Simulation of low solar radiation test days in thermal performance tests of factory-made solar systems

Fabienne Sallaberry*, Jonathan Vera, Alberto García de Jalón, Martin Gaston and Lourdes Ramirez

Solar Thermal Energy Department, National Renewable Energy Centre (CENER), Ciudad de la Innovación 7, 31621, Sarriguren (Navarra), Spain

* Corresponding Author, fsallaberry@cener.com

Abstract

The CENER Testing Laboratory in Seville performs outdoor efficiency tests for factory-made solar systems according to the ISO 9459-2 International Standard using the CSTG method. The efficiency test consists of three different parts: one for determining mixing in the storage tank during draw-off, one for determining daily system performance, and one for determination storage tank heat losses.

This daily system performance test characterizes the solar system output energy production depending on daily solar radiation and temperature differences. It requires test days with solar radiation evenly distributed between 8 and 25 MJ/m^2 which can hardly be reached during a sunny summer.

This paper analyses the arguments for the testing laboratory to use a reflective shield to simulate artificially cloudy days with low daily solar radiation during the daily system performance tests and its influence on the identification parameter of solar system thermal performance.

Keywords: solar system, testing, certification,

1. Introduction

According to the Spanish Technical Building Code (CTE) and Ministerial Order ITC/71/2007, all solar thermal systems on the Spanish market must be authorized by the Ministry of Industry to be eligible for government subsidies, and for this they have to pass all the UNE-EN 12976-2 European Standard tests. This Standard stipulates durability and efficiency tests, and user and installer documents to be checked.

The CENER Accredited Solar System Testing Laboratory in Seville has been performing all the tests for factory-made solar thermal systems according to the European Standard since 2008. And solar systems had been tested in this laboratory for 25 years before that. The European Standard efficiency test refers to two ISO Standards, ISO 9459-2 (CSTG method) and ISO 9495-5 (DST method). The CSTG method, named for the group which originally developed it, “Complete System Testing Group”, makes use of an input-output ratio, while the DST method, called the “Dynamic System Test”, makes use of dynamic software for parameter identification.

CENER can use both methodologies, but as the Spanish Technical Building Code (CTE) does not allow integrated auxiliary heating devices, systems are mostly tested using the CSTG method for solar-only systems.

For the last two years, the CENER has been studying the possibility of using a direct solar radiation shield for the CSTG daily efficiency test. We wanted to find out whether the use of "artificial" cloudy test days would influence the final test results. We therefore analyzed parameter identification using different input data with artificial and natural test days and then compared the measured power Q_{med} with the modeled power Q_{mod} calculated from the various regression coefficients.

2. ISO 9459-2Test Method

The test consists of conditioning the system at least six hours before solar noon, mixing circulating water in the tank until it is sufficiently uniform. Then, the solar system operates normally for 12 hours. Finally, six hours after solar noon, the tank water is drawn off until outlet and inlet temperatures are equalized, while the inlet water temperature is maintained constant.

The mathematical model for the output energy production of solar system Q is dependent on daily accumulated solar irradiation H and the temperature difference between mean ambient temperature $t_{a(day)}$ and inlet water temperature t_{main} as followed:

$$Q = a_1 H + a_2 \left(t_{a(day)} - t_{main}\right) + a_3$$

with:

- Q : output energy production.
- $t_{a\ (day)}$: mean test day ambient temperature .
- t_{main}: inlet water supply temperature during conditioning and draw-off.
- H: cumulative daily solar radiation from six hours before to six hours after solar noon
- a_1, a_2 and a_3: coefficients found by multiple linear regression of the thermal performance test.

The thermal performance results are coefficients a_1, a_2 and a_3. The test must be done on days with daily accumulated solar irradiation H evenly distributed between 8 and 25 MJ/m^2 and temperature differences $t_{a(day)}$ -t_{main} between -5K and 20K.

It is possible to change ($t_{a(day)}$ - t_{main}) conditions simply by changing the test bed t_{main} controller. However, solar radiation H cannot be changed, as it depends on the weather at the test location, and both the tilt and azimuth are fixed. The daily solar radiation in Seville is mostly around 25 MJ/m^2 during the summer and about 16 MJ/m^2 during winter, when the summer test duration must be extended.

