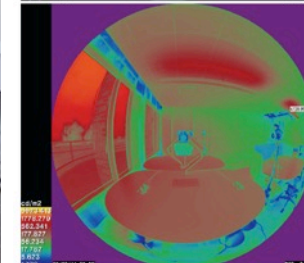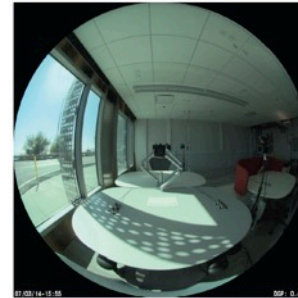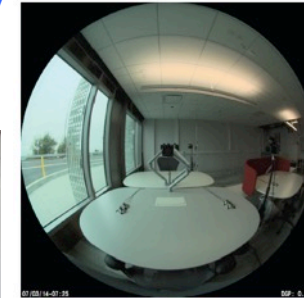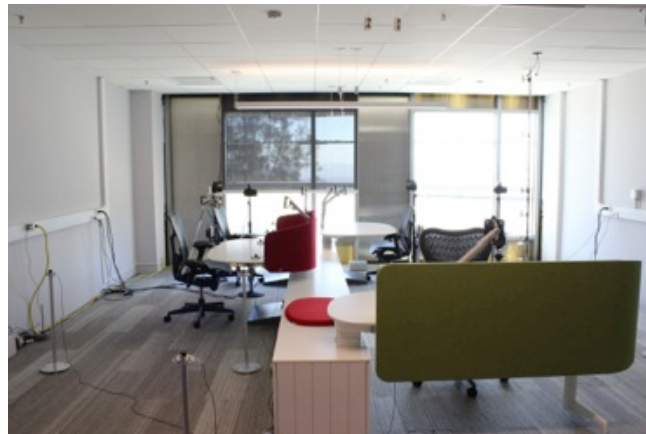# Quantifying Façade Performance: Advances in Simulation and Field Testing

Stephen Selkowitz

Group Leader, Windows and Envelope Materials

Senior Advisor, Building Technology and Urban Systems

Lawrence Berkeley National Laboratory

seselkowitz@lbl.gov
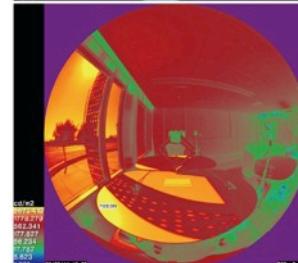
Two Challenges

We want design methods and solutions that are:

1) **Accurate; 2) Easy to Use; 3) Low Cost**

      (but you can't have them all – pick 2)

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

    But in practice, there is."

– Yogi Berra

Performance Expectations: What Does A "Manufacturer" Promise to a Customer?

- Aircraft: "2 litres/100 passenger km"
- Trains: "1 ton-450 miles/gallon"
- Automobiles: "42 miles/gallon highway"

- **Measureable Performance "guarantees"**
  - (with qualifiers)

- **Your Office Building: Energy Use/sf = ?????**

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# The Gap and the Challenge: Design Goals vs Measured Performance
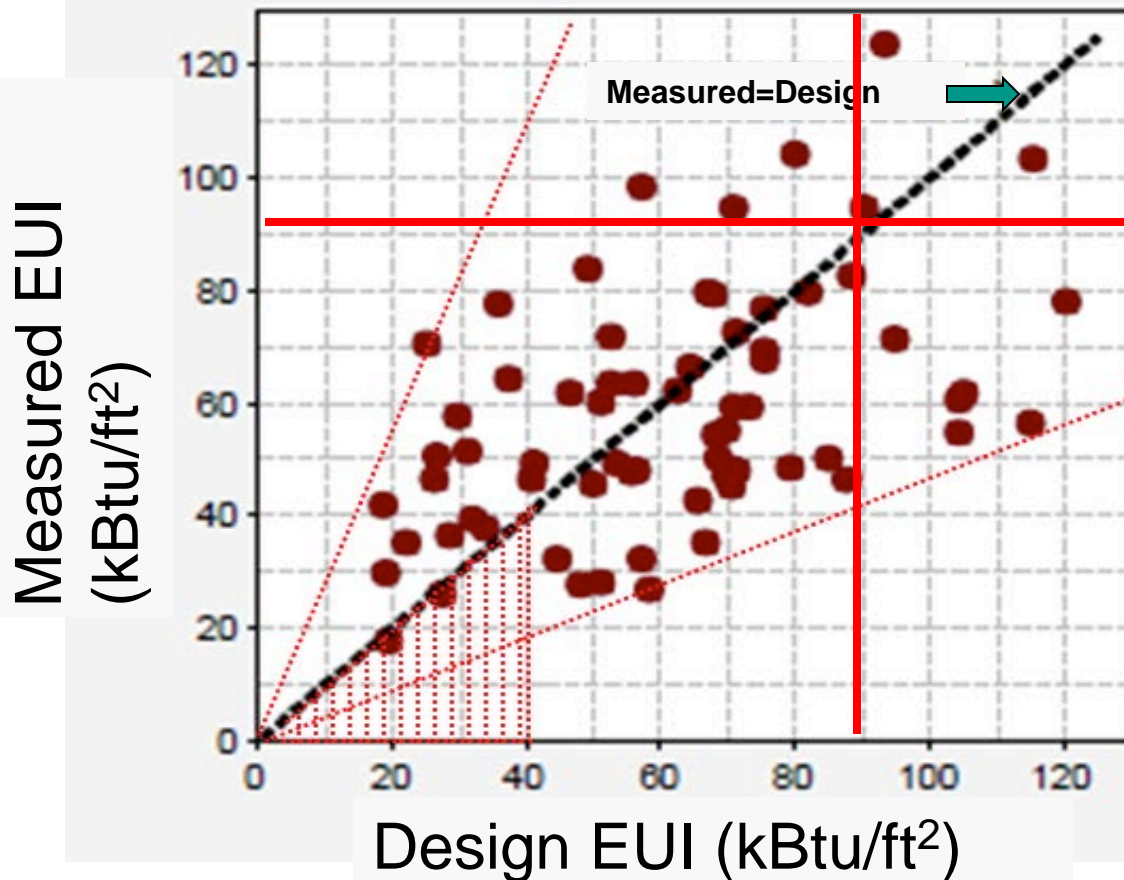
Observations:
1. Various building types, ages, locations
2. Average over all projects is not bad
3. Max over-predict by **120%**
4. Max under-predict by **65%**
5. **Almost all under-predicted for low energy designs** (red triangle: EUI <= 40)
6. Uncalibrated simulated results

Source: Energy performance of LEED-NC buildings, NBI, 2008

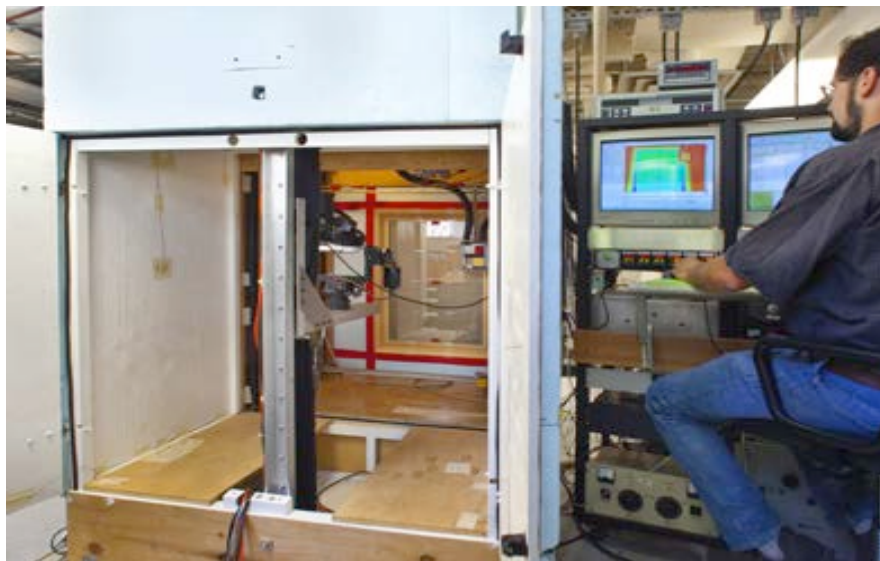# Focus: Overall System Performance for Advanced Facades and Daylighting
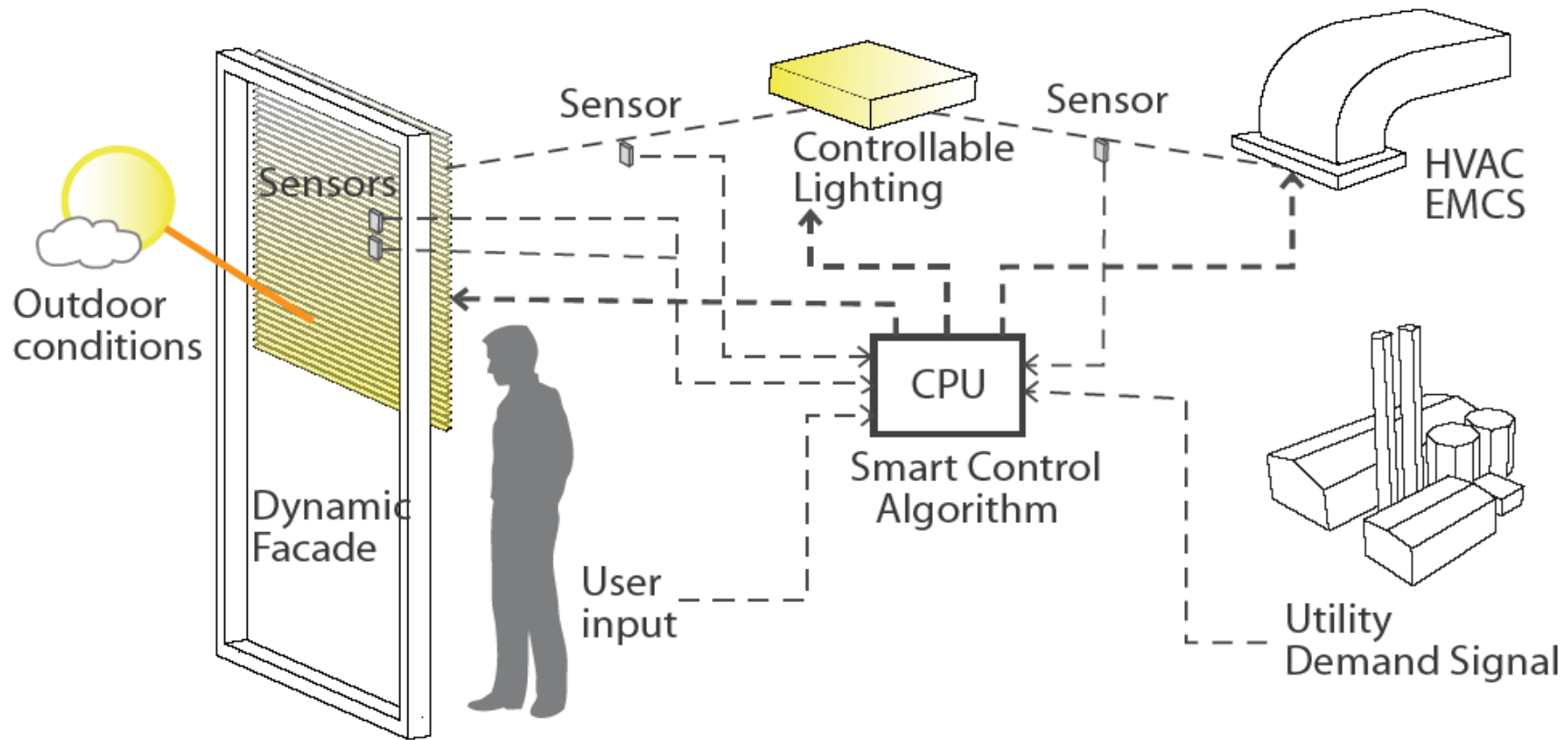
**Building Performance is Complex Façade = Complex "Kit of Parts":**

1. Do We Understand How the "Facade" performs in the building?
2. How the components perform?
3. How the sub-elements work?
4. Occupant interaction?

