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**Report: 30.3734.0-03-EN**  
**COMPARATIVE PHOTOVOLTAIC**  
**PERFORMANCE TESTS PVT COLLECTOR**  
**vs. PV MODULE**

**PHOTOVOLTAIC SOLAR ENERGY DEPARTMENT**  
**NATIONAL ENERGY RENEWABLE CENTRE (CENER)**

**PAMPLONA**

Ciudad de la Innovación 7  
31621 Sarriguren  
(Navarra) España  
T +34 948 25 28 00

**SANGÜESA**

Polígono Industrial  
Rocaforte G2-H1  
31400 Sangüesa  
(Navarra) España  
T + 34 948 87 17 45

**AOIZ**

Urbanización Área de  
Reparto Ar-3,  
31430 Aoiz (Navarra)  
España  
T + 34 948 80 24 12

**SEVILLA**

Pabellón de Italia  
C Isaac Newton nº 4  
Módulos A y B  
41092 (Sevilla) España  
T +34 902 25 28 00

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**Title:** COMPARATIVE TESTS PVT COLLECTOR  
vs. PV MODULE

**Code:** 30.3734.0-03-EN

**Report Emission Office:** Pamplona

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**Customer:** FEGEN SOLAR LLC.

**Contact:** Christos Nikolaidis

**Address::** 31, Pentelis Av.  
15235 Vrilissia,  
Athens (GREECE)

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**Written by:** Ildfonso Muñoz Technician  
Juan Manuel Cuadra Technician

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**Checked by:** Jaime Moracho PV systems Head of Service

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**Approved by:** Dra. Ana Rosa Lagunas PV Department Director

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# 1 EXECUTIVE SUMMARY

## 1.1 PRELIMINARY

This report is compiled according to the conditions laid in the offer No. 30.3734.0 presented to **FEGEN SOLAR LLC**, dated 12/03/2020.

## 1.2 OBJECT & SCOPE

The purpose of this report is to present the results of the comparison between the electrical performance of an individual PV module and the same type of module as being part of a PVT collector during their outside exposure for a full **autumn** day. This test has been done at two different tilts (5° and 35°). From the point of view of photovoltaic performance, both devices have been operating at their maximum power point system conditions (MPPT) during the test period. The PVT collector has been operated with a water flow across the heat exchanger for the duration of the tests. The PV module and the PVT have been electrically characterized including Electroluminescence technique before and after the exposure.

The results presented in this report relate only to tested samples with serial numbers listed in section 2.1 SAMPLES DESCRIPTION.

## 1.3 CONCLUSIONS

Following, summary results of PR and Efficiency for both tilts are presented in next table.

Sample	Tilt: 5° Date: 21/11/2020 Measurement Period: 6 h		Tilt: 35° Date: 22/11/2020 Measurement Period: 8 h	
	Performance Ratio PR (%)	Device Efficiency $\eta$ (%)	Performance Ratio PR (%)	Device Efficiency $\eta$ (%)
<b>30.3734.0-001</b> <b>FEGEN PVT</b> <b>CSK6-16PS.</b>	97.6%	17.4%	97.2%	17.4%
<b>30.3734.0-003</b> <b>CANADIAN SOLAR</b> <b>CS6K-295MS</b>	94.3%	16.8%	94.9%	17.0%

**Table A** Summary results of PR and Efficiency for a full day.

- Related to the location where these tests are performed, for the two tilts used (5° and 35°) as could be expected higher values of irradiation and energy production were

reached at 35° of tilt for both devices (PV and PVT) in the considered measurement time period on each device.

- For a tilt of 5° the irradiation values measured were quite low, due to the relative solar position with respect to the collector plane of the devices under study.
- High values of PR obtained must be carefully considered for the specific conditions of the measurement period of time, with a low ambient temperature.
- From a general point of view, for both cases under study (tilt of 5° and 35°) and considering the specific test conditions, daily values of energy production, PR and efficiency are slightly better in the PVT device; for PR in the range of 2%-3% and for efficiency about 0.5%.
- In the case of 35° of tilt, the effect of the temperature lower in the PVT device implies a slight increase of the energy production respect to the PV device. In the case of 5° of tilt, daily values show the same correlation that in 35° tilt case. However, some instantaneous measurements obtained might be unexpected, probably due to low values measured and its associated uncertainties.

After the exposure, the PV module and the PVT are characterized with the Performance at STC test and Electroluminescence:

- No changes are observed in the electrical parameters of the PV module and the PVT. The maximum power values show a variation of +0.1% and -0.3% in each sample, taking into account that the estimated uncertainty of the measurement of the maximum power is around 2.2 – 2.5%.
- No new defects are detected in the EL images of both samples after the exposure. The defects observed in the previous characterization remain unchanged.



## 2 TECHNICAL REPORT

### 2.1 SAMPLES DESCRIPTION

REFERENCE DATA			
Number of samples		2	
Reception date of samples		25/05/2020	
Test period		28/10/2020 – 04/01/2021	
TESTED SAMPLES DESCRIPTION			
INTERNAL CODE	MANUFACTURER	MODEL	SERIAL NUMBER
30.3734.0-001	CANADIAN SOLAR & FEGEN	CS6K-295MS (PV MODULE)	11810481170589
		P-FHE16PS (THERMAL COLLECTOR)	100122190621
30.3734.0-003	CANADIAN SOLAR	CS6K-295MS	11810481170711
ELECTRICAL CHARACTERISTICS			
MODEL		CS6K-295MS 30.3734.0-001	CS6K-295MS 30.3734.0-003
TYPE OF MODEL		PVT collector	Standard PV module
Maximum power ( $P_{MP}$ ) .....		295 W	
Short-circuit current ( $I_{SC}$ ) .....		9.75 A	
Open-circuit voltage ( $V_{OC}$ ) .....		39.5V	
Current at maximum power ( $I_{MP}$ ) .....		9.14 A	
Voltage at maximum power ( $V_{MP}$ ) .....		32.3 V	
Maximum voltage system .....		1000 V	
Short-circuit current temperature coefficient ( $\alpha$ ) <sup>1</sup> .....		5.17 mA/°C	
Open-circuit voltage temperature coefficient ( $\beta$ ) <sup>1</sup> .....		-118.5 mV/°C	
Maximum power temperature coefficient ( $\gamma$ ) .....		-1150 mW/°C	
Maximum over-current protection rating .....		15 A	
1) The short-circuit current temperature coefficient ( $\alpha$ ) and the open-circuit voltage coefficient ( $\beta$ ) used in the performance at STC test have been obtained from the manufacturer datasheet. They can affect the validity of the results.			



