BERKELEY LAB

Lawrence Berkeley National Laboratory

U.S. DEPARTMENT OF ENERGY

UNIVERSITY OF CALIFORNIA

WINDOW ATTACHMENTS CHARACTERIZATION – CURRENT STATE OF THE ART, KNOWLEDGE GAPS AND PLANS FOR FUTURE WORK

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Scientist
Leader
Windows and Envelope Materials Group

July 16, 2012

OVERVIEW

- Introduction
- Simulation Methods
- Measurement Methods
- Performance Indices
- Software Tools
- Standards and International Collaboration

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- Introduction
- Simulation Methods
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- Conclusions and Recommendations

Context

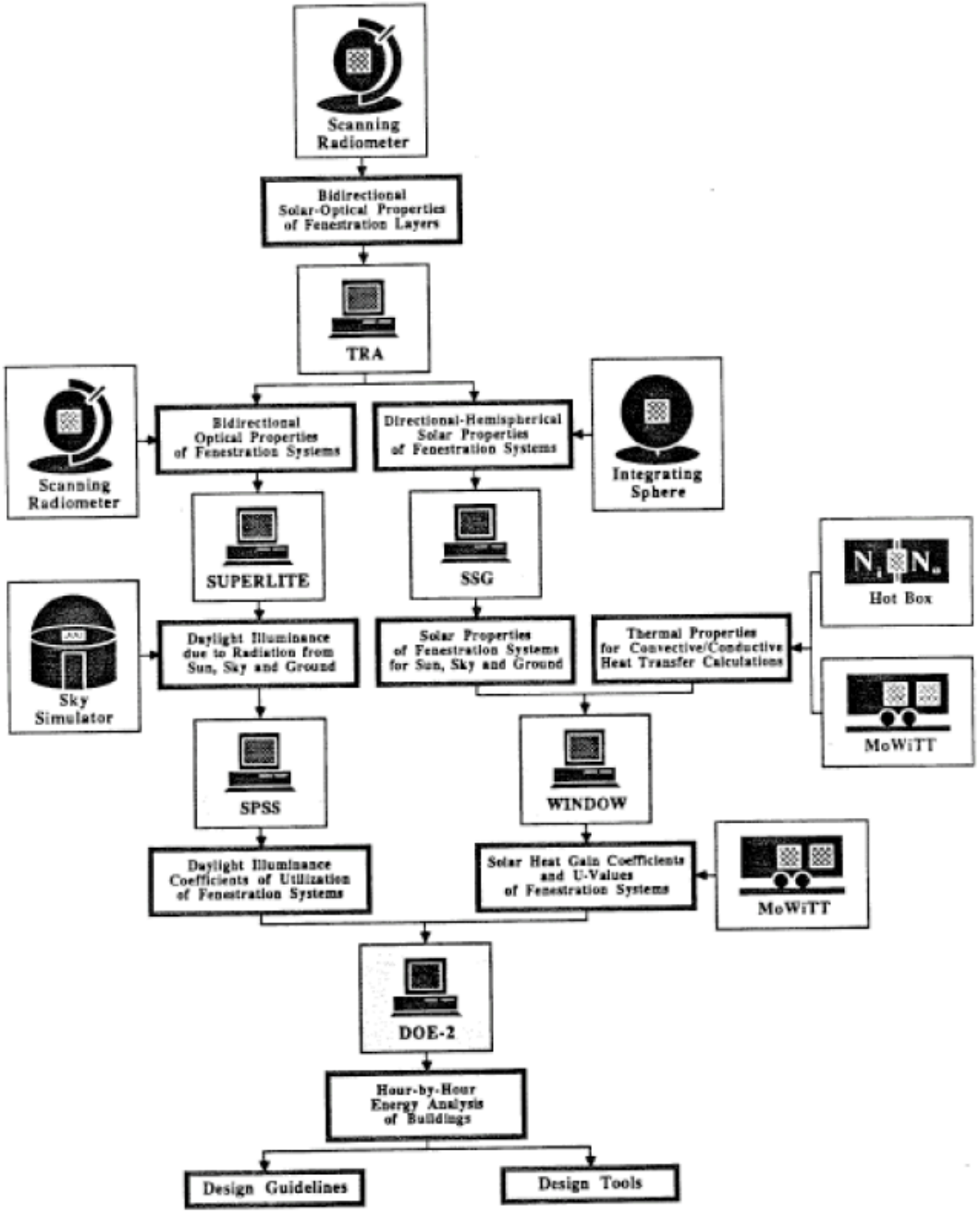
- Aggressive Energy Savings Goals
  - Convert windows from 4Q net loss to 1Q net gain
- **Scope** = Large
  - Residential, Commercial
  - New, Retrofit
  - All Climates
- **Objectives**
  - **Technical:** e.g. “R100 window at $2/sf”
  - **Market/Deployment:** ….become standard practice
- Timing/Resources
  - ASAP/Declining

Complex Problem – but Solvable

- **“Technical” issues**
- “Program development” issues
- “Program Implementation” issues
  - Separable - but intertwined

- Learn from Existing models: e.g. Window Ratings
- But, Don’t Blindly Replicate Existing Models

- Build on past efforts…
- 80/20 rule



BS-251
LBL-23581

Presented at the ASHRAE Annual Meeting, Ottawa, Ontario, Canada, June 26 - 29, 1988, and published in *ASHRAE Transactions*, Vol 94, Part 2.

An Indices Approach for Evaluating the Performance of Fenestration Systems in Nonresidential Buildings

R. Sullivan, D. Arasteh, K. Papamichael, J.J. Kim,
R. Johnson, S. Selkowitz, R. McCluney

Applied Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

November 1987

This work was supported by the Electric Power Research Institute and the New York State Energy Research and Development Administration. Project management was provided by the Lighting Research Institute. Additional support was provided by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings and Community Systems, Building Systems Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

Context, Scope and Objectives
Outline of the Workshop

Stephen Selkowitz
Windows and Daylighting Research Group
Lawrence Berkeley National Laboratory

Complex Glazing Workshop
June 1st, 2009

Day 1

Complex Glazings Workshop: Day 1 and 2 Outline

DAY 1 – Complex Fenestration Systems Properties, Perseverance Hall (Building 54, Cafeteria)

Time	Topic
8:30 – 9:00	Refreshments available (Pastries, juice, coffee, tea) *Webinar participants should log on*
9:00 – 10:00	**Introduction to Workshop** *(Steve Selkowitz)* • Introductions • Overall scope, objectives of the workshop • Overview of Work to Date on Characterizing Fenestration Performance • Types of Systems; Types of metrics • Organization of Day 1, 2, 3 – schedule, lunches, places; follow-on meeting to address NFRC rating issues • Discussion
10:00 – 11:00	**Complex Fenestration Systems (CFS) - Why, What and How** *(Marilyne Andersen)* • Types of systems, control light or sun penetration, effects generated • Describing their properties – definition and interpretation of BSDFs • Evaluating the performance of a CFS
11:00 – 11:15	**Break**
11:15 – 12:30	**Characterization Process overview** 1) **Overview of Workflow Process** *(Christian Kohler)* 2) **Methods for Determining Optical Properties of Complex Fenestration Systems** *(Mike Rubin)* 3) **WINDOW 6: Description of Modeling Capabilities** *(Christian Kohler)* 4) **Visual Comfort Impacts of Complex Fenestration Systems A Case Study of The New York Times Headquarters** *(Eleanor Lee)* 5) **EnergyPlus: Windows Modeling Overview** *(Tianzhen Hong / Christian Kohler)*
12:30 – 1:45	**LUNCH** AND NETWORKING *(webinar will sign off from Lunch until 3:30 when we return from Building 25A tour)* **Box lunches provided in the meeting room**

