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Effect of thermal collection temperature of BIPVT module on power generation characteristics and total efficiency[#]

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ABSTRACT

The Building Integrated Photovoltaic Thermal (BIPVT) module is a composite module that combines a photovoltaic module and a solar thermal collector module and has the advantage of producing power and heat at the same time. BIPVT module is affected by electric generation performance by heat collection performance. It is important to know the correlation between changes in power generation performance according to temperature changes of the BIPVT module. This study conducted a comparative experiment on temperature and power characteristics between different types of BIPVT modules without a glass cover. Three BIPVT modules with different thermal collection methods were installed in the mock-up facility at a vertical angle of 90˚ vertically facing to the south. As the experimental result, the total efficiency of BIPVT module was highest in Case (1) at 34.8%, followed by Case (2) at 19.8%, Case (3) at 17.2%, and Reference at 10.9%.

Keywords: Solar energy, BIPV, BIPVT, Electric generation, Thermal collection

NONMENCLATURE

Abbreviations	
BIPV	Building Integrated Photovoltaic
BIPVT	Building Integrated Photovoltaic Thermal
G to B	Glass to Back sheet
HSP	Heat Sink Plate
FPMHP	Micro Flat Plate Heat Pipe
HTDP	Heat Transfer Source Pipe
Symbols	
c-Si	Silicon Solar Cell

1. INTRODUCTION

Increasing energy consumption is accelerating the global environmental and energy crisis in the worldwide [1]. The development and use of renewable energy is a solution to overcome this crisis, and solar energy is an alternative as an abundant and sustainable energy source [2]. The solar energy is representative of PV and ST technology, and recent research on electric generation and heat collection performance of PVT is actively underway [3].

The electric generation of solar modules is reported to decrease by 0.3% to 0.5% for every 1 °C increase in temperature [4]. Many previous studies have also been conducted on the impact of power output for BIPV due to temperature changes [5-8]. However, previous research has not been conducted to study the temperature change of the module according to the thermal collection method of the BIPVT module applied to the facade of the building and the effect of this temperature on the power characteristics. Therefore, we developed three types of BIPVT modules without glass covers and different thermal collection methods and identified the correlation between temperature and power characteristics according to the thermal collection methods of these modules.

2. DEVELOPMENT OF BIPVT

2.1 Specification of the BIPVT module

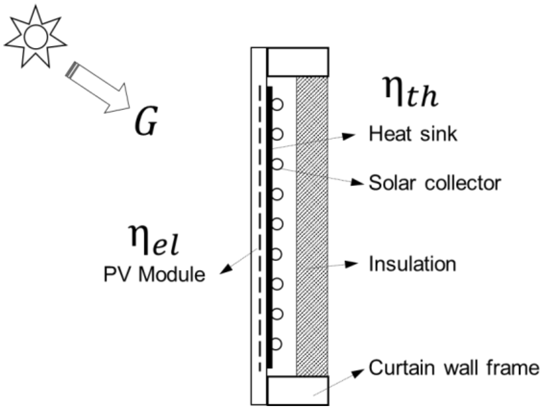

Figure 1 Section view of BIPVT model

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The total efficiency of BIPVT is expressed as the combined efficiency of PV power efficiency η_{el} and thermal collection efficiency η_{th}.

$$\eta_{combined} = \eta_{el} + \eta_{th} \tag{1}$$

$$\eta_{el} = \eta_r(1 - \beta * (T_{pv} - T_r)) \tag{2}$$

$$\eta_{th} = \frac{Q_u}{I_c * A_c} = \frac{mC_p(T_o - T_i)}{I_c * A_c} \tag{3}$$

