



SolarPACES

Concentrating Solar Power, Thermal,
and Chemical Energy Systems

SolarPACES Task III
Solar Technologies and Advanced Applications

Update of guideline: Recommendations for reflectance measurements on soiled solar mirrors

Report WP4

Proposal of a simplified set-up (SSUp) for measuring the solar near-specular reflectance

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Executive Summary

In Concentrating Solar Power (CSP) plants, mirrors are used to redirect solar radiation onto a receiver. Because from the earth the sun is not a point source, solar radiation is diverging; the typical (half) angle is about 4.7 mrad.

As shown in Fig. 1, generally the solar radiation impinges on the mirror at the incidence angle θ , conveniently set to redirect the radiation towards the receiver, which size determines the acceptance (half) angle φ_R within which the reflected radiation is intercepted. In practical cases, the mirror surface is more or less soiled, thus diffraction and scattering enlarge the distribution of the reflected radiation around the specular direction; on the other hand, the part of reflected radiation travelling in the cone with (half) apex-angle φ_R is successfully intercepted by the receiver and can be exploited for CSP purposes. As a consequence, the most important mirror parameter to be evaluated is the so called near-specular solar-weighted reflectance, measured in the range 320-2500 nm, by means of an incident light beam with $\varphi_s = 4.7$ mrad divergence (half angle), at the incidence angle θ and acceptance angle φ_R of interest for the specific plant. Approximately, θ and φ_R are contained in $[35,45]$ deg and $[6,25]$ mrad intervals, respectively.

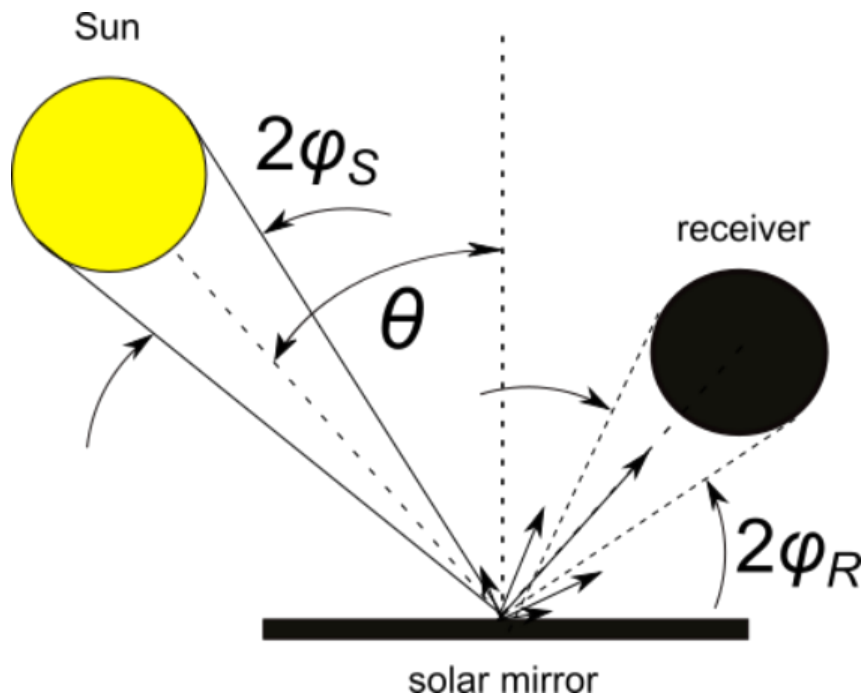


Figure 1: schematic of relevant parameters for CSP applications.

Unfortunately, the market lacks of suitable commercial instruments to accomplish the above- described measurement. Only highly specialized optical laboratories have developed several set-ups, among them S2R [1] is certainly the most versatile and accurate even for soiled specimens.

Now the work-package 4 of the second soiling project funded by SolarPACES aims to cover that gap by outlining a Simplified Set-Up (SSUp) based on commercial components which can be replicated by anyone having just basic skills in optics. Even better if an industrial player interested in engineering and commercializing that prototype will be found.

The present document summarizes the results obtained with the first prototype assembled at ENEA-Casaccia.