Day 2

DAY 2 Š Window and Building Performance metrics, Perseverance Hall (Building 54, Cafeteria)

11:15 – 12:15	**Evaluating performance objectively - Conceptual steps towards a rating strategy** *(Marilyne Andersen)* Presentation of alternative pathways: A) default: normal incidence Tv, SHG, U (NFRC), B) inclusion of angular dependency without changing the format C) detailed analysis applied to a standardized set of buildings D) project-specific performance evaluation Discussion of conflicting goals depending on space use and importance of parameters choice.
12:15-12:30	**Sample Results for Prototypical Systems** *(Christian Kohler / Robin Mitchell)*
12:30 – 1:30	**LUNCH** AND NETWORKING *(webinar will sign off during Lunch)* **Box lunches provided in the meeting room**
1:30 – 2:30	**Charrette/Discussion: Which metrics should we use and for what?** Divide into discussion groups: Define and prioritize "metrics", discuss business requirements for producing them, summarize for reporting
2:30 – 3:30	**Presentation and Discussion of each Group Report** *(Steve Selkowitz, moderator)* Each group will present a summary of their discussion around key topics: 1) Can we define the needed metrics? 2) Can we prioritize needs? 3) Is there agreement how the metrics would be generated?
3:30- 3:45	**Coffee Break**
3:45 – 5:00	**Summary/Next Steps** *(Steve Selkowitz, Discussion leader)* Meeting short term and longer term industry needs How might this be implemented- e,g, business model? How does this relate to other programs, needs?

Two Challenges

We want methods and solutions that are:

Accurate; Fast; Low Cost

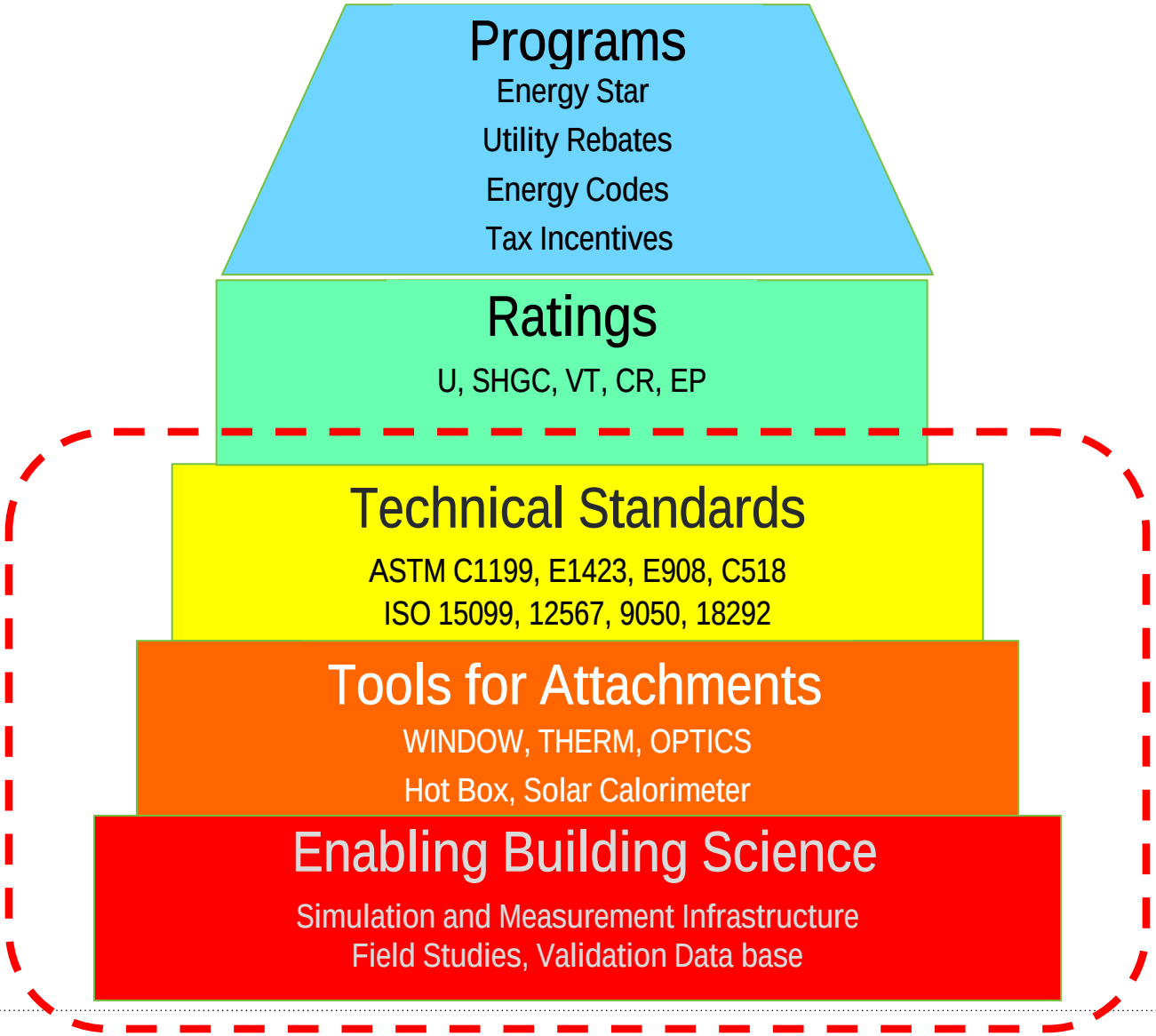
(pick 2)

In theory, there is no difference between theory and practice.

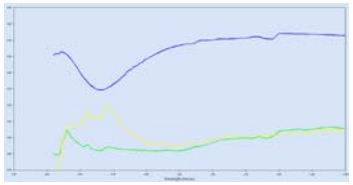
But in practice, there is.