η_r is the reference efficiency, β is the temperature coefficient, T_{pv} is the PV temperature(°C), and T_r is the reference temperature(°C), Q_u is the heat gain(W), I_c is the solar radiation(W/m^2), A_c is the heat collection area(m^2), m is the flow rate(m^3), C_p is the specific heat (kcal/kg °C), T_o is the heat source outlet temperature(°C), and T_i is the heat source inlet temperature(°C). This paper indicates the model specification of the developed BIPVT prototypes in Table 1. Three models used the PV module with 365W of the power capacity. The difference between models is the configuration of the thermal collecting device attached to the back of the PV module. Case (1) consisted of a heat source circulating serpentine piping to move heat to a heat sink plate that can absorb the heat of the PV module. Case (1) and Case (2) have multiple micro flat plate heat pipes consisting of an evaporation section and a condensation section joined to the back of the module. The heat collected in the evaporation part of the micro flat plate heat pipe is moved to the condensing part and the heat is obtained from the manifold in the condensing part. The difference between Case (2) and Case (3) is the shape of the manifold. Case (2) is an indirect heat transfer method with pipes inserted into the manifold, whereas Case (3) is a direct heat transfer method with no pipes inserted into the manifold.

Table 1 Specification of the BIPVT prototype

Items	***Case (1)***	***Case (2)***	***Case (3)***
*Size (W*H, mm)*	*1100x2100*	*1100x2100*	*1100x2100*
Thickness (mm)	*5*	*5*	*5*
Cell type	*c-Si*	*c-Si*	*c-Si*
Capacity (W)	*365*	*365*	*365*
Thermal Collector	*HSP + HTSP*	*FPMHP + HTSP + Manifold*	*FPMHP + Manifold*

2.2 *Model of the BIPVT prototype*

The full-scale mock-up facility for performance evaluation of each model was constructed by applying BIPVT as the finishing material to the exterior wall of the building using the curtain wall method.

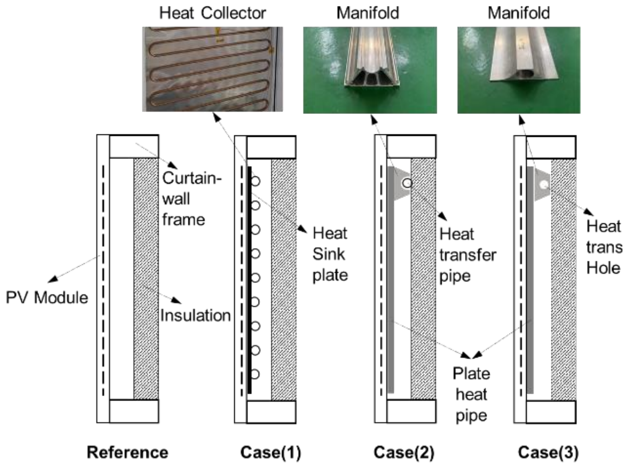

Figure 2 Section view of reference module and BIPVT prototype; Case (1), Case (2), Case (3)

Figure 3 View of full-scale Mock-up facility: (a) Front side view, (b) Rear side view

Each BIPVT prototype was installed at a vertical angle of 90° facing the south. The power produced from the BIPVT module was measured (GEMS3500) using a micro inverter (LGE-LM320KSA2) model connected to the main power system. The thermal collection was calculated by measuring the temperature (Thermocouple T-type) and flow rate (Vortex SV-4200) at the inlet and outlet of the model, respectively. Solar radiation was measured using a solar irradiance meter (CMP21) at the same installation angle as the module. Measured data was collected every minute for 30 days from March 26th to April 25th. The analysis used 442,860 pieces of data from 7 consecutive days when solar radiation was high.

3. RESULTS AND DISCUSSION

3.1 Temperature and power output

The power output of PV modules is affected by temperature and is reported to decrease by 0.3% to 0.5% for every 1°C increase in temperature under STC conditions. For this reason, it is necessary to estimate the operating temperature of the PV modules in the array during the day. PV modules change temperature in response to changes in plan-of-array (POA) solar radiation, air temperature, wind speed, and even relative humidity (humid air has a higher heat capacity). The most widely used module temperature model used in PV system models is based on Faiman[4] and has the following form.

$$T_c = T_a + \frac{\alpha E_e(1-\eta_m)}{U_0 + U_1 WS} \qquad (4)$$

Here, T_a is the temperature (°C), α is the absorption rate of the module (typical value is 0.9), η_m is the module efficiency (typically 0.08-0.2), and WS is the wind speed (m/s). U_0 represents the constant heat transfer coefficient (W/m^2 °C) and U_1 represents the convective heat transfer coefficient (W/m^3 s °C). Typically, U_0 and U_1 are 23.5 - 26.5 W/m^2 °C and 6.25 - 7.68 W/m^3 °C range of values, respectively.

