Deriving BSDFs for building performance analysis

2017 Radiance International Workshop
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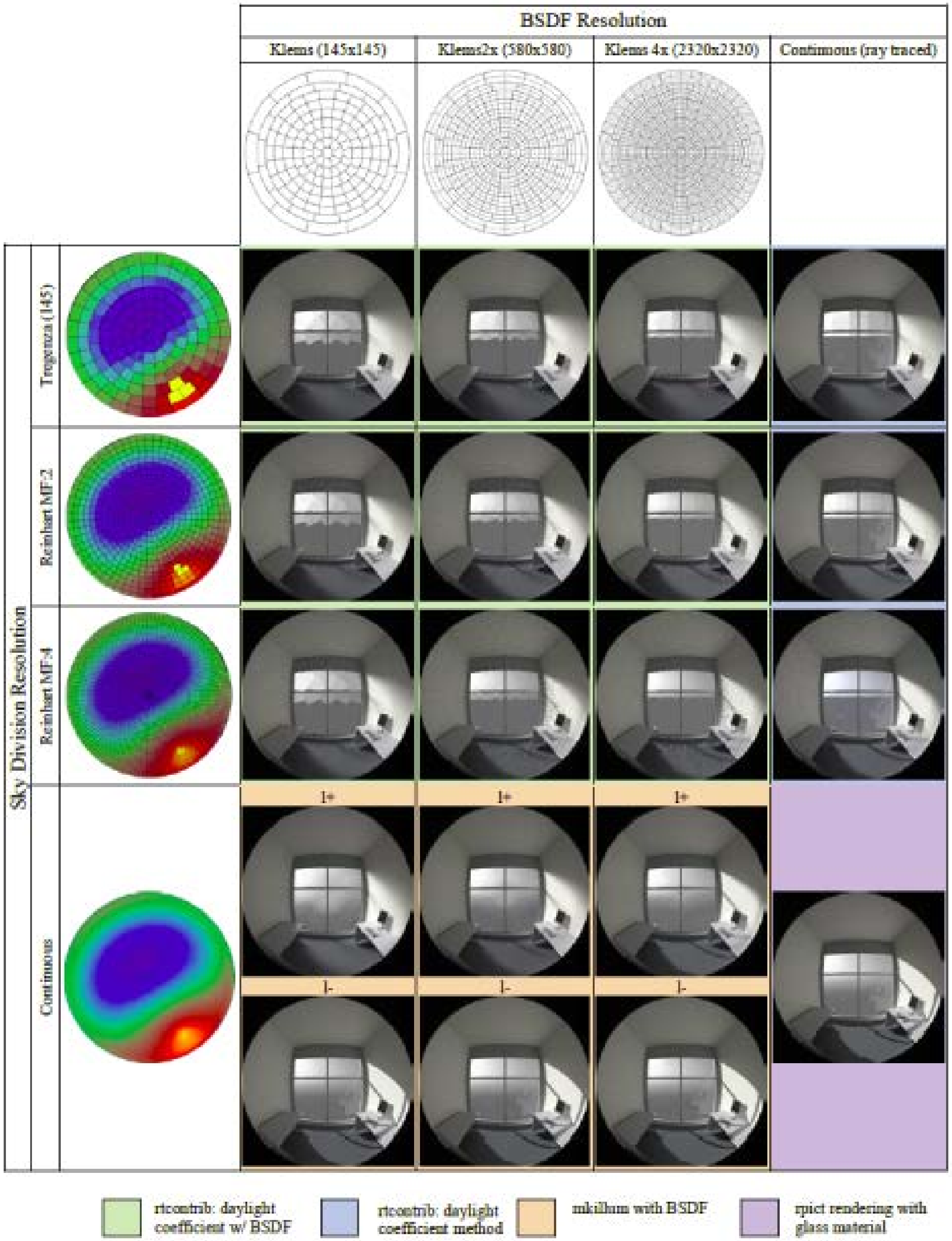
Greg Ward, Anyhere Software

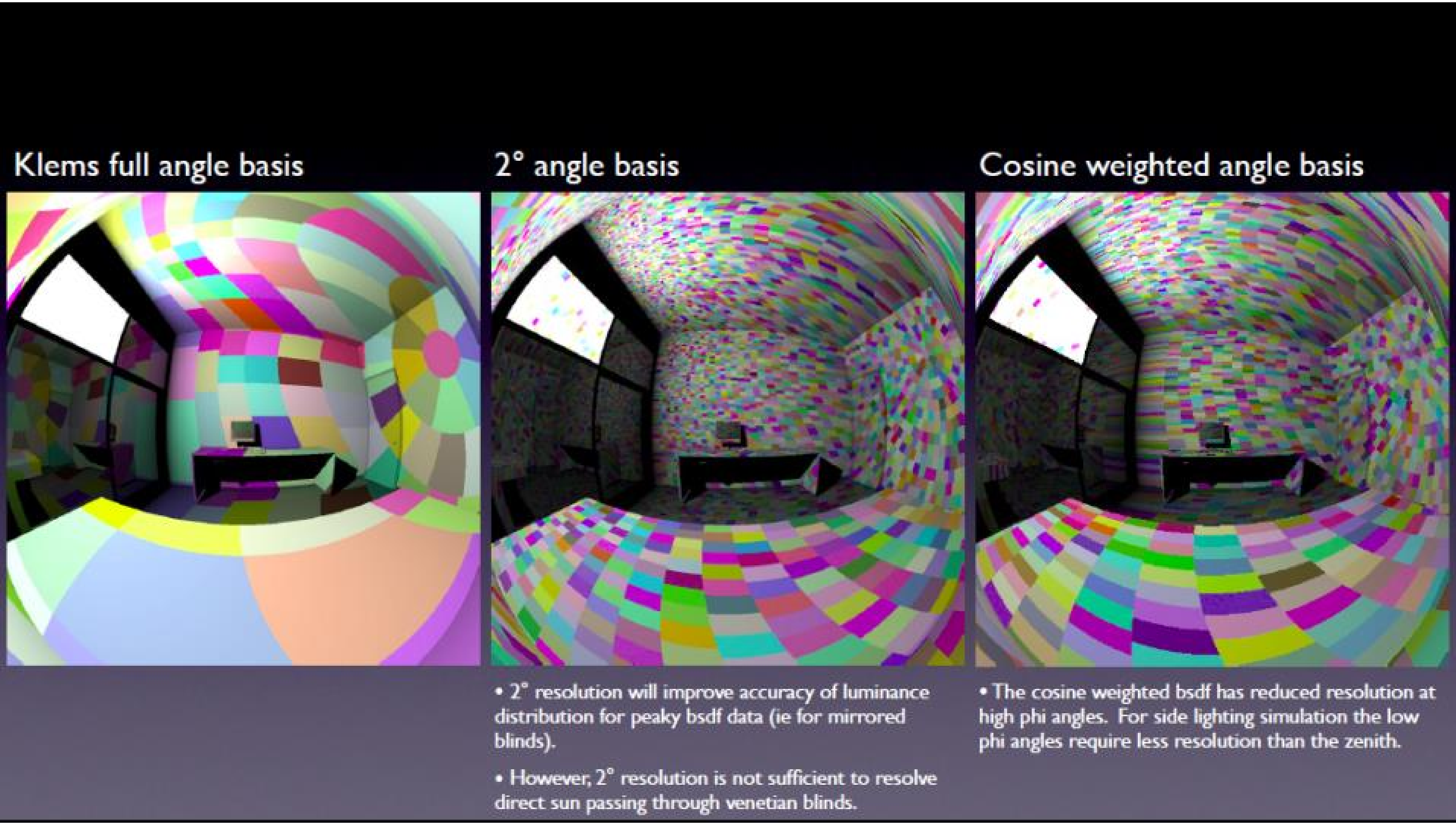
Context

Matrix approach for annual simulations

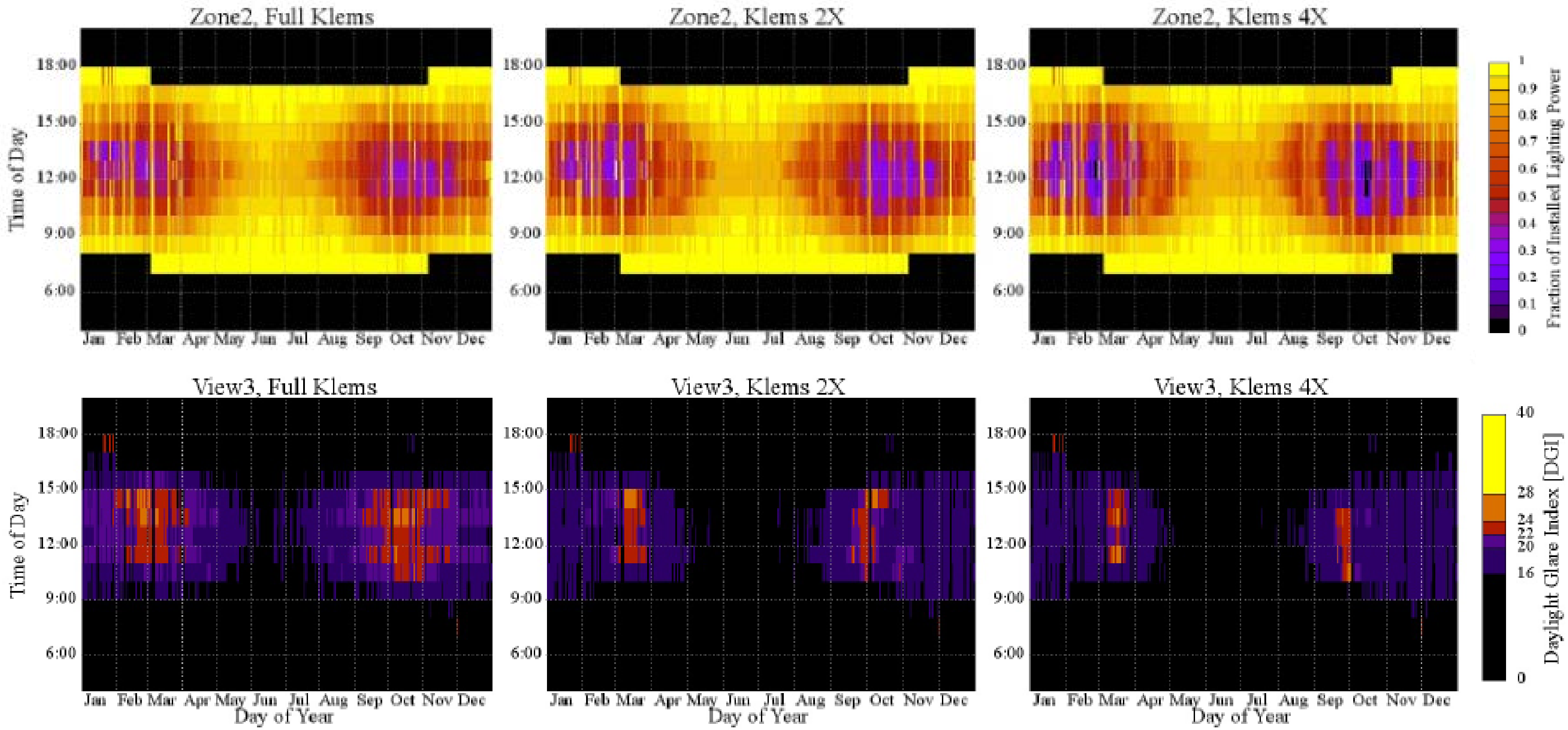
- Validation of 5-phase and 6-phase methods
  - Geisler-Moroder et al., IBPSA 2017 conference
  - Wang et al., Radiance 2017 conference
- Comparison of methods
  - Brembilla, IBPSA 2017 conference (& dissertation)
  - Iversen et al., Daylight calculations in practice (SBi 2013:26, www.sbi.dk)
- Conclusion
  - Modeling approaches that provide adequate resolution of the **direct sun component** yield significantly more accurate results



Ward et al. Simulating the daylight performance of complex fenestration systems using BSDFs within Radiance. Leukos, J. IESNA 7(4), 2010.



Comparing Klem's full angle basis with two notional high-resolution angle bases, Andrew McNeil, LBNL, March 2010 (internal deliverable).