# 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
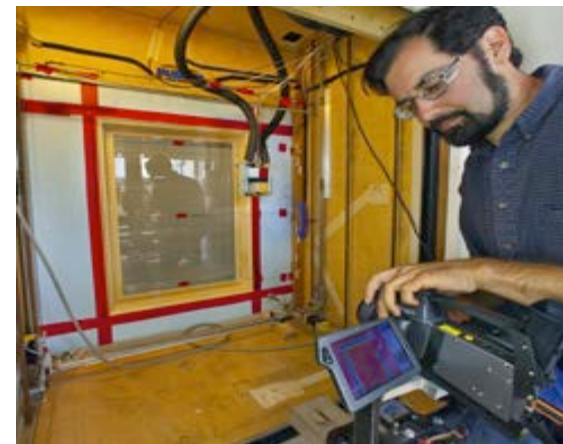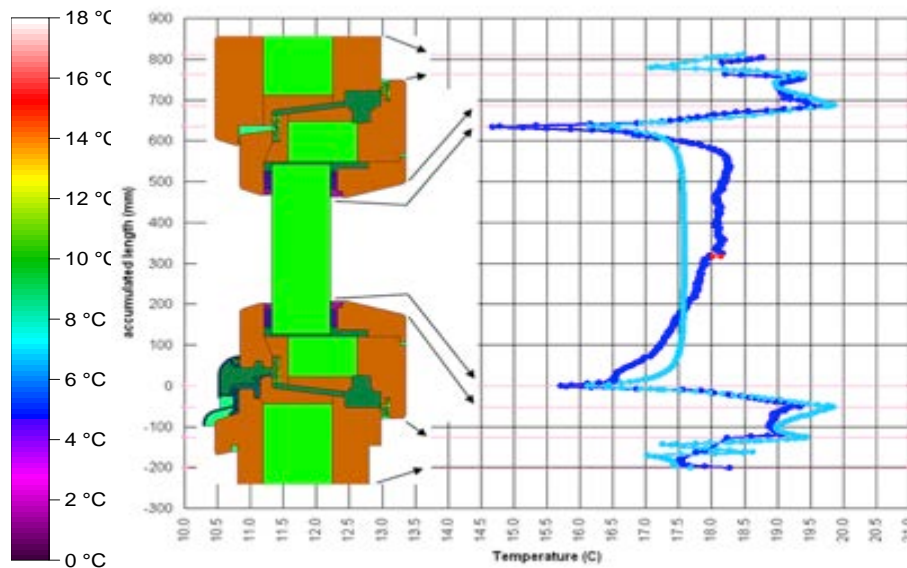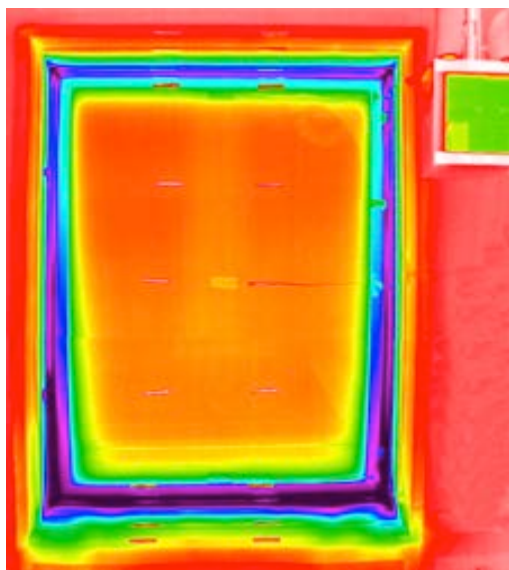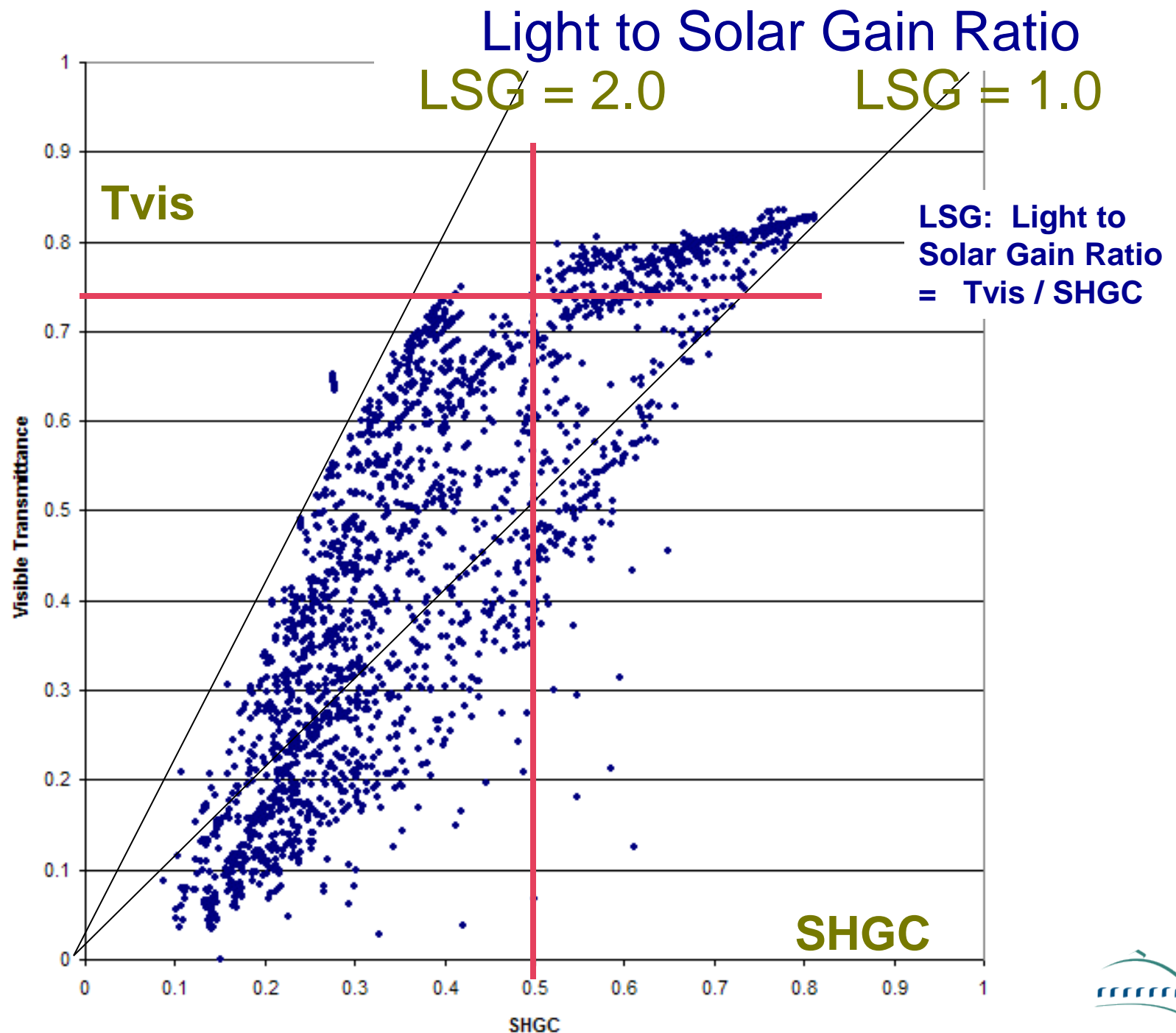
Measurement: LBNL IR Thermography Lab
Quantitative Analysis
Lab cold chamber and Field Tests
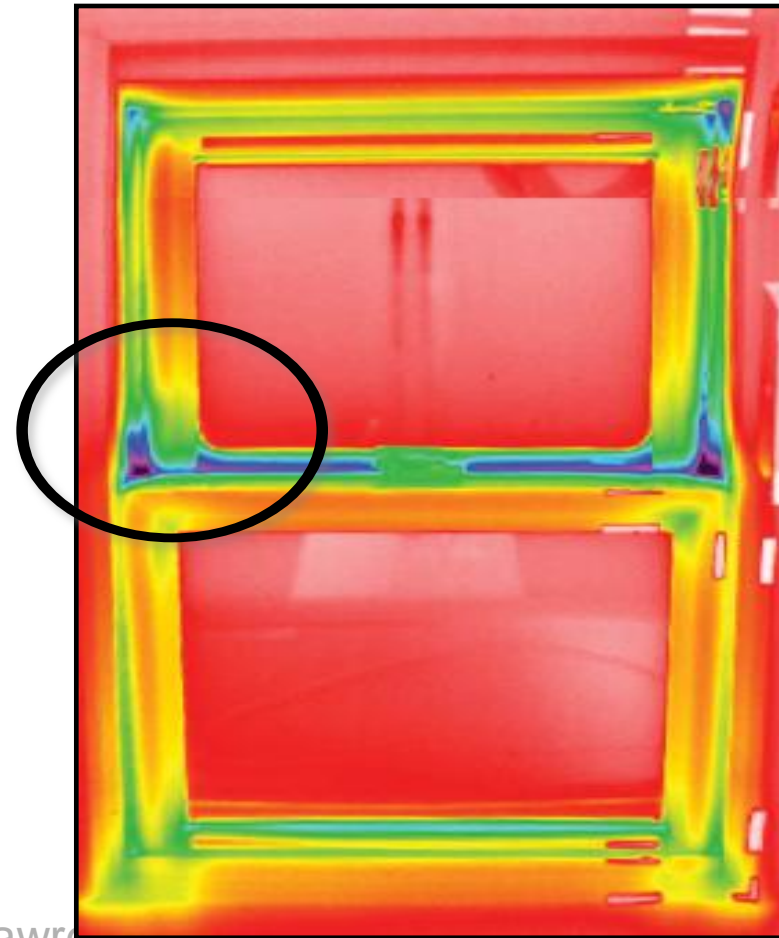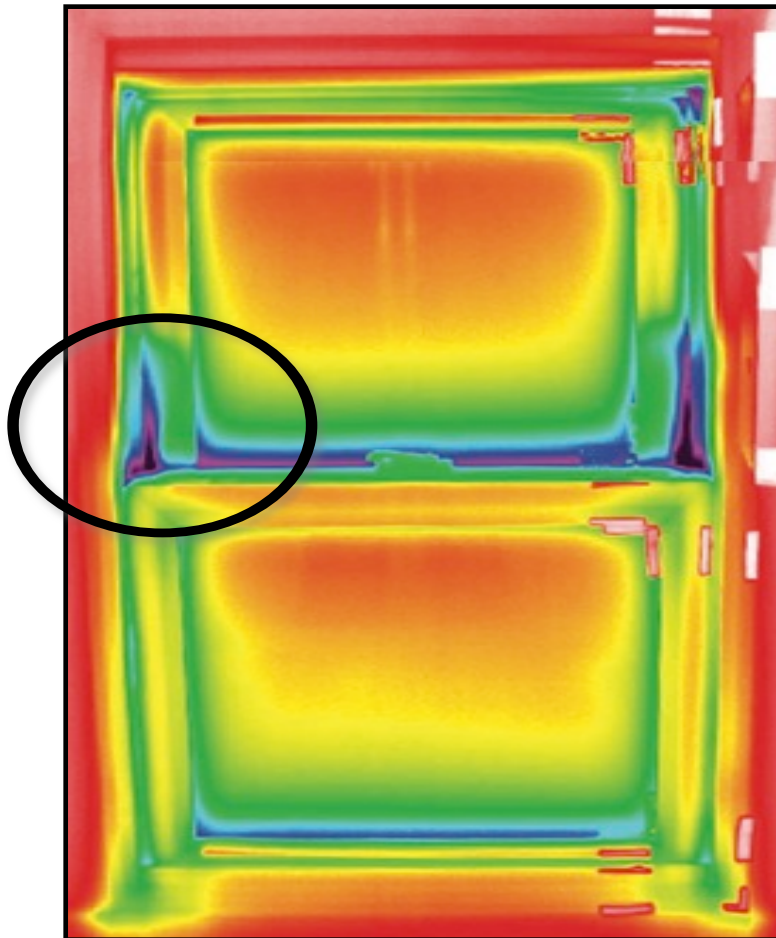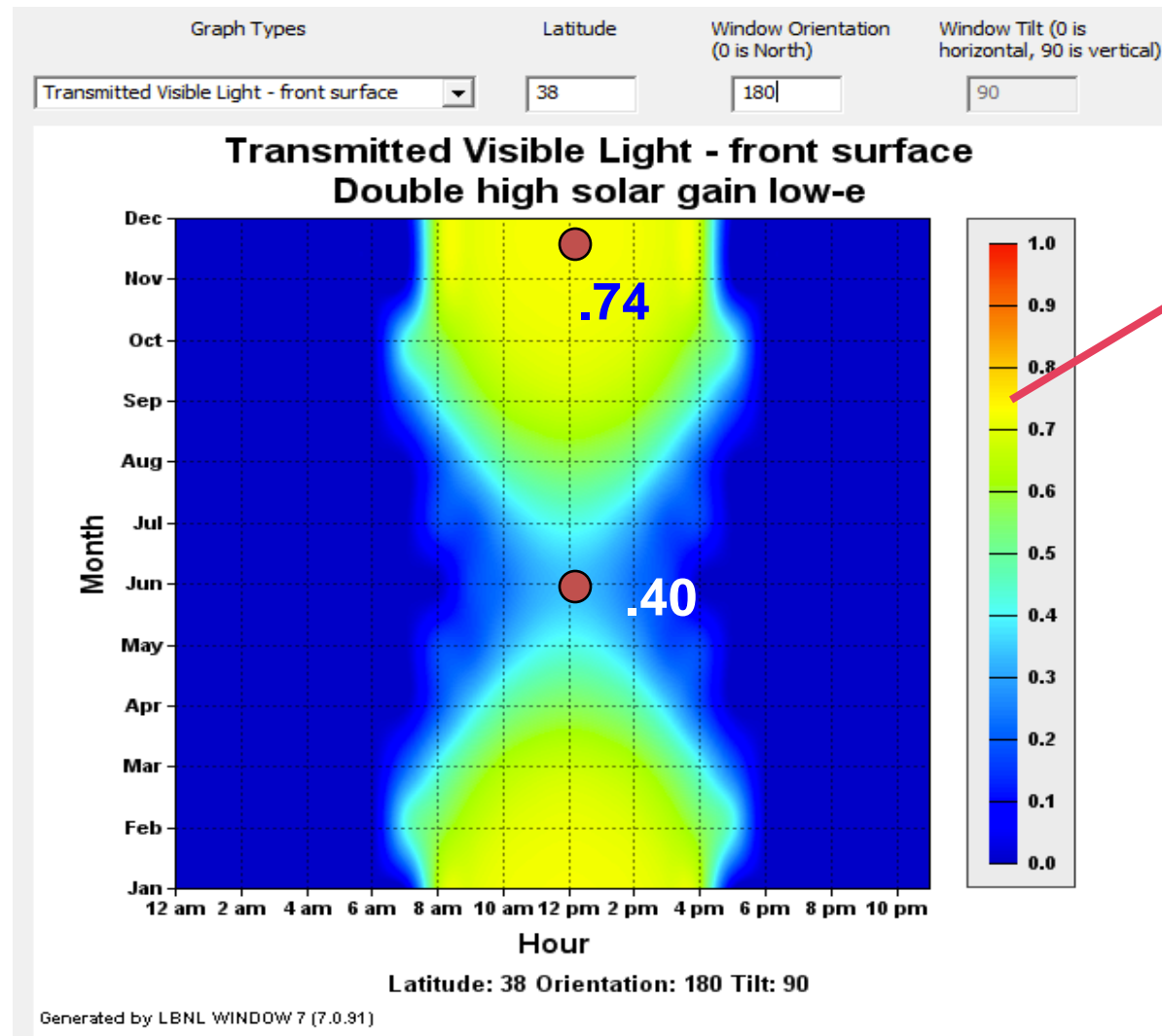
Light to Solar Gain Ratio for insulating glass units for all glasses in LBNL's IGDB (International glass data base)

Light to Solar Gain Ratio

LSG = 2.0   LSG = 1.0

Tvis

LSG: Light to Solar Gain Ratio = Tvis / SHGC

SHGC

"Nominal" Tv = .74 (NFRC value, normal incidence)
# Vs. "Actual" Hourly Monthly Transmittance (WINDOW7)

Tv = .74

Latitude 38
Vertical glass
South facing

W7: View location dependent annual transmittance variation for an optical system

Why 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 at other angles Tvis varies widely**
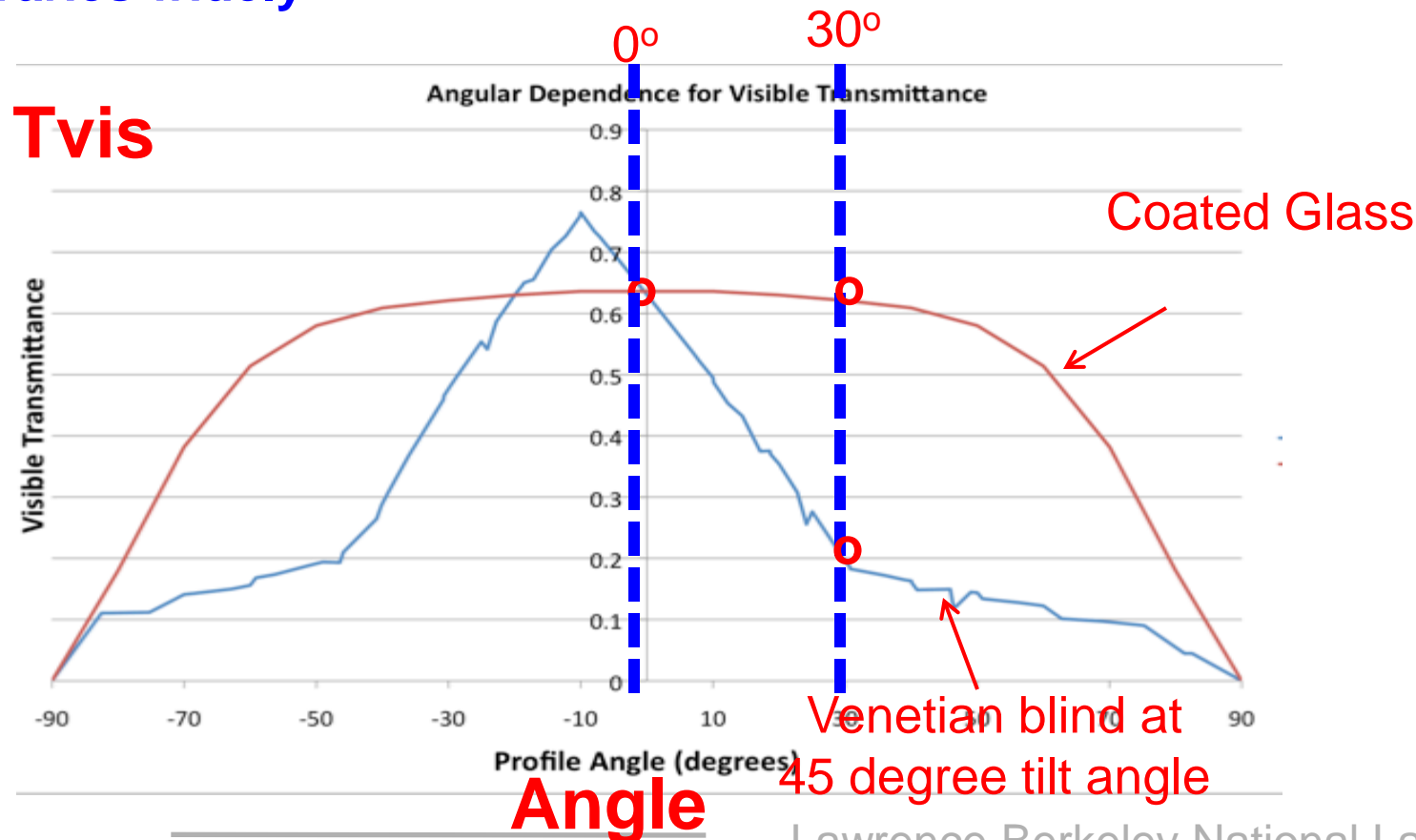
Field Measurements:
Insights into
Energy-Related Performance
in the Real World

Dimensions of Building Performance

Building "Demonstrations"

Building as "Living Laboratory"

Single Building System Test Labs: R&D

Public Buildings GSA, FEMP, DOD, State and Local, Schools, Campuses

Integrated Building Systems Testbeds: National User Facilities FLEXLAB

Utility Billing Data

Private Buildings Corporate, Non-Profit Campuses

Component Test Labs: Testing Rating Certification

Simulation Tools: Component → System Design <--> Operations

Disclosure Law Data

Tools: Ratings, Labels, Certification

National Building Performance Data Base CBECS, CEUS, USGBC, Public, Private…..

Past LBNL "Testbed" Experience

DOE- EC and Dimmable Lighting 2010

MoWiTT Field Tests 1985-2000

NY Times Mockup and Test bed 2003-2007

DOE/CEC/PG&E Electro-chromic Daylighting Testbed Oakland CA, 1999

Time EC Fluor
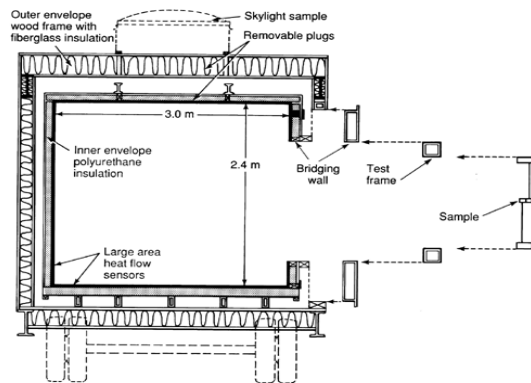10:30 0.38 80%
10:40 0.36 30%
10:50 0.18 40%
11:00 0.11 42%

DOE/CEC Advanced Façade SystemsTestbed LBNL 2004-2012

BERKELEY LAB
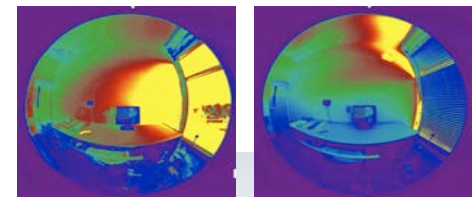
Mobile Window Thermal Test Facility (MoWiTT) 1982->
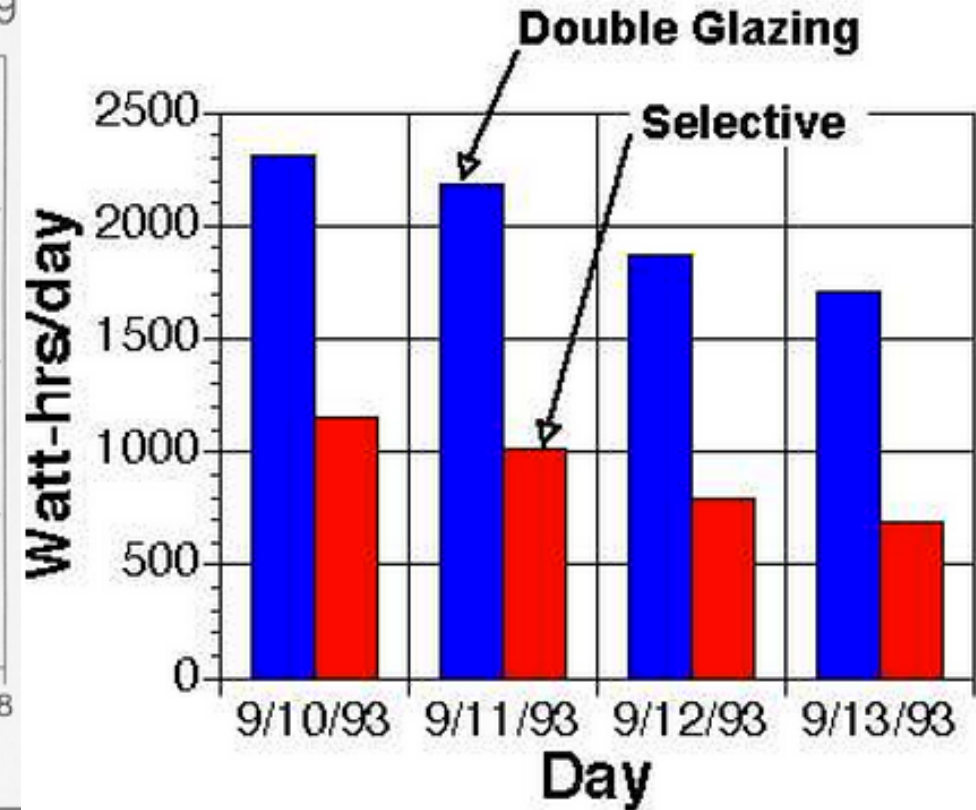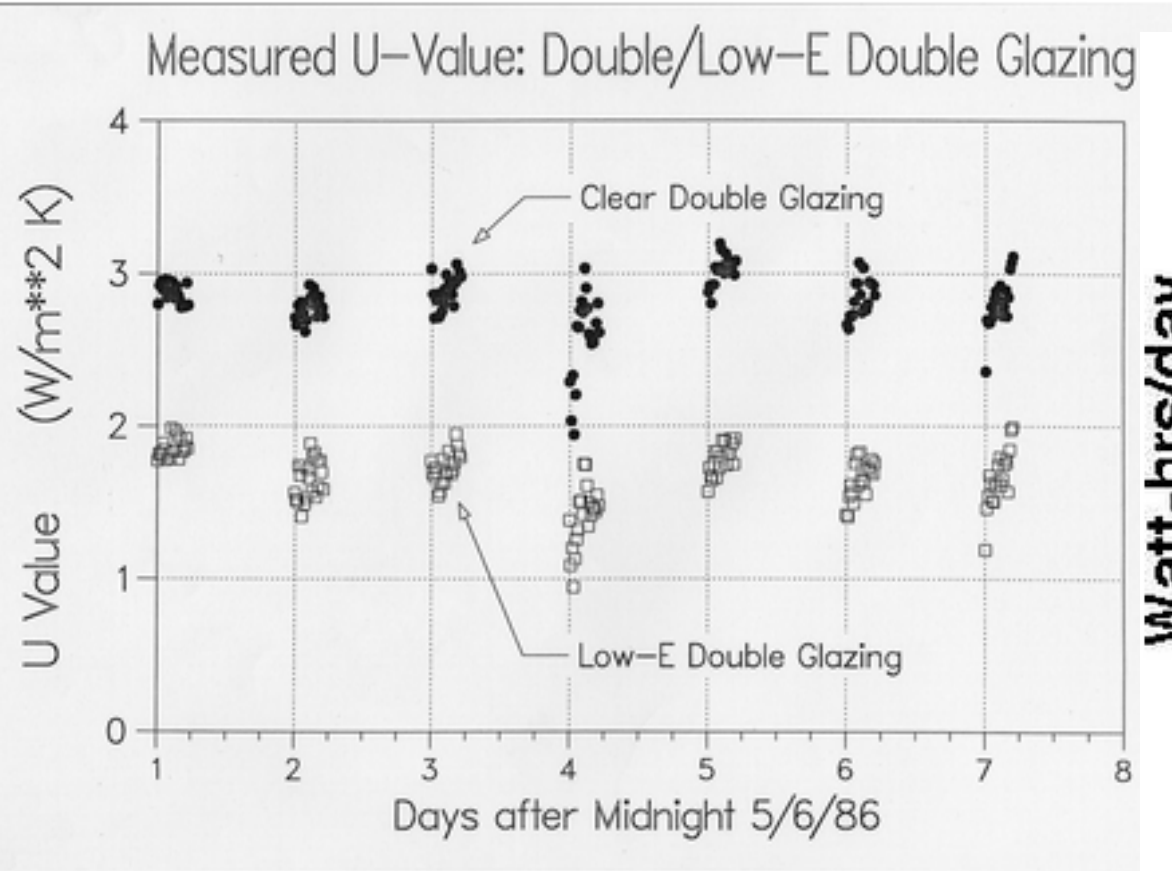
MoWiTT Provided "Real" Performance Data

