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Research Article

The Experimental Performance of an Unglazed PVT Collector with Two Different Absorber Types

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Photovoltaic-thermal collectors combine photovoltaic modules and solar thermal collectors, forming a single device that produces electricity and heat simultaneously. There are two types of liquid-type PVT collectors, depending on the existence or absence of a glass cover over the PV module. The glass-covered (glazed) PVT collector produces relatively more thermal energy but has a lower electrical yield, whereas the uncovered (unglazed) PVT collector has a relatively low thermal energy and somewhat higher electrical performance. The thermal and electrical performance of liquid-type PVT collectors is related not only to the collector design, such as whether a glass cover is used, but also to the absorber design, that is, whether the absorber is for the sheet-and-tube type or the fully wetted type. The design of the absorber, as it comes into contact with the PV modules and the liquid tubes, is regarded as important, as it is related to the heat transfer from the PV modules to the liquid in the tubes. In this paper, the experimental performance of two liquid-type PVT collectors, a sheet-and-tube type and a fully wetted type, was analyzed.

1. Introduction

The photovoltaic/thermal (PVT) concept offers an opportunity to increase the overall efficiency of a PV module through the use of the waste heat generated in the module in a BIPV system. It is well known that PVT systems enhance the PV efficiency through a cooling effect. Moreover, this can be achieved by circulating a relatively cold fluid, water, or air on the underside of the PV module.

PVT collectors combine a photovoltaic module and a solar thermal collector, forming a single device that converts solar energy into electricity and heat at the same time [1]. The heat from PV modules can be removed in order to improve their electrical performance; this heat can be converted into useful thermal energy. As a result, PVT collectors can generate more solar energy per unit surface area than can side-by-side photovoltaic modules and solar thermal collectors [2].

In general, regarding liquid-type PVT collectors, two types can be distinguished. The first is the glazed PVT collector (Figure 1), which has the advantage of heat production, and the second is the unglazed PVT collector (Figure 2), which produces relatively less thermal energy but shows better electrical performance than the former type.

Glazed PVT collectors are very similar in appearance to flat-plate solar thermal collectors, consisting of a PV-covered absorber in an insulated collector box with a glass cover. This glass-covered insulation leads to high thermal efficiency with some reduction of electrical efficiency due to solar radiation reflection and the increase in the PV module temperature caused by the glass cover. Unglazed PVT collectors are more similar to regular PV panels. They consist of a PV-covered absorber with no additional glass cover. The configuration without a glass cover results in lower thermal efficiency compared to the glazed PVT collector. On the other hand, the electrical efficiency of an unglazed PVT collector is higher

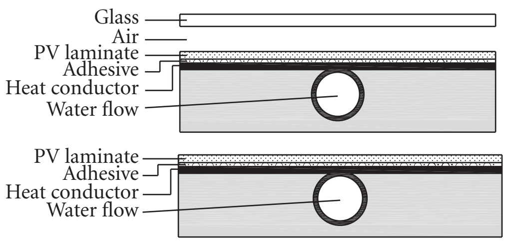


Figure 1: Sectional view of a glazed (above) and unglazed (below) PVT collector.

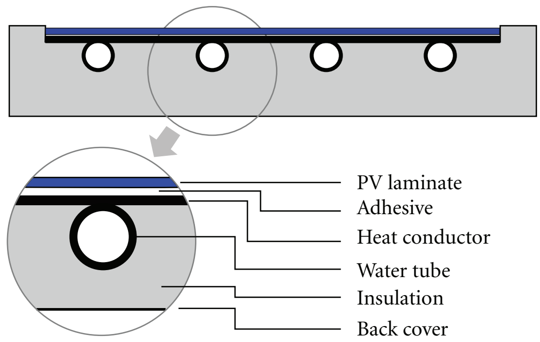


Figure 2: Sectional view of the sheet-and-tube PVT collector.

