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Solar Retrofit

ENERGY RATING OF SOLAR RETROFIT SYSTEM WITH TWO TYPES OF SOLAR REFLECTOR

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SUBJECT TEN MONTHS REPORT FOR SOLAR RETROFIT SYSTEM IN TREVANO

TITLE **ENERGY RATING OF SOLAR RETROFIT SYSTEM WITH TWO TYPES OF SOLAR REFLECTOR (SHORT VERSION)**

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INDEX

1 Introduction

This preliminary investigation has the goal to verify the impact of two types of solar reflector when installed in the Solar Retrofit system. Previous simulation study (elaborated in November 2012) demonstrated the potential of using a solar reflector to increase the insolation on the PV modules surface.

This monitoring campaign would like to investigate this potential under real conditions.

2 Solar Retrofit stand description

The photo of the stand is presented in fig. 1. According to the picture, two identical (in terms of electrical characteristics and dimensions) crystalline silicon modules were mounted at 30° inclination in two different rows, one on top (labelled **13-045/A/5/noRefl**) of the other (labelled **13-045/A/6/Refl**). Between the two modules a reflector was installed and on top of the 13-045/A/5/noRefl module a black panel was installed to simulate the similar shadows behaviour as the lower one.

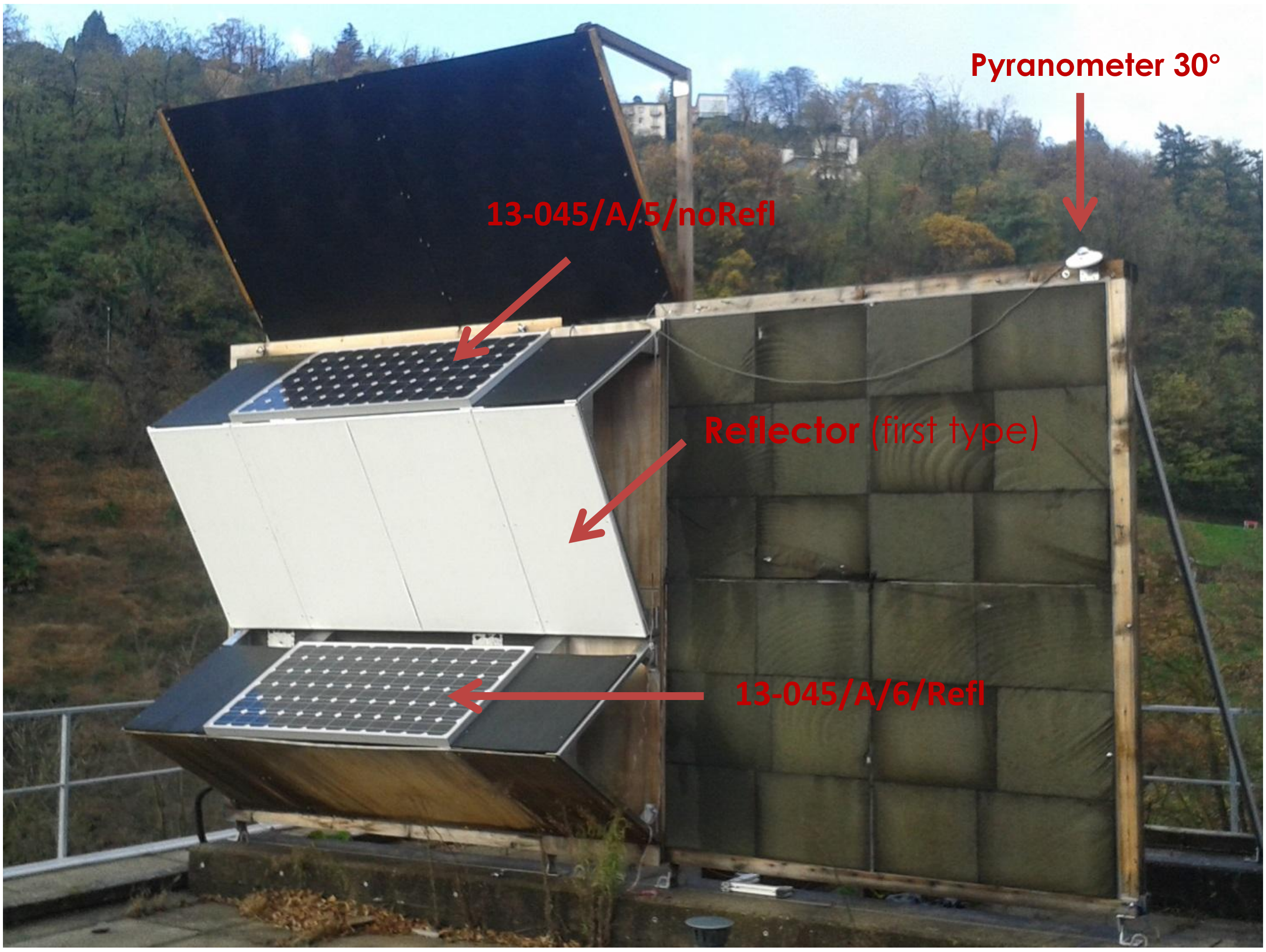

Figure 1: Solar Retrofit stand on SUPSI-ISAAC roof.

The first reflector is white colored and has a good reflectance in the diffuse part with partial specular reflectance. Further measures have to be done to optically characterize the material.

2.1 Second reflector

On the 17th December a new reflector was mounted.

In Fig. 4 the new reflector can be seen. The second reflector present an higher reflectance than the previous one.

Figure 2: Second configuration. In December the first reflector was substituted by a new material. 13-045/A/5/noRefl module during the month of January

3 Indoor measurements

The modules used for this project were measured before mounting. These indoor measurements ($P_{ISAAC\_measured}$) were used for the calculation of the performance of the modules and are presented in table 1. More details concerning the indoor measurements performed (Voc, Isc, FF values, etc..) can be found in the analytic report that can be provided if needed.

