TEST STAND SOLUTION FOR PHOTOVOLTAIC THERMAL HYBRID SOLAR COLLECTORDEVICES UNDER REAL OPERATING CONDITIONS

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ABSTRACT: Today the market is open to new solutions that integrate solar thermal and photovoltaic (PV) devices into a single element in order to generate electricity and thermal energy, the so-called photovoltaic thermal (PVT) hybrid solar collectors, or simply hybrid modules. The PVT modules can improve the performance of the PV part due to the cooling of PV cells. A test-stand for hybrid PVT systems was design to develop new solutions and for better understanding their performance under real operating conditions. An innovative low-cost prototype of PVT module was developed using a radiant pipe system with a liquid heat-transfer medium used to cool photovoltaic cells. To improve the module design and to check their thermal behaviour for typical domestic hot-water systems, two different PVT solutions were compared with an identical PV module without the heat transfer system. The new stand test was used in order to test the overall performance of the modules. The characteristics of two different collector types are here described by the authors.
Keywords: Photovoltaic thermal hybrid solar collector; PVT Module; PV-Hybrid; Solar Thermal System comfort

1 INTRODUCTION

The photovoltaic thermal (PVT) energy is obtained removing heat from photovoltaic (PV) cells that reach temperatures above 40°C and 50°C (Tnoct) during the electricity generation, keeping them cooled. The performance of a PVT system strongly depends on the system configuration (type of fluid used, the different material layers that compose the whole system, circuit connection mode and the cooling system, module dimensions, PV technology), operating parameters (flow rate) and of course climatic parameters (air temperature and irradiation).

Fluid temperatures that can be achieved with the most efficient systems vary between 30°C and 60°C depending on the PV technology used. The most basic and simplest way to build a PVT panel is coupling the back of a PV panel to a heat exchanger. The fluid circulation on the back of the PV panel allows cooling it and the thermal energy removed is then transferred into a thermal storage tank to be used in low temperature thermal applications (e.g. pre-heating domestic hot water, heating systems, increasing the efficiency of a heat pump, etc.). The energy produced by the system is used for the building energy consumption demand.

This paper is a summary of what has been achieved, within Framework Agreement between CNR and the Lombardy Region (Italy), WP5 "Testing and development of new technological solutions by using renewable sources". A research project is being carried out at IRcCOS with the aim of designing and development of an economic, cost-effective, prototype of a new PVT collector.

The purpose of this research project was to check the feasibility of a new PTV module self-assembled with cheap materials and components usually available in the building industry, easily adapting also to existing PV plants and different sizes of PV panels. In the experiment electrical and thermal parameters were monitored in order to verify the effectiveness of a higher PV panel electrical efficiency.

The conceptual design of a new cost-effective PVT component and the first test in order to assess the best cooling plate configuration is presented here.

2 BACKGROUND

Political statements and directives are aiming already towards zero-energy buildings building with zero net energy consumption and zero carbon emissions annually [1, 2]. Energy can be harvested on-site — usually through a combination of energy producing technologies while reducing the overall building consumption, also using high efficiency technologies for conditioning and lighting. Strive for energy autonomy and for the reduction of greenhouse gases emissions leads to see the importance of using solar technology in buildings. In the future to achieve these goals the area available for integrating solar devices will become more and more important and there will be a need of a seamless integration of these technologies in buildings. Furthermore, one key points of sustainability is the need for an increase in the densification of the built environment. Architecture models are shifting towards new solutions that increase densification however; it means a reduction in the area per person that can be used for on-site renewable energy generation from the solar resource. Major space requirement to have a photovoltaic array and solar water heater side-by-side on multi-family housing may not be achievable in high-density cities.

These concerns have begun to raise awareness on new energy technologies' development. PVT solar collectors collect solar radiation in order to produce simultaneously electricity and thermal energy in a single device reducing space. In the late 1970s however, numerous research studies tried to match PV and solar thermal into a single device. Research about these issues deepens trying to develop new marketable solutions [3-8].

Moreover in a PVT system, the heat exchanger helps reducing the solar cells temperature increasing their efficiency and the output yield of the PV panel. It is worth noting that the yield of a PV module depends strongly on the solar cell technology, decreasing as its temperature increases. High values of temperature coefficients crystalline silicon, c-Si (ca. -0.5%/°C for the maximum power Pmax) reduce considerably power losses at typical operating temperatures that may get higher for fully integrated installations. PVT with the same exposed surface allows reducing the average modules operating temperature, thus reducing the loss of power.

