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Experimental performance of a photovoltaic-thermal air collector

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Abstract

A photovoltaic-thermal (PVT) collector is a solar collector that combines a photovoltaic (PV) module with a solar thermal collector, and which produces electricity and heat at the same time. Depending on the medium used for collecting thermal energy, there are two types of PVT collectors: air-based and water-based. The integration of PV modules with thermals collectors could cause higher temperatures in the PV module, and this decreases the efficiency of PVT collectors. In order to have better performance of air-based PVT collectors, it is necessary to extract the heat, in the form of hot or warm air, from the PV module and thus decrease its temperature. The warm air extracted from the PVT collector can be utilized as a heat source for the building. In this study, an air-based PVT collector with a mono-crystalline PV module was designed, and its electrical and thermal performance was analyzed with the experimental results. The results indicated that the thermal and electrical efficiencies of the PVT collector were, on average, 22% and about 15%, respectively.

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Keywords : PVT air collector, thermal efficiency, electrical efficiency, pre-heated fresh air,building energy

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1. Introduction

A photovoltaic-thermal (PVT) collector is a solar collector that combines a photovoltaic module with a solar thermal collector, and which produces electricity and heat simultaneously. Depending on the medium used for collecting thermal energy, there are two types of PVT collectors; air-based and water-based.

PVT air collectors have an important advantage over PVT liquid collectors, as the latter need thermal collecting materials attached to conventional PV modules. On the other hand, the air type requires a high volume of air flow to obtain good thermal efficiency and bring up the corresponding matters of large diameter tubing, noise and fan losses. The large tubing required may cause problems, especially in retrofitting.

The use of air as a heat transport medium has some advantages, but also some big disadvantages in comparison with water. It has the advantages that there is no freezing, no boiling of the collector fluid and no damage if leakage occurs. However, the disadvantages are rather severe: low heat capacity and low heat conductivity, which result in a low heat transfer and low density; requiring high volume transfer. For the PVT air collector with a ventilated system, since the heat transfer from the PV to the airflow is generally not very good, losses to the surroundings are large and thermal efficiencies are generally in the range of 10% to 20% [1].

With that background, for the utilization of PVT air collectors in buildings, the performance evaluation of a PVT air collector is important. The performance of a PVT air collector depends on climatic, operating and design parameters including ambient temperature, solar radiation intensity, wind speed, solar cell temperature, back surface temperature, inlet and outlet air temperature, inlet air velocity, and the length and width of PVT air collector.

Therefore, in order to have better performance of PVT air collectors, with sufficient design consideration of the PVT air collector, it is necessary to properly extract the heat in accordance with its use, as a form of hot or warm air, from the PV module such that its temperature decreases. The extracted air from the PVT air collector can be utilized as a heat source for the building. The heated air from the PVT collector can be supplied into the ventilation system in the building as pre-heated fresh air. It is necessary to take in fresh, outside air in order to improve Indoor Air Quality (IAQ); however, this increases the ventilation energy load of building. Thus, a Heat Recovery Ventilation (HRV) system has been introduced to improve IAQ and thermal efficiency of buildings with heat recovery.

A considerable amount of research has been conducted regarding the performance of air-type PVT collectors. One study focused on such collectors [2], involved various designs of PVT air collectors (e.g., air channel above PV, air channel below PV, PV in single pass and PV in double pass); these were designed and their overall electrical and thermal performance was evaluated through numerical modeling. In another study [3], various types of PVT air collectors were also suggested for improving performance. These included such as the absence of a glass cover, use of a single cover, attachment of metal fins and incorporation of a metal sheet. In addition, the study proposed improved models of PVT air collectors that incorporated a corrugated sheet, wire mesh (RIB) and metal air tubes [4]. Solanki et al. reported on the design, fabrication and performance assessment of a PVT air collector [5]. Sopian et al. compared the performances under normal conditions of the single and double pass PVT air collectors [6]. They concluded that the double pass-type PVT air collector showed better performance regarding the cooling of a solar cell. A study of PVT air collectors with numerical calculations was published by Garg and Adhikari [7]; dealing with the modeling and simulation of a PVT air collector. They described the algorithm of a simulation model for making quantitative predictions regarding the performance of the system. In other studies, numerical models of a PVT air collector were presented in order to appreciate the effect of factors such as air flow, air channel depth and length, and an absorber plate [8, 9]. Furthermore, other studies evaluated the effective efficiency of a PVT air collector depending on the utilization conditions and linkage to facilities [10, 11, 12, 13]. Crawford et al. compared the energy payback time (EPBT) of a conventional BIPV system with BIPV systems incorporating heat recovery units [14]. They reported that with integration of the heat recovery unit, the EPBT can be cut by almost one half.

