Measurement procedure for opaque Venetian blind slats for use in WINDOW

Jacob C. Jonsson
Lawrence Berkeley National Laboratory

Windows and Envelope Materials Group
Building Technology and Urban Systems Department
Envirnmental Energy Technologies Division

2013

Disclaimer

Abstract

WINDOW 6 can model diffuse Venetian blind slats of different orientation, size, and curvature. The optical properties that are required for the model is the direct-hemispherical reflectance and the emissivity, these are the only properties required assuming that the slats are opaque in both the solar optical range and thermal infrared.

This paper describes the necessary steps to measure and report the data needed.

1 Introduction

The integrating sphere was designed as a detector to capture light scattered over a hemisphere[1]. Inter-laboratory comparisons have in the past shown that different instruments can give quite different, and sometimes unphysical, results for the same sample [2, 3, 4]. The signal measured with an integrating sphere furthermore depends on the scattering properties of the sample [5, 6] in a way which is individual for each sphere. The uncertainty and instrument variation is larger for thick translucent samples and samples with an inhomogeneous scattering distribution. Despite these shortcomings the integrating sphere is still the preferred detector for studying direct-hemispherical optical properties of scattering samples, a high-signal and a compact form factor allows for measurements with specular resolution. In inter-laboratory comparisons of specular samples the integrating sphere has shown good agreement.

LBNL has not conducted or obtained results from an inter-laboratory comparison of Venetian blind slat measurements using spectrophotometers fitted with an integrating sphere. However, in the inter-laboratory comparison carried out in 2011 at LBNL there was a thin and reflective material included. Figure 1 shows the results for this material, and the agreement is within ± 0.02 for the majority of the spectrum. The data shown is not corrected using a calibrated diffuse reference, something that could possibly improve the agreement. The conclusion is that the instruments typically used for measurement of data that is submitted to the IGDB could be used for opaque Venetian blind slats which can be accurately modeled by the LBNL WINDOW software[7] versions 6 and later.

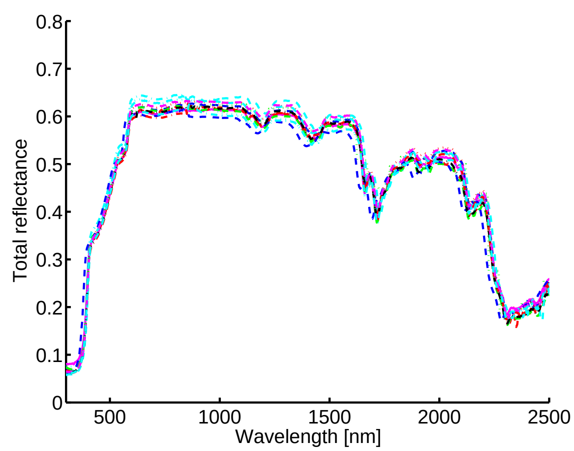

Figure 1: Measured spectral direct-hemispherical reflectance for a thin and reflective material. Each curve represents the data from a different laboratory. The total spread is approximately ± 0.02.

2 Measurement steps

There are several differences when measuring a diffuse sample compared to when measuring a specular sample. This document assumes the reader is familiar with the use of a spectrophotometer fitted with an integrating sphere for measurement of specular samples. The following list describes the steps of the procedure and each step is described in further detail throughout this section.

1. Measure 100% reference baseline using a known diffuse reference standard.
2. Verify that the sample is opaque by measuring the transmittance.
3. Measure direct-hemispherical reflectance of the sample.
4. Measure diffuse-only reflectance of the sample.
5. Calculate the haze factor for each wavelength to verify that the sample is diffuse.
6. Multiply the measured direct-hemispherical reflectance with the reflectance of the diffuse reference.
7. Measure the sample emissivity either using an emissometer or using an FTIR fitted with an integrating sphere.

2.1 Calibrated diffuse reflectance standard

An integrating sphere is a relative detector when studying diffuse samples, i.e. the measured reflectance is relative to the reflectance of the sample used when carrying out the baseline measurement. No known diffuse material has a reflectance of 1.0 over the whole solar range which means that the measured result is influenced by the reflectance of the reference sample. Diffuse samples can be purchased with calibration data or sent to NIST for calibration. The important part of the reference is that the spectral reflectance is known.

Most integrating spheres are made of Spectralon™ or coated in $BaSO_4$. Both these materials are suitable since they have high reflectance values throughout the solar wavelength range. One of the reasons Spectralon became popular was that is is more stable and easier to handle than $BaSO_4$, however, even Spectralon deteriorates over time [8]. This directly impacts the accuracy of the reference sample. The accuracy of an integrating sphere is not directly impacted, but the signal goes down so the noise will be more prominent.

