Simulation of low solar radiation testing days using solar radiation shield during thermal performance tests of factory-made systems according to the CSTG method

SOLAR THERMAL ENERGY DEPARTMENT
INTRODUCTION

CENER Testing Laboratory in Seville performs outdoor efficiency test for factory–made solar systems according to the International Standard ISO 9459-2. This thermal performance test requires testing days with solar radiation evenly distributed between 8 and 25 MJ/m² which could be hardly reached during sunny summer. In the paper, we analyze the influence of artificial cloudy testing days on the identification parameter of the solar system thermal performance.

According to the ministry order ITC/71/2007, all the solar thermal systems on the Spanish market which could access to government subsidies must be homologated by the Spanish Industry Ministry, and to do so they must pass all the tests according to the European Standard UNE-EN 12976-2. This Standard includes durability and efficiency tests and also documentation checking for the user and installer.

CENER Testing Laboratory for factory made solar thermal systems in Seville was accredited last year to perform the efficiency test according the European Standard. Before that, solar thermal systems had been tested in this laboratory for 25 years. CENER performs all the tests for factory-made solar thermal systems according to this European Standard, previously mentioned and specifically to the International Standard ISO 9459-2 for the efficiency test, on 4 outdoor test-benches.

The efficiency tests consists in 3 different tests: one for the determination of the degree of mixing in the storage tank during draw-off, one for the determination of daily system performance and one for the determination of storage tank heat losses. During the last year CENER realized a study to analyze the possibility to use a direct solar radiation shield during daily efficiency tests.
TESTING METHOD ACCORDING TO STANDARD ISO 9459-2

Before 6 hours of solar noon at the morning, the solar system is conditioned circulating water until outlet and inlet temperatures are equalized, so that the water in the tank is sufficiently uniform. Then, the solar system operates during 12 hours. Finally, when 6 hours after solar noon have passed, there is storage tank water drawn-off until outlet and inlet temperatures are equalized meanwhile the inlet temperature water is maintained constant.

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

with \( Q = \sum_{i=1}^{n} Q_i = \sum_{i=1}^{n} \Delta t_i V_i \rho_c c_p \left[ t_{di}(V_i) - t_{\text{main}} \right] \)

\( t_{a\text{(day)}} \) mean temperature for the day.

\( t_{\text{main}} \) inlet water supply temperature during the conditioning and draw-off.

\( H \) cumulative daily solar radiation for 12 hours around solar noon

\[ H = \sum_{i=1}^{n} H_i = \sum_{i=1}^{n} G_i \Delta t_i \]

\( a_1, a_2 \) and \( a_3 \) are the coefficients obtained by multiple linear regression of the thermal performance test.

According to Standard ISO 9459-2, part 7.2 - Range of test conditions

Results shall be obtained for at least four different days with approximately the same values of \( (t_{a\text{(day)}} - t_{\text{main}}) \) and irradiation values evenly spread over the range 8 MJ/m\(^2\) to 25 MJ/m\(^2\). Results shall also be obtained for at least two additional days with values of \( (t_{a\text{(day)}} - t_{\text{main}}) \) at least 9 K above or below the values of \( (t_{a\text{(day)}} - t_{\text{main}}) \) obtained for the first four days. The value of \( (t_{a\text{(day)}} - t_{\text{main}}) \) shall be in the range -5 K to +20 K for each test day.
Figura 2. Graphics of ideal testing days according to Standard ISO 9459-2

It is possible to change the conditions of \((t_\text{a(day)} - t_\text{main})\) simply by changing \(t_\text{main}\) controller of the test bench. However, changing the solar radiation \(H\) conditions is not possible as it depends on the climate of the test location, and both the tilt and azimuth are fixed. The daily solar radiation in the town of Seville is mostly around 25 MJ/m\(^2\) per day during the summer and about 16 MJ/m\(^2\) per day during winter, which extends the test duration during summer.

**METHOD DESCRIPTION OF SOLAR RADIATION REDUCTION**

We base our methodology on the Standard ISO 9459-5, part 6.3.5 Store-loss test sequence

c) Cooling period: takes 36 to 48 h starting from the last draw-off of the heating period. During the cooling period there shall be no draw-off and low solar irradiance. If a solar irradiance higher than 200 W/m\(^2\) is expected, the solar energy input into the storage tank shall be avoided by one of the following measures.

