AERC 1.1

Procedures for Determining the Optical and Thermal Properties of Window Attachment Materials

Revision 5

Foreword

The Attachments Energy Rating Council (AERC) is an independent, public interest, non-profit organization whose mission is to rate, label, and certify the performance of fenestration attachments.

This document, AERC 1.1, provides the technical procedures to determine the optical (openness factor, transmission, reflection, absorption) and thermal (emissivity, infrared transmittance, permeability factor) properties of materials used in fenestration attachments. This document is in support of AERC 1 and AERC 2 which provide the technical rating procedures to determine the energy performance properties of complete fenestration systems that include the window attachment and standardized glazing system.

The fenestration attachment material types currently covered by this standard are listed in Section 2. Other fenestration attachment material types such as light redirecting films may be added in future versions of the standard as technical procedures are developed.

1. Introduction

The purpose of this standard is to define the technical procedures to determine the optical and thermal properties of materials used in fenestration attachments. The optical properties covered in this standard include optical openness factor (OF), visible transmittance (Tvis), solar transmittance (Tsol), visible reflectance (Rvis), solar reflectance (Rsol), bi-directional scattering distribution function (BSDF), emissivity (ɛ), and infrared transmittance (Tir). The thermal properties covered in this standard include permeability factor (PF) and thermal conductivity (k). The methods described in this standard include minimum required technical procedures as well as optional procedures for materials that may have improved performance that would not be captured by the minimum methodology.

Any individual measurement procedure outlined in this document can be tested and submitted to the Complex Glazing Database (CGDB) either from any third party lab or directly from a material manufacturer's internal lab, if the lab has been successfully validated as a part of Lawrence Berkeley National Laboratory's (LBNL) inter-lab comparison process (ILC).

2. Scope

This standard shall apply to materials used in interior and exterior fenestration attachment products.

The technical procedures of this standard apply to material types used in the following attachment product types:

- *Exterior Shades* (e.g. exterior solar screens, exterior solar shades)
- *Interior Blinds* (e.g. interior venetian blinds)
- *Interior Shades: Insulating* (e.g. interior cellular shades)

- *Interior Shades: Non-insulating* (e.g. interior roller shades, interior solar screens):

This standard does not apply to or address:

- Specular glazing or storm window materials as covered in NFRC 300.
- Changes in performance properties of fenestration materials over time due to stretch, UV degradation, or other changes throughout the life of the material product.

3. References

AERC 1 Version 1.2(2018), *Procedures for Determining Energy Performance Properties of Fenestration Attachments,* Attachments Energy Rating Council, New York NY, www.aercnet.org.

AERC 2 Version 1.0(2018), *Procedures for Determining Heating and Cooling Annual Energy Performance Ratings of Fenestration Attachments*, Attachments Energy Rating Council, New York NY, www.aercnet.org.

NFRC 101-2017, *Procedure for Determining Thermophysical Properties of Materials for Use in NFRC-Approved Software*, National Fenestration Rating Council (NFRC), Greenbelt MD, 2017.

NFRC 300-2017, *Test Method for Determining the Solar Optical Properties of Glazing Materials and Systems*, National Fenestration Rating Council (NFRC), Greenbelt MD, 2015.

Collins M, Wright JL, Kotey N, *Off-normal Solar Optical Property Measurements using an Integrating Sphere*, Measurement, Volume 45, Issue 1, 2012.

Jonsson JC, Curcija C, *Inter-laboratory comparison using integrating sphere spectrophotometers to measure reflectance and transmittance of specular, diffuse, and light-redirecting glazing products*, Available: http://windowoptics.lbl.gov/data/igdb/interlaboratory-comparison-2011/part-2-complex-glazing-ilc-2011, 2012.

Complex Glazing Database (CGDB), Lawrence Berkeley National Laboratory, Berkeley CA, 2019. https://windows.lbl.gov/software/

4. Terminology

4.1. Definitions

See Appendix A for complete list of definitions. Where there is a difference in definition between AERC 400 Appendix A and AERC 1.1 Appendix A, the definition from AERC 400 shall take precedence.

4.2. Acronyms

AERC   Attachments Energy Rating Council

ASHRAE   American Society of Heating and Refrigeration Engineers

ASTM   American Society of Testing Materials

BSDF   Bi-directional scattering distribution function

CPD   Certified Product Database

CGDB   Complex glazing database

IGDB   International glazing database

IEEE   Institute of Electrical and Electronics Engineers

ISO   International Standards Organization

LBNL   Lawrence Berkeley National Laboratory

NFRC   National Fenestration Rating Council

5. Technical Procedures

This section provides the procedures for determining optical and thermal properties of materials used in window attachments. Each material type, as described in section 2, may have different technical procedures to determine the value for a given material property.

5.1. Sample Selection and Testing Process

The following process describes the sampling and test methods required to add a material product to the CGDB. These procedures are specifically defined for the primary window covering materials as part of AERC 1.1 scope. Additional material properties needed to conduct a simulation per AERC 1 (such as polymers, metals or woods used in headers or part of the attachment structure) are permitted to be added to the CGDB when tested for Tvis, Tsol, Rvis, and Rsol in accordance with all the provisions of NFRC 101. Glazing systems can be added to the International Glazing Database in accordance with all the provisions of NFRC 300, but can also be utilized through the AERC program.

5.1.1. Testing Process for a Single Material Product

Individual material products shall be tested to be included in the CGDB. However, the material properties for a given material product, even within a material manufacturer, can vary both within a manufacturing lot, as well as from one lot to another. Therefore, testing of a single sample as representative of the material product may be insufficient. For individual material product testing, the manufacturing tolerance is unknown so a more rigorous sampling process is necessary to determine the representative material properties.

To understand the consistency of material properties, multiple material product samples must be tested for Tvis only. The Tvis is then used to indicate the consistency of the material properties throughout the

manufacturing process. Below are the steps to get a single certified material product into the CGDB:

(1) Obtain samples of the material product according to Section 5.1.1.1.

(2) Measure and record the Tvis of all samples using a spectrometer (see Section 5.1.1.2 for requirements). This can be done by the material manufacturer or an AERC approved ILC test lab. An example of this documentation is shown in Appendix B, Section 1.

(3) Select the representative sample according to 5.1.1.3.

(4) Send the Tvis data (from step 2) and the representative sample, to an AERC approved ILC test lab (see Section 5.7).

(5) The test lab validates the selection of the representative sample and computes the material product tolerance based on 5.1.1.4.

(6) The test lab conducts full material property testing on the representative sample according to Sections 5.2 and 5.3.

(7) The manufacturer or test lab submits the material properties to the CGDB.

5.1.1.1.   Material Sampling

A minimum of 18 samples must be tested for each material product. These 18 samples shall come from three different manufacturing lots, six from each. If multiple suppliers are used for the same individual material product, then at least one lot must be tested from each material supplier. If more than three suppliers are used for the same material product, then the number of manufacturing lots tested will need to match the number of suppliers so a lot from each supplier is tested.

To obtain the six samples from each lot, a single strip of material the width of the roll shall be cut from both the beginning and the end of the lot. In the lab, these strips shall be cut into three samples, one from each side of the strip and one from the center. See Figure 5.1.1.1a for more details (the dashed lines indicate locations where test strips need to be cut, and the red bold squares indicate samples to be tested). If the roll is not wide enough to allow multiple samples to be taken across the width, additional strips at the start and end of the lot may be taken to achieve the 3 samples at each end.

Figure 5.1.1.1a: Locations of test strips and material samples.
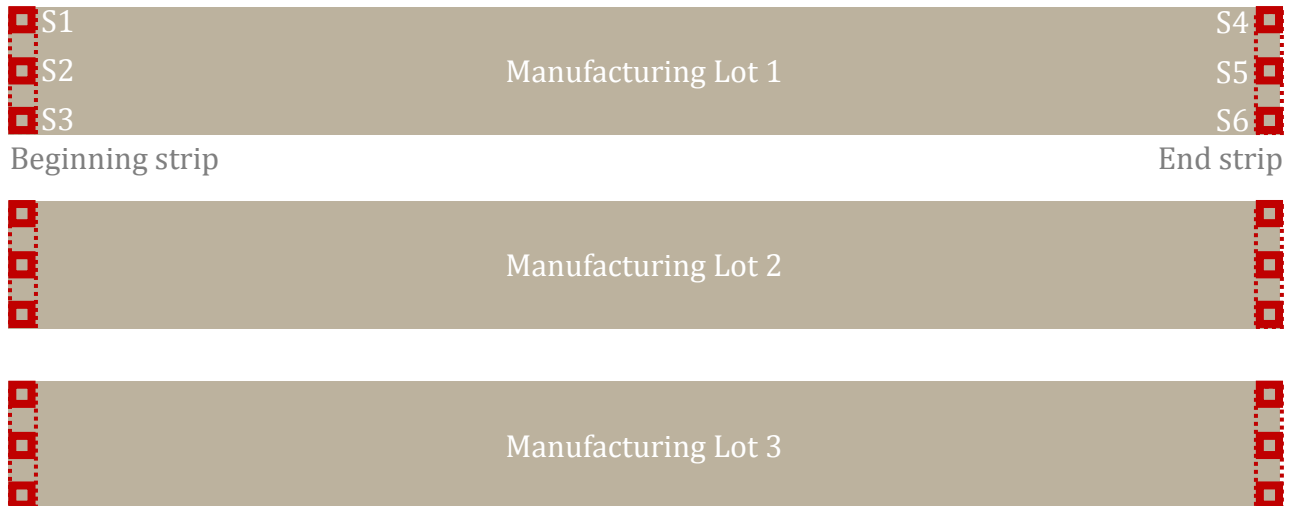
5.1.1.2.   Spectrometer Specifications for Tolerance Testing

This test can be performed using a photospectrometer measuring the total (direct and diffuse) transmittance and reflectance of either (a) the integration of the entire visible spectrum (minimum of 380nm to 780nm), or (b) the integration of a calibrated light source. The device must measure transmittance or reflection at a maximum of 10nm steps and the transmission and reflection aperture must be a minimum of 20mm in diameter, or if the port is rectangular, of a minimum area of 3.1 cm^2.

5.1.1.3.   Determine the Representative Sample

From the variability testing, the tolerance of the 95% confidence interval of Tvis (or Rvis) around the representative sample shall be determined. If Tvis of all samples is less than 0.01, then Rvis shall be used to determine the representative. Otherwise, Tvis shall be used to determine the representative. If Tvis of 10 or more samples are <0.01, use Rvis. The representative sample is selected by:

(1) Rank the material samples by Tvis (or Rvis).
(2) Choose the two samples at the center of the data set.
(3) Of the two samples, select the sample that is closest to the mean value of the data set. If Tvis is being used, then Tvis' shall be set equal to Tvis of the mean sample. If Rvis is being used, then Rvis' shall be set equal to Rvis of the mean sample.

5.1.1.4.   Computing the Material Product Homogeneity

From the sample testing, the tolerance of the 95% confidence interval of Tvis (orRvis) around the representative sample shall be

6

determined. This will be used to understand the material product homogeneity.