2.2 Verification that the sample is opaque

Some materials are known to be opaque, e.g. an aluminum slat will be opaque at all wavelengths. However, materials can look opaque in the visible but have transmittance for infra red wavelengths, several polymer materials have this property. This is also true for samples that are extremely thin.

To verify that the sample is opaque, measure the transmittance of the sample over the whole wavelength range. Calculate the integrated solar transmittance. If the value is larger than 0.02 the sample is not considered opaque.

When measuring values close to zero it is recommended to always verify that the instrument does this correctly by measuring the transmittance of something that is very opaque, e.g. a thick piece of metal. There are multiple reasons why an instrument could report values that are too high when measuring 0.

2.3 Determination of haze

The sample has to be diffuse for the WINDOW Venetian blind model to give accurate results. The way to determine if this is true is to measure the haze factor of the sample. The limit set for materials to work with acceptable accuracy in the WINDOW model is a haze factor of 0.85 or higher.

The haze, $H(\lambda)$ is defined as the ratio between the diffuse-only reflectance, R_{diff}, and the total direct-hemispherical reflectance, R_{dh},

$$H(\lambda) = \frac{R_{\text{diff}}}{R_{\text{dh}}}. \tag{1}$$

A diagram describing how the sphere is set up for the two different reflectance measurements is shown in figure 2.

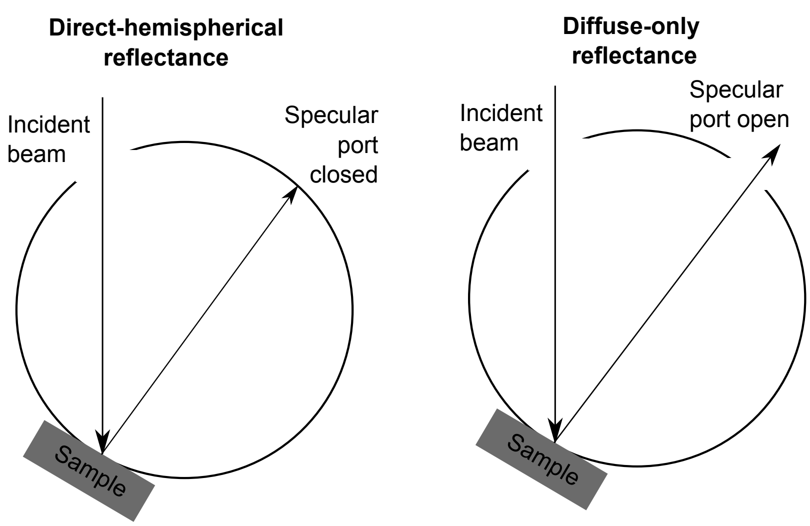

Figure 2: The integrating sphere can be modified to measure the diffuse-only reflectance of a sample by opening the specular port. With the port in place the direct-hemispherical reflectance is measured.

The difference between the measurements is that a specular port is opened in the diffuse-only configuration, letting out the specular portion of the reflectance. The solid angle of the specular port is instrument-dependent and therefore it is possible to get different haze values for different instruments. The selected number 0.85 is based on 150 mm diameter integrating sphere with an acceptance angle of approximately 5 degrees.

The haze factor is wavelength dependent and the condition of haze larger than 0.85 should be fulfilled in the full solar range from 300 nm to 2500 nm. However, for small values of reflectance the instrument noise could easily result in haze values outside the approved range (even unphysical results such as haze larger than 1). Samples where this occurs can still be considered diffuse as long as the solar integrated haze is above 0.90. The procedure to calculate the solar haze is done by calculating the haze at each wavelength and then integrating the haze value using the following equation

$$H_{sol} = \frac{\int_{\lambda=300}^{2500} R_{\text{diff}}(\lambda)/R_{\text{dh}}(\lambda)I(\lambda)\text{d}\lambda}{\int_{\lambda=300}^{2500} I(\lambda)\text{d}\lambda}, \tag{2}$$

where $I(\lambda)$ is the solar intensity as a function of wavelength.

2.4 Diffuse reference samples

All the diffuse reflectance values measured, R_{measured}, should be corrected by multiplying the result with the reflectance of the reference,$R_{\text{reference}}$ used at the 100% baseline calibration as described by the relationship

$$R_{\text{corrected}} = R_{\text{measured}} \cdot R_{\text{reference}}. \tag{3}$$

The easiest way to remember that the result should be multiplied is to imagined that the reflectance of the reference is measured. Since it is the same as the baseline the instrument will respond 1 which is corrected by multiplying with the calibrated values, e.g. 0.99, which makes the corrected result agree with the calibration data. Some instruments allows for automatic correction during measurement time according to this method.