CONSTRUCTIVE CHARACTERISTICS		
CELL CHARACTERISTICS		
Cell type reference .....	Monocrystalline cells	
Cell dimensions .....	156 mm x 156 mm	
MATERIALS		
Front cover .....	3.2 mm tempered glass	
Rear cover .....	Thermal collector	Standard substrate
Frame .....	Anodized aluminium alloy	
COMPONENTS IDENTIFICATION		
Junction box .....	IP67 3 diodes	
Cable .....	4 mm <sup>2</sup> & 12 AWG	
Connector .....	T4	
MODULE DESIGN – DIMENSIONS		
Module dimensions (width x length x height) .....	1650 mm x 992 mm x 40 mm	
Module area .....	1.64 m <sup>2</sup>	
Weight .....	22.2 kg	18.2 kg
MODULE DESIGN – ELECTRICAL CONFIGURATION		
Total number of cells .....	60	
Serial/parallel connection of cells.....	60/1	
Cells per bypass diode .....	20	
No. of bypass diodes .....	3	

**Table 1** Description of tested samples. Information obtained externally (not verified by CENER).



Brand Name	Heat Exchanger
Model	P-FHE16PS
Manufacturer	Fegen
Serial Number	100122190621
Maximum operation pressure	6 bar
Volume of heat transfer fluid	
Weight of empty collector	4 kgs
Gross area of collector	1.150 m <sup>2</sup>
Stagnation temperature at 1000 W/m <sup>2</sup> and 30 °C	70 °C
Dimension of collector	1550 x 960 x 18
Made in	Greece
Year of Production	2019

**Figure 1** Marking of CS6K-295MS model (standard module) and PVT collector



**Figure 2** Front cover of CS6K-295MS model

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## 2.2 CHARACTERIZATION TESTS

The samples have been characterized before and after the exposure with the following tests:

- **PERFORMANCE AT STANDARD TEST CONDITIONS (STC)** according to IEC 61215-1-1:2016 standard clause 11.6.

The test includes the I-V curve measurement of the module at Standard Test Conditions (STC:  $(25 \pm 2) ^\circ\text{C}$ ,  $1000 \text{ W/m}^2$  with AM1.5G spectral distribution).

The values presented correspond to the data corrected to STC so all of them are exactly at the same conditions.

- **ELECTROLUMINESCENCE CHARACTERIZATION** according to CENER internal procedure ME.511/36.

This technique with spatial resolution (pictures) allows identifying cells or defective areas within the module.

The measurement will be done at dark conditions, applying 2 different biasing conditions to extract the maximum information about the defects detected: (1) Biasing current close to the current at the maximum power point defined by the manufacturer ( $I_{\text{APPL1}} \approx I_{\text{SC}}$ ) and (2) a biasing current ten times below the current at maximum power point ( $I_{\text{APPL2}} \approx I_{\text{SC}}/10$ ).

The obtained results are depicted in the following clauses.

### 2.2.1 PERFORMANCE AT STANDARD TEST CONDITIONS (STC)

Results of performance of samples at Standard Test Conditions (STC) are summarized below.

TEST PARAMETERS					
MODEL	CS6K-295MS	TEMPERATURE COEFFICIENT OF $I_{SC}$	5.17 mA/°C	TEMPERATURE COEFFICIENT OF $V_{OC}$	-118.5 mV/°C

**BEFORE EXPOSURE**

TEST RESULTS									
TEST NUMBER	SERIAL NUMBER DATE	T	IRRAD.	$P_{MAX}$	$I_{SC}$	$V_{OC}$	$I_{MP}$	$V_{MP}$	FF
30.3734.0-001-MQT06.1FCEM-R004	11810481170589 28/10/2020	25 °C	1000 W/m <sup>2</sup>	292.2W ± 2.2%	9.54A ± 2.0%	39.8V ± 0.4%	8.99A ± 2.1%	32.5V ± 0.8%	76.9% ± 0.6%
30.3734.0-003-MQT06.1FCEM-R004	11810481170711 28/10/2020	25 °C	1000 W/m <sup>2</sup>	292.0W ± 2.2%	9.48A ± 2.0%	39.7V ± 0.4%	8.96A ± 2.1%	32.6V ± 0.8%	77.5% ± 0.6%

**Table 2** Performance at STC results (initial)

**AFTER EXPOSURE**


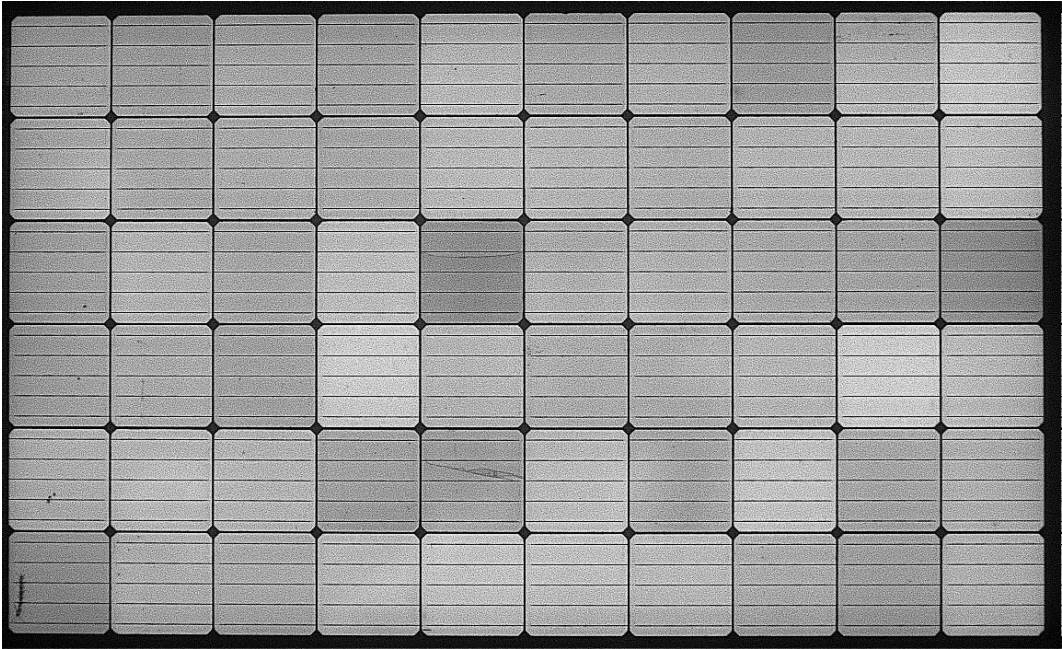
TEST RESULTS									
TEST NUMBER	SERIAL NUMBER DATE	T	IRRAD.	$P_{MAX}$	$I_{SC}$	$V_{OC}$	$I_{MP}$	$V_{MP}$	FF
30.3734.0-001-MQT06.1FCEM-R005	11810481170589 04/01/2021	25 °C	1000 W/m <sup>2</sup>	292.6W ± 2.3%	9.54A ± 2.1%	39.8V ± 0.4%	9.01A ± 2.3%	32.5V ± 0.8%	77.1% ± 0.6%
30.3734.0-003-MQT06.1FCEM-R005	11810481170711 04/01/2021	25 °C	1000 W/m <sup>2</sup>	291.1W ± 2.3%	9.46A ± 2.1%	39.7V ± 0.4%	8.96A ± 2.3%	32.5V ± 0.8%	77.5% ± 0.6%

