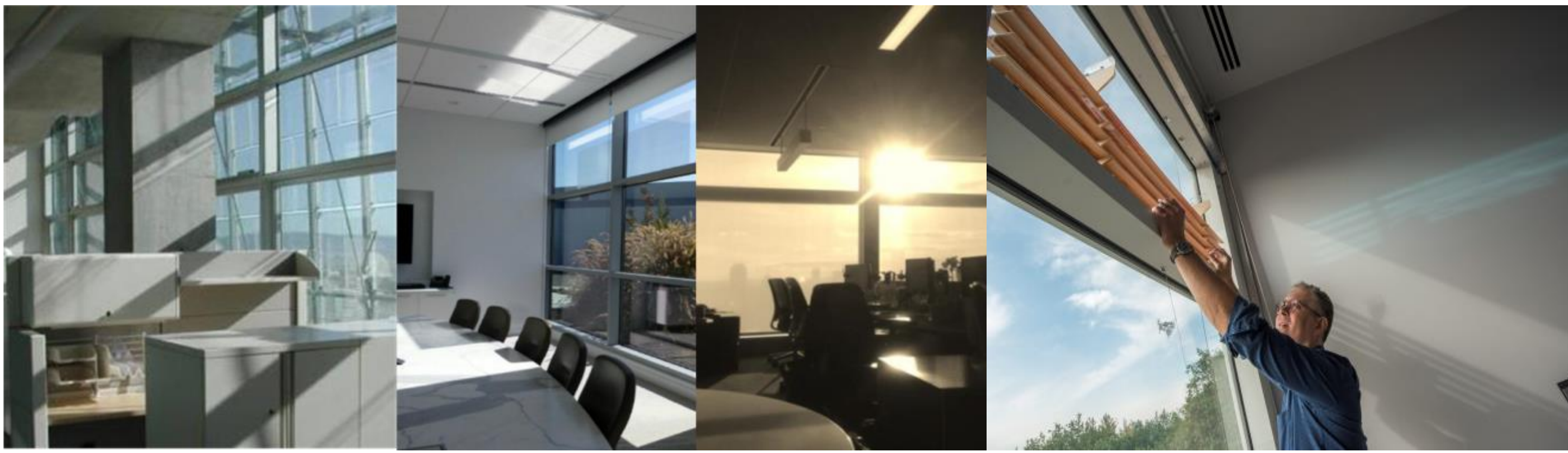
FUNDING PROVIDED BY THE CALIFORNIA ENERGY COMMISSION

U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Daylighting commercial buildings: Case studies and simulation models

The Daylighting Symposium:
California Investor-Owned Utilities in partnership with the
National Electrical Manufacturers Association Daylight Management Council
Sacramento, California, April 29, 2019

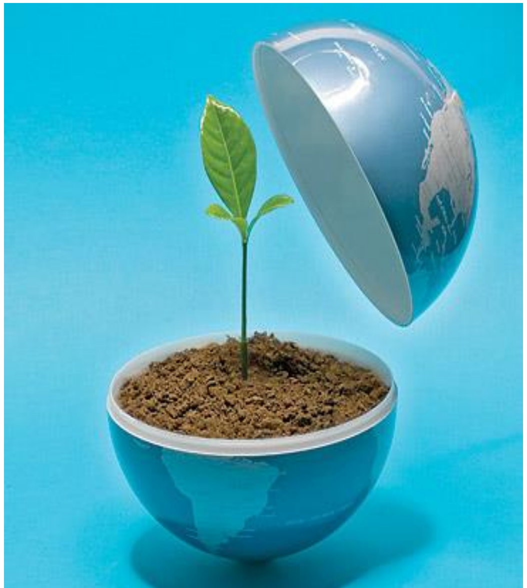


Eleanor S. Lee, Taoning Wang, Christoph Gehbauer, Andrew McNeil, Luís Fernandes, Jacob Jonsson, Stephen Selkowitz, Sabine Hoffmann, Anothai Thanachareonkit, Jordan Shackelford, Samir Touzani, Arman Shehabi, Lawrence Berkeley National Laboratory; Gregory Ward, Anyhere Software

BERKELEY LAB
BUILDING TECHNOLOGY & URBAN SYSTEMS DIVISION
Energy Technologies Area