The reported tolerance shall be computed according to the following calculations:

$$\sigma_t = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Tvis,i - Tvis')^2}$$

$$\sigma_r = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Rvis,i - Rvis')^2}$$

$$CI_t = 2.8 \times \sigma_t$$
$$CI_r = 2.8 \times \sigma_r$$

$$TvT_t = \frac{CI_t}{Tvis'} \times 100\%$$
$$TvT_r = \frac{CI_r}{Rvis'} \times 100\%$$

where N is the number of samples, and Tvis,i (or Rvis,i) is the measured Tvis (or Rvis) of the i sample. The equations shown above include calculations using both Tvis and Rvis. Reporting of TvT shall be done based on the rules outlined in Section 5.1.1.3, such that TvT_t is reported when Tvis is used and TvT_r is reported when Rvis is used. TvT is a required reported value to be included in the CGDB. Although there are no current limits of Tolerance or Confidence Interval (CI) to be included in the CPD, limits may be added in the future. In addition, AERC 400 may include the Tolerance or CI values in the validation of a material property during a CGDB product challenge.

5.1.1.5.   Temporary Listing for Newly Developed Materials

The material manufacturer shall be permitted to conduct the testing procedure on the sampling for a single manufactured lot (the six samples per lot outlined in 5.1.1.1) to list the performance immediately. To be included in the reduced temporary listing test method, the manufacturer must provide written affirmation to the AERC that the material product samples cannot be obtained as outlined by 5.1.1.1.

The initial material properties shall be determined from the representative sample, defined by 5.1.1.2 through 5.1.1.4, as taken from the initial six sample set. This is only a temporary listing and the remaining 12 samples from the two additional manufactured lots must be tested and submitted within 18 months or the material will be removed from the CGDB, the associated products will be removed from the CPD, and the product label will no longer be allowed.

Once the additional 12 samples are obtained by the material manufacturer, the full material set must be evaluated according to the full testing procedure of the 18 samples based on Section 5.1.1. If transmittance (as outlined in 5.1.1.3) of the initial representative sample, based on the 6 original samples, falls within the updated tolerance (as outline in 5.1.1.4) of the transmittance (as outlined in 5.1.1.3) of the new representative sample, based on all 18 samples, tested in accordance with Section 5.1.1.3, then only the fabric tolerance needs to be updated in the CGDB and no new simulations are needed to update the CPD. Otherwise, the new representative sample needs to be tested in accordance with Section 5.2, the CGDB listing needs to be updated based on the properties of the new representative sample, and products simulated with the original material properties shall be re-evaluated to update the CPD.

5.1.2. Simplified Testing Process for a Material Product Family

Material Product Families that meet the tolerance limits outlined below shall be permitted to utilize a simplified testing process. The following describes the simplified process for testing a material product family:

(1) Select two representative material products within the material product family. These must include at least one material product with a light color and one with a dark color. For material products with multiple openness factor listings (openness factor not permeability factor) at least one sample must be taken at both the lowest and highest listing. For example, a material product family with three openness factor categories (1%, 3%, 5%) and multiple color options could choose a 1% openness factor with a light color and a 5% openness factor with a dark color.

(2) Each material product shall be sampled and tested (Tvis or Rvis only) according to section 5.1.1.

(3) If the homogeneity of any of the material products, as evaluated using the tolerance (TvT) or confidence interval (CI), exceeds the family homogeneity limits, then all material products in the material product family must be tested individually according to section 5.1.1. If both material products meet the material product family homogeneity

limits, then all material products in the material product family shall be permitted to move to step (4) below.

> When using Tvis for homogeneity testing: For material products with an average visible transmittance (Tvis') greater than or equal to 0.05, as determined from 5.1.1.3, the material family homogeneity limit is a TvT$_t$ of 20%, as determined from 5.1.1.4. For all other material products, the material family homogeneity limit is a confidence interval (CI) of 0.01, as determined from 5.1.1.4.

> When using Rvis for homogeneity testing: For material products with an average visible reflectance (Rvis') greater than or equal to 0.05, as determined from 5.1.1.3, the material family homogeneity limit is a TvT$_r$ of 20%, as determined from 5.1.1.4. For all other material products, the material family homogeneity limit is a confidence interval (CI) of 0.01, as determined from 5.1.1.4.

(4) Using only the single sample for each material product in the material product family, conduct the optical property testing as described in 5.2 and the thermal property testing as described in 5.3. Only the properties of the representative sample shall be reported in the CGDB for thermal and optical properties. For all material products in the material product family, report the tolerance value to the CGDB as the maximum variability (TvT or CI) of the two samples tested in step 3.

5.1.3. Recertification Process

This section outlines the recertification necessary for a material product to remain in the CGDB.

Material properties must be revalidated every four years. Fabrics that have not changed in terms of manufacturing methods, materials and properties from the date of original listing in the CGDB may qualify for subsequent periods on a single written affirmation, submitted to AERC, by the material manufacturer proclaiming the product continues to be as represented in the previous inclusion in the database provided:

- For material products with Tvis' (or Rvis') greater than or equal to 0.05, the original reported TvT is equal to or less than 20%.
- For material products with Tvis' (or Rvis') less than 0.05, the original reported CI is less than 0.01.

For material products that do not meet this homogeneity requirement, a new single sample (one sample, not the full Tolerance test outlined in 5.1.1.4) must be tested according to the test procedures outlined in 5.2 and 5.3. The single sample will be tested as the representative sample. If the Tvis (or Rvis) of the sample is within existing homogeneity (TvT or CI) of the material product as listed in the CGDB, then all other material

properties shall be updated based on the tests of only the new single sample. If the Tvis (or Rvis) is outside the listed homogeneity, then the full testing process of Sections 5.1 and 5.2 is required as if the material was completely new starting with the homogeneity test outlined in 5.1.1.4.

5.2. Procedures for Measurement of Optical Properties

5.2.1. Test Methods for Determining Solar and Visible Optical Properties

According to the sampling requirements of 5.1.1, samples shall be tested for solar and visible optical properties of OF, Tvis, Tsol, Rvis, Rsol. Optionally, the BSDF can also be tested if desired. The pre-defined accepted test methods for determining the solar and visible optical properties are specified in Appendix C of this document. The full spectral data must be submitted to the CGDB.

5.2.1.1.   Simplified Test Methods for Determining Solar Optical Properties

Material product families that meet the homogeneity requirements of 5.1.2 (3) may use a simplified test procedure according to Appendix D of this document. However, performance modifications to values included in both the CGDB and the CPD are required to account for additional uncertainty of performance when using a simplified measurement method.

Partially characterized material products, those that utilize this method instead of the method outlined in Appendix C, must increase the Tolerance computed in Section 5.1.1.4 prior to listing in the CGDB, by the quantity specified in Appendix D. In addition, if a partially characterized material product is used in the creation of a certified product, according to AERC 1, both the EP_c and EP_h values must be reduced by the quantity specified in Appendix D.

5.2.2. Test Methods for Determining Emissivity and Infrared Transmittance

According to the sampling requirements of 5.1.1, samples must be tested for Ɛ and Tir. Test methods for determining these properties are outlined in Appendix E of this document.

5.3. Procedures for Measurement of Thermal Properties

5.3.1. Thermal Conductivity (k)

The thermal conductivity of the material product shall be determined according to NFRC 101. A single value for thermal conductivity must be reported to be included in the CGDB. A proprietary value of thermal conductivity will be accepted if tested according to Section 3 in Appendix E of this document.

5.3.2. Permeability Factor (PF)

Air spaces created by installation of window attachments may be connected to the interior or exterior environments, or to other spaces. This air movement affects the overall thermal performance of the system. The permeability factor (PF) is a performance metric for how easily air moves through an attachment material.

Permeability factor of a general material is equivalent to the openness factor. If any transparent coating or film is applied to base material that may reduce permeability with little to no change in openness factor, then the permeability factor is determined in one of two ways:

1. Permeability factor is zero if the material is coated or covered by an impermeable coating or a film.
2. The material product permeability is determined according to ASTM D737 Standard Test Method for Air Permeability of Textile Fabrics and calculation procedure described in Appendix F of this document.

5.4. Reporting Checklist

Appendix G provides a checklist for reporting requirements to be included in the CGDB depending on submittal type (submittal of a single product, submittal to create approved material product family, submittal of a material product within an approved material product family, or submittal of an independent material product for temporary listing).

5.5. Validation of Test Lab

Test facilities, including those part of the material product manufacturer, that intend to submit material property data for inclusion in the CGDB must be validated against an inter-lab comparison as outlined in Appendix H.

5.6. Use of Alternate Test Procedures

The decision to accept different test methods than those recommended in this document will be evaluated on a case by case basis. Alternate methods shall be submitted to the AERC and will be evaluated by the committee chair of the AERC Technical Committee and AERC staff. When alternate test methods are approved for use, the specification will be added to AERC 1.1.

5.7. Grouping Rules for use in AERC 1

AERC 1 includes allowances for material product grouping. Applicable material product grouping rules are documented in Appendix I of this document.

Appendix A: Definitions

Basket weave: A woven material created with orthogonal interlacing of weft and warp threads where one or both includes a bundle of two or more threads.

Bi-directional scattering distribution function (BSDF): The mathematical function that describes both the incident and exitant angular dependency of light which is scattered by a surface through transmittance and reflectance.

Emissivity (Ɛ): The relative ability of a surface to reflect or emit heat by radiation. Emissivity ranges from 0.00 to 1.00.

Exterior face: The side of a window attachment that faces the building exterior.

Knit fabric: A material type created by interlooping one or more sets of yarn.

Infrared transmittance (Tir): The ratio of transmitted radiant flux in the infrared spectrum (5000nm to 25000nm) to incident radiant flux in the infrared spectrum.

Interior face: The side of a window attachment that faces the building interior.

Material group member: A specific listing in the CGDB whose material properties are derived from those of the Material group representative in accordance with Program Requirements.

Material group representative: A specific listing in the CGDB that undergoes full testing and whose material properties are used to derive properties for Material group members in the CGDB in accordance with Program Requirements.

Material product: A unique material based on variation in any of the following: material product family, openness factor, or color.

Material product family: A group of material products (materials) that are manufactured according to the same process, material structure (plain weave, basket weave, twill weave, knit, or other), applied coatings, and yarn construction (yarn color not included).

Openness factor (OF): The ratio of transmitted radiant flux in the visible spectrum (380nm to 780nm) that is not diffused or redirected to the incident radiant flux in the visible spectrum.

Partially characterized material product: A material product, material group member, that has used the simplified test procedure to determine the material properties.

Plain weave: A woven material created with orthogonal interlacing of a single weft thread with a single warp thread.

Representative sample: The individual sample, determined during the initial sampling and testing process, to be used in full material property testing.

Solar transmittance (Tsol): The ratio of transmitted radiant flux in the solar spectrum (300nm to 2500nm) to incident radiant flux in the solar spectrum.

Solar reflectance (Rsol): The ratio of reflected radiant flux in the solar spectrum (300nm to 2500nm) to incident radiant flux in the solar spectrum.

Thermal conductivity (k): Heat transfer property of materials expressed in units of energy per time per length per degree temperature difference.

Twill weave: A material type with a pattern of diagonal ribs, created by having the weft threads skip over two or more warp threads until the desired pattern is achieved.