U-Value: Clear Double vs. Low-E Double (1986)

**Cooling Load: Clear Double vs. Selective Double (1993)**

Measured U−Value: Double/Low−E Double Glazing

Clear Double Glazing

Low−E Double Glazing

U Value (W/m**2 K)

Days after Midnight 5/6/86

Double Glazing

Selective

Watt-hrs/day

Day

Full-Scale Test Bed Built into Oakland GSA Federal Building, 1990- 1992

- Side-by-side test offices; occupancy effects (interior changes only)
- Owner engagement
- **Stage 1: Unshaded large-area electrochromic windows**
- **Stage 2: Automated interior blinds with "optimal" controls**
- **Integrated controls optimize energy and demand for window and lighting system**

Time   EC   Fluor
10:30 0.38 80%

10:40 0.36 30%

10:50 0.18 40%

11:00 0.11 42%
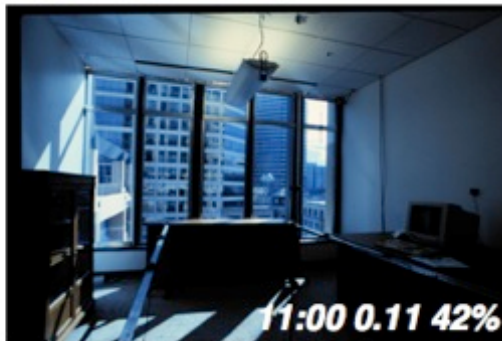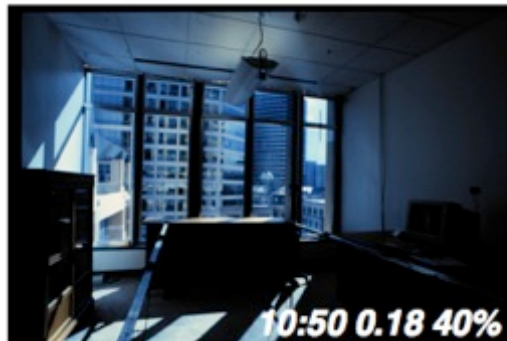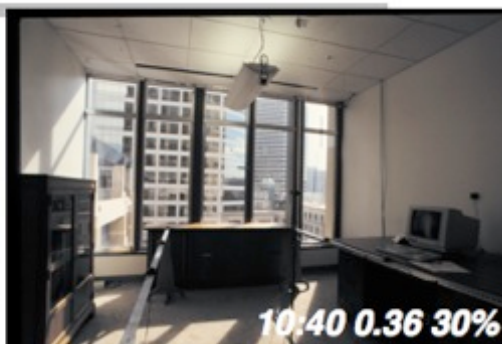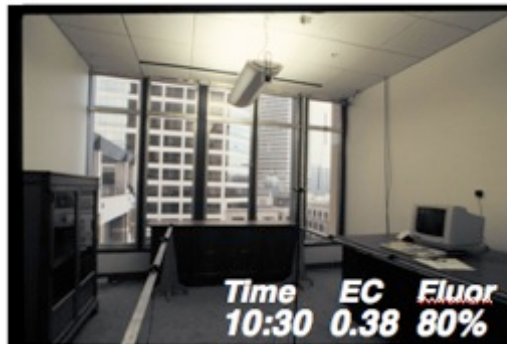
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LBNL Advanced Façade Testbed Facility

2003-2006 Electrochromic windows

2007-2015 Automated Shading;

Daylight Redirecting;

Integrated PV and storage

- **Berkeley, South facing 3 Rooms**
- **Changeable façade**
- **Lighting, HVAC**
- **Heavily instrumented**
- **Static/Dynamic**
- **Occupant Studies**
- **Controls/Automation**

Exploring Performance of Integrated Shading and Lighting Controls in LBNL Facade Testbed Facility

Daylight Redirecting Glass

External Dynamic Shading
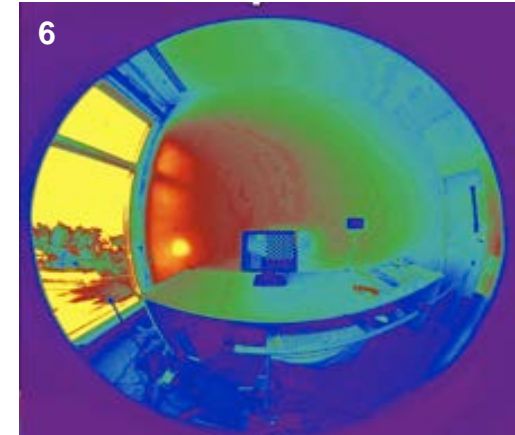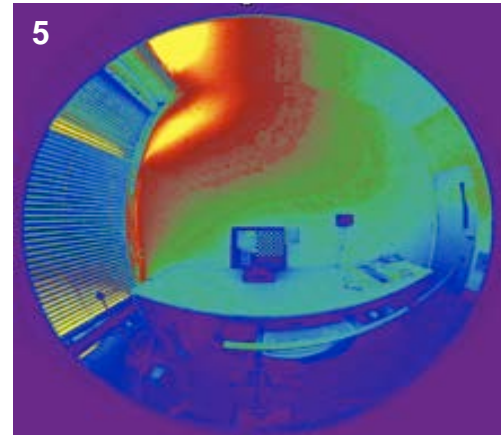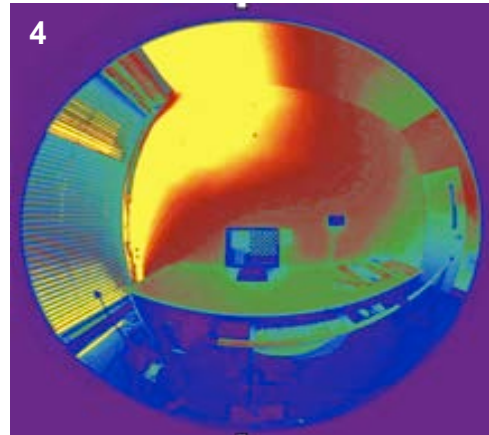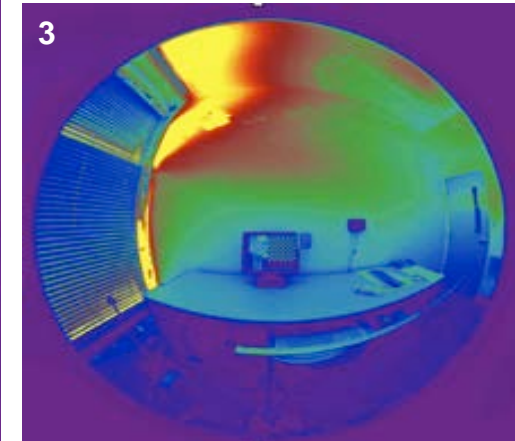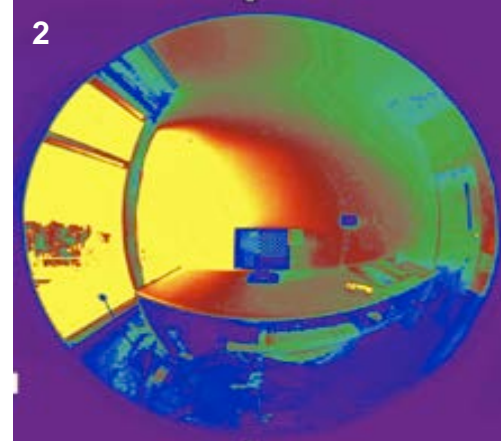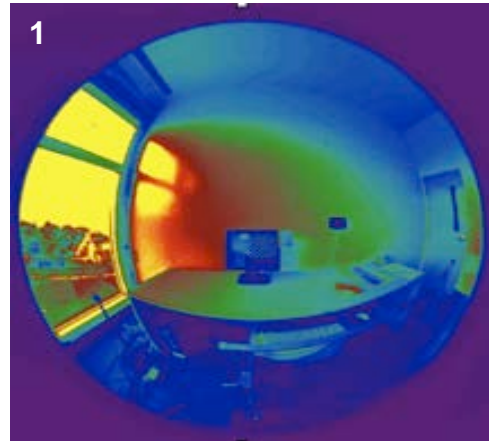
Electrochromic Glass
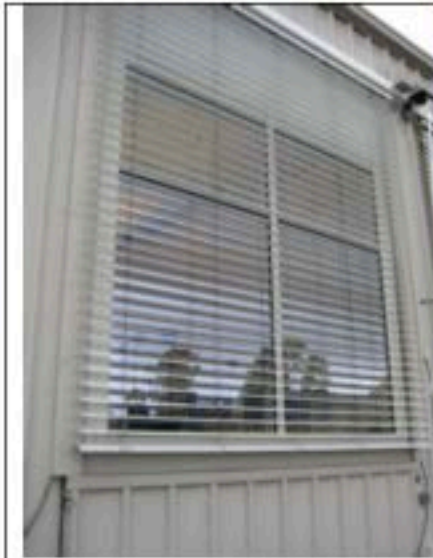
Automated Shading Controls Glare Throughout the Day
Time Lapse from Tests in LBNL Façade Test Facility:
Interior Daylight Luminance Patterns with Dynamic Shading

Comparative Shading System Performance: 8 Systems
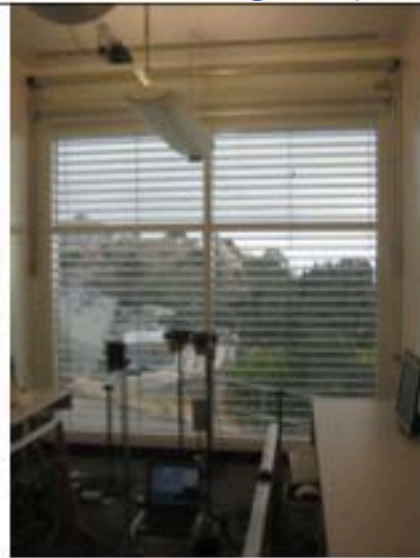
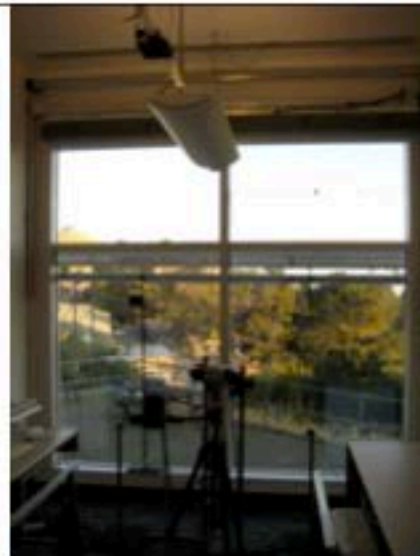|			
VB-E1n (exterior)	VB-E1n (interior)	VB-E3opt (exterior)	VB-E3opt (interior)
VB-E2n (exterior)	VB-E2n (interior)	RS-E-autol1 (exterior)	RS-E-autol1 (interior)

Source: K Konis

Lawrence Berkeley National Laboratory
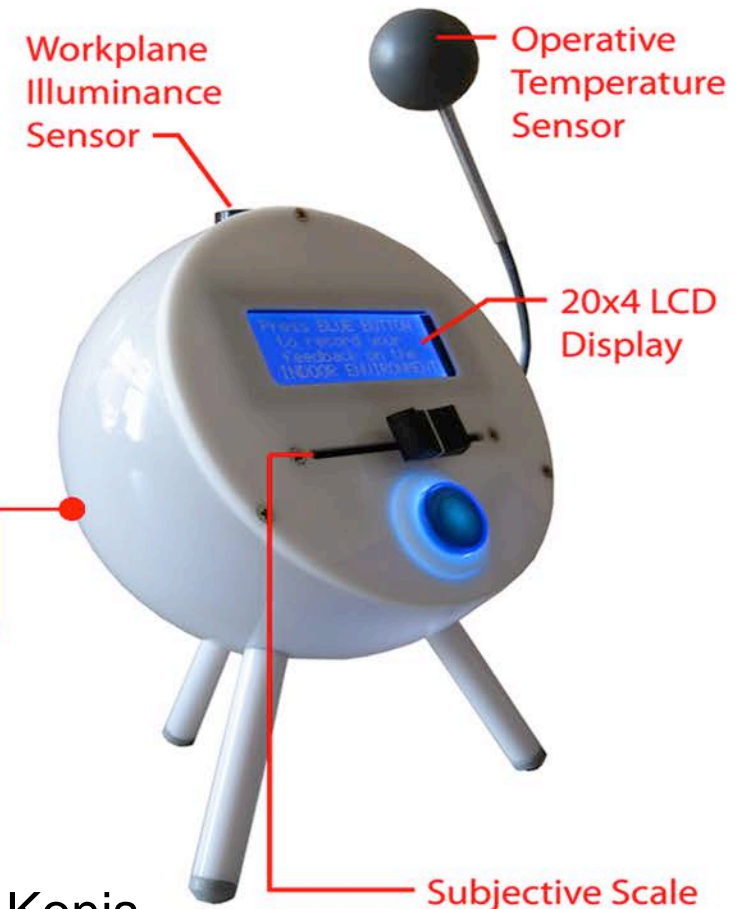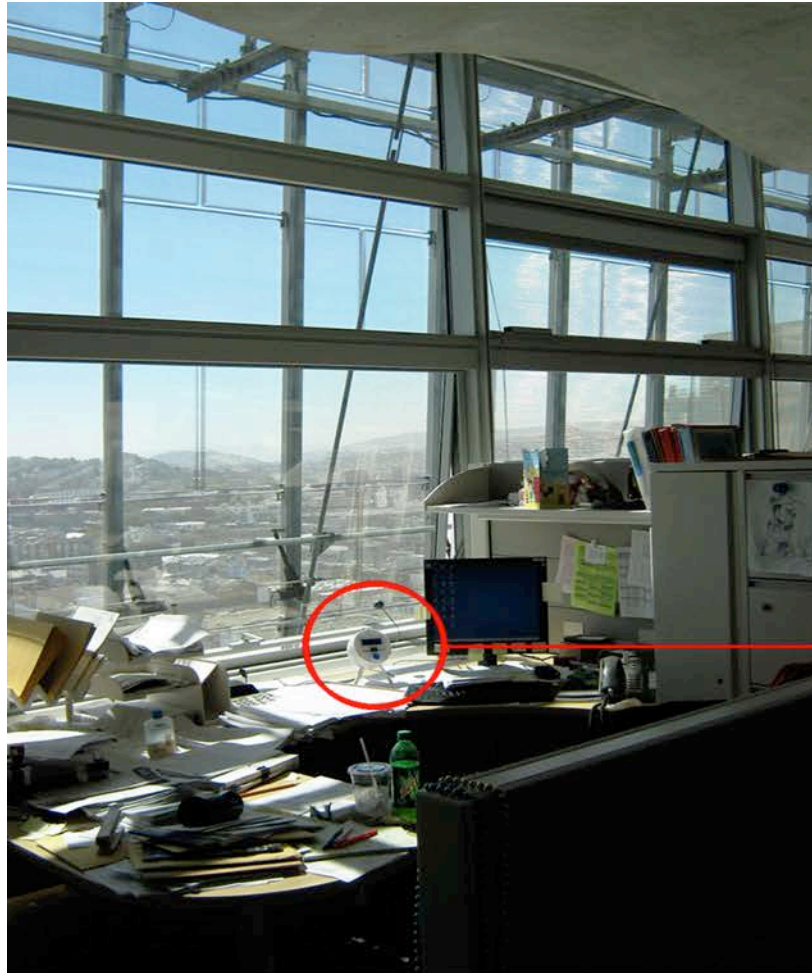
Exploring Intelligent Control Systems:
Maximum performance requires full integration with all building systems (manual control??)