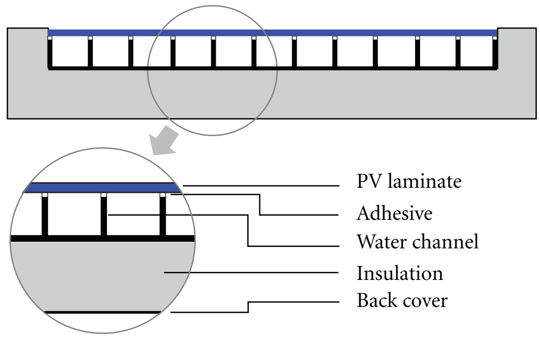


Figure 3: Sectional view of fully wetted PVT collector.

than that of a glazed PVT collector and is even higher than that of regular PV panels due to the PV cooling effect [3].

The thermal and electrical performance of liquid-type PVT collectors is also related to the absorber design. The absorber, which comes into contact with the PV modules and the liquid tubes, is regarded as important, as it is related to the heat transfer from the PV modules to the thermal medium. Two types of the PVT collectors can be distinguished according to absorber attached to the PV module, that is, whether it is a sheet-and-tube absorber (Figure 2) or the fully wetted absorber (Figure 3). It is believed that the latter has better thermal performance, as it increases the heat transfer surfaces.

In a study focused on an absorber design of liquid-type PVT collector, Bergene and Løvvik [4] thoroughly analyzed the electrical and thermal efficiencies of a liquid-type PVT system and the energy conversion between different factors. Sopian et al. [5] compared the performances of single-pass and double-pass combined PVT collectors with steady-state models. They concluded that the double-pass PVT collector had better performance due to the cooling effect of solar cell. Another study [6] introduced a dynamic model for analyzing performances of sheet-and-tube PVT collector. It analyzed the heat transfer between the encapsulated solar cell and the absorber plate; it also analyzed the heat transfer between the absorber plate and the water tube.

Various types of liquid PVT collectors have also been suggested, such as a channel-type PVT collector [7], a PVT collector with polymer square tube absorbers [8], and thermosyphon PVT collectors [9–11].

Chow et al. [12–14] designed the aluminum-alloy flat box absorber with rectangular shape for PVT collectors and tested their performance. Ibrahim et al. [15] studied the performance simulation of PVT collectors with different absorber collectors design, such as rectangular and round tubes. This study involved new design configurations of absorber collectors such as parallel, direct, spiral, oscillatory, serpentine, and web flow, which were modelled and compared. They concluded that the best design configuration is the spiral flow design. In another study [16], the collector was constructed with commercial PV modules attached on a corrugated polycarbonate absorber plate with square-shape box channels.

Various designs of liquid type PVT systems have since been proposed, and the theoretical and experimental performances of PVT systems have been evaluated.

The aim of this study is to compare the electrical and thermal performance of the sheet-and-tube and the fully wetted PVT collectors, both categorized as unglazed. In this paper, two different types of liquid-type PVT collectors were created, and their thermal and electrical performances were measured outdoors. The results were then compared. In addition, the electrical performance of the PV module alone, identical to the modules used for the PVT collectors, was compared to the performance of the fully wetted PVT collector.

2. PVT Collector Design

Liquid-type unglazed PVT collectors with the two types of absorbers, that is, the sheet-and-tube type and the fully wetted type of absorber, were designed and made for this study. The sheet-and-tube absorber is widely used in solar thermal collectors. Regarding the fully wetted absorber, the rectangular shape of the water flow channel can reduce the thermal resistance between the PV module and the collector fluid [17]. The fully wetted absorber has no absorber sheet, as the PV module forms one side of the channel.

The PVT collectors consist of PV modules in combination with water heat extraction units made of aluminum in both cases. Also, the PVT collectors consist of a PV-covered absorber with no additional glass cover. They are both thermally protected with 50 mm of glass-wool insulation.

Table 1: PV module specifications.

Cell type	Monocrystalline silicon
Maximum power	240 W
Maximum voltage	29.93 V
Maximum current	8.15 A
Shot current	8.56 A
Open voltage	37.55 V
Size	1656 ∗ 997 ∗ 50 mm

For the sheet-and-tube absorber PVT collector, the aluminum sheet-and-tube absorber was attached to the back side of the PV module using a thermal conduction adhesive. The PV modules used for the collectors were 240 W_p mono-Si PV modules which show an electrical efficiency rating of 16.5% under standard test conditions (STCs). The specifications are shown in Table 1.