Table 1: Description / Specifications of modules.

ISAAC Label	Manufacturer	Technology	$P_{Nominal}$ [W]	$P_{ISAAC\_measured}$ [W]	ΔP [%]	Inclination	Reflector
13-045/A/5/noRefl	SWISSWATT	sc-Si	190	190.37	0.2	30°	No
13-045/A/6/Refl	SWISSWATT	sc-Si	190	187.76	-1.2	30°	Yes

4 Outdoor measurements (Monitoring)

The outdoor measurements followed the standard procedure of outdoor monitoring at SUPSI-ISAAC.

The recorded data during the 10 months monitoring (June 2013 until March 2014[1]) of this project were the:

- I-V curves of both modules
- electrical parameters of both modules (V_m, I_m)
- irradiance at 30°
- temperature at the back of each module (T_{bom})
- ambient temperature

All data above were registered every minute apart from the I-V curves which were registered every five minutes.

5 Analysis

5.1 Irradiance

The meteorological data acquired during the monitoring period are presented in this section. Fig. 5 shows the amount of insolation measured by the pyranometer at 30° for the given period.

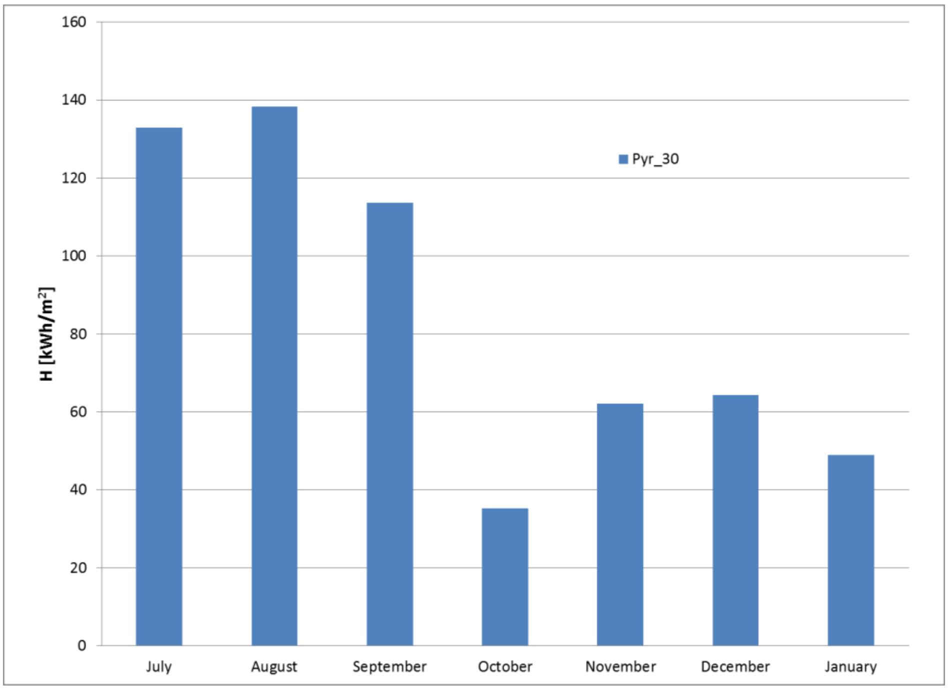

Figure 3: Monthly insolation at 30°.

The monthly average ambient temperature (Ta) during the same monitoring period is presented in Fig. 6.

[1] The outdoor measurement are still running in order to assess the second reflector also during the summer period.

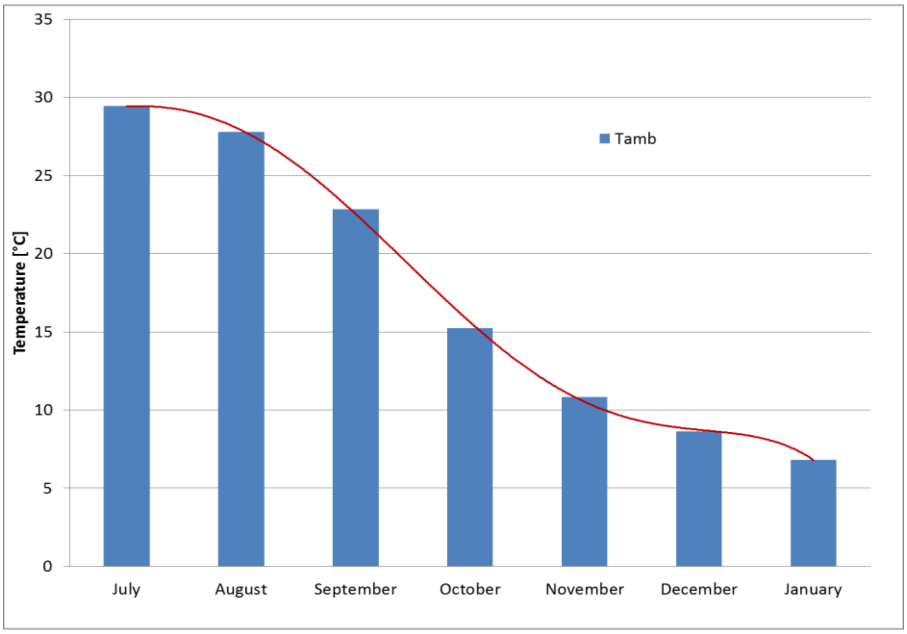

Figure 4: Monthly average ambient temperature (Ta).

5.2 Performance analysis

Usually, the performance ratio (PR) is used for the comparison of modules in different locations or at different inclinations. It is expressed by dividing the final yield with the normalized irradiation. In this case and as seen in Fig. 7, the PR of the two modules is presented for a better understanding of the different behaviour due to the presence of the reflector (13-045/A/5/noRefl).