There is a more correct way to calculate the correction which is important for samples with lower haze. This is based on the theory that the integrating sphere produce absolute reflectance results for specular samples[9]. Based on that theory only the diffuse part, i.e. $H(\lambda)$, should be multiplied with the reference reflectance and the specular part is correct as it is. This is described by the following equation

$$R_{\text{corrected}}(\lambda) = H(\lambda)R_{\text{measured}} \cdot R_{\text{reference}} + (1 - H(\lambda)) \cdot R_{\text{measured}}. \tag{4}$$

As long as both $H(\lambda)$ and $R_{\text{reference}}$ are very close to 1 the effect of this improved correction is very small. But it is prudent to apply it rather than the simplified correction.

2.5 Emissivity

Emissivity for specular samples are based on measurements the specular-only reflectance in the thermal infra red spectrum, $5\mu m$ – $25\mu m$. This method is not applicable for diffuse samples and therefore two alternatives are accepted.

2.5.1 FTIR with integrating sphere

Some FTIR instruments are fitted with an integrating sphere and if so the same procedure used for measurement of the direct-hemispherical solar reflectance. The reflectance is then reported.

2.5.2 Emissometer

An emissometer is an instrument that directly measures the hemispherical emissivity of a surface. Rather than reporting the reflectance, the emissivity is reported directly.

The accuracy of the emissometer is highly dependent of the calibration standards used (just like the FTIR).

3 Reporting

The reflectance should be reported on the same format as an IGDB submission[10] with the exception that if the emissivity was measured using an emissometer it should be reported in a header line on the following format:

```
{ Emissivity, front back } Emis= 0.420 0.420
```

If the slat has a different color on the top and the bottom, it is the top surface that is considered the front surface.

Note that both the opacity test and the haze factor measurement require no reporting, they are only designed to help verify that the product is correctly modeled by WINDOW.

4 Example

As an example an aluminum slat painted off-white was characterized going through the steps.

4.1 Verification of opacity

Even though the sample was expected to be opaque this was verified to be sure and also to give a record of how a zero result looks with the used instrument. The integrated solar result came out to 0.004 and the spectral result is shown in figure 3.

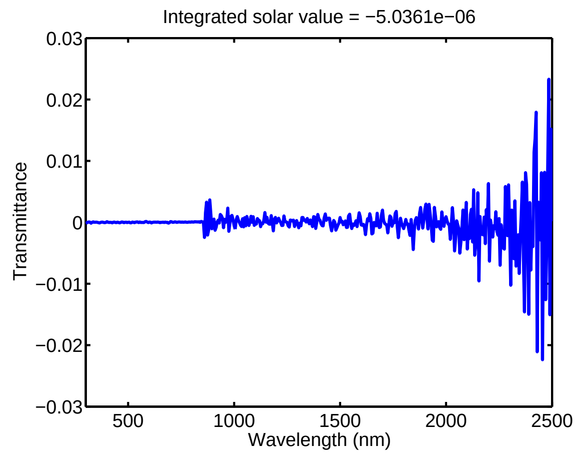

Figure 3: Measured spectral transmittance for a thin aluminum slat. Despite the noise it is possible to determine that the material is opaque in the complete wavelength region.

4.2 Haze measurement

The diffuse and direct-hemispherical reflectance was measured individually. The haze for each wavelength was calculated using (1) and is shown with the two measurements in figure 4.

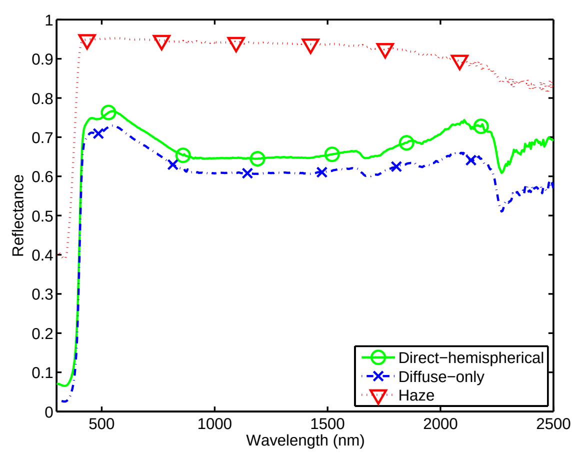

Figure 4: Measured diffuse and direct-hemispherical reflectance as well as the calculated haze factor.

The reflectance in the UV is low and the glossy properties of the sample dominates in this region resulting in a haze of as low as 0.4, which is much less than 0.85. Therefore the sample is not considered glossy unless the integrated solar value of the haze comes out to greater than 0.90. The value for the data in figure 4 comes out to $H_{solar} = 0.9411$ and it can be considered diffuse enough.