**Table 3** Performance at STC results (after exposure)



## 2.2.2 ELECTROLUMINESCENCE CHARACTERIZATION

### BEFORE EXPOSURE

TEST PARAMETERS				
TEST NUMBER	SERIAL NUMBER	DATE	$I_{APPL.1}$	$I_{APPL.2}$
30.3734.0-001-EL.02ELDP-R004	11810481170589	28/10/2020	9.75 A	0.92 A
TEST RESULTS				
				
				
<b>Figure 3</b> High-biasing and low-biasing electroluminescence of module 30.3734.0-001				



TEST PARAMETERS

TEST NUMBER	SERIAL NUMBER	DATE	$I_{APPL.1}$	$I_{APPL.2}$
30.3734.0-003-EL.02ELDP-R004	11810481170711	28/10/2020	9.75 A	0.92 A

TEST RESULTS

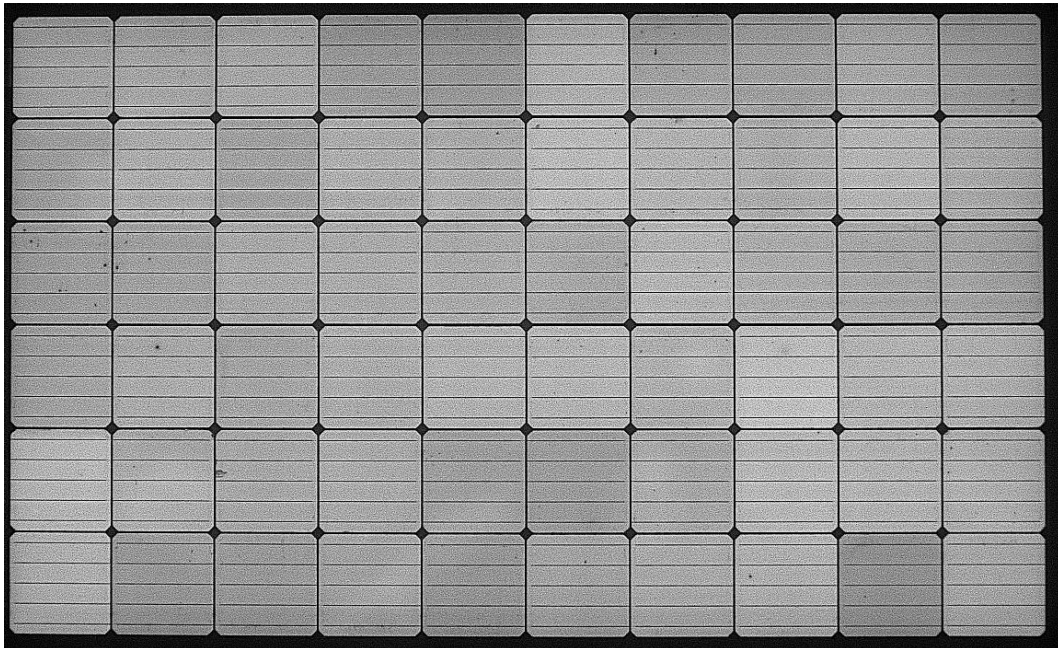
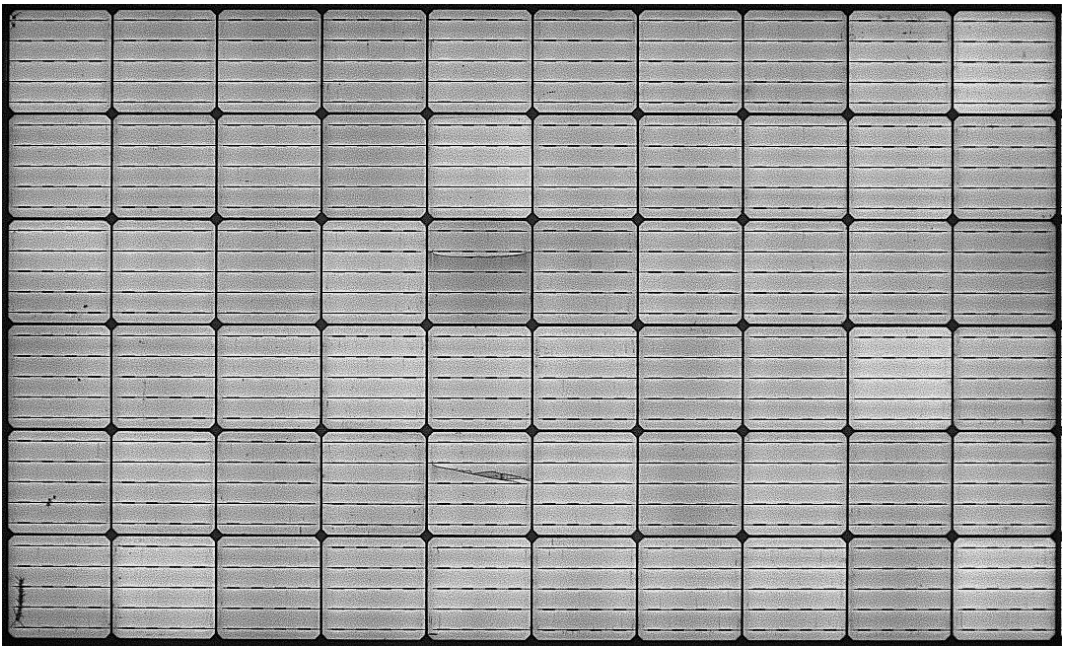
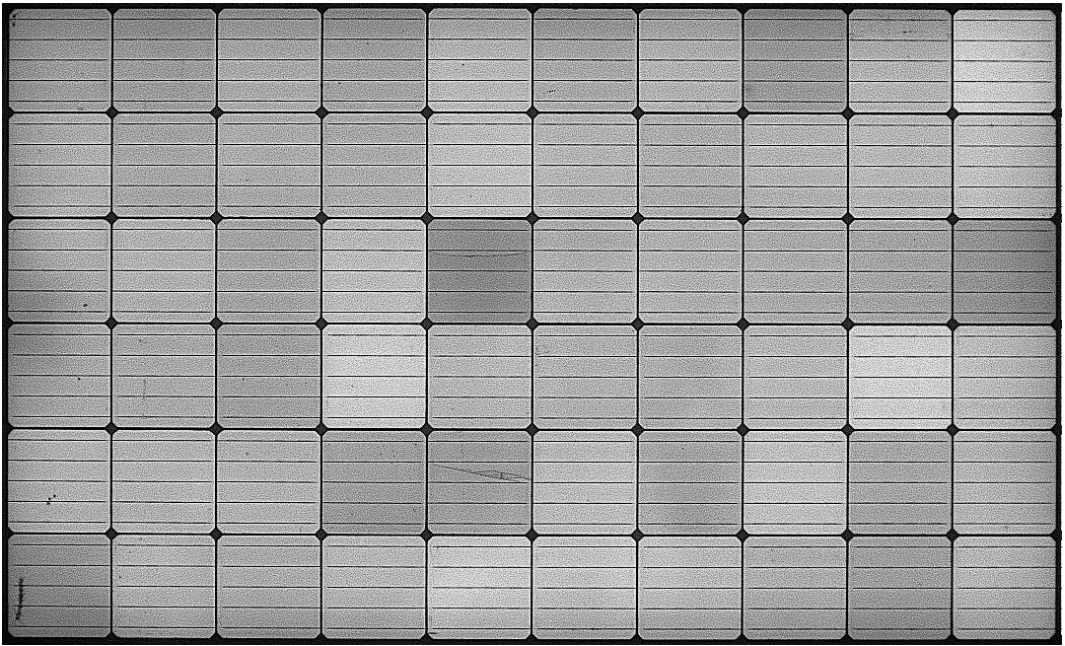