3 COST EFFECTIVE PVT PROTOTYPE - DESIGN AND DEVELOPMENT

3.1 Approach

Most of the water-cooled PVT panels in the market today are based on the assumption of cooling the PV cells removing heat through a circuit in which the heat transfer fluid circulates. For the cooling system copper pipes or "roll bond®" panels are usually used on the back of the PV module; these are custom made expensive materials. These cooling systems may be placed either in direct contact with the Tedlar or welded on a copper or aluminum plate so as to increase the heat exchange surface area.

After the analysis of different PVT modules available in the market, it has been decided to develop the new PVT prototype with low cost materials easily available on the market and easy to handle. To create the absorber plate it has been decided to use dry radiant systems components. These systems are composed by insulated polystyrene pre-shaped panels which are laid on thin galvanized steel slats for heat distribution with 0.5 mm thickness (figure 1). The steel slats are equipped with a groove to accommodate the piping. The panel-slats-tube set was placed on the back of the module in order to collect and transfer the greatest amount of thermal energy to the heat transfer fluid. The polystyrene ensures a high thermal insulation minimizing heat losses. In order to ensure a perfect adherence between the whole elements a plywood was added. The entire package is then kept under pressure through a tie rods tubular steel system to ensure that the "cooling" surface keeps in contact to the PV panel so as to maintain always the highest heat exchange surface.

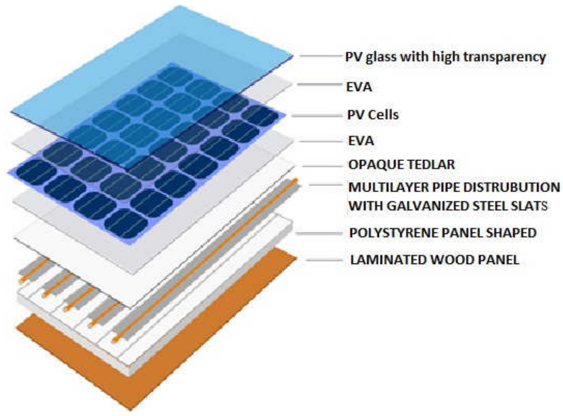
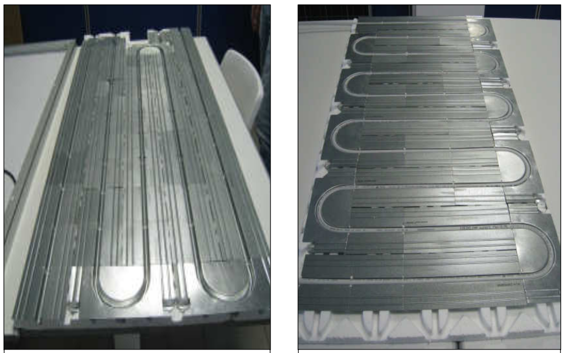


Figure 1: Prototype PVT package scheme. Heat absorber materials and components using multilayers pipes with DN10 (14x2 mm) diameter and 0.5 W/mK of thermal conductivity.

Two different types (PVT_1 and PVT_2 in figure 2) of heat absorber were constructed so as to identify the best configuration of coils. The best solution of the two PVT developed was then checked with the same PV module without the heat transfer system and in future with other PVT panels available in the market today.



PVT_1	PVT_2

Figure 2: Two versions of the heat thermal absorbers (Module PVT_1 and PVT_2) with different polystyrene shaped panel and slat galvanized steel heat diffuser configuration.

The two version PVT prototype as presented above were monitored on the 17th of May 2012. The following parameters were measured:

- Instantaneous radiation measured with a pyrometer (every second);
- Ambient temperature: Ta;
- Electrical performance of each PVT modules (Isc, Voc), IV curve, the power-voltage or P-V (every second);
- Water parameters: flow, input temperature Tin, output temperature Tout for both modules;

3.2 Test facility for testing PVT components

In order to test a new PVT prototype panel and to compare the performance with other solutions, a hydraulic circuit with two different loops was installed between the fifth floor and the terrace of the IRcCOS headquarters building. The design layout of the circuit system and the scheme of the test ring are shown in figure 3.

Figure 3: Stand Test Facility at Tecnocity Alto Milanese IRcCOS headquarters.

