ghkang@kier.re.kr

³Photovoltaic Research Centre / KIER, Daejeon, South Korea, hikim@kier.re.kr

⁴Photovoltaic Research Centre / KIER, Daejeon, South Korea, y-gj@kier.re.kr

⁵Dept. of Architecture, KNU, Kongju, Chungnam, South Korea, jtkim@kongju.ac.kr

ABSTRACT: Building Integrated Photovoltaic (BIPV) is one of the best fascinating PV application technologies in these days. To apply PV module in building, various factors should be considered such as installation angle and orientation of PV module, shading, temperature, and so on. Especially the temperature of PV modules is important factor, as it affects both electrical efficiency of a PV module and energy load in a building. This study investigates the electrical and thermal performance of a semi-transparent PV module that is designed for window. It evaluates the effect of thermal characteristic of the PV module on PV electrical generation performance. The experiment was performed under both standard test condition (STC) and outdoor conditions. The results showed that 1 °C rise reduced about 0.48% of output power.

Keywords: Building Integrated Photovoltaic (BIPV), PV module, Temperature variation, generation performance

NOMENCLATURE

Symbol	Description [Units]
I _{sc}	Short Circuit Current [A]
I _{mp}	Current at Maximum Power
V _{oc}	Open Circuit Voltage [V]
V _{mp}	Voltage at Maximum Power [V]
P _{max}	Maximum Power [W]
Eff.	Efficiency [%]
FF	Fill Factor [%]

1. INTRODUCTION

As photovoltaic(PV) industry is booming, PV system has been advanced both in the technological aspect and in the economical aspect. In this trend, the installation capacity with various application types has expanded in the world wide. Especially, BIPV is becoming a popular option among various PV application technologies. It seems a

more promising option in Korea where useable land is limited. Recently various PV modules are used in buildings. In particular, semi-transparent PV module can play multifunctional roles as electricity producer, building envelope component, glazing component and so on.

In order to achieve multifunctional effects of BIPV systems, it has to be taken into consideration of various factors, such as PV module temperature, shading, installation angle and orientation and so on. Among them, PV module temperature should be considered as the most important factor, since it affects both electrical efficiency of BIPV system and energy performance of buildings.

This paper analyzed the characteristic of electrical generation of the semi-transparent PV module in relation to PV module temperature. The experimental study was performed under the standard test condition and in outdoor. The experimental monitoring was started from May in 2007. The experiment was performed with the variation of PV module temperature from 25°C to 65°C under irradiance of 1000W/m².

2. SEMI-TRANSPARENT PV MODULE

Modern buildings are constructed and finished by various materials and methods. PV modules can be used as one of special finishing materials for old buildings as well as contemporary ones. It is not difficult to find buildings around covered with glass for the whole envelope. A semi-transparent PV module which was the subject in this paper is suitable for those buildings. For the transparency of the PV module, the opaque crystalline PV cells were connected to maintain space between them. This section describes the module in detail.

2.1 PV Cell

Before manufacturing a PV module for the experiment, PV cell tests were performed. Figure 1 shows the testing

results. The 5x5 inch polycrystalline silicon (p-Si) PV cells had the electrical generation performance from maximum power of 2.457W to the minimum power of 2.346W. The average output of about 500 cells was 2.417W and the uniformity is 2.938%. They were sorted by the test results and used for PV modules.

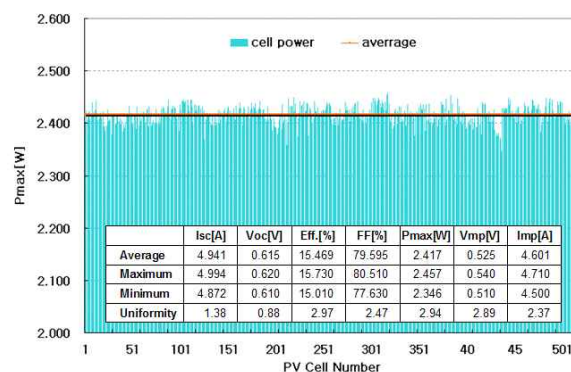


Figure 1: Result of the PV cell tests

2.2 Glass

The PV module consists of triple glasses as Figure 2 shows. A low-iron tempered glass was used as the front cover and various glasses were used as the supporting back cover. Those glasses included clear, coloured, and reflected. In order to apply 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. The glass is also low iron tempered same as the front glass.