Task Requirements

User Preferences

Interior Conditions

Weather Conditions

Load Shedding/ Demand Limiting Signal

Sensors, meters,…

Smart Controllers

Energy Information System

Dynamic Window
(active control of daylight, glare, solar gain)

Lighting Systems
(with dimming ballasts, sensors)

H V A C

Building Performance
(cost, comfort, operations)
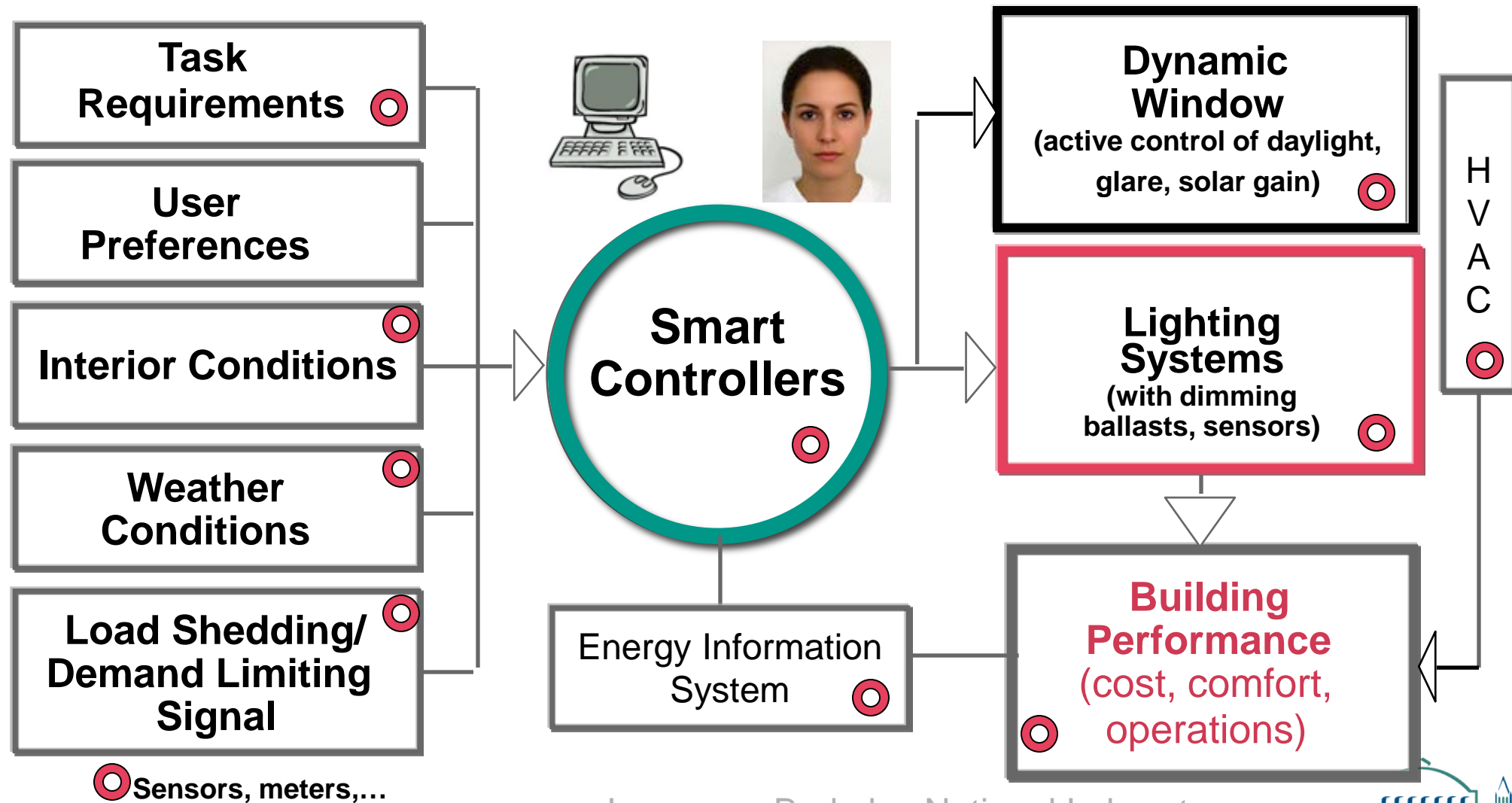
The NY Times: Intelligent Lighting, Shade Control, UFAD
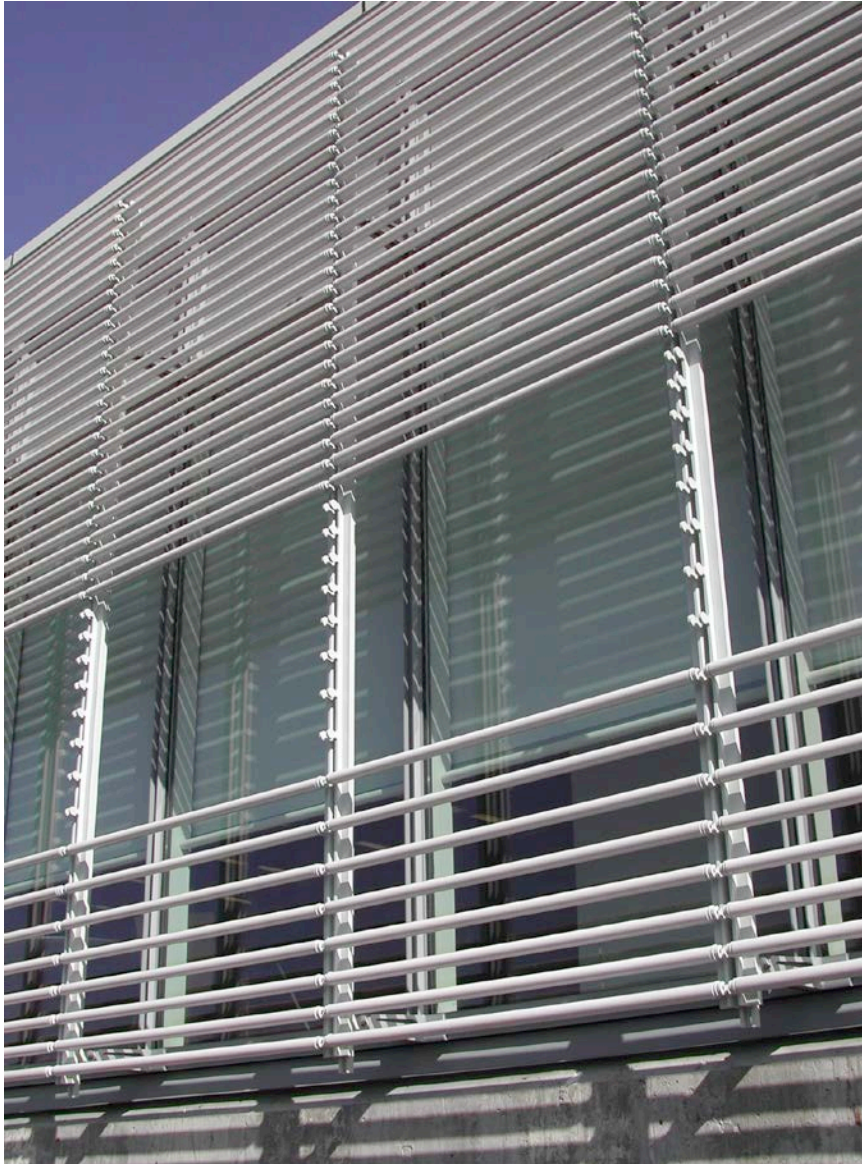## (Field Energy Measurement Study Completed 2013)

- Automated Shaded

- Automated Dimmable lighting
  - Addressable
- Underfloor Air Distribution

Occupied 2007

New York Times office with dimmable lights and automated shading

Façade Layers

Façade Layers: In to Out

External layer: Fixed

-- Shading, light diffusion

Glazing layer: Fixed

-- Low-E, spectrally selective

- thermal control

- solar gain control

-- Frit - solar, glare control

Internal layer: Dynamic

-- Motorized Shade system

-- Solar control

-- Glare control

Façade Layers: Floor to Floor

floor to desk

desk to head

head to ceiling

plenum

NY Times Testbed: Optimize: Physical & Virtual

Phase 1: Physical Testbed, 18 month field study

- Evaluate Shading, daylighting, employee feedback and constructability in a ~5000 sf testbed

- Fully instrumented; 1 year testing
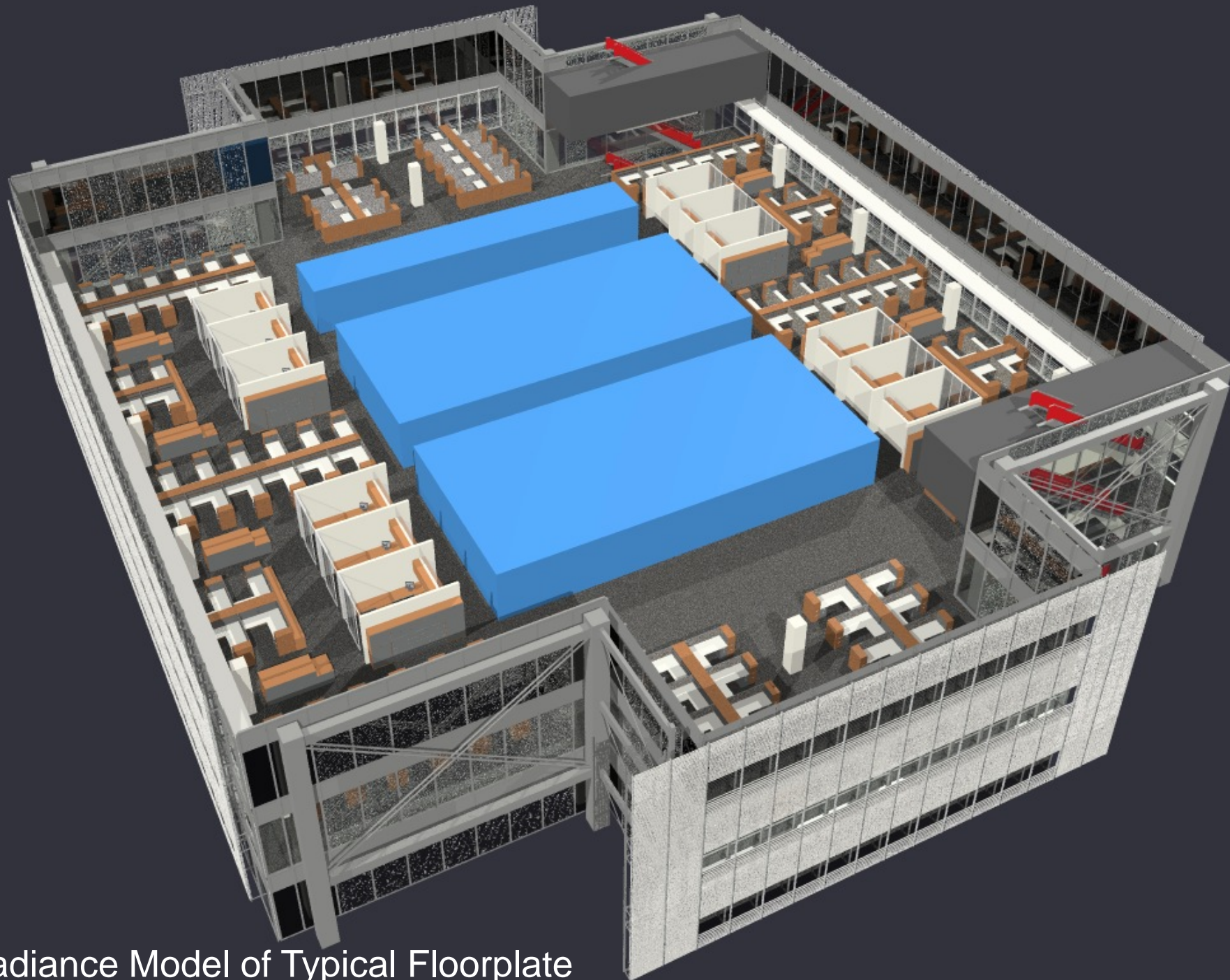
Phase 2: Virtual Model, extend measured data

- Extend Test Data: more Orientations and Floor Levels
- Shade Control Algorithms for Motorized Shades Developed using Simulation
- Built a virtual model of the building in its urban context using hourly weather data to simulate performance
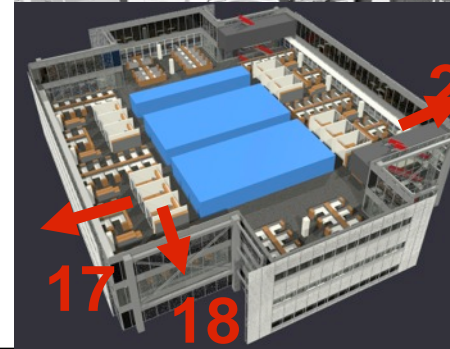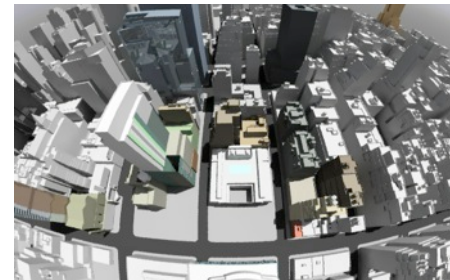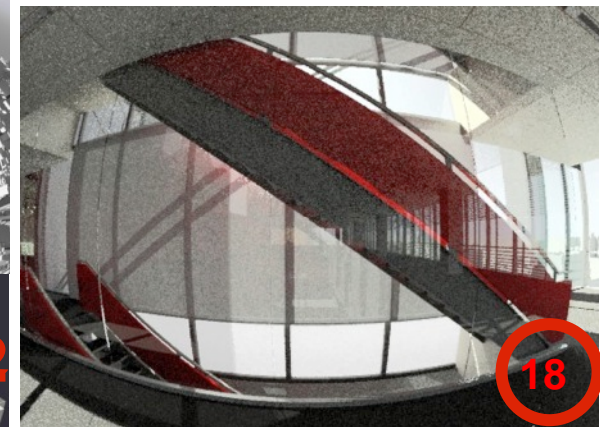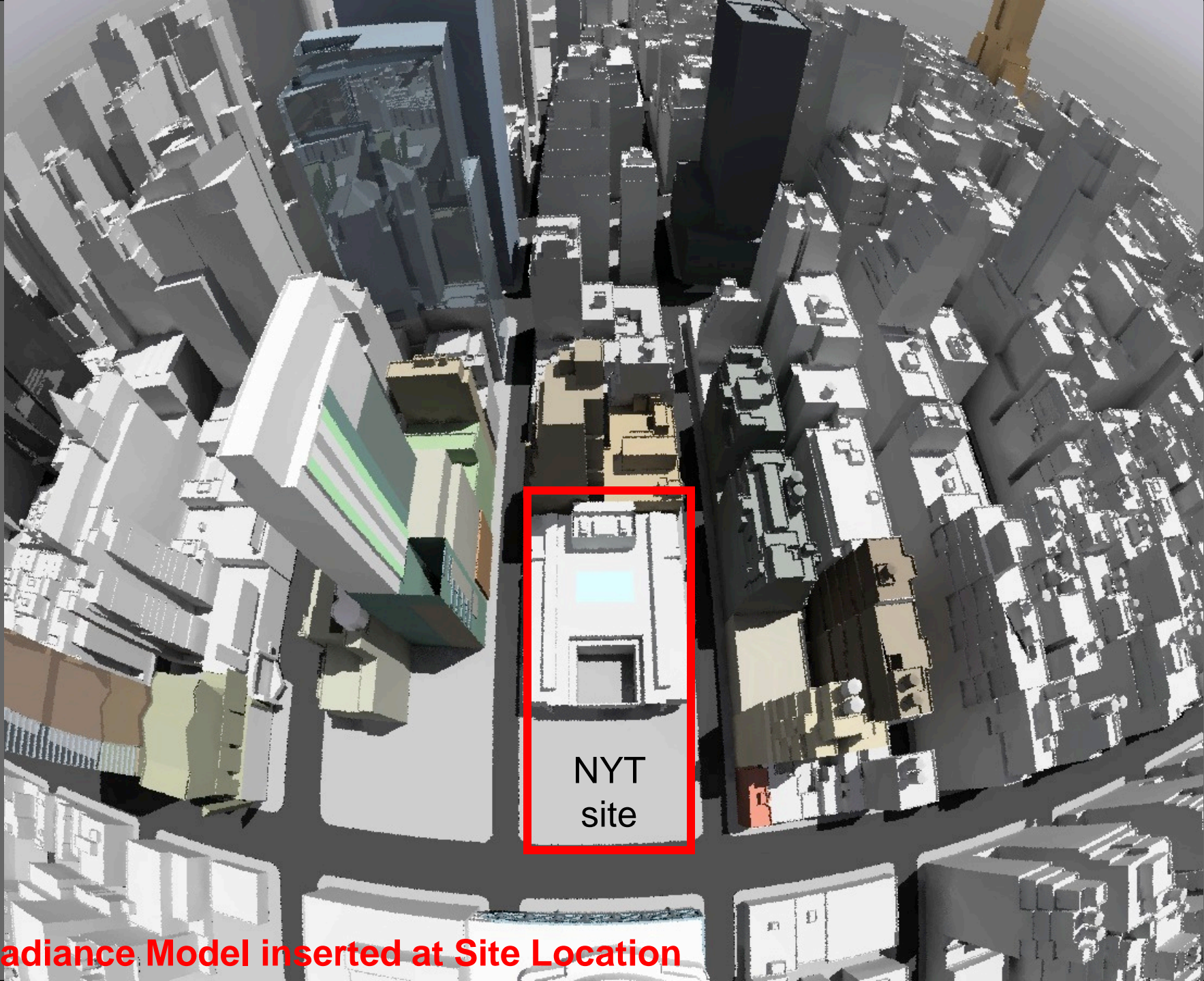
Simulated Views from 3 of 22 view positions
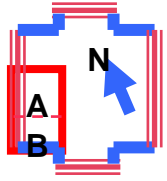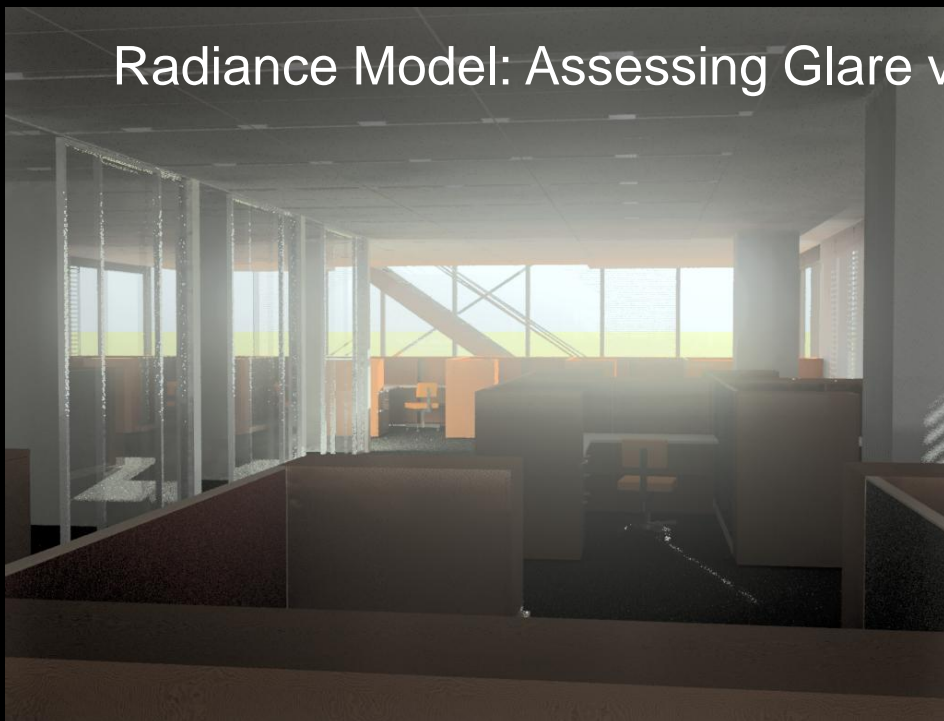
Radiance Model of Typical Floorplate

