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

- 2° resolution will improve accuracy of luminance distribution for peaky bsdf data (ie for mirrored blinds).
- However, 2° resolution is not sufficient to resolve direct sun passing through venetian blinds.
- The cosine weighted bsdf has reduced resolution at high phi angles. For side lighting simulation the low phi angles require less resolution than the zenith.
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
\[ I_{3\text{ph}} = \text{VTDS} \]

Five-phase method
\[ I_{5\text{ph}} = \text{VTDS} - V_d T D_d S_{ds} + C_{ds} S_{sun} \]

145xN resolution
* The 3-phase method overestimated glare due to averaging direct solar into a large solid angle.
Validation results

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

20-40% more time when 5-phase method was more accurate (<10% error) than 3-phase method
5-phase
6-phase
7-phase....

WHY???
What are the consequences of poor design?
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

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.
“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

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,
Electrochromic window demonstration, Portland
Phase I manual overrides, private offices, 40 zones

Almost all overrides to a darker tint

May

December

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. 
Thermal comfort with direct solar irradiance ➔ multi-node physiological model
Other considerations
Product differentiation through rating and labeling
Definition: BRDFs and BTDFs
bi-directional reflectance and transmittance functions

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

Venetian blind reflecting light upwards
Klems basis
Tensor tree BSDF data format

Specular glass

Prismatic Lens
Option 2: genBSDF

McNeil, genBSDF Tutorial, 


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

Option 3: BSDF library

SV 3%
9 colours

> 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:

<table>
<thead>
<tr>
<th>Composition</th>
<th>36% Fibreglass - 64% PVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight per m²</td>
<td>375 g/m² ± 5%</td>
</tr>
<tr>
<td>Thickness</td>
<td>0.48 mm ± 5%</td>
</tr>
<tr>
<td>Visible transmittance</td>
<td>6 %</td>
</tr>
<tr>
<td>Internal solar factor (gsv=0.59)</td>
<td>glot : 0.47</td>
</tr>
</tbody>
</table>
LBNL Software Suite
(window heat gains, solar-optical, thermal)
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

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

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

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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• Andrew McNeil, Terrestrial Light
• Eleonora Brembilla and John Mardaljevic, Loughborough University
• Stephen Selkowitz, Christoph Gehbauer, and other LBNL colleagues
CREATING LOW-ENERGY FAÇADE SOLUTIONS FOR TODAY'S BUILDINGS

New fenestration technologies and systems that optimize the synergies between the façade, lighting, and mechanical systems can deliver high performance throughout a building's lifespan. These "integrated" solutions represent a key opportunity to significantly reduce energy and demand, helping to move us toward our goal of zero net energy buildings by 2030.