Permeability factor (PF): A performance metric for how easily air moves through an attachment material from a value of 0, indicating no air movement, to a value of 1, indicating no resistance to air movement.

Visible transmittance (Tvis): The ratio of transmitted radiant flux in the visible spectrum (380nm to 780nm) to incident radiant flux in the visible spectrum. Visible reflectance (Rvis): The ratio of reflected radiant flux in the visible spectrum (380nm to 780nm) to incident radiant flux in the visible spectrum.

Warp thread: In woven materials, this thread extends the entire length of the woven material and held in tension while the weft thread is used to weave the material.

Weft thread: In weaved materials, this thread is drawn through, over and under, the lengthwise threads.

Appendix B: Sample Homogeneity Report

Manufacturer	<Indicate manufacturer name as reported in CGDB>
Product Name	<Indicate product name as reported in CGDB>
Location of Sample Testing	<Indicate if initial sample testing was done by manufacturer or the test lab>
Spectrometer Type	<Provide manufacturer and model #>
Name of Test Lab	<Indicate the name of the AERC test lab that is submitting data for CGDB>

Material Sampling Data

Sample #	Lot #	Position (l)	Position (w)	Tvis	Rvis	T/Rvis	Rank
1	**1**	**start**	**left**	**22.1%**	**40.1%**	**22.1%**	**10**
2	1	start	center	24.5%	39.5%	24.5%	1.5
3	1	start	right	24.5%	41.5%	24.5%	1.5
4	1	end	left	24.1%	42.1%	24.1%	4
5	1	end	center	24.3%	38.3%	24.3%	3
6	**1**	**end**	**right**	**22.4%**	**40.4%**	**22.4%**	**9**
7	2	start	left	20.4%	42.4%	20.4%	16.5
8	2	start	center	21.9%	39.9%	21.9%	12
9	2	start	right	19.7%	40.7%	19.7%	18
10	2	end	left	22.5%	41.5%	22.5%	8
11	2	end	center	23.0%	41.0%	23.0%	7
12	2	end	right	21.4%	39.4%	21.4%	13
13	3	start	left	21.0%	42.0%	21.0%	14
14	3	start	center	20.4%	38.4%	20.4%	16.5
15	3	start	right	23.7%	39.7%	23.7%	6
16	3	end	left	24.0%	40.0%	24.0%	5
17	3	end	center	22.0%	40.0%	22.0%	11
18	3	end	right	20.9%	41.9%	20.9%	15

T/Rvis'= 22.4%	
TvT= 19.0%	

AERC 1.1 APPENDIX C — Measurement procedure for solar optical properties of attachment fabrics and products

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Disclaimer

Abstract

It is possible to model scattering layers such as roller shades, bug screens, and other flat and parallel layers since version 6 of the WINDOW program.

The optical properties that are required for the model are reflectance and transmittance, both direct-hemispherical and diffuse. Furthermore the geometrical openness has to be recorded and reported.

Challenges such as inhomogeneity, translucency, and angle dependence are covered.

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 spectral resolution. In inter-laboratory comparisons of specular samples the integrating sphere has shown good agreement.

A roller shade fabric was included in the 2011 inter-laboratory comparison conducted at LBNL[7] to give a picture of how good the agreement between the participants was. 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 the submitted data which, according to the instructions, was not supposed to be corrected for the reflectance of the diffuse reference. A procedure described by Roos [8] is expected to have reduced the variation between laboratories. The conclusion is that the instruments typically used for measurement of data that is submitted to the IGDB could be used for measurement of fabrics which can be accurately modeled by the LBNL WINDOW software[9] versions 6 and later.
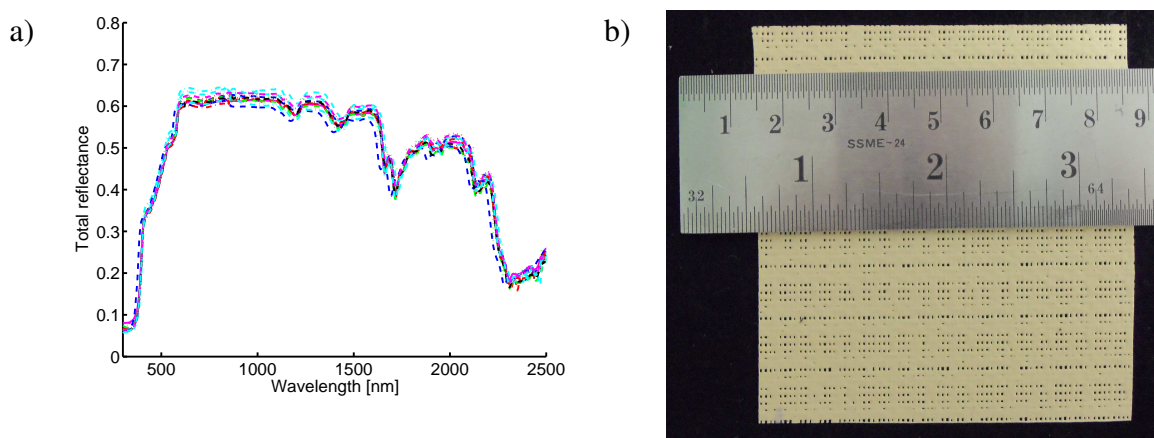

Figure 1:   a) Measured spectral direct-hemispherical reflectance for a thin and reflective material. Each curve represents the data from a different laboratory. The total spread is approximately ± 0.02. b) Photograph of the fabric shown relative to a ruler marked in centimeter and inches. The thickness is 0.4 mm and the holes are distributed in an uneven pattern for a geometrical openness of 5%.

By obtaining both the diffuse and specular components of the transmitted and reflected

light it is possible to better model the light scattering by just assuming the sample to be Lambertian.

The procedures described in this document target a majority of shading fabrics and similar materials. However there is such a large variety of materials that it is easy to find examples that in some way result in inaccurate measurement results. This section tries to cover the ideal physical characteristics that would result in the most accurate measurements. The measurement error for samples which do not display "ideal" properties can be significantly larger than e.g. for specular glass samples. Characteristics that might induce uncertainty in the measurement include

Homogeneity Having the same optical properties on every part of the surface of the material. Ideally the sample is homogeneous, but in reality fabrics are woven with holes to a certain openness, have multiple different colored threads, and/or have a macroscopic pattern. Sheerness and color are two properties that can vary between different parts of the sample. Samples with macroscopic patterns can have each area measured separately and then area weight the properties according to the design of the fabric. The problem is most prevalent when the size of the inhomogeneities is of the same order as the area of the illuminating beam.

Rotational symmetry Maintaining the same optical properties even if the material is rotated around its normal. There are two parts to this, both the incident appearance and the outgoing scattering. In practice this is not true for a large number of inhomogeneous samples, e.g. when a weave with square holes is rotated, its angle-dependent transmittance will vary as a function of its rotation.

Fidelity How well the design pattern is replicated in the fabric. Depending on the fabrication method there could be variations between different areas of the fabric (e.g. close to edge vs. center) or along a roll or between different rolls or between rolls manufactured at different factories.

Thickness The sample should not be so thick that it yields a significant error in an integrating sphere measurement. Inter-laboratory comparisons of thick samples [7] have shown that the result is sample and instrument dependent. There is no easy cut-off but fabrics between 0.5 mm and 1 mm seem to be fine.

Elasticity The optical properties should not vary under different amount of tension. For fabrics with stretch it is important to try to match tension of the sample mounted for the measurement to the tension that the fabric is expected to experience in its installed state.

Double-sided The optical properties of the sample can be different for the front and back of the material.

2 Scope

Procedures and formats described in this document are intended for use when measuring optical properties of thin optically complex materials, such as shade fabrics and their inclusion in LBNL's complex glazing database (CGDB). The objective is to provide a path that multiple laboratories can follow and obtain the same results. There are other methods to study shades that get limited room in this document. This is a choice to make the document as clear and brief as possible. The drawback is that other viable methods get less coverage.

This document describes measurement procedures for fabric materials seen in e.g. woven shades, cellular shades, drapes, and roller shades.

In addition to fabrics, the procedures can be useful for characterization of materials with similar properties, such as thin suspended scattering polymer films.

The solar optical spectrum is defined from 300 nm to 2500 nm and data should be recorded every 5 nm.

It is furthermore assumed that absorbed energy is converted to heat rather than more exotic pathways such as fluorescence. Photo-voltaic materials where absorbed light is converted to electricity are not covered either.

3 Definition of terms

Absorptance The fraction of incident light absorbed by the sample. Calculated by subtracting the transmittance and reflectance from one. In most materials the absorbed energy is converted to heat, special care has to be taken with e.g. photovoltaic and fluorescent materials.

Angle of incidence The angle between the incident beam and surface normal. Light incident parallel to the normal is defined as at 0 degrees angle of incidence.

Diffuse Pertaining to reflectance, transmittance, or incident light. For reflectance and transmittance it denotes the component of light that is scattered as it interacts with the sample. In some models labeled as direct-diffuse. In measurements the property is defined by the instrument geometry through the size of the sphere and radius of the specular exit port in combination with the beam cross-section. Diffuse illumination describes light incident from all angles onto the sample.

Direct-hemispherical Pertaining to reflectance or transmittance. All outgoing light for a single angle of incidence, i.e. the sum of direct-direct and direct-diffuse light.

Inhomogeneity A material where the properties being measured are not constant over the surface, e.g. a woven fabric can be a mixture of holes and threads.

Normal Used to describe the angle of incidence perpendicular to a sample surface.

Near-normal Used as an approximation for normal in the case of reflectance measurements. It is considered to be less than 10 degrees off normal.

Reflectance The fraction of incident light reflected from a sample toward the hemisphere containing the source of the incident light.

Solar Integrated weighted average of a spectral property. A spectral function from 300 nm to 2500 nm is converted to a single value. The result depends on the solar, or source, spectrum used for the integration.

Spectral Qualifier used to specify that the optical property is resolved as a function of wavelength.

Specular Pertaining to reflectance or transmittance. The component of light that is not scattered as it interacts with the sample. In some models labeled as direct-direct. In measurements the property is defined by the instrument geometry.

Total Pertaining to reflectance or transmittance. The sum of the direct and diffuse components. In some models labeled as direct-hemispherical.

Transmittance The fraction of incident light transmitted through a sample.

Visible Integrated weighted average of a spectral property. A spectral function is converted to a single value. The result depends on the solar, or source, spectrum used for the integration as well as a detector spectrum representing the sensitivity of the eye. The ASTM E308 spectrum that is used for visible calculation covers 380-780 nm.

4 Measurement steps

There are several differences when measuring a fabric sample compared to when measuring a specular sample. Standards such as ASTM E903, EN 410, and ISO 9050 do describe the general principles of using an integrating sphere well, but leaves out details for making accurate and repeatable measurements of scattering samples. 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 with a known diffuse reference standard mounted at the reflectance port.

2. Measure 0% baseline.

3. Position inhomogeneous sample in the transmittance position.

4. Measure diffuse and direct-hemispherical transmittance of the sample at normal angle of incidence.

5. Position inhomogeneous sample in the reflectance position. Ensure that light transmitted through non-opaque samples does not get back into the sphere.