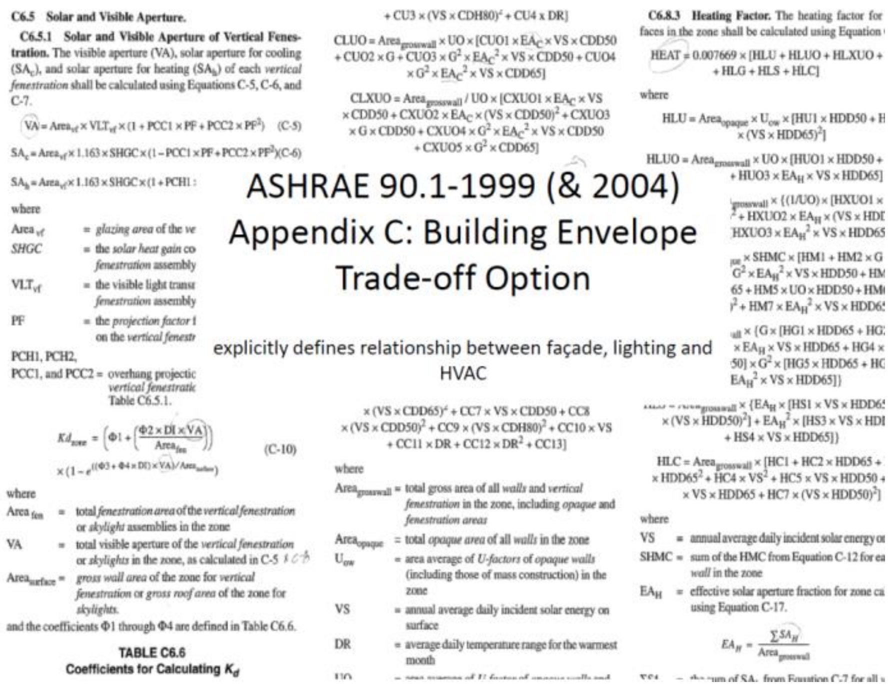
Where do we want to go?

- Reduce building energy use: one of many "stabilization wedges" towards reducing carbon emissions[1]
- Significant progress is still needed to meet California's requirements for greenhouse gas (GHG) emission reductions of 40% below 1990 levels by 2030 and 80% below 1990 levels by 2050.
- How does daylighting contribute to California's goals?



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

[1] **Pacala, S. and R. Socolow**. 2004. Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies. *Science* 305: 968-972.

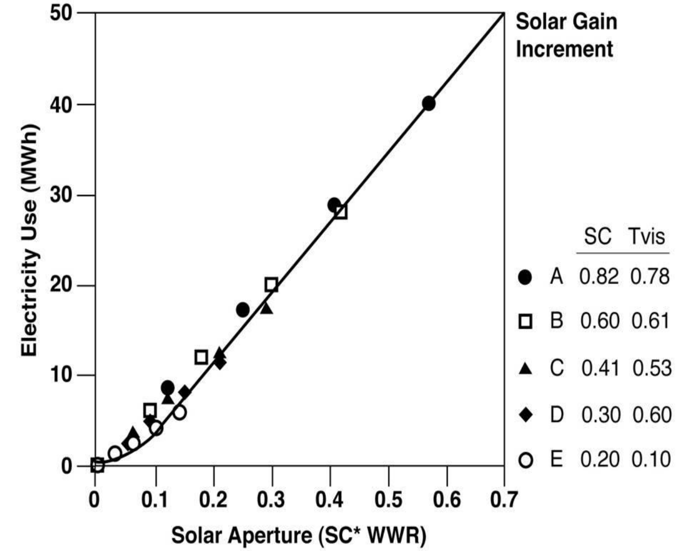


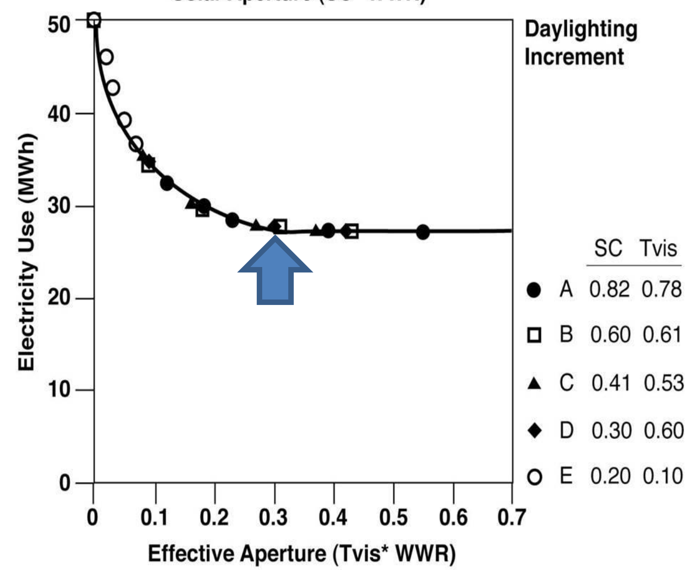
ASHRAE 90.1-1999 (& 2004)
Appendix C: Building Envelope Trade-off Option