Annual percent lighting energy savings

	Full Klems	Klems 2x	Klems 4x
Zone 1	72%	73%	74%
Zone 2	20%	21%	23%
Zone 3	8%	7%	7%

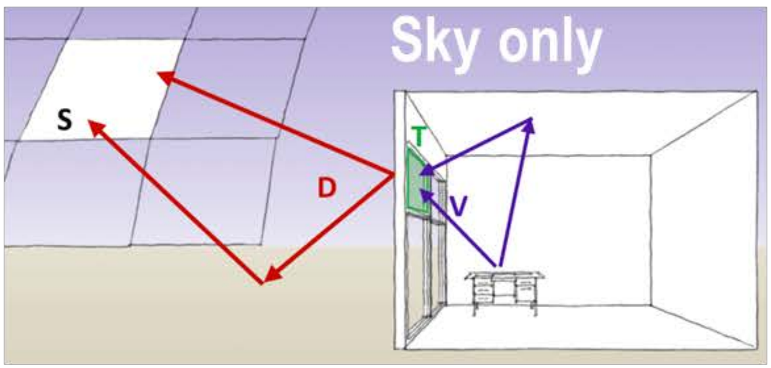
Annual percentage hours when DGI>22

	Full Klems	Klems 2x	Klems 4x
View 1	0%	0%	0%
View 2	3%	0%	0%
View 3	9%	3%	2%

Conclusion: Significant difference in annual glare evaluations, minimal difference in lighting energy savings

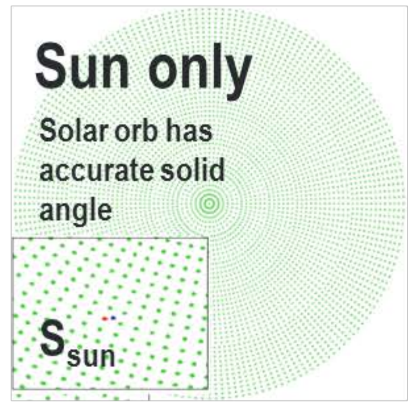
Andrew McNeil, LBNL, Sept 2011 (internal deliverable);
passive optical light shelf modeled with 1x, 2x,and 4x Klems basis.

Five-phase method
Separate sun and sky contributions

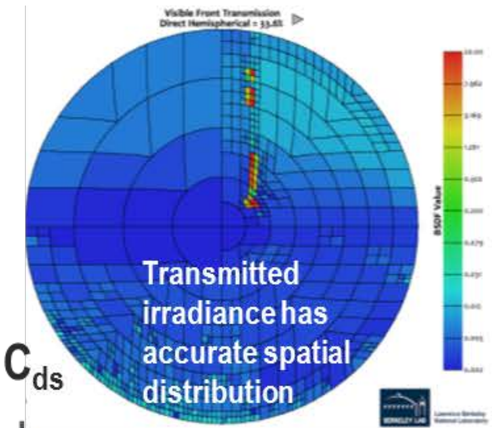


Three-phase method

$$I_{3ph} = VTDS$$



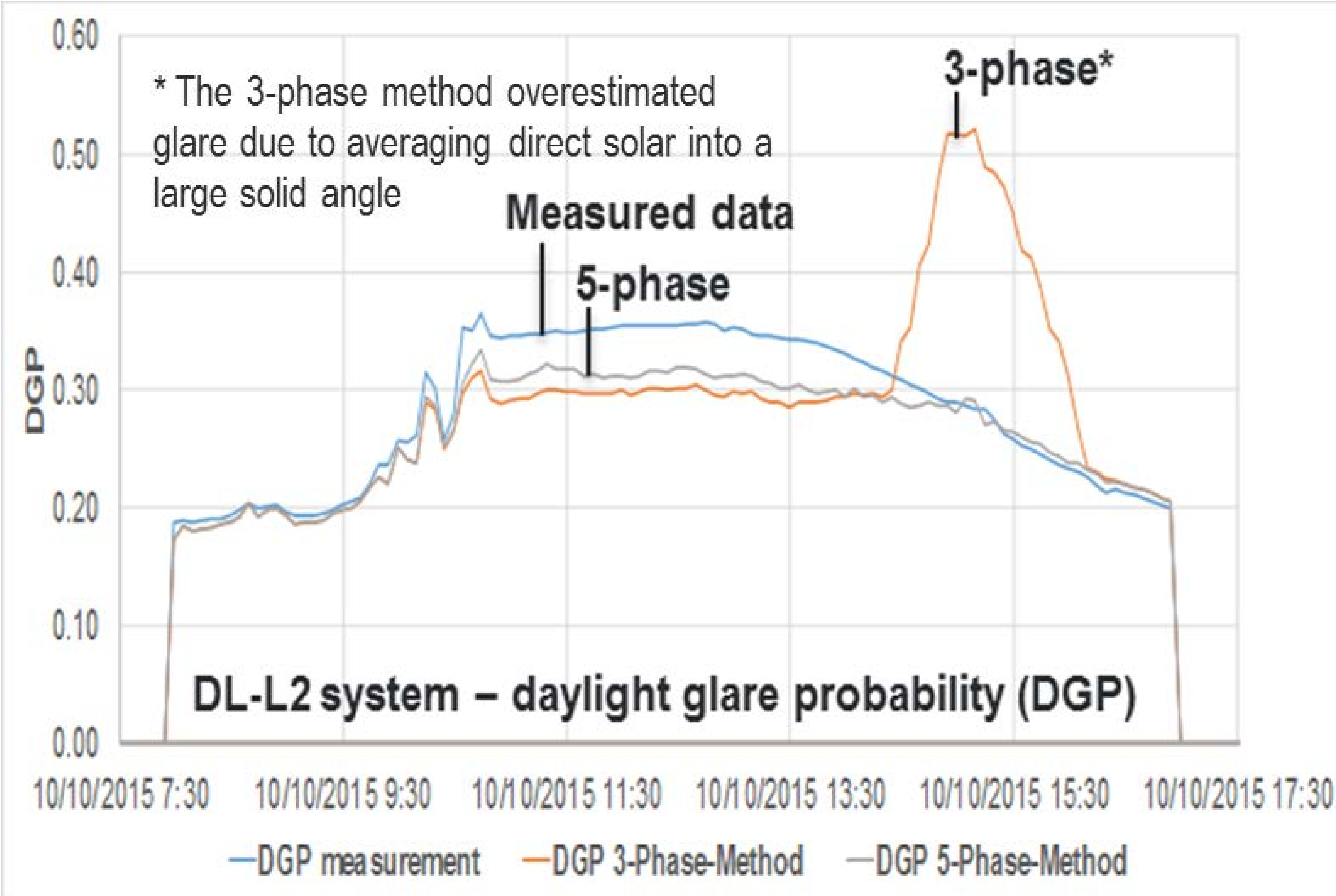
C_{ds}



Five-phase method

$$I_{5ph} = VTDS - V_d T D_d S_{ds} + C_{ds} S_{sun}$$

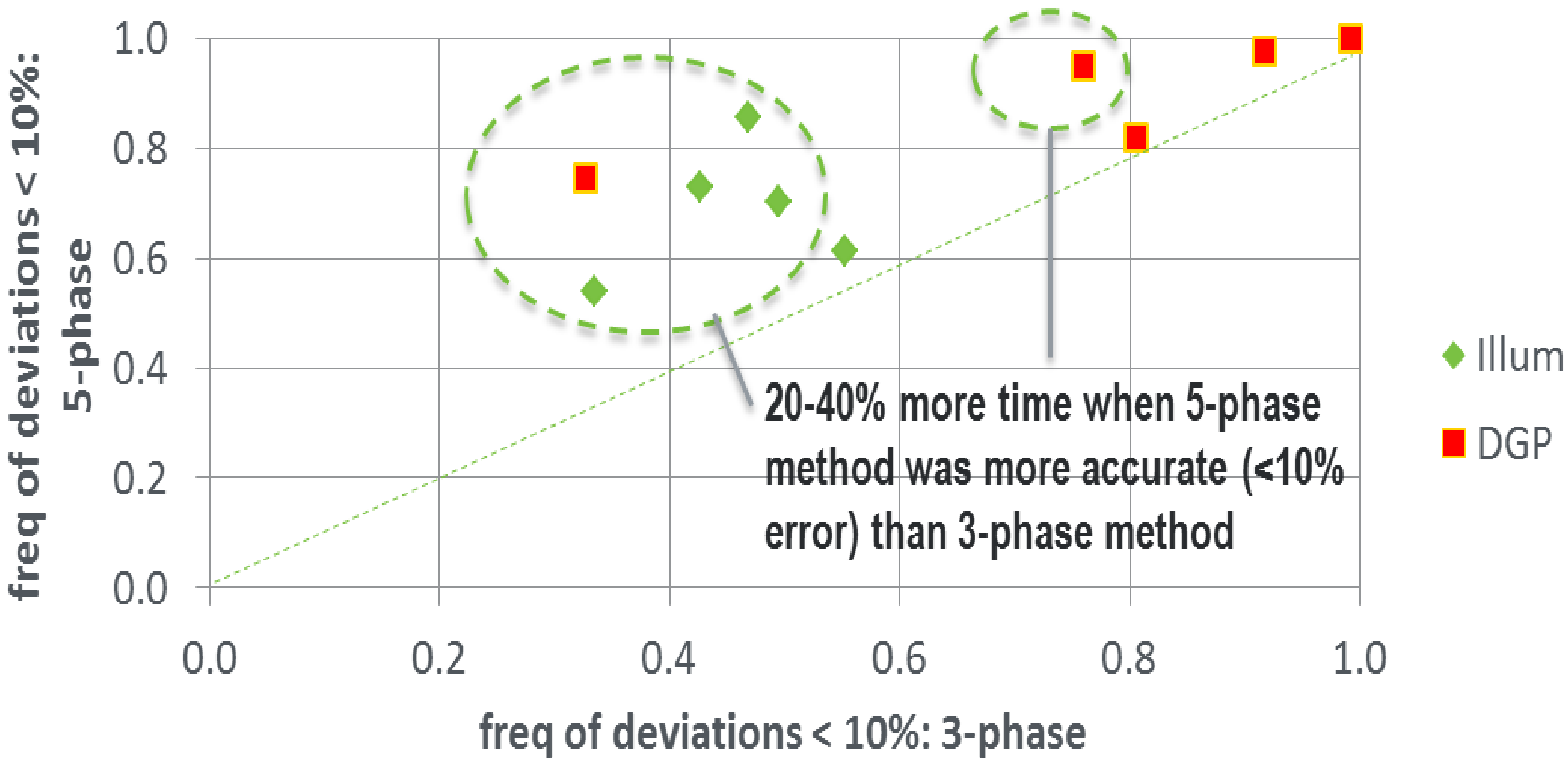
145xN resolution



Geisler-Moroder et al., Validation of the Five-Phase Method for Simulating Complex Fenestration Systems with Radiance against Field Measurements, Proceedings of the 15th International Conference of International Building Performance Simulation Association, San Francisco.

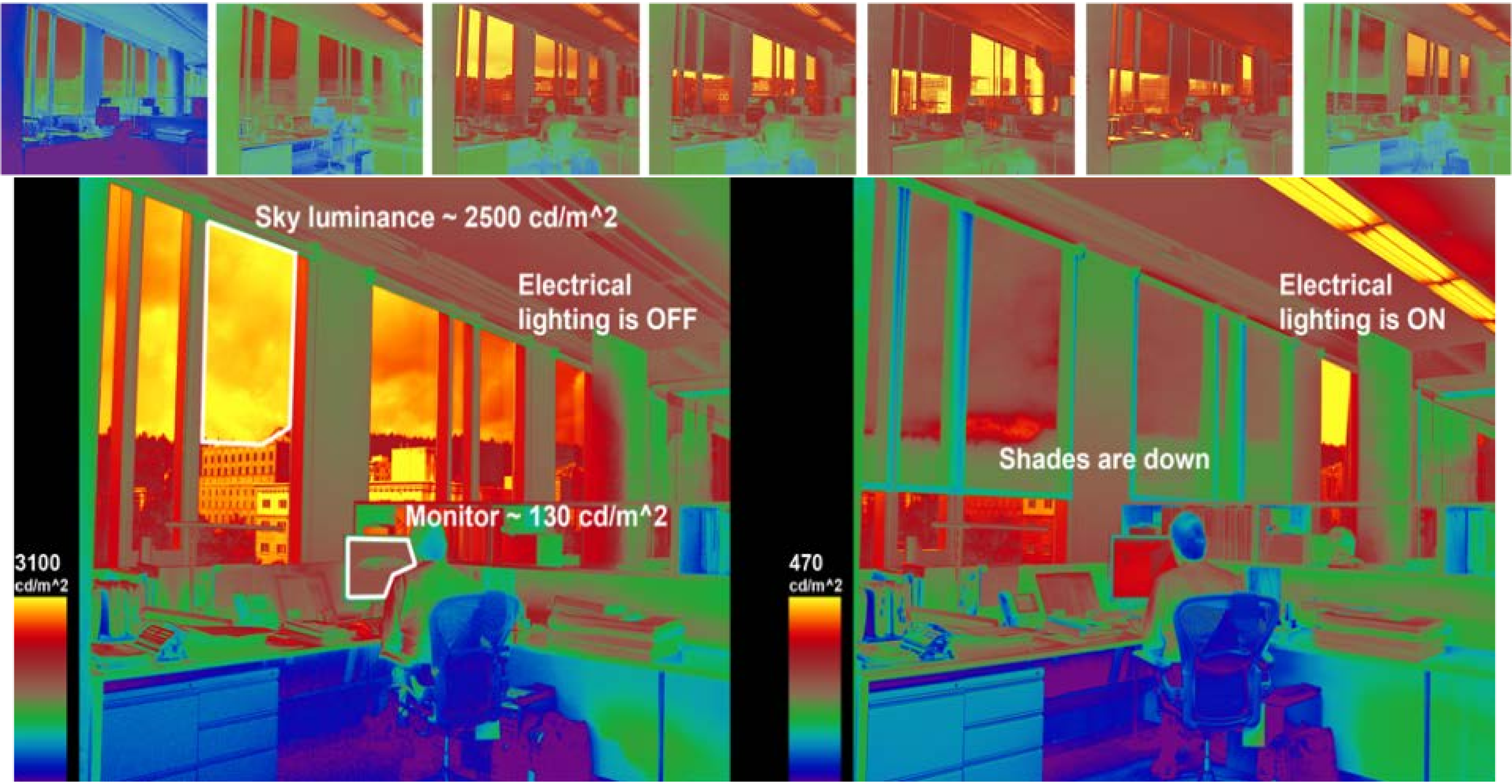
Validation results

Five-phase yields lower error for greater percentage of time than three-phase method




5-phase
6-phase
7-phase….
WHY???

