CSI Building Product Manufacturers Alliance: Roadmap to Energy Efficiency and Sustainability, December 9, 2008

High-Performance Commercial Building Facades

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Lawrence Berkeley National Laboratory

Where do we want to go?

- Reduce building energy use: one of many "stabilization wedges" towards reducing carbon emissions to 2005 levels[1]
- 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/

[1] **Pacala, S. and R. Socolow**. Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies. *Science* 305: 968-972.

Can we attain Zero-Energy goals?

- EnergyPlus simulations used to estimate ***technical*** potential of reaching ZEB goals across the entire US commercial buildings sector (all building types) and to prioritize technologies
- Energy efficiency reduced sector-wide consumption by 43% on average.
- With photovoltaic PV rooftop systems and unrestricted export of power across the grid, 62% of commercial buildings can reach net zero if buildings first complied with ASHRAE 90.1-2004.
- No *single* technology was found to produce dramatic improvements in efficiency
- *Combinations* of efficiency measures resulted in larger reductions than use of individual measures alone.

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

Technology comparison of impacts

R10 Switchable windows

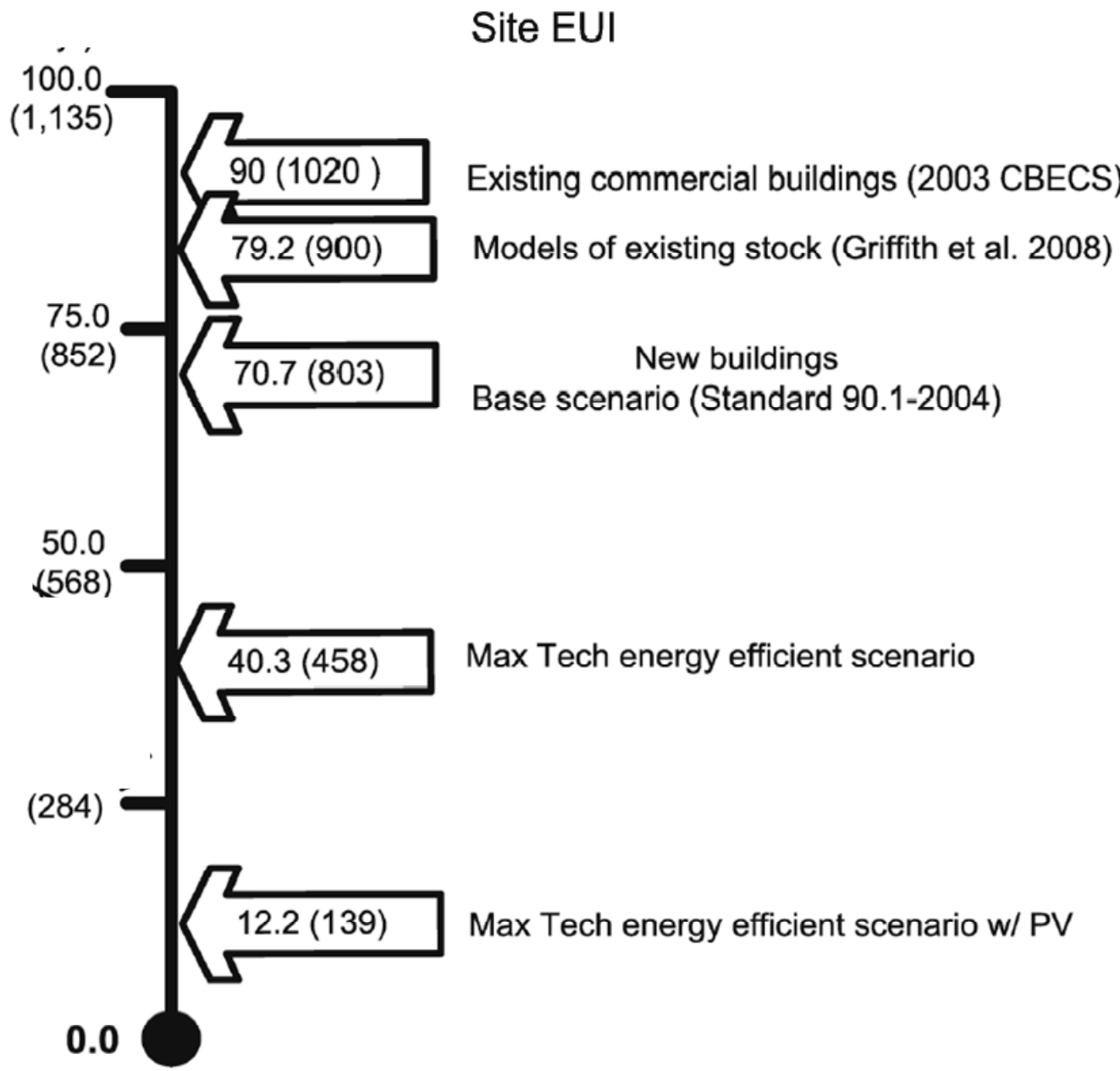
- SHGC=0.40-0.06,
- Tv=0.65-0.02
- **7.5%** average reduction in sector wide EUI

Solid state lighting

- 80 lumens/W → 160 lumens/W
- **10%** average reduction in sector wide EUI

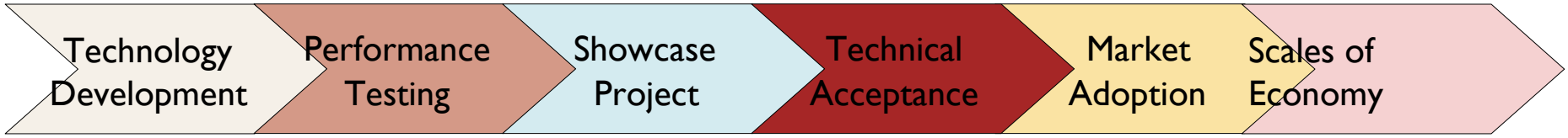
Opaque insulation increased

- From ASHRAE 90.1-2004 to 189P levels
- **7%** average reduction in sector wide EUI

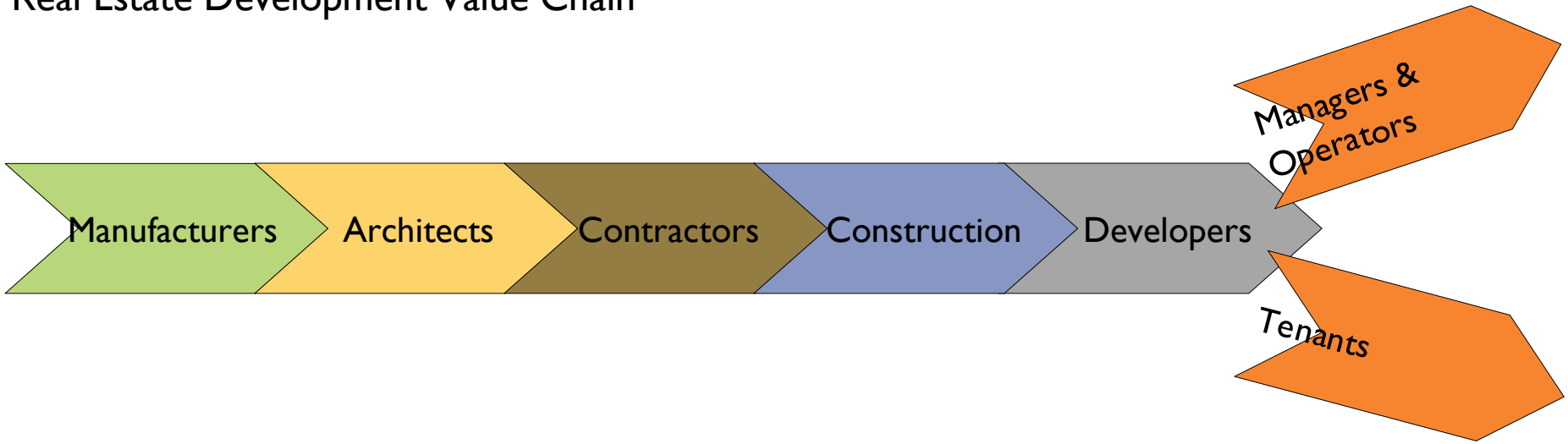


Adopting Innovation: Risk-Averse, Fragmented Value Chain

Product Development Value Chain



Real Estate Development Value Chain



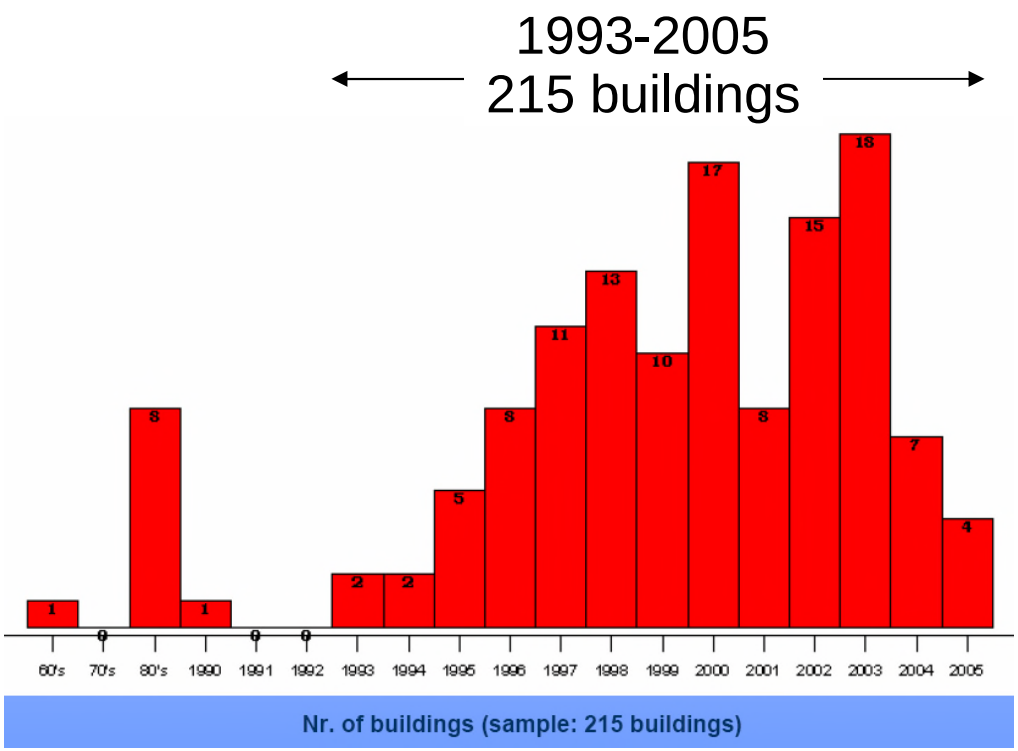
Where are we today?

Pre-1990s: Occasional use of smart facades (Hooker Building with double-envelope facade, Bateson Building, etc.).

1990s: Landmark status double envelope facades used in numerous EU buildings

2000s: Interest in smart façade technologies and systems increasing

- Increased pressure to deliver smarter buildings with greater functionality in a competitive marketplace: *market differentiation*
- Decreased cost for networked intelligent whole building systems
- Increasing interest in optimizing performance across multiple parameters → sustainable architecture



IEA-ECBCS Annex 44 Perino and Serra
Advanced Integrated Facades: An Overview,
March 2006.

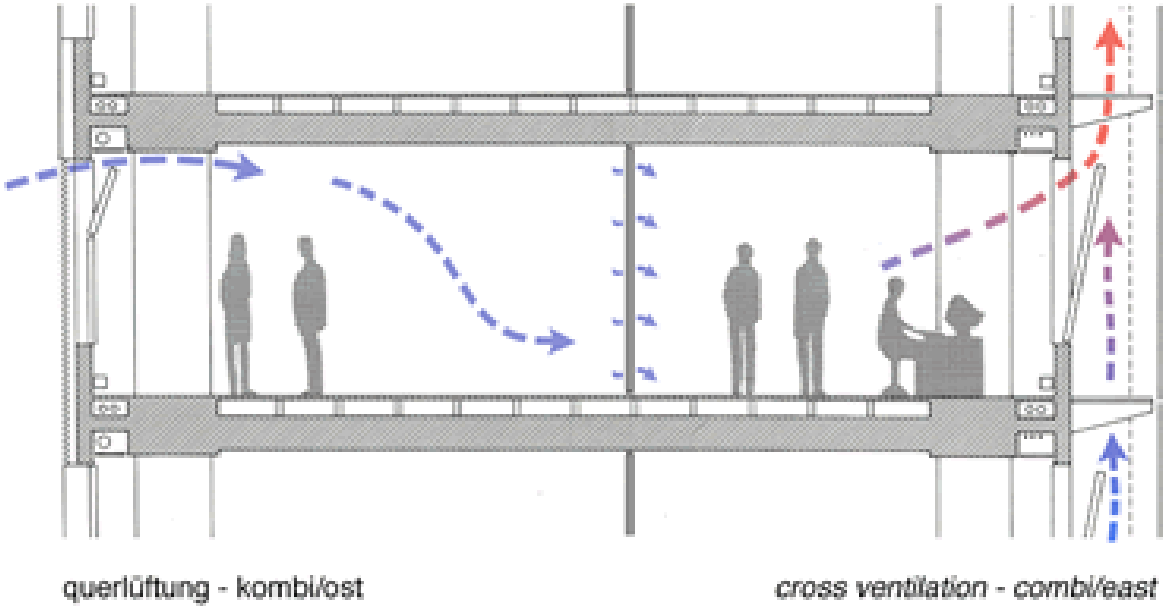
Lingotto Factory Conversion, Turino, Italy

Open horizontal louvers if part of façade is shaded by urban obstructions (and there are no other control constraints)

Example: Automated louvers,

European Commission Headquarters, Berlaymont, Brussels, Belgium

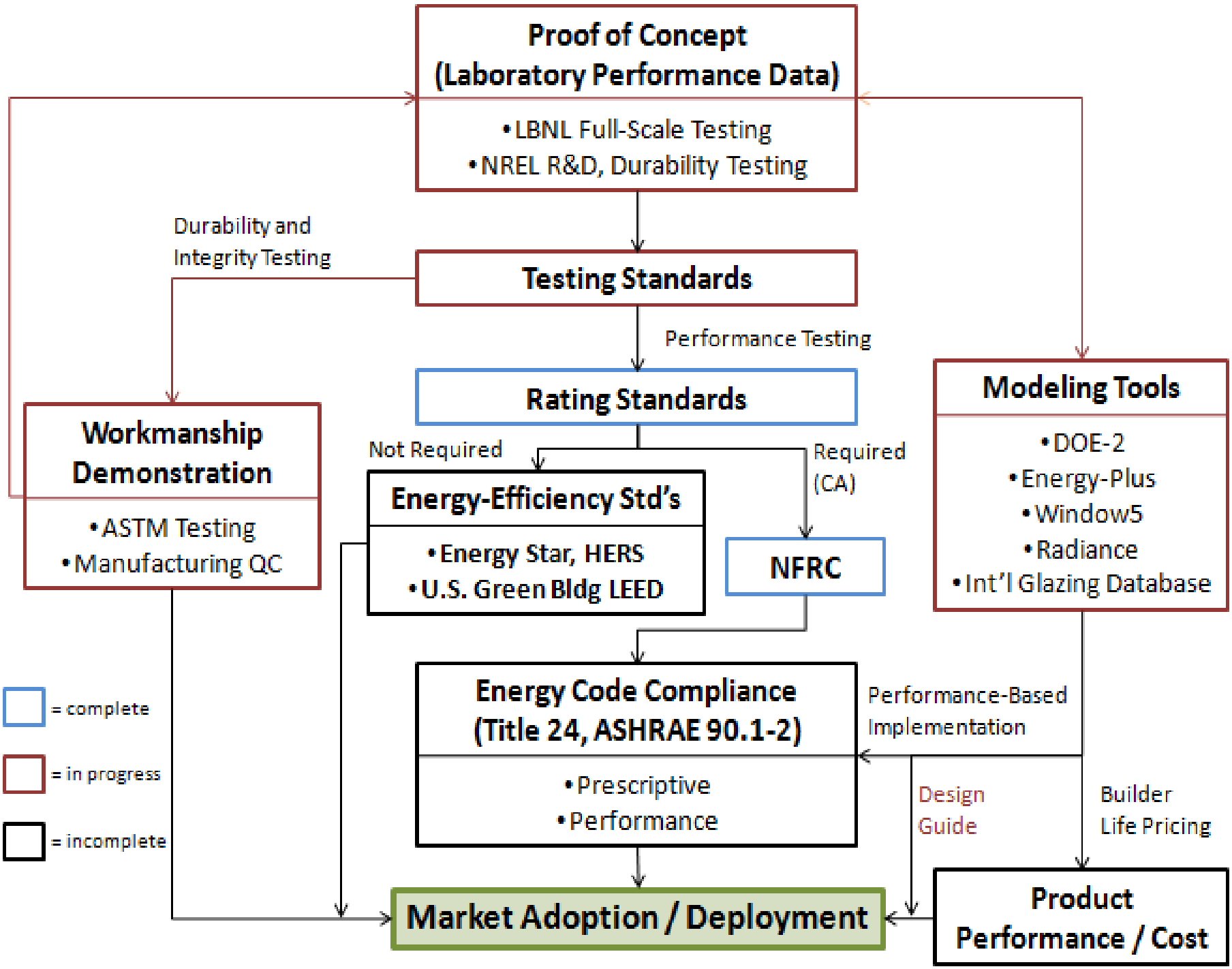
Exhaust-air façade
with operable window shades