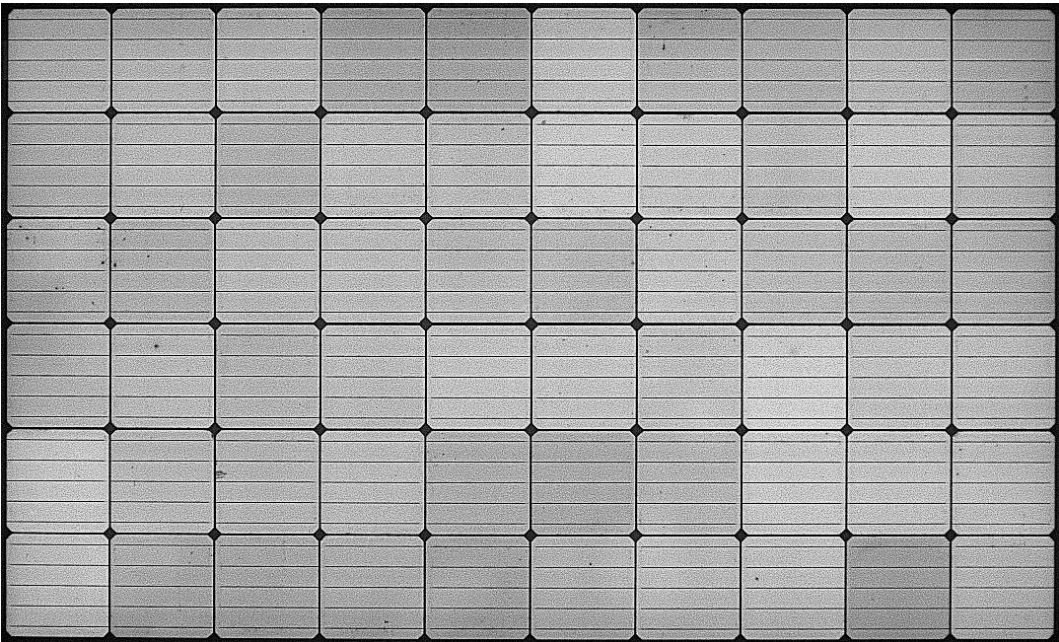
Figure 4 High-biasing and low-biasing electroluminescence of module 30.3734.0-003



## AFTER EXPOSURE

TEST PARAMETERS				
TEST NUMBER	SERIAL NUMBER	DATE	I <sub>APPL.1</sub>	I <sub>APPL.2</sub>
30.3734.0-001-EL.02ELDP-R005	11810481170589	29/12/2020	9.76 A	0.92 A
TEST RESULTS				
				
				
<b>Figure 5</b> High-biasing and low-biasing electroluminescence of module 30.3734.0-001				



TEST PARAMETERS				
TEST NUMBER	SERIAL NUMBER	DATE	$I_{APPL.1}$	$I_{APPL.2}$
30.3734.0-003-EL.02ELDP-R005	11810481170711	29/12/2020	9.76 A	0.92 A
TEST RESULTS				
				
				
<b>Figure 6</b> High-biasing and low-biasing electroluminescence of module 30.3734.0-003				

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### **2.2.3 TEST RESULTS SUMMARY**

#### **PERFORMANCE AT STC TEST**

No significant changes are observed in the electrical parameters after the exposure.

The maximum power of module 30.3734.0-001 shows a variation of +0.1% and the maximum power of module 30.3734.0-003 shows a variation of -0.3%.

#### **ELECTROLUMINESCENCE CHARACTERIZATION**

After the exposure, no new defects are detected in the EL images of both modules.

The defects observed in the previous characterization remain unchanged.

