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ScienceDirect

Energy Procedia 105 (2017) 961 – 966

Energy Procedia

The 8th International Conference on Applied Energy – ICAE2016

Water PVT collectors performance comparison

N.Aste[a], C. Del Pero[a], F. Leonforte[a]*

[a] *Department of Architecture, Built environment and Construction Engineering, Politecnico di Milano, Via Bonardi 9, 20133 Milano, Italy*

Abstract

Flat plate PVT water based technology presents many advantages in terms of overall performance and space saving than the PV modules and the solar thermal collectors installed separately. However, the electrical and the thermal performances of the PVT technologies are more deeply related to different influences factors, among which: the presence or absence of the air gap formed by the transparent frontal cover, the absorber configuration and the adopted PV technology. For that reasons, the proposed research is aimed to assess, under the energy point of view, a comparison between a covered and an uncovered PVT water collectors, realized with different PV cells coupled to two aluminium roll-bond absorbers characterized also by different channel arrangements. The performance analysis is based on energy simulations carried out with two mathematical models validated on experimental data at the Test Facility of the Politecnico di Milano.

Peer-review under responsibility of the scientific committee of the 8th International Conference on Applied Energy.

Keywords: PVT; covered; uncovered

1. Introduction

As well known, hybrid PVT systems, merging PV and solar thermal technologies, are very promising for the simultaneous production of electrical and thermal power [1-4], offering several advantages, such as better overall performances and space saving than the two separated systems [5]. The PVT concept could be very effective, especially using water as heat removal fluid rather than air [6].

The PVT modules performance is also related to the presence or the absence of an air gap between the transparent frontal cover and the absorber [2]. The two types of PVT collectors are called “covered” and “uncovered”. In uncovered collectors, the absorber is in direct contact with the outdoor environment, so the heat losses are considerable and the fluid temperatures are very influenced by external parameters (e.g. ambient temperature, wind speed, etc.).

At the same time, the electrical performance of the PVT solution is mainly related to the PV technology implemented in the PVT collectors and to its configuration [7,8]. Nowadays the most widespread technology on the market to realize PVT modules is the crystalline silicon (c-Si), characterized by an efficiency typically in the range between 13 % and 22 % and a temperature coefficient on power between 0.3 and 0.5 %/K [9,10]. However, in order to overcome the high temperature

* Corresponding author. Tel.: +39-02-2399 3891
E-mail address: fabrizio.leonforte@polimi.it

Peer-review under responsibility of the scientific committee of the 8th International Conference on Applied Energy.
doi:10.1016/j.egypro.2017.03.426

coefficient that can significantly affect the electrical performance of a PVT module, in various research work the behaviour of amorphous silicon cells applied to hybrid components has been studied [11, 12]. The a-Si technology in fact is characterized by lower temperature coefficients, typically equal to 0.2 - 0.3 %/K [13], but also by lower electrical efficiency, in the range between 7 and 13% [10].

It is therefore crucial to study the performance of PVT components as a function of technological and environmental parameters. For that reasons, the proposed research is aimed to assess, under the energy point of view, a comparison between a covered and an uncovered PVT water collectors, realized with different PV cells coupled in two aluminium roll-bond absorber characterized also by different channel arrangement, described in the following section. The performance analysis is based on energy simulations carried out with two mathematical models validated on experimental data at the PV Test Facility of the Politecnico di Milano University [14-16]. The work represents, in fact, a prosecution of previous research developed in the PVT field. The information reported in such work is significant since only few researches are focalized on the performances of PVT water collector realized with PV microcrystalline technology.

2. PVT modules and systems description

In this section the characteristics of the two compared PVT modules, installed at the test facility of the Politecnico di Milano are described.

2.1. Uncovered and covered tested PVT collectors

The first analyzed PVT module is a commercial product, which well represents the typical uncovered PVT modules available on the market [14]. It integrates five strings of six poly-crystalline cells (mc-Si) connected in series (total power of 230W_p) placed in a glass-tedlar sandwich. The PV laminate has an efficiency of 14.17% at STC and a temperature coefficient on power equal to 0.5%/°C.

On the back side of the PV module, a roll-bond aluminum heat exchanger is attached. In Fig. 1 the configuration of plate is shown. The flow rate of the water flowing through the channels has been set according to the technical specifications of the module at 0.055 kg/s.

The absorber is thus contained into the PV module frame and a thermal insulation material (1 cm thick)is applied on the back side of the absorber (Fig. 1).

Second module, a so called covered PVT collector, is a prototype component which integrate a silicon thin-film double-junction sandwich (stabilized peak power of 125 W_p) characterized by a low temperature coefficient, equal to -0.25 %/K [15]. This microcrystalline technology (μc-Si) combines an amorphous silicon top layer over a microcrystalline silicon layer. The cell at the top absorbs and converts the visible solar spectrum, while the bottom one is sensitive to near infrared wavelengths. Furthermore, as well known, the a-Si PV technology if subjected to prolonged exposure to high temperature, is able to recover some or all of its initial conversion efficiency before stabilization [11].