The configuration of the fully wetted PVT collector was identical to that of the sheet-and-tube PVT collector except for the absorber design.

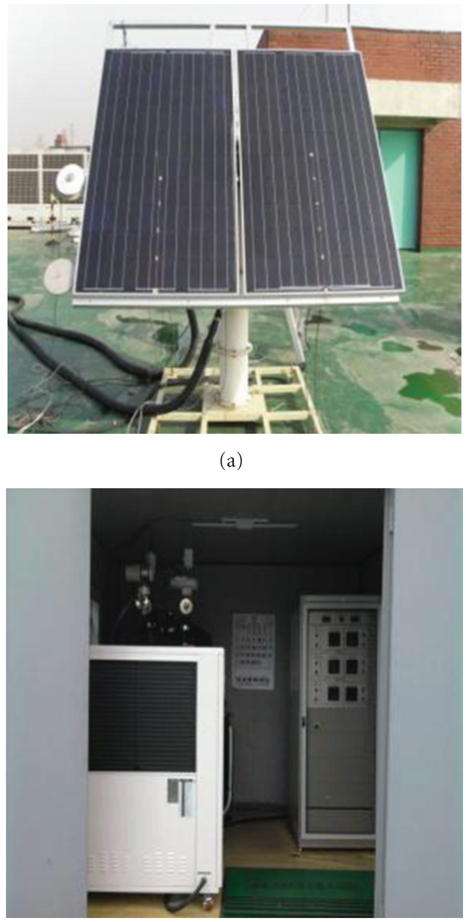
3. Experiment

The two different PVT collector types were tested at a solar radiation level that exceeded W/m^2 and at a liquid flow rate of 0.02 kg/s m^2, based on ASHRAE Standard 93 [18] and the PVT performance measurement guidelines of the ECN [19]. The electrical and thermal performance measurements were carried out under a quasi-stationary condition in an outdoor environment at the same time (Figure 4). In addition, a conventional PV module of the type used in PVT collectors was tested under the same outdoor conditions.

Several experimental devices were installed to measure the data related to the thermal and electrical performance of the PVT collector.

The PVT collector was tested at steady-state conditions to determine their electrical and thermal performance for various inlet operating temperature. Inlet and outlet temperature of PVT collector were monitored and measured using an RTD-type thermocouple with a measurement error of ±0.1% at 0°C. The inlet temperature of PVT collector was controlled by set temperature equipment and the inlet temperature remained constant, while an outlet temperature varied. Also, the ambient temperature was measured by a T-type thermocouple with measurement error of ±0.2°C. Antifreezing liquid was supplied to the PVT collector at an uniform flow rate of 0.02 kg/sm^2 from a pump. The mass flow rate at inlet pipe of the PVT collector was measured by an electronic flow meter. The normal quantity of solar radiation on the PVT collector surface was measured by Epply pyranometer installed parallel to the collector plane.

Electrical loading resistors and a power meter were installed in order to measure the electrical performance of the PVT. All of data related to the thermal and electrical performance of the PVT collector were monitored and recorded at 10 s intervals through a data acquisition system.



(a)

(b)

Figure 4: View of two types of PVT collector (a) in the experiment and the measuring equipment (b).

4. Results and Discussion

With the results of the outdoor test of the PVT collectors, the thermal and electrical performances were analyzed.

4.1. Thermal Performance. The thermal efficiency is determined as a function of the solar radiation (G), the input fluid temperature (T_i), and the ambient temperature (T_a). The steady-state efficiency is calculated by the following equation:

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

where η_{th} is the thermal efficiency [—]; A_{pvt} is the collector area [m^2]; T_o is the collector outlet temperature [°C]; $T_i$is the collector inlet temperature [°C]; $\dot{m}$ is the mass flow rate [kg/s]; C_p is the specific heat [J/kg K]; G is the 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