explicitly defines relationship between façade, lighting and HVAC

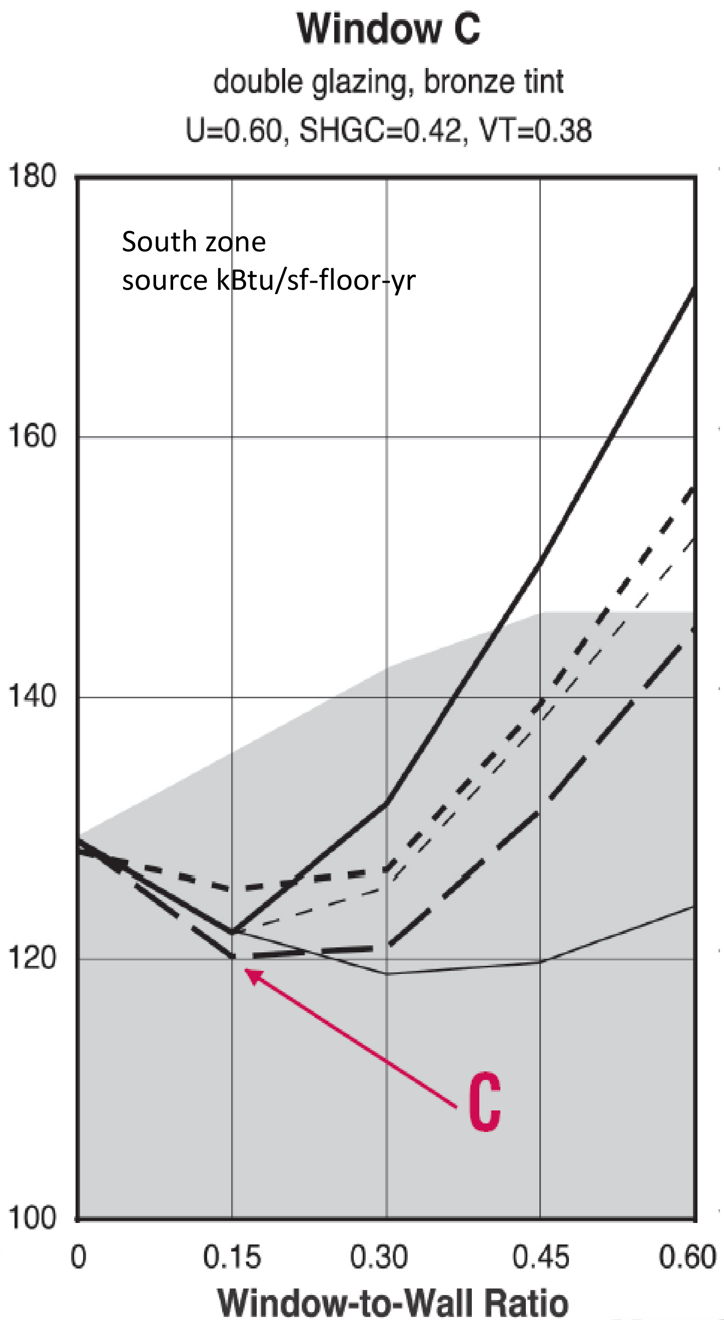
Basis for envelope trade-offs in Title-24 code: LBNL DOE-2 study