6. Measure diffuse and direct-hemispherical reflectance of the sample at near normal angle of incidence.

7. If needed, repeat measurements for oblique angles of incidence.

8. Calculate the haze factor for each wavelength both for transmittance and reflectance.

9. Correct the measured reflectance value using the reflectance of the reference and the haze of the sample.

4.1 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, or similar national metrology institutes, for calibration. The important part of the reference is that the spectral reflectance is known.

Most integrating spheres are made of Spectralon™ or coated with $BaSO_4$. 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 [10]. 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.

4.2 Measurement of inhomogeneous samples

The correct approach depends on the geometry of both the sample and the light beam of the instrument used.

4.2.1 Inhomogeneity significantly smaller than the illuminated area

The first step for measurement of inhomogeneous samples is to maximize the mismatch between the pattern shape to the beam shape. If the beam is rectangular and the sample has a rectangular pattern, simply rotating the sample pattern 45 degrees drastically improves the accuracy.

The second step is to use the instrument real-time mode for broadband or a single visible wavelength illumination and translate the sample manually, at least over an area the size of the beam, and while reading the instrument response. Simulations show that the average of the maximum and minimum values are not always the average of the fabric. Therefore it might be more representative to measure the full spectrum with the sample in a position where the value is close to the median of a sample selection.

As long as maximum and minimum results seen in the interactive measurement mode is within the specified tolerance need it is safe to use this method. If the range is larger you will have to consider the inhomogeneity to be of a similar size as the illuminated area.

4.2.2 Inhomogeneity significantly larger than the illuminated area

This covers the case where a material has two or more very larger areas with different properties. It is then possible to measure the properties of each area as if it was a single product. The answer for the total product is the weighted average based on the area of each part.

4.2.3 Inhomogeneity of similar size as illuminated area

The sample has to be measured in multiple positions in case the range of possible randomly measured results are outside of the tolerance. Start with three different positions. Maximize mismatch between pattern and beam as described in section 4.2.1. Calculate the mean and standard deviation of the measured solar reflectance and transmittance. If the standard deviation is outside of the tolerance more measurements have to be carried out until standard deviation is within tolerance.

4.3 Optical properties at oblique angles of incidence

Optical material properties are often measured at a normal or near-normal angle of incidence. The reason for this is increased simplicity in design of the experiment and it also reduces or even removes the influence of the polarization state of the incident illumination.

Shade fabrics can, in theory, be designed with geometries that result in behavior that is not easily predictable based on normal angle of incidence measurements. However, for thin fabrics with low openness it is possible to find empirical equations that give a reasonable estimate.

However, for those cases where intricate design of the fabric is expected to yield a different result from the empirical case it is possible to measure the values using an angular tube measurement accessory to the spectrophotometer which gives direct-hemispherical values for different angles of incidence. An example could be a fabric designed to be see-through at normal angle of incidence but opaque at oblique angles. Full goniophotometer measurements will give more detailed information which might be needed for anisotropic materials with highly directional scattering patterns, however it is not considered necessary for most fabrics.

4.3.1 Empirical extrapolation method

Measurement only at normal angle of incidence would use the following method to calculate the off-angle properties.

Kotey et al [11] did define a simple equation for the angle dependence of fabrics. Research at LBNL refined the empirical equation by using a larger data set which resulted in the following equations based on the transmittance measured at normal angle of incidence, $T_{meas}(0)$,

$$T^{Kotey}(\theta) = T^{meas}(0)\cos^{b}(\theta),\tag{1}$$

where b is given by

$$b = \max[-0.35\ln(\max[T(0), 0.01]), 0.35].\tag{2}$$

This limits the effect of the exponential slope of the transmittance at increasing angles for transmittance values larger than 0.4. Equation 1 can be applied to the measured transmittance on a wavelength by wavelength basis.

Similar equation exist for reflectance,

$$R_y = \frac{R_{meas}(0)}{1 - T_{spec}(0)}\tag{3}$$

$$R^{Kotey}(90) = R_{meas}(0) + (1 - R_{meas}(0))(0.7R_y^{0.7})\tag{4}$$

$$R^{Kotey}(\theta) = R_{meas}(0) + (R^{Kotey}(90) - R_{meas}(0))(1 - \cos^{0.6}(\theta)),\tag{5}$$

where $T_{spec}(0)$ is the measured specular transmittance at normal angle of incidence for the sample, $R_{meas}(0)$ is measured reflectance at normal incidence.

4.3.2 Measurements using angular tubes accessory

A spectrophotometer accessory consisting of a series of angle tubes were designed and constructed to allow measurements at oblique angles of incidence. The LBNL design[12] was inspired by the work of Kotey[13] and described in[14]. Pictures of some tubes and how it looks when mounted are shown in figure 2. The principle is to cut a piece of fabric to fit the aperture of the tube. The outer part of the tube has a lip and the fabric is kept in place by pressing it to that lip with an inner sleeve. The tube fits in the sphere aperture which results in a measurement at an incidence angle equal to the slope of the tube.

Inserting the tube changes the response of the sphere but not to a significant degree. However, it is important that the sample is not in the detector field of view, hence, the tube is rotated so that the white backing is in the detector field of view rather than the fabric.

One limitation of the angle tubes is that the sample is cut to size to fit the tube. This limits the ability to reposition the sample in case it is inhomogeneous. There are minor translations that can be carried out, e.g. rotating the sample and inserting the sample upside down, but not the same degree of freedom available as for normal angle of incidence
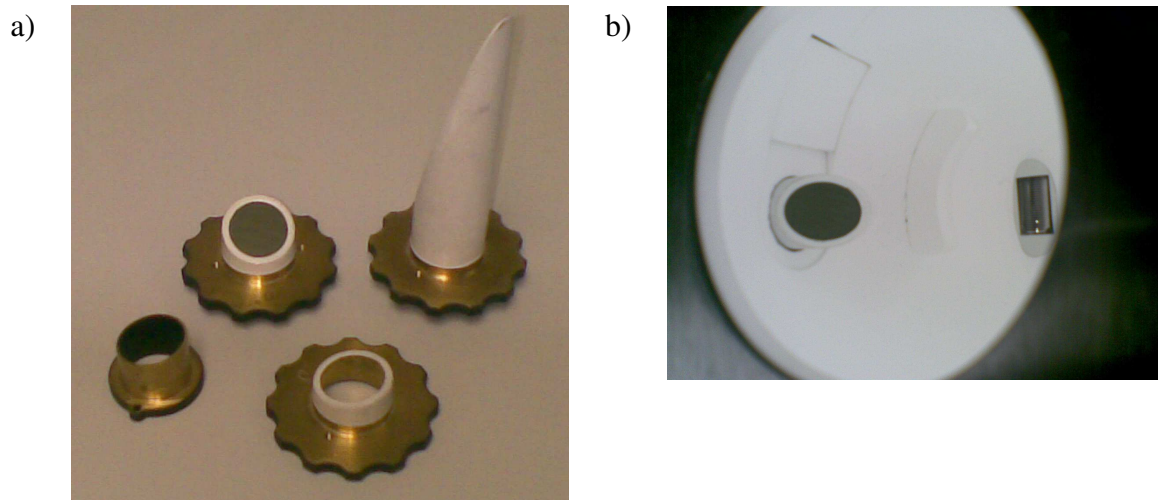
9

Figure 2: Pictures of the angle tubes. In a) the tube and inner sleeve are shown for a low angle tube as well as a high angle tube with a fabric mounted. The inside of an integrating sphere with the angle tube mounted is shown in b).

measurements. Analogously to the measurements at (near-)normal incidence, it is recommended to rotate the fabric pattern by 45 degrees relative to the beam so that the warp is diagonal with respect to the axes of the elliptical sample shape used with angle tubes.

4.4 Determination of haze

A sample with very sheer fabric and/or large openness will scatter light less than some translucent synthetic spun fiber fabric. The measurement of both total and specular transmittance allows for the calculation of the haze value of the fabric which quantifies this property. In addition to giving a quantitative number on how scattering a material is, the haze factor is used to correct for the reference material used.

The haze value can be used to develop a more sophisticated method to split the properties than to purely designate the specular component as undisturbed and then let the diffuse component be perfectly Lambertian. Any but the simplest of fabric models will take the sample haze in consideration. The way to determine if this is true is to measure the haze factor of the sample.

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

$$H(\lambda) = \frac{R_{diff}}{R_{dh}}. \tag{6}$$

The definition for transmitted haze is similar but uses the diffuse transmittance instead of the reflectance. A diagram describing how the sphere is set up for the two different reflectance measurements is shown in figure 3.
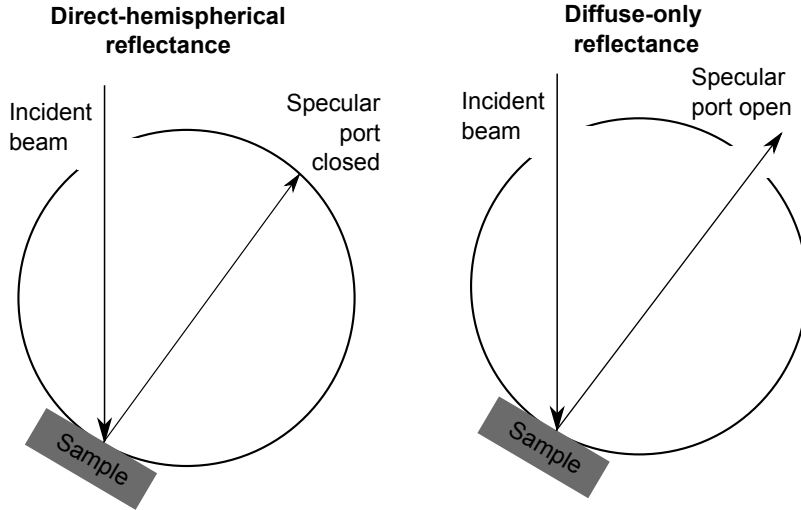
Figure 3: The integrating sphere can be modified to measure the diffuse-only reflectance of a sample by opening the specular port. With the port in place the direct-hemispherical reflectance is measured.

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 haze factor is wavelength dependent for most scattering materials. However, for small values of reflectance the instrument noise could easily result in large haze values or even unphysical results such as haze larger than 1. The procedure to calculate the solar haze is done by calculating the haze at each wavelength and then integrate the haze value using the following equation

$$H_{sol} = \frac{\int_{\lambda=300}^{2500} R_{\text{diff}}(\lambda)/R_{\text{dh}}(\lambda)I(\lambda)\mathrm{d}\lambda}{\int_{\lambda=300}^{2500} I(\lambda)\mathrm{d}\lambda}, \tag{7}$$

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

4.5 Correcting for Specular and Diffuse reference samples

For non-Lambertian samples it is prudent to correct for the reflectance of the diffuse reference used differently for the diffuse and specular component of the light. Roos developed methods for correcting both reflectance[8] and transmittance [15]. The simplest interpretation of those methods is described here, assuming that all scattered light is treated the equally by the sphere without further differentiating between different scattering angles. Without more information about the sphere and the sample it is questionable to apply more detailed models that would require input that can not be easily obtained.