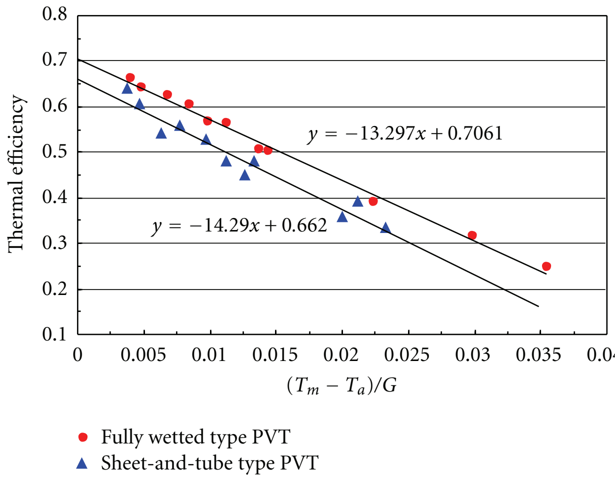


FIGURE 5: Thermal efficiency of the fully wetted and sheet-and-tube PVT collectors.

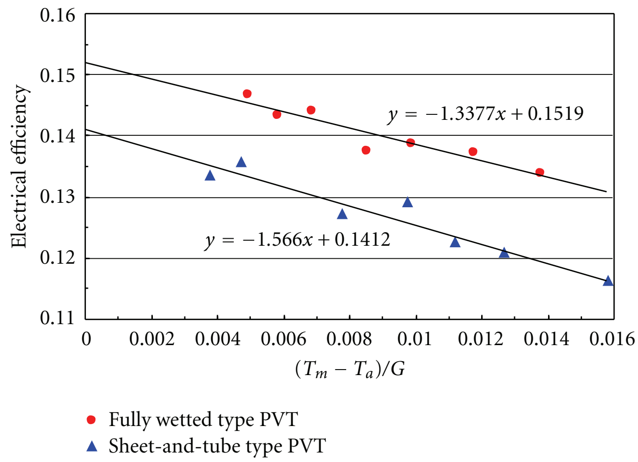


FIGURE 6: Electrical efficiency of the fully wetted and sheet-and-tube PVT collectors.

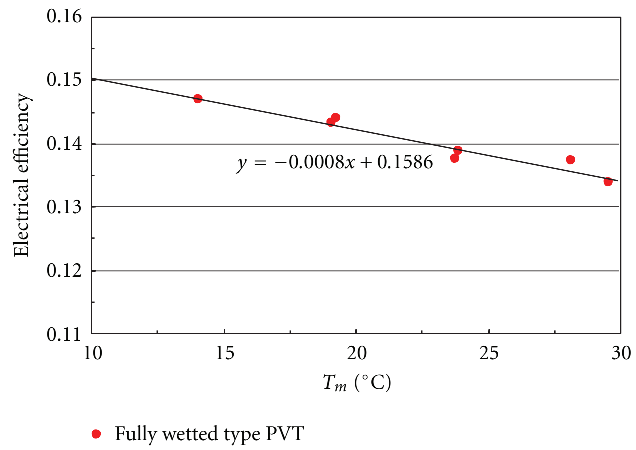


FIGURE 7: Electrical efficiency of the fully wetted PVT collector as a function of the mean fluid temperature.

G is the solar radiation on the collector surface. Hence, ΔT denotes the measurement of the temperature difference between the collector and its surroundings relative to the solar radiation. The thermal efficiency, η_{th}, is expressed as

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

where η_0 is the thermal efficiency at zero reduced temperature and α_1 is the heat loss coefficient.

With the measurement results of the unglazed PVT collectors with the two absorber types, the thermal performance is shown in Figure 5. The thermal efficiencies of the sheet-and-tube and the fully wetted PVT collector can be expressed with the following relational expressions: $\eta_{\text{th}} = 0.66 - 14.29(\Delta T/G)$ and $\eta_{\text{th}} = 0.70 - 13.29(\Delta T/G)$, respectively. Thus, the thermal efficiencies (η_o) at zero reduced temperature are 0.66 and 0.70, respectively, showing that the efficiency of the fully wetted PVT collector is about 4% higher than that of the sheet-and-tube PVT collector. Also, the heat loss coefficients (α_1) are $-14.29\,\text{W/m}^{2\circ}\text{C}$ and $-13.29\,\text{W/m}^{2\circ}\text{C}$, respectively; the fully wetted PVT collector had better thermal performance than the sheet-and-tube PVT collector, but their heat losses were similar.