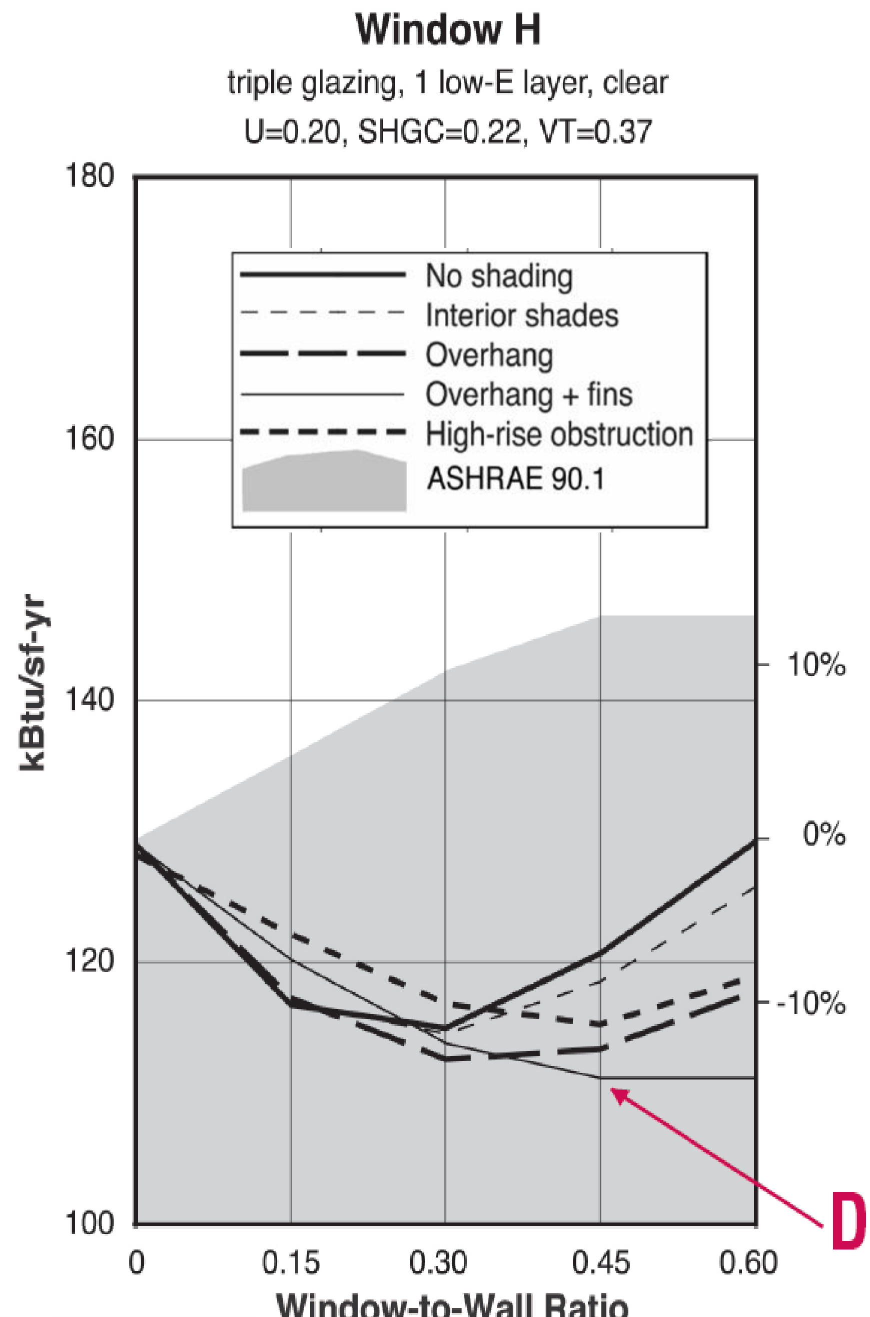
http://eta-publications.lbl.gov/sites/default/files/16770.pdf **(1983)**





http://eta-publications.lbl.gov/sites/default/files/32931.pdf





Hot Climates: Houston, TX

Carmody, J. et al., Window Systems for High Performance Commercial Buildings, New York: W.W. Norton and Company, Inc. , 2004.

Challenge

Optimize tradeoffs between

HVAC savings, visual + thermal comfort vs.

Lighting energy savings, daylight + view

Case studies

Methods of problem solving and evaluation over different phases of the building life cycle

Case study #1: Envelope design, new construction

Southeast Aerial

Output

Achieve sustainability and indoor environmental quality objectives in daylit occupied spaces in the new B40 building.