4.5.1 Reflectance

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

$$R_{\text{corrected}} = R_{\text{measured}} \cdot R_{\text{reference}}. \tag{8}$$

Some instruments allows for automatic correction during measurement time according to this method, in which case it is important to not apply it a second time.

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 produces absolute reflectance results for specular samples, if they have been measured versus a light-scattering reference[8]. 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

$$R_{\text{corrected}}(\lambda) = H(\lambda)R_{\text{measured}} \cdot R_{\text{reference}} + (1 - H(\lambda)) \cdot R_{\text{measured}}. \tag{9}$$

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.

4.5.2 Transmittance

In the case for transmittance the reference beam is through specular air. This results in a situation where the diffuse component of the transmitted light reaches the detector with effectively one less reflection in the reference material.

Using the transmitted haze the resulting calculation ends up being the same as the reflectance case but using the diffuse and total transmittance according to

$$T_{\text{corrected}}(\lambda) = H_T(\lambda)T_{\text{measured}} \cdot R_{\text{reference}} + (1 - H_T(\lambda)) \cdot T_{\text{measured}}, \tag{10}$$

where H_T is the transmitted haze according to

$$H_T(\lambda) = \frac{T_{diff}}{T_{dh}}. \tag{11}$$

4.6 Correcting for fluorescence

Some fabrics have components that are fluorescent. This is an absorption effect that emits light, instead of the more common effect of turning the absorbed energy to heat. The emitted light will be of longer wavelengths (lower energy photons) than the absorbed light.

A scanning wavelength spectrophotometer illuminates the sample with light of a single wavelength and does not filter what wavelengths comes out from the sample before it
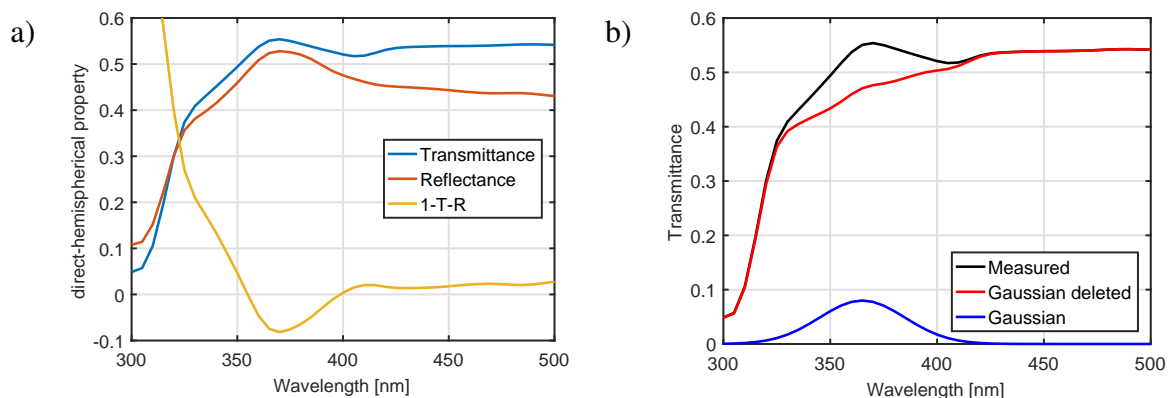
Figure 4: Data obtained for a material exhibiting fluorescence. In a) the measured reflectance and transmittance adds up to more than 1 resulting in negative absorption. In b) a Gaussian peak is subtracted from the transmittance curve to obtain physical values.

reaches the detector. The detector is in some cases more sensitive, i.e. reports higher signal, to the longer wavelength photons. So while there is really less reflected or transmitted power, the detector gives a higher response which gives an unphysical (absorption of -0.1 is bad) result as shown in the figure 4a.

A simple method to make the measured spectra not break the conservation of energy is to identify the edges, shortest and longest wavelength, for the influence of the fluorescence and simply make a linear interpolation between those end points.

An alternative method, which is slightly more physical, is to subtract a Gaussian curve from each the spectra, and fit the width and height parameters of that Gaussian curve so that the transition is smoother. An example of this is shown in figure 4b.

However, both these methods are quite crude and it is hard to define strict rules as the error depends on the measurement instrument as well as the molecules responsible for the effect. The goal is to reduce the transmittance and/or reflectance to obtain a set of physical properties.

The method can also be applied for materials where there is a strong peak in the UV but the absorption is not negative. I.e. there is a pronounced dip in absorption in the UV.

Submitted data shall be flagged that it has been modified to account for fluorescence. This will make it easier for peer reviewers to interpret the data and can be used as a warning for applications where UV transmittance is a crucial parameter.

The decision to allow this method is governed by an expectation that the accuracy error of this method should be small for energy calculations. Only small part of solar energy resides in the UV region to begin with, and we are treating a small fraction of that light as absorbed UV instead of diffusely scattered visible.

5   Reporting

A total of eight spectral properties shall be reported for each measured angle of incidence:

1. Transmittance, front, direct-direct

2. Transmittance, front, direct-diffuse

3. Transmittance, back, direct-direct

4. Transmittance, back, direct-diffuse

5. Reflectance, front, direct-direct

6. Reflectance, front, direct-diffuse

7. Reflectance, back, direct-direct

8. Reflectance, back, direct-diffuse

The direct value of each property is calculated by subtracting the measured diffuse from the measured total value. The values reported should be the corrected values according to sections 4.5.1-4.5.2. Data should be given at least every 5 nm in the range from 300 nm to 2500 nm.

In addition to measured values the measurement accuracy of the instrument and maximum and minimum measured value should be reported.

6   Calculation of visible and solar integrated values

Integrates solar values are a weighted average where the intensity of the solar spectrum dictates the weight of each wavelength. It is a way to condense the wavelength dependent variable from hundreds of data points to a single number. The solar integration is carried out the same way for both transmittance and reflectance, the equation below uses transmittance as an example.

$$T_{sol} = \frac{\int_{\lambda=300}^{2500} T(\lambda)I(\lambda)\mathrm{d}\lambda}{\int_{\lambda=300}^{2500} I(\lambda)\mathrm{d}\lambda}, \tag{12}$$

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

The visible integrated value is defined in a similar way, but a detector function adding the sensitivity of the eye is included in addition to the solar intensity,

$$T_{vis} = \frac{\int_{\lambda=380}^{780} T(\lambda)I(\lambda)D(\lambda)\mathrm{d}\lambda}{\int_{\lambda=380}^{780} I(\lambda)D(\lambda)\mathrm{d}\lambda}, \tag{13}$$

where $D(\lambda)$ is the detector function characterizing the sensitivity of the eye as a function of wavelength. The source and detector spectra to use for the solar and visible calculations are:

Solar $I(\lambda)$ Table 1, Column 2 of Standard ISO 9845-1

Visible $D(\lambda)$ CIE 1931 $\bar{y}$ (also used in ASTM E308)

Visible $I(\lambda)$ CIE D65 standard illuminant

7 Calculation of openness

The sample openness is defined as the total visible transmittance minus the diffuse visible transmittance.

8 Summary

This document provides guidelines how to measure the optical properties needed to calculate the solar and visible transmittance and reflectance of thin fabrics and similar attachment product materials.

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Appendix D: Simplified Measurement Procedure for Solar Properties of Attachment Fabrics and Products

At this time, there is no validated simplified procedure. Evaluate each material product according to Appendix C.

AERC 1.1 APPENDIX E — Measurement procedure for thermal emissivity and IR transmittance of fenestration shading fabrics using an emissometer

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Disclaimer

Abstract

The thermal emissivity and IR transmittance are two properties that are important for calculation of energy performance of shade fabrics. The surface roughness and inhomogeneity of fabrics makes them ideal to characterize with an emissometer.

Transparent samples can be characterized by measurement with different backing materials, varying the backing materials emissivity. From such a pair of measurements both the transmittance and emissivity can be calculated.

Since version 6 of the WINDOW program, it can model scattering layers such as roller shades, bug screens and other flat and parallel layers for which these values are needed.

1 Introduction

The procedures described in this document target a majority of shading fabrics and similar materials. However there is such a large variety of materials that it is easy to find examples that in some way result in inaccurate measurement results. A definition of the ideal physical properties serves as a starting point that would result in the most accurate measurements. The measurement error for samples which do not display "ideal" properties depend on the sample and its interaction with the apparatus used to characterize it.

The thermal properties of a fabric will influence the U-value and SHGC of a glazing system, and therefore impact the energy performance of the system. The thermal IR range is typically defined by the range from $5\mu m$ to $25\mu m$, which is a range where most of the black body radiation is contained for bodies close to room temperature.

The emissivity influences how much energy is being radiated from a surface after it has been absorbed as heat in the fabric. The IR transmittance gives the fraction of the thermal radiation that is being transmitted through the fabric without interacting with it. The thermal conductance is used to calculate how much heat is transported through the material through conduction.

The complexity of measuring inhomogeneous samples makes it challenging to write a standard procedure that guarantees a specific accuracy level. A well designed inter-laboratory comparison exercise is required to obtain data on a range of sample types.

This document focuses on one way to obtaining the parameters required for calculation of energy performance. This is in an attempt to make the document as clear and brief as possible, not an attempt to disqualify or diminish those methods. Standards ASTM E408[1] and ASTM E434[2] covers other methods to obtain emissivity which can be used as well assuming that they complete the inter-laboratory comparison and show at least the same level of accuracy as the method describe in this document.

2 Instrumentation for emissivity and IR transmittance

The properties that are used in calculation of U-value and of interest for energy simulation are emissivity and transmittance. The emissivity, which for a given wavelength of radiation is equal to the absorption, is usually not measured directly but rather indirectly from measurements of transmittance and reflectance and then calculated using the relationship

$$R + T + A = 1. \tag{1}$$

2.1 Emissometer

An emissometer is an instrument that directly reports the hemispherical reflectance of a surface. Rather than reporting the reflectance, the emissivity is reported directly as $1 - R_{measured}$. This holds true if the sample is opaque. Measurement time is typically less than 2 minutes per measurement after an initial warm-up time of 30 minutes.
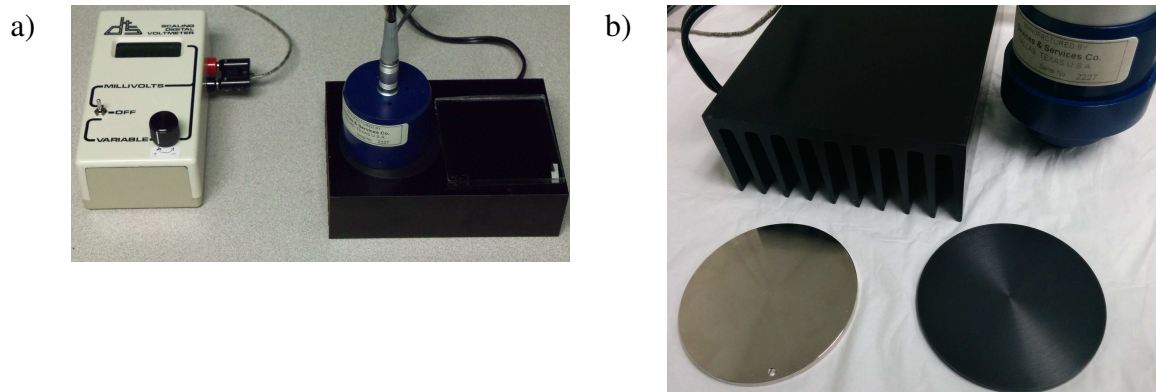
Figure 1: Photographs of the emissometer used. In a) the blue measurement head is shown in reference to a 3"x3" glass sample on the heat sink. In b) an aperture has been attached to limit the measurement area, useful for smaller samples. The high and low emissivity references are shown as well as the heat sink.