We have therefore developed a method for finding clear days with low solar radiation, which we call “artificial days”, using a solar radiation shield.

3. Description of solar radiation reduction method

Our methodology is based on ISO 9459-5 Standard Part 6.3.5 Storage-loss test sequence, which describes the characteristics of a radiation shield for reducing solar global irradiance.

Actually, the two effects that influence the collector thermal losses during testing are the radiation and convection losses.

To simulate cloudy weather, opaque reflective blankets are used to shield the collectors from solar radiation by covering the aperture area. The pyranometer that measures the solar irradiance during the test is also covered. The resulting solar radiation is between 8 and 25 MJ/m^2.

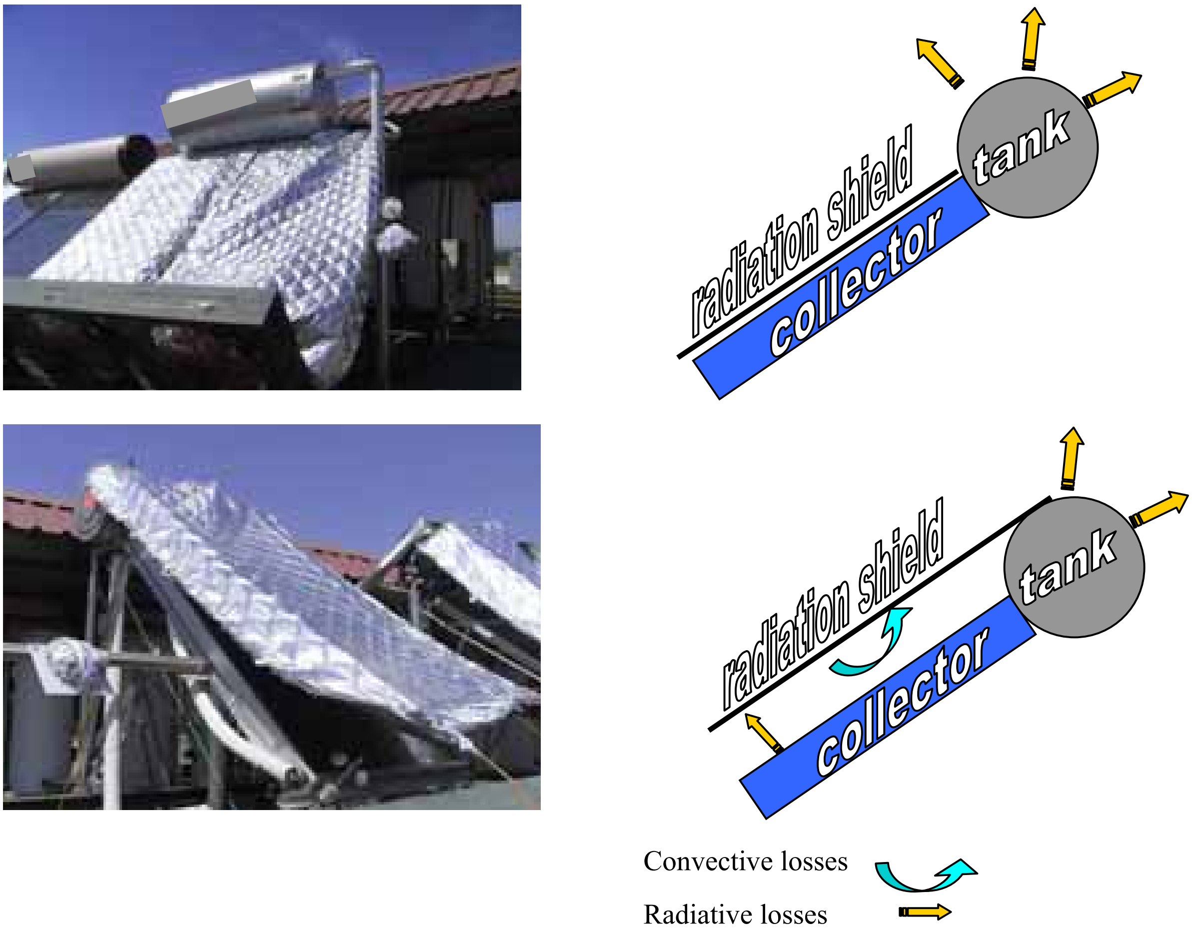


Fig. 1. Shield covering the collector aperture and a little above it

In order to check the validity of the data found using artificial days simulating cloudy weather, the performance coefficients were compared by including or not the artificial days in the data treatment to see if including them disturbs the final performance coefficients.