The temperature at the center of the back of the BIPVT module according to time in the mock-up is shown in Figure 4. As of 1 p.m., the highest temperature of reference module rose to 55.7 °C. CASE (1) was 41.6 °C, CASE (2) was 52 °C, and CASE (3) was 52 °C, with CASE (1) having the lowest temperature.

This shows that the thermal collection performance of each model is clearly different. When the average temperature of the top, center, and bottom of each module is CASE (1) 36.3 °C, CASE (2) 44 °C, and CASE (3) 43.9 °C, the average temperature of the lower part is CASE (1) -0.2 °C, CASE (2) 1.1 °C, CASE (3) 1.1 °C difference. In other words, CASE (1) had good thermal collection performance of the entire area regardless of the area, whereas CASE (2) and CASE (3) had uneven collection performance of the lower part.

This is due to differences in the thermal collection performance of the heat source. As shown in Figure 5, the temperature difference between the inlet and outlet of the thermal collection flow rate of each CASE is larger for CASE (1) than for CASE (2) and CASE (3). The temperature difference between the inlet and outlet of the heat source widened when solar radiation was high and the temperature difference between each case was also larger. It was found that the thermal collection method had a significant impact on the thermal collection performance and the temperature of the module.

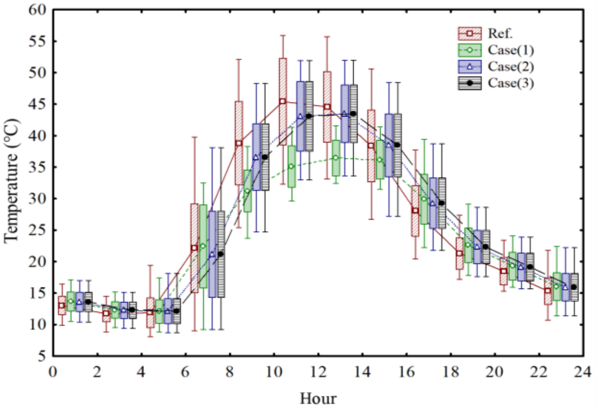

Figure 4 Temperature on rear surface of the BIPVT module

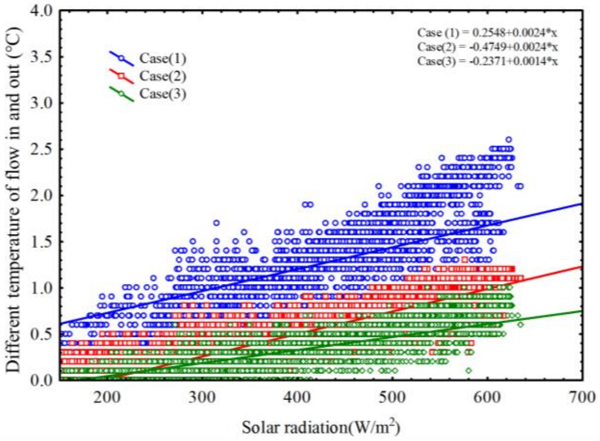

Figure 5 Temperature difference between the inlet temperature and outlet temperature of the BIPVT module Thermal collector

3.2 Total efficiency

Figure 6 shows the total efficiency analyzed by combining the power generation performance and thermal collection performance using continuous data for 7 days when solar radiation was good. The total efficiency showed a greater difference depending on the thermal collection efficiency than the power generation efficiency.