NYT site
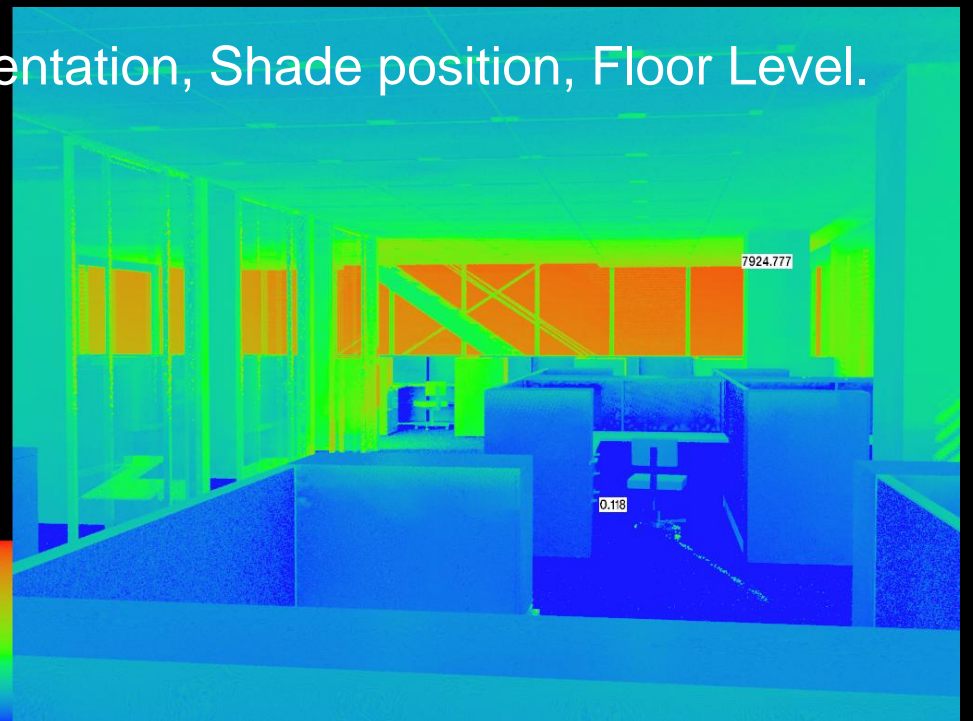
Radiance Model inserted at Site Location
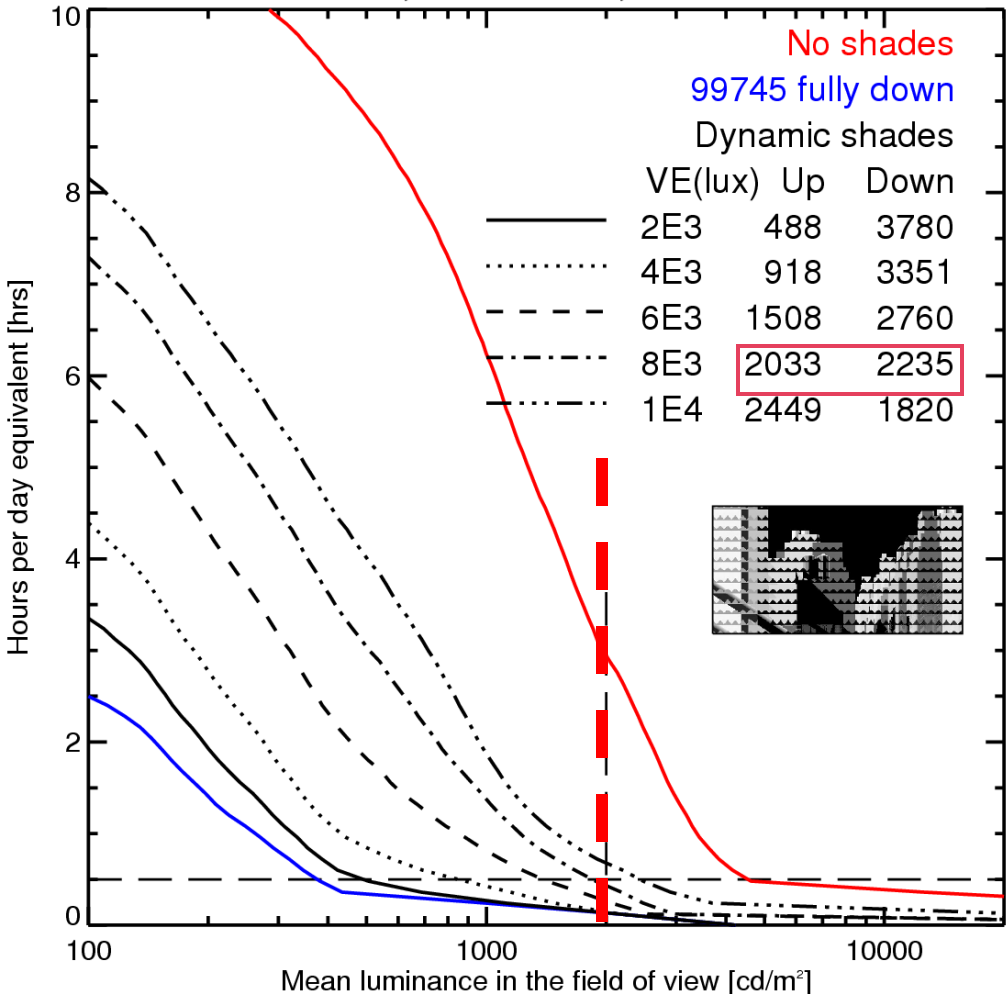
Radiance Model: Assessing Glare vs Orientation, Shade position, Floor Level.

Glare Assessment vs Shade Operating Strategy
West facade

Floor 6

Floor 6, West facade, view wc11

No shades
99745 fully down
Dynamic shades

VE(lux)	Up	Down
2E3	488	3780
4E3	918	3351
6E3	1508	2760
8E3	2033	2235
1E4	2449	1820

Hours per day equivalent [hrs]

Mean luminance in the field of view [cd/m²]

Floor 26

Floor 26, West facade, view wc11

No shades
99745 fully down
Dynamic shades

VE(lux)	Up	Down
2E3	460	3902
4E3	870	3492
6E3	1408	2955
8E3	1954	2409
1E4	2392	1971

Hours per day equivalent [hrs]

Mean luminance in the field of view [cd/m²]

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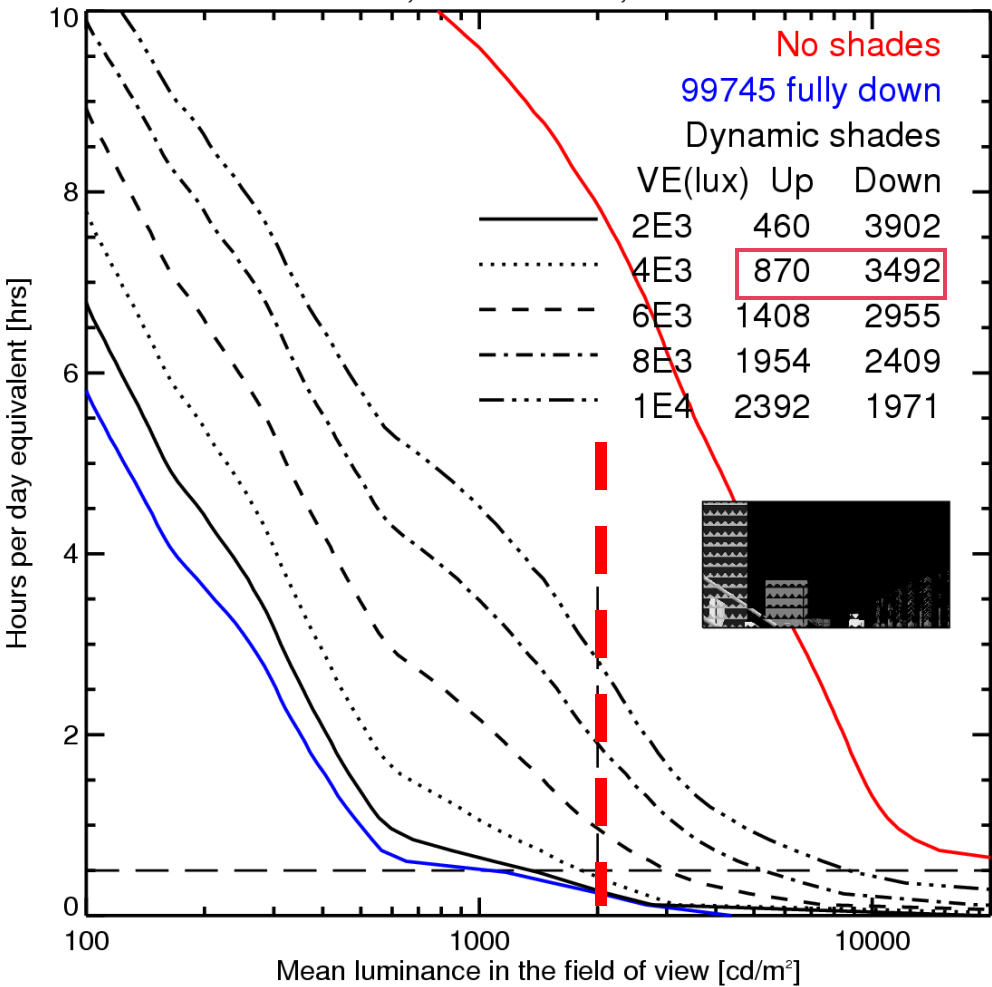
Automated Shading:
Manages Glare, Reduces Cooling Load
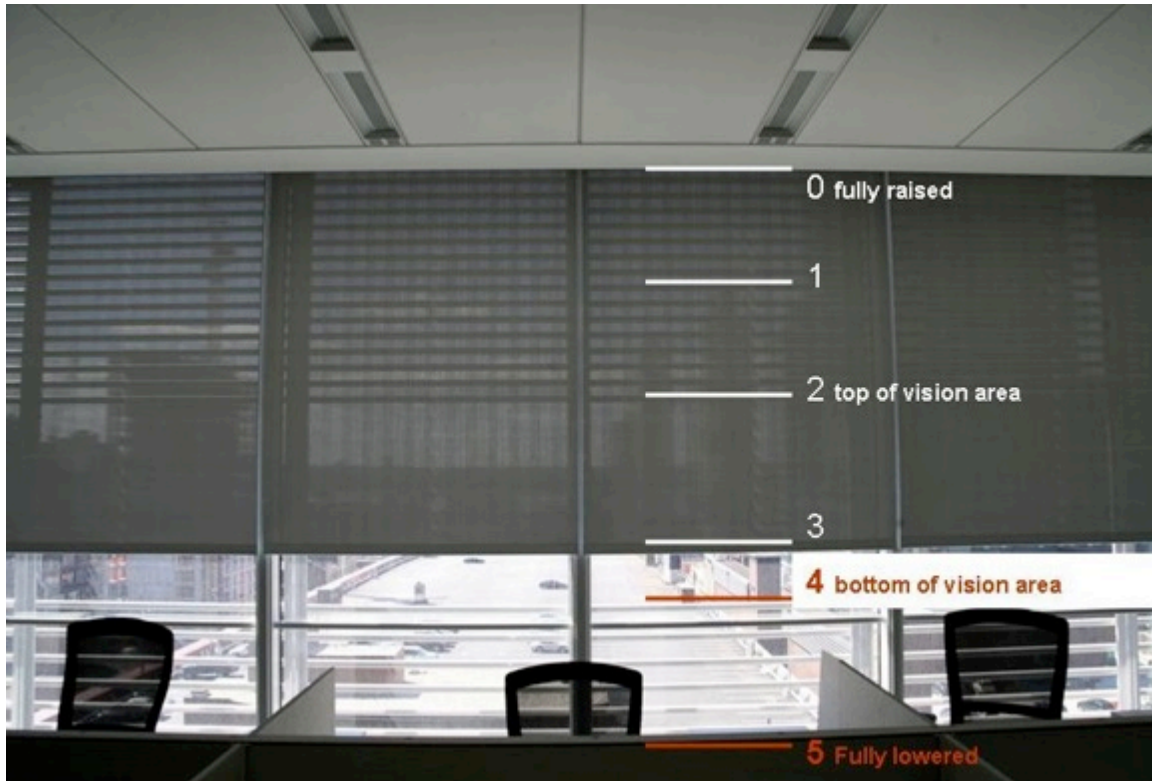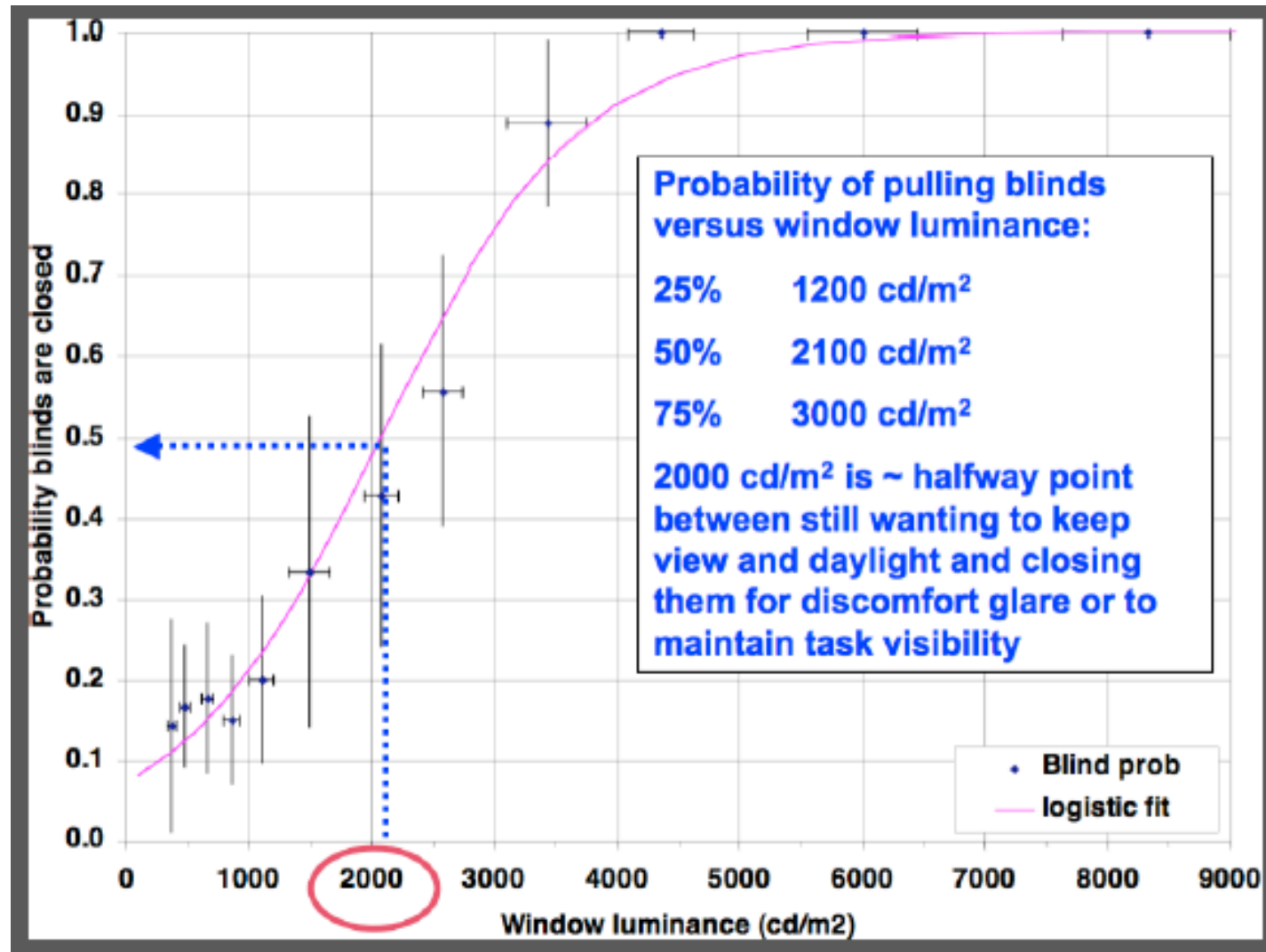
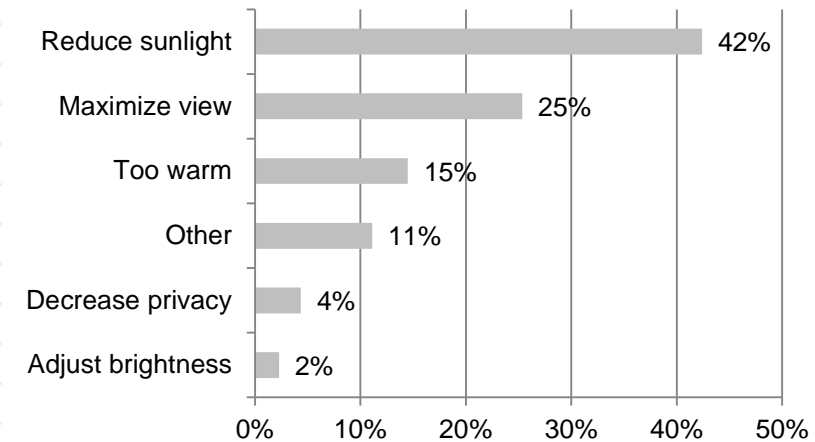# Occupant Studies in Testbed Identify When to (automatically) Close the Blinds....