We used those artificial cloudy days in two solar systems efficiency tests.

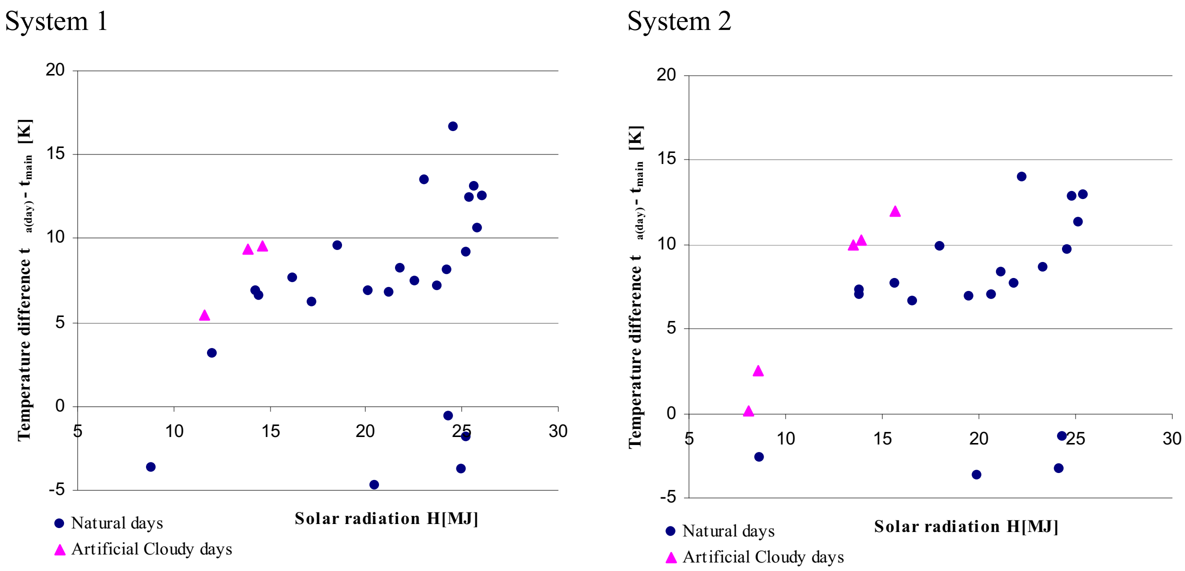


Fig. 2. Daily integrated solar radiation H and temperature difference $t_{a(day)}$ - t_{main}

A first linear regression was performed with all the natural points and the performance coefficients were found:

Table 1. Performance coefficients for natural test days.

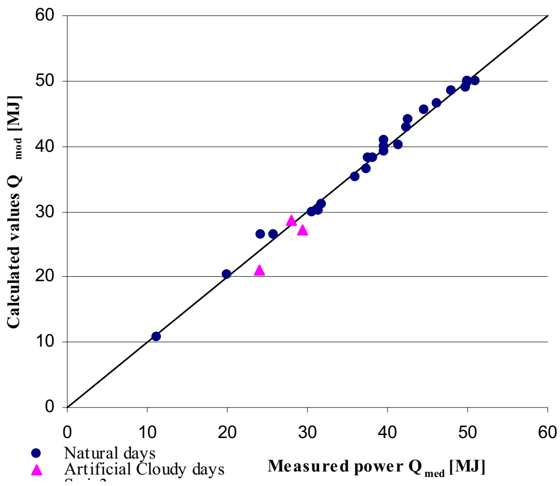
	System 1		System 2	
Parameters	**Value**	**Standard deviation**	**Value**	**Standard deviation**
a_1 [m^2]	1.71	0.04	1.06	0.03
a_2 [MJ/K]	0.61	0.04	0.35	0.02
a_3 [MJ]	-2.23	0.89	-2.60	0.55

4. Comparison results

4.1. Comparison of the regression with natural data

First a linear regression was performed with natural data, and then the measured output power Q_{med} was compared to the calculated Q_{mod}. Then we performed the same comparison of Q_{med} and Q_{mod} for test days using the radiation shield.

