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# An experimental comparison between commercial hybrid PV-T and simple PV systems intended for BIPV

M. Fuentes[a,*], M. Vivar[a], J. de la Casa[b], J. Aguilera[b]

[a] Grupo IDEA, EPS Linares, Universidad de Jaén, Linares 23700, Spain
[b] Grupo IDEA, Universidad de Jaén, Jaén 23071, Spain

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ABSTRACT

The idea of combining both thermal and photovoltaic collectors in hybrid photovoltaic-thermal (PV-T) modules actually shows a great potential for integration on facades and rooftops of buildings, mainly because of the reduced available space and the benefits of the on-site electricity and thermal generation. The objective of this work is to compare the real performance (experimental data obtained under real sun during a year) of a commercial hybrid PV-T system vs. a simple PV system using microinverters, assessing the suitability of one-unit hybrid PV-T systems vs. two separated units – PV systems + Thermal systems – for building integration. The combined efficiency over the span of a full day could reach values up to 80%, but this apparent high value needs to be analysed in detail. From the experimental results, it can be observed that both systems, PV and PV-T, have a good electrical performance. But the PV-T system output does not benefit from the lower module temperatures that it should achieve from the active cooling in its back, presenting the same performance as the simple PV system. Regarding the microinverters configuration performance, it has been very positive working with high efficiencies above 96%, justifying its use in this type of applications. In conclusion, the commercial PV-T system has not performed as expected, showing problems with the integration of the active cooling in the back of the PV modules. At this moment, and despite the potential of PV-T systems for BIPV due to space limitations, commercial PV-T systems are still far from PV and Thermal systems using separately.

## 1. Introduction

Hybrid photovoltaic-thermal (PV-T) modules aim to convert the solar energy into electrical and thermal energy, increasing the total system efficiency. A PV-T collector typically consists of a PV module with a heat extraction device attached on the back. The purpose of this heat extraction device is twofold: to cool the photovoltaic (PV) module and thus improve its electrical performance; and to collect the thermal energy produced, which would have otherwise been lost as heat to the environment. This collected heat could be used for low temperature applications. There is a crucial problem for the optimal exploitation of PV-T technology. The electricity production from PV cells is favoured by low temperatures, whereas the usability of the thermal energy gets higher at high temperatures. The first systematic research into the possibilities of combining photovoltaic and solar thermal techniques was performed in the early 1980s by a group at MIT. A major research and development work on the PV-T hybrid technology has been done since last 30 years. The scientific literature shows a wide number of studies with research and development in solar PV-T technology: general design and technology [1–3], flat plate solar PV-T [4], performance and applications [5] and performance and simulation [6].

As it is a new technology in the early stages of commercialisation, there is a lack of specific standards and certifications, mainly due to the gap on real performance of these PV-T collectors. Policies from governments, with reduced incentives for manufacturers, and low acceptance from final users, are hampering their widespread and full commercialisation now. There are technical studies that could serve as an initial basis for the full development of standards and certification to guarantee performance and to increase the final user acceptance [7]. The standards used to test these systems have been EN 12975-1,2 [8] and ISO 9806 [9] for solar thermal collectors and IEC 60904-1,2 [10,11] for photovoltaic modules. Nevertheless, standard EN 12975-1 has been revised to restructure it and include an extension of the applicability of the standard to cover PV-T collectors [12] and it will been publish soon.

The objective of this experimental work is the comparison the real performance of a fully commercial hybrid PV-T vs. a purely PV system, considering that no studies about this case working integrated in a

* Corresponding author.
*E-mail address:* mfuentes@ujaen.es (M. Fuentes).

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**Nomenclature**

| | |
|---|---|
| $T_{amb}$ | Ambient temperature *(°C)* |
| $T_{envHtop}$ | Top envelope hybrid temperature *(°C)* |
| $T_{envPVtop}$ | Top envelope PV system temperature *(°C)* |
| $T_{m1}$ | Back PV module 1 temperature *(°C)* |
| $T_{inlet}$ | Inlet module PVT temperature *(°C)* |
| $T_{inlet\_tank}$ | Inlet tank temperature *(°C)* |
| $T_{envHbott}$ | Bottom envelope hybrid temperature *(°C)* |
| $T_{envPVbott}$ | Bottom envelope PV system temperature *(°C)* |
| $T_{m2}$ | Back PV module 2 temperature *(°C)* |
| $T_{outlet}$ | Outlet module PVT temperature *(°C)* |
| $T_{tank}$ | Tank temperature *(°C)* |
| $T_{in}$ | Inlet temperature *(K)* |
| $T_{out}$ | Outlet temperature *(K)* |
| $T_O$ | Reference temperature *(K)* |
| $Q$ | Flow rate – Hybrid system *(l/s)* |
| $\dot{Q}_t$ | Useful thermal power *(W)* |
| $\dot{m}$ | Water mass flow rate per unit area *(kg/s/m²)* |
| $c_p$ | Specific heat of water *(J/kg K)* |
| $\dot{E}_Q$ | Thermal exergy rate *(W)* |
| $\eta_O$ | Thermal Efficiency |
| $G_i$ | Solar irradiance |
| $W_S$ | Wind speed *(m/s)* |
| $P_e$ | Electrical power *(W)* |
| $V_{MOD,M}$ | Maximum Voltage *(V)* |
| $I_{MOD,M}$ | Maximum Current *(A)* |
| $V_{MOD,OC}$ | Open Circuit Voltage *(V)* |
| $I_{MOD,SC}$ | Short Circuit Current *(A)* |
| $V_{DC,PV1}$ | DC voltage PV module 1 *(V)* |
| $V_{DC,H1}$ | DC voltage Hybrid module 1 *(V)* |
| $I_{DC,PV1}$ | DC current PV module 1 *(A)* |
| $I_{DC,H1}$ | DC current Hybrid module 1 *(A)* |
| $I_{AC,PV1}$ | AC current PV module 1 *(A)* |
| $I_{AC,H1}$ | AC current Hybrid module 1 *(A)* |
| $V_{DC,PV2}$ | DC voltage PV module 2 *(V)* |
| $V_{DC,H2}$ | DC voltage Hybrid module 2 *(V)* |
| $I_{DC,PV2}$ | DC current PV module 2 *(A)* |
| $I_{DC,H2}$ | DC current Hybrid module 2 *(A)* |
| $I_{AC,PV2}$ | AC current PV module 2 *(A)* |
| $I_{AC,H2}$ | AC current Hybrid module 2 *(A)* |
| $V_{AC}$ | AC voltage total (PV + PV-T) (V) |
| $A_{PV}$ | Photovoltaic area *(m²)* |
| $A_C$ | Collector area *(m²)* |
| $\eta_e$ | Electrical efficiency |
| $\eta$ | Module efficiency |

