A unified global investigation on the spectral effects of soiling losses of PV glass substrates: preliminary results

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Abstract — **The present work shares the initial results of an international collaboration aiming to investigate the spectral effects of soiling losses in different locations worldwide. Weekly direct and hemispherical transmittance measurements are compared. Initial results suggest that the spectral character of the losses depend both on the amount and the type of dust. While the abstract focuses on a few of the sites, the full paper will present transmission data from a larger number of sites in order to refine the analysis and to include an investigation on the relations between the soiling type and composition and the local environmental parameters.**

I. Introduction

The accumulation of dust is one of the major concerns for photovoltaic (PV) systems since it reduces the sunlight transmitted by the glass surface and, thus, the energy converted by the modules. The dust composition and the particle size play a fundamental role in the impact of soiling losses [1], [2]. Several works have analyzed the relation between the dust and the soiling losses in different locations [3]–[5]. All these analysis are generally site-specific or highly regionalized. Other works have instead analyzed the effect of artificially deposited dust [6], [7]. The present work is the result of an international collaboration among academic and research institutes and private partners that aims to investigate the spectral effects of soiling naturally deposited on PV glasses installed at various locations worldwide. These preliminary results are presented in this abstract and will be updated in the full paper.

II. Materials and Methods

Tests have been conducted at eight locations worldwide, listed in Table I, chosen to represent a wide variety of climates and environmental conditions. Each partner used a spectrophotometer to weekly measure the change in transmission due to the accumulation of soiling. Seven identical 4 cm × 4 cm sized and 3 mm-thick Diamant® low-iron glass from Saint-Gobain Glass were shipped to each location. Coupons were numbered from 0 to 6: six of them (coupons 1 to 6) were installed outdoors, at zero tilt angle, using the supporting structure shown in Fig. 1. Coupon 0 was instead kept in a safe, dust-free container and used to calibrate and compare the different spectrophotometers.

Weekly transmission measurements were taken on coupons 1, 2 and 3. Coupon 1 was cleaned weekly, coupon 2 was cleaned every 4 weeks (twice during the data collection) and coupon 3 was never cleaned. A dry cleaning is performed by using a microfiber cleaning cloth. Coupons 4, 5 and 6 were not cleaned nor moved until the end of the data collection, since they will be used for the dust characterization analyses. Daily weather data have been recorded at each location. Where available, data on mean daily concentrations of particulate matter (PM) have been collected.

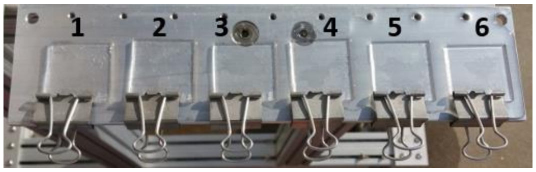

Fig. 1. Supporting structure holding six glass coupons. These are held with binder clips on a horizontally-mounted aluminum plate. Weekly transmittance measurements are taken for coupons 1, 2 and 3, whereas coupons 4, 5 and 6 will be used for dust characterization.

III. Initial Results

A. Impact of soiling on broadband hemispherical transmittance

The data collection commenced in January 2017. An example of the results, obtained by the measurements performed in Golden, Colorado, USA, is shown in Fig. 2. Coupon 1, cleaned every week, shows a weekly average reduction of 0.5% in hemispherical transmittance. In contrast, this value increases to 2% in Chennai. This result agrees with the expectations: mean daily concentrations of $PM_{2.5}$ of 11 $\mu g/m^3$ and 41 $\mu g/m^3$ were recorded in January 2017 from monitoring stations nearby Golden and Chennai, respectively. After 6 weeks, Coupon 3 had lost 1.5% in Golden and 10% in Chennai respectively. During the same time period, maximum losses of 6% have been registered in Jaén, whose daily mean $PM_{2.5}$ concentrations have been 17 $\mu g/m^3$. Results from additional sites will be added to the full paper for more complete analyses of the weekly losses and their relation to local meteorological and atmospheric pollution conditions.

TABLE I
List of Monitored Locations and Climate Classifications, Sourced from [8].

City, Country	Coordinates	Climate classification
Chennai, India	13.08, 80.27	Equatorial savannah with dry winter (Aw)
Dubai, UAE	28.36, 75.59	Desert climate (Bwh)
Penryn, UK	50.17, -5.13	Warm temperate climate, fully humid (Cfb)
Golden (CO), USA	39.74, -105.18	Snow climate, fully humid (Dfb)
Jaén, Spain	37.79, -3.78	Warm temperate climate with dry summer (Csa)
El Shorouk City, Egypt	30.12, 31.61	Desert climate (Bwh)
San José (CA), USA	37.29, -121.91	Warm temperate climate with dry summer (Csb)
Tezpur, India	26.70, 92.83	Warm temperate climate with dry winter (Cwa)

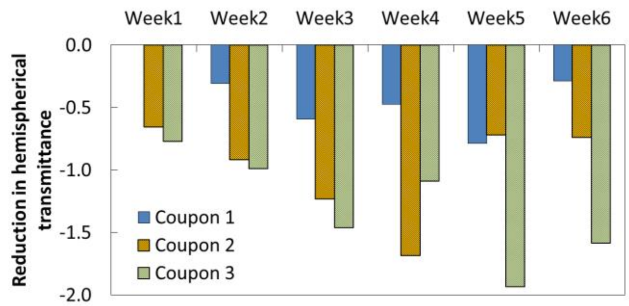

Fig. 2. Progressive absolute drop in hemispherical transmittance, compared to the initial conditions, registered in Golden, CO. Transmittance is obtained by averaging the data recorded between 200 and 1100 nm, with a 1 nm step. Coupon 1 was manually cleaned every week and coupon 2 was cleaned on week 4.

