National Pyranometers comparison of solar thermal labs in Mexico

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Abstract. The results of the first national comparison of pyranometers used in testing laboratories of solar water heating are reported. In the comparison carried out at the facilities of Centro Nacional de Metrología (CENAM-México) participated three testing laboratories, a university and CENAM with seven secondary standards and first class pyranometers. The measurement results for all instruments were adequate, considering that the deviations found in all cases for global irradiance measurements greater than 500 W / m² were in a band of +/- 2.5%, even though pyranometers have different dates of calibration.

1. Introduction

In order to support the implementation of quality infrastructure in the México market of solar water heating systems (SWH)- which is understood as the interrelation between standardization, conformity assessment and metrology - Mexican test laboratories of solar water heating systems were invited to participate in a pyranometers comparison exercise in the facilities of Centro Nacional de Metrología (CENAM) as part of the PTB-German Mexican project: “Fortalecimiento de la Infraestructura de la Calidad para Energías Renovables y Eficiencia Energética”.

CENAM was chosen to host the comparison due to their development in measurement capabilities for instruments related with renewable energy, including calibration of pyranometers in laboratory with traceability of measurements to the international system of units via a cryogenic radiometer. Metrological support developed in the country is critical to the national net of secondary laboratories that test photovoltaic devices and solar water heaters. The metrological support ensures the measurement values and specifications that consumers receive on efficiency labels of products.
The pyranometers comparison exercise was held from August 31st to September 2nd, 2015 on the facilities of CENAM located at 20º 32.246’ North latitude, 100º 15.320’ west longitude. The exercise was thinking as a first pyranometers comparison between laboratories, regardless of the time of the last calibration of their instruments. Short measurement periods were considered to evaluate the agreement between the measurements of the pyranometers that laboratories use for routine testing of SWH.

Since the CENAM does not have facilities specifically designed for outside solar radiation measurements, the exercise place was the roof of the building D of the optical and radiometry section. In this location a steel platform levelled and prepared to accommodate up to nine pyranometers with a distance between them of 0.43 m was mounted. The height of the platform with respect to other buildings not allow measurements for large angles of incidence with respect to normal, however in the measurements, were not considered the response of instruments for angles greater than 60 degrees from the normal and even some measurements were made near the noon, for periods up to 90 minutes.

2. Participants in the comparison
In the comparison participated testing laboratories, a university and CENAM. The participants were:

- Laboratorio de Pruebas de Equipos de Calentamiento Solar from Instituto de Energías Renovables, IER-UNAM, who participated with two pyranometers, identified as IER1 e IER2.
- Instituto de Investigación y Desarrollo de Energías Renovables y Eficiencia Energética (IIDEREE), who participated with one pyranometer, identified as IIDEREE.
- Laboratorio Mexicano de Pruebas Solares, (MEXOLAB), who participated with one pyranometer, identified as MEXOLAB.
- Centro Nacional de Metrología, (CENAM), who participated with two pyranometers, identified as CENAM1 and CENAM2, calibrated inside of laboratory in the previous months of the comparison [1].
- Universidad Autónoma del Estado de México (UAEMéx), who participated with one pyranometer, identified as UAEM.

The objective of this first comparison was to obtain the deviation of the measurements of each participant pyranometer with reference to the arithmetic mean of the group without a reference instrument. The participants defined prior to exercise, the best sensitivity coefficient of their instruments in the units of [µV / (W / m²)] and also its measurement uncertainty. With this coefficient the global solar irradiance values were calculated and also the deviation of each instrument compared to the group average.

According to [2] the CMP6 instruments are first class pyranometers and CMP11 and CMP21 are secondary standards with technical specification compatible with high accuracy measurements.
### Table 1. Identification of participant’s instruments in the comparison.

| ID     | Measurement number | Manufacturer | Model | Serial  | Sensitivity coefficient [µV m²/W] | Uncertainty of coefficient [%], k=2 | Response time* [s] |
|--------|--------------------|--------------|-------|---------|-----------------------------------|-------------------------------------|-------------------|
| CENA M1 | 4                  | KIPP & ZONEN | CMP 21| 140336  | 9.43                              | 2.0                                  | < 15              |
| CENA M2 | 5                  | KIPP & ZONEN | CMP 6 | 140666  | 18.87                             | 2.0                                  | < 30              |
| IER 1  | 5                  | KIPP & ZONEN | CMP 6 | 140542  | 15.58                             | 2.6                                  | < 30              |
| IER 2  | 5                  | KIPP & ZONEN | CMP 6 | 140541  | 17.06                             | 2.6                                  | < 30              |
| UAEM   | 5                  | KIPP & ZONEN | CMP 11| 126917  | 9.50                              | 2.6                                  | < 15              |
| IIDERE E** | 2                  | KIPP & ZONEN | CMP 6 | 123269  | 12.39                             | 2.6                                  | < 30              |
| MEXO LAB | 1                | KIPP & ZONEN | CMP 21| 110594  | 8.67                              | 1.5                                  | < 15              |

* These data were obtained from the manufacturer.
** The laboratory changes the sensitivity value of their pyranometer during comparison.