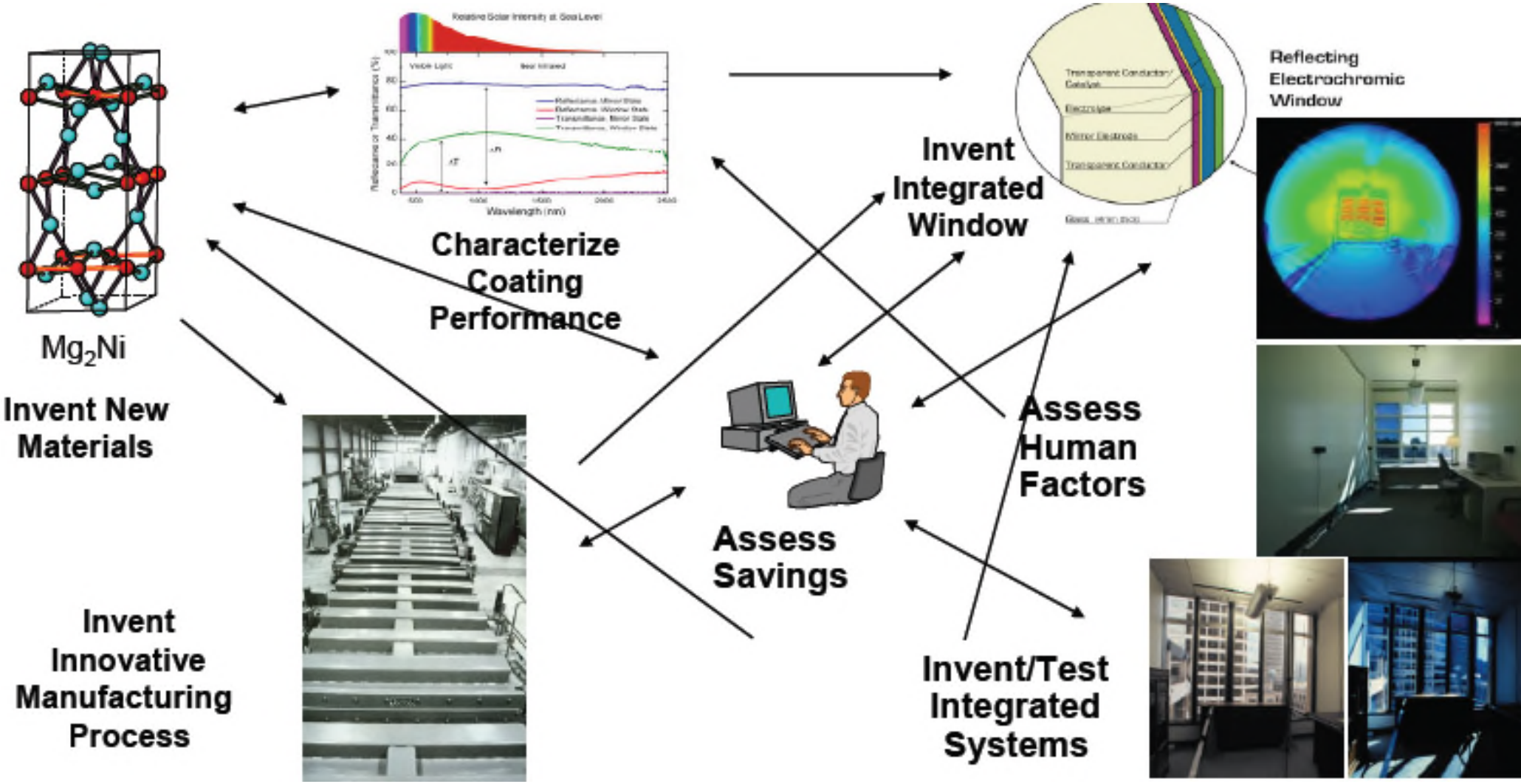
GSW's Eco Skyscraper, Berlin (52°N)
Architect: Saurbruch Hutton
Completed: 1998

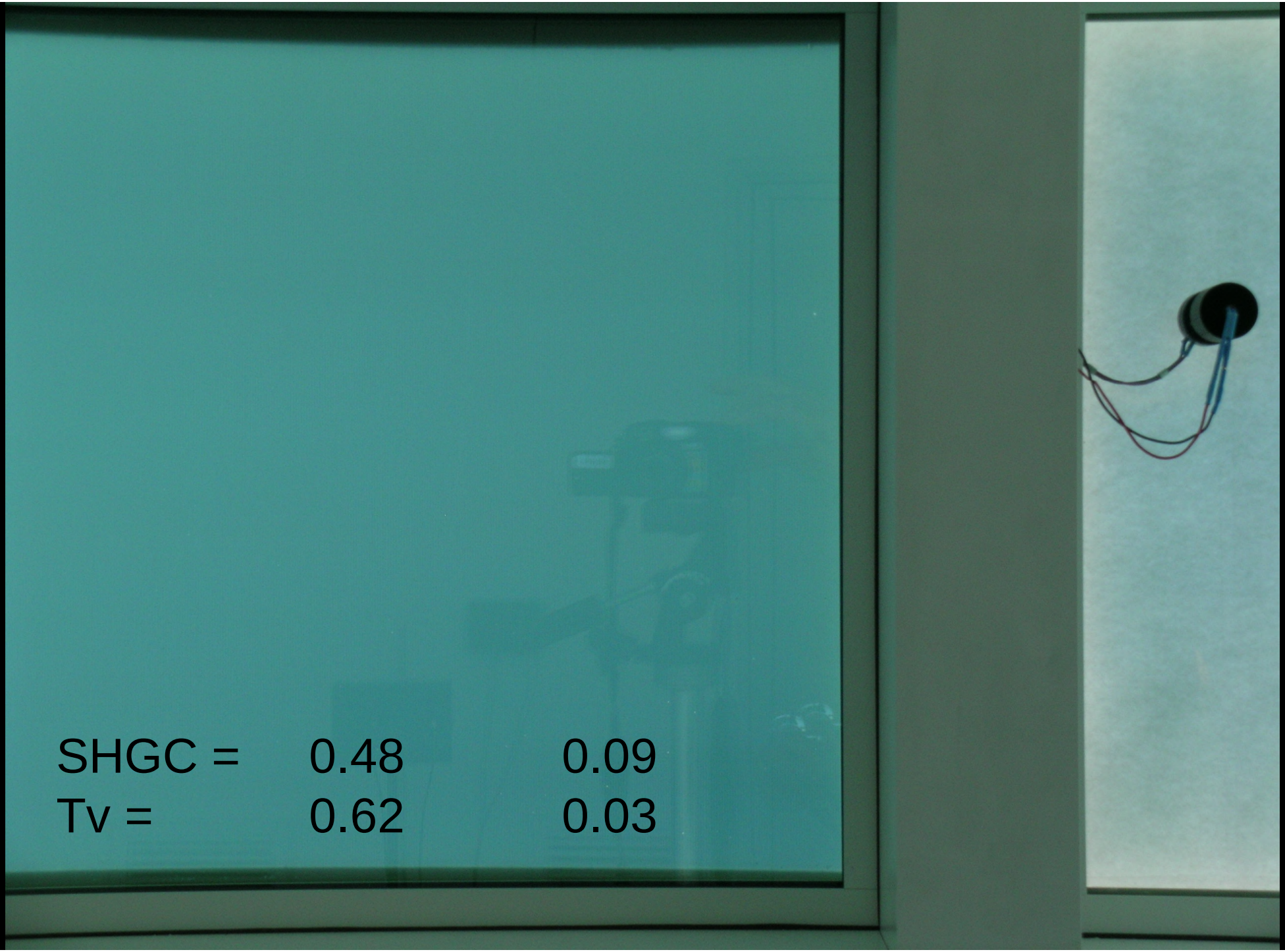
An “Intelligent” Facade

- **Provide solar control**
  - Block direct sun to avoid thermal and visual discomfort
    - ASHRAE 55 Thermal comfort: subject is not irradiated by direct sun
    - IES RP-1-04: orb of sun is not within field of view
  - Control solar heat gains to minimize heating or cooling energy use and ensure thermal comfort
    - Collect solar heat gains and distribute as a heating source
    - Reject solar heat gains to reduce cooling loads
- **Provide comfortable daylight**
- **Provide fresh air** to interior while minimizing noise
- **Enhance occupant health, comfort, and performance:** maintain view to outdoors, combat SAD, etc.
- **Reduce operational cost** based on energy cost signal from the utility
- **Gather energy** (photovoltaics)


Proof of Concept
(Laboratory Performance Data)
• LBNL Full-Scale Testing
• NREL R&D, Durability Testing
Durability and
Integrity Testing
Testing Standards
Performance Testing
Rating Standards
Modeling Tools
• DOE-2
• Energy-Plus
• Window5
• Radiance
• Int'l Glazing Database
Workmanship
Demonstration
• ASTM Testing
• Manufacturing QC
Not Required
Required
(CA)
Energy-Efficiency Std's
• Energy Star, HERS
• U.S. Green Bldg LEED
NFRC
Energy Code Compliance
(Title 24, ASHRAE 90.1-2)
• Prescriptive
• Performance
Performance-Based
Implementation
Design
Guide
Builder
Life Pricing
= complete
= in progress
= incomplete
Market Adoption / Deployment
Product
Performance / Cost

Electrochromic Windows R&D




SHGC = 0.48 0.09
Tv = 0.62 0.03

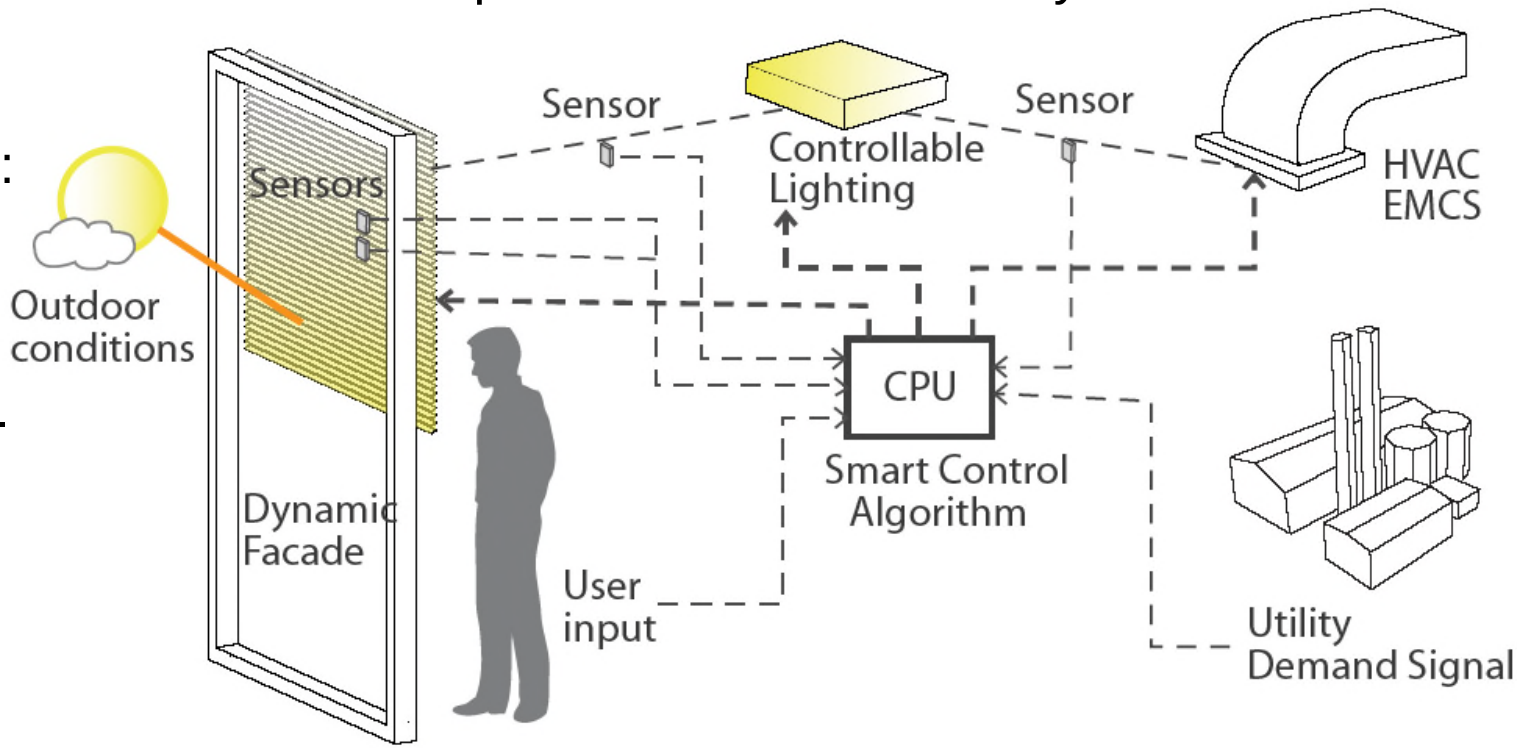
If Glare and Solar Control is so important, Why not integrate this function into the glazing?

Switchable electrochromic glazings (dimmable via 0-3VDC)

Definition of a smart building skin

Interior or exterior **sensors** that measure relevant quantities that are used by the controller

Operable façade components: Motors or actuators for shading devices, light-redirecting elements, operable windows, or switchable glass coatings

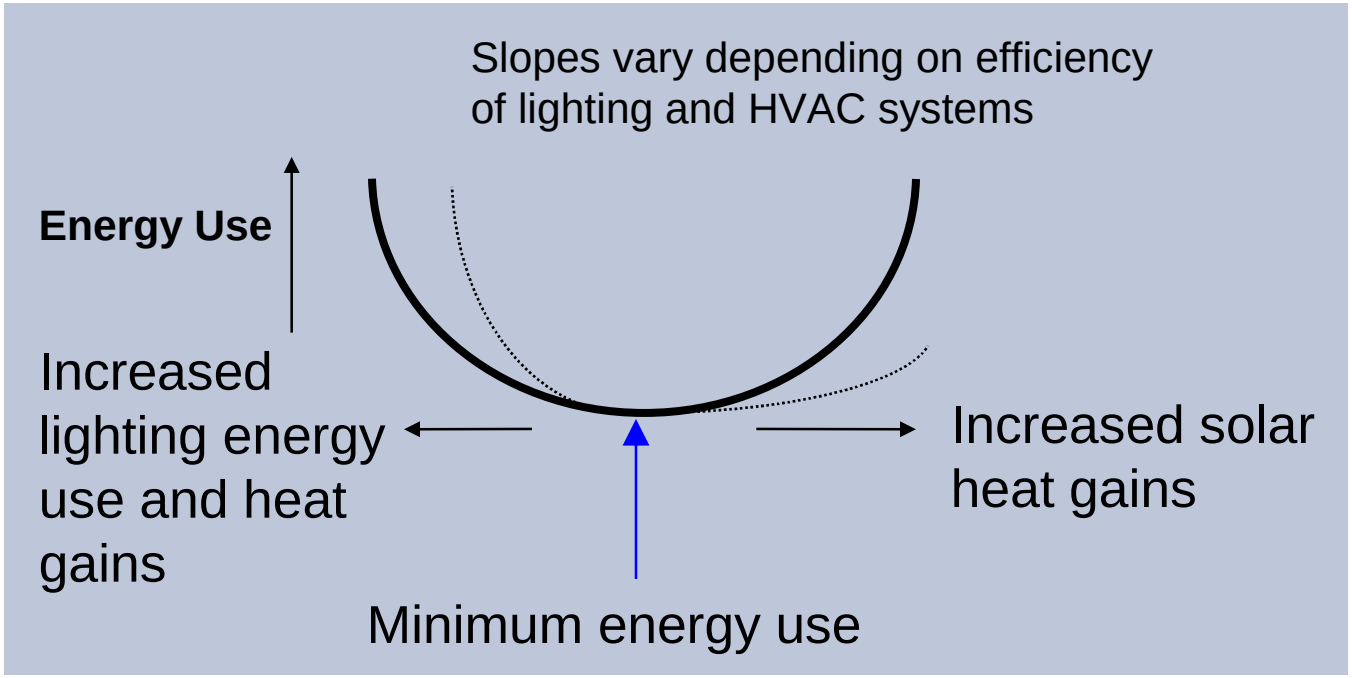


Control algorithms: Accepts input from sensors or computations then determines how to position the operable façade components