Therefore, the thermal performance difference according to the absorber type was found to be relatively small. The average thermal efficiency of the sheet-and-tube type and the fully wetted type of PVT collector is about 48% and 51%, respectively, under the same outdoor condition.

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

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

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

The electrical efficiencies of the PVT collectors under the outdoor condition are shown in Figure 6. The performance of the sheet-and-tube and fully wetted PVT collectors can be expressed with the following relational expressions: $\eta_{\text{el}} = 0.14 - 1.56(\Delta T/G)$ and $\eta_{\text{el}} = 0.15 - 1.33(\Delta T/G)$, respectively. Thus, the electrical efficiencies (η_o) at zero reduced temperature are 0.14 and 0.15, respectively, and the electricity loss coefficients are -1.56 and -1.33, respectively. These results show that the electrical efficiency of the fully wetted PVT collector is approximately 8% higher compared to the sheet-and-tube PVT collector. This difference appears to be significant, as it reflects a difference of about 1% regarding the overall electrical efficiency of the PV module. On the other hand, the average electrical efficiencies of the sheet-and-tube and the fully wetted PVT collectors were found to be approximately 12.6% and 14.0%, respectively.

It was found that the fully wetted PVT collector had better electricity performance as well as better thermal performance.

The PV module temperature of PVT collectors is closely related to the cooling effect by the fluid that circulates the collectors. The electrical performance levels can be analyzed by means of the fluid temperature. Figures 7 and 8 show

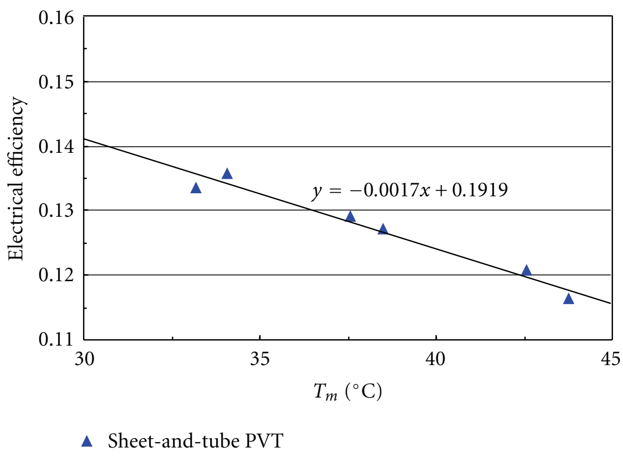


FIGURE 8: Electrical efficiency of the sheet-and-tube PVT collector as a function of the mean fluid temperature.

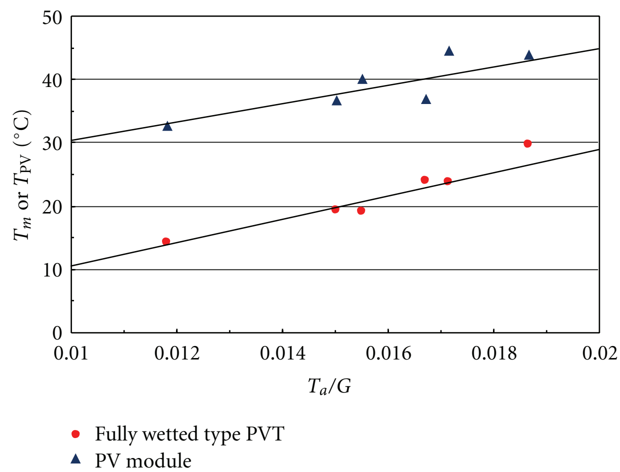


FIGURE 9: Mean temperature of the fully wetted PVT collector and PV temperature of as a function of the ambient temperature and solar radiation.