In this paper a PVT air collector system was designed, and its electrical and thermal performance was analyzed through the experimental results.

2. Experiment of the PVT air collector

The air-type PVT collector that was built is shown in Fig.1. It was installed at the orientation of due south and a tilt angle of 35°. The PVT collector was made with a mono-crystalline PV module of $250W_p$, with a 1.6 ㎡ surface area and an air layer of 60mm for collecting hot air. Exhaust air pipes 10 cm in diameter were installed to extract heated air from the space in an effort to cool the rear the of the PV laminate. The specifications of the PV modules used shown in Table 1.

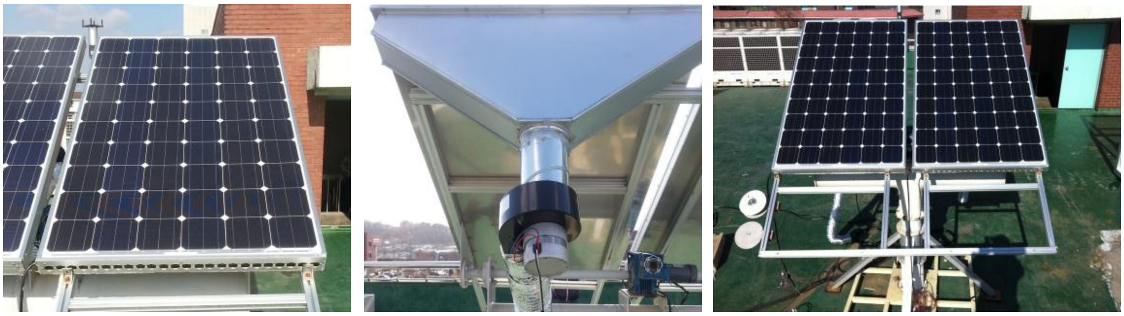

Fig. 1. Experimental view of the PVT air collector

Table 1. PV module specification of the PVT air collector

Subject	Specifications
Maximum power (Pmax)	250W
Maximum voltage (Vmp)	31.9V
Maximum current (Imp)	7.84A
Open voltage (Voc)	38.2V
Shot current (Isc)	8.59A
Module size	1645*983*40 mm
Cell type	Mono-crystalline silicon
Cell efficiency (STC condition)	15.46%

Several experimental devices were installed to measure the data related to the thermal and electrical performance of the PVT collector. A fan was installed in the exhaust air pipe for forced ventilation. Several experimental devices were installed to measure the temperature of the PV laminate rear, the air layer and exhausted air, and the electrical power of the PVT collector. A T-type thermocouple was used to measure their temperatures, and an electrical load resistor and a power meter were installed for measuring electrical performance. A data acquisition instrument was also connected to record all of the data related to the thermal and electrical performance of the PVT collector and the outdoor conditions. For the measurement of the air flow rate, flow meters were installed inside the exhaust pipes. For the PVT collector experiment, an air flow rate of 240m^3/h was continually maintained.

3. Results and discussion

The electrical and thermal performance of the PVT collector was measured outdoor, and the results are analyzed, as shown in Fig. 2 ~ 5.

3.1. Thermal performance

With the experimental results, the temperatures at the rear of the PV laminate and the exhaust air are presented in Fig. 2. It can be seen in this figure that the temperature at the rear of the PV laminate was 12 to 32℃ and the exhaust air temperatures were 3.5 to 14℃ outdoors; at ambient temperature, -1.6 to 9.5℃. The solar radiation reached a maximum of 910 W/㎡. This result indicates that the PV temperature of PVT collector was kept low due to the hot air exhausted from the PVT collector; in spite of high solar radiation. It also found that the collected warm air could be used as a heat source for building heating and ventilation. The temperature difference between inlet air and exhaust air through the collector was about 5℃. Therefore, the warm air from the PVT air collector could be utilized, as pre-heated fresh air, into the HRV system of the building.