The circuit system is equipped with a storage tank of 300 L (figure 3) where in the lower level a double feed fully indirect coil type is integrated, for the thermal exchange with the PVT panels, while in the upper part an indirect coil is connected to a cooling system to cool the fluid in the storage system. The primary circuit, through actuated valves, is divided into two independent loops that run direct to the panels. For both circuits, a fixed speed circulating pump is used. Exploiting a secondary hydraulic circuit that uses a small mini chiller it is possible to break down and quickly adjust the fluid temperature inside the tank. This solution is very important both to avoid possible overheating phenomena of the storage tank and to define with precision the set-point of the fluid temperature to cool the PVT panel. Each loop of the test-stand is equipped with flow-meters for volumetric flow measurement and Pt100 resistance thermometers by immersion wells. Full description of test facility and cost-effective PVT prototype was presented by authors in [9].

4 MONITORING RESULTS

4.1 Set-up for monitoring campaign

An outdoor measurements campaign was carried out on the two version's prototype. A computer based real time monitoring system was installed to measure the thermal and electrical performance of the system. Three systems were analysed and monitored in different days on September 2011 and on May 2012. The experimental set-up and test facility described above allows a complete performance evaluation of different PVT hybrid solar devices under real weather conditions.

Table 1 and figure 4 show the thermal and electrical power output by the PVT module prototype on the same test day, compared to the analogous PVT module with different heat thermal absorber circuit. As the charts show, PVT_1 prototype electrical and thermal power production (absorber plate disposed in longitudinal in PV module) is higher than PVT_2 version prototype (absorber plate arranged transversally). PVT_1 electrical efficiency is only 0.4% higher however thermal efficiency is 6.7% higher.

Table I: Thermal and electrical power output by the two version of PVT module prototype under real environmental conditions, on almost clear-sky condition on May 17 2012.

17/05/2012	PVT_1	PVT_2
Electrical energy production [Wh]	827.06	796.89
Thermal energy production [Wh]	1753.09	1203.06
Heat removal factor FR [%]	23.59	16.20
ηel electrical efficiency [%]	10.02	9.66
ηth thermal efficiency [%]	21.23	14.58

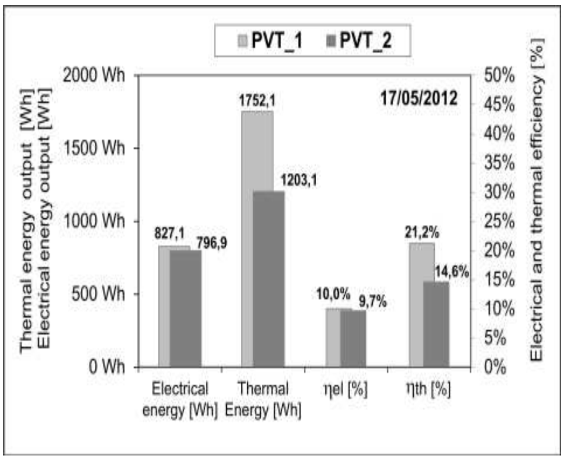


Figure 4: Thermal and electrical power output delivered by the two PVT solutions (PVT_1and PVT_2); Thermal and electrical efficiency of both PVT.

By using an infrared thermal imaging camera it was possible to note that the absorber plate in PVT_1 version was evenly heated while in PVT_2 version there was heated in a non-uniformly way. Thanks to thermography imagines it is possible to detect system failure and also localized overheating that could cause PV module efficiency losses (figure 5).

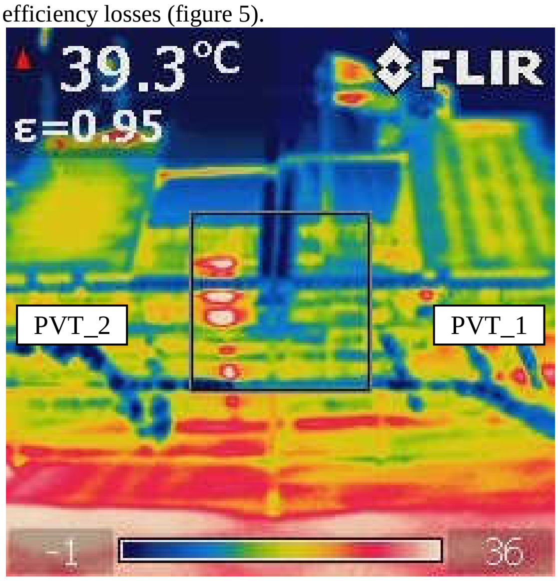


Figure 5: Infrared image of the two PVT prototypes. In PVT_1 version, the heat exchanger surface covers the whole PV surface homogenously while in PVT_2 version there is a part of the PV module not fully covered

4.2 Interpretation of results

Measurements in figures 6, 7 and 8, shows that the electrical power production of PVT_1 module is higher than PVT_2 prototype. Cumulative thermal energy production and useful heat delivered (q_u) also.