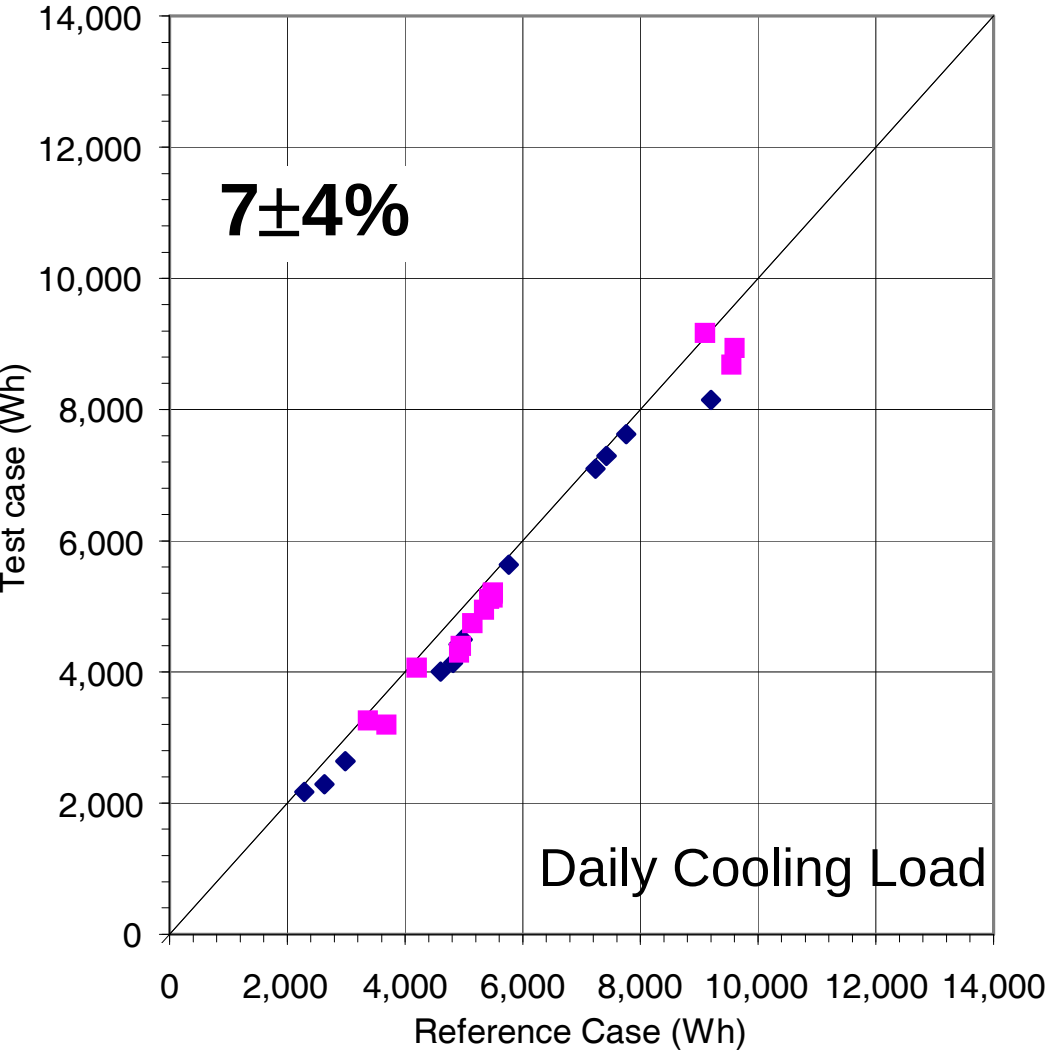
LBNL Windows Testbed

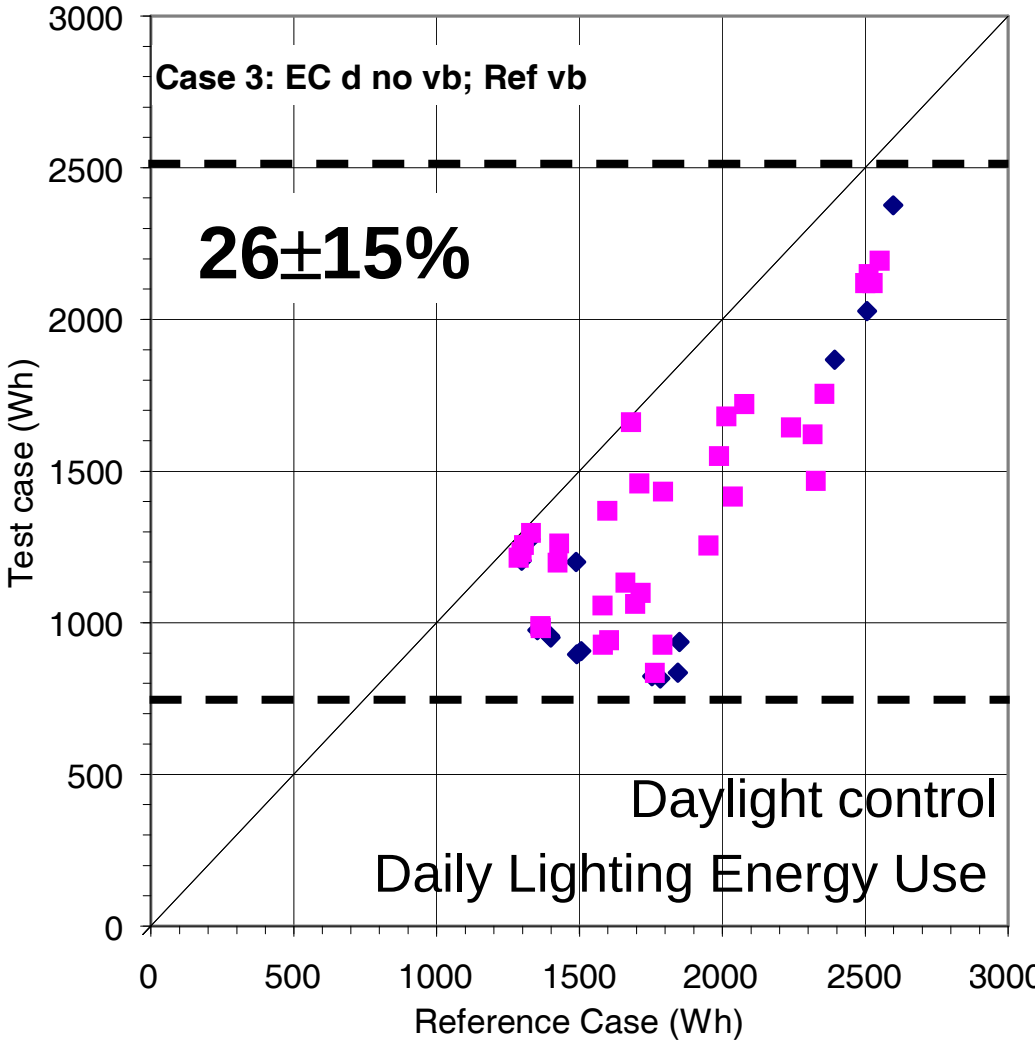
Integrated Facades Approach

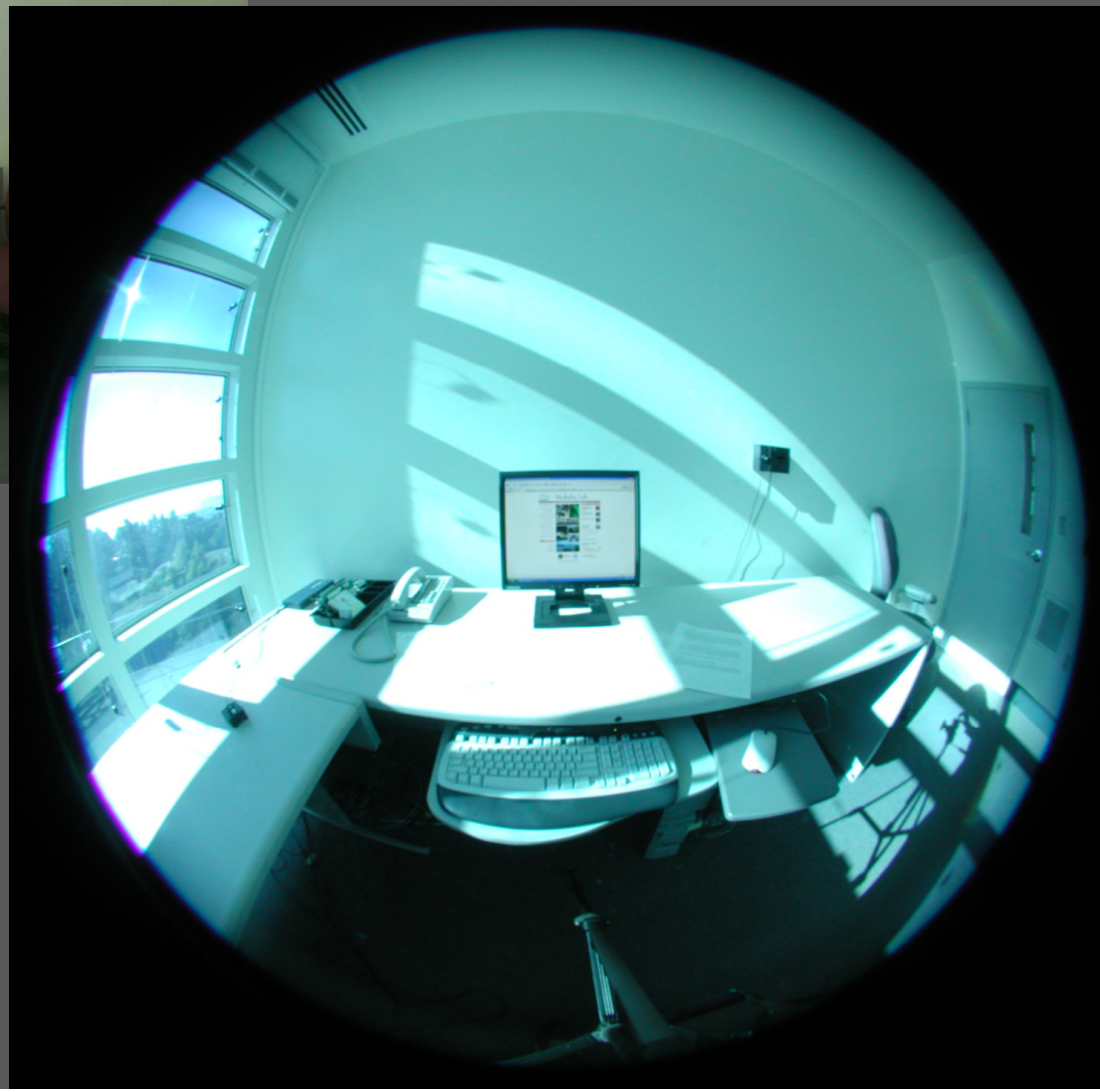
- *Ideal:* Integrated approach to façade-lighting-HVAC building systems to achieve optimum energy-efficiency and comfort.



Occupied: SS Low-E with blinds vs EC with daylight control, no blinds

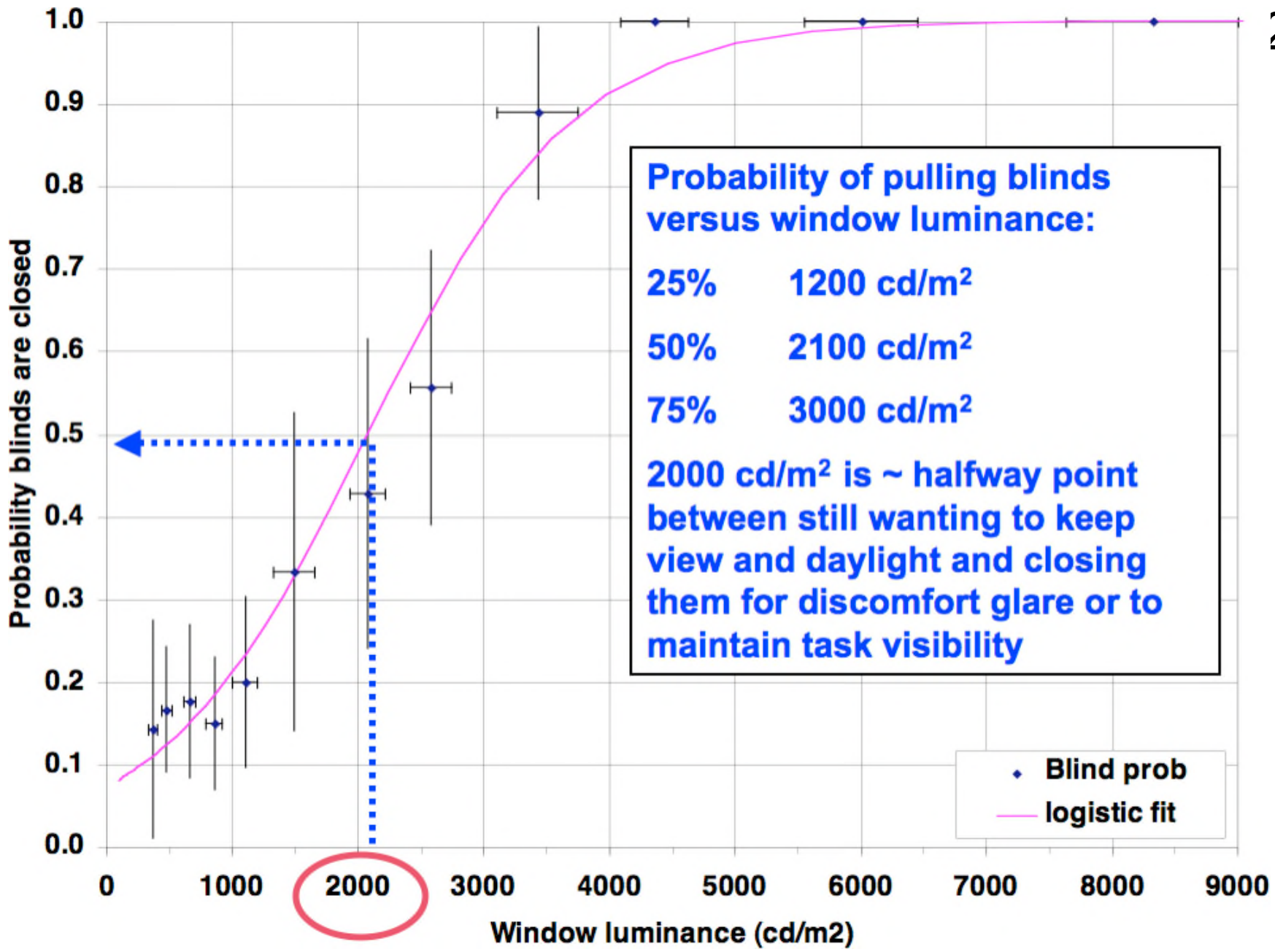


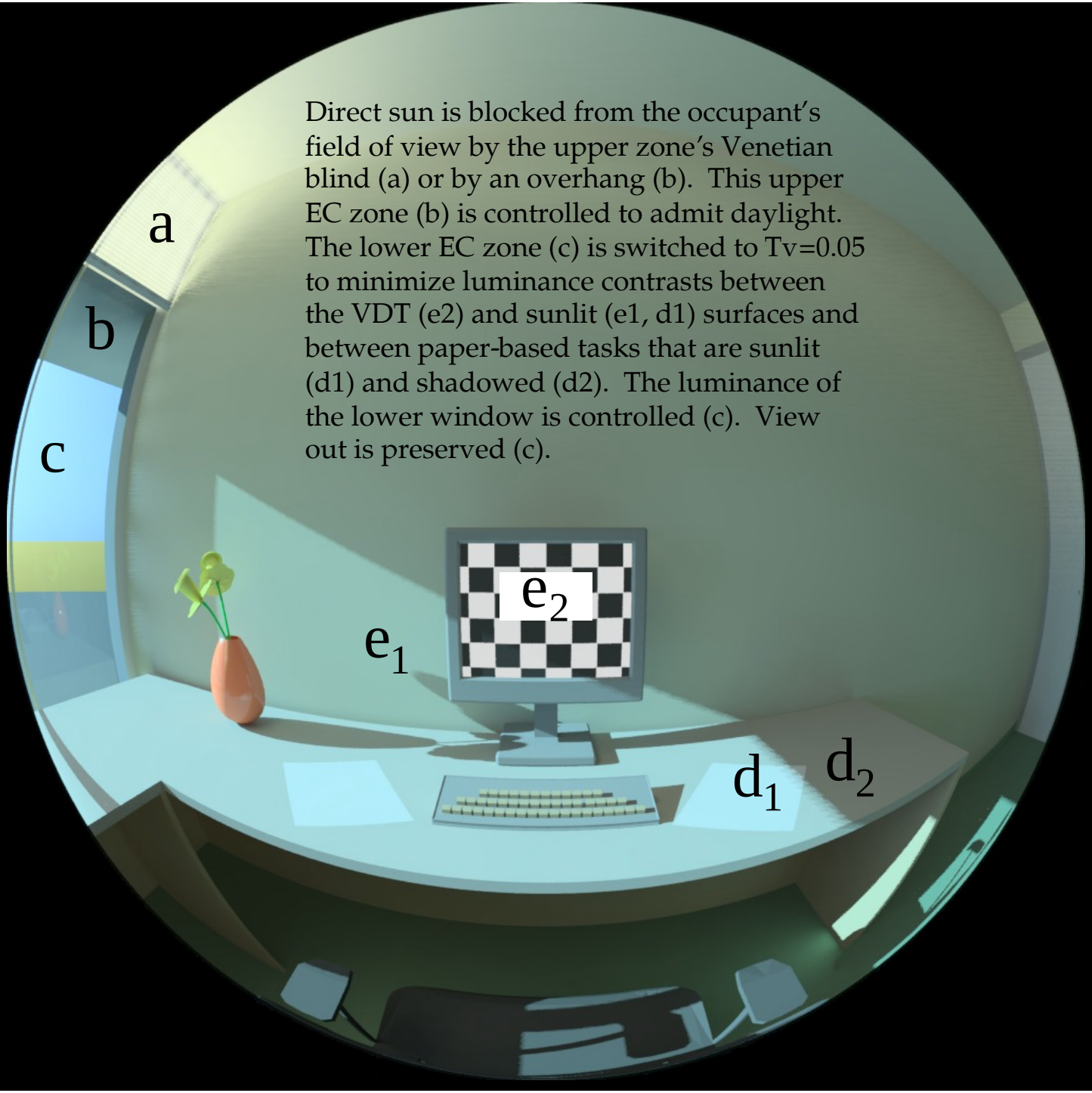




Human subjects study in LBNL windows test facility

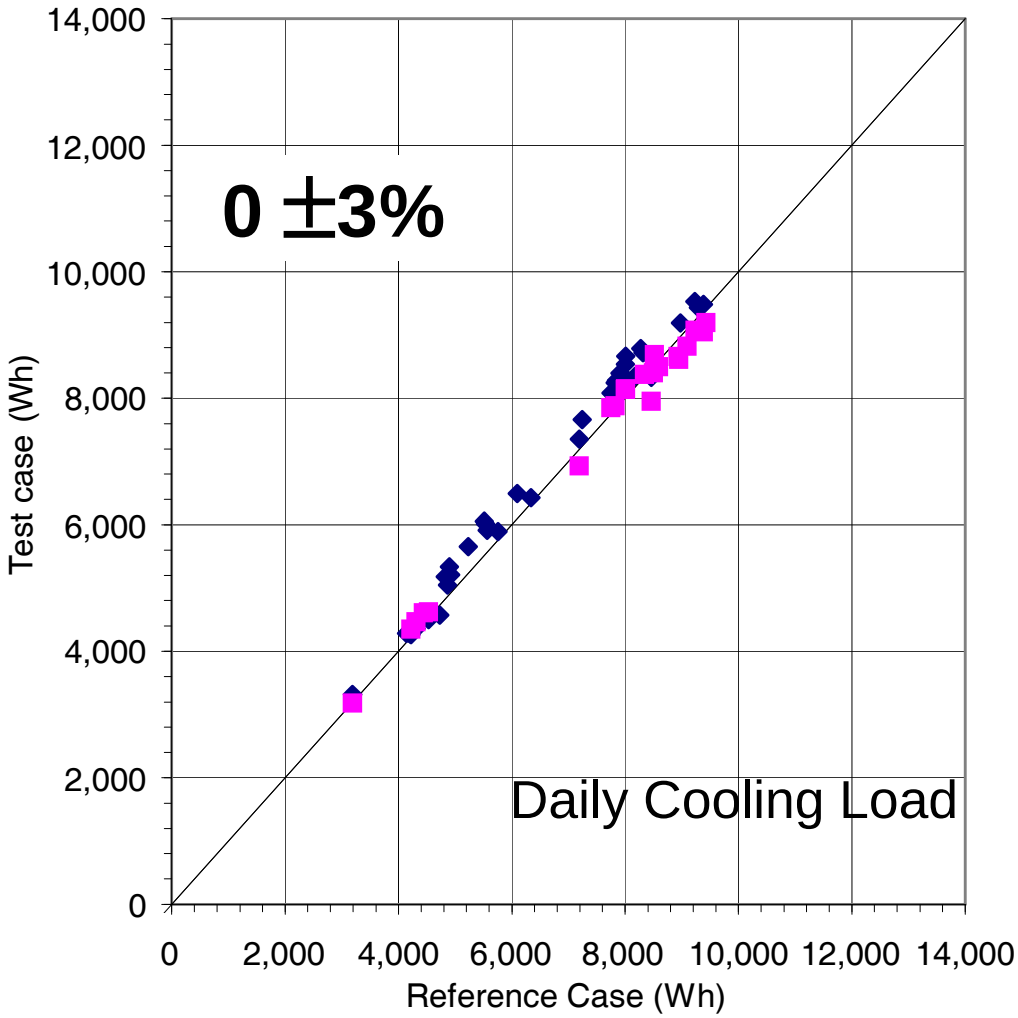
(switchable electrochromic windows)

