D11.9

First yearly report

SFERA II Project	
Solar Facilities for the European Research Area -Second Phase	
Grant agreement number:	312643
Start date of project:	01/01/2014
Duration of project:	48 months
WP11 – Task 11.0	Deliverable 11.9
Due date:	01/2015
Submitted	07/2015
File name:	D11.9_SFERA-II_Deliverable_WP11_YearlyReport.pdf
Partner responsible	DLR
Person responsible	Marc Röger
Author(s):	Marc Röger, Stefan Wilbert, Christoph Hilgert
Dissemination Level	PU

List of content

Executive Summary

The EU-funded research project - SFERA - aims to boost scientific collaboration among the leading European research institutions in solar concentrating systems, offering European research and industry access to the best research and test infrastructures and creating a virtual European laboratory. The project incorporates the following activities:

- Transnational Access: Researchers will have access to five state-of-the-art high-flux solar research facilities, unique in Europe and in the world. Access to these facilities will help strengthen the European Research Area by opening installations to European and partner countries' scientists, thereby enhancing cooperation.

- Networking: These include the organisation of training courses and schools' to create a common training framework, providing regularised, unified training of young researchers in the capabilities and operation of concentrating solar facilities. Communication activities will seek to both strengthen relationships within the consortium, creating a culture of cooperation, and to communication to society in general, academia and especially industry what SFERA is and what services are offered.

- The Joint Research Activities aim to improve the quality and service of the existing infrastructure, extend their services and jointly achieve a common level of high scientific quality.

This deliverable is the result of WP 11 (D11.9 First yearly report) within the Joint Research Activities. The WP 11 “Development of Joint Calibration Procedures and Facilities for Sensors” establishes calibration facilities and agreed procedures to calibrate sensors which are used for thermal performance testing and for measuring the solar resource. In particular, WP 11 is focused on the standardized calibration of solar irradiance sensors comprising both thermal sensors and Rotating Shadowband Pyranometers (RSIs, Task 1) and on a calibration facility for heat transfer fluid mass flow sensors and thermal heat capacity (Task 2).

The principal performed work in Task 1 during the reporting period was the preparation and the start-up of a calibration facility for field pyrheliometers and pyranometers at the Plataforma Solar de Almería and the analysis and standardization of methods to calibrate RSIs. The work performed in Task 2 was the enhancement of the measurement accuracy of a bypass to measure inline the heat capacity of heat transfer fluids used in a parabolic trough plants and its upgrade to calibrate mass flow sensors in existing test facilities.

These sensor calibrations and agreed procedures lead to the required high measurement accuracy for reliable testing capabilities in European research centres and industries, thus providing the basis for innovative products (collectors, receivers, solar sensors, etc.) and their optimization.

This deliverable reports the actions performed during the first 18 months of the project.

Project Objectives in the first 18 months

Regarding Task 1 (Standardized Calibration of solar irradiance sensors), the following objectives are planned during the reporting period:

Calibration facility for thermal irradiance sensors

- Preparation and set-up of calibration facility for field pyrheliometers and field pyranometers at PSA operated/used by the different research institutions following ISO 9059, ISO 9846 and ISO 9847
- Parallel measurements of the aerosol optical depth, circumsolar radiation and documentation of the sky conditions with all sky imagers
- Ensure WRR (World Radiometric Reference)-traceability of solar radiation calibration by participation in absolute cavity radiometer calibration campaigns with DLR's and Ciemat's absolute cavity radiometers
- Calibration campaign of field irradiance sensors to improve and standardize the quality of European research facilities.