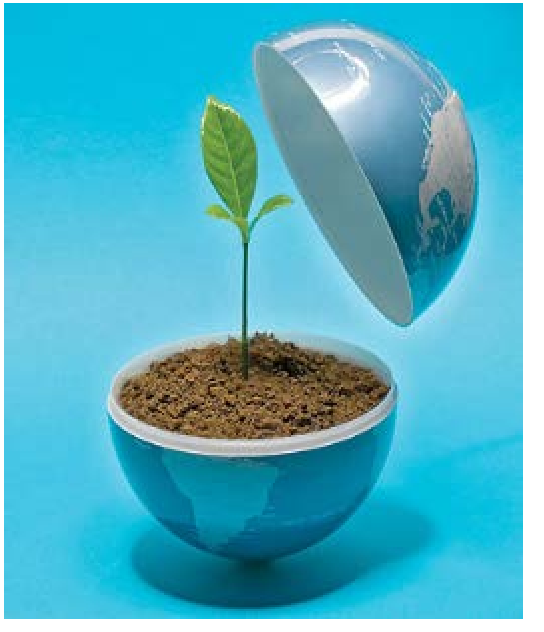
What are the consequences of poor design?



Kyle Konis, UCB/ LBNL

Where do we want to go?

Goal: Zero-energy buildings (ZEB) by the year 2025 using *leap-frog* technologies such as dynamic façade systems in combination with renewable energy sources



http://www.time.com/time/specials/2007/environment/

Pathways to NZEB

Develop a targeting strategy for selecting technology areas on which to focus based on different priority criteria: (1) how significant the savings potential is for current practice and (2) how significant the savings potential is for ZEBs. For ZEB commercial buildings, current research programs for lighting and dynamic windows should be augmented with efforts to improve thermal insulation levels, increase the efficiency of appliances and HVAC components, and promote publication and adoption of aggressive energy standards such as BSR/ASHRAE/USGBC/IESNA Standard 189P. Daylighting technology should not be neglected because it has relatively low technical risk (compared to advanced lighting) and because it can have a powerful positive effect in some building types (daytime operating hours and much of the regularly occupied floor plate within 20 feet of an outside surface) and on productivity and health. Though not modeled directly in this study, attaining performance levels suggested by the modeling results will also depend on success in the areas of integrated design, controls, commissioning and operation.

NREL/TP-550-41957. December 2007. Assessment of the Technical. Potential for Achieving Net. Zero-Energy Buildings in the. Commercial Sector. B. Griffith, N.

“Goldman Sachs was interested in reducing energy use, but we also wanted to significantly improve the environmental quality of our offices.”

– Cindy Quan, Goldman Sach’s head of environmental, social and governance for corporate services and real estate. [https://facades.lbl.gov/nyclivinglab]

What defines high-performance?

Thermal comfort

Visual comfort

Natural daylight

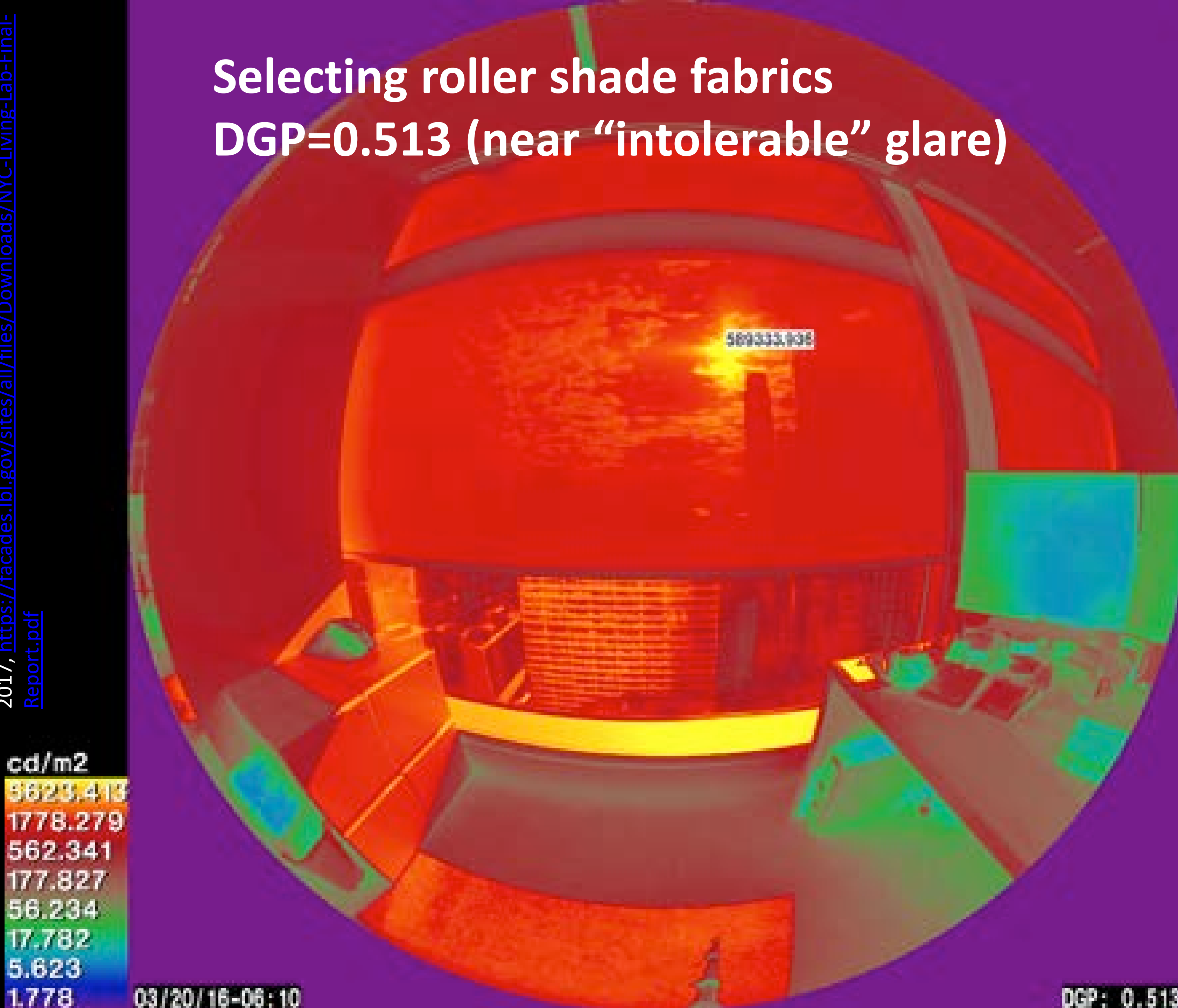
Outdoor views

Sustainable

Energy efficient

https://eta.lbl.gov/news/article/shading-and-lighting-retrofits-slash
http://be-exchange.org/resources/event-media/352

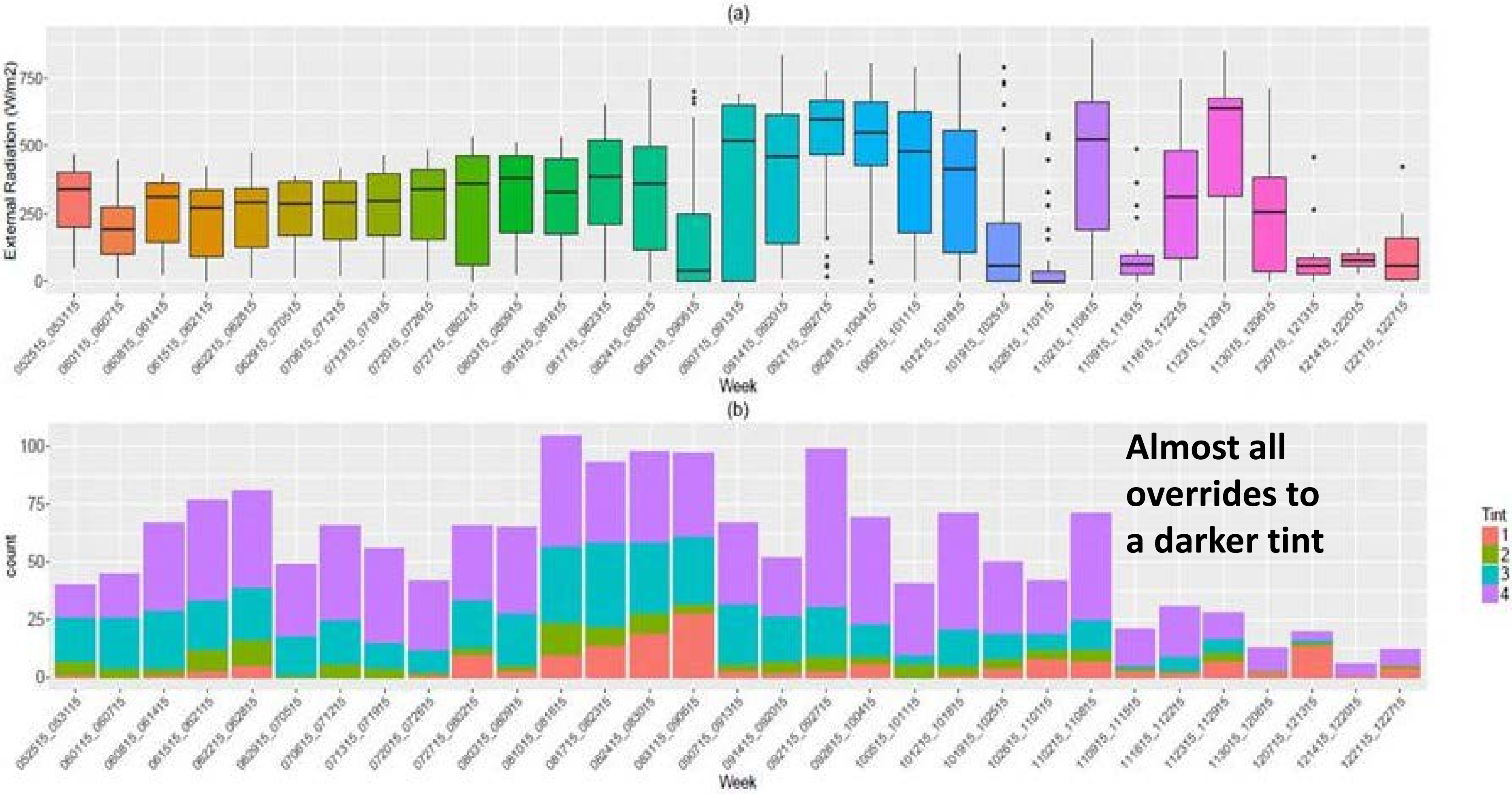
Selecting roller shade fabrics
DGP=0.513 (near “intolerable” glare)