This document describes the use of the Devices & Services' AE-1 emissometer shown in figure 1.

2.1.1 Calibration

The accuracy of the emissometer is highly dependent on the calibration standards used as it is not designed to directly measure the absolute emitted energy of the source used.

The procedure for the AE-1 specifies that the high calibration sample is used first and then the low. This allows for a linear correction, using two measurements to fit slope and offset. The calibration should be iterated until the correction at the high reference is less than 0.01.

Depending on environmental condition in the space it is being used the drift may vary. It is recommended that the high reference is remeasured every third measurement, i.e. measure two samples then the high reference again. The frequency with which the reference is checked can be reduced if drift is less than 0.01 between the reference checks. The low reference should be checked at least every half hour of measurement, more often if you notice significant drift when checking the high reference.

2.1.2 Measuring transparent/translucent samples

If the sample is not opaque it is possible to get both the transmittance and emissivity through measurement of the sample on two different opaque backing surfaces[3]. The measured emittance, E_a, in each case is given by

$$E_a = E_s + T_s \left(1 - T_s \frac{1 - E_b}{1 - (1 - E_s - T_s)(1 - E_b)} \right),\qquad(2)$$

where E represents emittance, T transmittance, index s denotes sample, and b backing material. By doing this for two known backing materials with a large difference the equation system of two equations can be used to solve for T_s and E_s. No simple closed solution to the system of two equations exists, so an iterative solution needs to be applied. An implementation of a solution in MATLAB is included in appendix A. It is not important exactly which numerical solver is used to find a minimum error of the solution.

This method becomes sensitive to the measurement precision for low values of TIR. Therefore the recorded values of E_a have to be at least three significant digits. To increase the accuracy of this high precision result, the sample should be conducted at least three times, or more if the variation in result is greater than the required tolerance. Ideally tolerance should be checked versus the calculated T and E_s values rather than E_a.

A negative TIR is the mathematical result if E_a measured with the low-E backing material is higher than the E_a measured with the high-E backing material, which is a situation that could occur for very low values of TIR combined with instrument noise. To avoid reporting an unphysical TIR, the two E_a values is averaged, which results in a T_s of 0 and E_s as the average of the two measurements.

2.2 Measuring inhomogeneous samples

Woven fabrics with a physical openness or samples with a pattern of different materials should be measured so that the reported value represents the average over an infinite area of the material.

In figure 2 different size apertures and different measurement locations are shown to exemplify how different values can be obtained as a result from an patterned sample. Each component of the material should be measured if the individual components are larger than the measured area. E.g. in the figure that would correspond to measuring a dark square and a light square and taking the average.
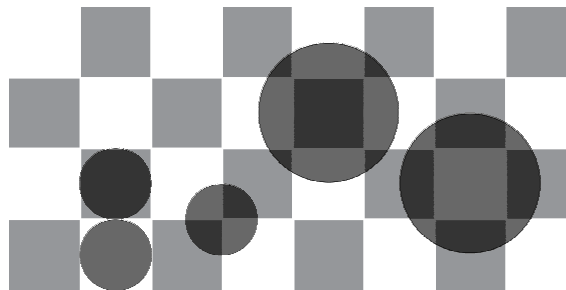

Figure 2: An example material with a chess board pattern. Different measurement areas are demonstrated.

2.2.1 Inhomogeneity significantly smaller than the illuminated area

The first step for measurement of inhomogeneous samples is to maximize the mismatch between the pattern shape to the beam shape. If the beam is rectangular and the sample has a rectangular pattern, simply rotating the sample pattern 45 degrees drastically improves the accuracy.

The second step is to use the instrument real-time mode for broadband or a single visible wavelength illumination and translate the sample manually, at least over an area the size of the beam, and while reading the instrument response. Simulations show that the average of the maximum and minimum values are not always the average of the fabric. Therefore it might be more representative to measure the full spectrum with the sample in a position where the value is close to the median of a sample selection.

As long as maximum and minimum results seen in the interactive measurement mode is within the specified tolerance need it is safe to use this method. If the range is larger you will have to consider the inhomogeneity to be of a similar size as the illuminated area.

2.2.2 Inhomogeneity significantly larger than the illuminated area

This covers the case where a material has two or more very larger areas with different properties. It is then possible to measure the properties of each area as if it was a single product. The answer for the total product is the weighted average based on the area of each part.

2.2.3 Inhomogeneity of similar size as illuminated area

The sample has to be measured in multiple positions in case the range of possible randomly measured results are outside of the tolerance. Start with three different positions. Maximize mismatch between pattern and beam as described in section 2.2.1. Calculate the mean and standard deviation of the measured emissivity and transmittance. If the standard deviation is outside of the tolerance, more measurements have to be carried out and added to the set of results that is being averaged. Keep doing more measurements and recalculate mean and standard deviation until the standard deviation is within tolerance.

3 Thermal Conductivity

It is acceptable to use default value for polymers of 0.2 $Wm^{-1}K^{-1}$. Alternatively, the thermal conductivity can be measured using guarded hot plate according to ASTM standards C176 and C518. Those standards were developed for measurement of homogeneous slab samples and may not give accurate results for fabrics with large openness. These measurements can be difficult because the fabrics are so thin. The procedure given in NFRC 101[4] describes how to stack multiple layers of the material with conductive paste to avoid contact resistance.

Future research is suggested on the topic on how to measure thin inhomogeneous samples accurately.

3.1 Other measurement methods

There are other methods to obtain the required properties of fabrics. AERC does not disqualify those and if a method is shown to provide accurate results in the inter-laboratory comparisons that are conducted it should be allowed to be used.

3.1.1 FTIR with integrating sphere

An alternative to using an emissometer is to use an FTIR instrument fitted with an integrating sphere. It allows for measurement of direct-hemispherical transmittance and reflectance. The emissivity is then calculated as $E = 1 - T - R$.

Typically these results are obtained spectrally and the answer must then be weighted using a black body radiation curve to get a single emissivity value.

The process for measurement of IR properties using an integrating sphere is similar to that of using an integrating sphere for measurement of the solar optical properties. Those procedures are outside the scope of this document. Make sure to pay special attention to the properties measured of inhomogeneous samples following the instructions in section 2.2.1.

3.1.2 Calculation of integrated emissivity value based on spectral data

If the test method used results in emissivity, $E_m(\lambda)$, and transmittance, $T_m(\lambda)$, as a function of wavelength, λ, it should be integrated using 300 K black body radiation curve as weighting function according to

$$\varepsilon = \frac{\int_{5\mu m}^{25\mu m} E_m(\lambda) E_b(\lambda)\, d\lambda}{\int_{5\mu m}^{25\mu m} E_b(\lambda)\, d\lambda}, \tag{3}$$

where $E_b(\lambda)$ is calculated according to

$$E_b(\lambda) = \frac{C_1}{\lambda^5 \left(\varepsilon^{C_2/\lambda T}\right)}, \tag{4}$$

where the emitted black-body radiation, $E_b(\lambda)$, is given by

C_1 Planck's first constant ($3.743 \times 10^8 W \mu m^4/m^2$)

C_2 Planck's second constant ($1.4387 \times 10^4 mum K$)

T temperature (K)

λ wavelength (μm).

The transmittance is calculated the same way as the emittance in (3) by simply replacing E_m with T_m. The wavelength range covered should span at least from $5\mu m$ to $25\mu m$.

4 Summary

There are multiple ways to measure the thermal properties of fabrics and the one described in this document is a straight-forward path to do so.

References

[1] A. S. for Testing and Materials, "ASTM E408: Standard test methods for total normal emittance of surfaces using inspection-meter techniques," 2013.

[2] A. S. for Testing and Materials, "ASTM E434: Standard test methodd for calorimetric determination of hemispherical emittance and the ratio of solar absoptance to hemispherical emittance using solar simulation," 2010.

[3] Devices and S. Co., "Use of emissometer for semi-transparent materials measurements," tech. rep., D&S Thecnical Note 81-1, 1981.

[4] National Fenestration Rating Council, "NFRC101: Procedure for determining thermophysical properties of materials for use in nfrc-approved software programs," 2010.

A MATLAB solution to the problem calculating emissivity of transparent samples

Implementation of a solution for the equation system of equations given in equation 2.

```
function [Es, Ts] = transE(Edark,Elight ,EdarkRef, ElightRef)
%
% [Es, Ts] = transE(Edark,Elight ,EdarkRef, ElightRef)
%

%Iterative function finding the minimum
X = fminsearch(@(x) fEd(x,Eadark, Ealight, EdarkRef, ElightRef),...
          [.5;.5]);
Es = X(1);Ts=X(2);

function err = fEd(X,Eadark, Ealight, EdarkRef, ElightRef)
%
% Calculates error, heavily penalizes nonphysical answer
%
Es = X(1);Ts=X(2);
Rbd = 1-EdarkRef;
Rbl = 1-ElightRef;
darkerr = Eadark - Es - Ts.*(1- Ts.*Rbd./(1-Rbd.*(1-Es-Ts)));
lighterr = Ealight - Es - Ts.*(1- Ts.*Rbl./(1-Rbl.*(1-Es-Ts)));
err = darkerr.^2+lighterr.^2;
if Es > 1 || Es < 0 || Ts > 1 || Ts < 0 || Ts+Es>1
   err = err + 100;
end
```

AERC 1.1 APPENDIX F – Permeability Factor (PF) of Fenestration Shading Products – Definition and Determination Method

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Disclaimer

Abstract

This document describes the permeability factor (PF), a performance metric for how easily air moves through a window attachment layer. PF can typically be assumed equivalent to the optically measured openness factor (OF). This is not the case though for thick layers or layers incorporating some specular material that is impermeable to air flow, such as a thin transparent polymer sheet, coating or film. The theory, measurement and calculation methods to determine PF in these non-standard cases is described along with example calculations and sample code.

1   Introduction

Window attachments, most notably shade fabrics that might be incorporated into roller shades, solar screens, pleated shades, etc., typically have openings in the layer that allow air to pass through them. There is no standard agreement for defining this property. We have decided to define a non-dimensional quantity called Permeability Factor (PF). It is a measure of how permeable the window attachment layer or product is to the passage of air.

For thin layers such as most solar screens, PF is defined similarly to porosity as the ratio of open area in the layer to the total area of the layer. For example, if there are no openings through which air can flow through the layer is impermeable and PF is 0. If a layer has 10% of its area open to airflow then PF is 0.10. PF is distinct from porosity in that it is equal to the apparent porosity of a layer, not the geometric quantity.