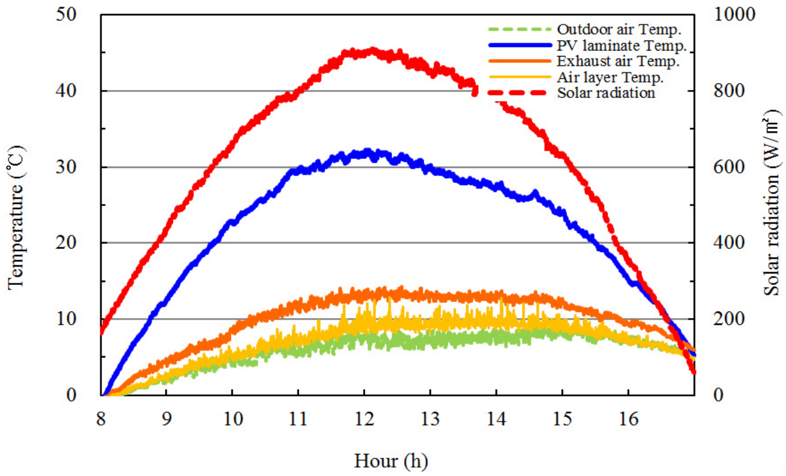

Fig. 2. Temperature of PV module, air layer and exhaust air of the PVT air collector

The thermal efficiency is determined as a function of the solar radiation (G), the mean fluid temperature (T_m) and the ambient temperature (T_a). The steady state efficiency is calculated by the following equation:

$$\eta_{th} = \frac{\dot{m} C_p (T_o - T_i)}{A_{pvt} G} \tag{1}$$

η_{th} thermal efficiency [-]
A_{pvt} collector area [m^2]
T_o collector outlet air temperature [$^{\circ}C$]
T_i collector inlet air temperature [$^{\circ}C$]
$\dot{m}$ mass flow rate [m^3/h]
C_p specific heat [J/kg K]
G irradiance on the collector surface [W/m^2]

The thermal efficiency of the PVT collectors was conventionally calculated as a function of the ratio $\Delta T/G$, where $\Delta T = T_m - T_a$. Here, T_m and T_a are the PVT collector's mean fluid temperature and the ambient temperature, respectively, and G is the solar radiation at the collector surface. Hence, ΔT denotes the measurement of the temperature difference between the inlet fluid and ambient air relative to the solar radiation. The thermal efficiency, η_{th}, is expressed as

$$\eta_{th} = \eta_o - \alpha_1 \left(\frac{\Delta T}{G}\right) \tag{2}$$

where η_o is the thermal efficiency at zero reduced temperature, and α_1 is the heat loss coefficient.

From the measurement results for the unglazed PVT collector, it can be seen that the thermal performance can be expressed as in Fig. 3. The thermal efficiency of the PVT collector can be therefore be described by the relational expression, η_{th} = 0.29-19.2$(\Delta T/G)$. Thus, the collector thermal efficiency (η_0) at zero reduced temperature is 29%, which indicates relatively high performance. However, the heat loss coefficient (α_1), which can have an effect on reduction of thermal efficiency, was 19.29 W/m^2 K. The average thermal efficiency of the PVT collector is about 22% under outdoor test conditions and with the given X axis coefficients ($\Delta T/G$).

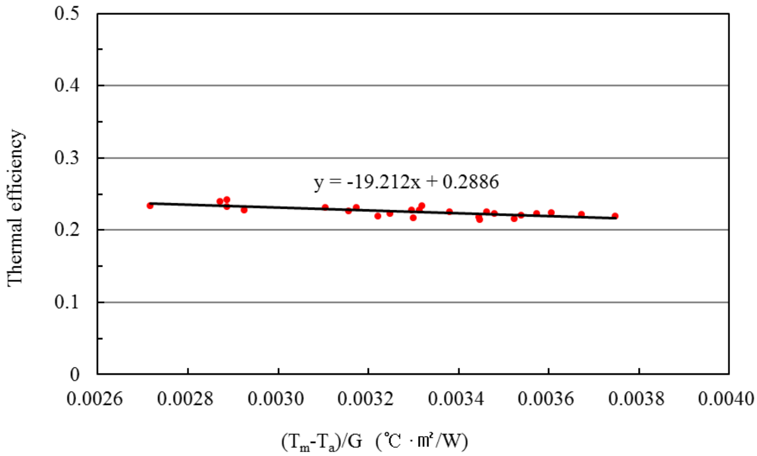

Fig. 3. Thermal efficiency of the PVT air collector

3.2. Electrical performance

The electrical efficiency depends mainly on the incoming solar radiation and the PV module temperature. It is calculated with the following equation:

$$\eta_{el} = \frac{I_m V_m}{A_{pvt} G} \tag{3}$$

where, I_m and V_m are the current and the voltage of the PV module operating under a maximum power.