After the mounting of the new reflector on 17th December, the performance of the module 13-045/A/6/Refl is significantly higher than that of the reference module (13-045/A/5/noRefl).

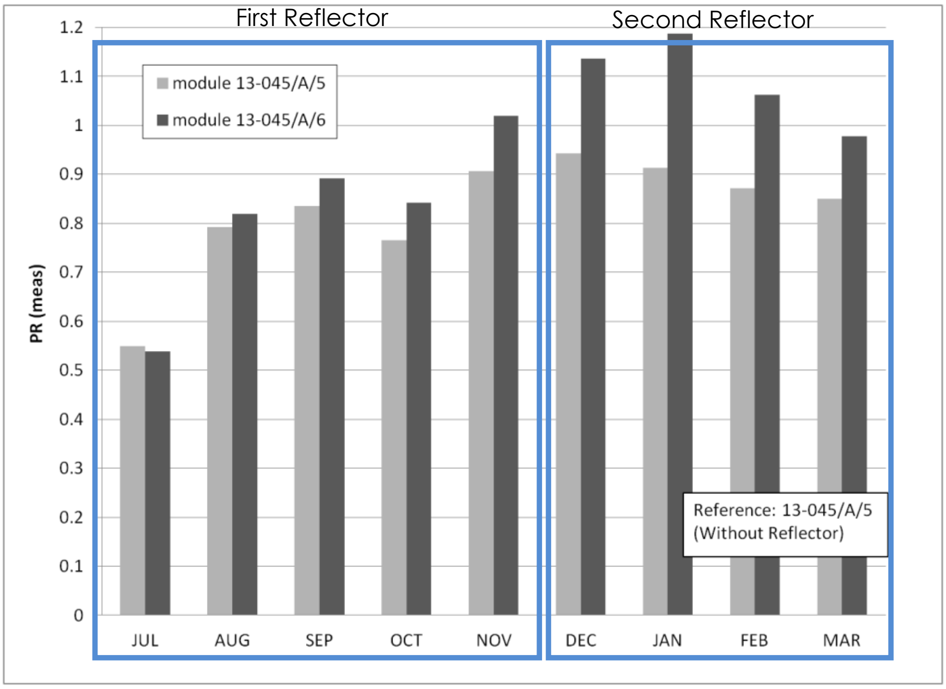

Figure 5: Performance Ratio comparison of the two modules between July 2013 and March 2014.

During the month of **July**, the shading effect is limited as shown in Fig. 8. Even though it starts a bit earlier in the morning and finishes later in the afternoon than in June, the surface that is being shaded is less and hence also the power loss. The **difference in PR** between the two modules is **-1.8%** with 13-045/A/5/noRefl (without the reflector) as a reference.

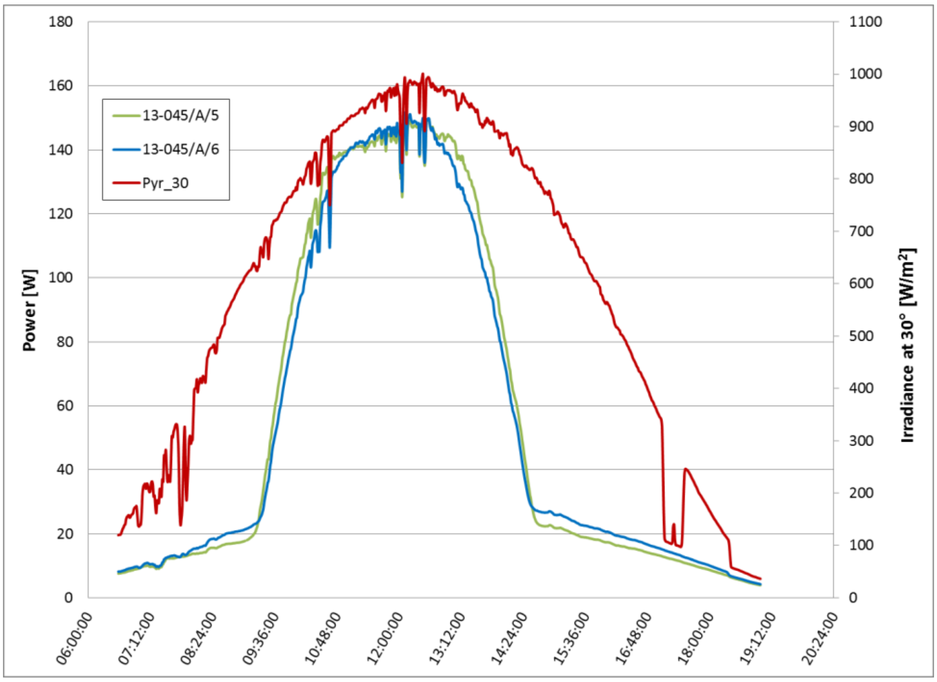

Figure 6: Power [W] for the 13-045/A/5/noRefl and 13-045/A/6/Refl modules and irradiance at 30° [W/m^2] on the 15.07.2013.

The situation starts changing significantly in **August** when the sun is lower and shadow on the 13-045/A/6/Refl caused by the upper module (13-045/A/5/noRefl) is avoided. In this case, as seen in Fig. 9, both modules are experiencing distant shading by the horizon very early in the morning and late in the afternoon Already form August the PR of the module with the reflector (13-045/A/6/Refl) is higher than that of the reference 13-045/A/5/noRefl (**difference in PR is 3.2%**).