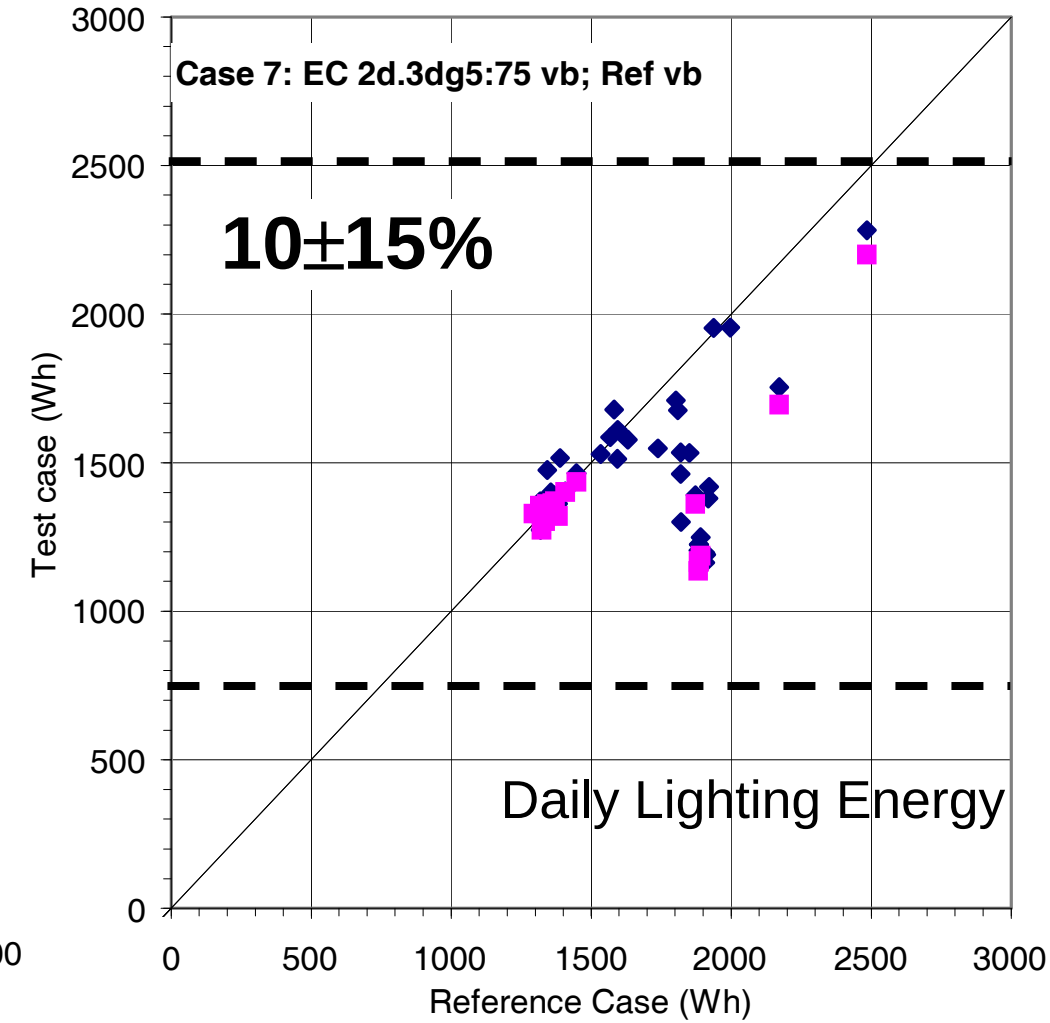

Probability of pulling blinds versus window luminance:
25% 1200 cd/m²
50% 2100 cd/m²
75% 3000 cd/m²
2000 cd/m² is ~ halfway point between still wanting to keep view and daylight and closing them for discomfort glare or to maintain task visibility
Blind prob
logistic fit
Probability blinds are closed
Window luminance (cd/m2)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1000
2000
3000
4000
5000
6000
7000
8000
9000



Direct sun is blocked from the occupant's field of view by the upper zone's Venetian blind (a) or by an overhang (b). This upper EC zone (b) is controlled to admit daylight. The lower EC zone (c) is switched to Tv=0.05 to minimize luminance contrasts between the VDT (e2) and sunlit (e1, d1) surfaces and between paper-based tasks that are sunlit (d1) and shadowed (d2). The luminance of the lower window is controlled (c). View out is preserved (c).

SS Low-E with blinds vs EC with daylight/glare control





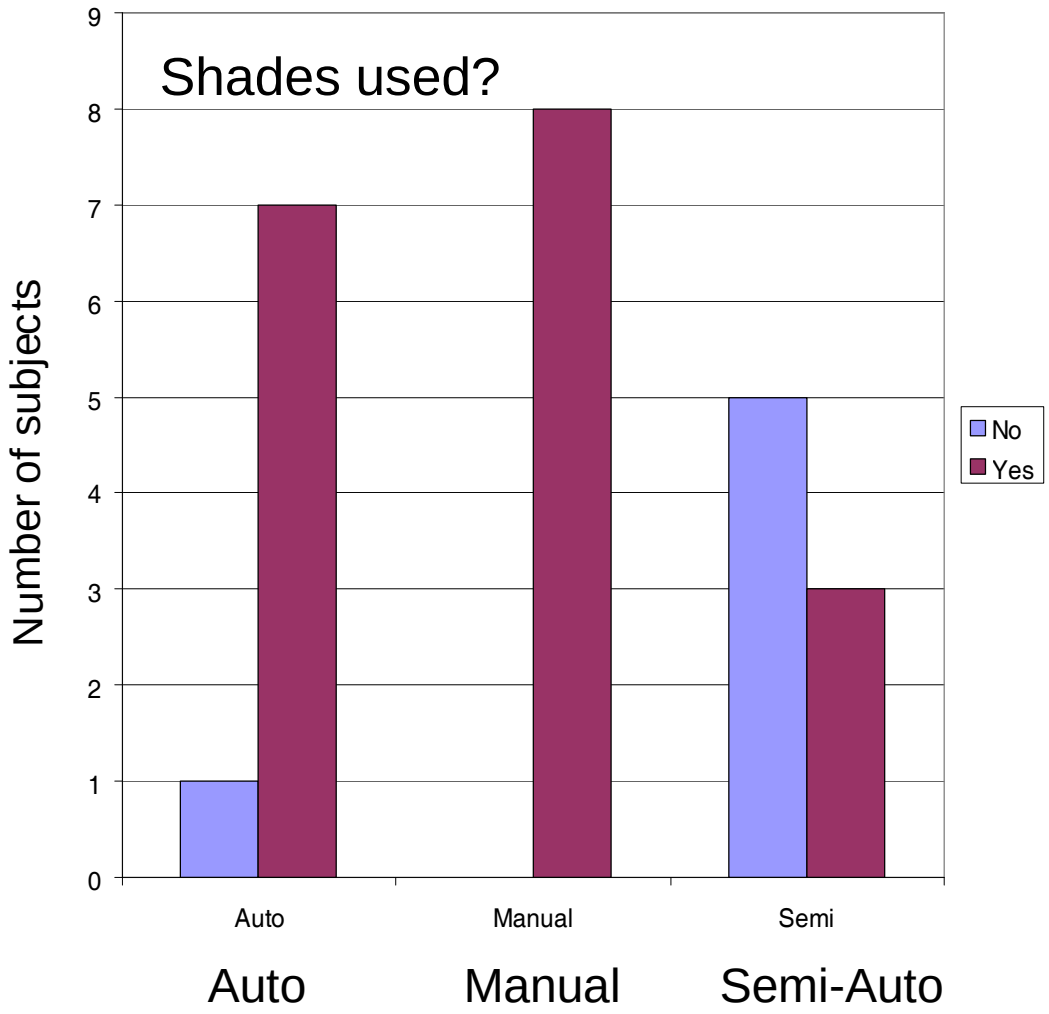
Human Factors

- **The semi-automatic and automatic modes of the EC were judged significantly more desirable than the reference mode (static window with Venetian blind)**
- Occupants were more satisfied with the EC window control system than the reference mode due to:
  - Glare control
  - Control of reflections on the computer screen
  - Ability to control windows and lighting system
- (South-facing, winter solstice test) With EC windows, Venetian blinds pulled definitively when window luminance exceeded 3000-4000 cd/m^2
- Size, switching speed and color were not major barriers to acceptance

Human factors: EC + shade use

- Subjects used the blinds significantly <u>less often</u> when they had some control over the EC window tinting and electric lighting.

- Semi-automatic and automatic modes resulted in significantly less blind use than reference mode. Blinds were fully raised for:
  - 77% of sessions in semi-automatic mode
  - 79% of sessions in automatic mode



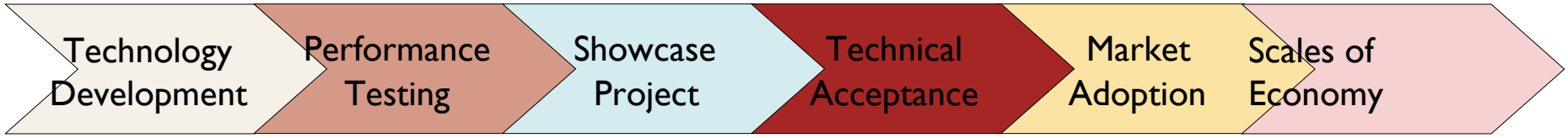
Experimental results - EPFL

Controller type	Energy saving	Thermal comfort (satisfaction)	Visual comfort (satisfaction)	Rejection after 4 weeks
Manual	**0 %**	**84 %**	**86 %**	**-**
Smart, not adaptive	**25 %**	**84 %**	**88 %**	**25 %**
Smart, adaptive to user's preferences	**24 %**	**86 %**	**89 %**	**5 %**

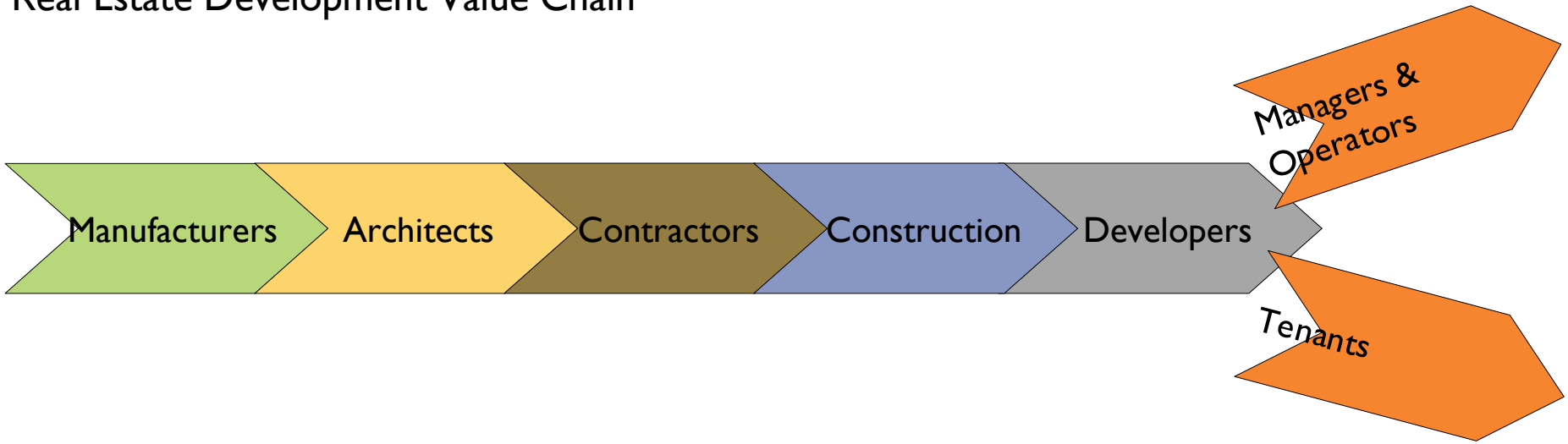
Guillemin, A. 2003. Using genetic algorithms to take into account user wishes in an advanced building control system. PhD. Dissertation, Ecole Polytechnique Federale de Lausanne (EPFL).

Adopting Innovation: Risk-Averse, Fragmented Value Chain

Product Development Value Chain



Real Estate Development Value Chain



The New York Times Headquarters, New York, NY

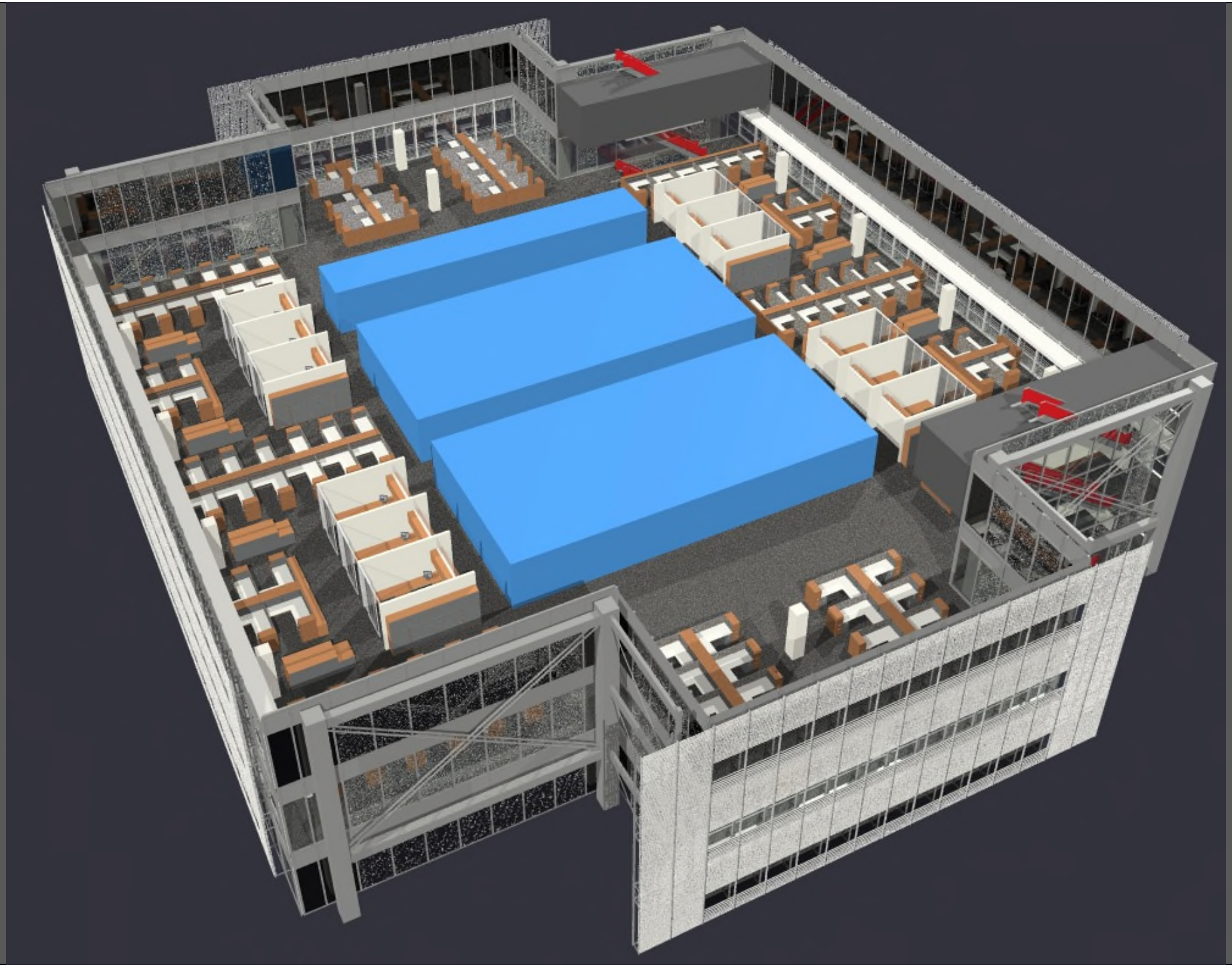
- In 2003, The New York Times approached LBNL regarding feasibility of using automated shade and dimmable daylighting control systems in their new headquarters building (1.2 Msf)
- Questions:
  - Cost versus potential benefits?
  - Features and performance of commercially-available systems?