The PV sandwich was mechanically coupled with two roll-bond aluminium absorbers with channels arrangement reported in Fig. 1. The flow rate has been set at 0.066 kg/s, according to circulation pump type and pressure drop. The whole components are enclosed into an aluminium frame and covered by a 4 mm thick glass. The air gap between the PV laminate and the glass cover is 20 mm. Moreover, a thermal insulation of mineral fiber material, 50 mm thick, is applied in the rear side of the absorber to further reduce thermal losses.

It has to be noted that the most advanced technique to connect the PV laminate with the absorber is the direct lamination of the whole package (Glass, PV cells, electrical insulation layer and absorber) in one step [17]. However, at the experimental stage, that technique was evaluated too expensive and difficult to realize.

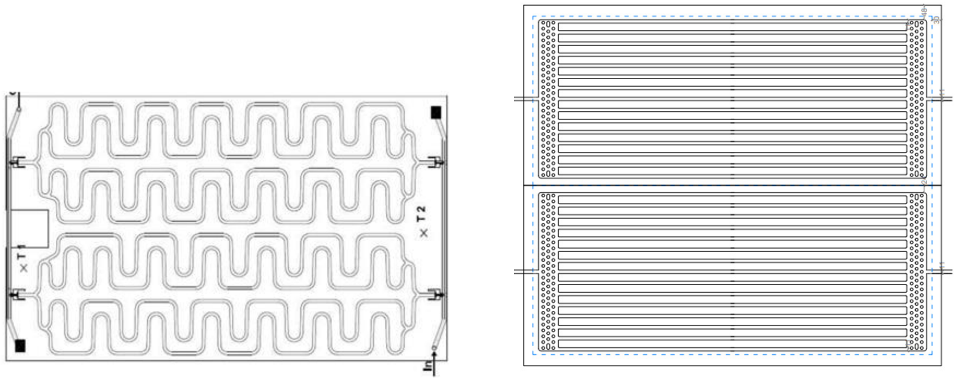

Fig. 1. Channel configuration of the absorbers used in the uncovered (left) and covered (right) PVT components

Table 1 summarizes the main features of the analysed PVT components.

Table 1. Main characteristics of the analyzed PVT collectors

Parameter	Uncovered PVT	Covered PVT
Front cover		
Thickness of the cover glass	-	0.004 m^2
Depth of air gap underneath	-	0.02 m^2
PV sandwich		
Module area	1.62 m^2	1.43 m^2
Nominal power	230 W_p	125 W_p
Nominal efficiency	14.17 %	8.9 %
Power temperature coefficient	-0.5 %/K	-0.25 %/K
Thermal absorber		
Absorber area	1.62 m^2	1.64 m^2
Pipe cross section area	0.000014 m^2	0.000014 m^2
Thermal insulation		
Thickness	0.01 m	0.05 m
Conductivity	0.035 W/mK	0.035 W/mK

2.2. System's configuration

Each PVT module was installed in the experimental PV Test Facility of the Politecnico di Milano with a tilt angle of 30° and an azimuth equal to 0°; each component is then connected by means of a hydraulic circuit to a cylindrical storage tank with a capacity of 200 litres. In the hydraulic loop between the PVT solar collector and the tank the water is circulating thanks to an electric pump. It should be noted that, since the two installed water pumps are characterized by the same features and the absorber arrangement in the collectors is different, the flow rate of the two analyzed collector is slightly different according the specific pressure drop of each component.

Finally, in both cases, the DC/AC conversion is operated by a transformerless microinverter characterized by a peak conversion efficiency equal to 97%.

3. Energy simulation

The energy performance analysis was carried out according to two mathematical models, based on the energy balances of the different components of the PVT systems, including the storage tank [12,13]. The models take into account all the factors and the losses involved in the energy balance of a PVT collector system, such as spectral efficiency of PV module or radiative heat exchange between the PV module and the sky. The used models were validated through the comparison between the experimental monitored data and the calculated ones, and subsequently implemented in TRNSYS, one of the world's most common software used, among other, to evaluate the thermal and electrical performances of PVT modules [18]. The simulations were carried out according to the system configuration validated at the Politecnico di Milano. The main climatic data for the reference site (Milan), were taken from the Typical Meteorological Year (TMY) of Meteonorm database [19,20].

4. Results and discussion

The results obtained from simulations show that the yearly overall efficiency of both collectors, evaluated as a total amount of the thermal and electrical efficiency [2], is almost equal to 35% for the covered PVT collector and to 36% for the uncovered one.

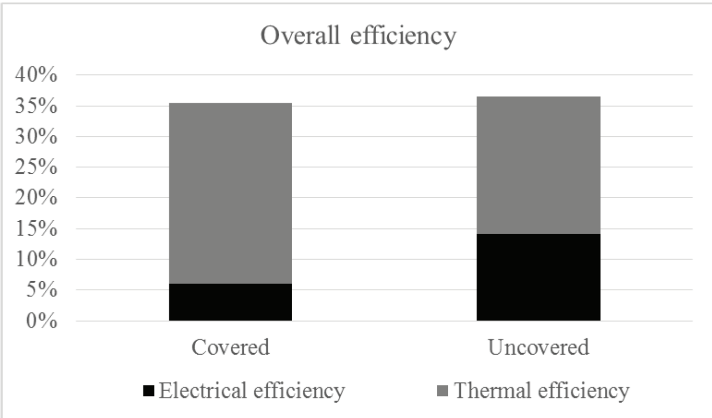

Fig. 2. Overall PVT efficiency

More in detail, the annual electrical efficiency of the covered PVT is 6.0% while the uncovered collector has a daily efficiency of 14.2%. However, during the year, the covered collector is able to produce more thermal energy, with an annual efficiency equal to 29.4% (Fig. 2).