Key questions at this stage of the design

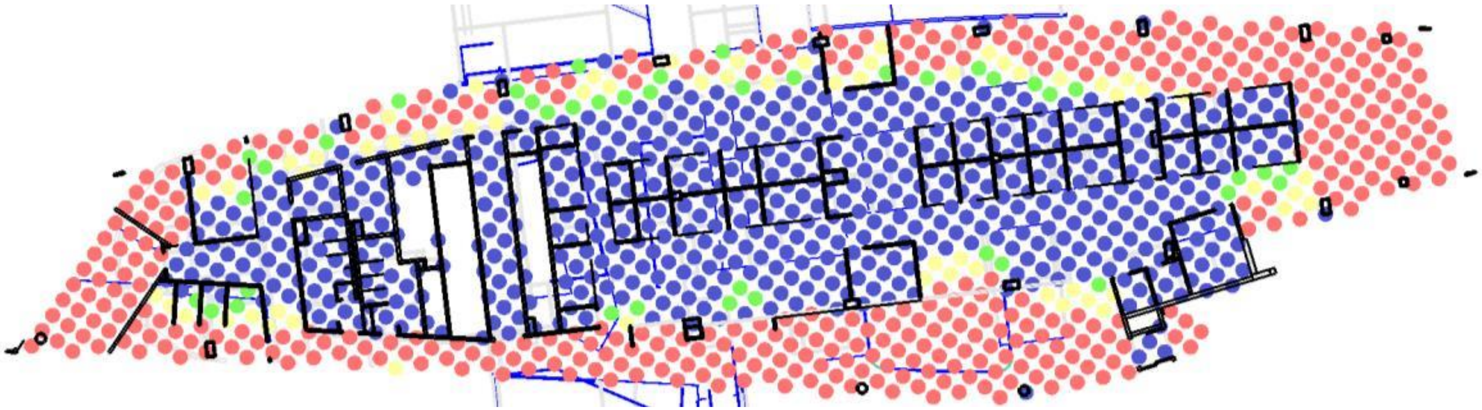
- What is the **daylight quality** in the spaces given the current design?
- What is the **daylight availability** for the current design
- What changes could be made to the core and shell design to improve daylight quality and minimize use of shades?
- When are shades needed to control direct sunlight on the workplane and glare?

Parameters

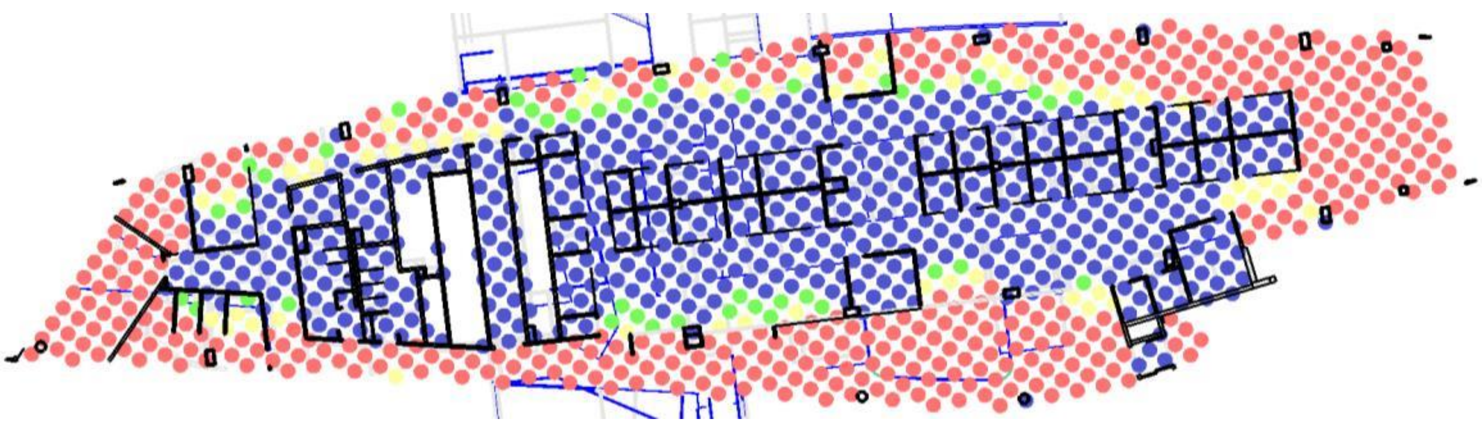
Window size and aperture location, glazing selection, indoor shade selection, daylight redirecting strategies, room finishes, furniture location

Floor 7 DA300

Glass scenario 1 (VRE 24-54, 59 upper) vs 2 (VNE 1-63, lower graph)



Tvis=0.50, 0.56

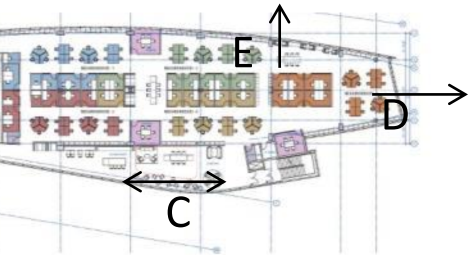


Tvis=0.62

%time
<25
25-50
50-75
>75

Update #2, 2/15/17 from 2/1/17 analysis; fixed walls, 8a-4p occ, glass type change