– Yogi Berra

INTRODUCTION

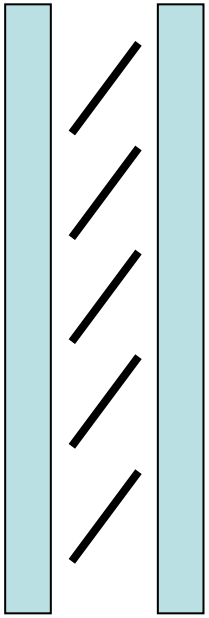


FROM COMPONENTS TO SYSTEMS



Material

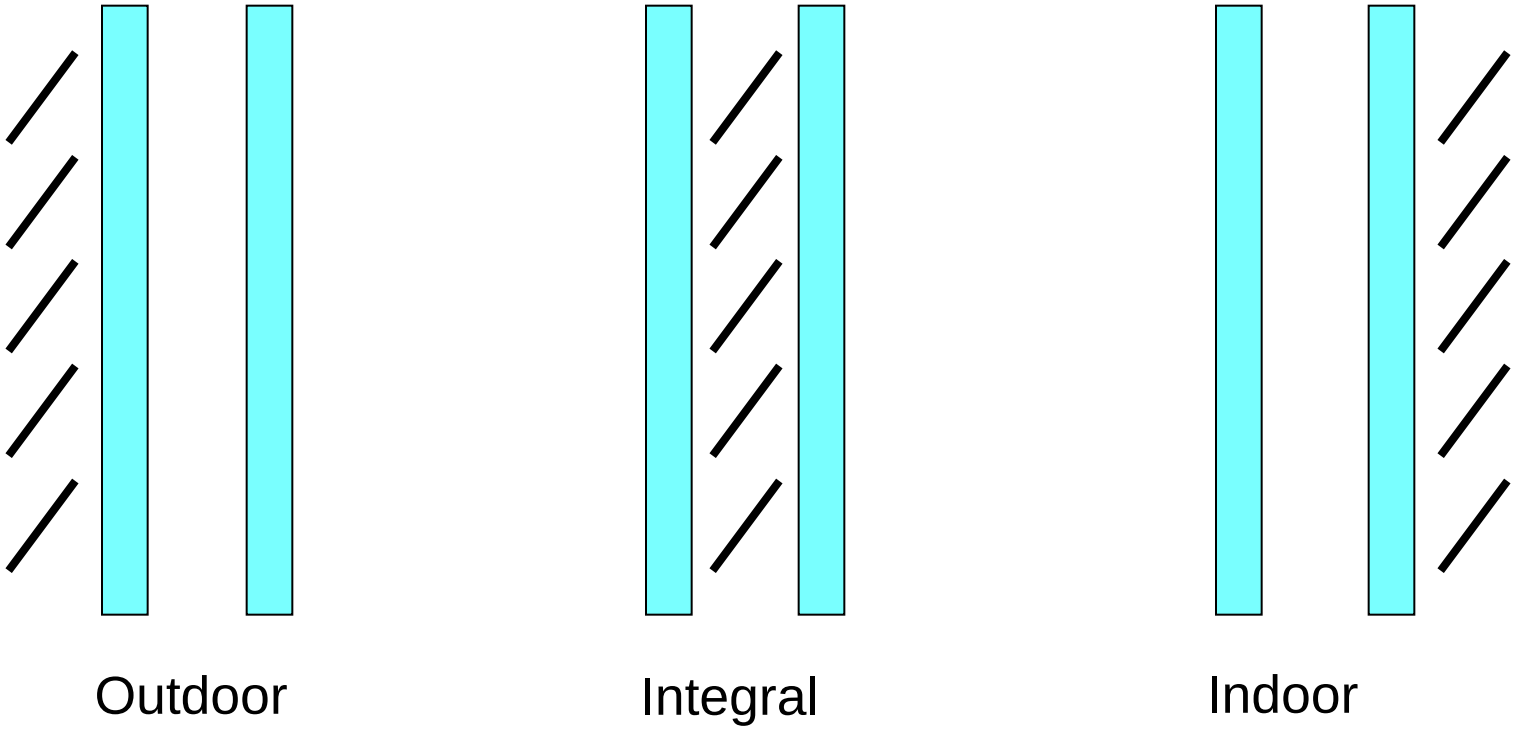
Layer



System

Building

SHADING DEVICE LOCATION



SIMULATION AND MEASUREMENT INFRASTRUCTURE

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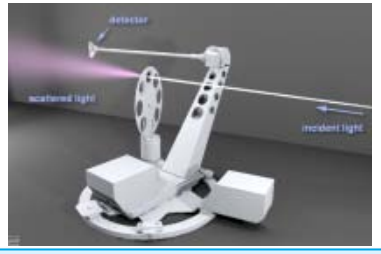

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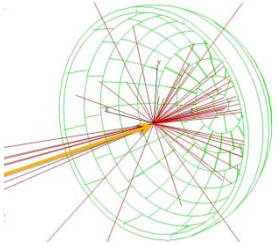

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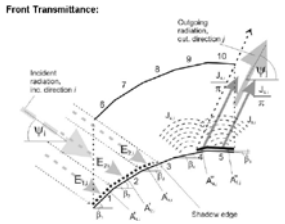


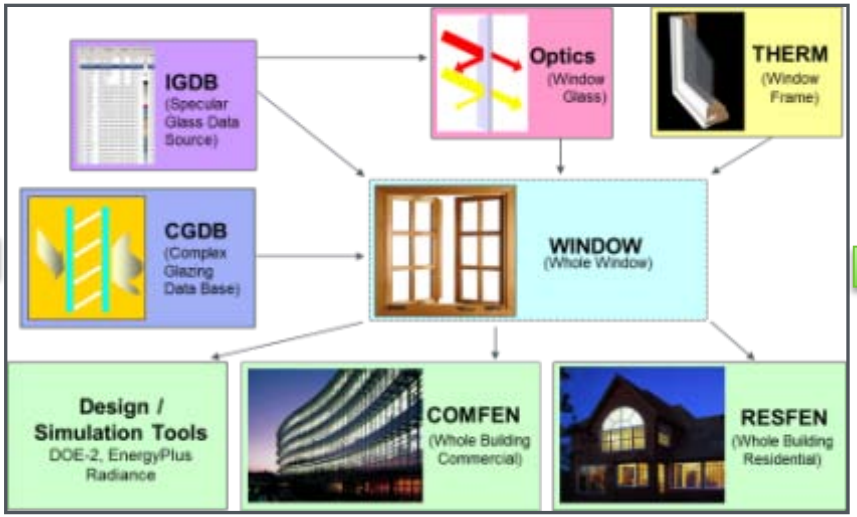
Building Science Infrastructure

Program A

Program B

Program C

Ratings



Tools, Standards, Product Data

Ratings

Program D

Program E

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Characterization – Status

Product Type	Test Procedure						Simulation Method					
	IN		OUT		BG		IN		OUT		BG	
	T	O	T	O	T	O	T	O	T	O	T	O
Cellular Shade												
Window Quilts												
Slat Shade (vertical/horizontal)												
Sheer Shade												
Louvered Shutter												
Roller Shutter												
Pleated Shade												
Solar Screen												
Roller Shade												
Roman Shade												
Drape												
Flat panel												
Surface applied Films												
Awnings												

Existing
Under development
Not developed

NOTES: **IN:** Indoor mounted; **OUT:** Outdoor mounted; **BG:** Between glazing
T: Thermal model; **O:** Optical model

Gaps in Knowledge Base: Simulation Methods Development – Phase I

Conduction & Convection heat transfer

- **Improve** models for which there are partial or non-validated **algorithms**
- Investigate effects of **porosity** of attachments
- **Validate** improved models through **research level testing**
- Investigate effects of **air flow** on and around interior and exterior attachments

Radiation heat transfer

- Improve handling of **IR transparency** of attachments
- **Redefine U-factor** for windows with interior and exterior attachments

Solar-Optical Calculations

- Develop universal calculation of SHGC and VT for **variable BSDF** attachments
- Improve **optical properties** calculation for partial or non-validated algorithms

Indices of Performance

- Develop layered reporting approach (analogy of **onion layers** – U, SHGC, VT → thermal resistance → angular optical properties → System BIM information)
- Develop **cloud-based system** for reporting, from top to innermost "onion" layers

Gaps in Knowledge Base: Simulation Methods Development – Phase II

Convection heat transfer

- Conduct detailed **three dimensional CFD simulations** with available models
- Refine convection models for the **porosity** effects in attachments
- **Validate** new models through **research level testing**
- Develop models for **air flow** on or around interior and exterior attachments

Radiation heat transfer

- Investigate effects of **frame geometry** on radiation heat transfer
- Add **mean radiant temperature** effects from environment and room surfaces
- **Develop** new radiation **models**

Solar-Optical Calculations

- Develop **ray-tracing based simulation engine** to generate BSDF's for attachments for which there are no existing models
- Develop optical models for **complex shaped** attachments

Indices of Performance

- **Refine layered approach** to reporting indices of performance
- Create robust **cloud-based system for reporting indices** of performance
- Develop **CMA method f**or attachment products