B. Impact of soiling on broadband direct transmittance

As expected, higher losses have been found when direct transmittance is considered instead of hemispherical. Figure 3 shows the results of the weekly measurements conducted on Coupon 3 in Golden, CO. When compared in the same wavelength range (500 nm to 1100 nm), the direct transmittance is found to drop by 6% in 6 weeks, while the loss in hemispherical transmittance is limited to 1.5%.

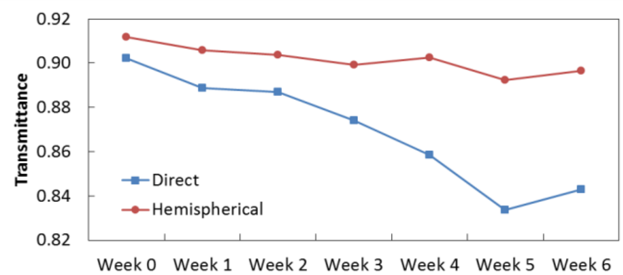

Fig. 3. Direct and hemispherical transmittance of coupon 3 in Golden. Wavelengths between 500 and 1100 nm have been averaged.

In El Shorouk City, weekly losses as high as 20% in direct transmittance have been registered. In Tezpur, a drop of 23% in direct transmittance was measured on coupon 3 after the longest dry period (2 weeks). The measurements taken at the end of the dry period, week 5, are shown in Fig. 4. Coupons 1 and 2 (both cleaned in week 4) have similar transmittance, although, they both show a drop in transmittance between 8 and 10%, compared to coupon 0, after only one week.

C. Impact of soiling on spectral transmittance

The data collection performed in this project allows for an analysis of the spectral losses occurring at the different locations. The normalized hemispherical transmittance in the visible region of the spectrum for coupon 3, at the end of the data collection, exposed in: Chennai, Jaén, San José and Golden are shown in Fig. 5. The transmittance is divided by that recorded for coupon 0 at each location and the data have been processed using a local regression technique to remove noise. This way, the effect of soiling on the transmission at each wavelength can be analyzed independently of the optical nature of the glass. The initial results show that soiling has a higher impact on the blue than on the red end of the spectrum, independently of the location and of the amount of losses. This is in agreement with the conclusions of Ref. [6] where coupons artificially soiled with dust collected in Kuwait were studied. Although, two low-soiling sites, Golden and San José, show a linear low slope trend, with a slight curvature at shorter wavelengths, a low soiling site (Jaén) and a high soiling site (Chennai) show a stronger change in slope at shorter wavelengths, with a clear steeper trend in the blue than in the red portion of the spectrum. These results suggest that the spectral transmittance of soiling is dependent on both the amount and the type of dust. Further analysis will be presented, using a larger number of sites, in the full paper.

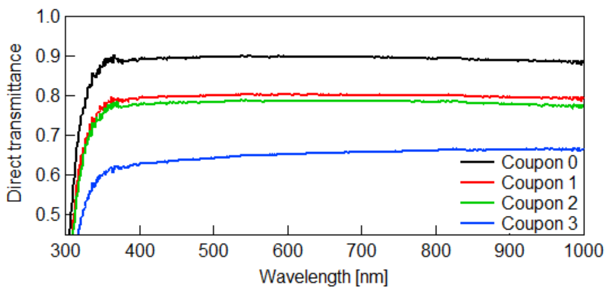

Fig. 4. Direct transmittance of coupons 1, 2, 3 in Tezpur, India, measured at week 5, after two dry weeks. Coupons 1 and 2 have similar transmittance since both have been cleaned at week 4.

IV. Preliminary Conclusions and Research Directions

Soiling is an issue affecting PV systems worldwide. It depends on a number of site-specific factors. The main aim of this work is the comparison of naturally-accumulated soiling on PV glass at different regions worldwide. Identical glass coupons have been exposed and cleaned at fixed time intervals. Transmissivity has been measured weekly and the preliminary results of this investigation have been presented. Weekly broadband losses as high as 2% and 20% in hemispherical and direct transmission, respectively, have been, mainly impacting the blue portion of the spectrum. More results will be shown in the full paper, which will include data from a larger number of sites and a more detailed spectral investigation. Moreover, initial dust characterization results will be presented in order to correlate transmittance losses with dust type and composition.

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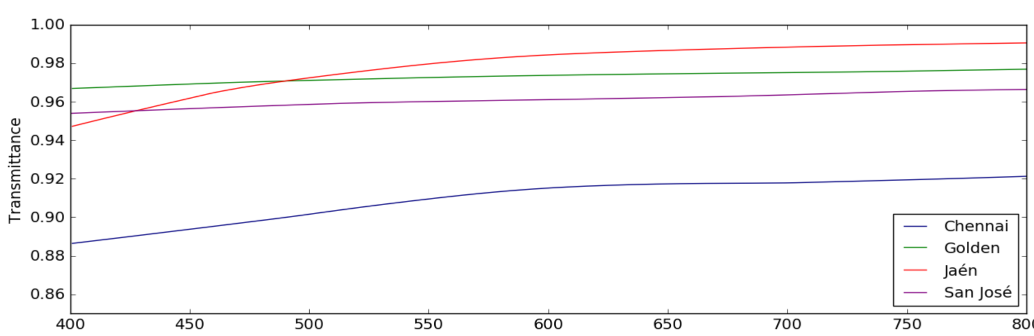

Fig. 5. Hemispherical transmittance in the visible range of coupon 3, referenced to the transmittance of coupon 0, in Chennai, Golden, Jaén and San José at the end of the data collection period. The spectra were measured with different spectrophotometers at each site.