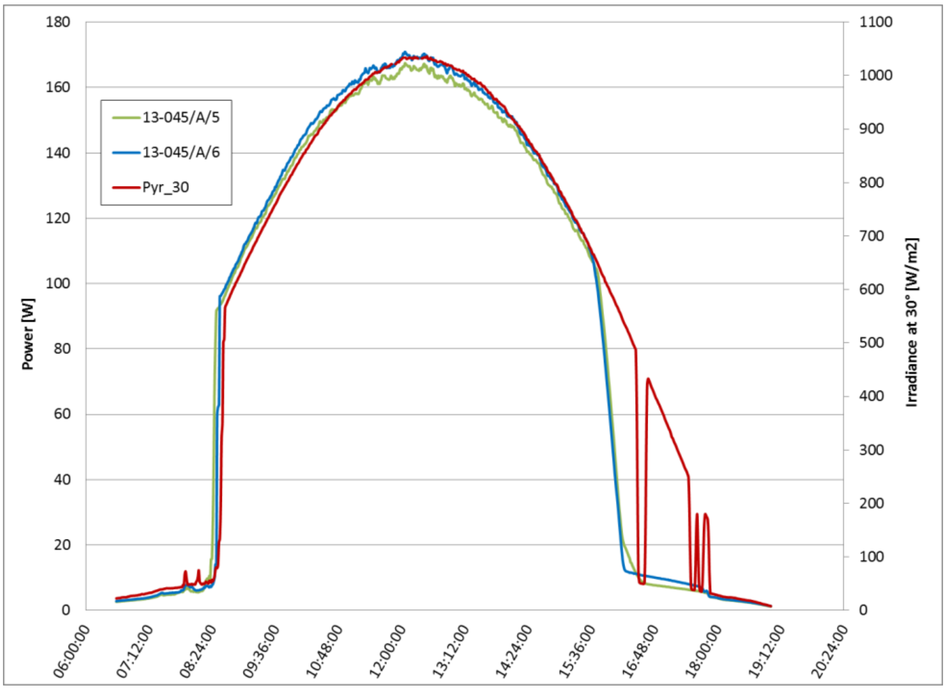

Figure 7: Power [W] for the 13-045/A/5/noRefl and 13-045/A/6/Refl modules and irradiance at 30° [W/m^2] on the 20.08.2013.

Already in **September**, according to Fig. 10, distant shading effects occur before and after the time interval of the data acquisition and the performance of the modules is not affected by them. It is clear that with no shading effects, the module with the reflector 13-045/A/6/Refl has a higher power output than the reference module and a **PR of 6.8%** higher.

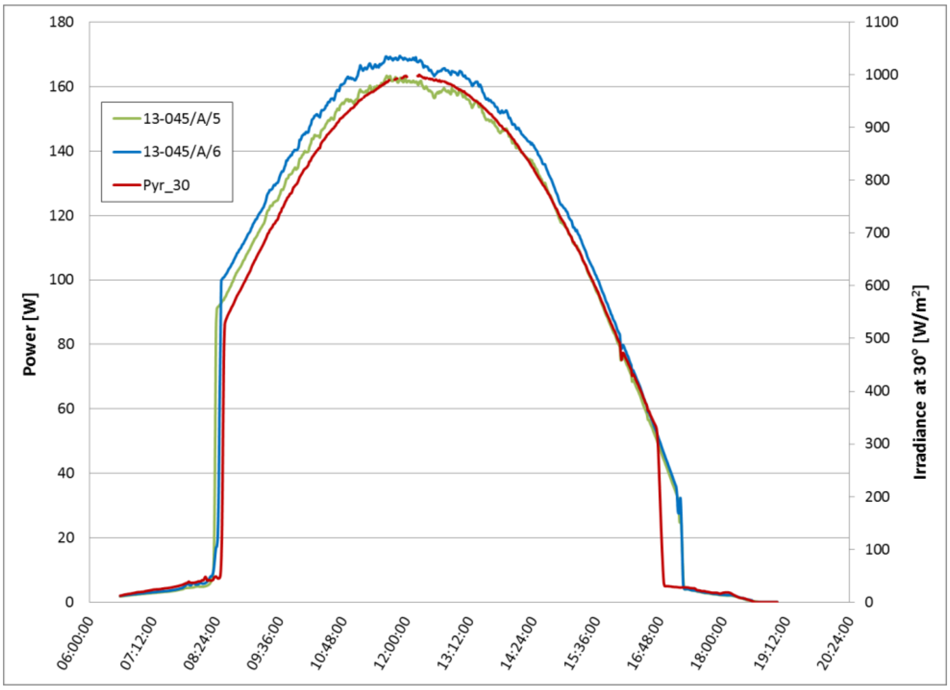

Figure 8: Power [W] for the 13-045/A/5/noRefl and 13-045/A/6/Refl modules and irradiance at 30° [W/m^2] on the 13.09.2013.

According to Fig. 11, the module with the reflector (13-045/A/6/Refl) continues to produce more than the reference module (13-045/A/5/noRefl) in **October** as all shading effects are extinct and are limited to the very early morning and late afternoon (out of the time interval of data acquisition for the location). The **difference in PR** during this month was found to be **10.0% in favor of the 13-045/A/6/Refl**.