Floor 7 DGP – Views C-E (no shades)

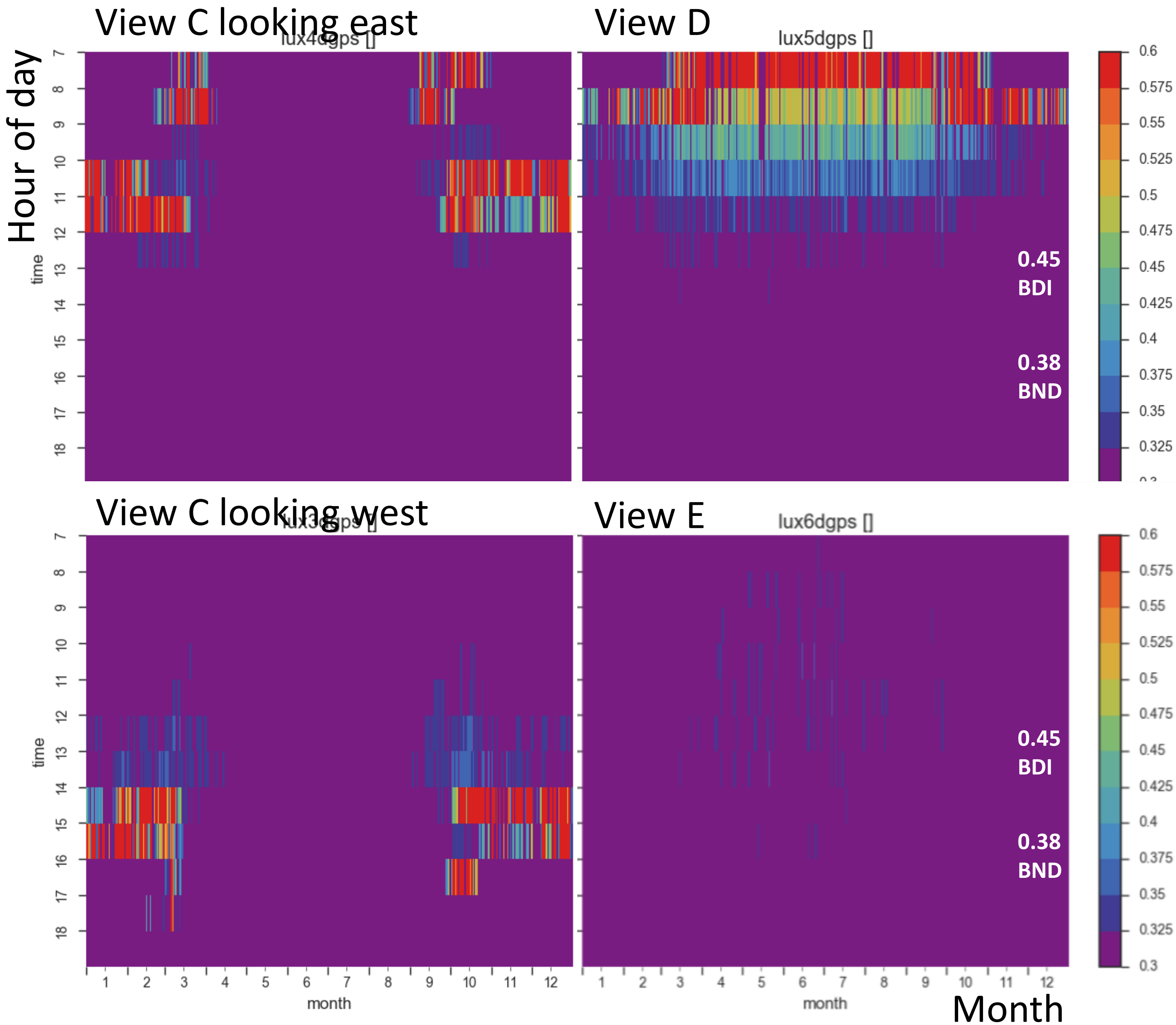


Potential shade requirement

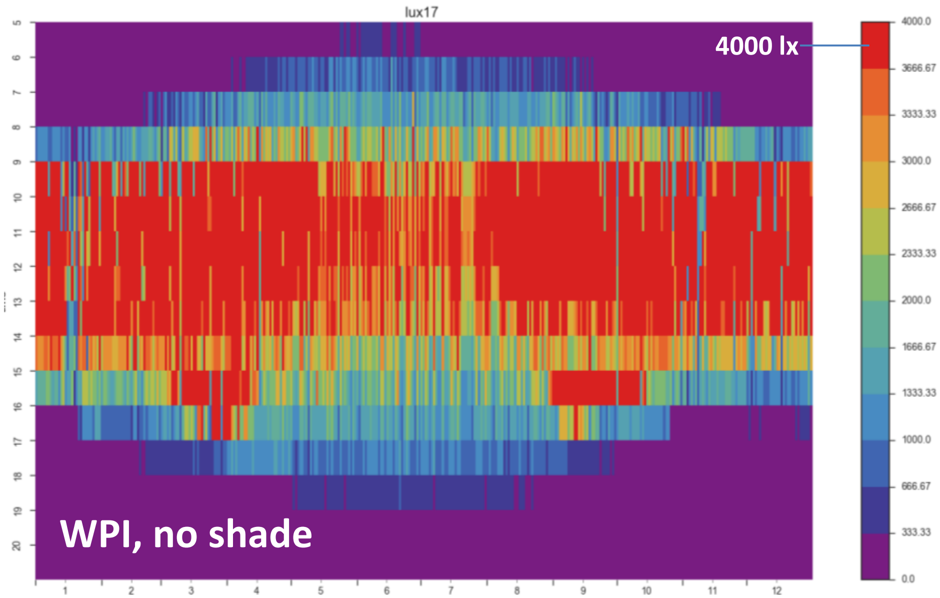
View C (east/west)
View 3 ft from window needs shades to