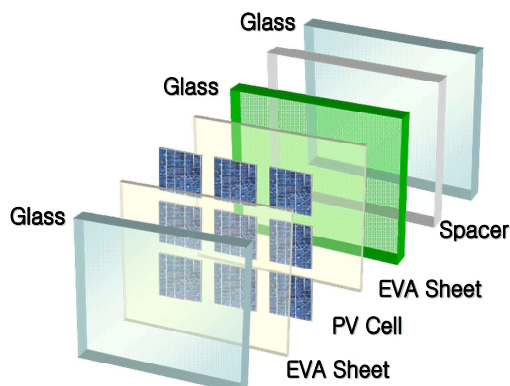


Figure 2: Layer structure of the PV module

2.3 PV Module

Each module consists of 32 p-Si cells. The cells are connected serially. This PV module includes bypass diodes to make preparation for hot spot according to partial shading and other partial damages. Figure 3 shows the circuit of the semi-transparent PV module.

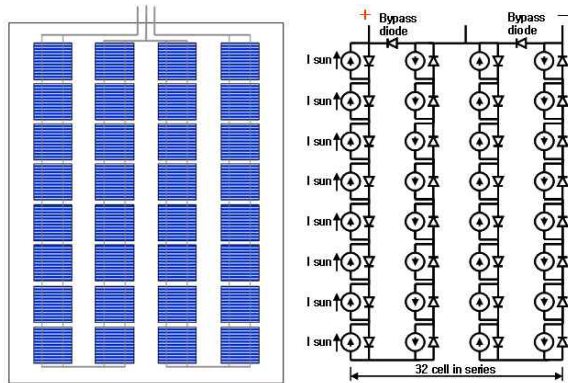


Figure 3: Configuration of the circuit of the PV module

3. DESCRIPTION OF EXPERIMENT

3.1 Temperature sensor setting

To analyze heat transfer and temperature variation between layers in more detail, we installed the temperature sensors in each layer - front side, back side, air gap, and inside as shown in Figure 4. To measure the temperature thermo couple (t-type) for each surface and RTD for air gap were used.

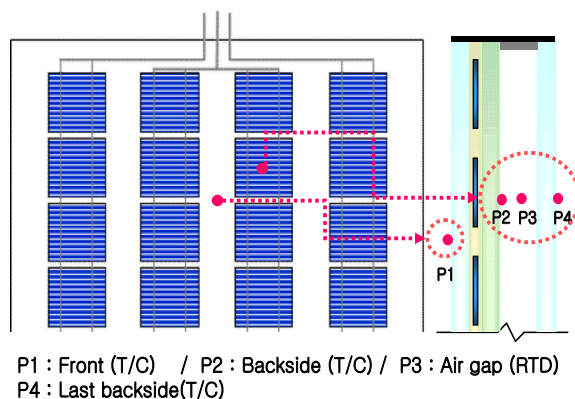


Figure 4: Position of temperature sensors

3.2 Installation

PV modules were applied as glazing component in a sunroom or covered balcony, as Figure 5 shows. The PV modules were installed on the top and in the front as glazing. And two pyranometers were installed at the same plane to measure global radiation. In this paper, the vertically installed PV module was only dealt.



Figure 5: Overview of PV module installation in a sunroom

4. RESULTS

4.1 Initial electrical performance of the PV modules in standard test condition

In this experiment, various glasses used as back side PV-cell supporting glass such as normal clear, green (normal and reflection), blue (reflection), and bronze glass. The electrical characteristic - current, voltage, and power - of these modules is similar in standard test condition (STC: $1,000\text{W/m}^2$, 25°C , AM 1.5). Figure 6 shows the initial I-V curve and temperature difference by PV module with coloured glass.

From the result, we found that the color of the glass in the back side has a little effect on the electrical generation of the PV module under STC. And we confirmed the output power uniformity of the manufactured PV modules that used for this study.

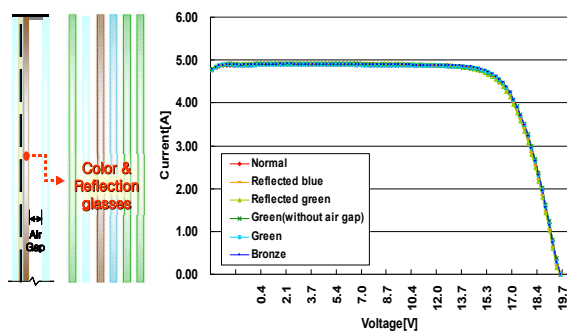


Figure 6: Initial I-V curve of modules with various glasses

4.2 Result of the temperature measurement of the PV module in outdoor

4.2.1 Temperature variation of a standard PV module

In this chapter, we analyzed the results of the experiment performed in outdoor. First of all, we analyzed the temperature variation of a standard PV module with clear glass as the front cover.