Standardization of RSI calibration

- Analysis of different approaches for RSI calibration
- Connection of calibration procedure to correction functions for systematic errors
- Investigation of spectral errors of semiconductor sensors (e.g. RSIs, with simulations of the solar spectrum)

Regarding Task 2 (Bypass facility for measuring the thermal heat capacity of heat transfer fluids and calibrating mass flow sensors), the following objectives are planned during the reporting period:

Enhancement of measurement accuracy of heat capacity measurement bypass

- Detailed measurement uncertainty analysis to identify sensitivities
- Enhancement of overall accuracy by decreasing uncertainty components (sensitivities)
- Enhanced operation of measurement facility and reduction of measurement uncertainty

Upgrading of heat capacity measurement facility

- Concept and layout to calibrate installed mass flow sensors in test facilities using the bypass
- Upgrading of heat capacity measurement facility to calibrate mass flow sensors in existing test facilities

Achievements in the first 18 months

Task 1: Standardized Calibration of solar irradiance sensors

Calibration facility for thermal irradiance sensors

A calibration test stand for pyrheliometers and pyranometers was implemented at the PSA METAS facility. Two PMO absolute cavity pyrheliometers (PMO6 0106 Ciemat and PMO6-cc 0807 DLR) for the DNI and one Kipp&Zonen CMP22 pyranometer (SN 110288) for the DHI are used as reference sensors. In June 2014, a first measurement campaign was successfully performed. In total 19 pyrheliometers and 9 pyranometers have been calibrated. The ISO 9059 (pyrheliometer) and ISO 9846 (pyranometers) are used as basis for the calibration process. The pyranometer calibration was performed according to the continuous sun and shade method.

A solar heliostat from CIEMAT is used as tracker for the pyrheliometers (see Figure 1). All sensors are mounted on a metal plate which is tracked by the heliostat. The DNI reference absolute cavity radiometers (ACR) are placed inside a weather-proof cabinet. During measurement two windows are opened which allow an irradiation of the reference sensors. The data acquisition system (DAS) and the heliostat control system are installed in two cabinets on the back of the heliostat, which allows short fixed sensor cables. This will allow the efficient calibration of other pyrheliometers in the next project years. Pyranometers were calibrated using a sensor table next to the reference pyranometer on top of the METAS BSRN platform. All sky images were taken and the aerosol optical depth and the sunshape were measured during the calibration.

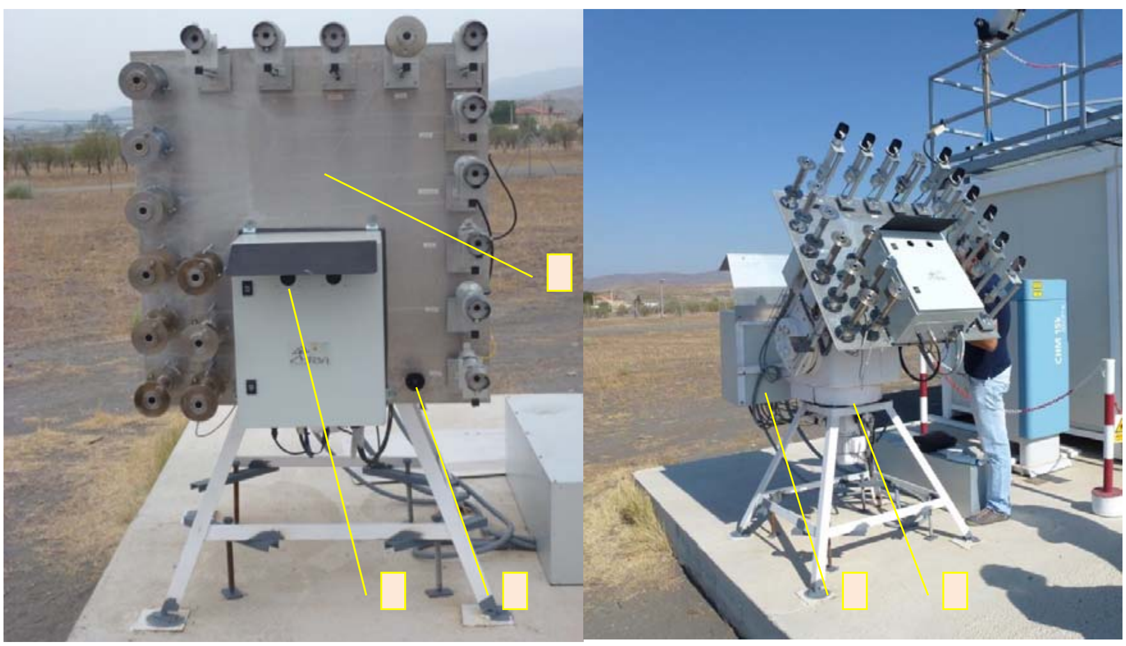

Figure 1: METAS pyrheliometer calibration test stand: 1) two axes tracked heliostat, 2) two reference ACR inside cabinet with windows, 3) sun sensor, 4) mounting plate with field pyrheliometers and 5) cabinet DAS and heliostat controlling