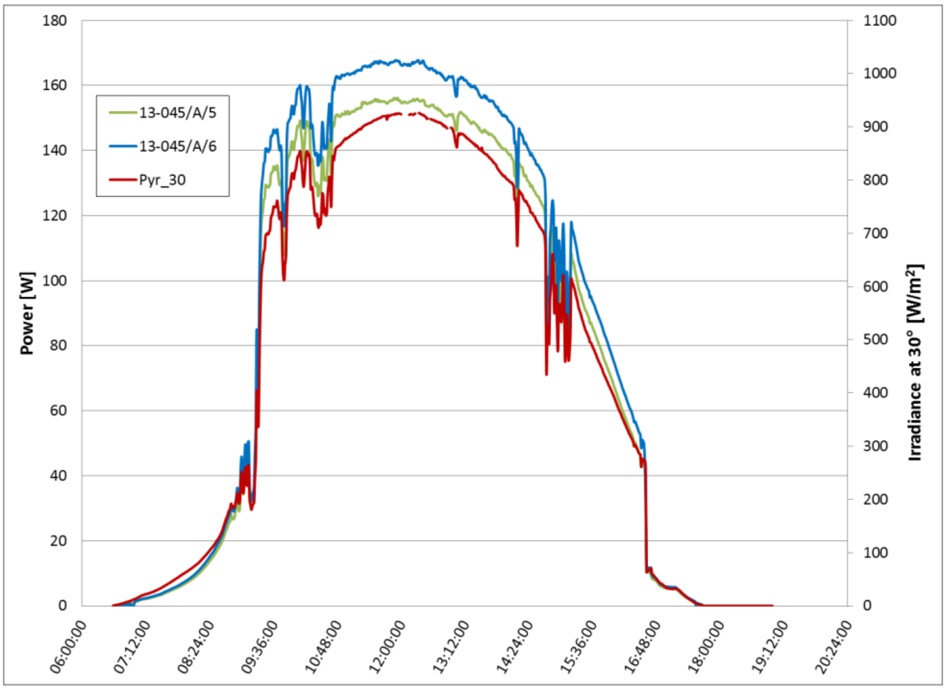

Figure 9: Power [W] for the 13-045/A/5/noRefl and 13-045/A/6/Refl modules on the11.10.2013.

During the month of **November** the same situation as in October occurs. The module 13-045/A/6/Refl (with the reflector) is performing better than the reference one, 13-045/A/5/noRefl (without a reflector) and that can be easily observed in Fig. 12. In this case, **the difference in PR is of 12.3%**.

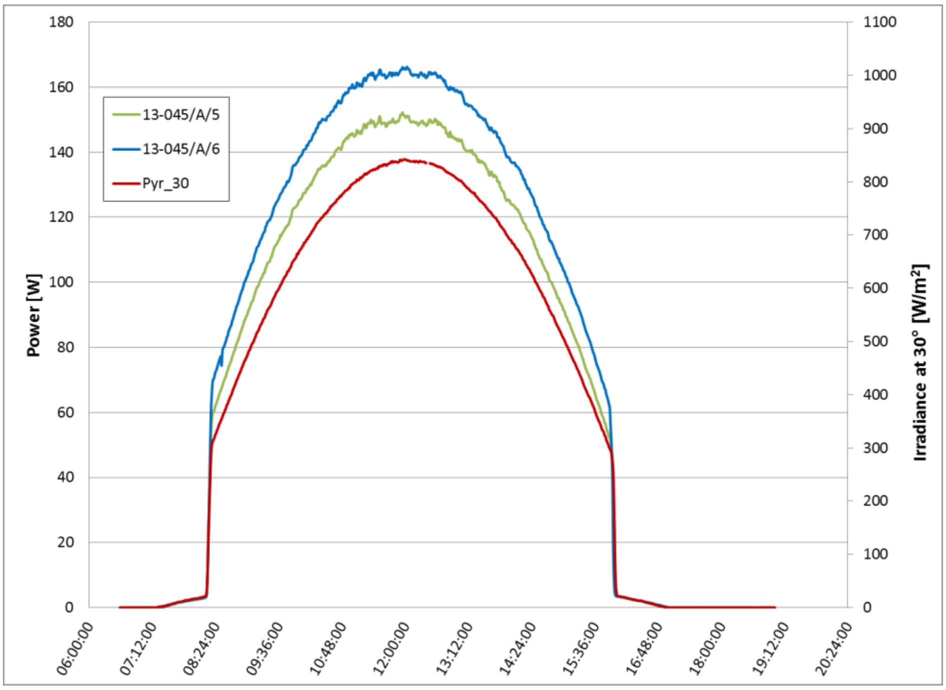

Figure 10: Power [W] for the 13-045/A/5/noRefl and 13-045/A/6/Refl modules and irradiance at 30° [W/m^2] on the 11.11.2013.

Fig. 13 presents an aggregated visualization of the individual monthly tables and graphs in the report for the difference in PR between the two modules (13-045/A/6/Refl with the reflector and 13-045/A/5/noRefl as reference) for the whole monitoring period.