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1. The optical scheme of SSUp

The first prototype of the Simplified Set-Up (SSUp) for measuring the solar reflectance of mirrors was assembled in ENEA-Casaccia on the basis of the available hardware components. Figure 2 shows its optical scheme: part of the radiation emitted by a QTH lamp is focused on the diaphragm D#1 (diameter Φ_1) by the lens L#1, and then collimated by the lens L#2 (focal length f_2), making a light-beam diverging for the (half) angle

$$\varphi_s = \frac{1}{2} \frac{\Phi_1}{f_2} \quad (1)$$

When the beam impinges the mirror surface (not reported in Fig. 2) with an incidence angle greater than 15 deg, the beam is *s* or *p* polarized by Pol; the (reflected) beam is finally focused on the diaphragm D#2 (diameter Φ_2) by the lens L#3 (focal length f_3), so that only the radiation diverging for less than the acceptance angle

$$\varphi = \frac{1}{2} \frac{\Phi_2}{f_3} \quad (2)$$

enters into the integrating sphere and can be detected by the spectrometer. The spot-size of the beam impinging the mirror surface can be adjusted by means of the iris diaphragm Ir, just placed at the exit face of L#2. The lens are made of fused silica to enhance the transmittance and minimize the focal length variation in the solar range 320-2500 nm.

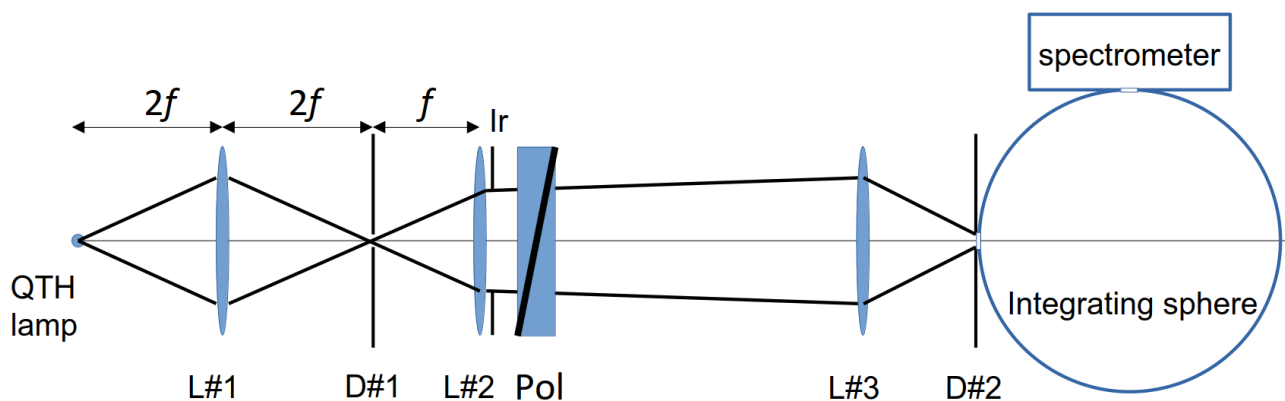


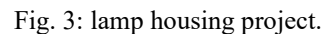
Fig. 2: optical sketch of the SSUp in the baseline configuration.

Table 1 lists the main features of the SSUp optical components.

Table 1: main features of the SSUp optical components.

Component	Producer	Model	Parameter	Value
QTH	Guerra S.A.S	G. 6,35	Electric power	100 W
L#1	Oriel	BC 39333	Focal length	~ 64 mm
L#2	Oriel	PC 41545	Focal length	~ 63 mm
L#3	Oriel	PC 41479	Focal length	~ 65 mm
D#1	homemade	NA	Diameter	0.6 mm
D#2	homemade	NA	Diameter	1.82 mm
Ir	Edmund Optics	57-577	Diameter	1.2 – 20.0 mm
Pol	Oriel	27306	Extinction	$10^{-5} - 10^{-1}$
Int. sphere	LabSphere	IS-040-SF	Diameter	4 inch
Spectrometer	Ocean Optics Inc.	USB2000	Range	400 - 900 nm

To obtain the collimated beam we take advantage of the lamp-housing already developed in the early 2000s, in the framework of the CMS experiment at the LHC of CERN, shown in Fig. 3.



On the left of Fig. 4 L#3, D#2, Integrating Sphere, and spectrometer are visible; these components are firmly installed on an optical rail to make the so-called *detector unit*, which can be moved on the table surface as a whole. More precisely, the centres of L#3, D#2 and the entrance port of the integrating sphere

have been aligned centrally to the light beam by conveniently adjusting position and height of each component on the rail.