## 2.3 TEST METHODOLOGY

The methodology for the electrical performance comparison was the measurement the following parameters:

- irradiance over the collection plane ( $\text{W/m}^2$ ),
- devices temperature ( $^{\circ}\text{C}$ ),
- voltage (V) and current (A) generated in each sample.

After that, the following calculations were done for PV module and PVT collector:

- irradiation ( $\text{Wh/m}^2$ ),
- electrical power (W),
- energy generated (Wh),
- efficiency (%),
- performance ratio (%).

Finally, comparison of results for both devices was done in numerical tables and graphics.

From the point of view of a photovoltaic device, both modules have been operating at their maximum power point through the connection to a maximum power point tracking system (MPPT). In addition, heat exchanger of the PVT collector has been operated with a water flow across the heat exchanger for the full exposure time.



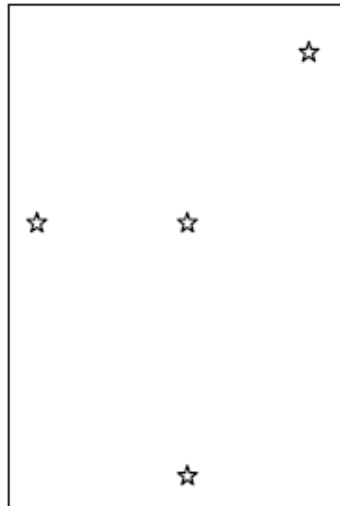
**Figure 7** Assembly of solar components at fixed tilt.  
Left, PV module. Center, Solar Thermal collector. Right PVT collector.  
Testing location: Sarriguren, Spain Latitude  $42,8^{\circ}$  Longitude  $-1,6^{\circ}$ .

This comparison was made during **autumn** season (21<sup>th</sup> and 22<sup>th</sup> of November) in two complete days (clear days or almost clear days with low wind speed). According to the client request, this

comparison of generated energy, efficiency and PR was performed at 5° and 35° of fixed tilt for the complete day. It should be noted that the sunlight hours of the measurement period were considerably shorter than in previous measurement periods (CENER reports 30.3734.0-01-EN and 30.3734.0-02-EN).

## 2.4 TEST CONDITIONS

Several parameters were monitored simultaneously for each sample such as solar irradiance, ambient temperature, sample temperature, DC output voltage and DC output current rate every 2 seconds. Sample temperature was calculated as average of the measures of four temperature probes (k-type thermocouple) placed at the rear side of the device according to IEC 60904-10 in order to obtain a representative average temperature for the whole device.



**Figure 8** Temperature probes placement at the rear side of the device, according to IEC 60904-10.

Following, maximum minimum and daily average test conditions reached for each day are shown.

Day 21/11/2020 – Tilt 5°				
Time Period 9:36:01 15:35:59	Global Irradiance $I_G$ (W/m <sup>2</sup> )	Ambient Air Temperature (°C)	PV Module Device Temperature (°C) (30.3734.0-001)	PVT Collector Device Temperature (°C) (30.3734.0-003)
Min.	239.3	5.6	9.9	14.8
Max.	536.4	15.5	31.4	23.9
Average	444.9	11.7	25.4	21.1

**Table 4** Data at tilt of 5° (21/11/2020).



Day 22/11/2020 – Tilt 35°				
Time Period 9:02:51 16:59:59	Global Irradiance $I_G$ (W/m <sup>2</sup> )	Ambient Air Temperature (°C)	PV Module Device Temperature (°C) (30.3734.0-001)	PVT Collector Device Temperature (°C) (30.3734.0-003)
Min.	194.6	0.3	7.2	14.6
Max.	873.9	13.7	45.5	31.5
Average	654.9	9.8	33.4	26.0

**Table 5** Data at tilt of 35° (22/11/2020).

## 2.5 RESULTS

In order to make a comparison, device efficiency during the exposure period has been calculated for both samples according to the expression shown below. Sample efficiency indicates the energy conversion ratio of the device between the total electrical energy generated versus the total solar energy collected in a specified period of time.

$$\eta = \frac{E}{H_G \cdot s}$$

Where:

- $\eta$ : Device efficiency (%).
- $H_G$ : Global irradiation on the collector plane during the considered period (Wh/m<sup>2</sup>).
- $s$ : Total effective surface of the energy conversion device (m<sup>2</sup>).
- $E$ : Electrical energy generated by the device during the considered period (Wh).

From the acquired data for each day, comparative graph and table energy values were analysed in order to compare electrical performance of both devices. In first place, Performance Ratio (PR) was calculated, taking into account the expression of the PR, according to IEC 61724-1 Ed.1. PR shows the difference between the real energy production and the expected energy production in a perfect condition without losses.

$$PR = \frac{E}{\frac{H_G}{I_{STC}} \cdot P}$$

Where:

- PR: Performance ratio (%).
- $E$ : Electrical energy generated by the device (Wh).
- $H_G$ : Global irradiation on the collector plane (Wh/m<sup>2</sup>).
- $I_{STC}$ : Reference irradiance at STC (Standard Test Conditions), value of 1000 W/m<sup>2</sup>.
- $P$ : Peak power of the photovoltaic device (W).



**NOTE:** Calculations of Global Irradiation ( $H_G$ ) and Electrical Energy generated (E) are made by integration of all measurements of irradiance and electric power registered each 2 seconds.

Tilt 5° – Day 21/11/2020; Time Period: 9:36:01 – 15:35:59					
Sample	Global Solar irradiation $H_G$ (Wh/m <sup>2</sup> )	Energy production E (Wh)	Performance Ratio PR (%)	Average Device Temperature (°C)	Device Efficiency $\eta$ (%)
30.3734.0-001 FEGEN PVT CSK6-16PS.	2669	761	97.6	21.1	17.4
30.3734.0-003 CANADIAN SOLAR CS6K-295MS	2669	736	94.3	25.4	16.8

Table 6 Results at tilt of 5° (21/11/2020).