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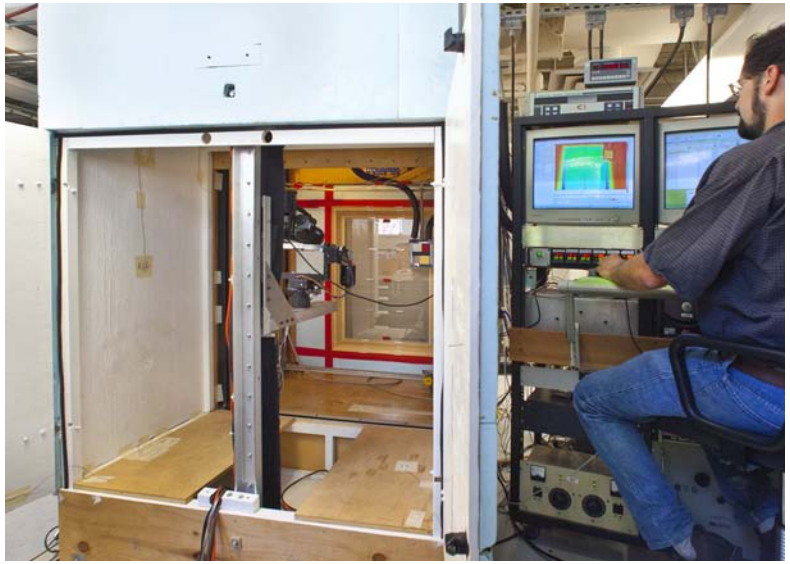
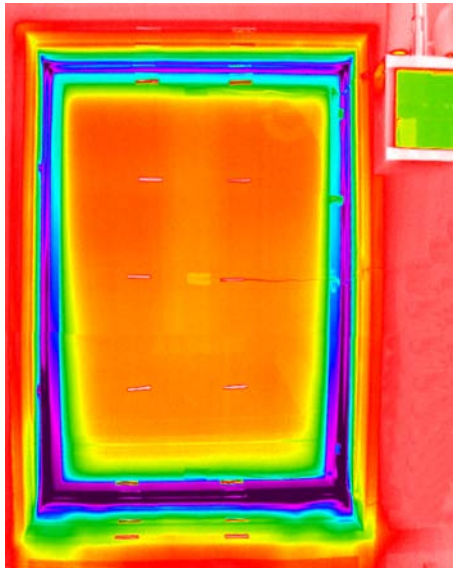
MEASUREMENT METHODS

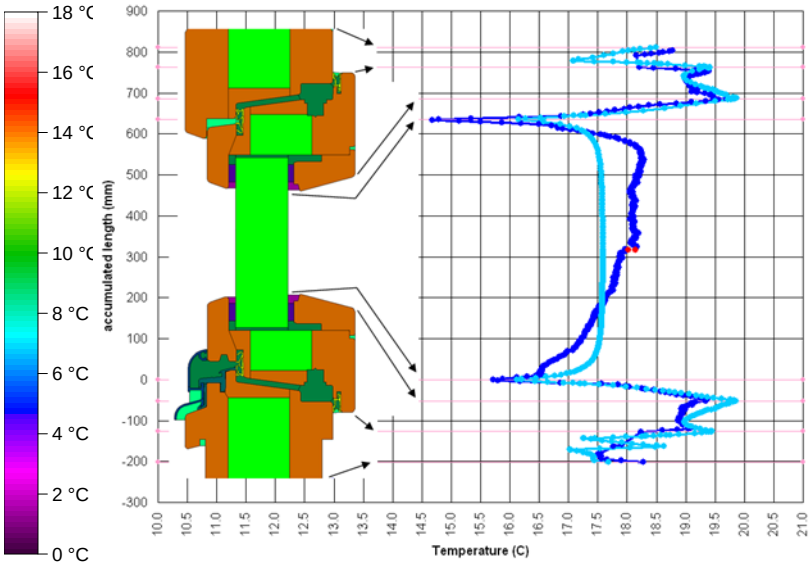
- Measurement of BTDF and BRDF of scattering products
- Measurement of BTDF and BRDF of scattering materials (“thin” material coupon size)
- Measurements of window attachments attached to prime windows
  - Thermal measurements (hot box)
  - Solar-calorimetric measurements (solar calorimeter)
- Measurements of projecting attachments:
  - Thermal measurements (??)
  - Solar-calorimetric measurements of projecting attachments (solar calorimeter)

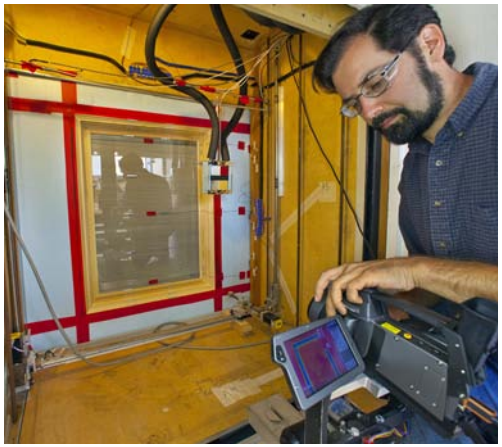
Quantitative Infrared Thermography



- Provides empirical data for thermal model validation and development
- Generates quantitative, high resolution surface temperature measurements
- Identifies local thermal bridging (detailed visualization of non-uniform thermal performance)
- Operates at a variety of steady state environmental conditions

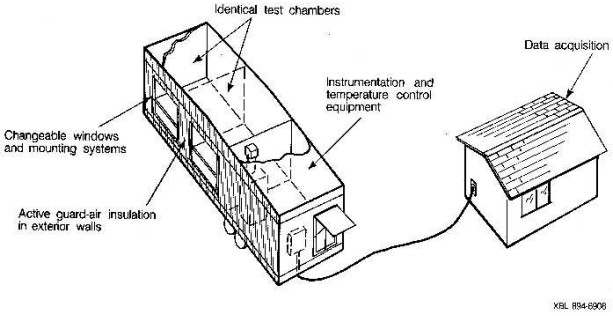


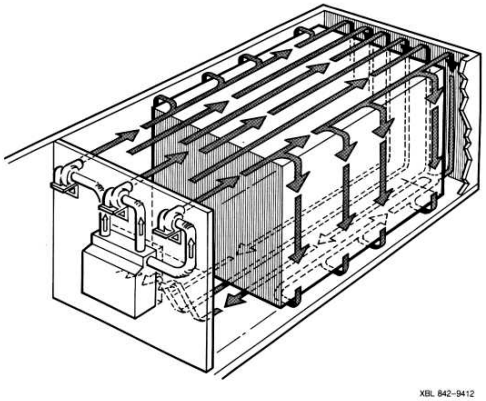


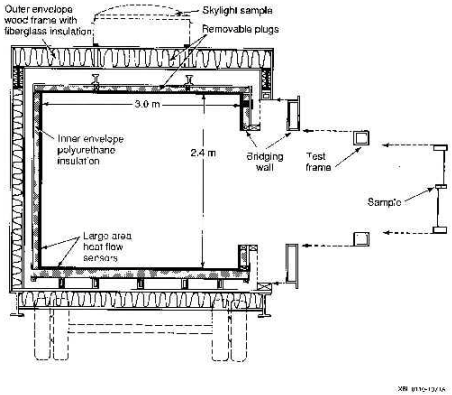


Mobile Window Thermal Test Facility (MoWiTT)

- Provides direct side-by-side comparison of two window/skylight systems using real weather conditions (can be moved to different climates)
- Determines effective U-factors and solar heat gain coefficients using a calorimetric method
- Provides verification of energy-savings calculations under real weather conditions (including solar radiation)
- Measures the energy performance of windows for which simulation models are unavailable or unreliable
- Validates and aids development of new simulation models