Nevertheless, the overall efficiency parameter described above may be misleading for the performance evaluation of the hybrid PVT component. It is, therefore, important to evaluate the annual performance of the two solar technologies in terms of primary energy (ηPES) [21], a useful parameter that allows to compare electrical energy with thermal energy. Such parameter can be calculated as follows:

$$\eta_{PES} = \eta_{th} + \eta_{el} / \eta_{Tpower} \quad (1)$$

where ηth is the thermal efficiency, ηel is the electrical efficiency and $\eta Tpower$ is the average generation efficiency of electricity of the national power system. It depends on the mode whereby the electric energy is generated in every reference context. For example a value of 0.46 corresponds to the typical fuel mix system for electricity production in Italy [22].

Therefore, results show that the covered collector is able to convert solar energy into primary energy with an annual efficiency of 42.3%, while the uncovered reach value of 52.6%. Of course, the results are mainly related to different adopted PV technology. In fact, although μc-Si usually has a lower cost per watt peak if compared to other technologies [23], it is generally characterized by a lower electrical efficiency [10].

However, it is important to note that, since, thermal annealing has not been yet translated into an analytical formula, the present work doesn't take into account possible regeneration phenomena, known as thermal annealing, which, as already said, could increase the electrical production of the PVT component up to 10% [11].

Moreover, analyzing the electrical and the thermal energy production, related respectively to the peak power and aperture area of each collector (Fig. 3), it is interesting to note that the covered collector is more effective during cold month, when the heating demand from residential building is generally higher. In fact, the glass cover is able to reduce the thermal losses, increasing the outlet fluid temperature and hence the thermal energy production (up to 84% in comparison to uncovered collector). At the same time, however, during winter, the electrical performance of the collector covered by glass is relatively lower than the uncovered one, since the transmittance properties of glass, change according to the incidence angle of the radiation. In particular, larger is the angle between incident radiation and the perpendicular to the glass surface, higher is the reflected fraction.

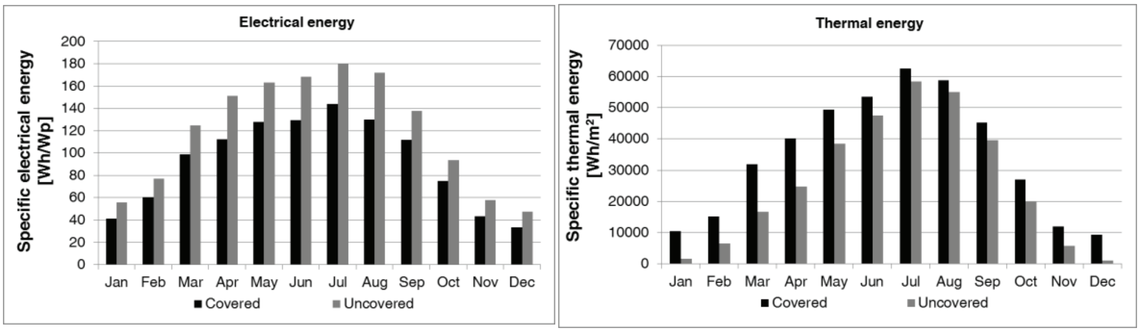

Figure 3. Specific electrical (left) and thermal (right) energy

5. Conclusion

PVT systems can contribute in the near future to cover fossil fuels energy consumption, in particular for building applications, where the available surfaces are often limited and electricity needs as long as hot water demands are considerable. A number of collectors exist, but the most investigated one in recent time is based on systems using water as heat transfer fluid. For that reasons the proposed work is aimed to assess, under the energy point of view, a comparison between a covered and an uncovered PVT water collectors, the most widespread types, realized with different PV cells embedded in two aluminium roll-bond absorber characterized also by different channel arrangement. The results of the energy simulation demonstrated that both module have almost the same overall efficiency. However, in terms of primary energy efficiency, the uncovered collectors is more effective than the covered one. Of course the result is due to the PV technology of the uncovered module, which has an higher efficiency. However the thermal performance of the covered collector is always higher than the uncovered collector, especially during winter season, in which the energy demand for heating and DHW is prevailing. Finally, in order to choose the most effective technology, a detailed analysis of the heating, cooling and DHW consumption should carried out.

6. Copyright

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Biography

Fabrizio Leonforte is a research fellow at Department of Architecture, Built environment and Construction engineering. He has carried out different theoretical and experimental works on renewable energy and energy efficiency in buildings. He has been also involved as advisor in national and international researches as well as in different project with NGOs and Universities for capacity building of local staff.