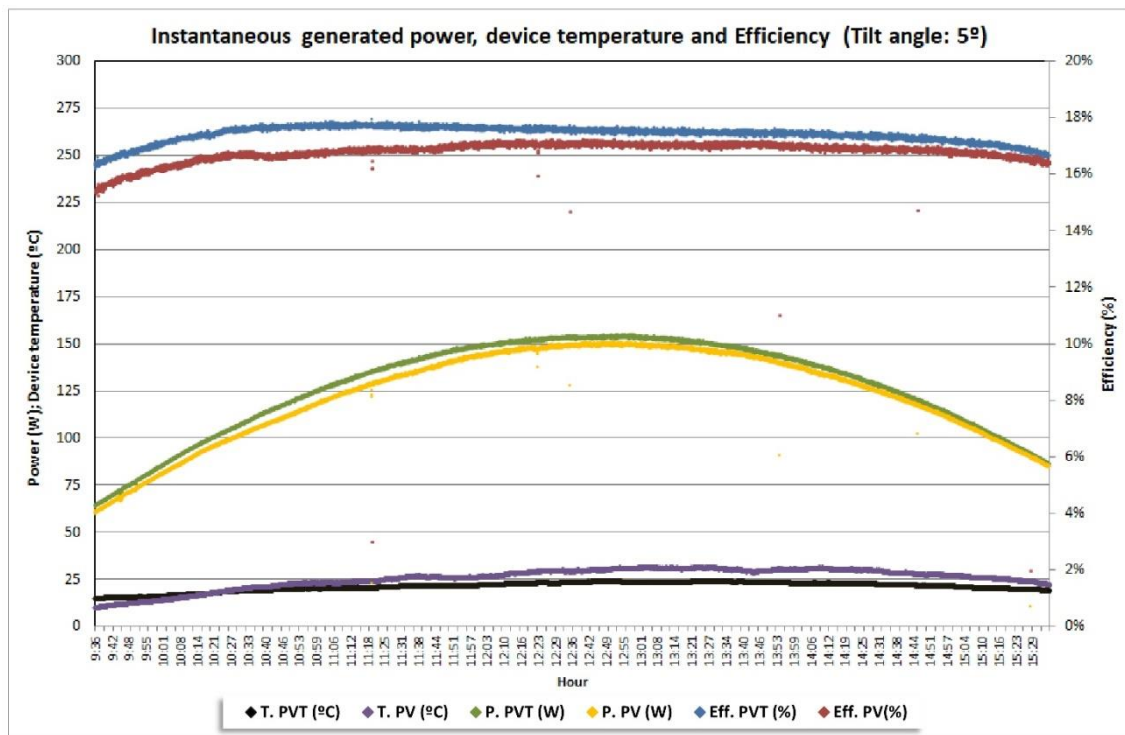


Figure 9 Comparative graph of electrical performance at tilt of 5° (21/11/2020).

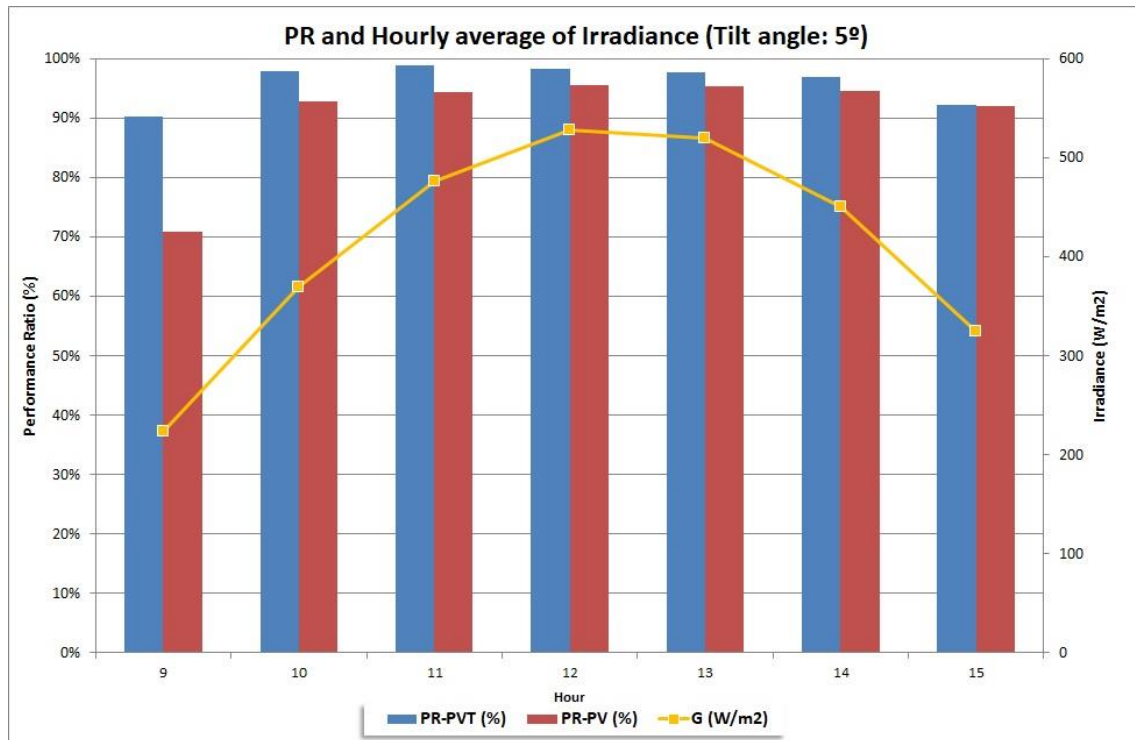


Figure 10 Comparative graph of PR at tilt of 5° (21/11/2020).