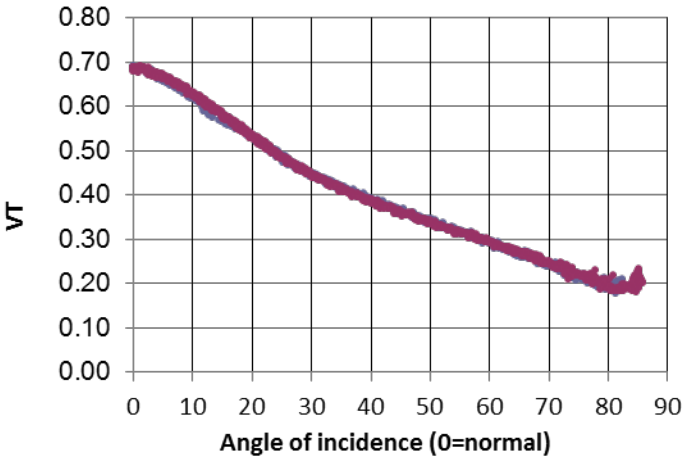


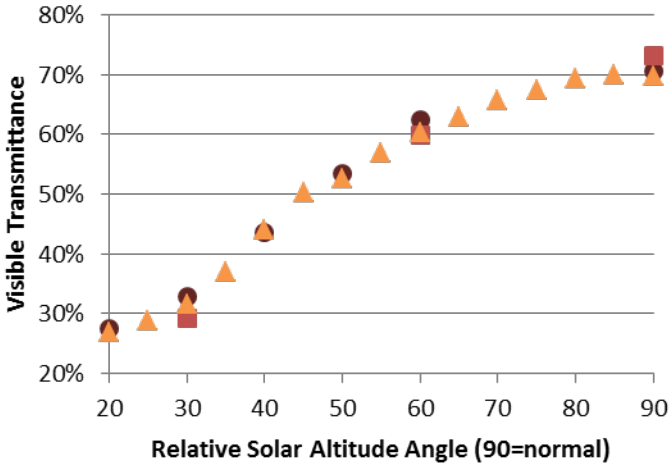


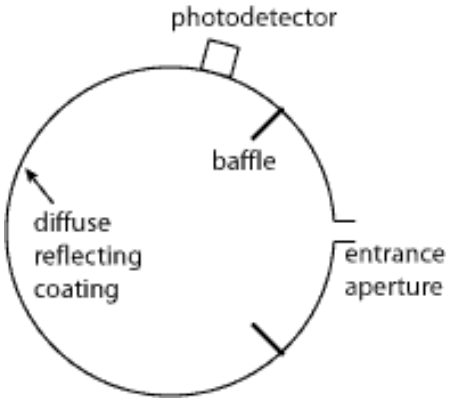


Large Diameter Integrating Sphere

- Measures total visible transmittance of complex light redirecting/diffusing samples with large scale non-uniformity
- 6.5 foot diameter sphere with up to 34 inch measurement aperture (11-15 inch typical)
- Motorized position relative to the sun allows rapid measurement of many incidence angles
- Validates optical models for light redirecting samples under variable angle of incidence

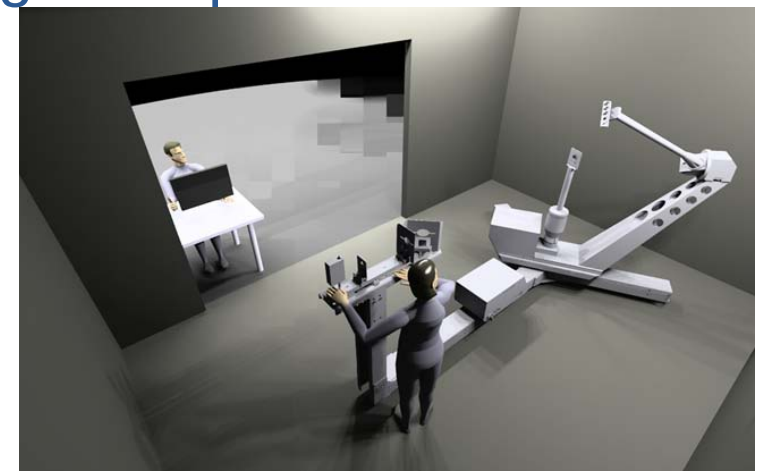






MEASUREMENT DEVICES FOR OPTICAL MEASUREMENTS

- Spectrophotometer
  - Venetian blind slats
  - Fritted glass
  - Diffusing laminates
- Angle Tubes
  - Woven shades / insect screens
- Large Integrating Sphere – Tvis, large sample
- Gonioradiometer
  - All Other Complex systems
  - BSDF



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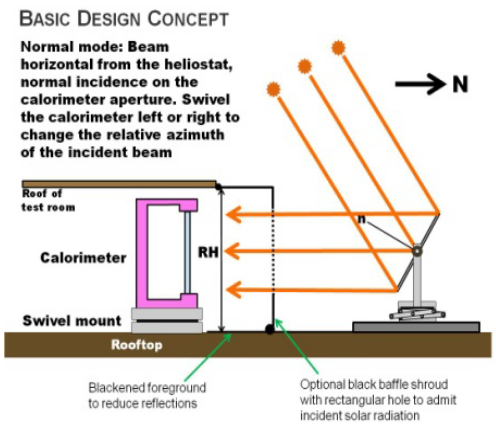
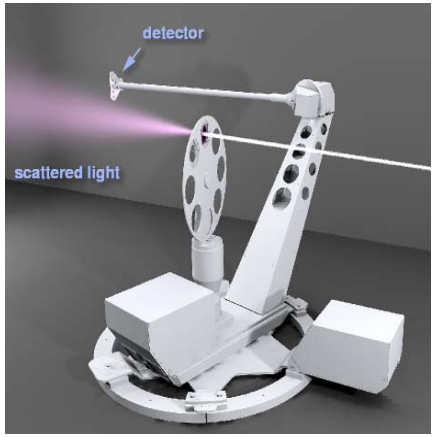
Gaps in Knowledge Base: Measurements – Phase I

- ***Thermal Testing:***
  - Identify gaps in **hot box testing** for attachment products
  - Modify existing measurement procedures for hot box testing to validate limited number of attachment products
  - Initiate revision of **ASTM C1199 and ISO 12567** to add hot box testing of attachment products
- ***Solar-Optical Performance Testing:***
  - Identify gaps in **solar calorimetric and optical measurements** for attachment products
  - Modify existing measurement procedures for solar calorimeter apparatuses to validate limited number of attachment products
  - Perform research to improve optical testing for limited number of attachment products
  - Initiate development of new **ASTM and ISO testing standards** for solar-optical measurements of attachment products

Hot Box Testing



Solar Calorimeter Testing



Optical Testing - Goniometer

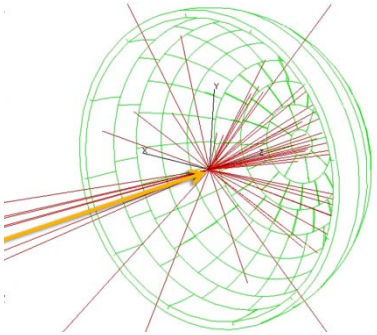
Optical Testing – Integrating Sphere

Gaps in Knowledge Base: Measurements – Phase II

- ***Thermal Testing:***
  - Identify additional deficiencies in **hot box testing** for attachment products
  - Perform research to determine new and improved hot box testing procedures
  - Modify **ASTM C1199 and ISO 12567** to add hot box testing of attachment products
- ***Solar-Optical Performance Testing:***
  - Identify gaps in **solar calorimetric and optical measurements** for attachment products
  - Perform research to determine new and improved solar calorimeter testing procedures
  - Perform research to determine new and improved optical testing for attachment products
  - Develop new **ASTM and ISO testing standards** for solar-optical measurements of attachment products
- ***Integrated Testing and Energy Performance Under Realistic Conditions:***
  - Develop standardized testing of integrated thermal and solar-optical performance under realistic conditions
  - Develop criteria for validating energy performance of typical building spaces with attachments incorporated into the fenestration system