The total efficiency was highest in Case (1) at 34.8%, followed by Case (2) at 19.8%, Case (3) at 17.2%, and Reference at 10.9%. As verified in Chapter 4.1, Case (1) showed much higher thermal collection efficiency than other cases due to its good thermal collection performance.

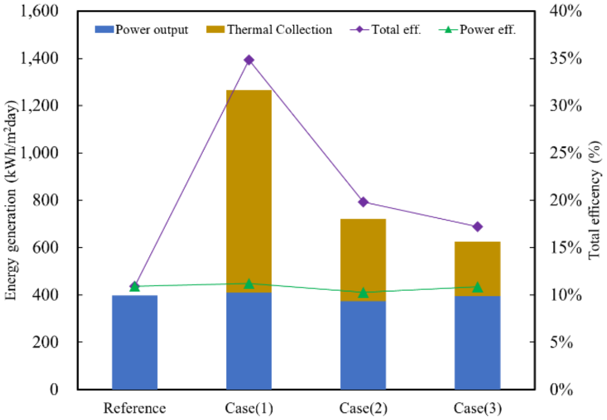

Figure 6 Total energy generation and efficiency of the BIPVT models

4. CONCLUSIONS

In this study, a comparison experiment was conducted between models with different types of thermal collection to analyze the power generation characteristics of a BIPVT module without a glass cover according to temperature changes.

The reference module had the highest temperature, followed by CASE (2), CASE (3), and CASE (1). The average temperature of the top, center, and bottom of each module was measured in CASE (1), and the collection performance of all areas was good regardless of the area. On the other hand, CASE (2) and CASE (3) had uneven collection performance at the bottom.

Analysis results of the correlation between module temperature and power generation performance according to the thermal collection method of each CASE. CASE (1) showed high power generation in the low temperature range in the same solar radiation range as the reference, but CASE (2) and CASE (3) showed small power generation improvement in the low temperature range.

The total efficiency of BIPV showed a greater difference depending on the thermal collection efficiency than the power generation efficiency. The total efficiency was highest in Case (1) at 34.8%, followed by Case (2) at 19.8%, Case (3) at 17.2%, and Reference at 10.9%.

we experimentally analyzed the effect of the thermal collection performance of BIPVT on the power generation performance of PV and confirmed that the thermal collection method can have a significant effect on improving the power generation of PV. Based on the results of this experiment, we developed a BIPVT module with improved heat collection performance, such as a thermal collection method.

ACKNOWLEDGEMENT

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REFERENCE

[1] Pietrosemoli, L. and C. Rodríguez-Monroy, The Venezuelan energy crisis: Renewable energies in the transition towards sustainability. Renewable and Sustainable Energy Reviews, 2019. 105: p. 415-426.

[2] Kuik, O., F. Branger, and P. Quirion, Competitive advantage in the renewable energy industry: Evidence from a gravity model. Renewable energy, 2019. 131: p. 472-481.

[3] Ma, X., et al., Building integrated photovoltaic-thermal systems (BIPVT) and spectral splitting technology: A critical review. Next Sustainability, 2024. 4: p. 100056.

[4] Stein, J., PV Performance Modeling Methods and Practices: Results from the 4th PV Performance Modeling Collaborative Workshop. 2017.

[5] Radziemska, E., The effect of temperature on the power drop in crystalline silicon solar cells. Renewable energy, 2003. 28(1): p. 1-12.

[6] Chatzipanagi, A., F. Frontini, and A. Virtuani, BIPV-temp: A demonstrative Building Integrated Photovoltaic installation. Applied energy, 2016. 173: p. 1-12.

[7] Soltani, S., et al., An experimental investigation of a hybrid photovoltaic/thermoelectric system with nanofluid application. Solar Energy, 2017. 155: p. 1033-1043.

[8] An, Y.-s., et al., Experimental performance analysis of photovoltaic systems applied to an positive energy community based on building renovation. Renewable Energy, 2023. 219: p. 119369.