- A radiative shield at a temperature of at maximum 5 K above ambient shall be placed in front of the collectors. The pyranometer dome shall also be covered. Alternatively, its measured output can be set to zero.

- For systems where the storage tank may have radiation losses to the sky, it is recommended to place the shield at some distance above the collector aperture, in order to shield direct radiation while leaving the collector open to most of the long-wave sky radiation effects.

Actually the two effects that have influence on the collector thermal losses during the testing day are the radiation and convection losses-

To simulate cloudy weather opaque reflective blankets are used to shield the solar radiation covering the aperture area of the solar collectors tested. The pyranometer that measures the solar irradiance during the test is also covered. The solar radiation values obtained are between 8 and 25 MJ/m\(^2\).
In order to check the validity of the data obtained by artificial days simulating clouds a comparison of the performance coefficients obtained by including the artificial days or not in the data treatment procedure has been performed in order to see if including them disturbs the final performance coefficients.

We realized some comparisons on a thermosiphon solar system with an tank of volume $V_s = 320$ l and with two solar collectors flat with an aperture area of $4.10 \, m^2$.

This solar system was first tested during 11 days from which 3 used the shield method.
The test went on until obtaining 17 valid testing days.

RESULTS

1. Coefficients comparison

First, we compare each of the coefficients of both linear regression results.
In both cases the coefficients are well correlated, i.e., that the values approach the standard error committed.

Moreover, we introduce an index to check the compatibility of the results using the standard deviations

\[
IC = \frac{|a_{X,1} - a_{X,2}|}{\sqrt{\sigma(a_{X,1})^2 + \sigma(a_{X,2})^2}}
\]

with \( a_{X,1}, \ a_{X,2} \) the coefficients obtained at the first and the second regressions, and \( \sigma(a_{X,1}), \ \sigma(a_{X,2}) \) the coefficients standard deviation. The values generally accepted as satisfactory for this parameter is \( IC \leq 1 \).

The test results were as follows:

<table>
<thead>
<tr>
<th>Parameters</th>
<th>First regression</th>
<th>Second regression</th>
<th>IC</th>
</tr>
</thead>
<tbody>
<tr>
<td>( a_1 ) [m(^2)]</td>
<td>1,55 ± 0,07</td>
<td>1,60 ± 0,08</td>
<td>0,5</td>
</tr>
<tr>
<td>( a_2 ) [MJ/K]</td>
<td>0,73 ± 0,06</td>
<td>0,74 ± 0,05</td>
<td>0,1</td>
</tr>
<tr>
<td>( a_3 ) [MJ]</td>
<td>-2,1 ± 1,37</td>
<td>-1,70 ± 1,53</td>
<td>0,2</td>
</tr>
</tbody>
</table>

It is confirmed that the compatibility index are all under 1 and the coefficients \( a_1, \ a_2 \) and \( a_3 \) are mutually compatible.

### 2. Long-term prediction solar fraction comparison

Then, we compare the two results of long-term prediction obtained using each of the datasets for the first and second regression. The comparison is made for load volumes of 250, 300 and 400 l/day y for the city of Lisbon.
Figura 8. Solar fractions for Lisbon and load volumes of 250, 300 and 400 l/day

Tabla 2. Comparison of predicted solar fractions for the system

<table>
<thead>
<tr>
<th>Load volume [l/day]</th>
<th>First regression</th>
<th>Second regression</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
<td>76,51%</td>
<td>78,53%</td>
<td>2,02%</td>
</tr>
<tr>
<td>300</td>
<td>70,22%</td>
<td>72,63%</td>
<td>2,41%</td>
</tr>
<tr>
<td>400</td>
<td>56,99%</td>
<td>59,60%</td>
<td>2,61%</td>
</tr>
</tbody>
</table>

Assuming an acceptable error of 2%, the coefficients are well correlated.

CONCLUSION

The main conclusions have been:

- The coefficients \( a_1, a_2, \) and \( a_3 \) of the system power output model are compatible for dataset using artificial low radiation days or using only natural days.
- The results of the long-term prediction are compatible with each other.