control glare from equinox to equinox (e.g., manual or automated with occupancy sensor)

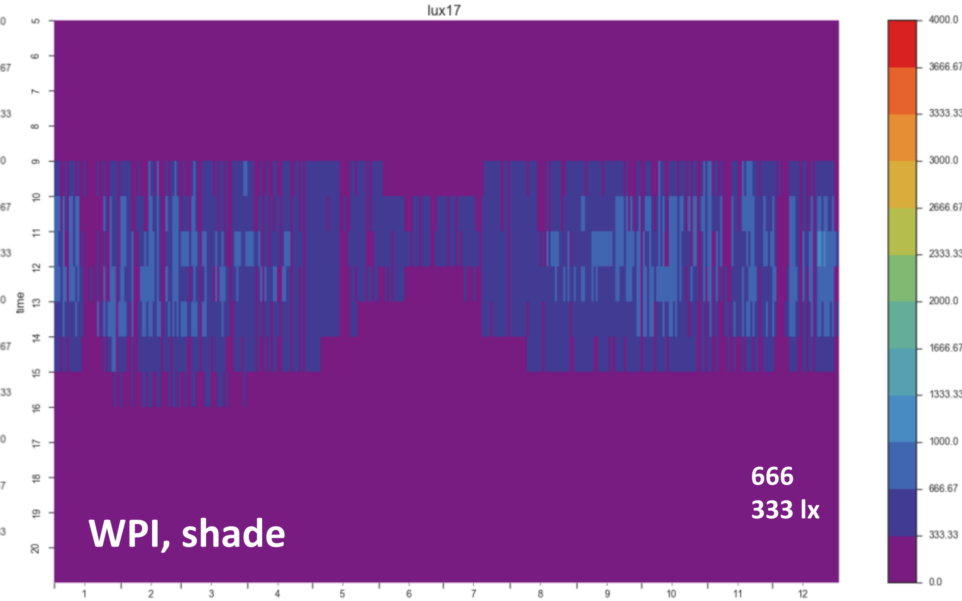
View D (east)
Needs shades to control glare in the morning through out the year