For thin layers constructed with materials that are opaque or fully scattering, one can approximate PF in a spectrophotometer as a purely optical property, where specularly transmitting radiation is equal to PF. This property is generally known in shading industry as Openness Factor (OF). Therefore, in the general case PF is equivalent to the OF. Refer to AERC 1.1 appendix A (2017) for details how to determine OF.

The equivalence of PF and OF breaks down for thick layers or layers incorporating some specular material that is impermeable to air flow, such as a thin transparent polymer sheet, coating or film. OF could significantly overstate PF of the layer in these cases. An alternative method to determine PF is therefore described here.

2   Theory

Permeability of the window attachment layer is determined with the help of the Darcy-Forchheimer Law, which is used to describe a steady moving flow (1 < Re < 10) through porous media, where Reynolds number (Re) is the ratio of inertial forces to viscous forces in a moving fluid. The Darcy-Forchheimer Law is expressed through the following equation:

$$\frac{\mu}{K} v + \rho \frac{Y}{K^{1/2}} v^2 = \frac{\Delta P}{t}$$

The linear term accounts for the momentum transfer from fluid to surface while the non-linear term accounts for the inertia effects. In the above equation ρ is the fluid density, μ is the dynamic viscosity, v is the velocity, P is the pressure, t is the

thickness, K is the permeability, and Y is the inertial factor (dependent on pore characteristics). Density and dynamic viscosity of air are well documented quantities as functions of temperature. Layer thickness is measured, and velocity is measured at a monitored and controlled pressure differential. K and Y are determined empirically.

Miguel (1998) correlated K and Y to a logarithmic model of the form shown below based on experimental analysis of screens.

$$X = a \cdot d_{surface}^{b}$$

X represents the correlation constant K or Y. $d_{surface}$ is the porosity (ratio of open fluid filled area to total area), and a & b are constants determined by regression analysis. The permeability, K, is of particular importance to determine porosity and Y is unessential for the purposes of this work. Miguel determined the following correlation through measurements of perforated screen materials with porosity from 0.04 to 0.90.

$$K = 3.44 \times 10^{-9} d_{surface}^{1.6}$$

Note that the definition of $d_{surface}$, is equivalent to our desired Permeability Factor (PF). If we can determine K from measurements, then PF is then calculated from K by reordering the previous formula:

$$PF = \left(\frac{K}{3.44x10^{-9}} \right)^{1/1.6}$$

The shapes of yarns and mesh geometry have negligible impact on airflow characteristics through thin screens, which allows the model to be dependent solely on porosity and thickness of the layer.

3   Measurement Method

The screen air permeability is equivalent to fluid velocity and is measured according to ASTM D737-04 (ASTM 2008). The test is performed at standard pressure differential and environmental conditions as defined in the standard. Several samples are tested to obtain confidence interval in result and sufficient examples to solve for the unknowns in the Darcy-Forchheimer equation. The output of this step is *n* measurements reporting the following parameters:

v measured air permeability/velocity (m^3 s^{-1} m^{-2})
T   temperature of air (C)
t   measured shade layer thickness (m)

ΔP   measured pressure differential of air permeability test (Pa)

Layer thickness is measured with calipers to the nearest 0.1 mm. Each sample utilized for ASTM D737 testing is measured and all sample thicknesses averaged.

4   Calculation Method

The calculation method to determine PF is described below.

The following thermo-physical properties are calculated as a function of air temperature:

     μ   dynamic viscosity (N s m^{-2})
     ρ   density (Kg m-3)

The method and equations to calculate these two properties is provided in NFRC 101 (NFRC 2016).

Measurements of v, T, t, and ΔP for n samples result in a system of n simultaneous equations. A formulation of the Darcy-Forchheimer in matrix form is shown below, where **P** is a vector of known pressure terms, **A** is the known coefficient matrix, and **K** is the vector of unknowns.

$$\mathbf{P} = \mathbf{A} \cdot \mathbf{K}$$

$$\mathbf{P} = \left[\frac{\Delta P}{t} \right]_{[n \, x \, 1]}$$

$$\mathbf{A} = \left[\mu v \; \rho v^2 \right]_{[n \, x \, 2]}$$

$$\mathbf{K} = \left[\begin{matrix} 1/K \\ Y/K^{1/2} \end{matrix} \right]_{[2n \, x \, 1]}$$

This initial set of equations contains two unknowns, K and Y. The over-determined system is solved by least squares resulting in an approximate solution for K. PF is solved for according to correlation developed by Miguel (1998)

$$\mathbf{K} = \mathbf{A}^{-1} \cdot \mathbf{P}$$

$$\mathbf{K} = \left[\begin{matrix} \mathbf{K}(1) \\ \mathbf{K}(2) \end{matrix} \right]$$

$$K = \frac{1}{\mathbf{K}(1)}$$

$$PF = \left(\frac{K}{3.44x10^{-9}}\right)^{1/1.6}$$

5 Example Calculation

Airflow measurements of five screen materials were made utilizing the methods outlined in ASTM D737. The properties of these shades and measurements are in Table 1. The test is performed at a differential pressure of 125 Pa at results are corrected and reported for standard environmental conditions of 21 C and 1 atm. The permeability [cm3 s-1 cm-2] measurements, shade thickness, and environmental conditions are combined in the equations from step 2 with the example MATLAB code included in appendix A to determine PF.

Table 1. Sample shade measurements and PF calculation results

ID	t [mm]	Measured Permeability [m3 s-1 m-2]										PF (-)
		1	2	3	4	5	6	7	8	9	10	
SE10	0.48	0.68	0.71	0.69	0.73	0.69	0.66	0.69	0.65	0.71	0.66	0.045
SE11	0.66	0.05	0.06	0.06	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.010
SE14	0.48	1.16	1.18	1.18	1.22	1.22	1.24	1.20	1.17	1.26	1.16	0.064
SE16	0.56	0.86	0.87	0.85	0.89	0.91	0.88	0.86	0.87	0.86	0.93	0.058
SE17	0.79	2.66	2.55	2.67	2.52	2.60	2.50	2.61	2.56	2.62	2.52	0.141

References

AERC (2017). AERC 1.1 Procedures for Determining the Optical and Thermal Properties of Window Attachment Materials. In manuscript.

ASTM International (2008). D737-04 Standard Test Method for Air Permeability of Textile Fabrics. West Conshohocken, Pa.

NFRC. 2016. NFRC 101: "", National Fenestration Rating Council. Silver Spring, MD. April, 2016.

Miguel, A. F. (1998). Airflow through porous screens: From theory to practical considerations. Energy and Buildings, 28(1), 63–69.

Appendix A. MATLAB solution to calculating permeability factor of shade layer

```
Function PF = permeabilityFactor(permeability, viscosity,

    density, thickness, pressureDrop)


% PF             1 x 1 Permeability Factor                (-)
% permeability   n x 1 vector of measured air permeability (m^3s^-1m^-2)
% viscosity      n x 1 vector of fluid dynamic viscosity  (N s m^-2)
% density        n x 1 vector of fluid density            (Kg m^-3)
% thickness      n x 1 vector of shade layer thickness    (m)
% pressureDrop   n x 1 vector of pressure differential    (Pa)


a1 = viscosity.*permeability;

a2 = density.*permeability.^2;

P = pressureDrop./thickness;

A = [a1 a2];

K = A \ P; %Least squares solution to over-determined system

K1 = 1 / K(1); %Inverse of first element in least square solution

PF = (K1 / (3.44e-9))^(1 / 1.6); %Miguel openness correlation
```

Appendix G: Reporting Checklist

Single Product (Section 5.1.1)	Product in a Product Family (Section 5.1.2)
Using either 18 samples (full test) or 6 samples (temporary listing), provide: ☐ Tolerance report (Appendix B) For representative sample (single sample) provide: ☐ Spectral transmittance data ☐ Spectral reflectance data ☐ BSDF data (optional) ☐ Emissivity ☐ Infrared transmittance data ☐ Thermal conductivity ☐ Permeability factor	Using 18 samples each for 2 products within the family, provide: ☐ Tolerance report (Appendix B) For all products (single sample each) provide: ☐ Spectral transmittance data ☐ Spectral reflectance data ☐ BSDF data (optional) ☐ Emissivity ☐ Infrared transmittance data ☐ Thermal conductivity ☐ Permeability factor

AERC 1.1 APPENDIX H — Process for inter-laboratory comparison

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Disclaimer

Abstract

An inter-laboratory comparison is a way to confirm that a measurement laboratory can follow a defined measurement procedure, as well as to give a measure of what the accuracy is for the the method.

1 Structure for inter-laboratory comparison

AERC requires data submitters to participate in an inter-laboratory comparison (ILC, also know as round-robin and inter-laboratory study (ILS)) as a way to verify that they understand the procedures and their equipment works. There are multiple ASTM standards describing how to run such an activity, but they are designed to validate the method rather than the labs, so while the procedure described here is inspired by them it is not perfectly described by them.

The entity which participate is called a lab in this appendix. It could be e.g. a manufacturer or a commercial test lab. It is a requirement that a lab has successfully participated in the most recent inter-laboratory comparison for data measured there to be approved for submission.

The ILC might be defined to test several different procedures (e.g. solar optical and thermal IR measurements) and should be set up so that it is possible to qualify to perform a subset of all measurements that are tested during the activity.

The outline of the process is as follows

1. Samples selection committee: Form a committee that decides what samples are required to verify the procedures under scrutiny.

2. Identify participants: Compile a list of participants to get a lower limit of the number of participants.

3. Acquire samples: Acquire samples that meet the specification of the sample selection committee. Each participant needs their own set in a parallel ILC, extra sets are needed to accommodate labs that want to qualify before the next ILC.

4. Organizer writes instructions: Prepare instructions on what to measure, and how to report the results.

5. Organizer characterizes samples for consistency: Perform limited characterization of all samples to quantify consistency.

6. Participants measure: Samples are received, characterized, and then the data is formatted and sent back to the organizer.

7. Organizer writes initial report: When a critical mass of participants has responded, an initial report is prepared by the organizer to determine what constitutes accurate results.

8. Measurement iteration: Participants that did not qualify get advice on how to improve their measurements.

9. Final report: Final report, including lessons learned and suggested improvements on the procedures, is published.

10. New participants: As ILCs are not run frequently it should be possible for new labs to participate in the time span between the final report and the next ILC. The new participant contacts the organizer, who sends samples, analyzes results, and makes sure the new participant qualifies. Before the organizer is running out of sample sets, it is advised to require the new submitters to send the box back after they have qualified, effectively turning the final boxes into a serial ILC.

The main benefit of running a parallel ILC is that it takes less time for a large number of participants, but it also allow the participants to have samples at hand to verify maintained accuracy if they update equipment or modify their measurement procedures. The drawback is the sample variation, which is handled by doing testing on the samples before they are packaged.

Appendix I: Grouping Rules for Use in AERC 1

1. Introduction

Grouping of properties with similar energy performance reduces the amount of measurements a manufacturer has to complete, the size of the product database, and complexity of communicating each manufacturers product line to consumers.

The process allows for grouping without sacrificing the quality of the rating program. The stringency of this procedure shows that the properties that are required for rating, are the properties that influence the rating.