Probability Blinds are Closed

Probability of pulling blinds versus window luminance:

25%	1200 cd/m²
50%	2100 cd/m²
75%	3000 cd/m²

2000 cd/m² is ~ halfway point between still wanting to keep view and daylight and closing them for discomfort glare or to maintain task visibility

- Blind prob
- — logistic fit

Window Luminance (cd/m2)

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Occupant Response to Automated Shading

80% of all motor groups have an average of: 12 overrides/yr for 11 work hours/yr

20% of all motor groups have: 174 overrides/yr for 408 work hr/yr

17% of all motor groups were never manually overridden

- number of overrides per motor group per year

- total override time (hours/year) per motor group during workhours of 8:00AM-6:00PM
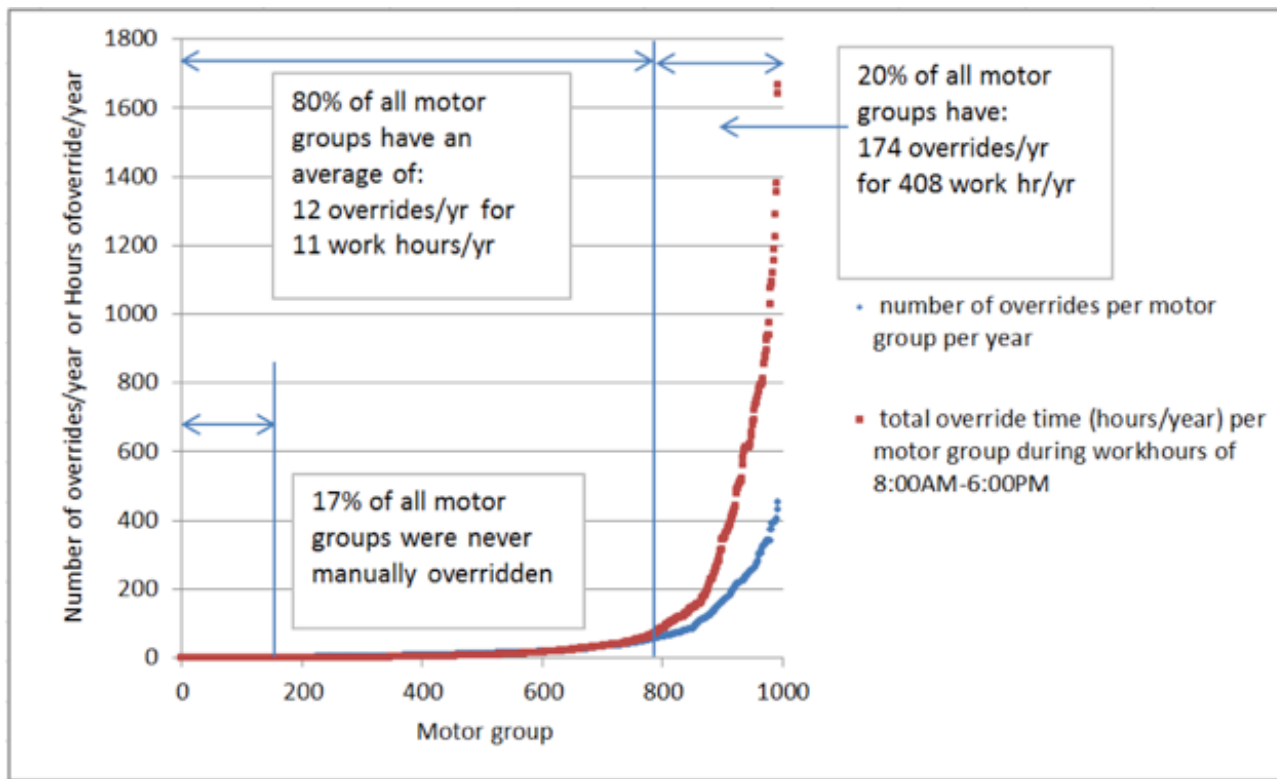
Override data: Answers to "Why did you change shade position?"

| Reason	Percent
Reduce sunlight	42%
Maximize view	25%
Too warm	15%
Other	11%
Decrease privacy	4%
Adjust brightness	2%

Observations:
- "You can't please all the people all the time…."
- Open office environments mixes people and locations; human variability
- New construction on Northwest corner of site – recalibration to exterior site
- Time Clock calibration issues

Occupant Satisfaction is High:
Quality of Light, Visual Comfort

In terms of the overall quality of light in your workpace, are you:

- Very satisfied — 31%
- 29%
- 18%
- Neutral — 12%
- 6%
- 3%
- Very dissatisfied — 2%
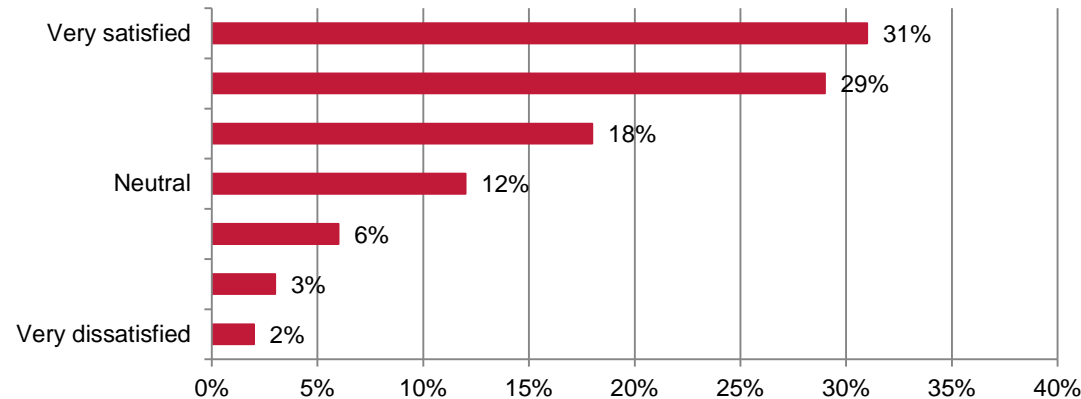
How satisifed are you with the visual comfort of the lighting (e.g., glare, reflections, contrast)?

- Very satisfied — 21%
- 26%
- 19%
- Neutral — 14%
- 11%
- 6%
- Very dissatisfied — 3%
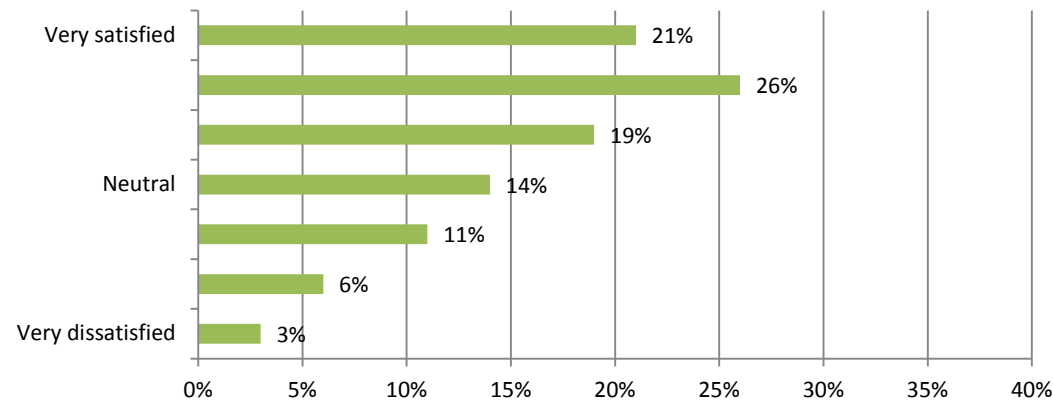
New Building Performance Studies

- **GSA *Green Proving Ground***

  o *Use existing GSA buildings to install, test and evaluate performance of emerging technologies and assess occupant response.*

- **"*Living Laboratory*" floor in high-rise office buildings**

  - *Aggressive retrofit of full floor in buildings*
  - *Occupant response*
  - *Energy assessment*
  - *Cost optimization*

- ***Genentech/Webcor SF Office Building***

  - *FLEXLAB mockup;*
  - *TI optimization- lighting, motorized shading, furniture layout*
  - *Occupant assessment*

- **FLEXLAB:**

  Facility for Low Energy eXperiments in Buildings

FLEXLAB:
Facility for Low Energy EXperiments in Buildings

4 Outdoor Testbeds:
3   1-story
1   2-story

3 Indoor Testbeds
Lighting/Plug Load
Sensors/Controls
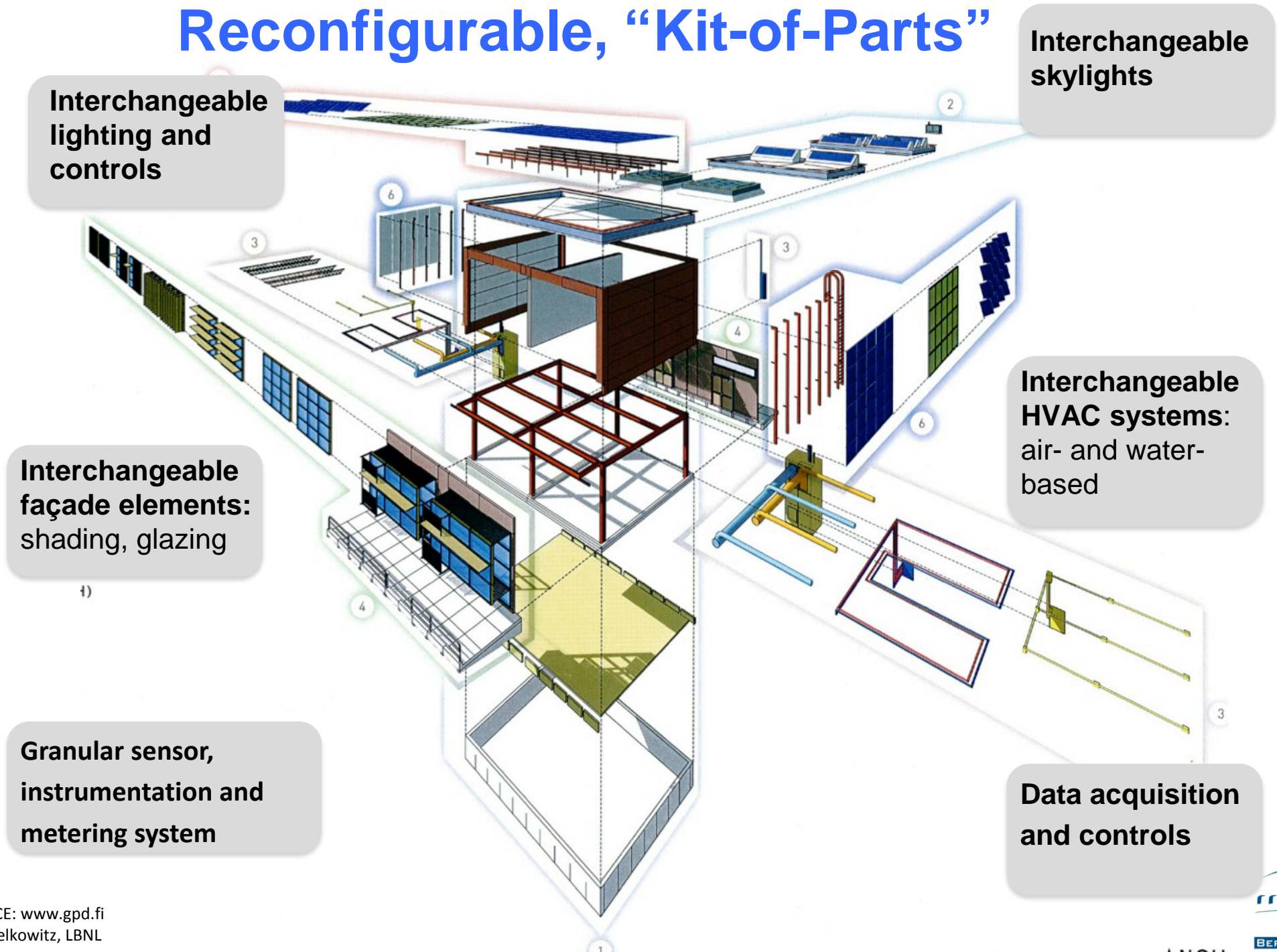Design Lab

Data Acquisition, Monitoring, Control System
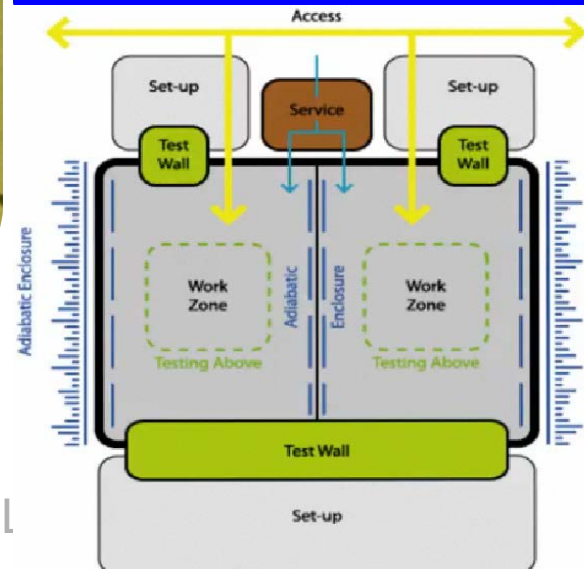
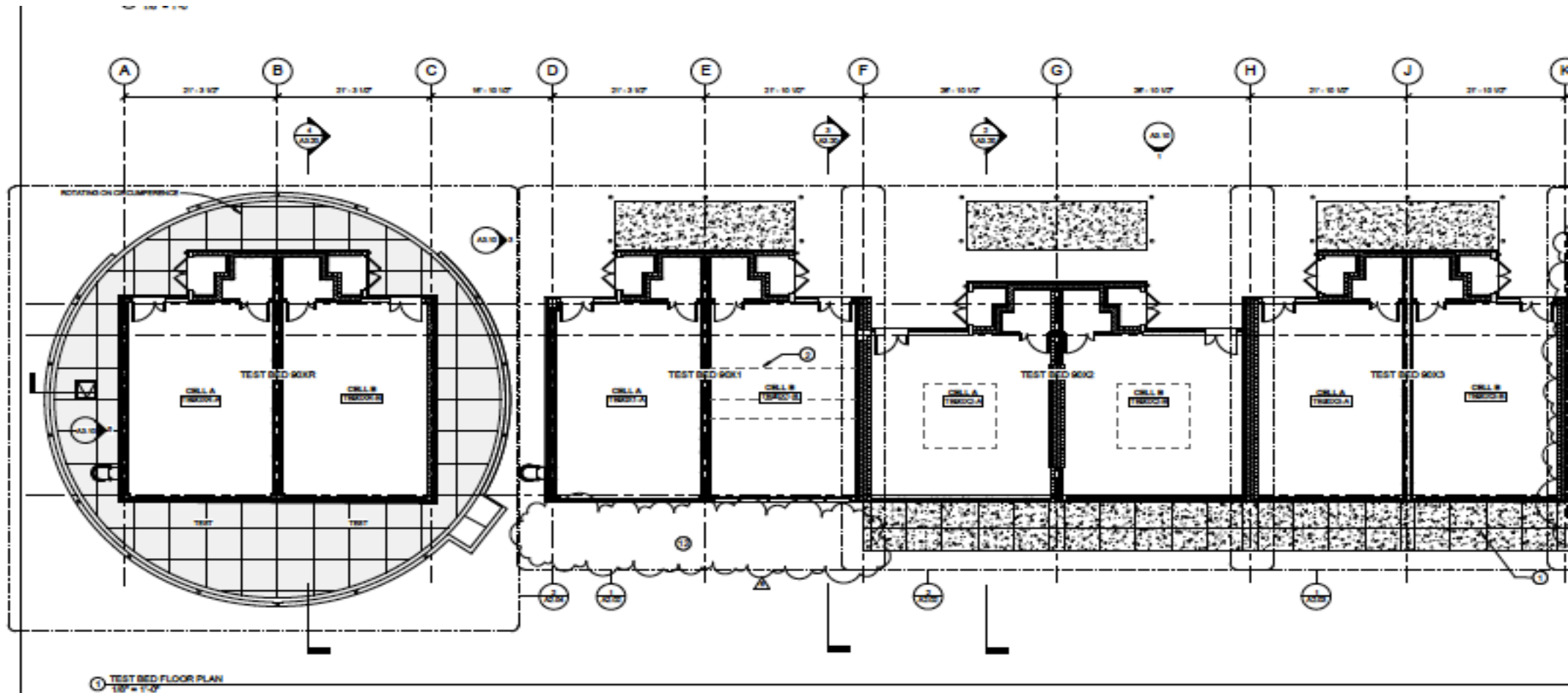# Reconfigurable, "Kit-of-Parts"

Interchangeable skylights

Interchangeable lighting and controls

Interchangeable HVAC systems: air- and water-based

Interchangeable façade elements: shading, glazing

Granular sensor, instrumentation and metering system

Data acquisition and controls

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Plan view of 4 exterior testbeds; rotating unit on left