The monitoring of PV module temperature was started on May in 2007. Figure 7 shows monitoring results of irradiance, outdoor temperature, and temperature variation of semi-transparent PV module on spring (May) and on summer (August). The temperature variation of each layers appeared to be similar. As the time passed, the difference of temperature in each layer had got more increased: it appears that the largest difference is from noon to 3p.m. After that time to sunset, the difference decreased, and after sunset the temperature of all layers became similar.

The air temperature of air space was the highest at all the time, followed by the temperature of the PV cell supporting glass. In this study, we assumed that the surface temperature of the PV cell supporting (backside) glass equals to the temperature of PV module which has an effect on the electrical generation of the PV system. As the air gap is not contacted with PV cell directly, and the front glass and outer inside glass seem to be more influenced by outdoor and indoor environment. The factors include

outdoor or indoor air temperature, heating or cooling sources, wind etc.

Under high temperature condition on a clear day in August, the module temperature rose up to 55°C. The maximum temperature difference between each layer was about 5°C.

The variation of the layers' temperature seems to be similar to all seasons. The temperature variation range varies according to outdoor temperature, irradiance gain, generation level, and characteristics of materials.

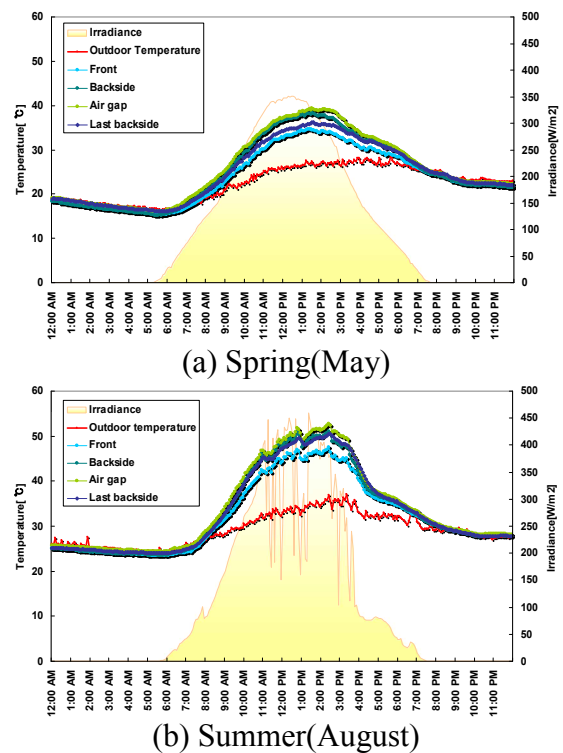


Figure 7: Temperature variation of PV module during one particular day

4.2.2 Comparison of module temperature according to glass type

In order to analyse the variation of the PV module temperature according to the PV cell supporting glass type, two modules with bigger temperature difference at the layers were compared. The first one is the module with normal clear glass and another is the PV module with bronze glass.

Figure 8 shows comparison of irradiance, outdoor temperature, and temperature

variation of semi-transparent PV module on summer (June) and on autumn (October). The temperature difference between those two modules was the smallest in June. On the other hand, it was measured above 5~6°C in October. The average ambient temperature in October was measured at 14.8°C, while that in June was 23.8°C. It is believed that this result is caused by the seasonal difference of radiation gains on the PV modules rather than the ambient temperature. A PV module applied at the vertical surface can gain less radiation in summer when the altitude of the sun is the highest.