MoWiTT Facility

Window Test Bed Facility



Virtual Goniometer

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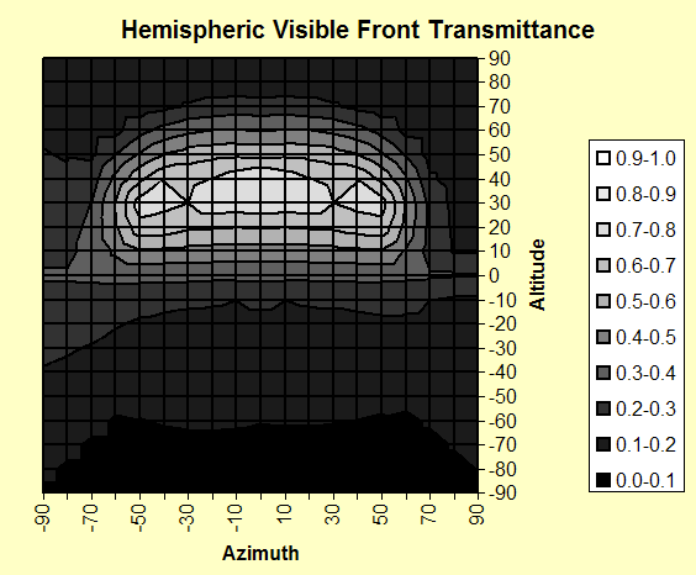
STANDARD METHODS OF EXPRESSING PRODUCT PERFORMANCE

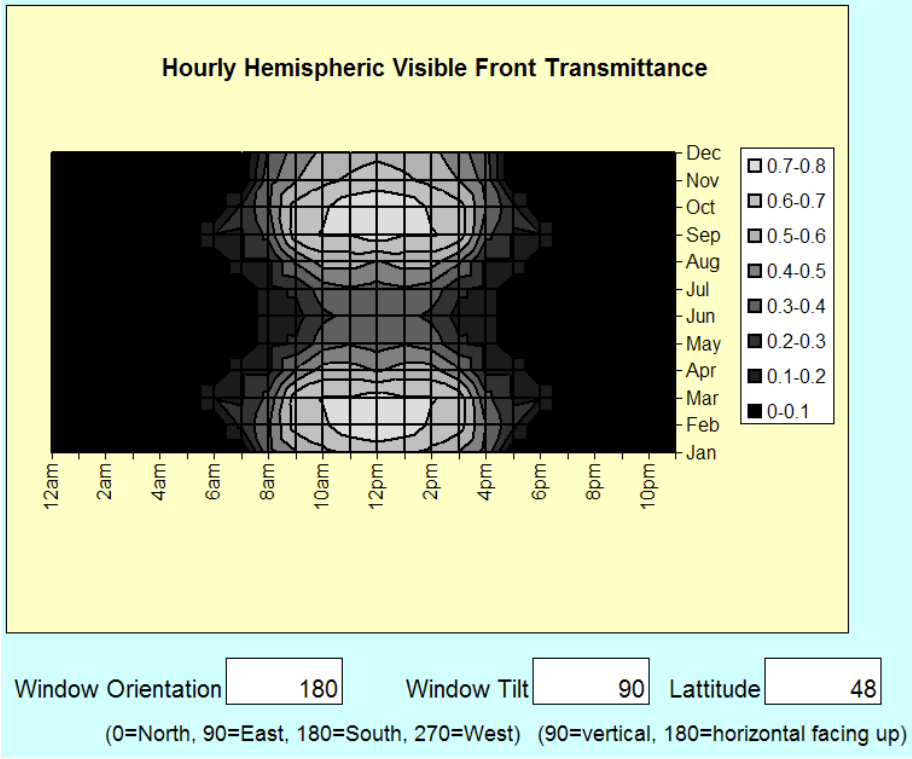
- Simple Indices of performance (*U, SHGC, VT)*
  - WINDOW, THERM, OPTICS
- Detailed performance information (angular SHGC, angular VT, BSDF, breakdown of convection and radiation heat transfer)
  - WINDOW, THERM, OPTICS
- Energy Performance (*EP*)
  - RESFEN, COMFEN
- Annual energy use: Model reference house/office, that could form basis for seasonal or annual metrics

Detailed Indices of Performance

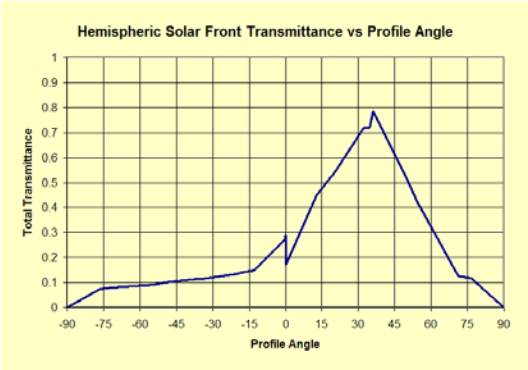
Tvis vs Altitude/Azimuth



Tvis vs Hour/Month of year

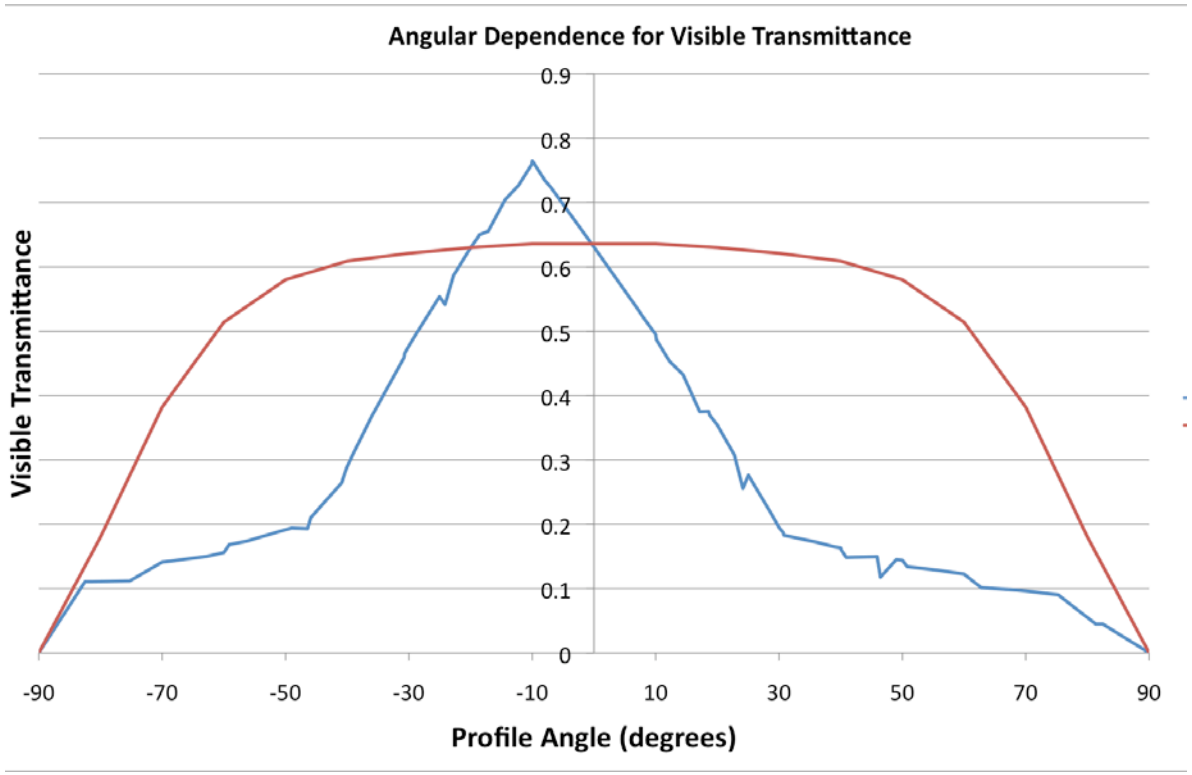


Tvis vs Profile Angle



Why Do We Need More Detailed Performance Indices

- A Venetian blind at 45 degree tilt angle behaves significantly different from a specular glazing
- At normal incidence they have identical performance, but not at other angles