System 1



System 2

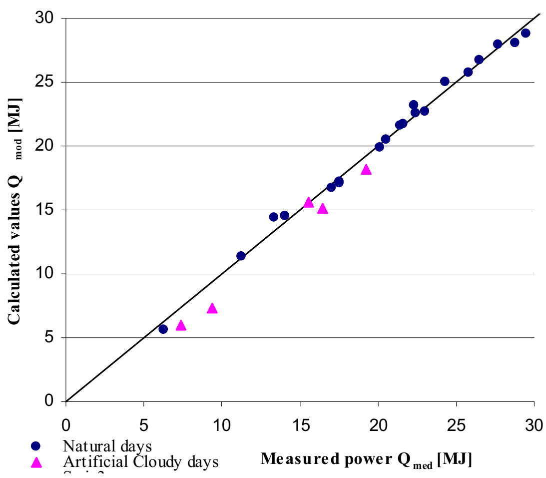


Fig. 3. Measured power Q_{med} and calculated Q_{mod}

The widest difference between Q_{med} and Q_{mod} is 2.3 MJ on natural days and 3.1 MJ on artificial cloudy days with System nº1, and 1.1 MJ on natural days and 2.0 MJ on artificial cloudy days with System nº2.

Error |Qmed-Qmod| is a little bit higher on the artificial days than with the natural data.

4.2. Comparison of the regression on low radiation days replaced by artificial days

The natural low radiation test days were replaced by two artificial test days. A new linear regression was performed and the results were compared to the first one.

Table 2. Comparison of performance coefficients with and without artificial test days.

	Natural		Artificial	
Parameters	**Result**	**Standard deviation**	**Result**	**Standard deviation**
System nº1				
a_1 [m^2]	1.71	0.04	1.65	0.04
a_2 [MJ/K]	0.61	0.04	0.63	0.03
a_3 [MJ]	-2.23	0.89	-0.84	0.81
System nº2				
a_1 [m^2]	1.06	0.03	1.04	0.03
a_2 [MJ/K]	0.35	0.02	0.36	0.02
a_3 [MJ]	-2.60	0.55	-2.30	0.58