4.3 Reference correction

The measured direct-hemispherical data was corrected using both equation 3 and equation 4. The results are shown in figure 5.

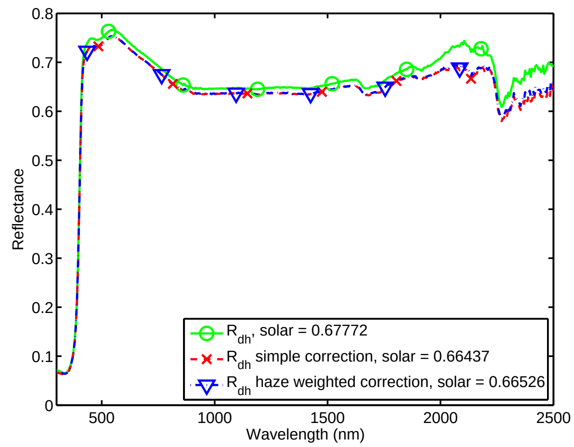

Figure 5: The measured reflectance and the corrected Measured diffuse and direct-hemispherical reflectance as well as the calculated haze factor.

The difference in integrated solar value between the two correction methods is less than 0.001, a very marginal improvement. However, not correcting for the reference reflectance would generate an error of more than 0.01, which is quite significant.

4.4 File generation

Create a text file just like for a regular IGDB submission. Use 0 for transmittance rather than any noisy data set used to verify opacity. The emissivity is filled out in the header.

```
{ Units, Wavelength Units } SI Microns
{ Thickness } .2
{ Conductivity } 1.000
{ IR Transmittance } TIR=0.000
{ Emissivity, front back } Emis= 0.829 0.829
{ }
{ Product Name: blindslatdemo.txt }
{ Manufacturer:  }
{ Type: Venetian blind slat }
```

```
{ Material: N/A}
{ NFRC ID: 51914 }
0.300    0.0000    0.0691    0.0691
0.305    0.0000    0.0686    0.0686
0.310    0.0000    0.0682    0.0682
0.315    0.0000    0.0674    0.0674
.
.
.
.
2.475    0.0000    0.6535    0.6535
2.480    0.0000    0.6497    0.6497
2.485    0.0000    0.6412    0.6412
2.490    0.0000    0.6619    0.6619
2.495    0.0000    0.6579    0.6579
2.500    0.0000    0.6448    0.6448
```

5 Conclusion

This is the first public procedure to submit data to the CGDB. As such we are interested in your comments. Feel free to contact `igdb@lbl.gov` with questions and/or suggestions.

References

[1] R. Ulbricht, "Die bestimmung der mitleren räumlichen lichtintensität durch nur eine messung," *Eklektrotechn. Zeit.* **29**, pp. 595–597, 1900.

[2] P. Polato, G. Rossi, J. Roucour, J. Simons, and H. Rose-Wilson, "Spectrophotometric determination of visible and solar parmeters of sand-blasted glass panes and translucent glass laminates," *Riv. Staz. Sper. Vetro* **33**(5), pp. 5–18, 2003.

[3] H. Wilson, M. Hutchins, N. Kilbey, and C. Anderson, "Intercomparison of transmittance and reflectance measurements of light-scattering and patterned glass with spectrophotometers and integrating spheres," 2009. ICG TC-10.

[4] J. C. Jonsson and C. Curcija, "Inter-laboratory comparison using integrating sphere spectrophotometers to measure reflectance and transmittance of specular, diffuse, and light-redirecting glazing products," in *Proceedings of SPIE*, L. M. Hanssen, ed., **8495**, p. 849509, 2012.

[5] D. I. Milburn and K. Hollands, "The directional response of an integrating sphere detector system," *Opt. Comm.* **115**, pp. 158–169, 1995.

[6] A. V. Prokhorov, S. N. Mekhontsev, and L. M. Hanssen, “Monte carlo modeling of an integrating sphere reflectometer,” *Applied Optics* **42**, pp. 3832–3842, 2003.

[7] Lawrence Berkeley National Laboratory, “WINDOW 6,” 2013. http://windows.lbl.gov/software/window/6/index.html.

[8] W. Möller, K. Nikolaus, and A. Höpe, “Degradation of the diffuse reflectance of spectralon under low-level irradiation,” *Metrologia* **40**, pp. 212–215, 2003.

[9] A. Roos and C. G. Ribbing, “Interpretation of integrating sphere signal output for non-lambertian samples,” *Applied Optics* **27**, pp. 3833–3837, 1988.

[10] Lawrence Berkeley National Laboratory, “IGDB – the International Glazing DataBase,” 2013. http://windowoptics.lbl.gov/data/igdb.