Lee et al., Demonstration of Energy Efficient Retrofits for Lighting and Daylighting in New York City Office Buildings, Final project report, April 2017, https://facades.lbl.gov/sites/all/files/Downloads/NYC-Living-Lab-Final-Report.pdf

Electrochromic window demonstration, Portland

Phase I manual overrides, private offices, 40 zones



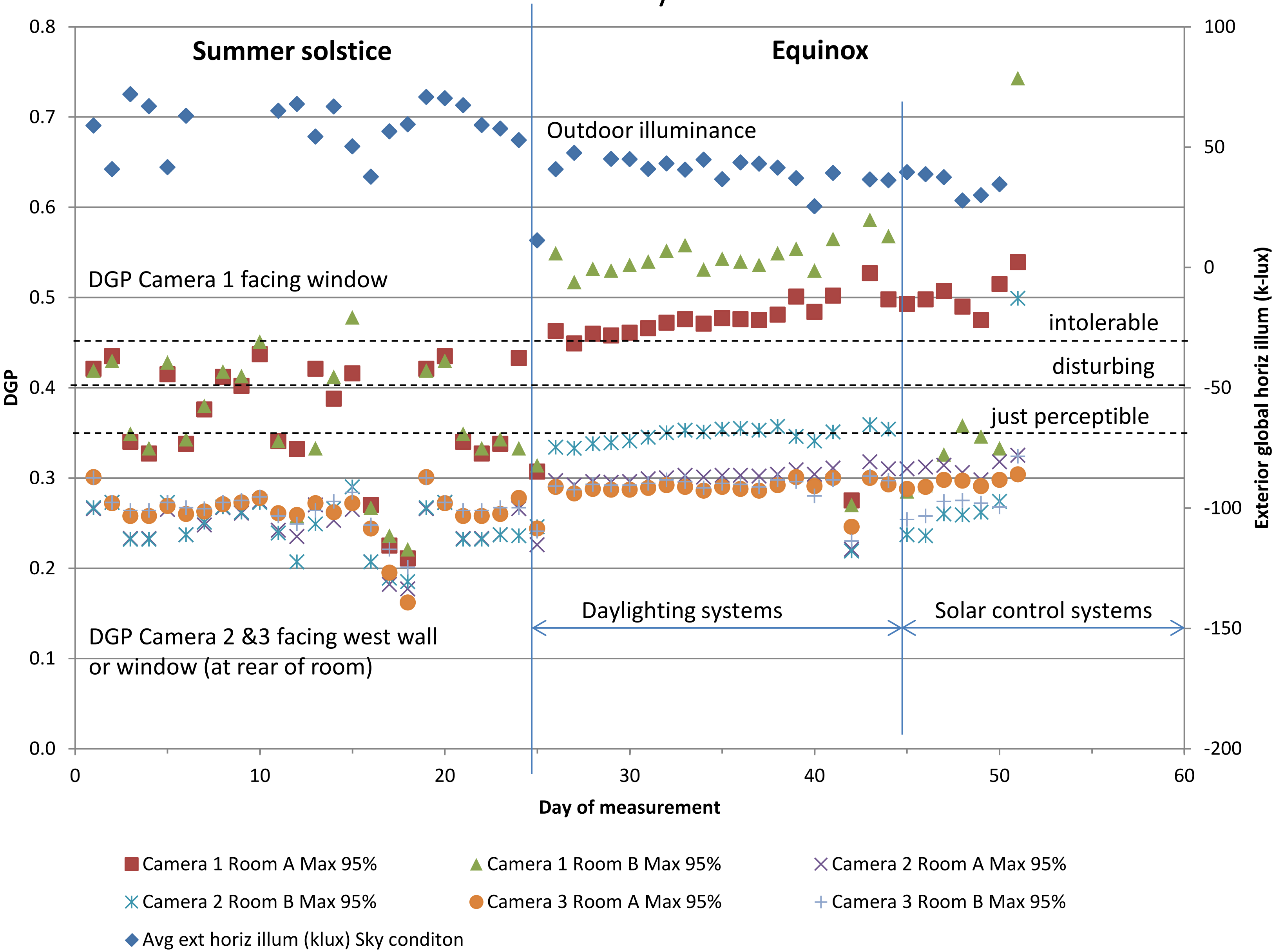
May

December

Lee, et al., Electrochromic Window Demonstration at the 911 Federal Building, 911 Northeast 11th Avenue, Portland, Oregon, General Services Administration, Green Proving Ground Report, November 2016.

Utility rebate & incentive programs

Monitored DGP: Six innovative systems



Lee et al., Technology Assessments of High Performance Envelope with Optimized Lighting, Solar Control, and Daylighting, 2016. http://etcc-ca.com/reports/technology-assessments-high-performance-envelope-optimized-lighting-solar-control-and


Thermal comfort with direct
solar irradiance →
multi-node physiological model

Other considerations

Product differentiation through rating and labeling

National Fenestration Rating Council

Attachments Energy Rating Council

AERC

National Fenestration Rating Council® CERTIFIED	World's Best Window Co. Millennium 2000+ Vinyl-Clad Wood Frame Double Glazing • Argon Fill • Low E Product Type: **Vertical Slider**
ENERGY PERFORMANCE RATINGS	
U-Factor (U.S./I-P) **0.35**	Solar Heat Gain Coefficient **0.32**
ADDITIONAL PERFORMANCE RATINGS	
Visible Transmittance **0.51**	Air Leakage (U.S./I-P) **0.2**
Condensation Resistance **51**	—

Manufacturer stipulates that these ratings conform to applicable NFRC procedures for determining whole product performance. NFRC ratings are determined for a fixed set of environmental conditions and a specific product size. NFRC does not recommend any product and does not warrant the suitability of any product for any specific use. Consult manufacturer's literature for other product performance information.
www.nfrc.org

Definition: BRDFs and BTDFs

bi-directional reflectance and transmittance functions

- The (spectral) Bidirectional Transmission or Reflection Distribution Function – BTDF or BRDF

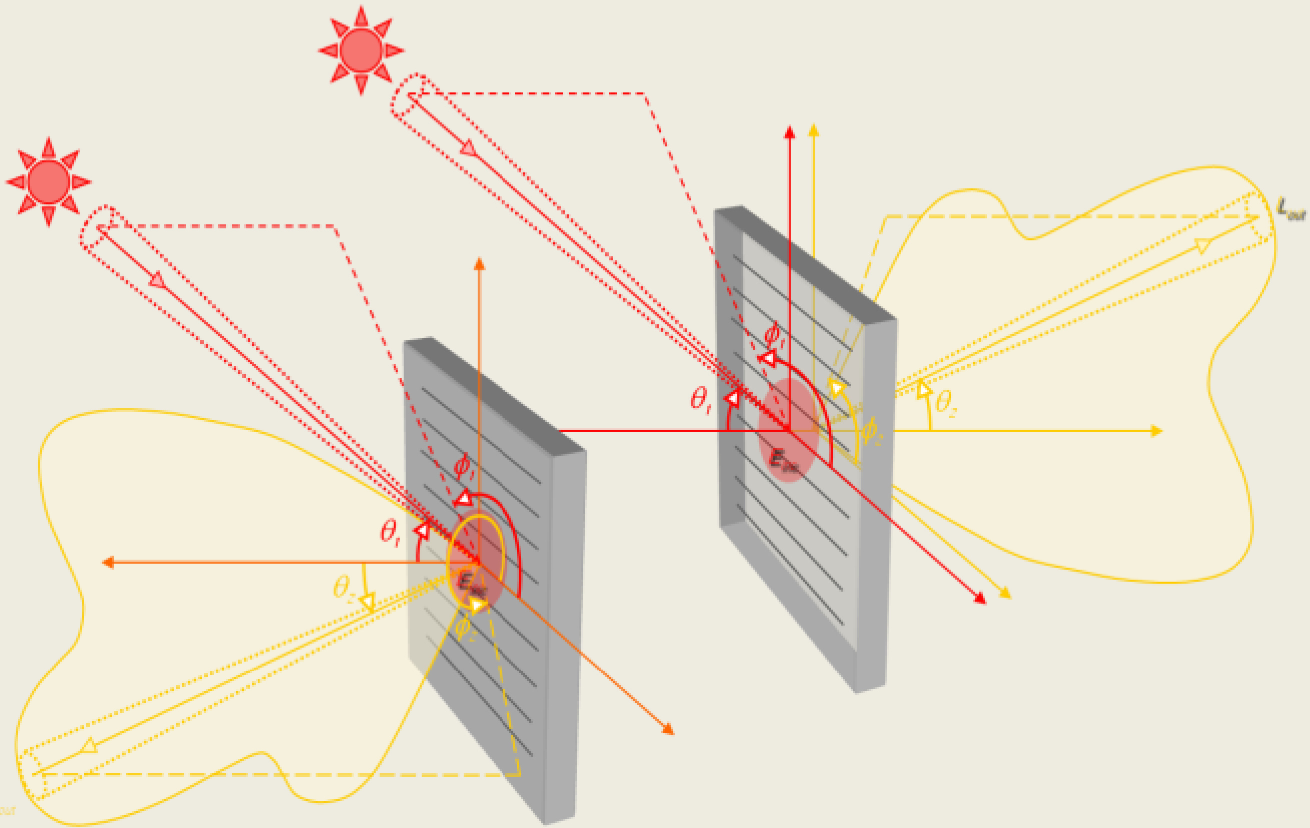
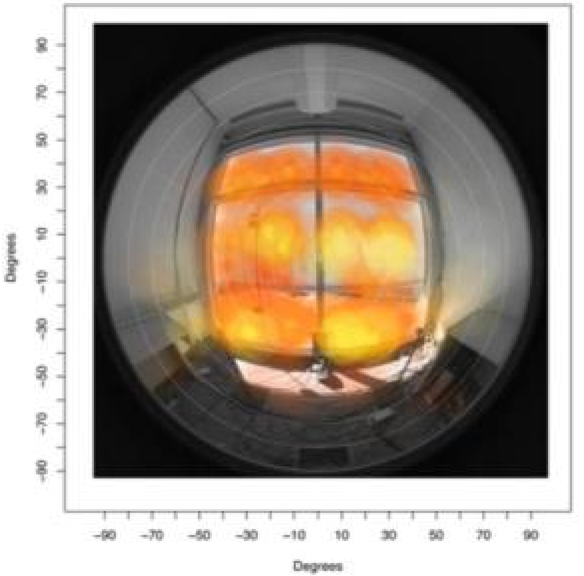
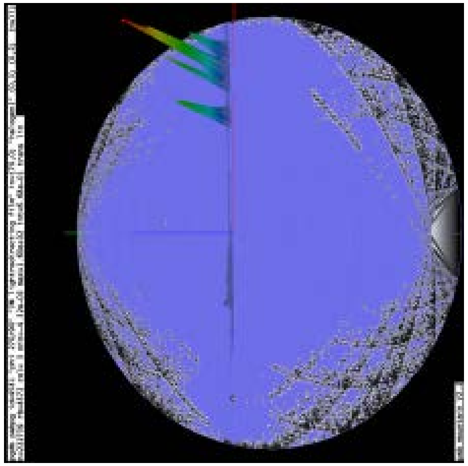


Image from Marilyne Andersen, 2004

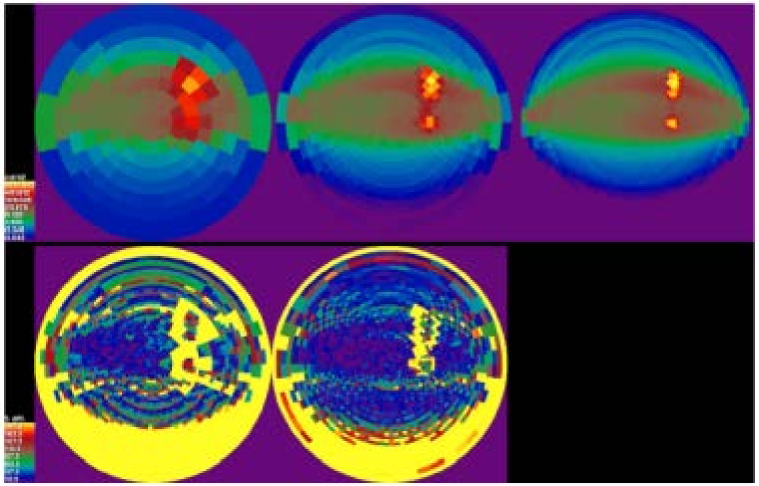
Option 1: Measure BSDF properties



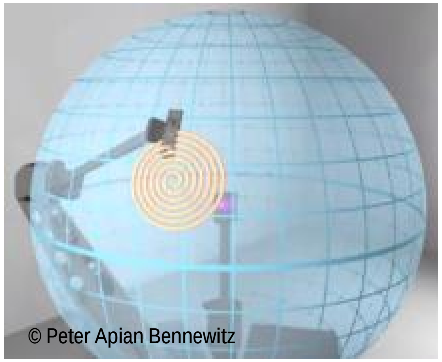
1 time-lapsed field measurements of glare