As the charts demonstrate and as it is possible to see in Table 1 and figure 4, the electrical energy yield of PVT_1 was 10% and PVT_2 slightly lower 9.7 %. Nevertheless the thermal efficiency or PVT_1 was about 21.2% while PVT_2 was 14.6%, 6.7% lower. The experiment demonstrates that PVT_1 module with longitudinal absorber plated heat distribution performs better.

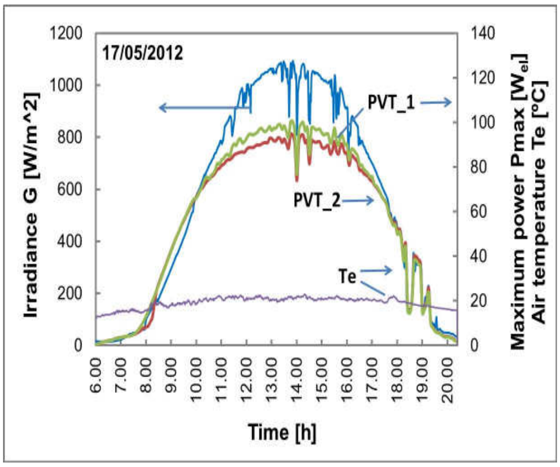


Figure 6: Comparison of the electrical power production of two solutions of a cost-effective PVT module under real conditions.

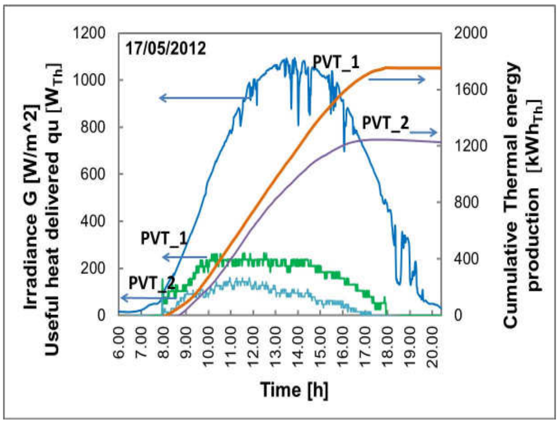


Figure 7: Cumulative thermal energy production of PVT_1 and PVT_2 module prototype, on May 2012.

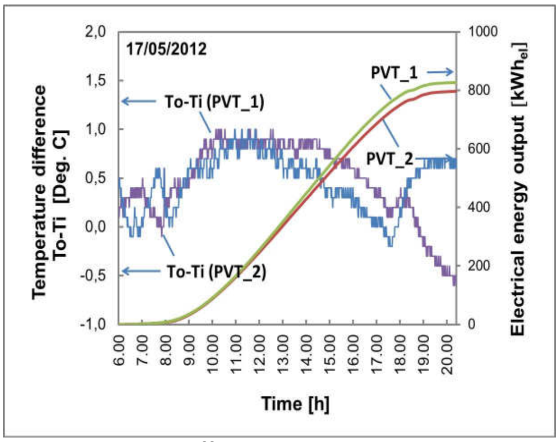


Figure 8: Fluid differential temperature between inlet and outlet; ambient temperature Ta and cumulative electrical energy delivered by the two PVT solutions (PVT_1and PVT_2).

5 CONCLUSIONS

A set of design parameters associated with the development of a new PVT solar collector have been proposed here by the authors. Two different version of a cost-effective prototype, using low cost materials from the building industry have been in order to determine the overall performance, and choose the best configuration. This paper shows the measured values of thermal and electrical efficiencies, the electricity and the thermal energy yield in one day compared with the available solar energy. A longer monitoring campaign is considered necessary to provide further information for better define performances of the new PVT prototype here presented, in terms of electric and thermal efficiencies under working conditions

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