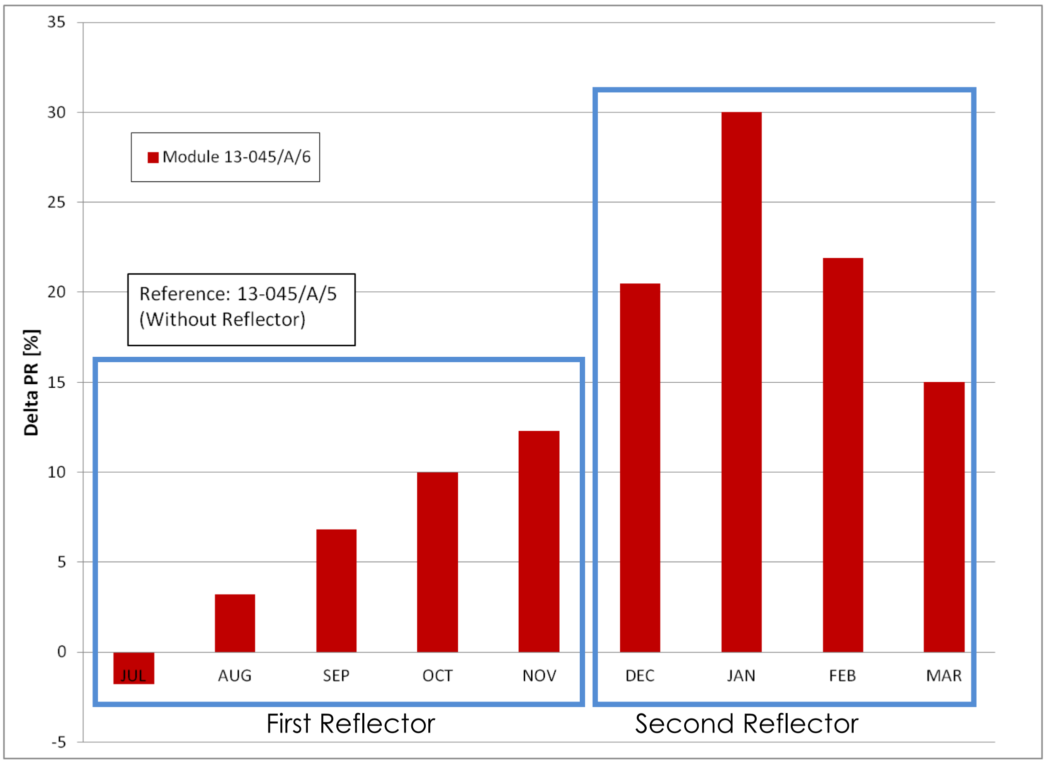

Figure 11: Aggregated results of the difference of PR between the two modules (13-045/A/5/noRefl and 13-045/A/6/Refl) for the whole monitoring period.

It is evident that for the month of July (DeltaPR=-1.8%) the performance of the 13-045/A/6/Refl module (with the reflector) is lower than that of the reference module 13-045/A/5/noRefl. This is mainly due to the shading effects caused by the stand structure analysed before.

After August the situation is significantly improved as becomes positive (**DeltaPR=3.2%**) for the 13-045/A/6/Refl module (with the reflector).

For the months of **September** (**DeltaPR=6.8%**), **October** (**DeltaPR=10.0%**) and **November** (**DeltaPR=12.3%**), when the sun is lower and shading on the 13-045/A/6/Refl module from the 13-045/A/5/noRefl module is avoided, the performance of the 13-045/A/6/Refl module with the reflector is higher.

In the month of **December** the 13-045/A/6/Refl module has shown a **difference in PR of 20.5%** than the 13-045/A/5/noRefl. A part of this improvement is following the general tendency of improvement of the specific structure in the winter months but another part of it is due to the mounting of the new reflector on the 17th December 2013.

During the month of **January** the **difference in PR** between the 13-045/A/6/Refl and the reference module (13-045/A/5/noRefl) was found to be **30%** and this is a evident result of the new reflector.

During the month of **February and March** the **difference in PR** between the 13-045/A/6/Refl and the reference module (13-045/A/5/noRefl) decreased to **21.9 and 15%** respectively. This is due mainly to the sun position, but it is still higher than the month with the first reflector.

For the overall analysis of the 9 months (July-March), the 13-045/A/6/Refl module (with the reflector) has exhibited a performance ratio of 8.6% higher than the 13-045/A/5/noRefl module that was used as a reference.

In particular the measurement shows the following results:

- **For the month of July-November, the first reflector demonstrated an increase in PR of about 5.2% (with a pick in November of 12.3%)**
- **For the month January-March, the second reflector demonstrated an increase in PR of about 19.7% (with a pick in January of 30.0%)**

Further investigation have to be done to assess the effect of the second reflector also in summer. and the effect of snow deposition in the winter season that can negatively affect the performance of the system.

In Fig. 14 the power of the two modules (13-045/A/5/noRefl and 13-045/A/6/Refl) and the irradiance at 30° on 11.12.2013 (before the new reflector mounting) and 30.12.2013 (after the new reflector mounting). In Table 2, the difference in power and irradiance are calculated.

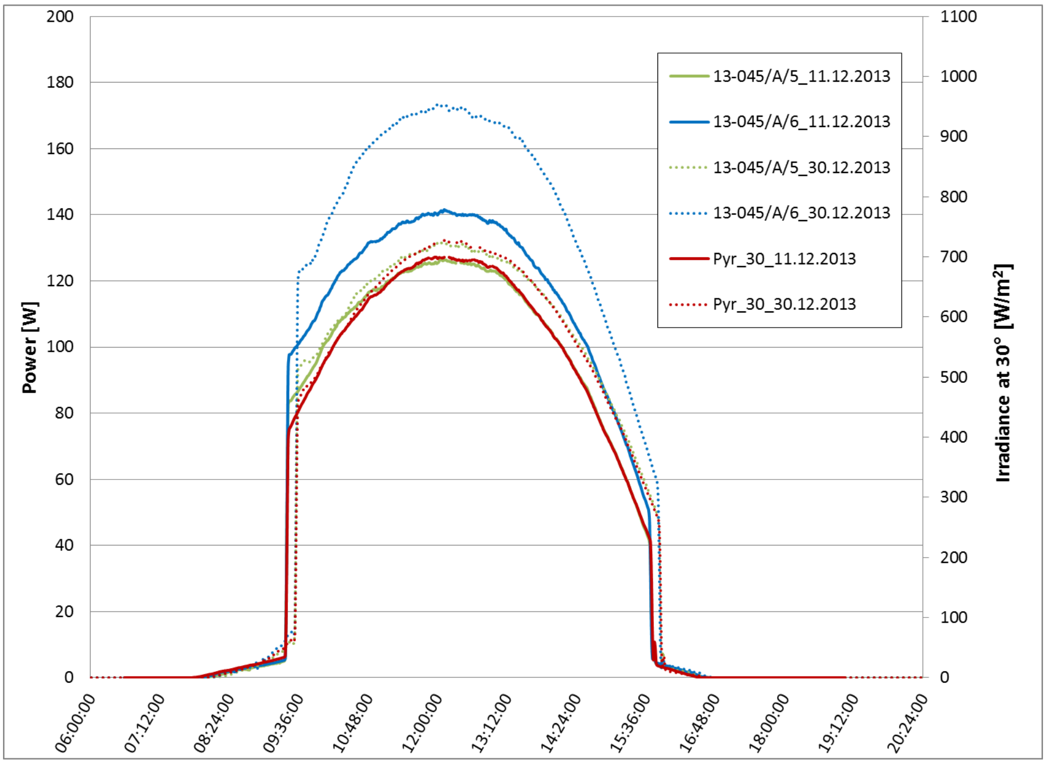

Figure 12: Power of the two modules (13-045/A/5/noRefl and 13-045/A/6/Refl) and irradiance at 30° on 11.12.2013 (before the new reflector mounting) and 30.12.2013 (after the new reflector mounting).