building have been found.

PV-T collectors can be flat plate or concentrating and are classified according to the type of the working fluid use. Fig. 1 shows different concepts of this type of hybrid modules. Flat plate thermal solar collectors are the most widely used in the world because of its low cost and easy and cheap maintenance [13] and they are an alternative promising system for low energy applications in residential, industrial and commercial building. Main studies highlight important factors in flat solar thermal collectors in last years [13] such as the effects of the heat sinking [14], the need of good thermal conductivity between the solar photovoltaic cells and the support structure [15,16], and the encapsulation method used (EVA degrades at high temperatures and in some cases it might not be suitable) [15]. The PV-T concept could be very effective, especially when using water as heat removal fluid [17]. Water flat plate PV-T collectors achieve higher overall efficiencies than air systems, due to the higher heat carrying capacity of water [18], and could be divided in two main categories:

- Covered PV-T collectors, characterized by the presence of an air gap between the transparent frontal cover and the absorber, in which a large amount of thermal energy can be produced, with a concurrent rise of the cell temperature, which can compromise the electrical performance.
- Uncovered PV-T collectors, where no air gap is present above the absorber; such collectors produce water at a lower temperature and reduce the overheating for the photovoltaic cells, obtaining higher electrical efficiency, despite the fact that less thermal energy is usually exploited compared to covered components.

Regardless of the lower overall efficiency, the most common product on the market is the latter [19,20]. For PV-T liquid systems, several manufacturers have tried to develop a PV thermal module, but this has not led to large-scale commercial manufacturing. Several reasons can be brought up to explain this. First, very little has been published on PV-T system and production technology, indicating that this area has scarcely been investigated. Secondly, there is very little experience with PV-T products. Good market research is necessary, especially as PV-T combines aspects of both PV and of solar thermal and these two market fields are quite different. A third reason could be that many of the companies that were involved in the PV-T initiatives were taken over by companies that did not place PV-T in their product range [1]. The main bottlenecks for the commercialisation of PV-T products are the lack of economic viability, public awareness, product standardization, warranties and performance certification, installation training and experiences. It is important for the reliability of the technology to be thoroughly assessed with more practical research for widespread its commercial acceptance [3,4]. In fact, it is possible to find recently reviews about the state of development of PV-T technology around the

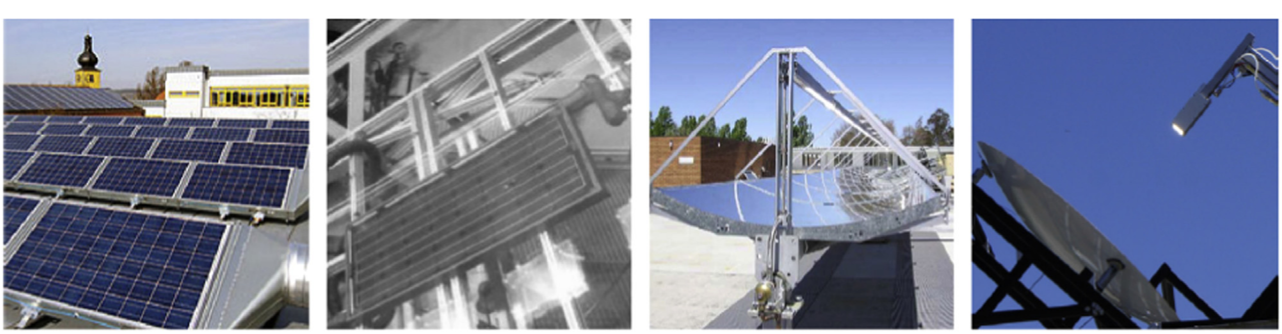

**Fig. 1.** From left to right: hybrid modules with air collector; hybrid modules with active cooling (water); hybrid modules with low concentration collectors; hybrid modules with high concentration collectors [7].