Standardization of RSI calibration

As a first step in this task, the existing RSI calibration techniques have been documented in detail. Furthermore, an investigation of the calibration duration has been carried out. Also the seasonal variation of calibration results was included this analysis. The results of long term calibration were compared to short term calibration. Further details can be found in Deliverable D11.1 “First version of report on calibration procedures for RSI sensors”. This documentation has also been summarized in form of a journal publication that has been submitted to the Journal of Atmospheric Measurement Techniques (AMT).

Further activities concern the spectral errors of semiconductor pyranometers. Thousands of global and diffuse irradiance spectra were simulated based on sun photometer data and used to investigate the spectral errors. The spectral error is the error introduced by the difference between the spectral response of the semiconductor radiometer with respect to a radiometer with completely homogeneous spectral response from 0.25 to 4 µm. A publication for the SolarPACES conference is under preparation. It could be shown that the spectral errors can reach 5 % for global irradiance and even 25 % for diffuse irradiance. The spectral error for diffuse irradiance is significantly reduced by correction functions to typically below 5 %.

Task 2 Calibration facility for heat transfer fluid mass flow sensors and thermal capacity

Enhancement of measurement accuracy of heat capacity measurement bypass

Task 2 was initiated with a comprehensive uncertainty analysis, calculating the combined uncertainty of the heat capacity (c_p) measurement bypass including a sub-device measurand resolved uncertainty weighting. This measure identified individual influences (sensitivities) in the heat capacity measurement of all single measurands and recognized effects on the measurement, such as heat losses for instance.

An electric heater heats up a fluid flow over a defined balance volume. The specific heat capacity can be calculated, applying

Equation 1:
$$c_p = \frac{\dot{Q}_{heater} - \dot{Q}_{Loss}}{\dot{m} \times (T_{out} - T_{in})}$$

by measuring the heat rate of the heater, the heat loss over the balance volume, the mass flow rate and the temperature difference between inlet and outlet fluid temperature. The sensitivities of the individual measurands for a typical measurement for c_p of water below 70°C can be seen in Fig. 2. The temperature difference measurement is the most sensitive parameter.

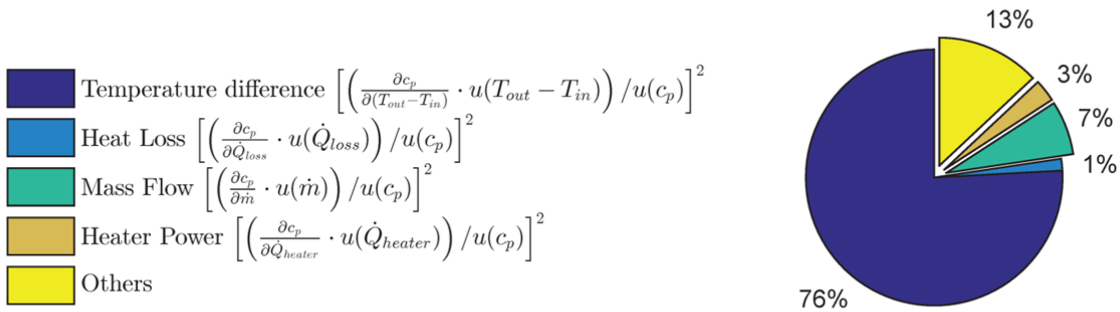

Figure 2: Uncertainty weighting at design measurement conditions for water between 25 and 70°C

For validation purposes the bypass device was hooked up to a water circuit. Demineralized water was used, because it is non-hazardous and its specific heat capacity is known with high accuracy. Comparing the combined measurement result to the data base heat capacity values of water at particular mean temperatures enabled the identification of uncertainties and the influence of non-steady-state effects e.g. fluctuations of the water temperature at the bypass inlet.