NYT Key Concerns: Optimizing Trade-offs

- Floor to ceiling, clear, low-iron, spectrally-selective low-e glass
  - Tv=0.75, SHGC=0.39, U-factor=0.28 Btu/h-ft^2-°F
  - Horizontal ceramic tubes,18-inches off exterior face of window

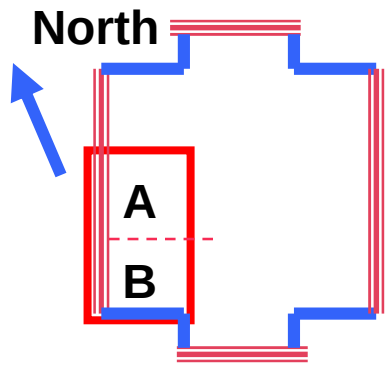
- **Control system trade-offs with automated shading:**
  - Direct sun control: thermal comfort with UFAD system + visual comfort
  - Absence of glare (disability, discomfort, luminance ratios, computer display visibility)
  - Reduced peak solar load (depending on fabric choice and control)

  - Maximize daylight (lighting energy savings, peak demand reduction)
  - Maximize interior brightness, combat gloom
  - Maximize view out (meaningful stimuli, reduction of stress)
  - Preserve design aesthetic of a “transparent” façade

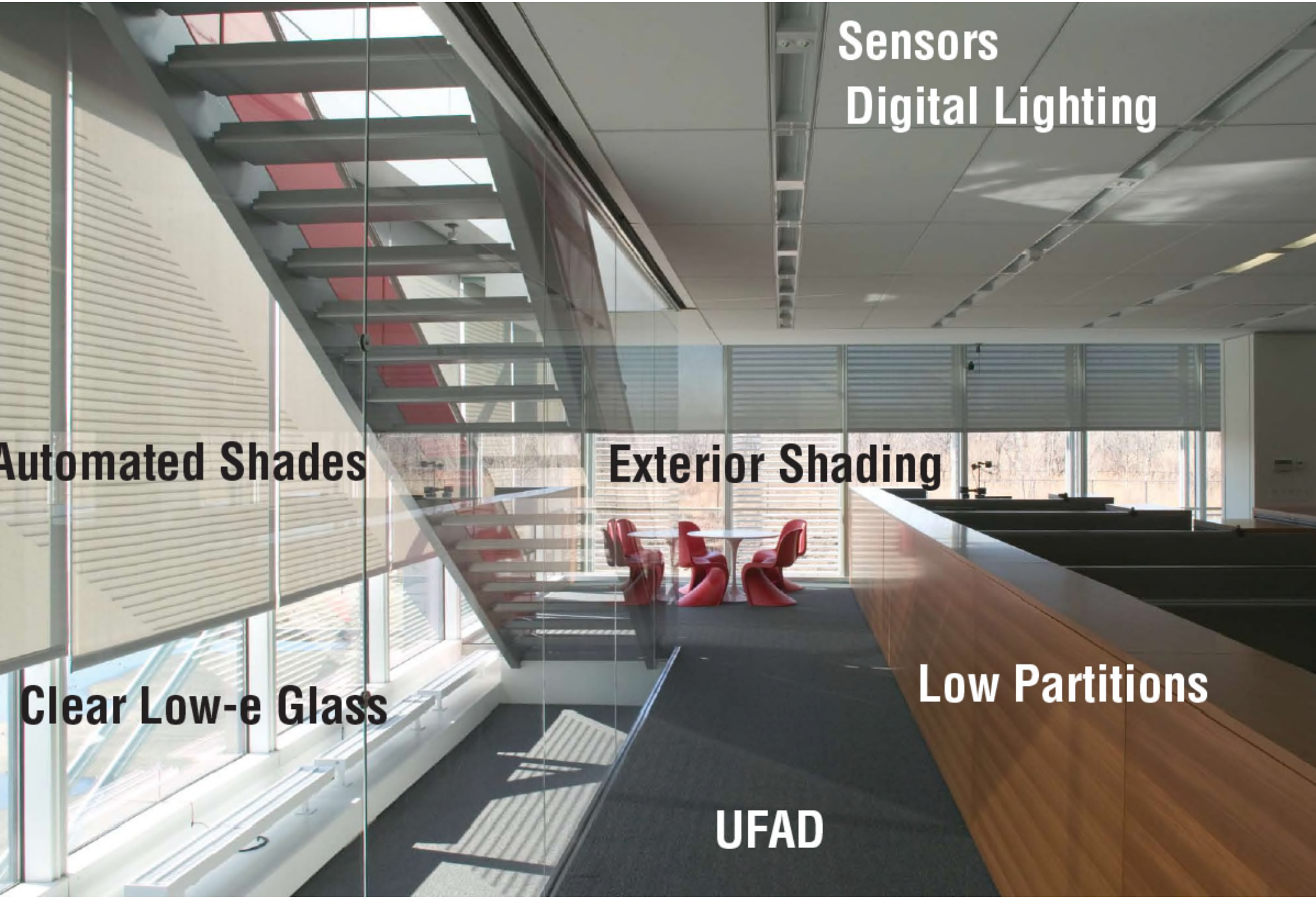


Approach: Test Energy/Comfort Performance in a Full-Scale Mockup

- **Furniture, daylighting, employee feedback and constructability: ~450 m², 4500 sf mockup**
- Core Concerns:
  - Window glare (Tv=0.75)
  - Daylight harvesting potentia



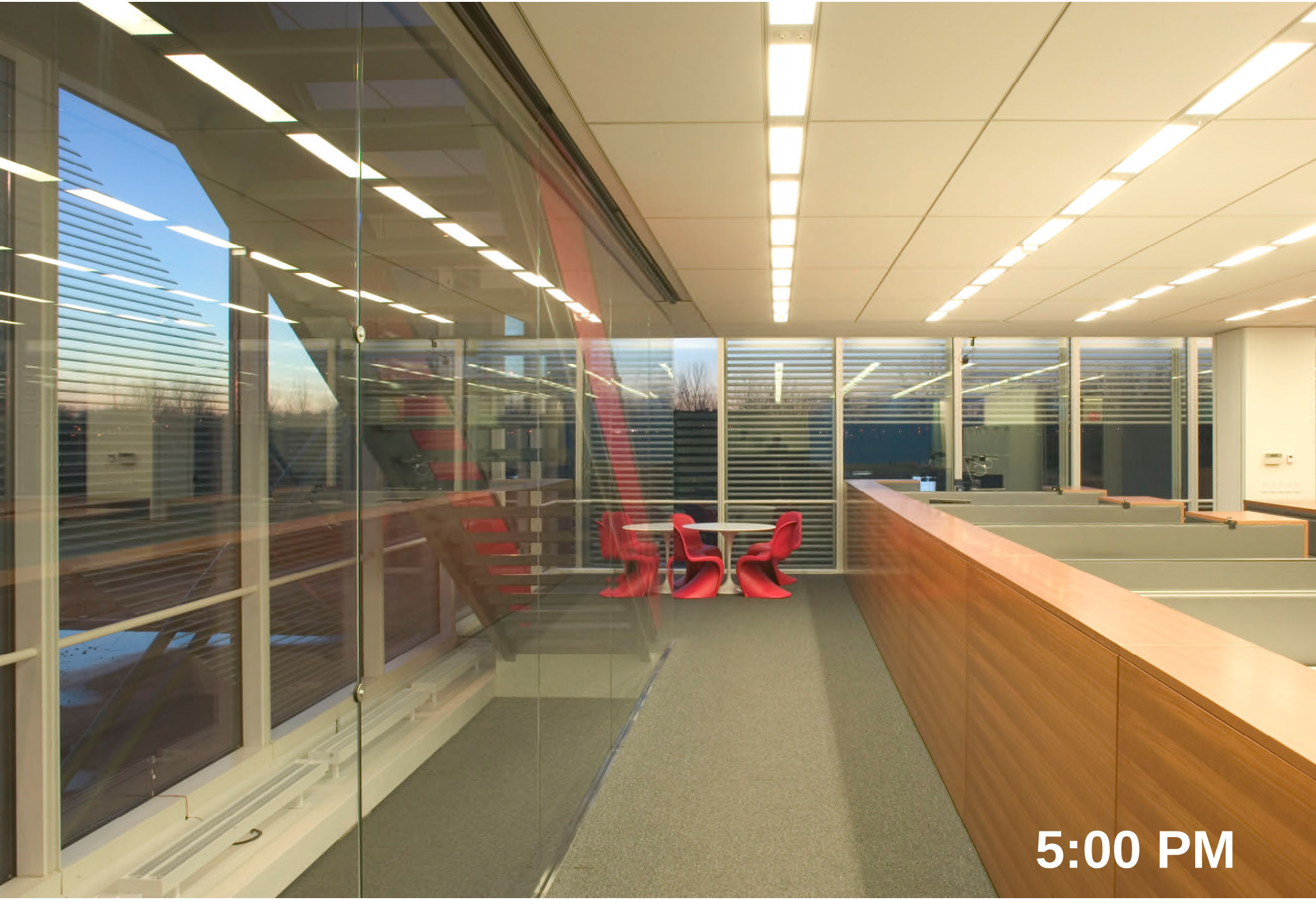
- Northwest – Southwest corner of a typical floor
- Investigate diverse technological solutions by multiple vendors
- Real sun and sky conditions in nearby climate zone, 6-month monitored period: winter to summer solstice


Sensors
Digital Lighting
Automated Shades
Exterior Shading
Clear Low-e Glass
Low Partitions
UFAD

South
West
9:00 AM

1:00 PM

4:00 PM


5:00 PM

Mock-up Instrumentation

Workstation instrumentation at occupant position with LCD screen

- Luminance and illuminance sensors
- Webcams (10-min time lapse throughout the day)

- Quantified lighting energy savings, visual comfort, and control system behavior
- Surveyed occupant comfort and satisfaction

Direct sun

3%-open shade fabric

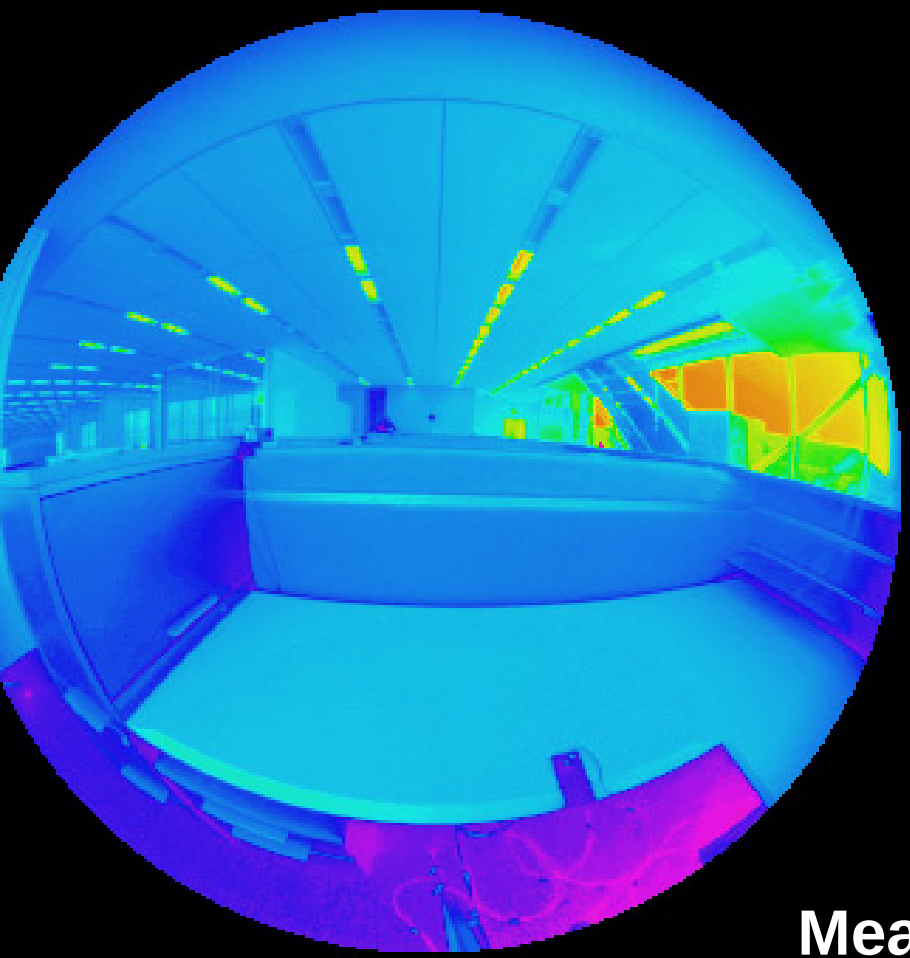
- direct source glare
- ~black out shades needed

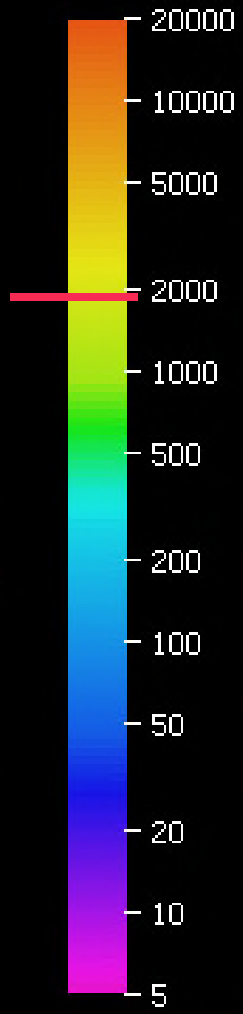
But

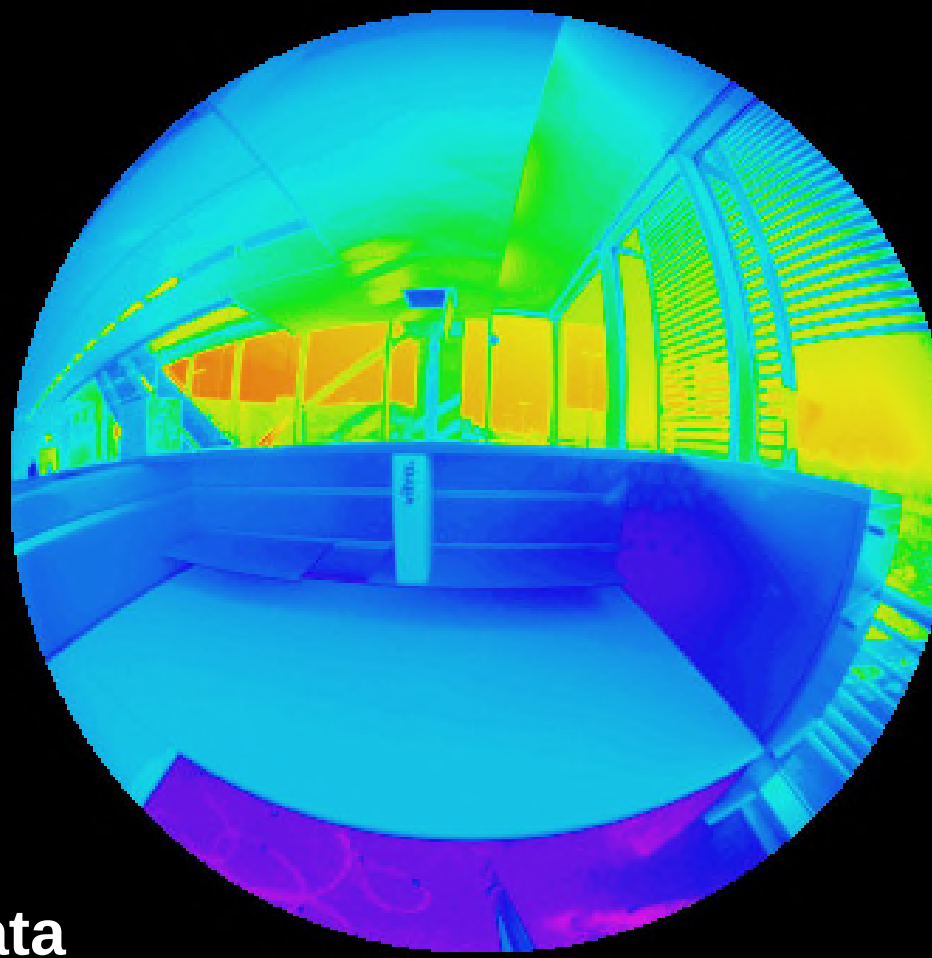
- More opaque fabric will block more daylight

Over the past several years, The New York Times Company's intranet and extranet Web sites have become vital links in our business units' value chains. Employees depend on intranets in many ways – most are fundamental to our business units' day-to-day operations. Likewise, subscribers, advertisers and others rely on our extranets to support many of their needs and critical business functions.
For the sake of clarification, we must devote a few words toward the definition of intranets and extranets in the context of this document.
• Extranet – Content and applications served by a business unit of The New York Times Company whose audience is companies and individuals with whom we interact or do business. In our context, extranets are generally not doors into our company network; rather sections of content and applications hosted within our public Internet Web sites.
• Intranet – The computer network and associated Web sites accessible only behind The New York Times Company firewall. This network's audience is our company's employees. Today, certain applications, such as XMS, ESS, and Webtime are accessible through what many, if not most, would term an "extranet". However, in the long term, many envision access to these and other resources within our company intranet being provided through a virtual private network (VPN). Therefore, in our discussion, we will refer to intranet content and applications as those hosted on hardware owned and operated by, and that serve employees of, The New York Times Company.

Sky Glare can be a Problem as well as Direct Sun





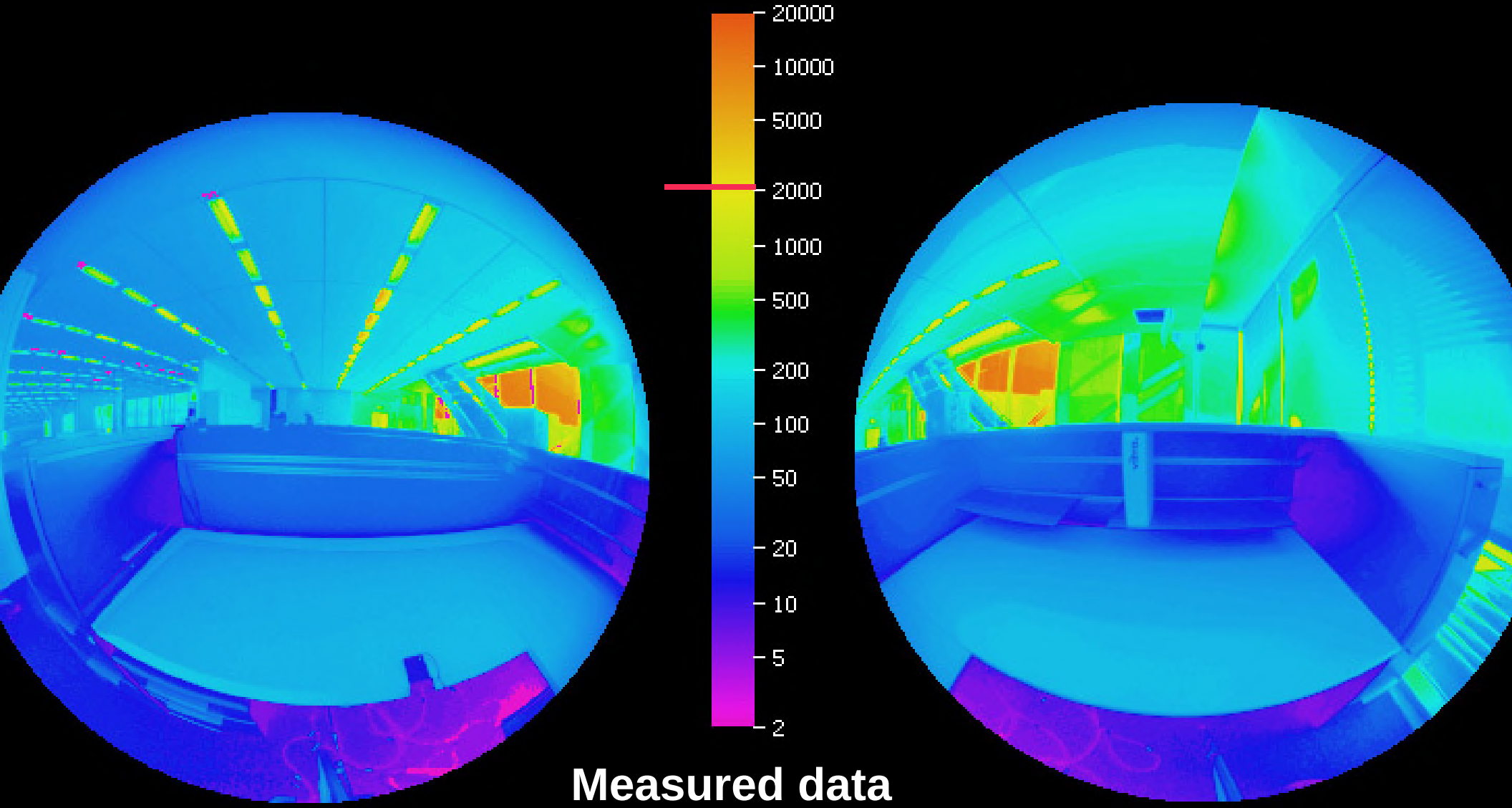


East view

Measured data
(cd/m²)
12/15, 10:00AM

South view

Shades down (partial on south)