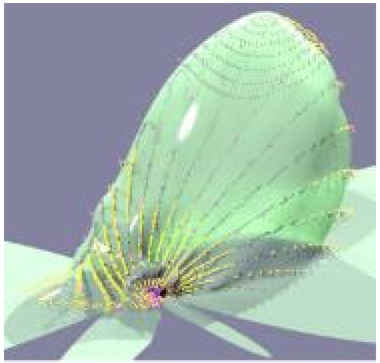
2 “peaky” bidirectional transmission data from goniophotometer



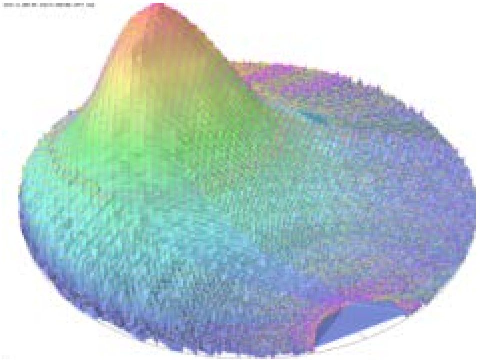
3 resolution of glare source for 1x, 2x, 4x klems basis (upper) and difference in luminance (lower); 4x captures peaks



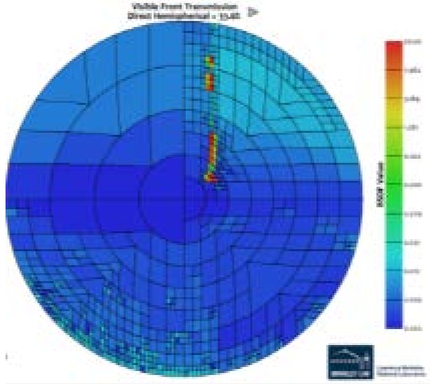
4 peak sampling with goniophotometer



5 interpolation models using gaussian lobes

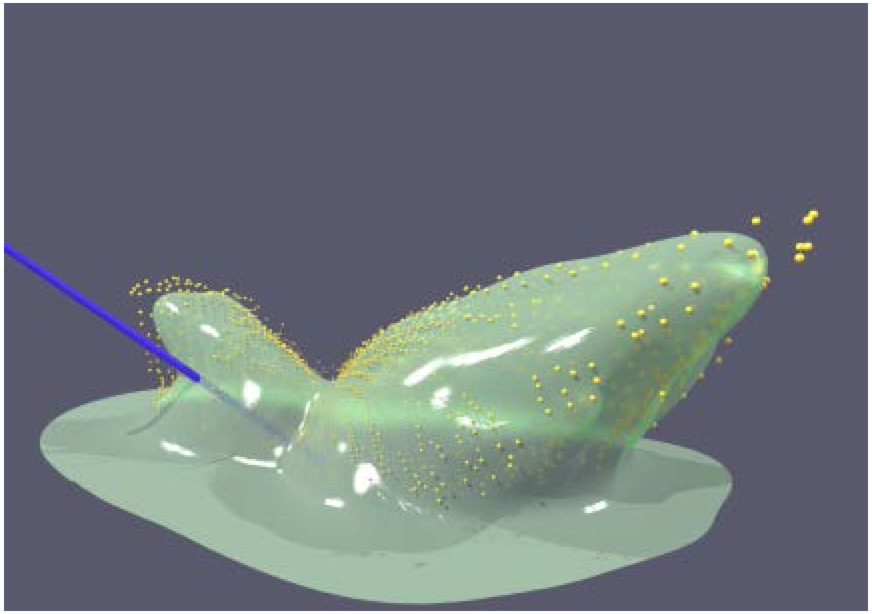


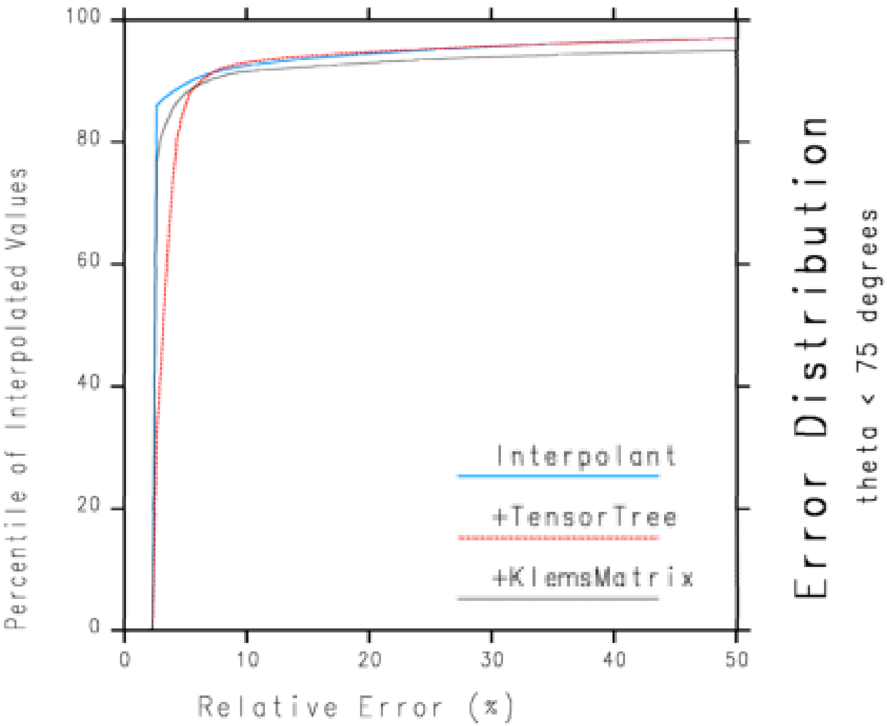
6 measured and fitted data (pink overlay)



7 variable resolution BSDF for light-redirecting system

BSDF Interpolation Model





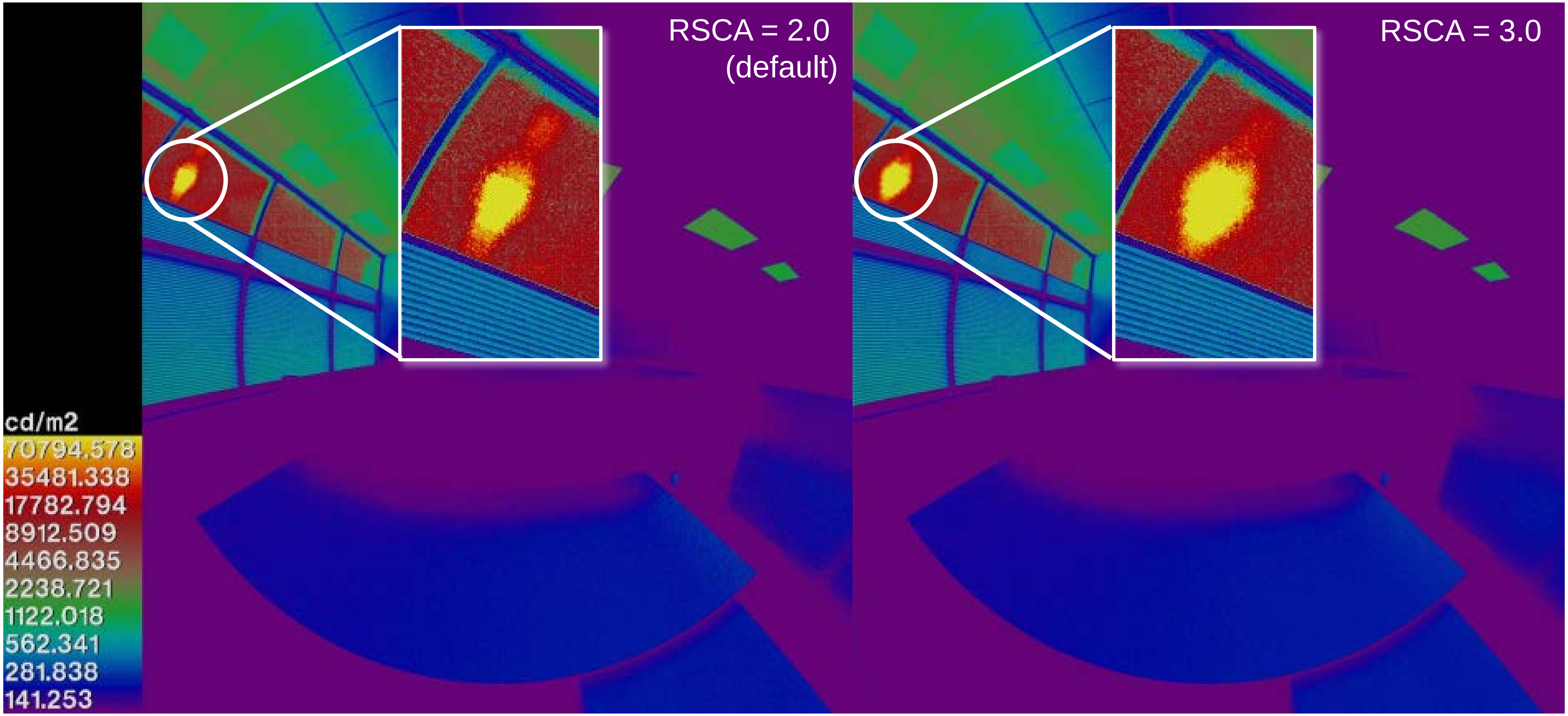
Interpolation of measured scattering values for a single incident direction, shown as blue line. Yellow dots are measurements, and green surface is interpolation using radial basis functions.

Error population of BRDF interpolant and tensor tree and Klems representations for 150M incident and exiting test direction pairs based on anisotropic Ward-Geisler-Moroder-Dür BRDF model (reference).

RMS error for ground truth vs interpolant:
0.243 (all angles)
0.114 (<75°)

BSDF Interpolation validation,
Greg Ward, Anyhere Software, Jacob Jonsson, LBNL,
December 2014 (internal deliverable).

Validation results (Geisler-Moroder)
Interpolation

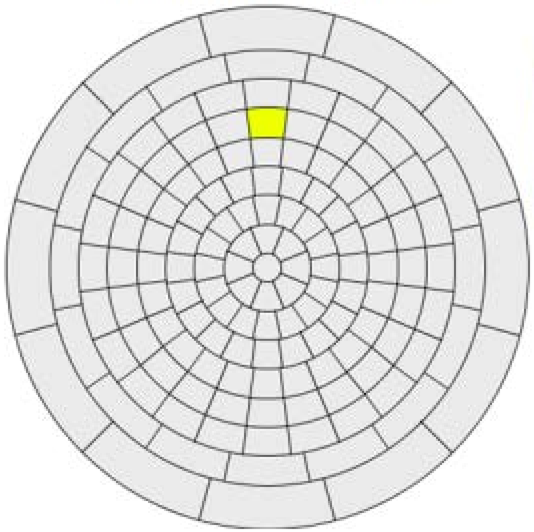


pabopto2bsdf -n 4 Rvis.txt / Tvis.txt > Rvis.sir / Tvis.sir
bsdf2ttree -p -g 7 -t 98 Rvis.sir / Tvis.sir > tt.xml

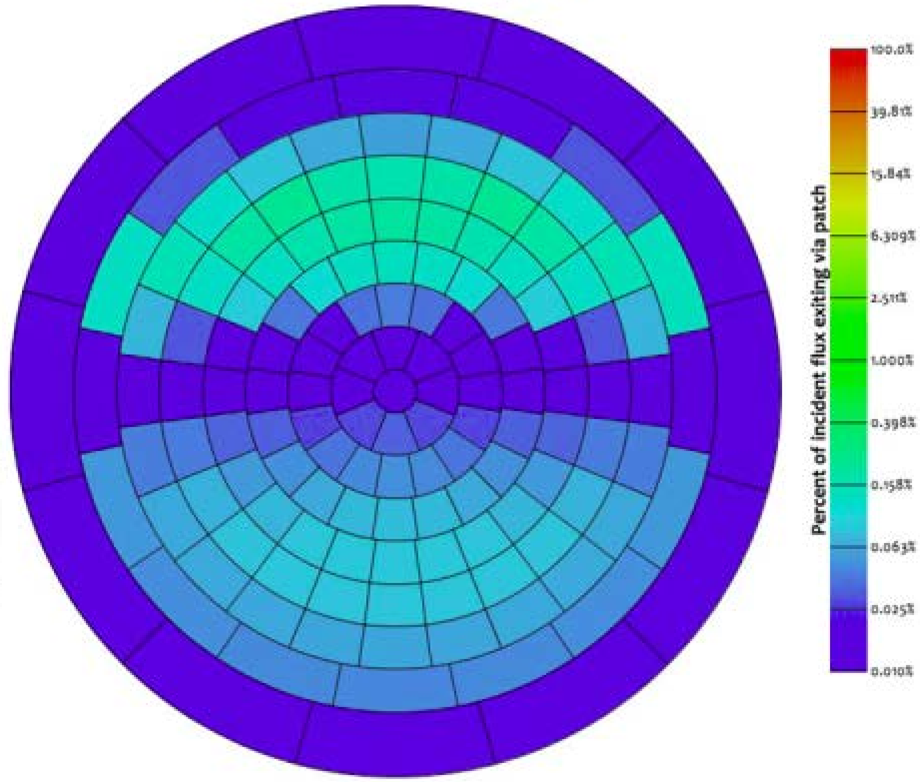
pabopto2bsdf_3.0 -n 4 Rvis.txt / Tvis.txt > Rvis.sir / Tvis.sir
bsdf2ttree -p -g 7 -t 98 Rvis.sir / Tvis.sir > tt.xml

Geisler-Moroder et al., Validation of the Five-Phase Method for Simulating Complex Fenestration Systems with Radiance against Field Measurements, Proceedings of the 15th International Conference of International Building Performance Simulation Association, San Francisco.