<- **Rotating Testbed**

Three south facing testbeds

Rotating Testbed Completed 2014
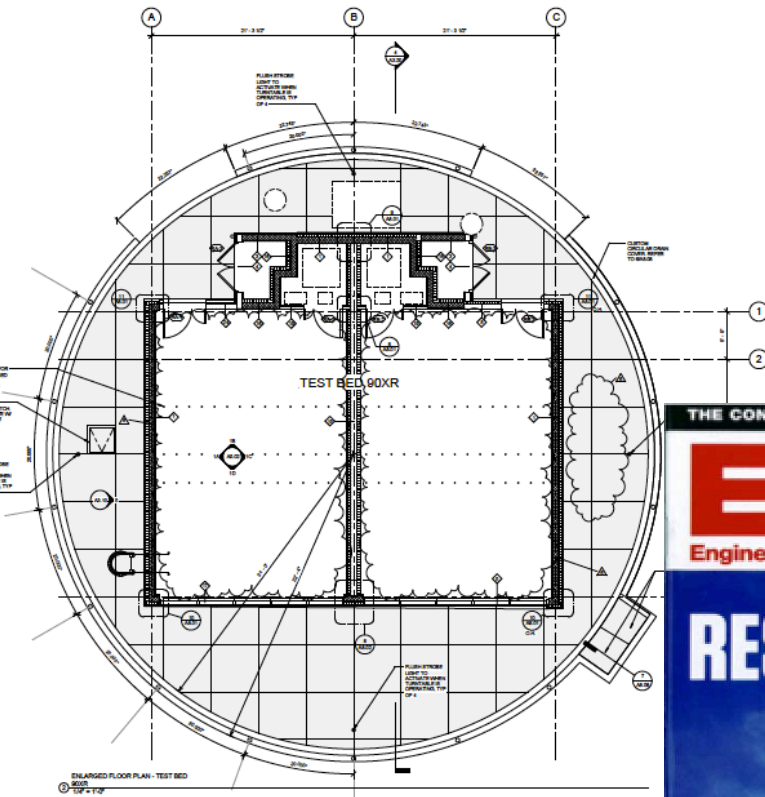
Webcor/Genentech Test Program
250,000 sf Office Building Under Construction

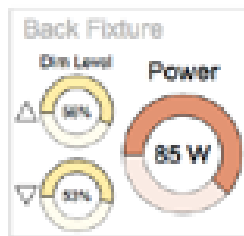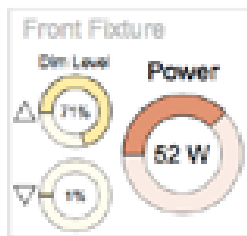Lighting/Daylighting Shading
Evaluation
in FLEXLAB
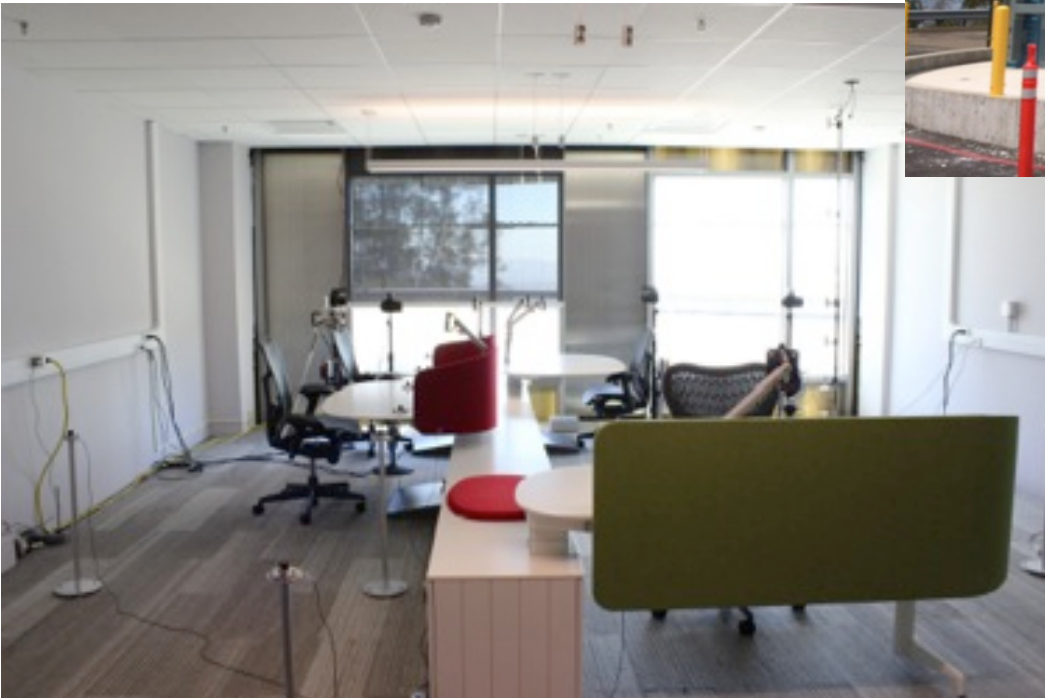
Typical Instrumentation for Evaluating Illuminance Distribution and Glare:
HDR Unit (right) automatically calculates DGP every 5 min and sends data over wifi

- Licor photometer
- HDR Camera
- Thermal Comfort Sensing Package
- Webcam
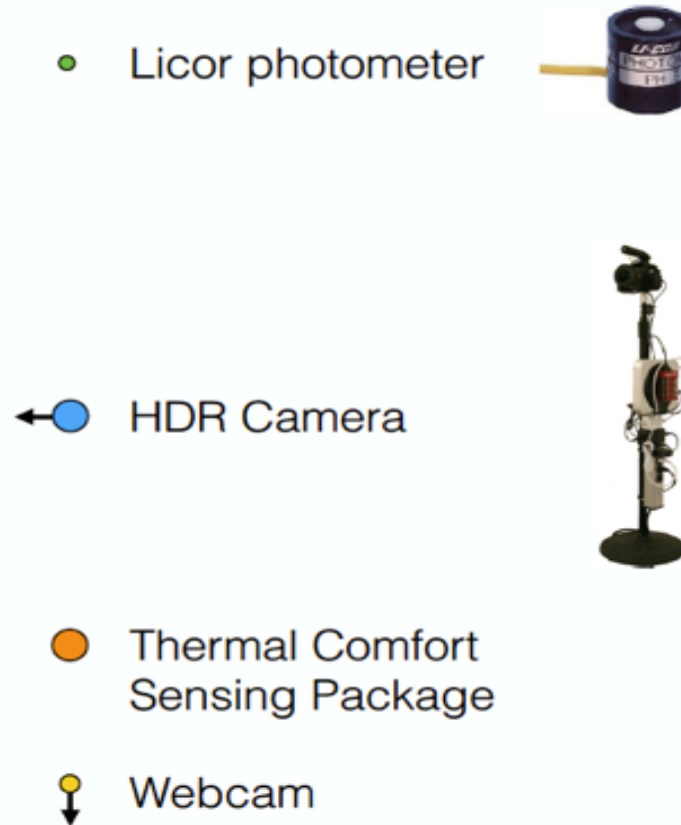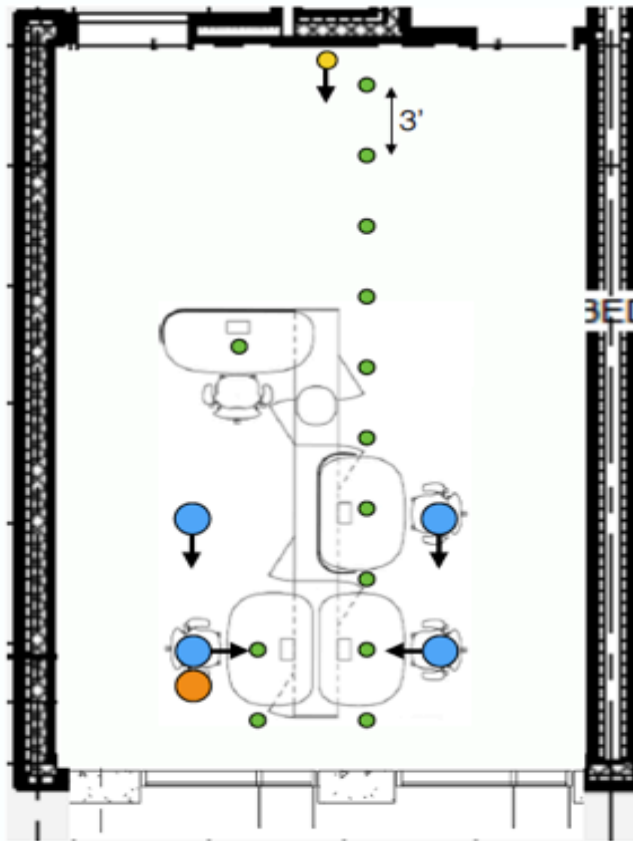
Lighting Levels, Lighting Energy Measurement
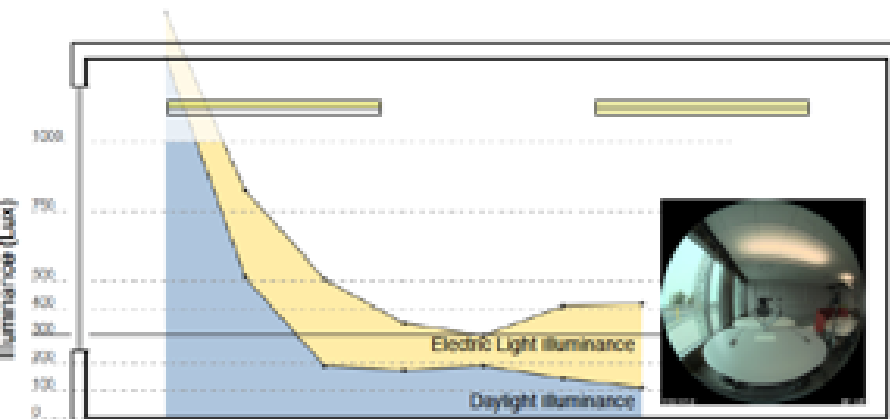
**HDR imaging: 4 viewpoints
Glare evaluated every 5 min.**

- Are the shades working?

- Does the fabric manage glare?

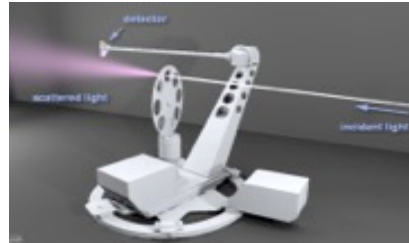- Are daylight levels adequate?

- Are the dimmable lights saving energy?

- Does the furniture layout work well?
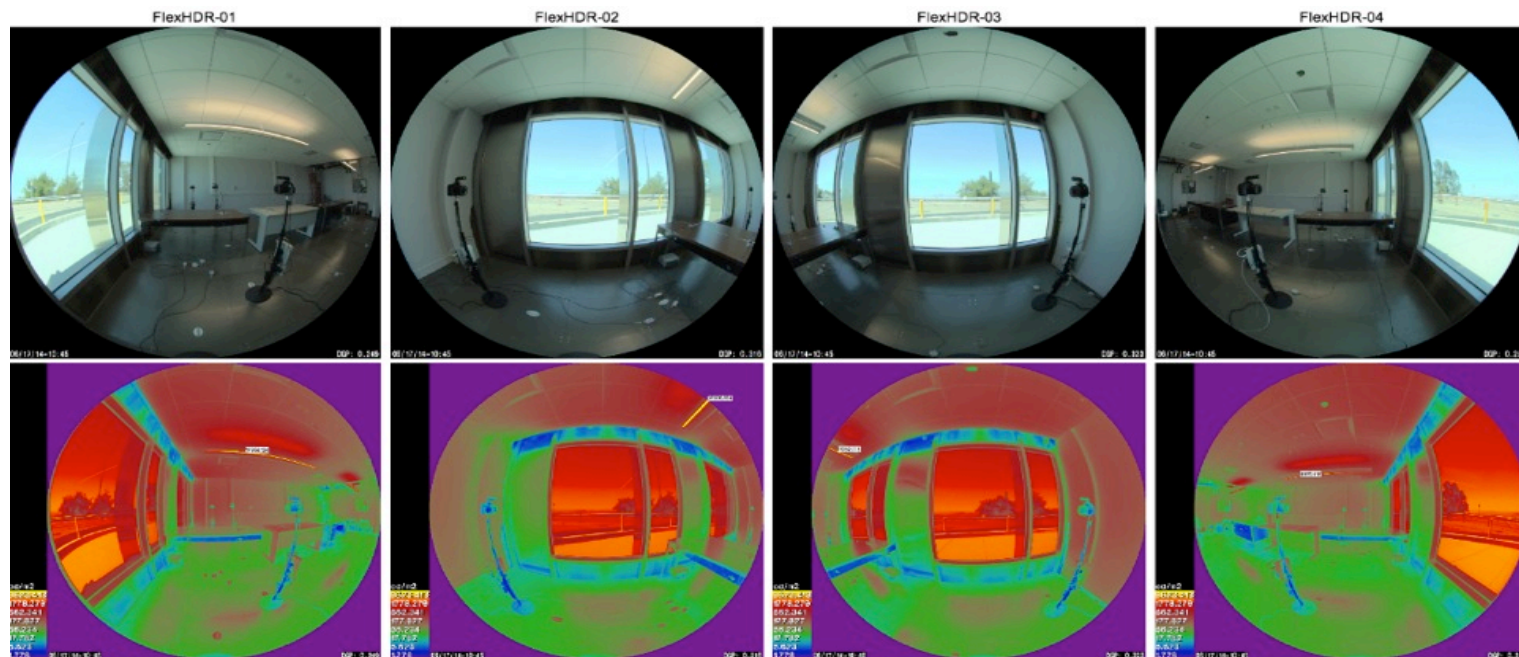
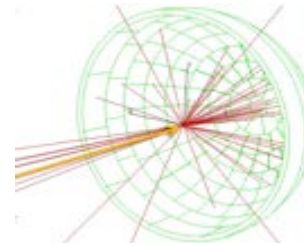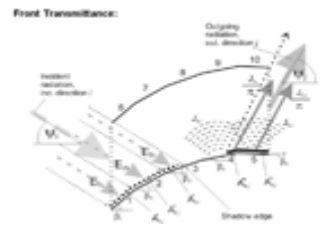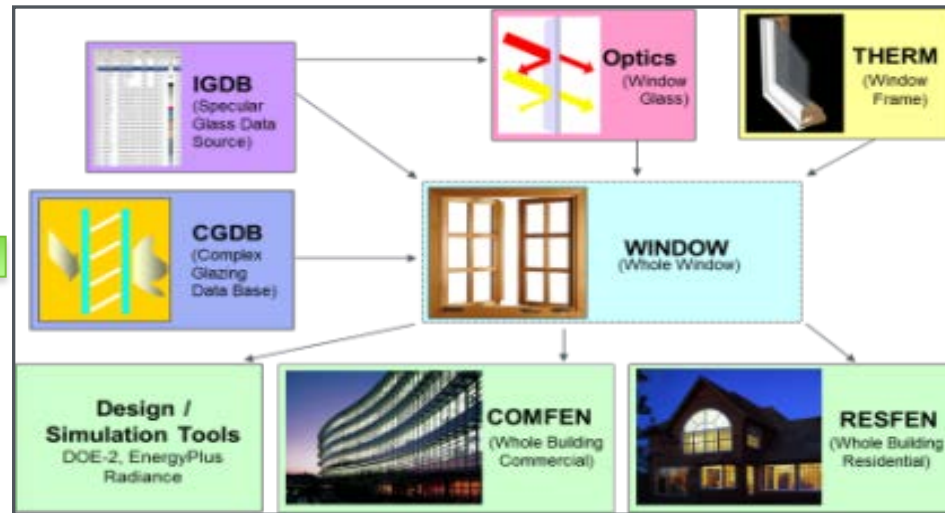# WORKFLOW for CREDIBLE PERFORMANCE SIMULATION

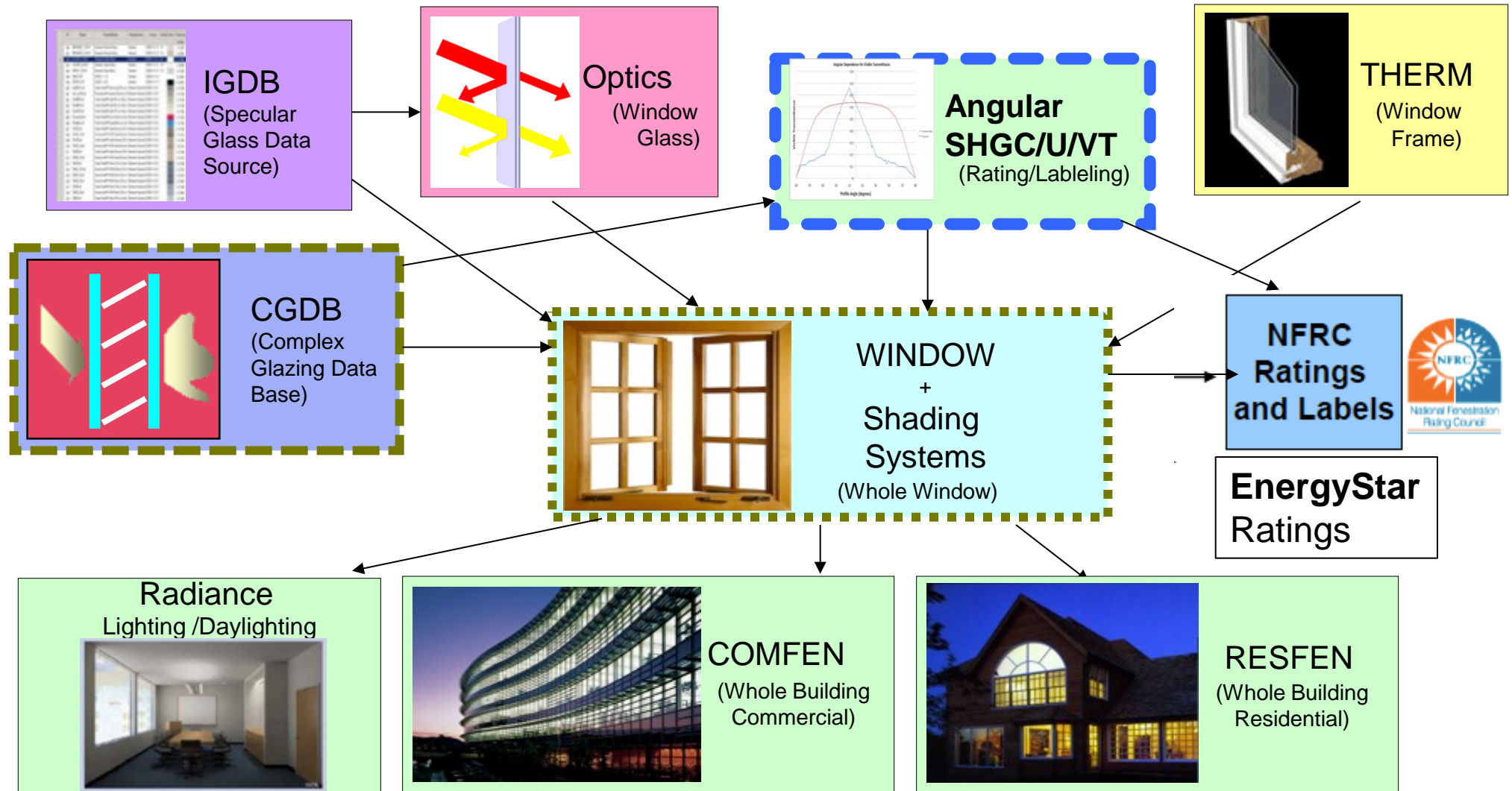Building Science Infrastructure

Product Design

Ratings / Deployment

Tools, Standards, Product Data

Glazing and Façade Decision-Support Tools

Download http://windows.lbl.gov/software/ 2014 ~ 40,000 Downloads

IGDB (Specular Glass Data Source)