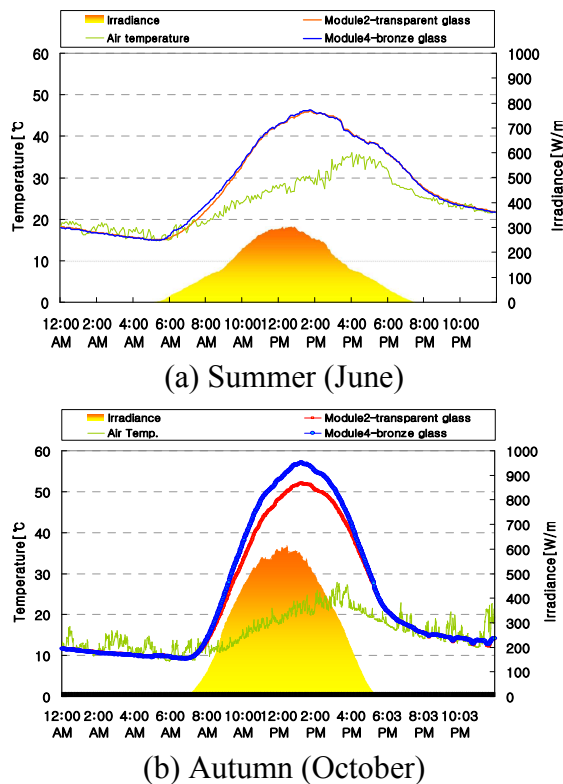


Figure 8: Comparison of the irradiance, outdoor temperature, and temperature variation of PV module on summer(a) and autumn(b)

4.2.3 Electrical generation characteristic according to temperature variation

As mentioned previously, we found that the temperature of PV module tends to rise up to 55°C in summer and autumn season.

In this chapter, we analyzed the electrical generation characteristic according to the PV module temperature variation. All the test conditions except temperature were set same as the standard test condition and the temperature was changed from 25 °C (standard test condition) to 65°C.

Figure 9 and 10 show the results. It was found that the voltage reduced as PV module temperature rose and the current increased a little. The power of PV module is similar pattern to voltage reduction, for the voltage reduction is larger than the current rise. Under the irradiance of 1,000W/m² and the temperature variation range from 25 °C to 65 °C, the voltage reduced about 0.49% per 1°C increase of the PV module temperature and the current increased about 0.01% per its 1°C increase. And the power also decreased about 0.48% per its 1°C increase.

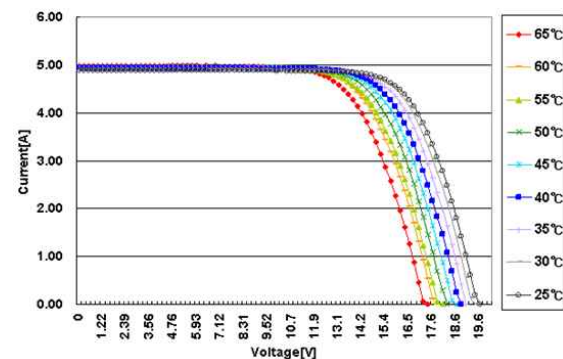


Figure 9: I-V curve characteristic by temperature variation

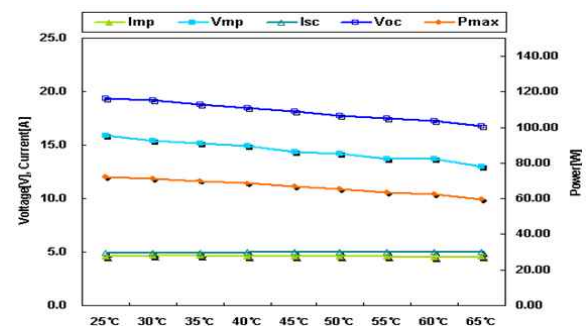


Figure 10: Current, voltage, and power characteristic by temperature variation

5. CONCLUSION

This paper reports on an experimental investigation about the electrical generation of a semi-transparent PV module that can be used for window in buildings. The analysis was performed with the results that were driven from measuring data under standard test condition and in outdoor.

At the PV module the temperature of air gap was the highest, followed by that of the PV cell supporting glass. With the assumption that the surface temperature of the backside glass is equivalent to PV module temperature, the temperature of the PV module rose by 55°C on clear day.

This study showed that the temperature of the PV module influences its electrical generation. In this study, we varied the temperature variation range from 25°C to 65°C under irradiance of 1,000W/m². As a result, the voltage reduced about 0.49% per 1°C increase of PV module temperature and the power also decreased about 0.48% per the 1°C increase.

To apply BIPV modules into buildings, it has to be considered both the electrical aspect and the architectural aspect. Because the temperature variation of PV module influences not only its electrical generation but also building's cooling and heating loads. In this study, it was found that the glass color of semi-transparent module hardly affected the PV module temperature or the generation performance of PV module under standard test condition. On the other hand, the glass color will influence on daylight and visual environment in buildings. It needs to perform analysis of the effect of semi-transparent PV module on thermal and visual environment in a building and on overall energy performance of a whole building.

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