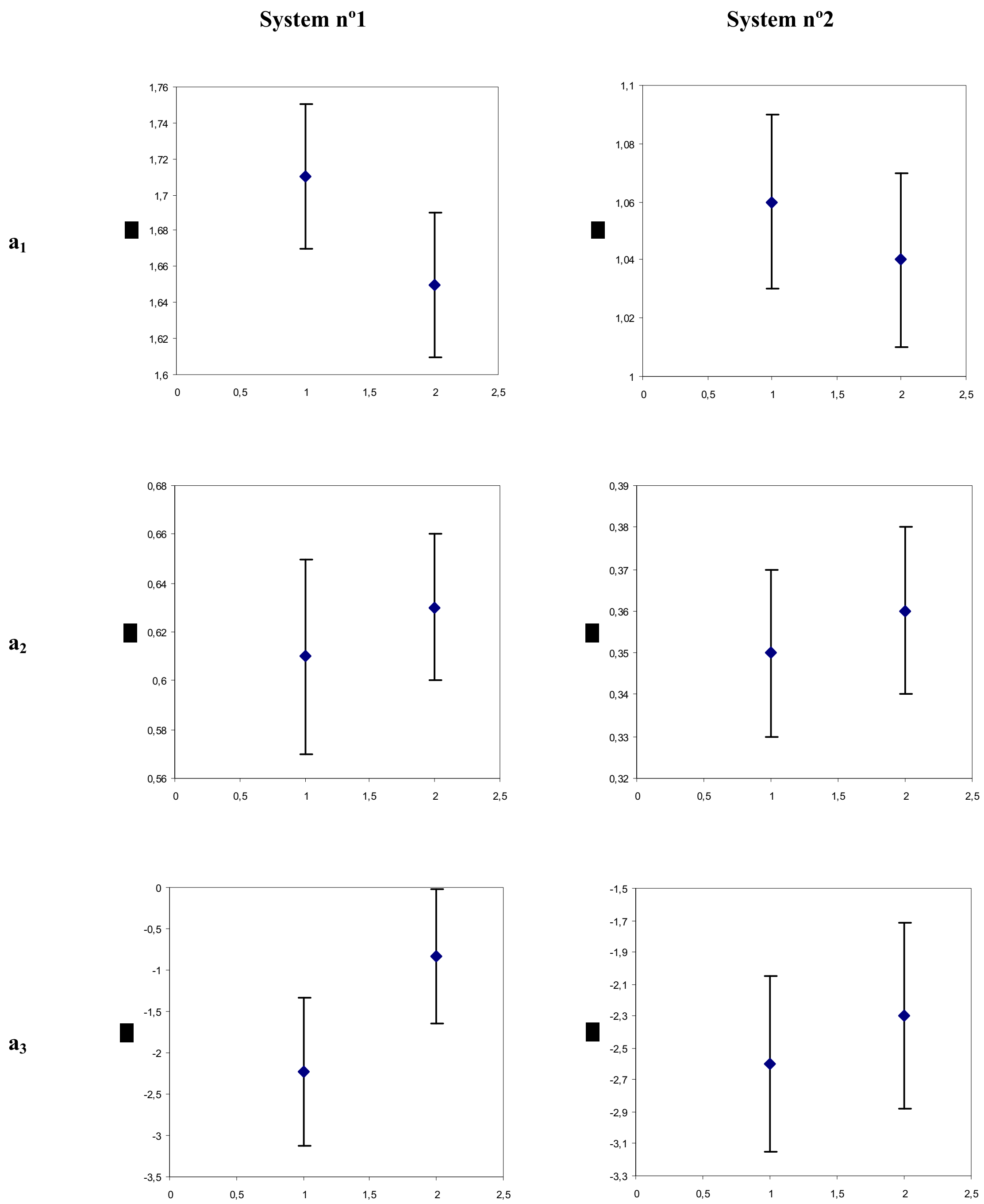


Fig. 4. The three performance coefficients with their standard deviations for the two regressions

In both cases, the coefficients are well correlated, i.e., the results approach the standard error.

4.3. Regression using both natural and artificial data

A linear regression was performed with all the data, for both natural and artificial low radiation test days. Then consecutive linear regressions were repeated after removing each single test day one by one. Final coefficients were compared. The first regression (called k = 0) was made with all the data and in the following regressions (k) test days are removed, one by one.