Optics (Window Glass)

Angular SHGC/U/VT (Rating/Lableling)

THERM (Window Frame)

CGDB (Complex Glazing Data Base)

WINDOW + Shading Systems (Whole Window)

NFRC Ratings and Labels

EnergyStar Ratings

Radiance Lighting /Daylighting

COMFEN (Whole Building Commercial)

RESFEN (Whole Building Residential)

Commercial Windows Website

Efficient Windows Website

Design /Simulation Tools

Lawrence Berkeley National Laboratory

BERKELEY LAB

Glazing/Shading/Daylighting Measurement and Validation

- **Façade/daylighting test facility**
- **Integrated Systems testbeds**
- Mobile Thermal Test Facility
- IR Thermography chamber
- Large integrating sphere
- Optics laboratory
- **Scanning Goniophotometer**
- HDR Imaging
- Field Data Collection systems
- Commissioning systems

- Virtual Building Controls Testbed
- Daylighting controls laboratory
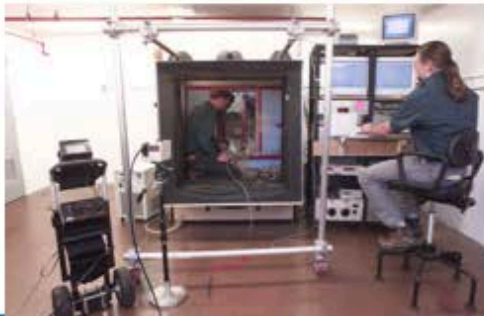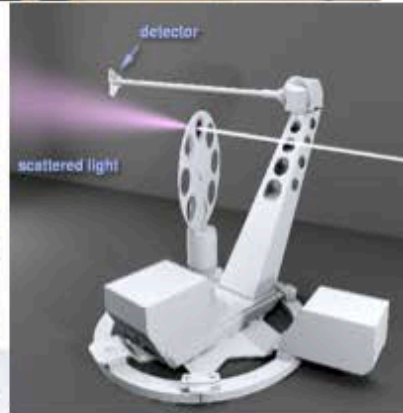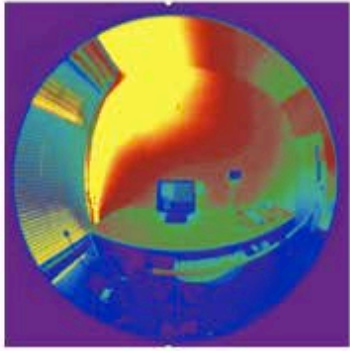
Ex: Creating Optical Properties of Window with Louvered Blinds using WINDOW & THERM 7

- **Louvered Blinds**

Radiance results for Jun 21

COMFEN: Façade Early Design Tool
Download: windows.lbl.gov/software

- Early Design Tool for Façade Systems: Thermal and Daylighting Impacts

- A tool to Optimize Energy Use, Carbon, Comfort…
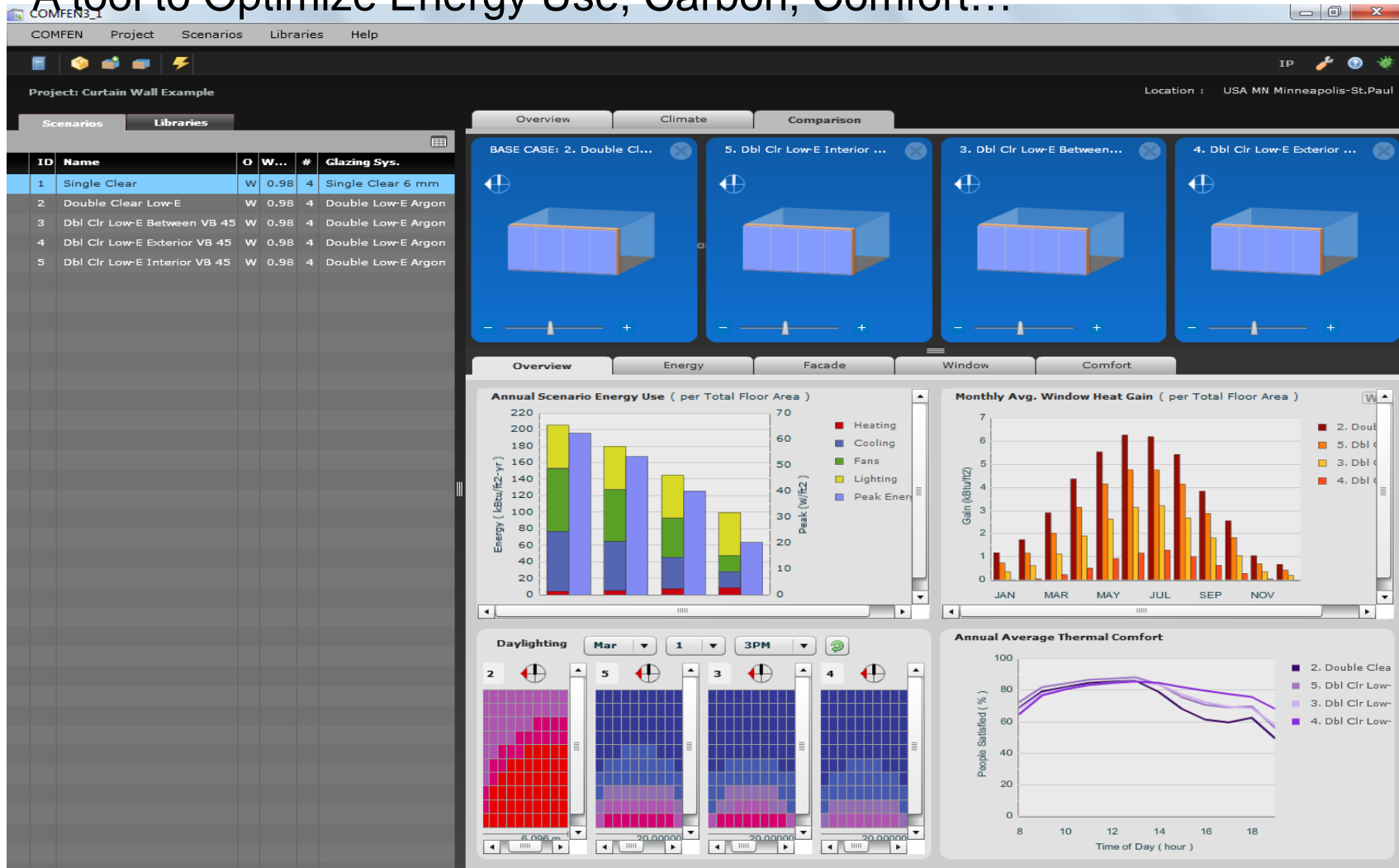
Diving Deeper: Exploring Performance Details
Solar Gain/Daylight/Glare Results

Window solar gain
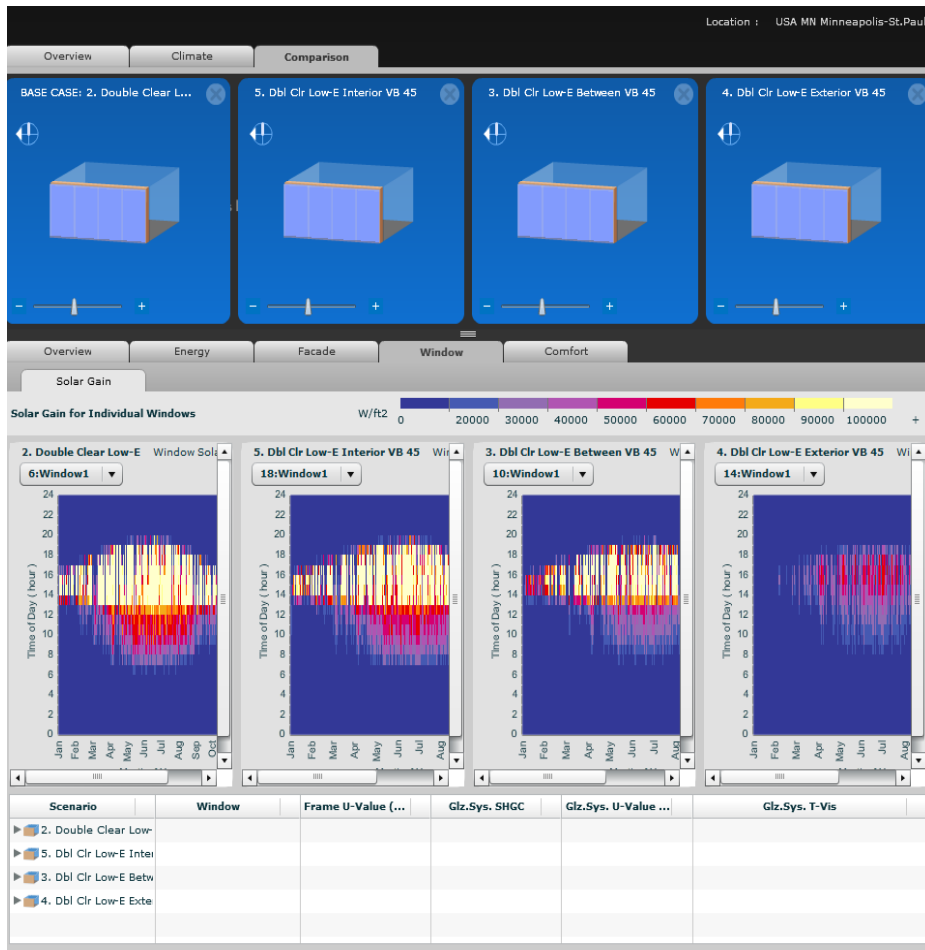
Glare Assessment w/ Radiance
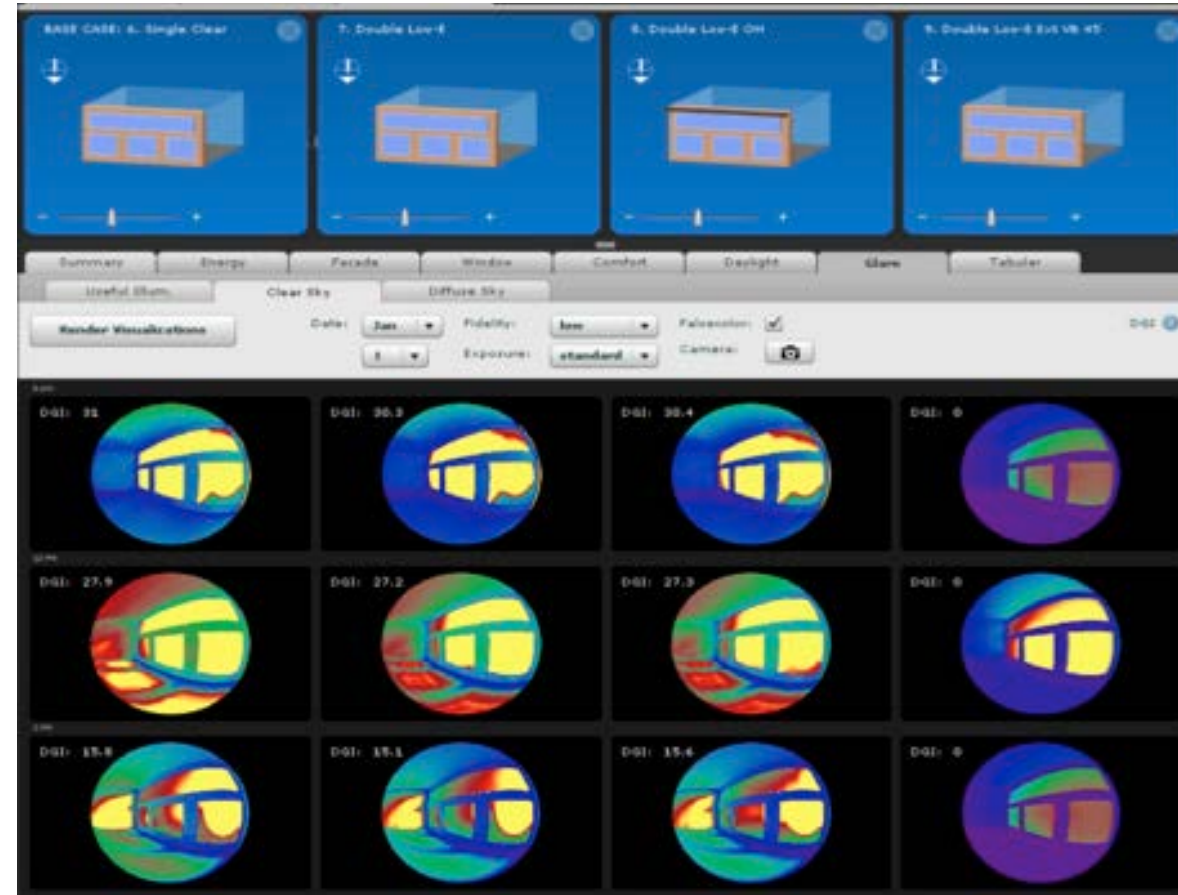
New Features: 5.1: Natural Ventilation, Cost Database; Electrochromics

Active Integrated Perimeter Building Systems
Optimal Performance of Dynamic Systems Requires Integration
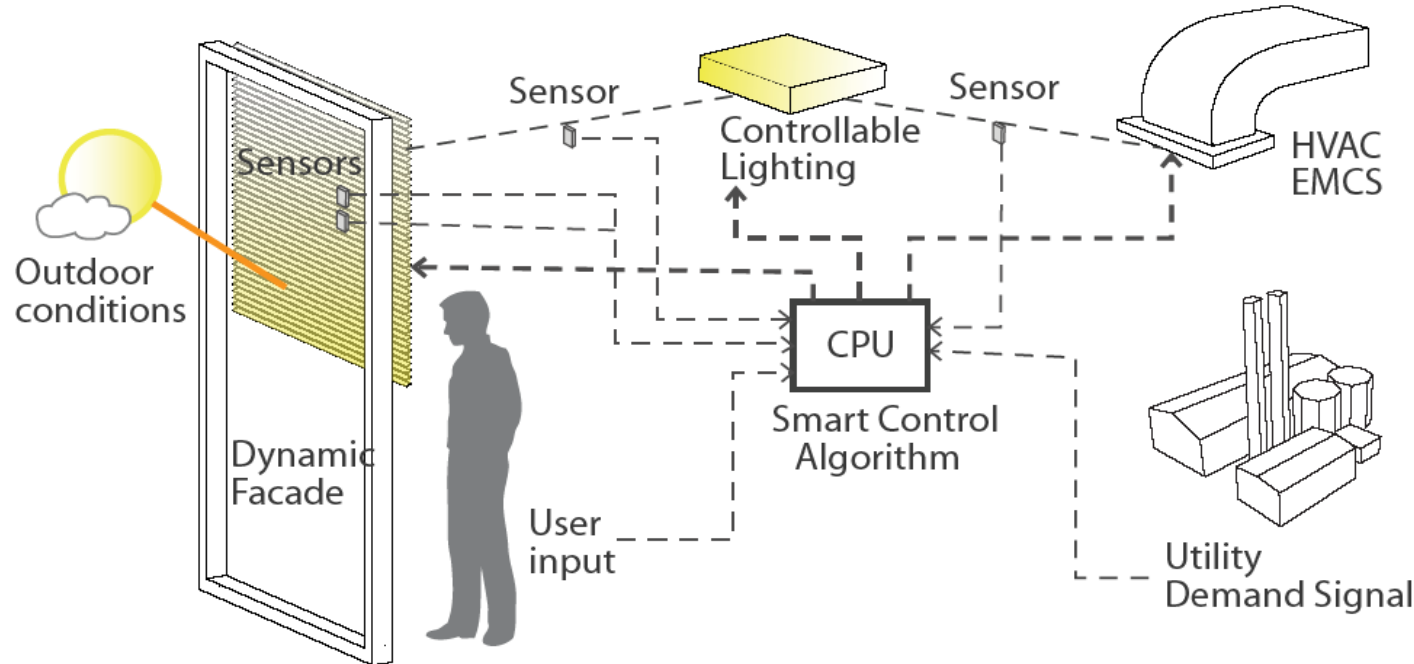
Goal: Plug and Play, Flexible, Responsive, …

Today's Reality: Multiple, incompatible systems, lack of standards

Challenges: Interoperability, Open Systems, Robustness, Low Cost, Resilience,….

Build "The Internet of Things" platform to integrate and link façade systems

Moving Forward: "Measuring" Performance…

- **Continue Movement to Design in Virtual World**
  - More Economical, Powerful Tools on the way…
  - Address most aspects of "performance"
  - Validate Tools with Measured Data
- **Set Design Expectations …. And Deliver Performance**
  - Building ratings, disclosure laws → "Guarantee"??
  - Static → Dynamic Performance
  - Design → Build → Operate : Life cycle solutions
- **New Business Models- Collaboration Across Disciplines**
  - Collaboration Risk but Opportunity
  - Shift from "payback" to broader "value proposition"
- **Field Test Data Critical to Building the Performance Case**

BERKELEY LAB

Capturing Assured Savings

- **New Proven Glazing Technology**
- **Performance Transparency**
- **Importance of Building Controls**
  - "Smart" controls;   Self-diagnostic
  - Learn from occupants
  - Address "Conflict": Occupant- owner-utility
- **Dynamic Load management**
  - "Smart windows" support building response to "grid"
- **Occupant issues**
  - Better environments for people
  - How do people interact with their built environment?
- Understand, quantify performance, reduce costs and risks

How Can You Help Us?

- **Feedback on Tools**
  – Try them; provide feedback
  – Crowd source cost data
- **Case Studies:**
  – Data on technology and process
- **Engage with FLEXLAB**
  – Partnerships for Field testing
- **Feedback on Occupant issues**
  – Fixed vs Dynamic; Manual vs Automated
- **Transform Markets –**
  – Market for New Offerings at Lower Cost

More Information

Stephen Selkowitz
E-mail: **SESelkowitz@lbl.gov**

Current information and downloads at:

http://buildings.lbl.gov

http://flexlab.lbl.gov

http://facades.lbl.gov

http://windows.lbl.gov/resources/LBNLresources.pdf

http://wem.lbl.gov

http://windows.lbl.gov/comm_perf/newyorktimes.htm