The electrical performance levels can be analyzed by solar radiation. Fig. 4 shows the electrical efficiency of a PVT collector as the function of the solar radiation. In this figure, it is clearly show that the electrical efficiency increased according to the increase in solar radiation, and then decreased since solar radiation was above 750 W/㎡. The reason for this was the increase in the PV temperature by the high level of solar radiation. As shown in Fig. 5, the PV temperature of the PVT collector continually increased according to the solar radiation. Therefore, it was found that, although the electrical generation of the PVT collector increased with increased solar radiation, the electrical efficiency decreased due to the increased PV temperature.

From these measurement results, it was determined that the electrical efficiency was highest 16% at the solar radiation value of 750 W/㎡, and that the average electrical efficiency was about 15%. Although the electrical efficiency of the PVT collector decreased due to the increase in the solar radiation, the PVT collector, under maximum solar radiation, can generate a power maximum similar to performance of standard test conditions (STC).

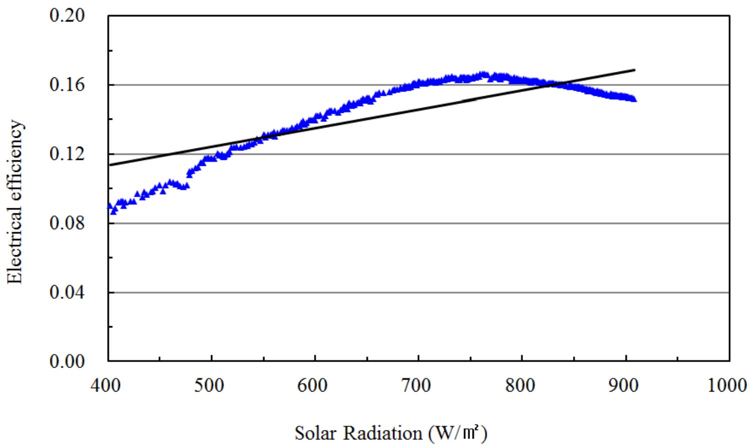

Fig. 4. Electrical efficiency of the PVT air collector in relation to solar radiation

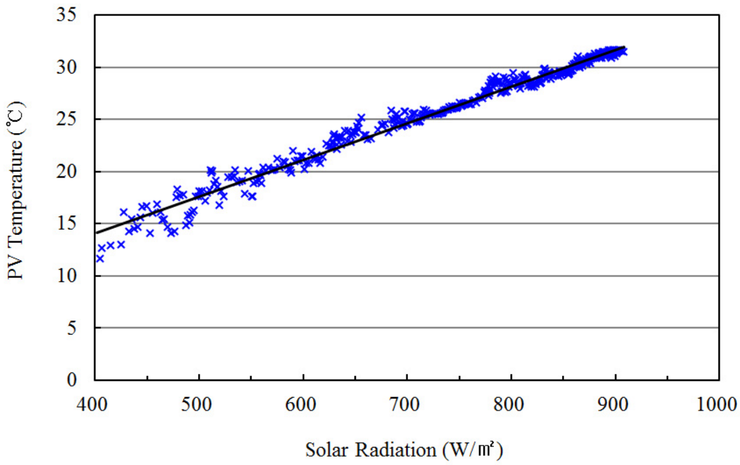

Fig. 5. PV temperature of the PVT air collector in relation to solar radiation

4. Conclusion

In this study, a PVT air collector with a mono-crystalline PV module was designed, and an experiment was performed in order to confirm its electrical and thermal performance in an outdoor environment.

From the experimental results, it was found that the heated air from air-based PVT collector had, on average approximately 5℃ higher temperature than the outdoor air. The experimental results indicated that the thermal and electrical efficiencies of the PVT collector were, on average, 22% and about 15%, respectively. For the electrical efficiency, the PVT air collector was operated as the maximum output due to the prevention of PV temperature rise through forced exhaust. These mean that the performance of the PVT air collector was similar to performance of standard test condition (STC) without a decrease in efficiency due to PV temperature. Therefore, it was concluded that the heated air taken from the PVT collector can be supplied into the ventilation system in building as pre-heated fresh air, and contribute to better electrical performance at the same time.

Verification of the performance of this PVT collector under standard test conditions is needed, and further studies are required to an establish an experimental model of the PVT collector linked to a building system such as heating and heat recovery ventilation in order to assess the contribution of the collector to the building energy performance.

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