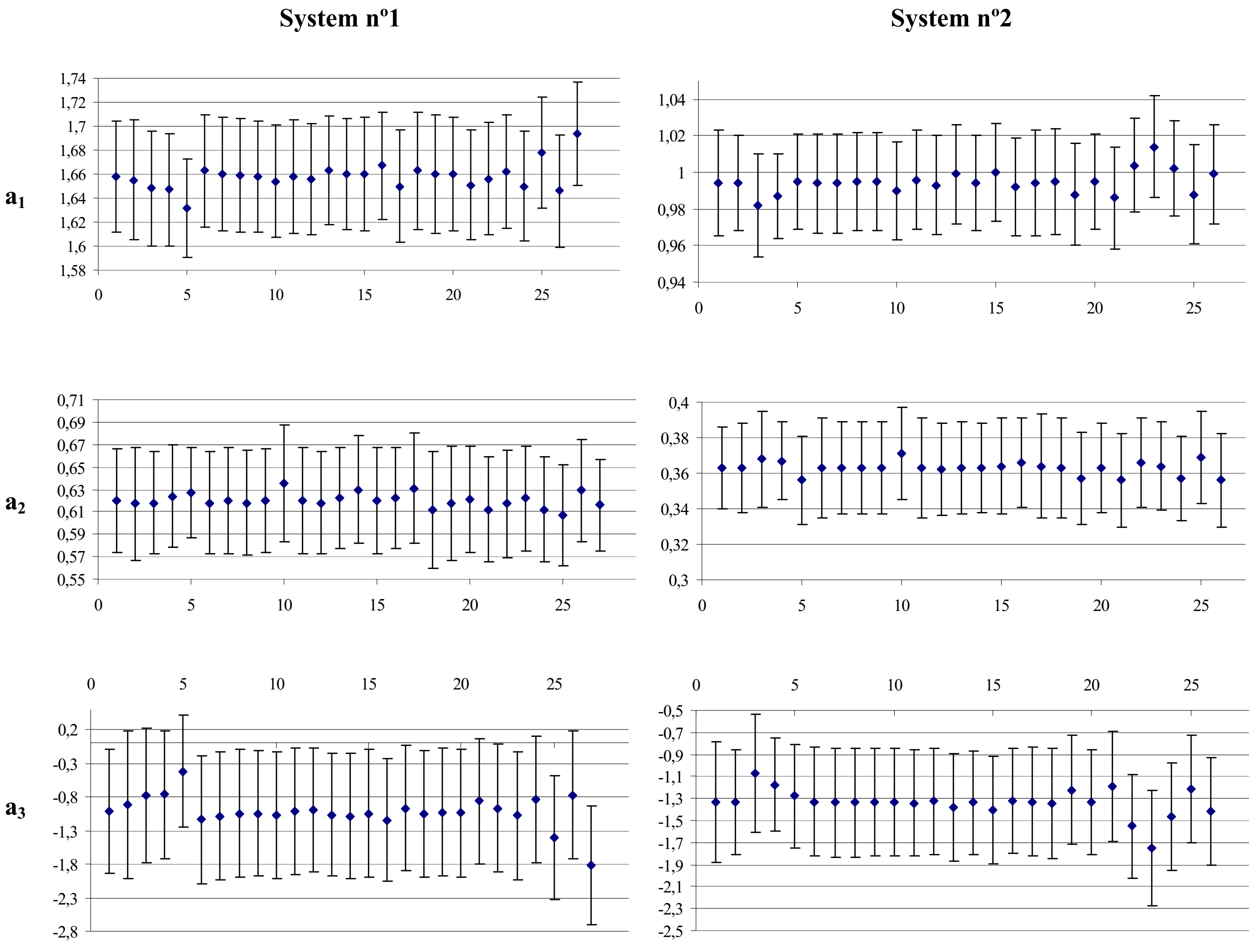


Fig. 5. The three performance coefficients with their standard deviations for all the different regressions

In all cases, the coefficients are well-correlated with each other. The low radiation days affect the model more, whether artificial or natural.

For all the different models created by removing the test days one by one, we performed a Kolmogorov-Smirnov test. When the p-values are close to 1 it shows that the results have the same probability distribution.

Table 3. Comparison of p-values with performance coefficients with and without artificial test days.

p-value	System nº1	System nº1
mean	0.9985	0.9962
max	1.0000	1.0000
min	0.9787	0.9894

The p-values are all very close to 1, indicating that the results are the same whether the data are artificial or not. It confirms that the models are statistically the same and are not affected by the use of artificial cloud data.

5. Conclusion

For the outdoor efficiency test for factory-made solar systems, the CSTG thermal performance test requires test days with solar radiation evenly distributed between 8 and 25 MJ/m^2 which can hardly be reached during a sunny summer.

In this paper, we have analyzed the use of a radiation shield to simulate clouds and its influence on the solar system thermal performance identification parameter. Output power after testing two solar systems using the CSTG method was assessed.

After analyzing all those results, we conclude that the natural and artificial data cannot be differentiated, and therefore, are not distinguished by any of the statistical or mathematical techniques used in the analysis.

The main conclusions are:

- Regression with natural data: The difference between | Q_{med}-Q_{mod} | is not significantly higher on artifical days than on natural days.
- Regression replacing some low radiation days by artificial cloudy days: In both cases the coefficients are correlated, i.e., they approach the standard error.
- Regression using all the test points: In all cases the coefficients are correlated with each other. The days with low radiation impact in the model more than the type of low radiation day (artificial or natural) .

References

[1] European Standard EN 12976-1:2006, Thermal solar systems and components. Factory made systems –Part 1: General requirements.

[2] European Standard EN 12976-2:2006, Thermal solar systems and components. Factory made systems –Part 2: Test methods

[3] International Standard ISO 9459-2, Solar heating – Domestic water heating Systems. Part 1 : Outdoor test methods for system performance characterization and yearly performance prediction of solar-only systems.