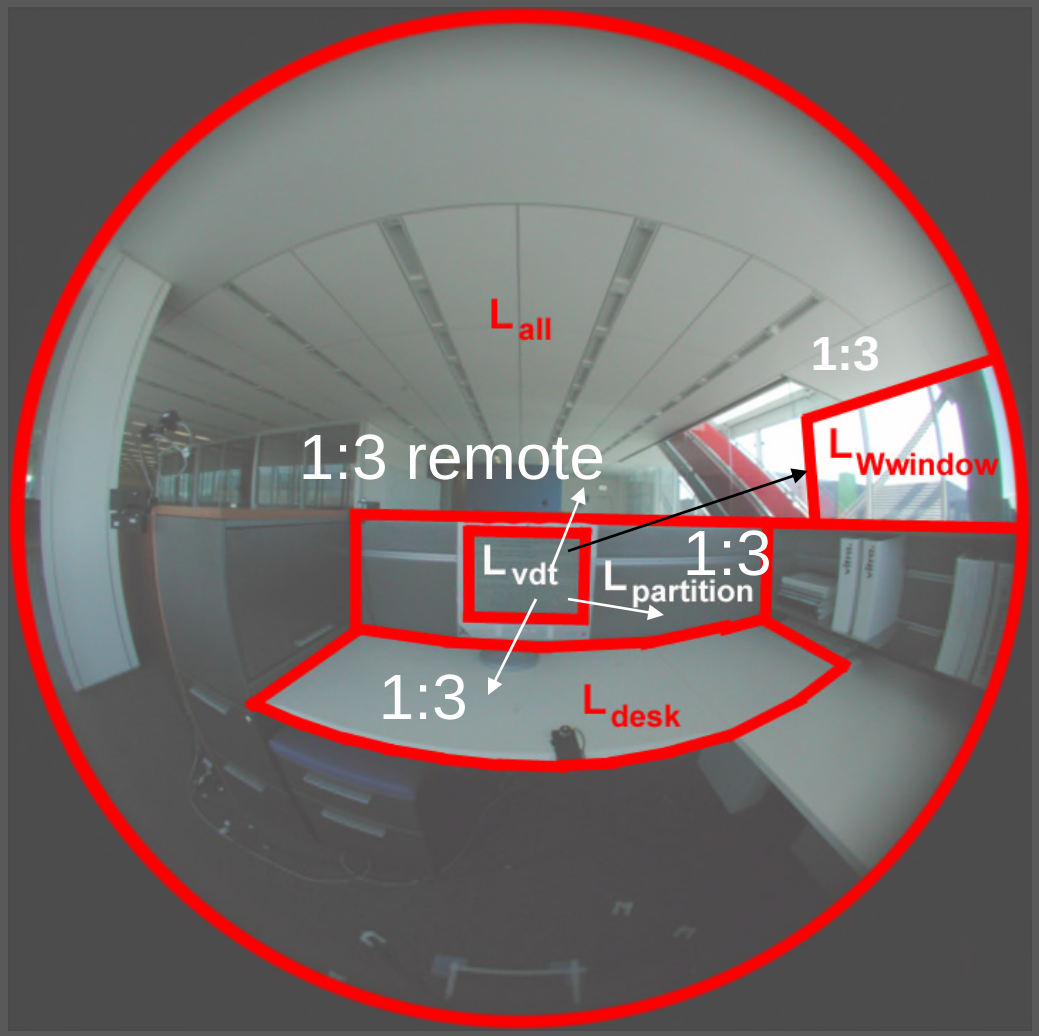
East view

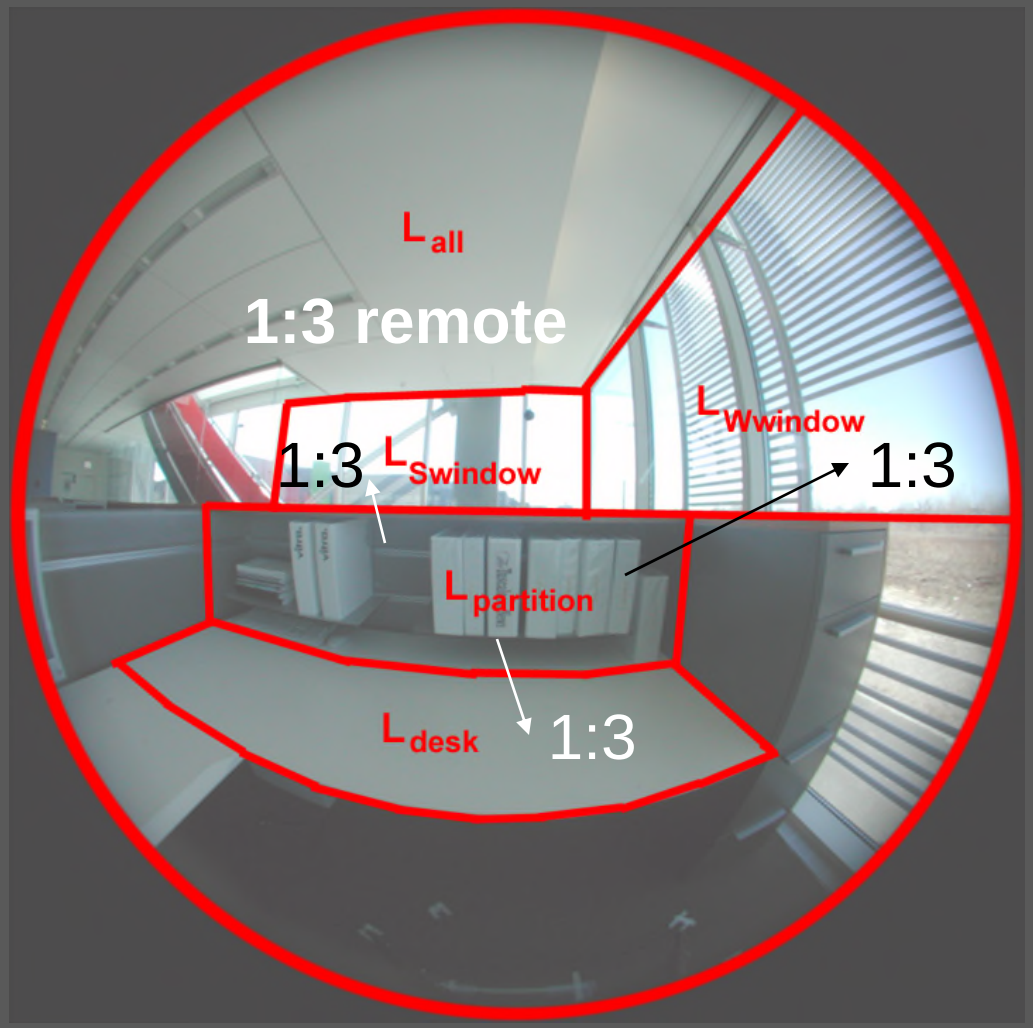
Measured data (cd/m²)

12/15, 10:00AM

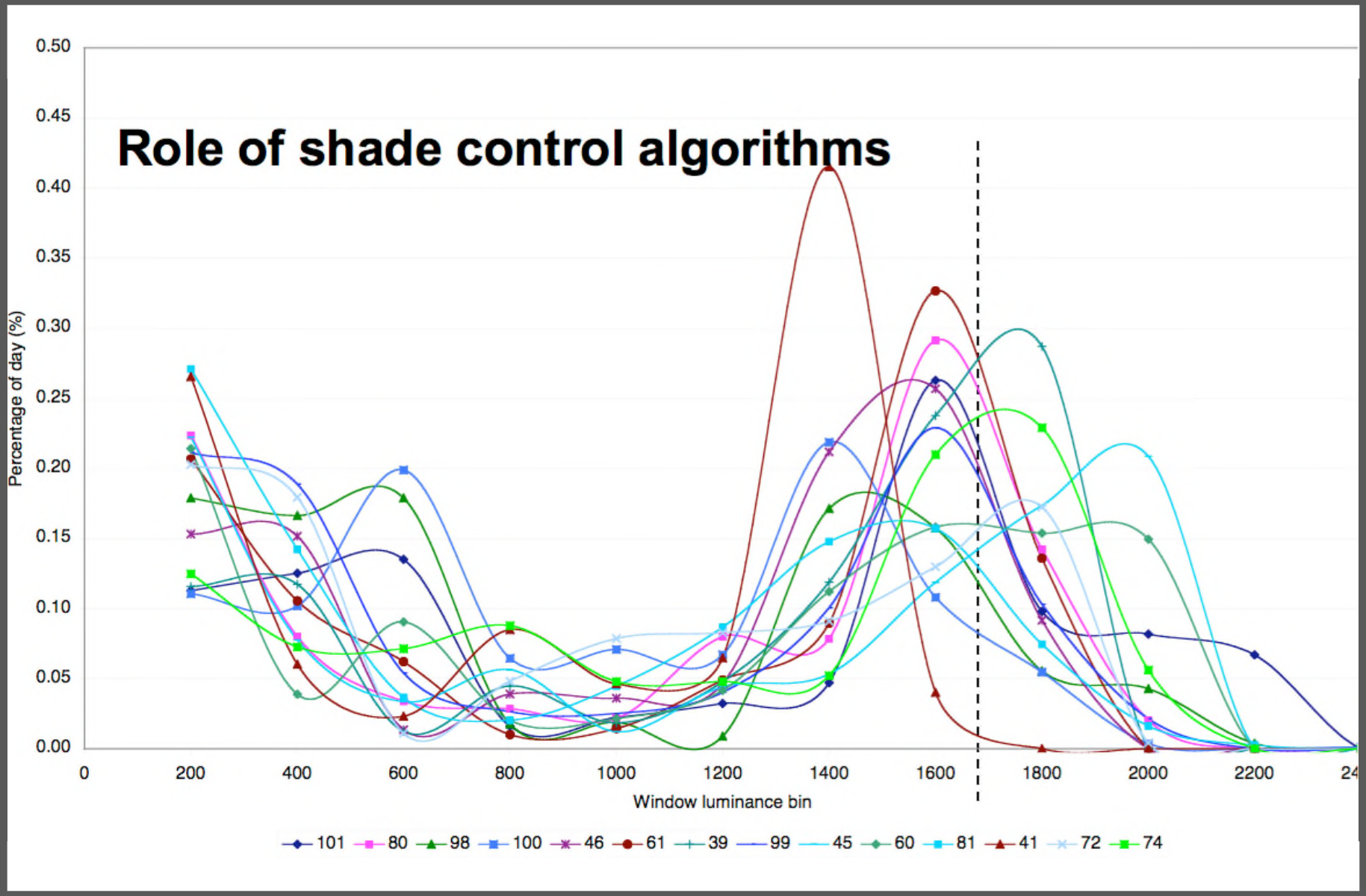
West view

Luminance Measurements at Typical Workstations

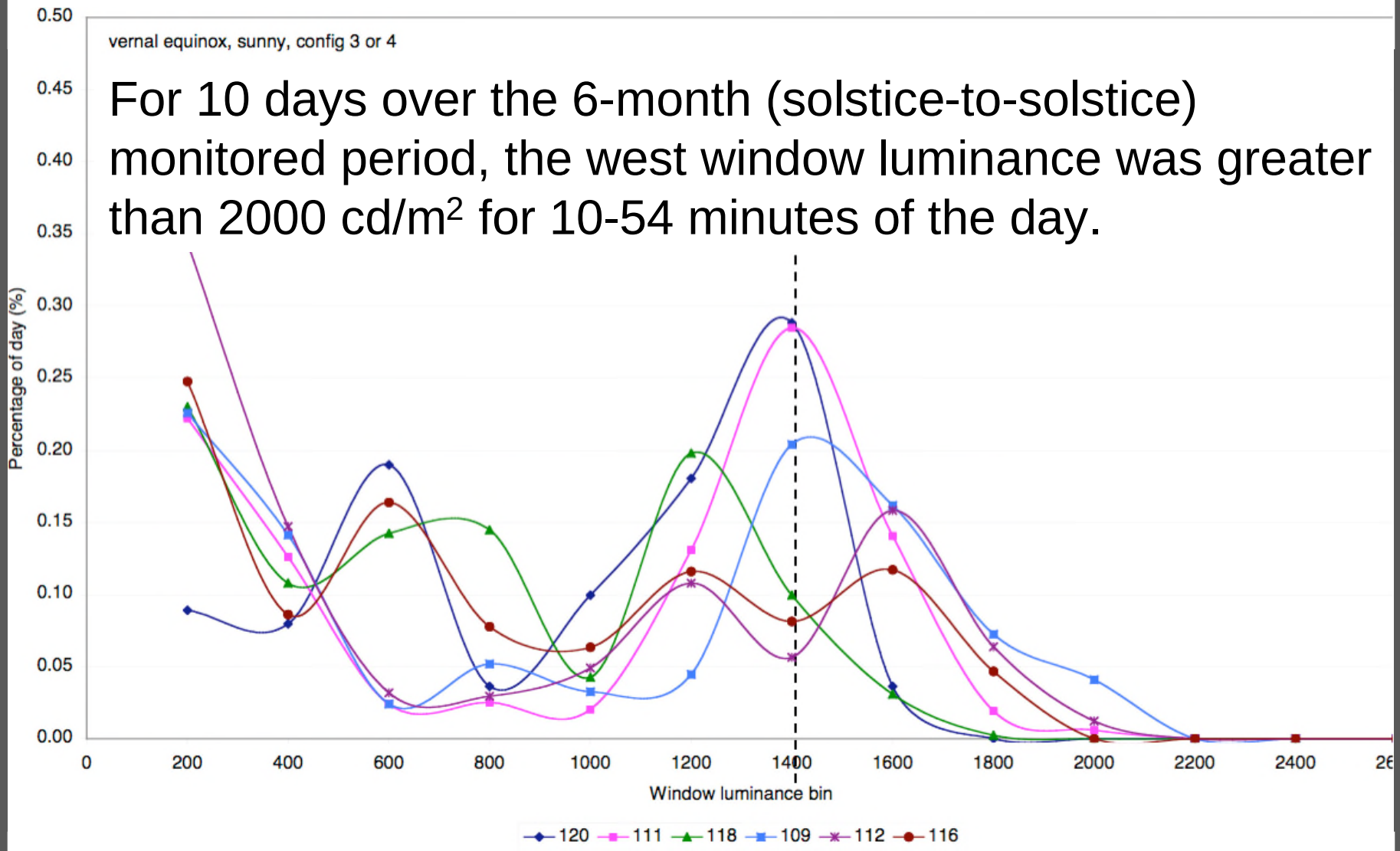




Window luminance: west, vernal equinox, config 1 or 2, sunny, Eglo.avg = 35-53 klux

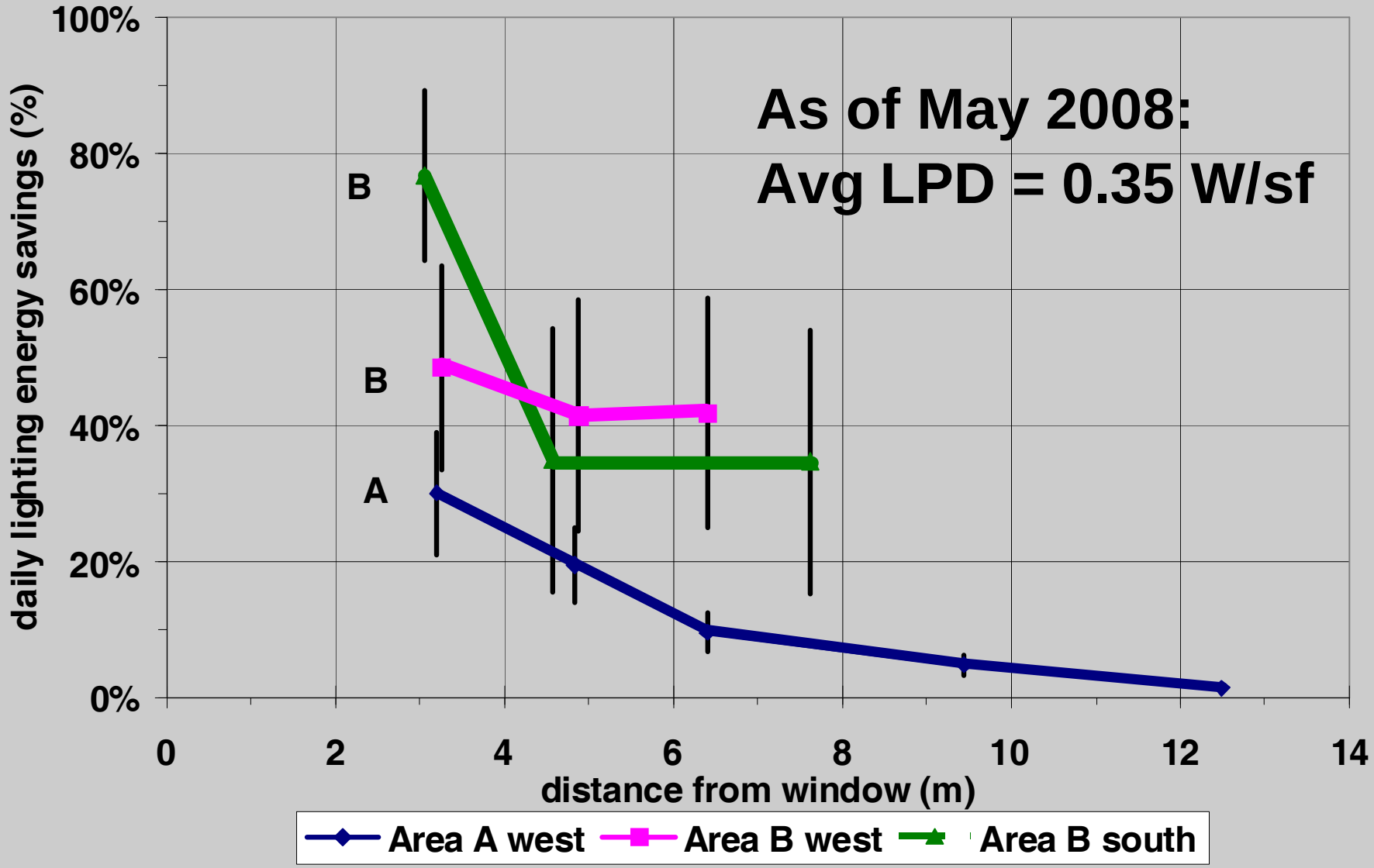


Window luminance: west, vernal equinox, config 3 or 4 sunny, Eglo.avg = 35-53 klux