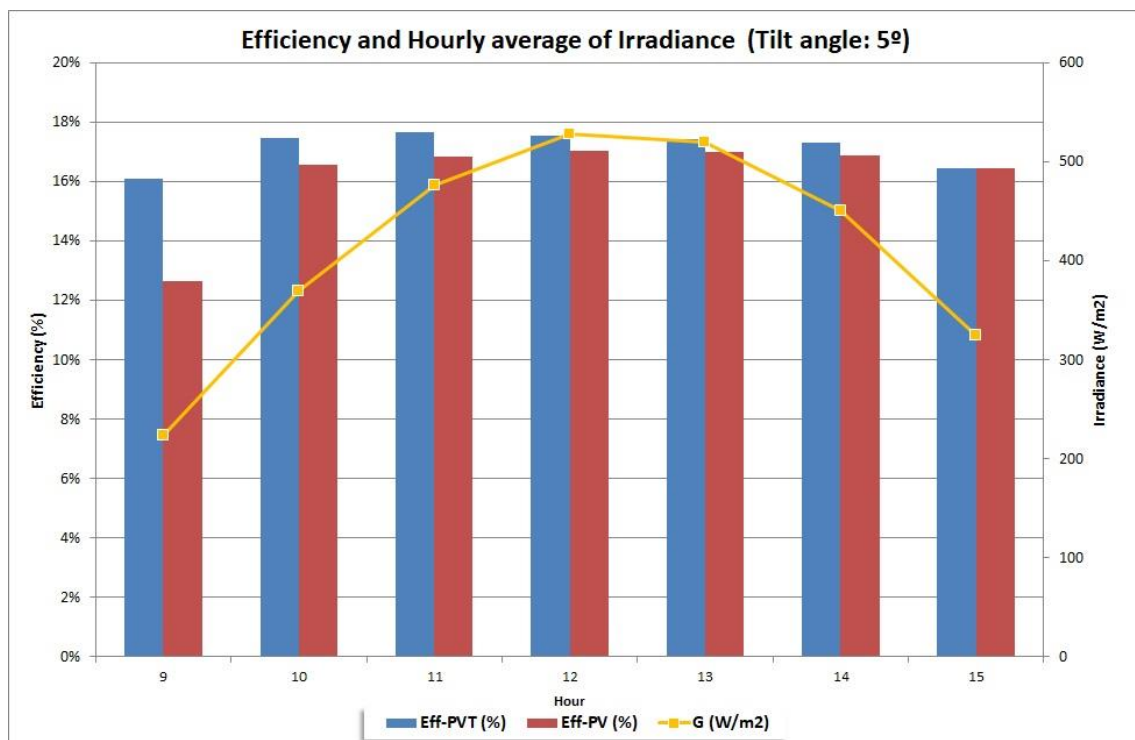


Figure 11 Comparative graph of Efficiency at tilt of 5° (21/11/2020).



Tilt 35° – Day 22/11/2020; Time Period: 9:02:51 – 16:59:59					
Sample	Global Solar irradiation $H_G$ (Wh/m <sup>2</sup> )	Energy production E (Wh)	Performance Ratio PR (%)	Average Device Temperature (°C)	Device Efficiency $\eta$ (%)
30.3734.0-001 FEGEN PVT CSK6-16PS.	5027	1479	97.2%	26.0	17.4%
30.3734.0-003 CANADIAN SOLAR CS6K-295MS	5027	1444	94.9%	33.4	17.0%

Table 7 Results at tilt of 35° (22/11/2020).

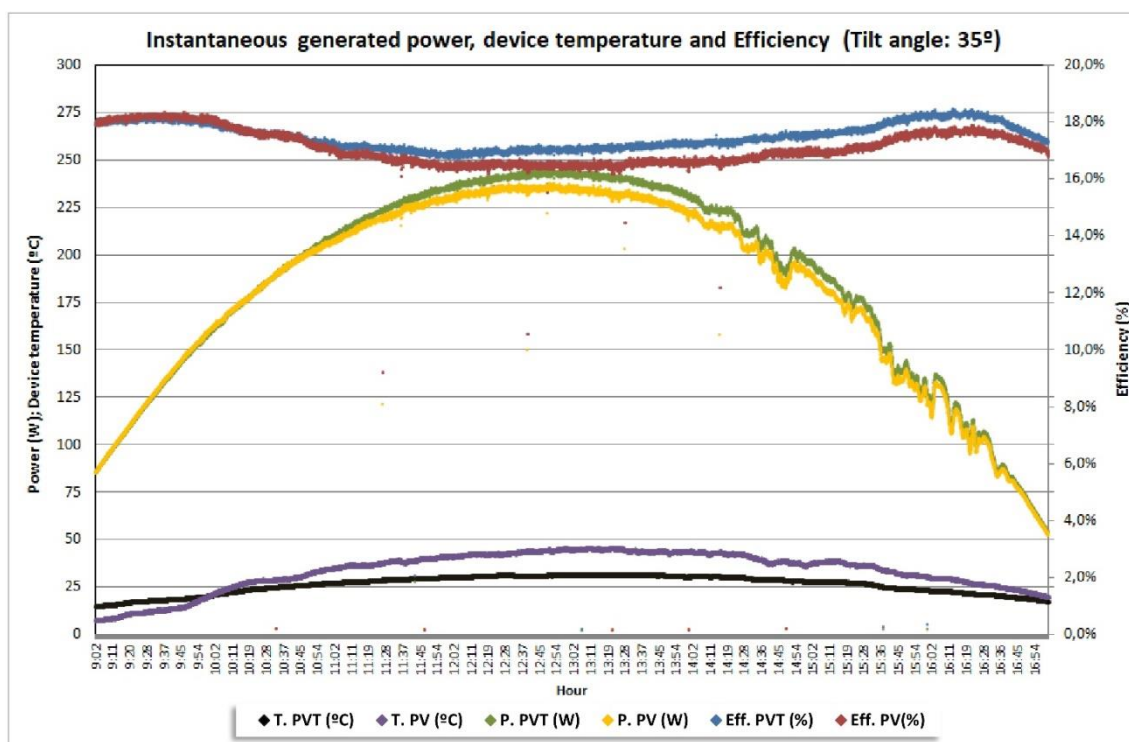


Figure 12 Comparative graph of electrical performance at tilt of 35° (22/11/2020).