### 3. Measurement conditions

The air temperature during the pyranometers measurement period ranged between (22-28) °C and barometric pressure measured every minute in the pressure laboratory of CENAM had maximum and minimum variations between values (81 396 to 80 990) Pa. During measurements there was cloudy sky, clear sky for short periods and even light rain.

Levelling of the instruments with respect to the horizontal was adjusted slightly every morning and also water cleaning condensation of domes was performed.

The measurement exercise considered only simultaneous comparisons of instruments for short measurement times because the interest was to know the results immediately to conduct a preliminary analysis of the measurements, and if necessary to find the causes of widely scattered data to establish calibration needs.
4. Measurement results

The benchmarking exercise was conducted over three days, with four measurement periods between 60 and 90 minutes each. In addition, during the early hours of September 1st a measurement was performed to confirm the behaviour of the instruments in the absence of solar radiation (night measurement) and the mean value of all the instruments was in the band of (-1 to -0.6) W/m².

Because the laboratory MEXOLAB had no connection cable for their pyranometer, he participated in a single measurement, corresponding to the morning of September 1st, using the pyranometer cable of CENAM1. The pyranometer IIDEREE participated in two measurements of September 1st. And pyranometers IER1, IER2, UAEM and CENAM2 participated in all measures of comparison.

The graphs of global irradiance measurements and relative deviations of each instrument to the average of the group are shown in Figures 2 to 5.

The measurement of August 31st is shown in left of Figure 2, which was de first test. It is a common irradiance curve of a cloudy day, since the irradiance value has sudden changes. In Figure 2, the right graph is showing the error percentage taking as the reference value the average value of all pyranometers. The maximum error values are ±10%, which correspond to abruptly changes of irradiance. In the stable periods the errors are from -4% to 2.5%. The following graphs will show the results for two other test days.

![Figure 2. August 31st measurement and results.](image)

Figures 5 shows three different stable periods obtained during two different test days. This Figure shows the irradiance of morning September 1st, the values are between (640 to 740) W/m², the
evening measurements are around 1200 W/m². On September 2nd was obtained irradiation between (400 to 500) W/m². The comparison was performed in a variety of irradiance values.

In case b of the Figure 6, between 10:16 y 10:19 a difference in the pyranometer path is appreciated. Two pyranometer experiments a greater increase of irradiance than the others (UAEM and Mexolab), a peak can see in the graph, the other irradiance paths has peaks but are smoother, this is due to the differences in the response time.
The high dynamic of global irradiance measurement during exercise allowed only a few windows of time with stable solar irradiance, however this type of weather offered the opportunity to appreciate low irradiance values during measurements.

The results for all participants during periods of high irradiance and half irradiance above 500 W/m² show lower deviation +/- 2.5% in all cases and there was unnecessary to discard or analyze any outlier data in the exercise.
(a) 1200 W/m$^2$ stable period (September 1$^{st}$, 2015).

(b) 700 W/m$^2$ stable period (September 1$^{st}$, 2015).

(c) 450 W/m$^2$ stable period (September 2$^{nd}$, 2015).

**Figure 5.** Measurement and results during three different stable periods.

To global irradiance values below 500 W/m$^2$ results are generally more dispersed with high variability of the fast CMP11 and CMP21 pyranometers. Scattering of measurements increases with decreasing irradiance values which is evident in the final part of the afternoon September 1$^{st}$ measurement. This phenomenon is related to the fact that the sensitivity coefficient is not linear with respect to intensity especially at low irradiance values [3], [4]. It is therefore important to know the specific sensitivity coefficient of these instruments at the ends of the scale (200 W/m$^2$ and 1200 W/m$^2$) if is desired to reduce measurement uncertainty below 3% in its operating range.
5. Conclusions
A first pyranometers comparison exercise between test labs of SWH systems was performed from 31 August to 2 September 2015 at CENAM. The results show high dynamic in global solar irradiance values due to the cloudy weather during measurements. The comparison was made on the roof of a CENAM’s building using a levelled steel platform as support for seven pyranometers, four pyranometers from test laboratories of SWH systems, one from a university meteorological institute and two pyranometers from CENAM. The deviation of the results obtained for medium and high irradiance levels of above 500 W/m$^2$ is $\pm 2.5\%$ at each instrument under test respect to the average of the group when the stability in the band of 100 W/m$^2$. The dispersion values for measurements increases below 500 W/m$^2$, due to effects of nonlinearity in the sensitivity coefficient of the pyranometers regarding the irradiance. The deviation obtained from measurements of the two CENAM’s pyranometers for medium and high irradiance is not greater than the uncertainty reported in the calibration laboratory, however for low irradiance, the measurements deviation respect to the average of the group is greater than 3% because it was considered a constant sensitivity coefficient at low irradiance, so it is necessary to study the CENAM1 pyranometer in subsequent calibrations at low intensity. The CMP21 and CMP11 instruments and participants in comparison, have fast measurement changes in irradiance while CMP6 instruments tend to integrate measurements in short time so they remain quasi-stable for rapid changes in irradiance values due to cloudy weather. Overall this first comparison shows good results for instruments with highly variable calibration dates and confirms the need for traceability of pyranometers measurements to reduce the measurement uncertainty in the testing results for solar water heaters systems carried by the test labs in Mexico.

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