2. Overview

There are two parts of the process, the first covers limitations on how different the members of a group can be from a composition stand-point and still be part of the same group. The second part required is a partial measurement of the optical properties that influence the energy performance the most, i.e. solar reflectance, solar transmittance, thermal IR emissivity, and thermal IR transmittance. Both parts of the process must be fulfilled to allow grouping.

The calculated difference in energy ratio between group leader and member, designated DER in this document, should be less than 0.025.

Window attachment products using material group members will receive a reduced EP rating compared to window attachment products using material group leaders. To obtain window attachment product group member EP ratings, subtract 0.025 from the energy ratio of the window attachment group leader that is simulated using the material group leader (before it is rounded). I.e. if the window attachment product group leader has a raw heating energy ratio of 0.365 and cooling energy ratio of 0.258, the members of that product group will receive a heating energy ratio of 0.340 and cooling energy ratio of 0.233. Labeled EP ratings will come from rounding identified in AERC 1. Group leaders may report their earned EP ratings or the rating of the group members. Group members may only report EP ratings derived from reduced energy ratios.

2.1. Limits on what can be grouped, including FAQ

The base material should be constant between all members of a material product family and no variation in surface treatment (other than color) should be applied. It is possible to group multiple fabrics according to the computational part of the process even though the openness is varying. So, while ER impact will not exclude grouping, it is quite probable that a glare prevention/daylight rating would not be allowed on grouped fabrics.

Group leaders must have a TvT tolerance value that shows a low variation. For material products with Tvis' greater than or equal to 0.05, the original reported Tolerance is equal

to or less than 20%. For material products with Tvis' less than 0.05, the original reported Tolerance is less than 0.01.

It is possible to group multiple fabrics based on limited testing according to the computational part of the process even though the openness is varying. So, while EP impact will not exclude grouping, it is quite probable that a daylight rating would be wrong if grouped with varying openness.

2.2. Computational process steps

An expected difference in energy ratio based on the sensitivity of each property can be calculated using partial data.

2.2.1. Measure physical properties

The physical properties that must be measured of all products (leader and members) are

Property	Description	Standard
Normal-hemispherical transmittance	At least from 400 nm to 1000 nm in steps smaller than or equal to 10 nm	Measurement of spectral data according to AERC 1.1 appendix C, calculation only on limited spectrum as described in section 2.3.2
Direct-hemispherical reflectance	At least from 400 nm to 1000 nm in steps smaller than or equal to 10 nm, incident angle for reflectance is less than or equal to 10 degrees	Measurement of spectral data according to AERC 1.1 appendix C, calculation only on limited spectrum as described in section 2.3.2
Thermal IR transmittance	Normal-hemispherical transmittance in the wavelength range 5-25 μm weighted with a black-body curve in the range between 280 K and 300 K	Measurement according to AERC 1.1 Appendix E
Thermal emissivity	Hemispherical emissivity in the wavelength range 5-25 μm weighted with a black-body curve in the range between 280 K and 300 K	Measurement according to AERC 1.1 Appendix E

Note that AERC 1.1 appendix C dictates measurement of a wider spectrum and specifies both direct-specular and direct-diffuse measurements that are not required for this limited test.

If the manufacturer has already validated that the product family meets the 20% max tolerance, then only a single sample is required for the reduced testing to determine grouping.

If the manufacture has not yet validated, or did not meet the 20% max tolerance, then each product in the family must go through the 18 sample Tvis/Rvis sample testing to determine which is the representative sample. Then the grouping analysis can be done on the representative samples.

2.2.2. Calculate Rm and Tm as approximation of solar reflectance and transmittance

The spectrally resolved data is integrated to single values according to $Tm = \int_{400}^{1000} T(\lambda)I(\lambda)d\lambda$, and $Rm = \int_{400}^{1000} R(\lambda)I(\lambda)d\lambda$ where I(λ) is the solar spectral energy density as a function of wavelength.

2.2.3. Select group leader and verify which products can be grouped as members

The manufacturer has full freedom to select the leader and then has to calculated DEP between leader and candidate members according to

a. $DER =$

$$\sqrt{\left((Rm^{leader} - Rm^{member})\frac{\partial ER}{\partial R_{sol}}\right)^2 + \left((Tm^{leader} - Tm^{member})\frac{\partial ER}{\partial T_{sol}}\right)^2 + \left((TIR^{leader} - TIR^{member})\frac{\partial ER}{\partial TIR}\right)^2 + \left((Em^{leader} - Em^{member})\frac{\partial ER}{\partial Em}\right)^2}$$

, where Rm is and Tm are the values calculated according to step 2.3.2., and TIR and Em are the measured thermal IR transmittance and emissivity, respectively. The partial derivatives for EP were determined from LBNL sensitivity analysis to be

Partial derivative	Number
$\partial ER/\partial R_{sol}$	0.005016
$\partial ER/\partial T_{sol}$	0.006942
$\partial ER/\partial TIR$	0.002544
$\partial ER/\partial Em$	0.002067

3. Material measurements

The spectrally resolved transmittance and reflectance for the materials should be measured using a spectrophotometer fitted with an integrating sphere of a diameter of at least 100 mm. The wavelength range should be at least from 400 nm to at least 1000 nm.

4. Reporting

A grouping report should contain the measured data of all products, leader and members as well as the calculated DEP for each group.

5. Assistance spreadsheet

LBNL provides a spreadsheet to assist with the selection of leaders/members which can also be used for reporting.

1. Save the workbook to your computer
    a. Allow macros to run
2. If you have already computed Tm and Rm, skip to step 6
3. In the 'Sheet Name List' tab, add the names of each material product into Column A starting at cell A2 and working your way down
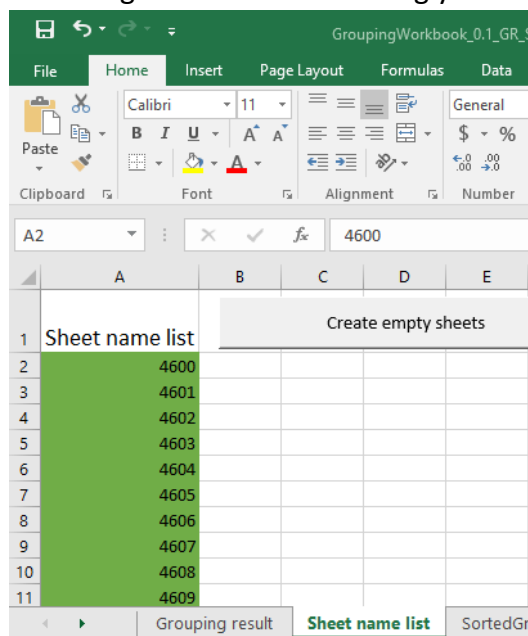

4. Once all material product names are documented, click the "Create empty sheets" button
    a. Workbook will generate a new tab for each material product and name the tab based on the product names provided in Column A of the 'Sheet Name List' tab
5. In each tab, copy and paste measured spectral transmittance and reflectance data for each material product representative sample into the appropriate cells in Columns C and D.
    a. Formulas in cells C8 and D8 will calculate Tm and Rm

b. Input the Tir and emissivity for the material product representative sample in cells E8 and F8.
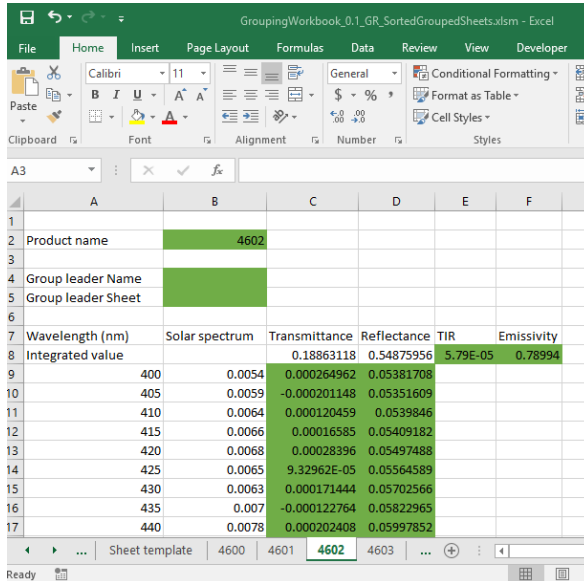
6. Once all data is completed in every material product tab, go to the 'Graphical Overview' Tab and click the "Copy sheets to Graphical Overview" button

a. Workbook will populate this tab with all of the data entered in all of the other tabs such that each row has a different material product
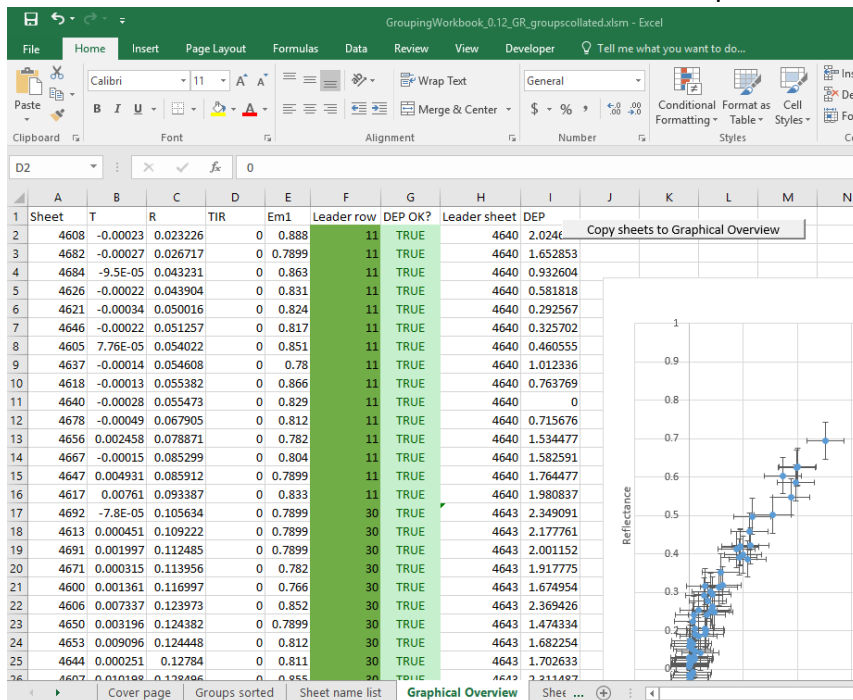
7. Test out different group leaders indicate which products should be grouped by manually filling out the values in Column F ("Leader row") to indicate the product that should serve as the group leader for the material product listed in that row. Reference the row number in the excel sheet for the group leader (For example, if

you want the material product in row 2 to be grouped under the material product in row 11, enter "11" in cell F2)

    a. Columns G and H have formulas that calculate DER and will read TRUE or FALSE with corresponding conditional green or red formatting if the member falls within the allowable DER range.

    b. The chart on the right will also help visualize which material products may be grouped together as the error bars estimate how close products have to be in the Reflectance/Transmittance plane to have a chance to be grouped.

8. To finalize groups, all of the cells in Columns G and H, should read "TRUE" with green highlighting

9. Copy 'Graphical Overview' data to new sheet to sort the groups by leader