Table 2: Description / Specifications of modules before the installation of the second reflector (11.12.2013) and after (30.12.2013).

	Module	11.12.2013	30.12.2013	Difference in Pmax between 11.12.2013 & 30.12.2013
Pmax [W]	13-045/A/5/noRefl	126	131	4%
	13-045/A/6/Refl	141	174	23%
Difference in Pmax between A5 & A6		12%	33%	**Difference in Irradiance between 11.12.2013 & 30.12.2013**
Irradiance [W/m²]	Pyranometer 30°	700	727	4%

From Fig. 14 and table 2, it is can be seen that while the difference (in term of Solar irradiation) between these 2 days is 4% in irradiance and 4% in power for the 13-045/A/5/noRefl, the 13-045/A/6/Refl has shown a difference of 23% of power between these 2 days.

5.3 Temperature analysis

Both modules exhibited similar average temperatures throughout the entire monitoring period as expected and can been seen in Fig. 15.

In particular, for the first months and until September, both modules reached temperatures of 20°C difference from the average ambient temperature.

The smallest difference between the modules' monthly average temperature and the monthly average ambient temperature is observed for the month of October (7°C of difference).

The highest average temperature of the modules approximately 50°C and was reached in July when the average ambient temperature was almost 30°C.

Figure 13: Monthly average ambient temperature (Ta) and monthly average temperature at the back of the two modules (13-045/A/5/noRefl and 13-045/A/6/Refl).

In general, it can be said that the reflector has not affected the temperature of the 13-045/A/6/Refl module (with the reflector) and therefore had no negative impact in the power output (due to the poor temperature coefficient of the crystalline technology modules).

During the half of December 2013 and the start of January 2014 the temperature sensor of the 13-045/A/6/Refl was disconnected and therefore, the temperatures acquired are not available. This affects the calculation of the monthly values that are depicted in Fig. 15.

The 2 modules continue to exhibit similar temperatures and it can be said that the new reflector has not brought any significant increase of temperature.

For this reason, Fig. 16 with the daily data of temperature is provided.

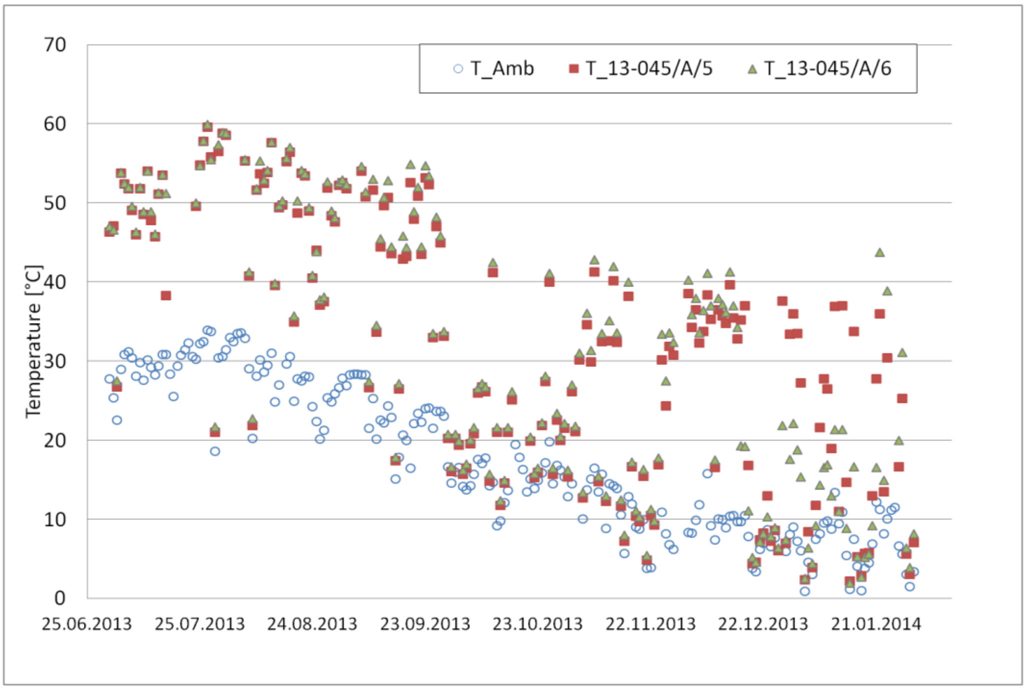

Figure 14: Daily average ambient temperature (Ta) and daily average temperature at the back of the two modules (13-045/A/5/noRefl and 13-045/A/6/Refl).

Fig. 17 presents the minute values of ambient and back of the modules temperature for 2 days, the 30.12.2013 (dotted lines) when the temperature sensor at the back of the 13-045/A/6/Refl was detached, and 28.01.2018 (continuous lines). The red arrow on the graph shows the false data acquired from the temperature sensor at the back of module 13-045/A/6/Refl.