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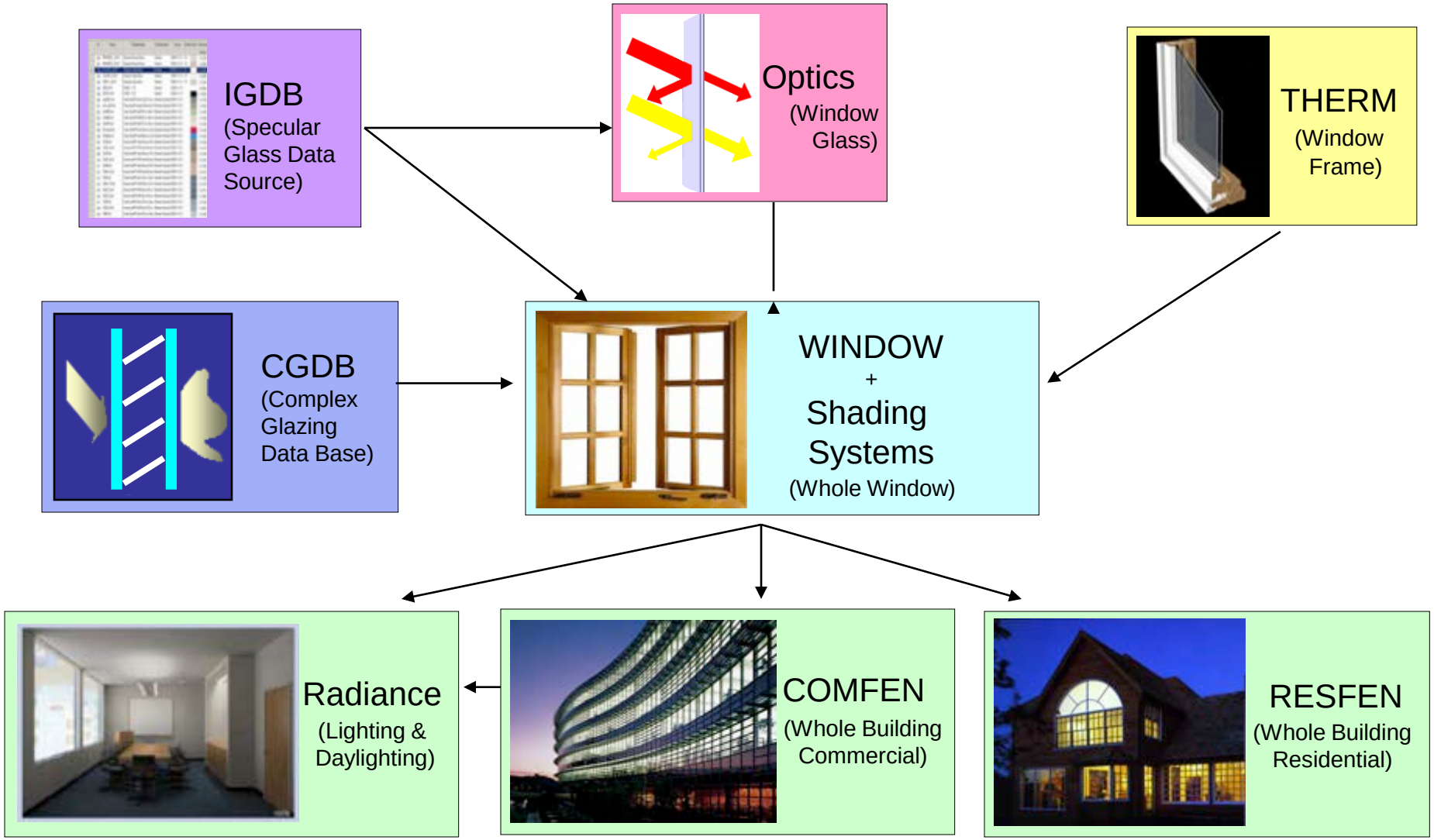
Software Tools Overview



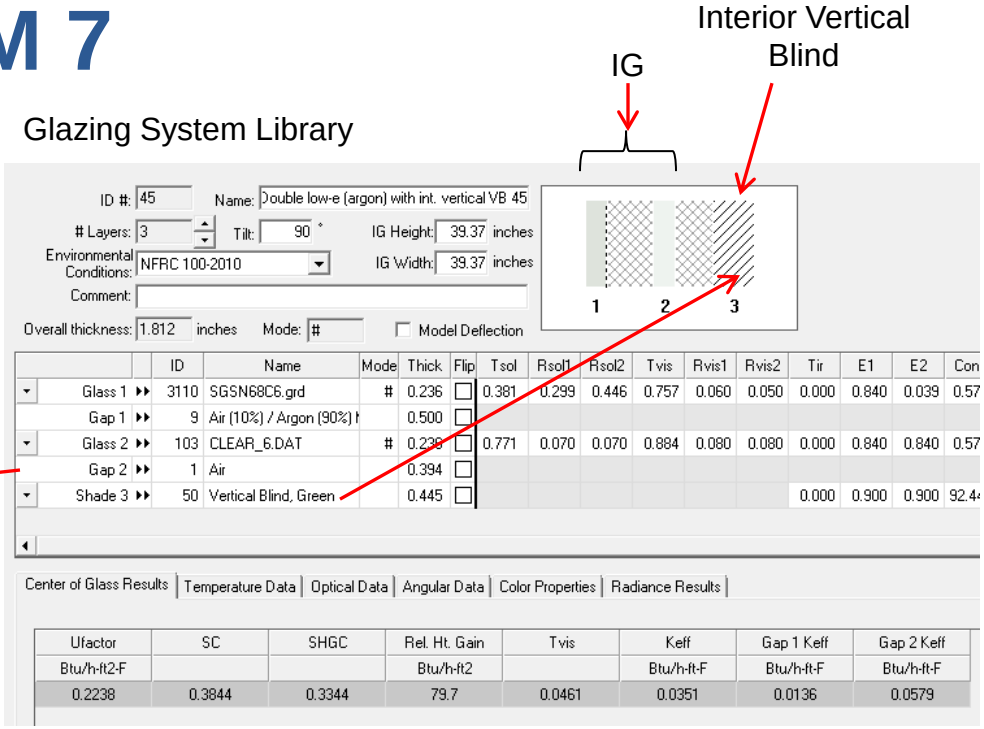
COMPLEX GLAZING DATABASE (CGDB)

- Conceptually comparable to International Glazing Database (IGDB)
- Designed for optically complex materials and devices
  - Venetian Blind slats
  - Woven Shades
  - Scattering (Diffusing) Interlayers
  - Scattering glass
  - Fritted Glass
  - Cellular shades
  - Other scattering layers/systems