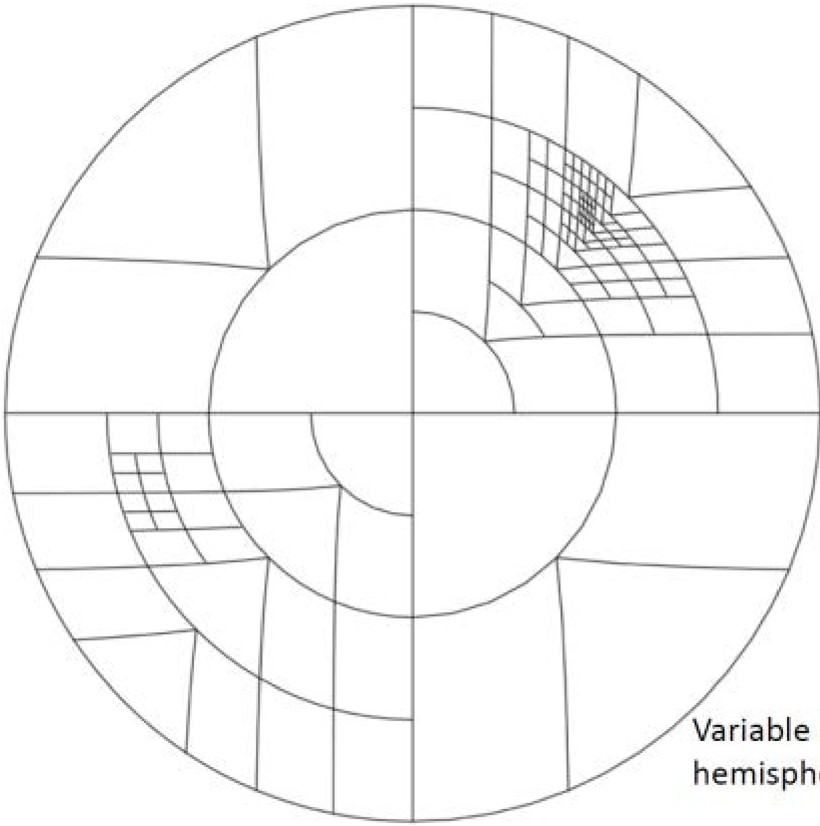
Incident Hemisphere



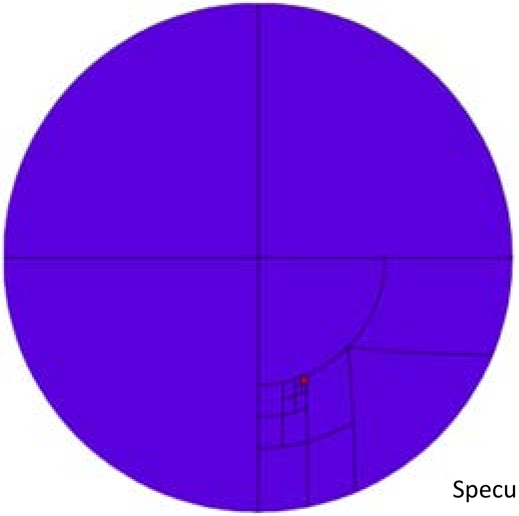
Transmission Hemisphere



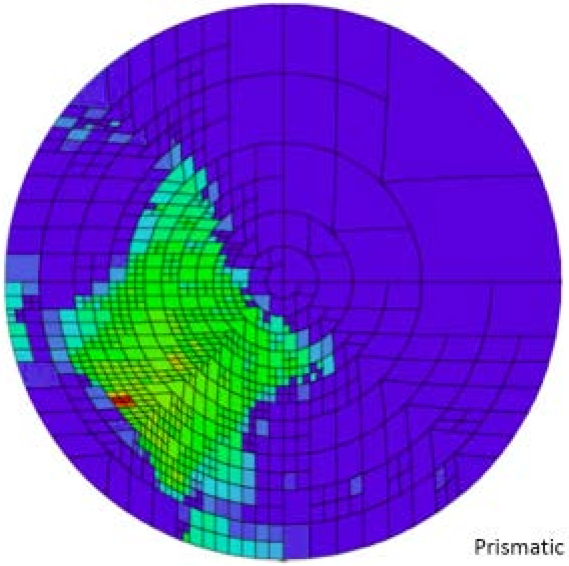
Venetian blind reflecting light upwards
Klems basis



Variable resolution
hemisphere subdivision



Specular glass



Prismatic Lens

Tensor tree BSDF data format

Option 2: genBSDF

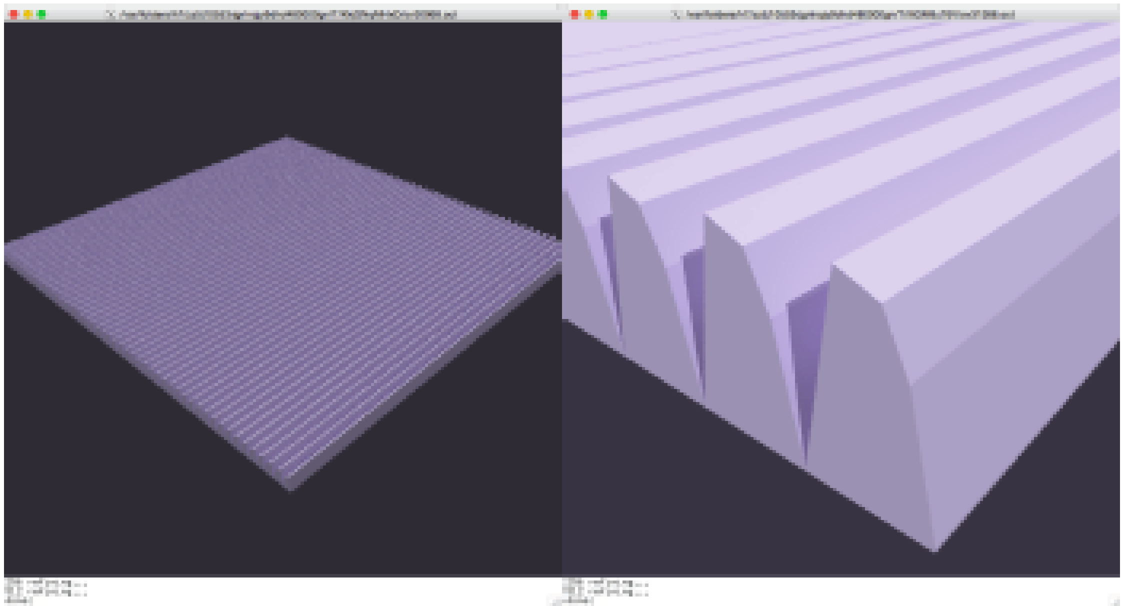


Figure 15 - screenshots of rvu window displaying the prism model (with dielectric material replaced by blue plastic so prisms are visible).

We'll use genBSDF's dim option to specify the location and size of the sampling face. The radiance program getbbox helps us by providing the bounding box for the prism model, so we can make sure we're sampling in the center.

```
getbbox prism.rad
   xmin    xmax    ymin    ymax    zmin    zmax
     0     2500   -1250    1250    -80       0
```

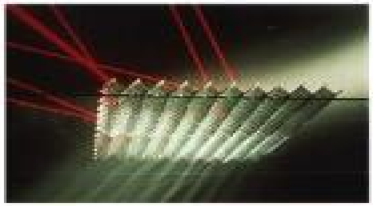
Since a single prism spans 50 mm in height (y-axis) we set the y-dimension to that distance in the center of the model. The model is consistent across the x direction, so we can sample a small width in the center, say

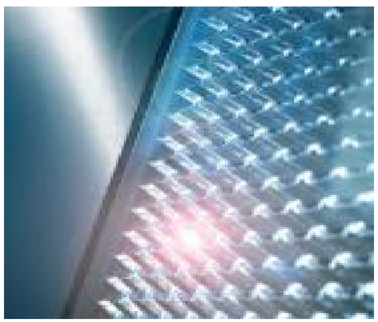
McNeil, genBSDF Tutorial, https://radiance-online.org/learning/tutorials/Tutorial-genBSDF_v1.0.1.pdf, 2015.

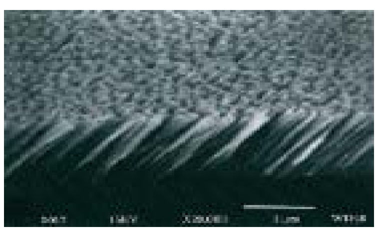
McNeil et al., A validation of a ray-tracing tool used to generate bi-directional scattering distribution functions for complex fenestration systems. Solar Energy 98 (2013): 404-414.

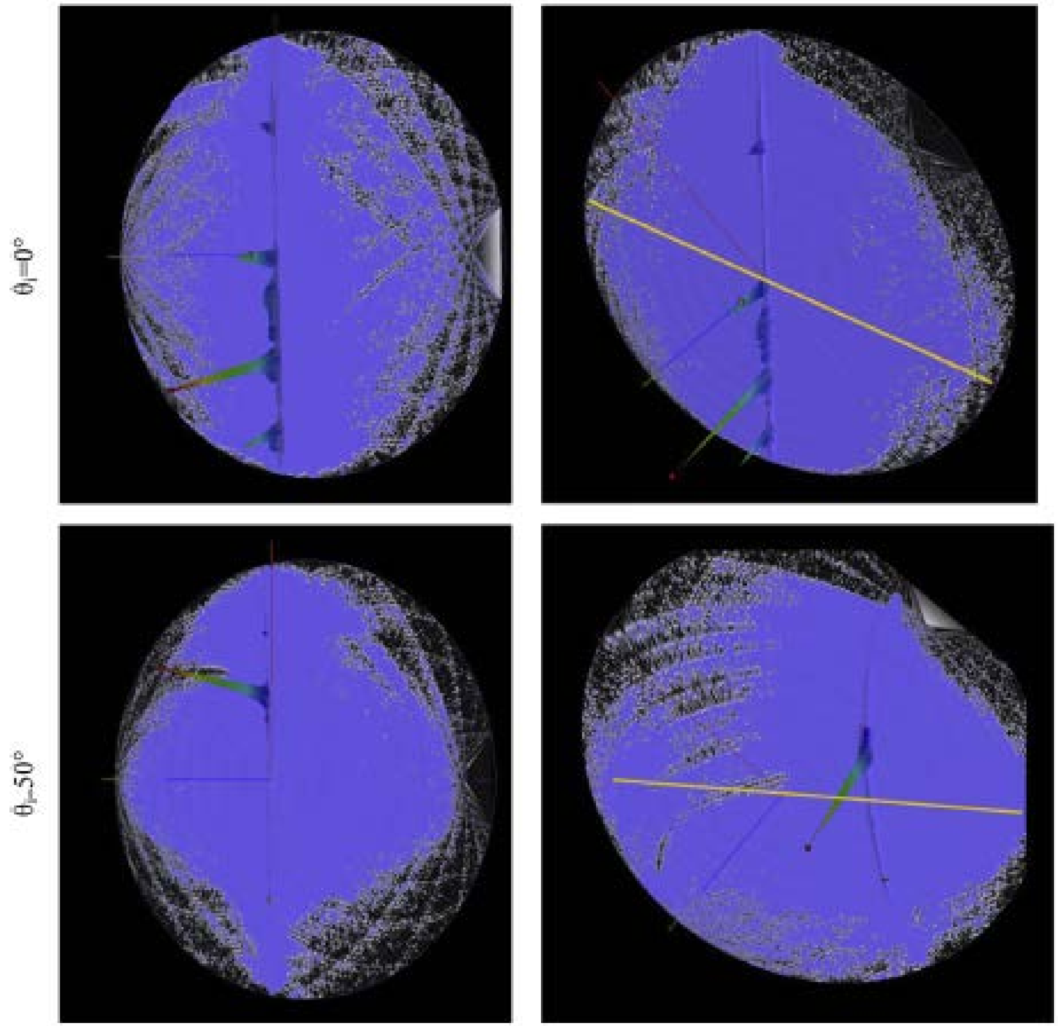
McNeil 2014, Radiance Workshop, https://radiance-online.org/community/workshops/2014-london/presentations/day1/McNeil_BSDFsandPhases.pdf

Capturing variations in manufacturing







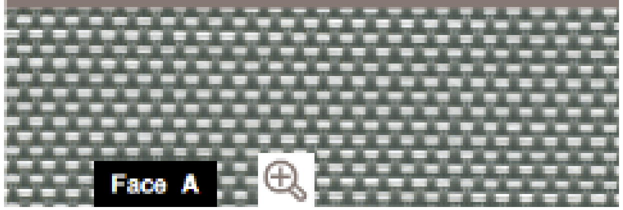


McNeil, et al. Daylight performance of a microstructured prismatic window film in deep open plan offices; Building and Environment 2017, 113: 280-297.