The distance between L#3 and D#2 has to be adjusted once for all according to the criterion of minimizing the diameter of the focused spot at the D#2 plane; the optimal distance between the lens flat side and D#2 resulted to be 63 mm. On the other side, according to the Oriel catalogue, the *nominal back focal length* from the lens flat side is 53.8 mm, while the nominal focal length is 65 mm; therefore the principal point is expected to be 11 mm far from the flat side (inside the lens). Therefore, at the optimized distance between L#3 and D#2, the effective distance between the L#3 principal point and the diaphragm is $63 + 11 = 74$ mm. That value is 9 mm greater than the focal length of L#3, maybe for compensating the beam divergence.



Fig. 4: SSUp configured for measurements at 60° of incidence.

In the end, after some preliminary tests, the D#2 diameter has been set to 1.82 mm to obtain $\varphi \simeq 12.3$ mrad, according to Eq. 2.

Unfortunately, at present we have not mechanical components suitable to hang the detector unit to a rigid arm, pivoting around the vertical axis of the sample-holder goniometer; therefore the detector unit has to be carefully realigned on the reflected/transmitted beam when θ is changed. Please note that this realignment just concerns the horizontal plane: thanks to the horizontality of the beam, the alignment in the vertical direction is maintained. Therefore, one has just to translate and rotate the unit to let the beam crossing the L#3 centre, and at the same time the centre of D#2. This operation takes only few seconds; the reproducibility is very good.

3. Comparison with S2R

The SSUp prototype has been validated by measuring the following coupons:

1. clean mirror (Tgy1)
2. sand-blasted mirror (S6)
3. hair-sprayed mirror (HO1)
4. black-paint-sprayed mirror (P2)

The S2R measurements were accomplished in the restricted range 320-860 nm because of a temporary malfunctioning of the spectrophotometer in the NIR region. The measurements have been done at 15°, 30° and 60° of incidence with 12.3 mrad of acceptance; at 15° of incidence the beam was not polarized, while in the other cases each sample was measured for both *s* and *p* polarizations.

As explained in Section 3, in the actual version the SSUp detector unit has to be manually realigned when the incidence angle is changed. To make the measurements more reliable, we run the baseline at the given angle and polarization on the clean mirror Tgy1; then the other coupons are measured getting the ratio of their reflectance to the one of the clean coupon; that ratio is the *cleanliness* of the mirror. That method offers a second important advantage: the results are completely not depending on the reference used in S2R.

With the actual spectrometer Ocean Optics USB 2000, the useful range of SSUp is 400-900 nm.

Figures 5, 6 and 7 show the comparison between S2R and SSUp. Considering the rather prototypical character of the SSUp, the agreement is quite satisfactory.

Completion of the prototype requires funding to purchase one or more spectrometers, or other kind of sensor, suitable for covering the 320-2500nm spectral range and with sufficient sensitivity to keep the error within a few fractions of one percent.

We conclude highlighting the short measurement time of SSUp: the acquisition of a single spectrum takes few seconds; the complete measurements of 4 specimens over 3 different incidence angles takes less than half hour, although, as already said, the detector unit has to be manually realigned when the incidence angle is changed.