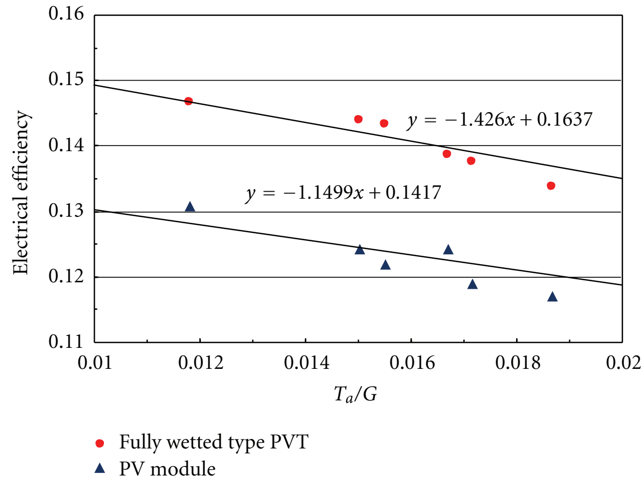


FIGURE 10: Electrical Efficiency of the fully wetted type of PVT collector and a PV module of as a function of the ambient temperature and solar radiation.

the electrical efficiency of a PVT collector as the function of the mean fluid temperature.

For the sheet-and-tube and fully wetted PVT collectors, the electrical efficiency decreased according to an increase of the mean fluid temperature in both cases. These results indicate that the fluid temperature of the PVT collector affected the PV module temperature, which in turn influences the PV performance.

To analyze the effect of the fully wetted absorber for a PVT collector, the electrical performances levels of the fully wetted PVT collector and a PV module alone were analyzed. They were compared as a function of the ambient temperature and the solar radiation (Figure 9).

There will be some thermal resistance between the fluid and the PV module in a liquid-type PVT collector, which may have an influence on the heat transfer between the two elements, thus determining their temperature and in turn the PV electrical performance. For example, for the sheet-and-tube absorber, nonoptimized adhesive contact between the PV and the metal absorber will result in a higher temperature difference between these two components. This indicates that the heat from the PV module may be transferred less to the liquid. However, for the fully wetted absorber, the temperature difference between the two parts may be lower, as there will be good heat transfer through the contact area of entire PV module. Therefore, the mean fluid temperature of the fully wetted PVT collector would be well close to the PV module temperature under the effective convective heat transfer condition.

The mean fluid temperature of the fully wetted PVT collector rises according to an increase in the T_a/G coefficient, as does the temperature of the PV module alone. Under the same T_a/G coefficient condition, the PV module presents a higher PV temperature as compared to the mean fluid temperature of the fully wetted type PVT collector. Therefore, the fully wetted PVT collector can maintain a lower PV temperature due to the fluid coming into the collector. As a result, it can be said that the PV temperature of the PVT collector is lower than that of the PV module alone due to the cooling effect of the liquid.

The electrical efficiency levels of the fully wetted PVT collector and the PV module as a function of the T_a/G coefficients are shown in Figure 10. In both cases, the electrical efficiency decreased according to the increase in the T_a/G coefficient. The electrical efficiency of the fully wetted PVT collector is nearly 2% higher than that of the PV module alone. These results indicate that this type of PVT collector has better electrical performance than the PV module alone.

5. Conclusion

This paper analyzed the experimental energy performance of two different unglazed liquid PVT collectors: one with a sheet-and-tube type of absorber and the other with a fully wetted absorber type of absorber.

The results show that at zero reduced temperature, the thermal and electrical efficiency levels of the sheet-and-tube PVT collector are 66% and 14%, respectively, while those of the fully wetted PVT collector are 70% and 15%, respectively. Therefore, the fully wetted PVT collector had better thermal and electrical performance than the sheet-and-tube PVT collector.

The overall energy performance of the collectors can be compared by combining the values of the average thermal and electrical efficiency. The fully wetted PVT collector presents a value of 65% and the sheet-and-tube PVT collector gives a value of 60.6%. Although the overall performance of the fully wetted collector is 5.6% higher than that of the sheet-and-tube collector, it cannot be concluded that the former is superior to the latter due to the fact that the fully wetted absorber may require a more difficult bonding technique than the sheet-and-tube absorber.

Also, it is clear that the electrical performance of PVT collectors depends on the cooling effect of the PV module by the fluid. In particular, it was found that the fully wetted PVT collector could maintain the electrical performance by similar level to the electrical efficiency in STC. Additionally, the electrical efficiency of the fully wetted PVT collector was, on average, approximately 2% higher than that of the PV module alone. These results show that unglazed PVT collectors provide better electrical performance than a PV module alone.

Acknowledgments

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