Option 3: BSDF library

◀ Previous sheet | Imprimer la fiche | sélectionner ce coloris | Download the data | Next sheet ▶

0102 Grey White



> Characteristics

M1 B1 BS F3

> Labels

SV 3%

9 colours

RETOUR À LA LISTE

> Width(s) :

250 cm

> Les plus produits :

+ Basket weave fabric to combine visual comfort with transparency
+ Outstanding glare control: up to 96% of light rays filtered (Tv = 4%)

> Applications :

Internal - Printable

Decorative panels / Roller blinds / Roman shades / Roof windows blinds / Skylight blinds / Tensile structures / Velums

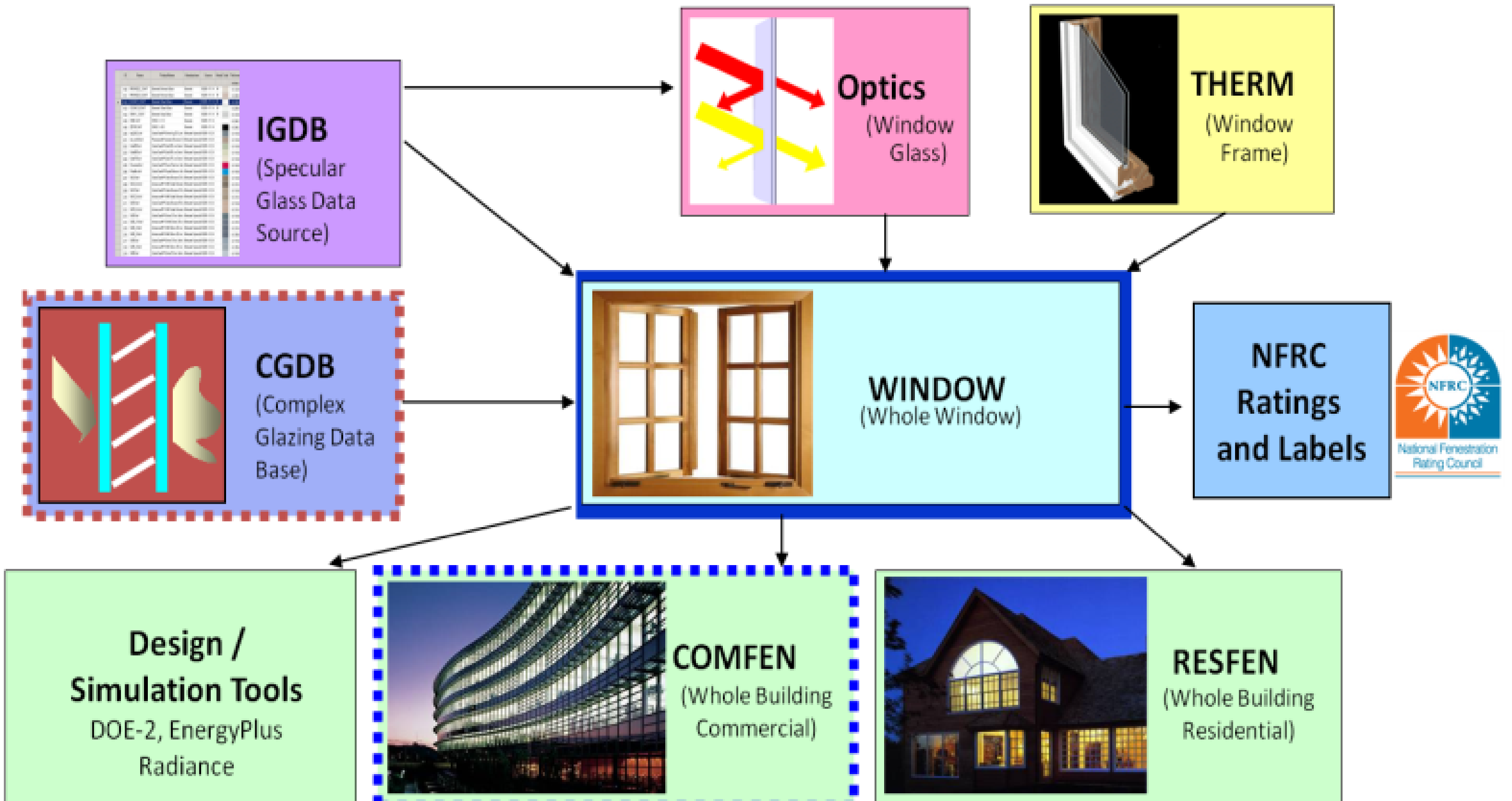
> Technical datas :

Composition	36% Fibreglass - 64% PVC
Weight per m²	375 g/m² ± 5%
Thickness	0.48 mm ± 5%
Visible transmittance	6 %
Internal solar factor (gv=0.59)	gtot : 0.47

McNeil 2014, Radiance Workshop, https://radiance-online.org/community/workshops/2014-london/presentations/day1/McNeil_BSDFsandPhases.pdf

LBNL Software Suite

(window heat gains, solar-optical, thermal)



- Design tools for advanced products
- ISO 15099 Compliant
- NFRC Ratings

http://windows.lbl.gov/software

LBNL’s current BSDF library

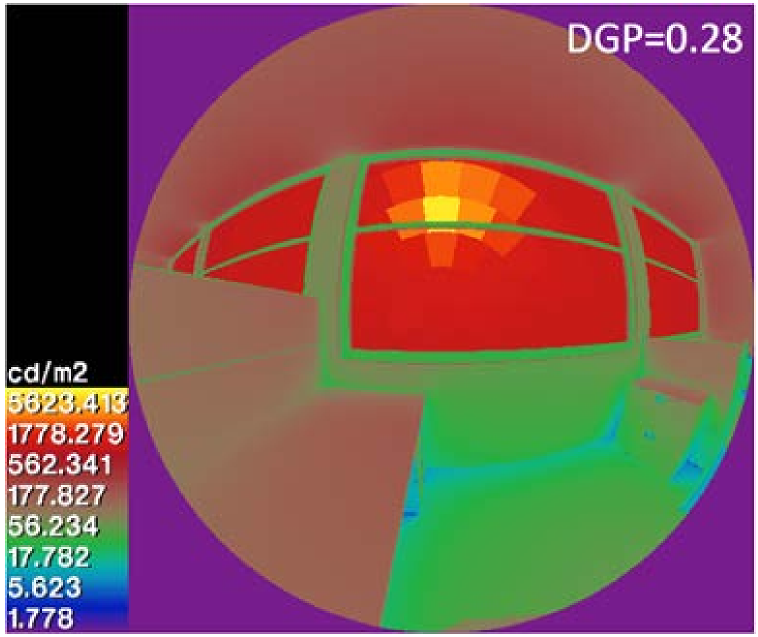
- Klems 145x145 basis only; BSDFs developed for solar heat gain, not daylighting; practical approach for shading types with 1000s of permutations; for example:
- Venetian blinds
  - BSDF based on material reflectance + geometric model; assumes Lambertian diffusion
- Roller shades
  - BSDF based on *single* measurement at normal incidence; direct-total and direct-direct transmission
  - Uses cosine function for off-normal incident angles (derived from empirical measurements of many fabrics)

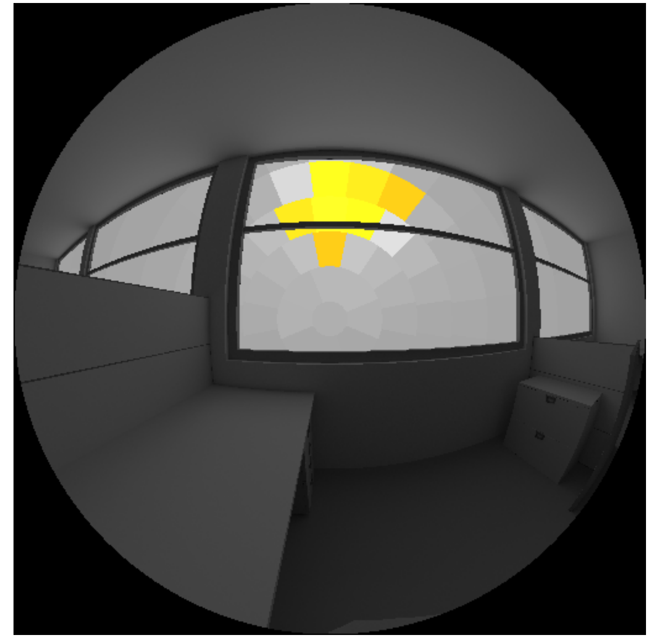
Pilot study: Roller shade fabric

Sensitivity of DGP and LE to BSDF input data

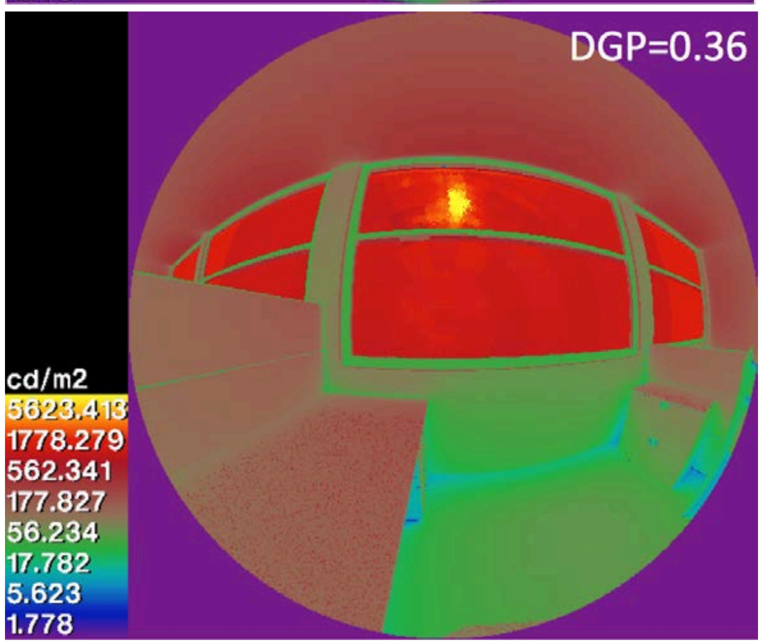
- BSDF datasets (Klems and -t3 7 or -t4 7)
  - "Gold standard": 81 incident angles with pgII scanning goniophotometer, sample B
  - Isotropic: 10 incident angles with pgII, samples A&B
  - Simple and detailed geometric model + normal-incidence direct-total & direct-direct data
  - Single incident angle measurement (spectrophotometer or pgII) + empirical model for angle-dependent properties → proposed for CGDB