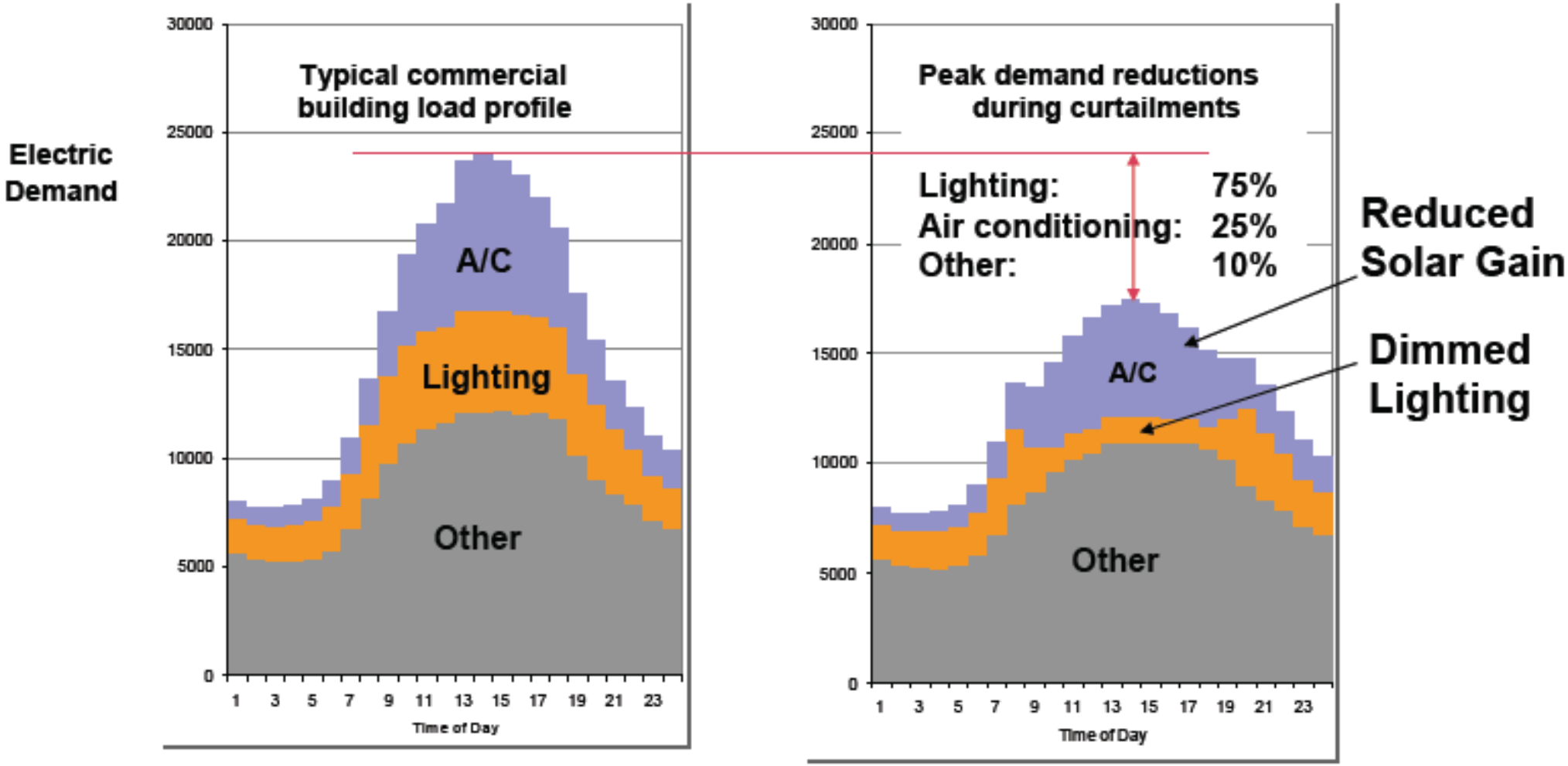


For 10 days over the 6-month (solstice-to-solstice) monitored period, the west window luminance was greater than 2000 cd/m^2 for 10-54 minutes of the day.

Measured Average Daily Lighting Energy Use Savings

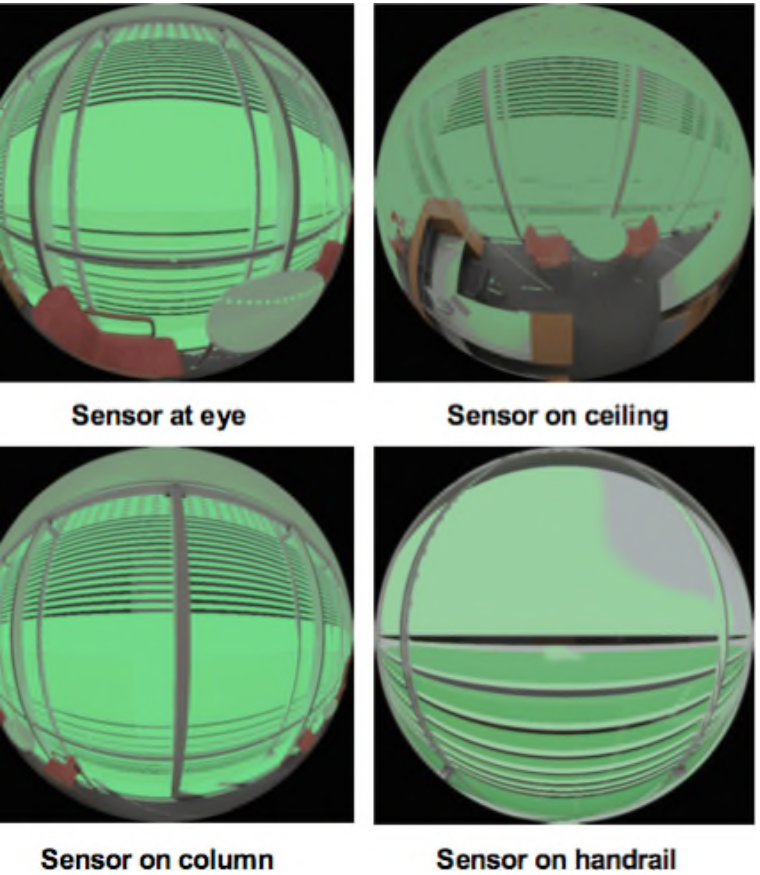


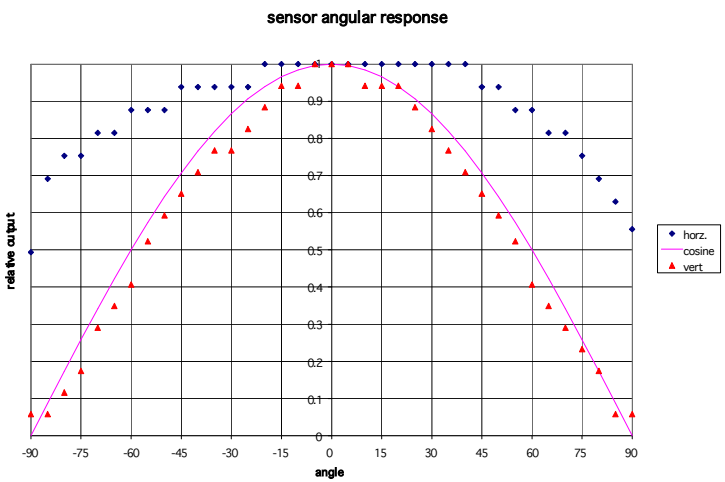
Energy/ Demand Management with Active Facades + Daylighting Controls

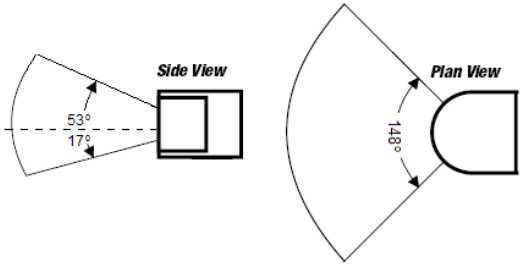


. Function: How does it do it?

Sensor Design and Placement
What is sensor measuring?





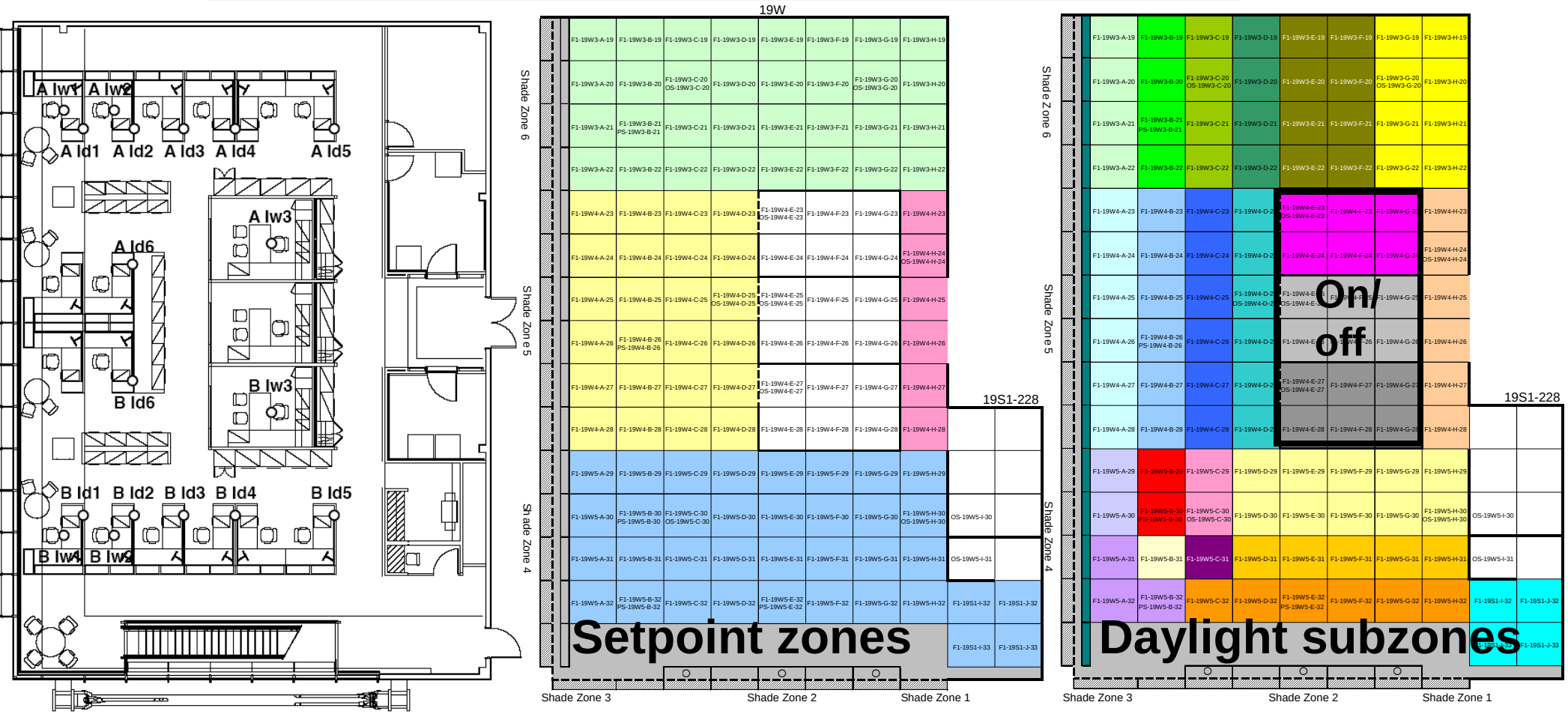


To AAC-PC
To AAC-PC
To Ethernet Hub
ICON Web-Interface
(ILON)
ICON
Bus Supply & Repeater
ICON
PC - Interface
16VAC
Power Supply
ICON
6 -Button Switch
Light Sensor
(Wall/Ceiling/Cove)
To Analog I/O
Ms-ICON
Motor-2
Ms-ICON
Motor-1
Turner
ABC

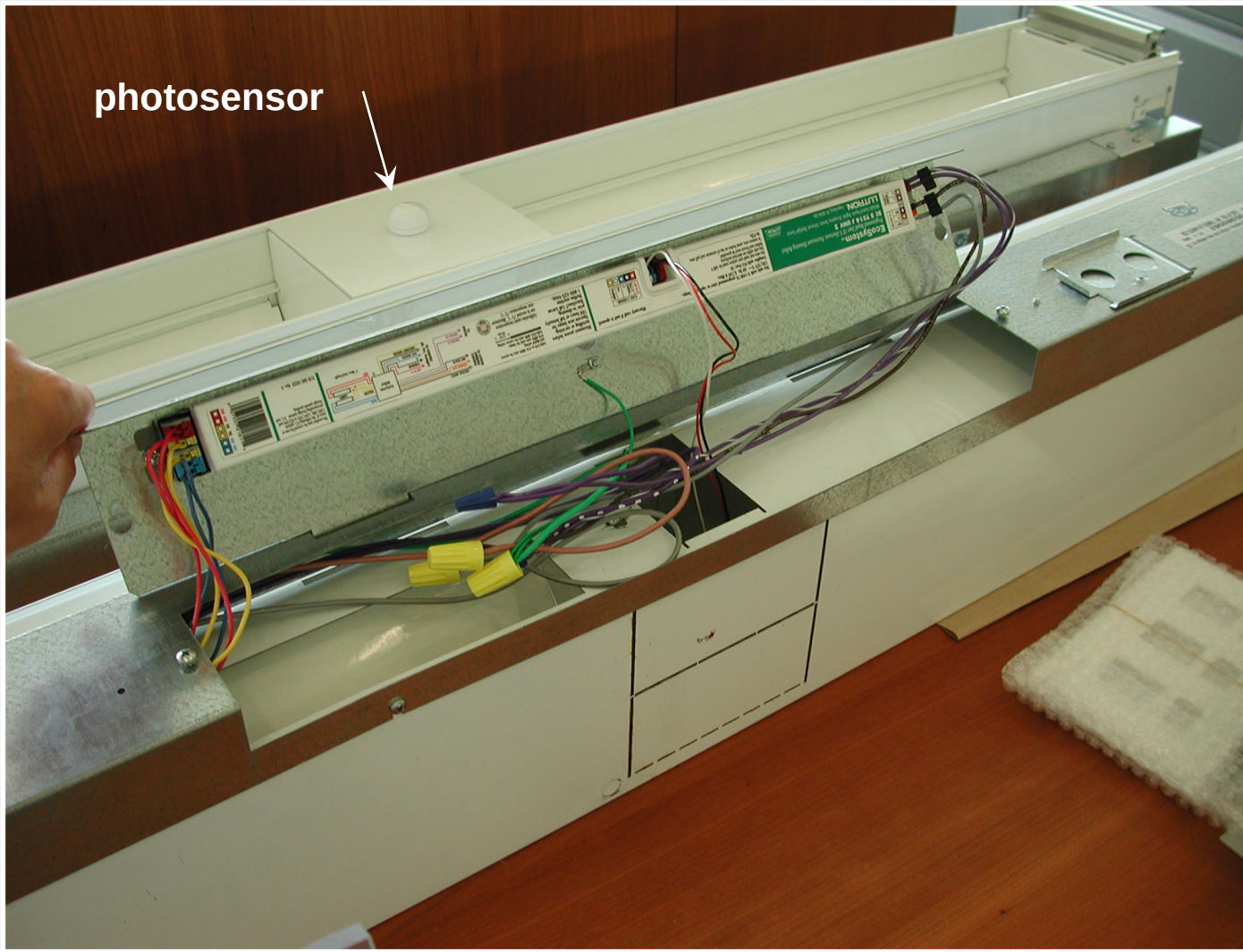
Photosensor correlation to work plane illuminance

f(x)=?