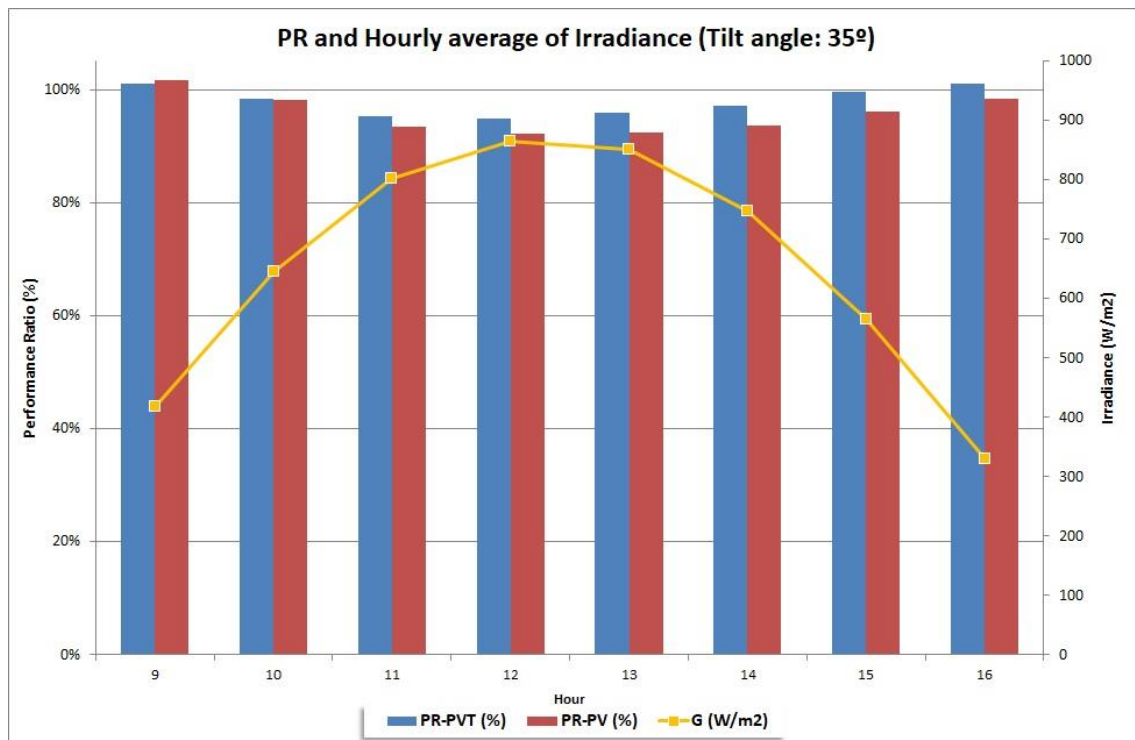


Figure 13 Comparative graph of PR at tilt of 35° (22/11/2020).

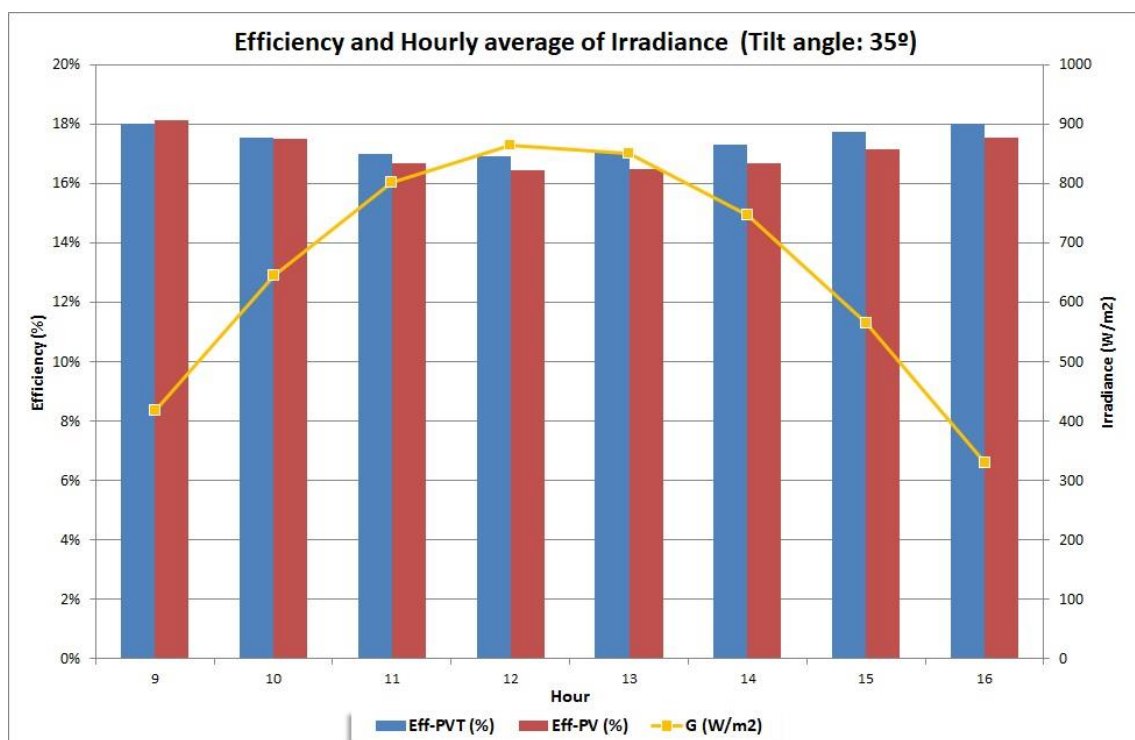


Figure 14 Comparative graph of Efficiency at tilt of 35° (22/11/2020).

Following, summary results of PR and Efficiency for both tilts are presented in next table.

Sample	Tilt: 5° Date: 21/11/2020 Measurement Period: 6 h		Tilt: 35° Date: 22/11/2020 Measurement Period: 8 h	
	Performance Ratio PR (%)	Device Efficiency $\eta$ (%)	Performance Ratio PR (%)	Device Efficiency $\eta$ (%)
<b>30.3734.0-001 FEGEN PVT CSK6-16PS.</b>	97.6%	17.4%	97.2%	17.4%
<b>30.3734.0-003 CANADIAN SOLAR CS6K-295MS</b>	94.3%	16.8%	94.9%	17.0%

**Table 8** Summary results of PR and Efficiency for a full day.

The main conclusions shown in this study are following exposed:

- Related to the location where these tests are performed, for the two tilts used (5° and 35°) as could be expected higher values of irradiation and energy production were reached at 35° of tilt for both devices (PV and PVT) in the considered measurement time period on each device.
- For a tilt of 5° the irradiation values measured were quite low, due to the relative solar position with respect to the collector plane of the devices under study.
- High values of PR obtained must be carefully considered for the specific conditions of the measurement period of time, with a low ambient temperature.
- From a general point of view, for both cases under study (tilt of 5° and 35°) and considering the specific test conditions, daily values of energy production, PR and efficiency are slightly better in the PVT device; for PR in the range of 2%-3% and for efficiency about 0.5%.
- In the case of 35° of tilt, the effect of the temperature lower in the PVT device implies a slight increase of the energy production respect to the PV device. In the case of 5° of tilt, daily values show the same correlation that in 35° tilt case. However, some instantaneous measurements obtained might be unexpected, probably due to low values measured and its associated uncertainties.

These conclusions can only be applied to the samples tested, same location and meteorological conditions of the day and time of the test.