All uncertainty components, estimations or information from manufacturers have been cross checked in a succession accordingly to the particular share in the overall/combined uncertainty. For instance, the uncertainty of the temperature difference measurement was proved to be smaller than 0.2 K making use of relative calibration measurements. The manufacturer denoted uncertainty of the power meter was compared to a factor ten more accurate power meter from a different company and proved to measure within defined tolerances.

The outcome of Task 2 is a detailed understanding of all uncertainty components and their combination, which is indispensable for any high precision measurement using heat transfer fluids. The overall combined measurement uncertainty of the cp-measurement was proved to be smaller than 1.2 % at mean operation temperatures between 25 and 70 °C. More details can be found in the Deliverable D11.6 “Report on measurement uncertainty”.

Upgrading of heat capacity measurement facility

Initially, an adequate mass flow sensor was selected to be operated at temperatures up to 350°C and under typical test loop mass flow conditions of about 5 kg/s. In a second step, the existing tubing configuration was extended to accommodate the selected Coriolis mass flow sensor, connecting it directly between inlet and outlet of the existing bypass facility (Figure 3).

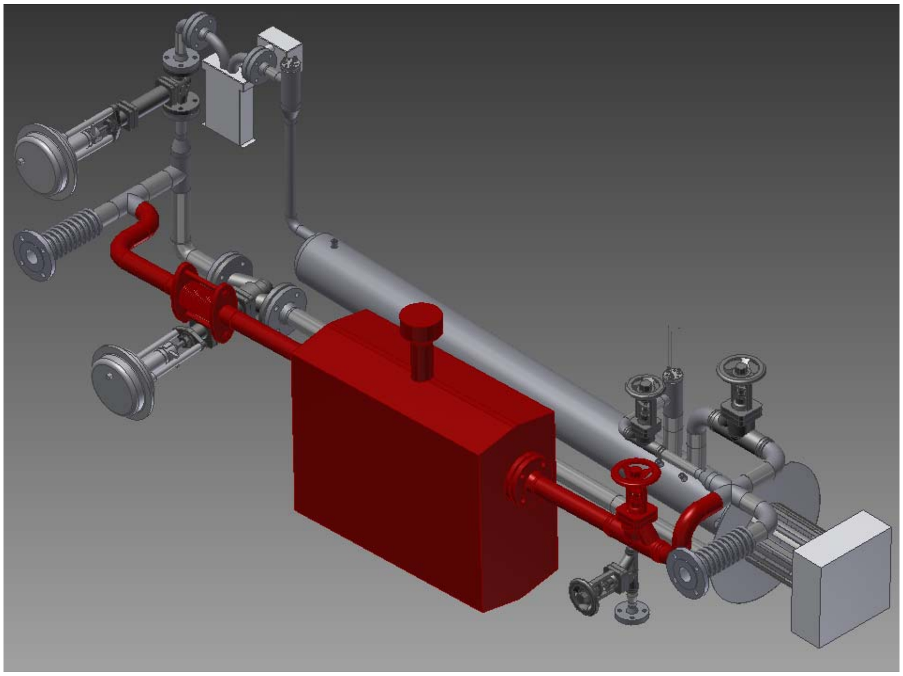

Figure 3: 3D view of the bypass facility without insulation. New tube section and Coriolis sensor highlighted in red

After mounting the new tubing sections, the Coriolis sensor and its peripheral devices were pressure tested and commissioned using water. Finally, the Coriolis sensor was connected to the existing data acquisition system and tested, executing plausibility checks using water at ambient temperatures.

The heat capacity measurement facility was successfully upgraded and proved to be operable on time. Further details can be found in Deliverable D11.7 “Report on extended mobile bypass to measure the mass flow rate”.