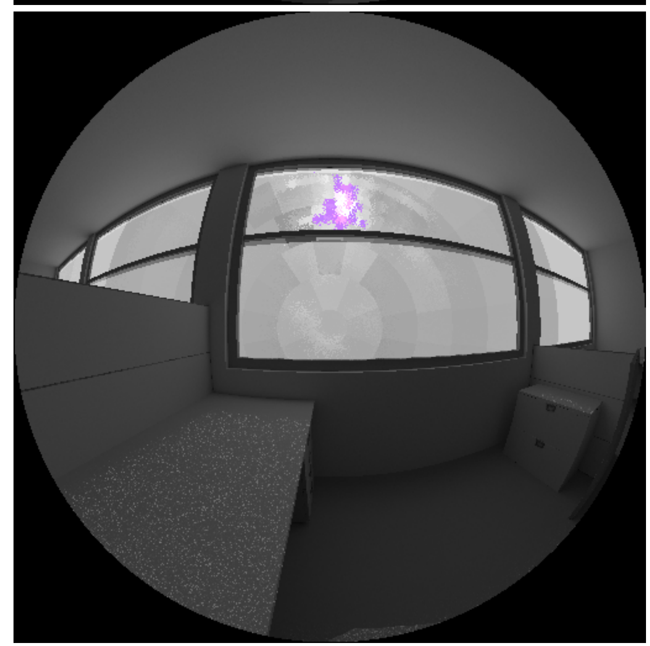
3-phase
10-15°
resolution





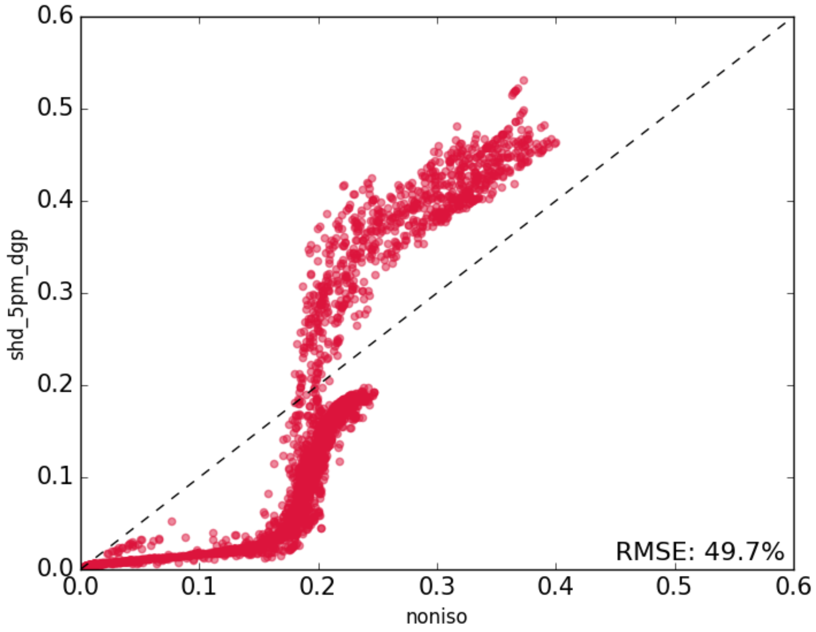
5-phase
1.5 °
resolution





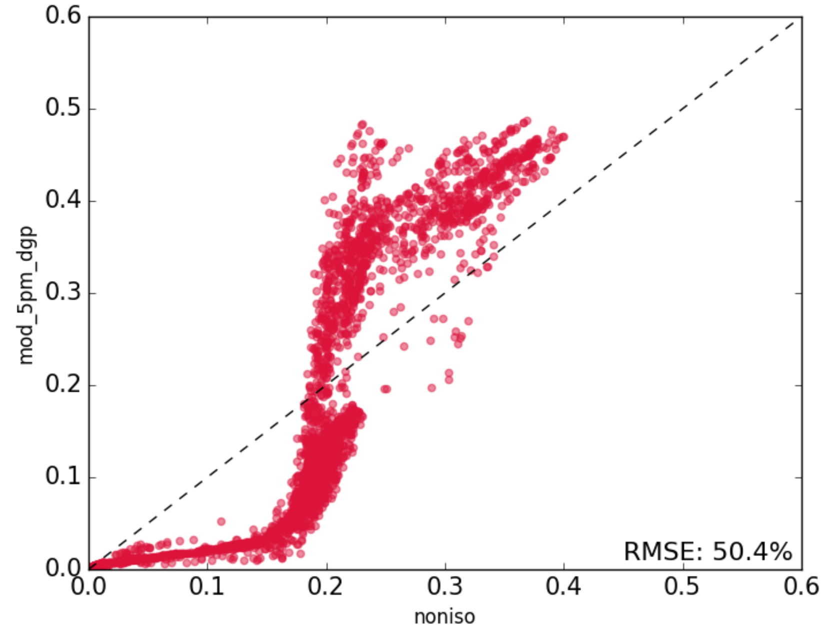
DGP hourly data
Alternate methods versus gold standard BSDF

Detailed geometric model



shade6220

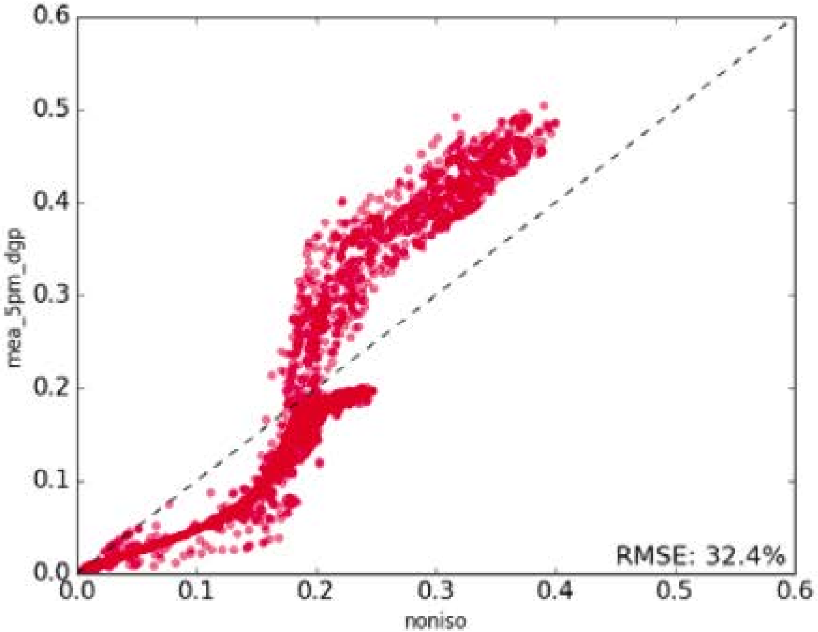
Simple geometric model



model6220

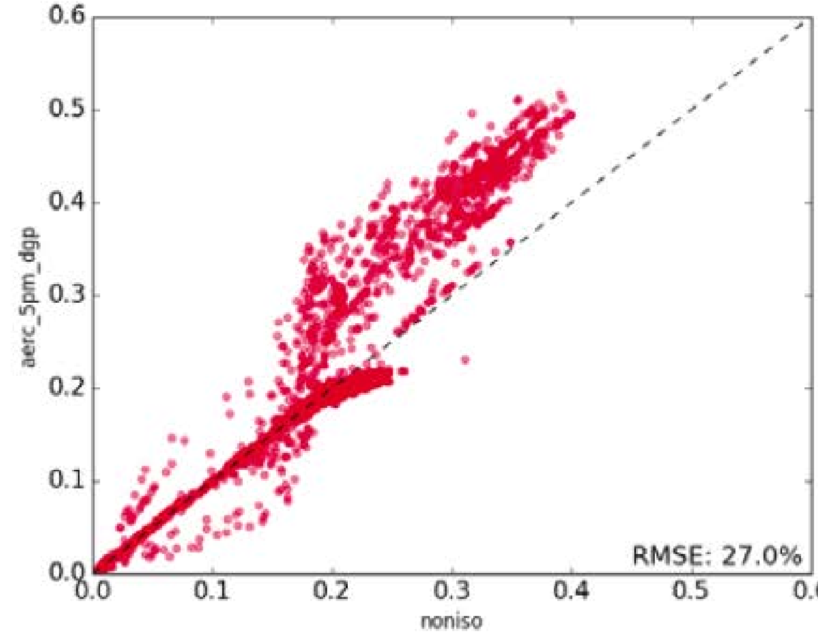
DGP computed using gold standard BSDF data (x-axis) versus alternate BSDF data (both modeled with 5-phase approach and high-resolution tensor tree format)

DGP hourly data
Alternate methods versus gold standard BSDF



meas6220 (isotropic, sample A)

Single measured angle + empirically-derived model

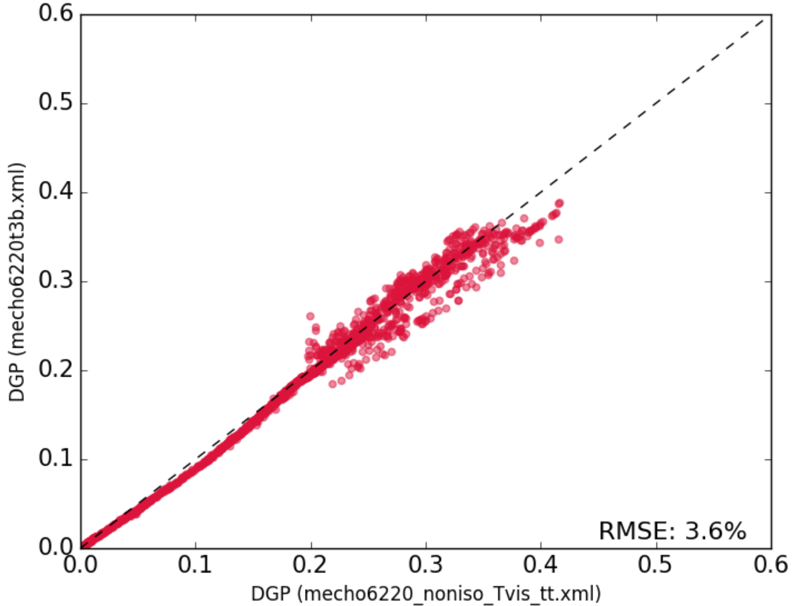


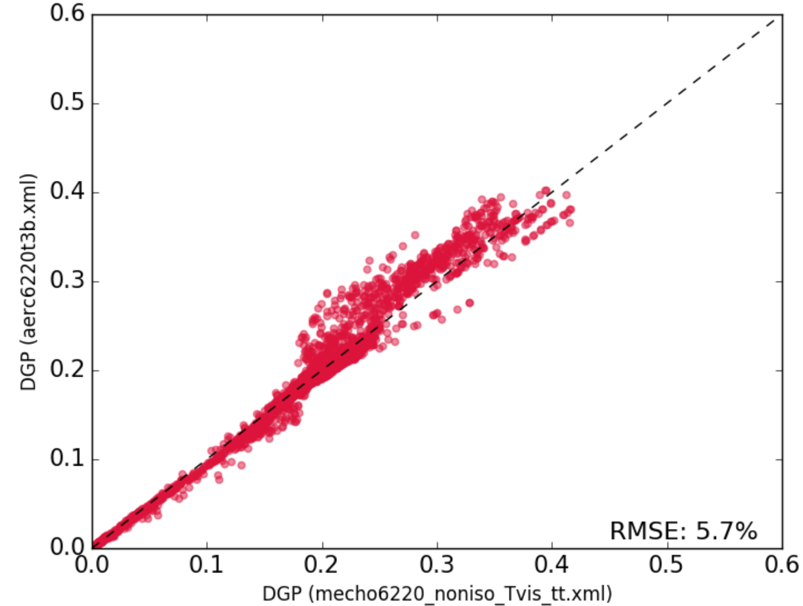
aerc6220

DGP computed using gold standard BSDF data (x-axis) versus alternate BSDF data (both modeled with 5-phase approach and high-resolution tensor tree format)

DGP hourly data
Alternate methods (based on gold standard data) versus gold standard BSDF

Single measured angle + empirically-derived model





DGP computed using gold standard BSDF data (x-axis) versus alternate BSDF data (both modeled with 5-phase approach and high-resolution tensor tree format)

Populating the BSDF Database

- BSDF data from LBNL's CGDB/ WINDOW may be insufficient for calculations that require accurate spatial distributions of solar intensity (e.g., discomfort glare, Annual Sunlight Exposure (ASE))
- → Collaborate with stakeholders to develop datasets to support variable resolution tensor tree BSDF data for semi-specular systems (e.g., roller shade fabrics, prismatic daylight-redirecting materials)

Defining BSDF measurement standards for daylighting

Bartenbach workshop in preparation for IEA Task SHC 50+ (Jan DeBoer, Fraunhofer IBP lead)

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