Daylight control zones with DALI ballasts

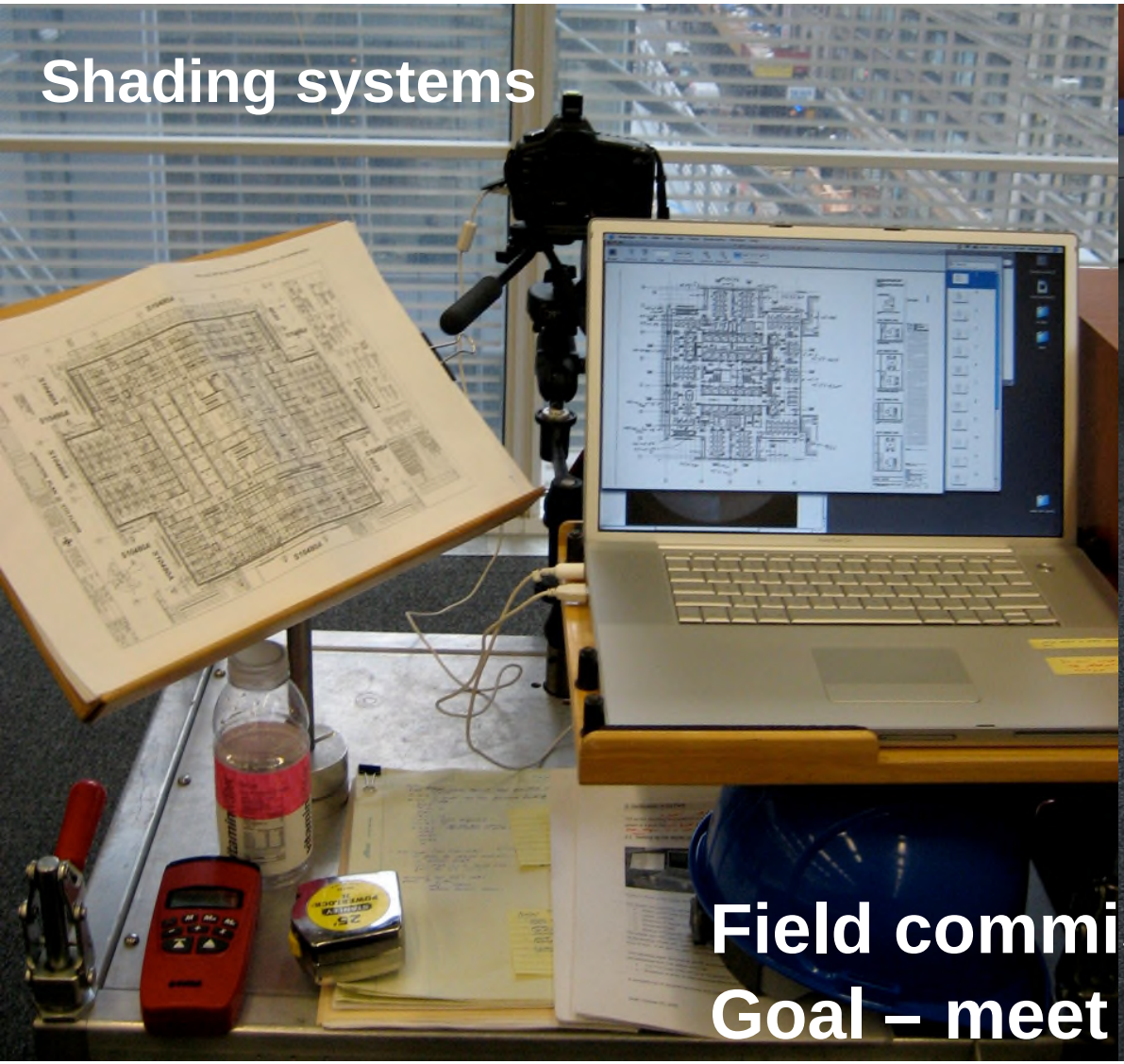


The Times daylighting mockup floor plan



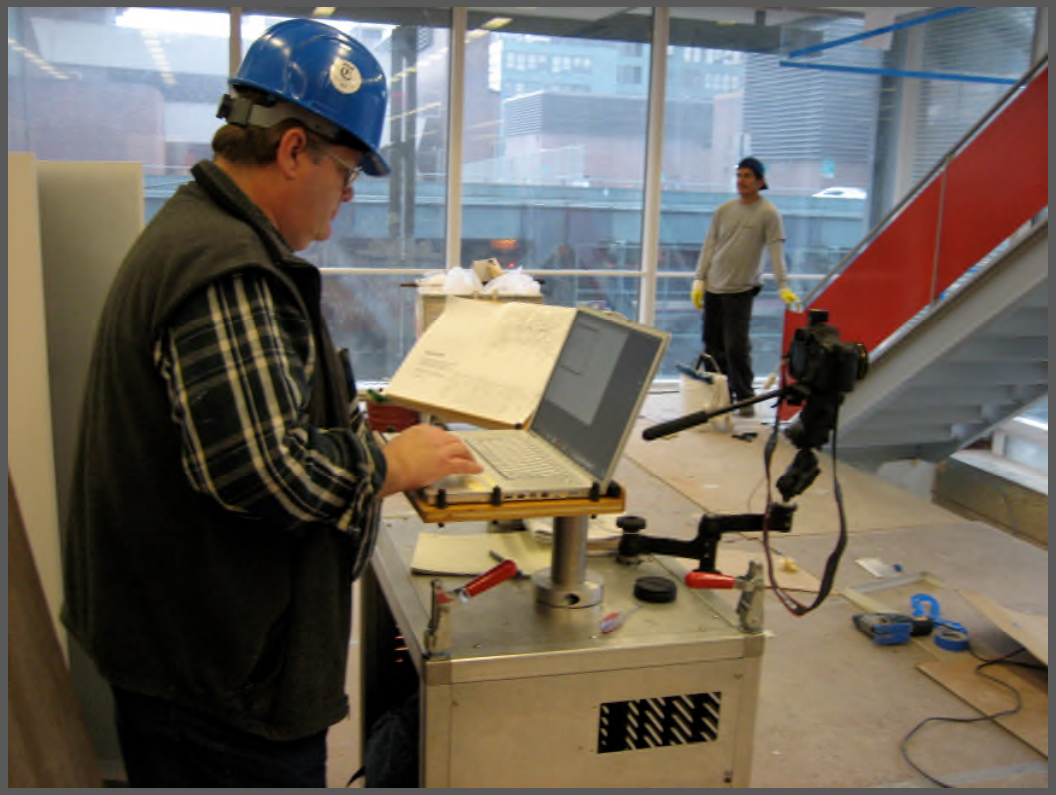
Simplify wiring and cabling to reduce install costs

5. Include commissioning and verification in the specifications



Field commissioning tools:
Goal – meet specs before occupancy

LBNL shade commissioning cart at The New York Times Headquarters Building



Step-by-step How-to Guide

5. Prepare the cameras

HDR Camera:

Prepare the camera prior to moving cart to test location. The high dynamic range (HDR) Canon camera must be configured as follows:

- Con
  on t
  man

6. Check cart inventory prior to transport

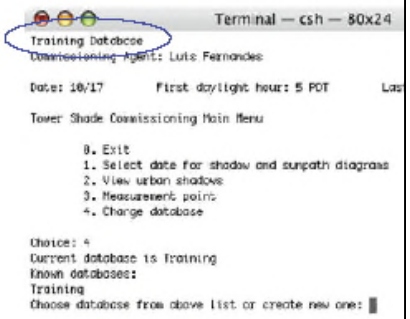
The shade commissioning cart transports the following equipment:

- Digital camera with fisheye lens and tripod mount on an extendable arm
- Digital camera with regular lens for site documentation (not shown)
- Laptop computer (with power cord to uninterruptible power supply shown above)
- Electronic or regular measuring tape

9. Select the database

Make sure that the current database is correct. The top line shows the name of the existing database (in the example above, the database is called "Training").

Change the database if you need to change or create a new database. There can be more than one database, such as one for training, another for commissioning, another for post-occupancy evaluations, etc.

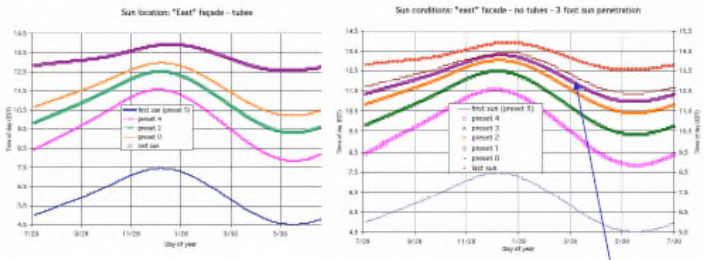


12. Check for direct sun/ attached exterior shading control problems and other control problems

c) If it is sunny, check whether the direct sun control mode is accounting for the exterior ceramic tubes:

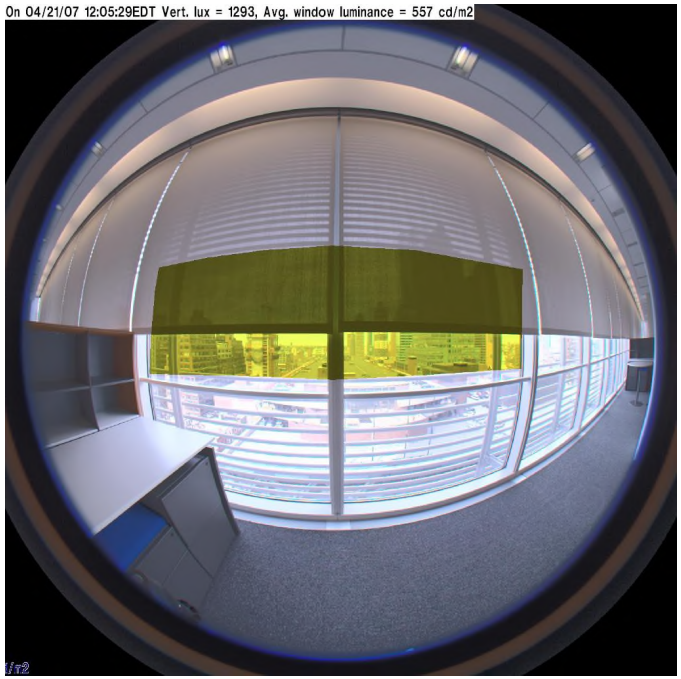
- Find the correct graph (located in scart/nytimes resources/R1-pdfs) to determine the approximate shade position. The tubes will be shading the façade when the sun has a high altitude and in the plane of the window. Compare for example, the graphs East-tubes.pdf versus East-NT3.pdf (NT=no tubes) and note when presets 1 and 2 are used in the NT case. These are times when you should check the façade with tubes.
- If the shades are lowered but the tubes shade the façade, document this failed control mode using the photo documentation procedures described in step 10 above.

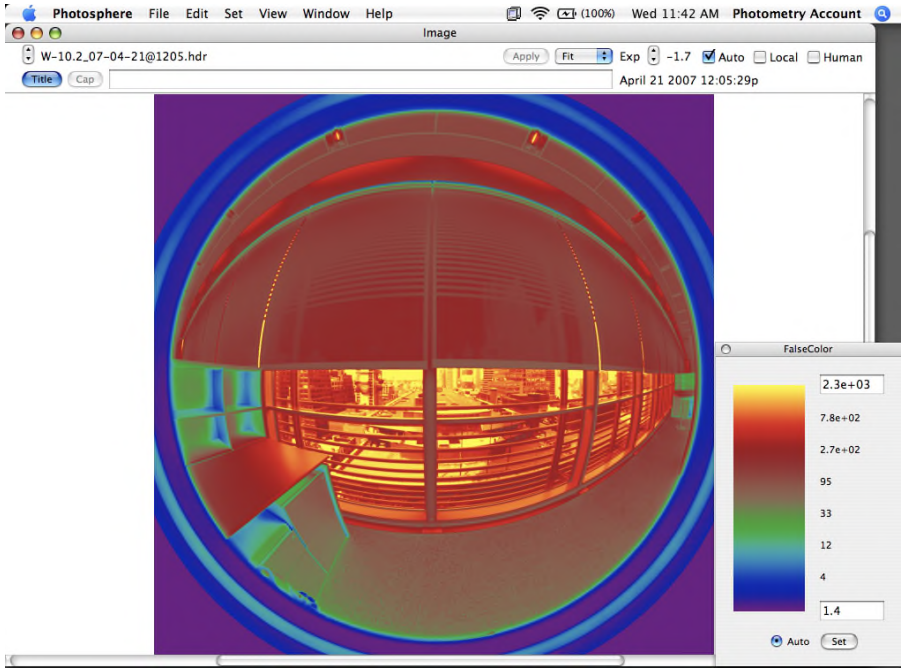
If there are any other problems (shade alignment, improper motor groupings, problems with touch screen user interface), then use the photo documentation procedures described in step 10 above.



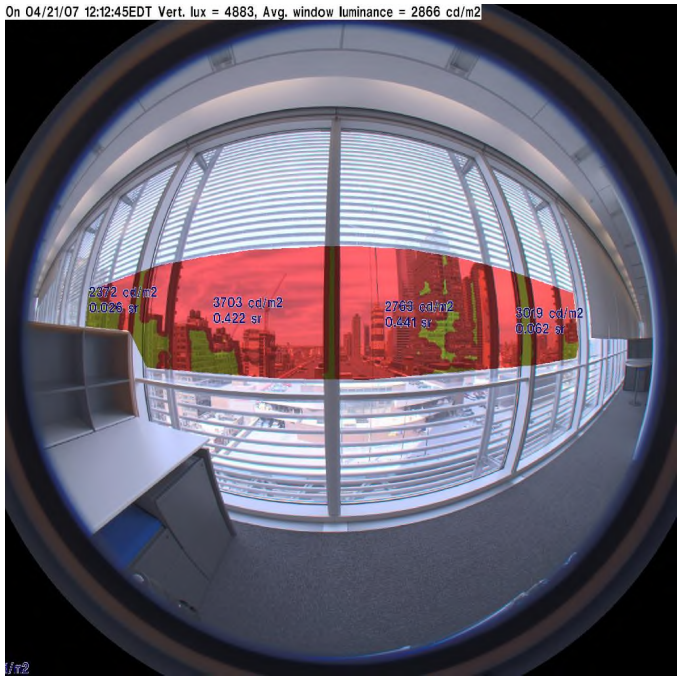
Ceramic tubes shade the east façade on March 30th from ~12:00-12:30 EST

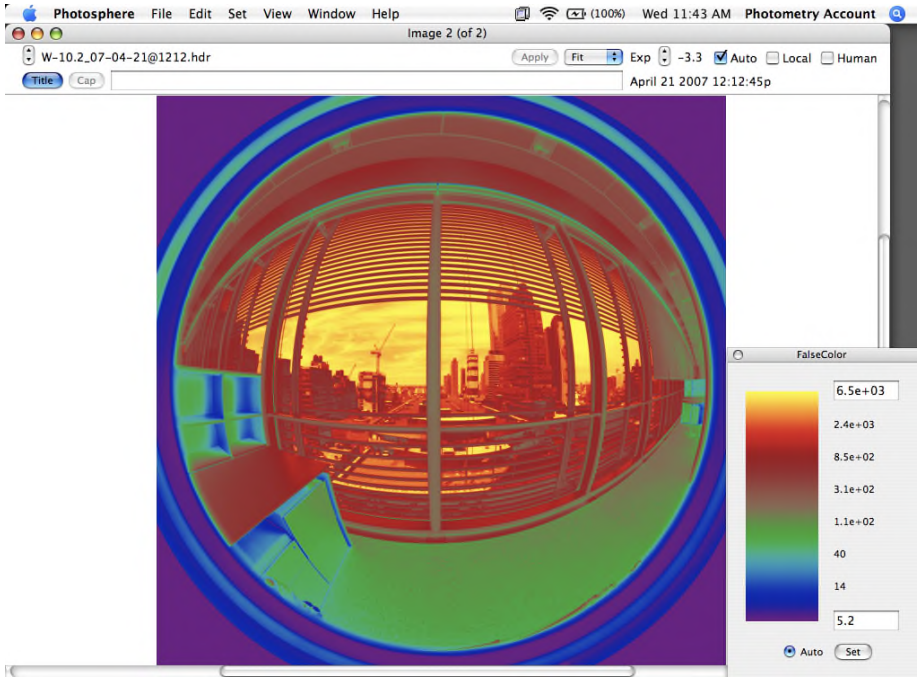
uto
ode:





verride
ode:





Significant Outcomes

Market Outcomes

- Single, largest procurement of automated shades and daylighting controls in the U.S.
- Tremendous industry response (established product demand): significant change in product offerings, features and capabilities at lower cost
  - Dimmable lighting controls:
    - From: fixed topology 0-10 V systems
    - To: digitally-addressable, open protocol systems with individual fixture control capability → enables zone reconfiguration, photosensor tuning, demand response, setpoint tuning all via software
  - Shading controls:
    - From simple direct sun control
    - To direct sun, solar heat gain, glare, view, and daylight control optimization
- Competitive pricing for both material and installation costs
- Procurement specifications, tools, and performance evaluation publicly available

Scientific Outcomes

- Major technical advances in façade-daylighting control systems
  - 1st extensive study showing that digitally addressable dimmable lighting has significant advantages over conventional hard-wired systems
  - 1st demonstration of automated shading control solutions that accommodate daylight-glare-view-solar heat gain trade-offs
- 1st large-scale field monitored study that quantified performance benefits of integrated daylighting solutions
  - 100+ datapoints, monitored 24/7, 1x/minute, 1+ year
  - Energy use, control system, visual comfort, human factors surveys data; results publicly available
- 1st time owner has verified performance of daylighting systems using on-site measurement tools prior to occupancy

Project Team and Partners

- Funding Agencies
  - New York State Energy Research and Development Authority, DOE, California Energy Commission (CEC)
  - In-kind cost share from CEC-DOE Electrochromics Field Test project
- Project Team
  - Diverse team of 23 LBNL staff members
  - The New York Times Corporation, Real Estate Division
- Consultants
  - Institute of Energy and Sustainable Development, DeMontfort University, UK
  - Greg Ward, Anyhere Software
- Collaborations
  - Fraunhofer Institute for Solar Energy Systems, ECCO-Build EU project
  - International Energy Agency (IEA) Task 31 Daylight in Buildings in the 21st Century
- Industry Partners
  - Advance Transformer Co.
  - Lutron Electronics, Inc.
  - MechoShade Systems, Inc.
  - Siemens Building Technologies
- Architectural/Engineering Consultants
  - Renzo Piano Building Workshop
  - Fox and Fowle
  - Gensler Interiors
  - SBLD Studio, Inc. Lighting
  - Flack + Kurtz
  - Turner Construction
  - Gardiner & Theobald
  - Constantin Walsh-Lowe, LLC
  - NaturalWorks

Conclusions

High-performance facade solutions require a cross-disciplinary approach to address:

- Direct sun control
- Glare control
- Lighting quality
- View
- Daylight admission for lighting energy savings
- Solar heat gain/ cooling load control for HVAC
- Daylighting control system performance

Industry is working toward more cost-effective solutions with features that address practical building owner and occupant needs

Further work is needed to make these solutions routine, cost-effective, and reliable for all applications.

Project Advisory Committee

http://lowenergyfacades.lbl.gov

High Performance Building Façade Solutions

Buildings Technology Department, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory

Home
Overview
Concepts
Technologies
Performance
Tools
On-line Tool
COMFEN
Complex Systems
Resources
Sponsors
Project Team

Tools

Commercial Windows Website

Façade design begins in the early concepts phase, making it difficult to conduct detailed engineering analysis to derive optimum solutions. Designers must be able to quickly assess trade-offs and quantify impacts on energy use, electric demand and comfort throughout the entire design process.

The Commercial Windows Website lets designers quickly assess energy and non-energy impacts of typical options with its on-line tool.

LBNL has developed, in collaboration with the University of Minnesota, the beginnings of this on-line tool for A/Es or owners to optimize designs and estimate savings quickly from glazing, shading and daylighting strategies. The goal here is to have a well developed site for each city that will use local utility rates and incentive programs. A redesigned version of the site has been launched at Greenbuild 2008.

Information Resources

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More Info:

http://lowenergyfacades.lbl.gov

Electrochromic windows

http://windows.lbl.gov/comm_perf/Electrochromic

The New York Times Headquarters

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

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