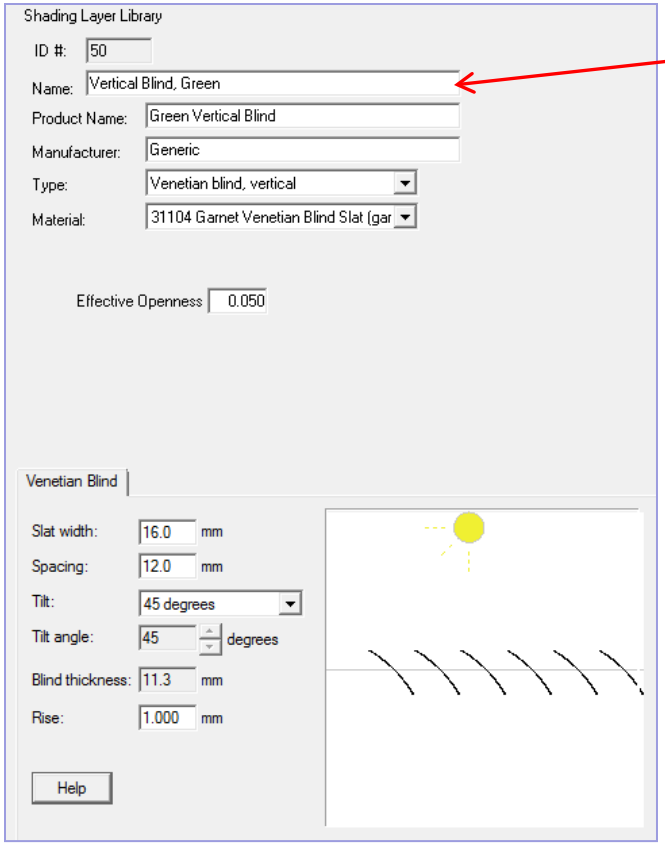
WINDOW & THERM 7

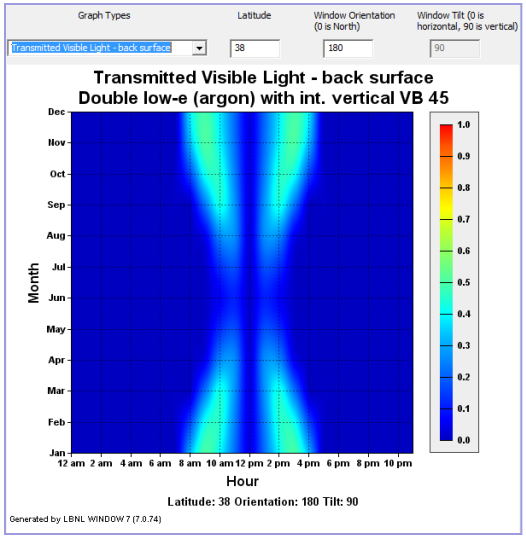
- Louvered Blinds

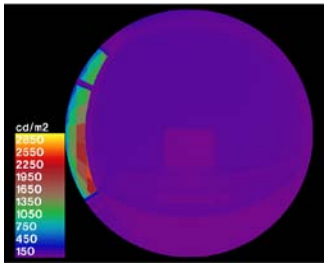
Glazing System Library



Shade Library

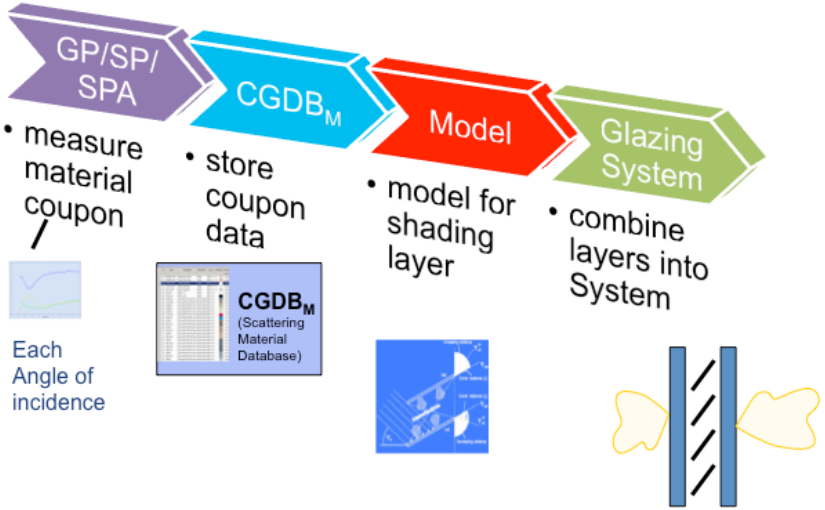




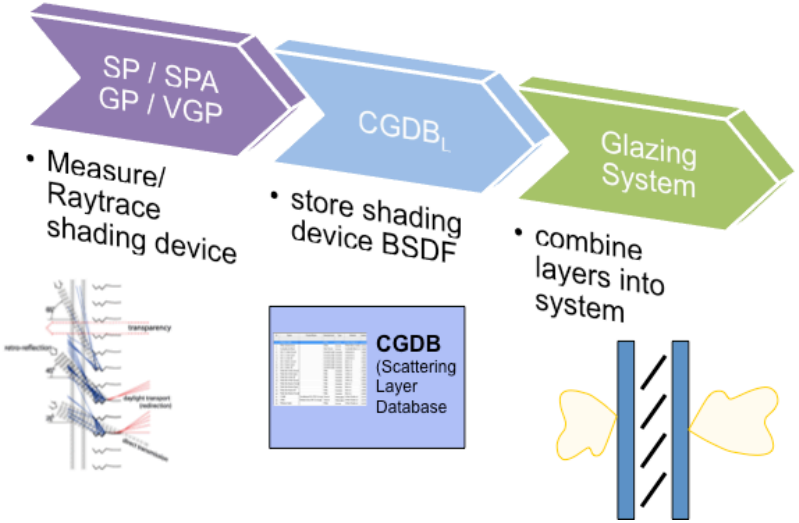


Radiance results for Jun 21

Software Tools – Optical Properties Flow



Process Flow for Systems for which there are analytical models and measurement data for material coupons



Process Flow for Systems for which there are no analytical models; direct system measurement required

Gaps in Knowledge Base: Tools Development – Phase I

Complex Glazing Database (CGDB)

- Finalize development of database infrastructure
- Process and publish results of complex glazing ILC (NFRC sponsored)
- Publish data submittal procedures
- Establish peer review process
- Develop requirements for outside laboratories for measuring and data submittal
- Start accepting data from outside laboratories and establish # sign for attachment products

WINDOW 7 and THERM 7

- Implement CGDB
- Implement new methods from Phase I simulation methods research
- Revise existing methods, based on current research
- Perform program testing and fix bugs
- Conduct limited programs release testing using selection of high end users
- Release final version 7.0

Gaps in Knowledge Base: Tools Development – Phase II

Complex Glazing Database (CGDB 2)

- Refine database infrastructure and create robust system for rating and certification
- Conduct second complex glazing ILC (Determine sponsorship based on rating organization choice)
- Publish revised data submittal procedures
- Review and revise requirements for outside laboratories for measuring and data submittal

WINDOW 8 and THERM 8

- Implement 2nd generation CGDB
- Integrate OPTICS into WINDOW
- Implement new methods from Phase II simulation methods research
- Revise existing methods, based on new research
- Perform program testing and fix bugs
- Conduct limited programs release testing using selection of high end users
- Release beta version 8.0 of programs
- Process and incorporate feedback from beta testers
- Conduct limited programs release testing using selection of high end users
- Release final 8.0 version of programs

OVERVIEW

- Introduction
- Simulation Methods
- Performance Indices
- Software Tools
- Measurement Methods
- Standards and International Collaboration
- Conclusions and Recommendations

Standards for measuring shades

Measurement standards

- British standard **BS EN** 14500:2008 is the best but no angle dependence
- **ASTM** – E903 being reinstated no special consideration for scattering samples, ASTM E44 is starting a new WG to create a scattering standard

Calculation standards

- **ISO** – 9050 mostly calculation of specular glazing, 15099 for multilayer calc of diffuse
- **CEN** – 410 calculation for multiple specular glazings, 673 thermal properties for materials opaque in thermal IR, 13363 for calculation of diffuse layers

IMPROVE STANDARDIZATION

- Establish new ISO WG for windows
- AHG for windows established 9/2011
- Unify thermal calculations under TC 163
- Unify optical calculations under TC 160
- Change ISO 10077 with new science
- *Develop new ISO standard for modeling complex glazing and shading devices,*
- *Develop new standard for measuring optical properties of complex products*
- *Develop new thermal measurement standard for window attachments*