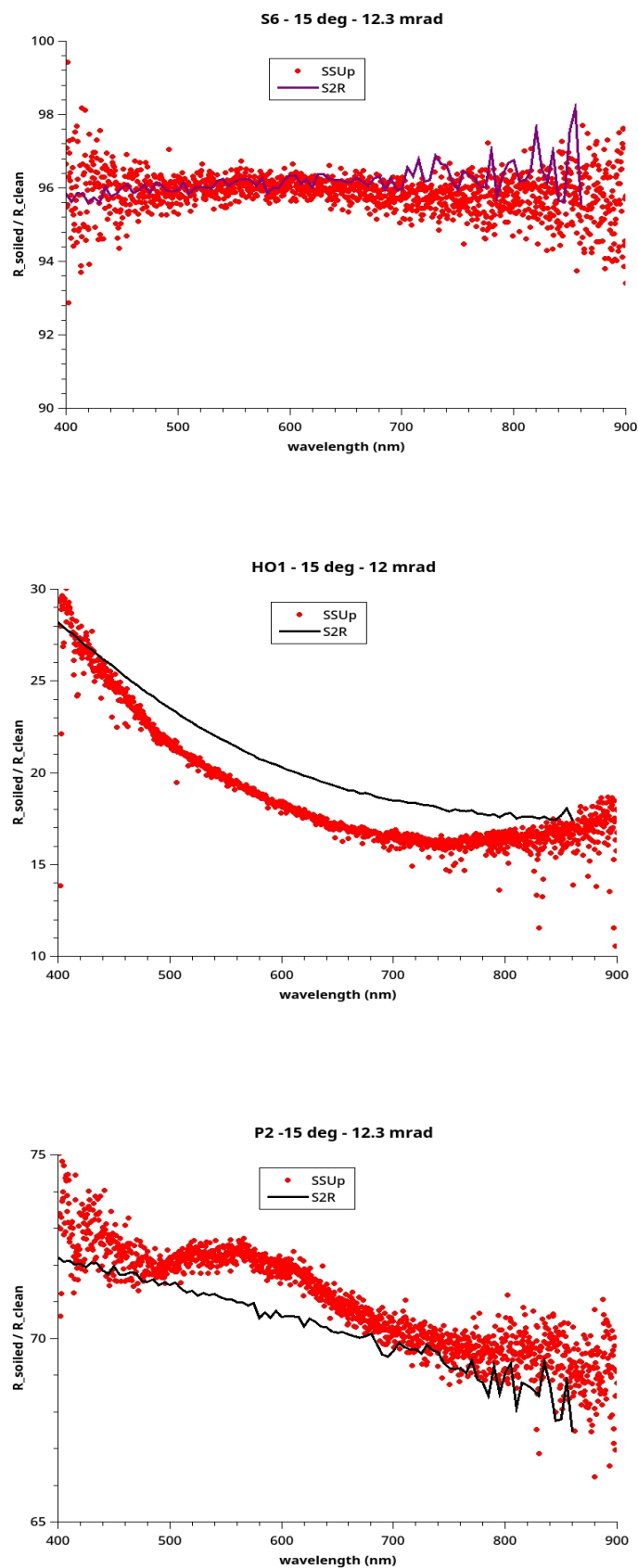


Fig. 5: S2R SSUp comparison at $\theta = 15$ deg

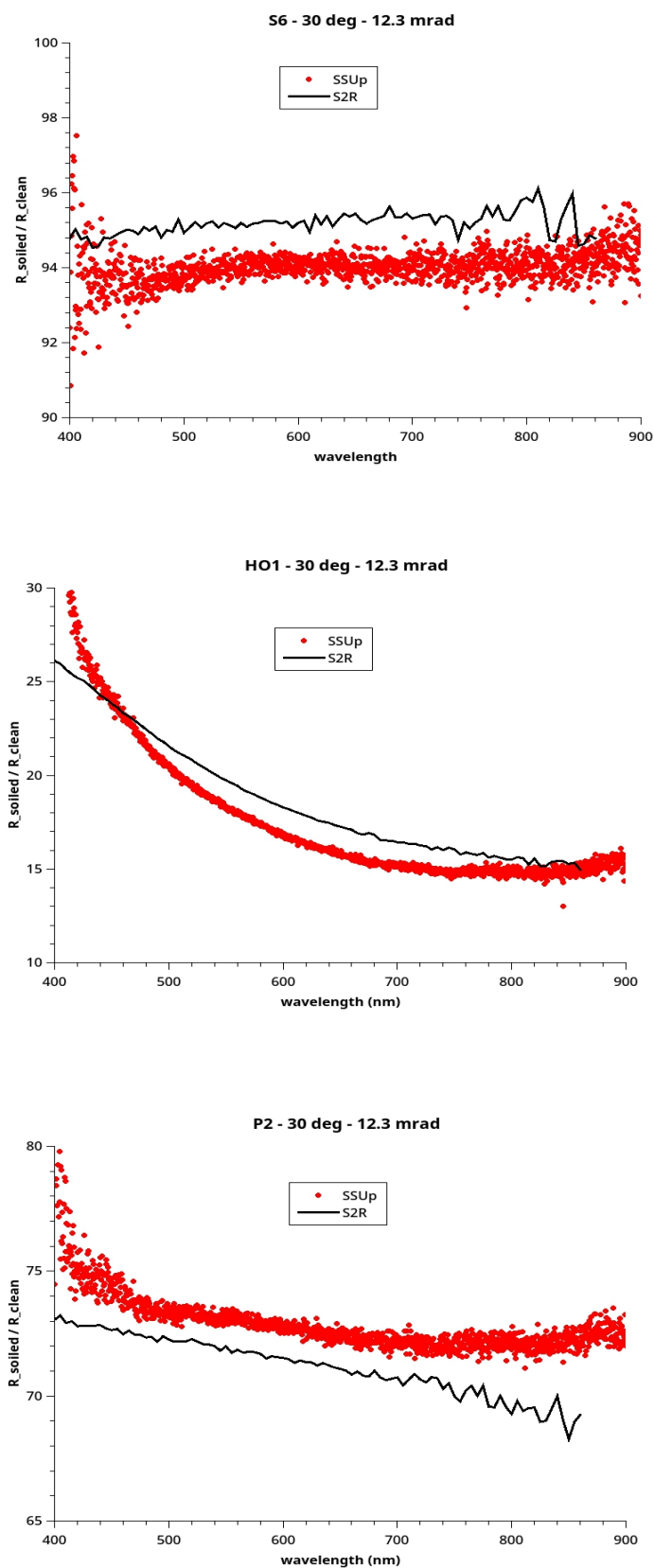


Fig. 6: S2R SSUp comparison at $\theta = 30$ deg.

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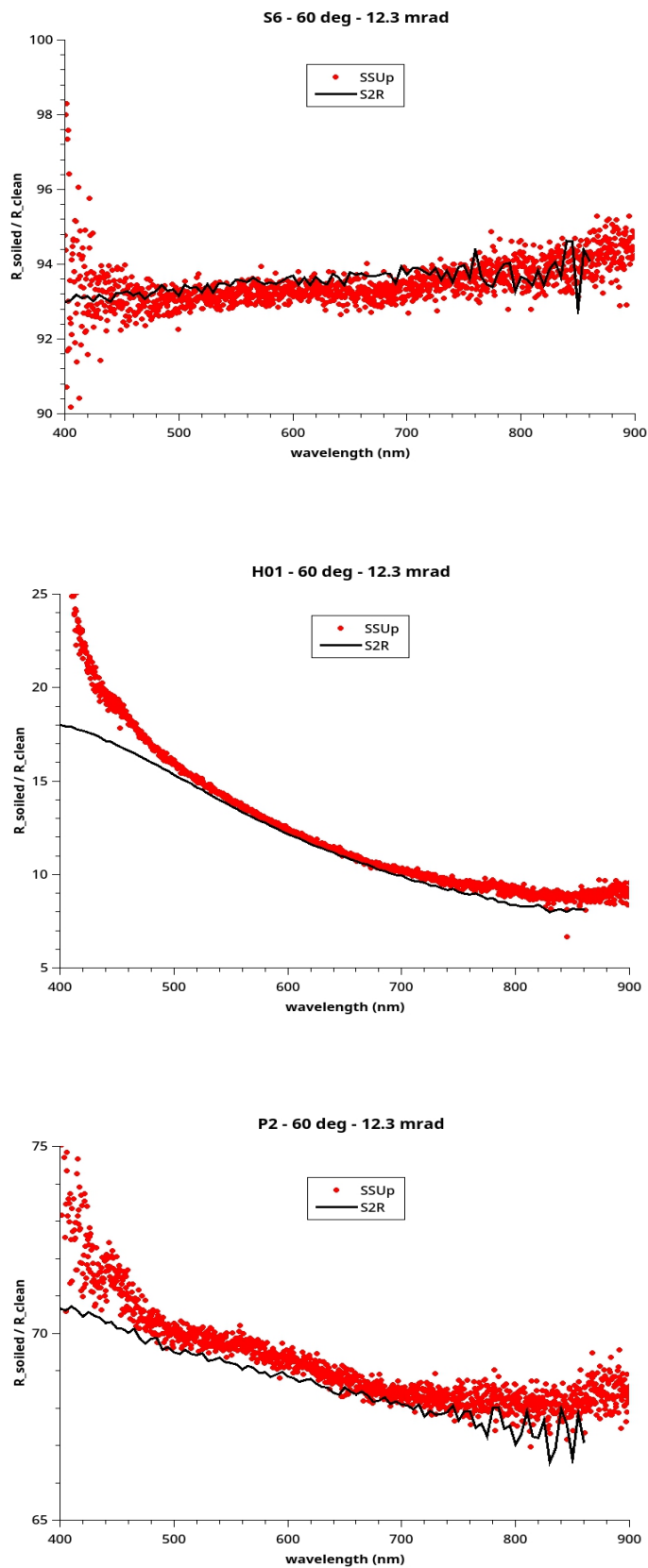


Fig. 7: S2R SSUp comparison at $\theta = 60$ deg.

4. References

[1] F. Sutter, S. Meyen, A. Fernandez-Garcia, P. Heller, "Spectral characterization of specular reflectance of solar mirrors." *Solar Energy Materials and Solar Cells* 145 (2016): 248-254