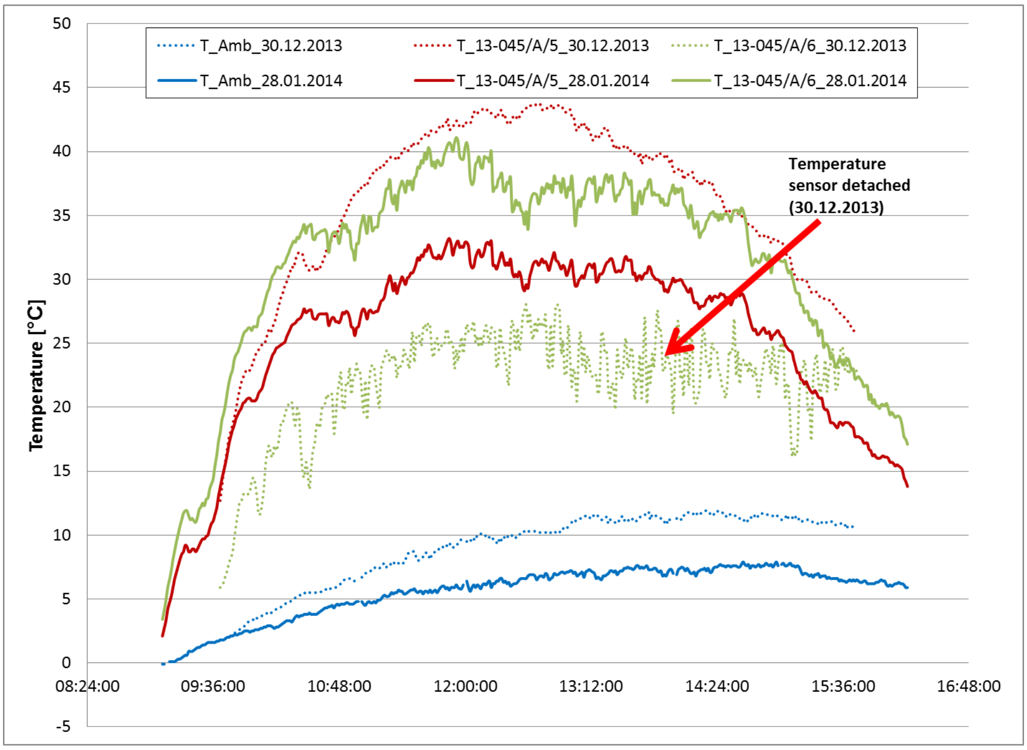

Figure 15: Minute values of ambient temperature (Ta) and minute values of temperature at the back of the two modules (13-045/A/5/noRefl and 13-045/A/6/Refl) for the 30.12.2013 (dotted lines, temperature sensor for A/6 detached) and 28.01.2014 (continuous lines).

6 Conclusions

The following picture (Fig. 18) shows how the inclination of the modules affects the shading losses of the row below.

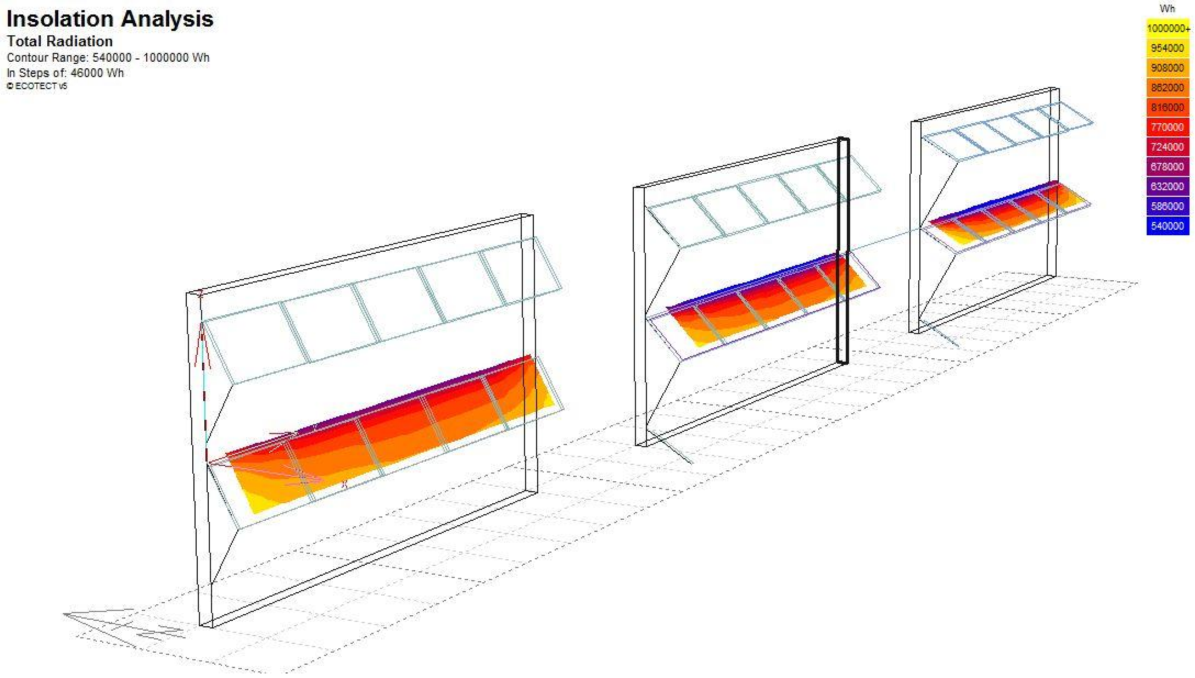

Figura 16: The picture shows the insolation on the PV modules with three different configurations: from the left situation the modules are tilted respectively of about 60°, 45° and 30°.

However, during autumn months, when the sun is lower and the shading effect disappears, the performance of the module with the reflector (13-045/A/6/Refl) is found to be higher than that of the reference module.

The mounting of the new reflector has resulted in significant performance increase for the 13-045/A/6/Refl with reference to the 13-045/A/5/noRefl. This increase of performance has been delivered without any further increase of temperature that may compromise the performance due to temperature coefficients.

This particular structure, for the specific location of Lugano where it was tested, appears to be not suitable for the summer months but tends to become favorable for the autumn months. Further monitoring, for an entire year, can reveal whether the overall performance of such an installation with this particular architectural layout can lead to positive results.

It is suggested to perform different simulations in order to evaluate more design configurations and different climate locations.

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