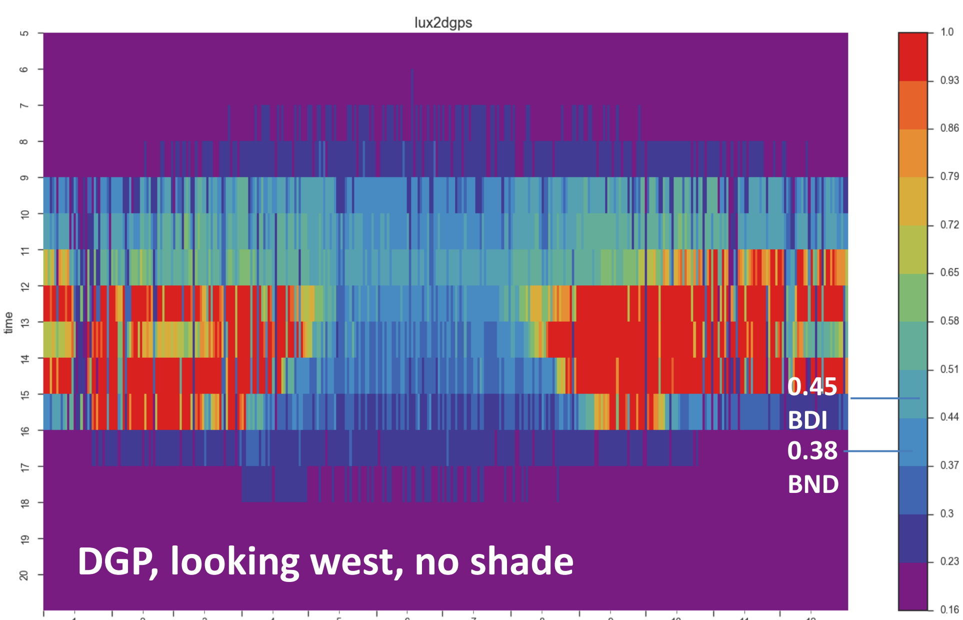
View E (north)
View 5 ft from window requires occasional shades to control glare between 7am-7pm

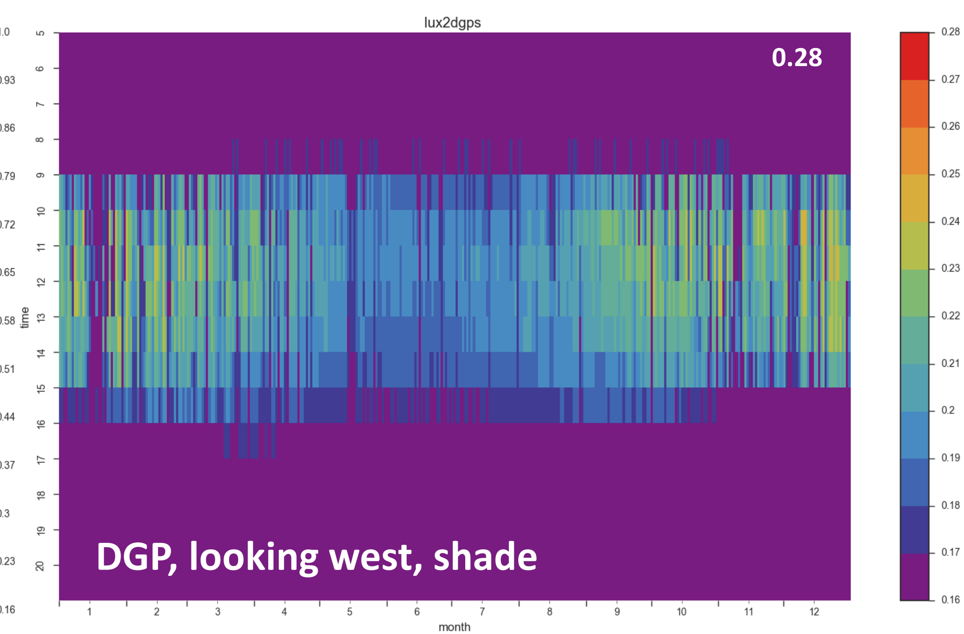


Floor 3, south, 6 ft from window









Design: 12/2/16, Tvis=0.70, shade OF=6%

Case study #2: New construction – Following through on specifications, construction, and commissioning

© Perkins & Will

Broaden opportunities for daylight:

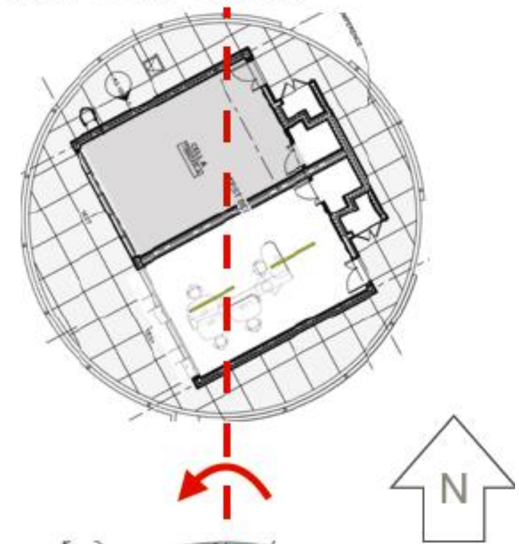
Control sunlight, bring in diffuse daylight, scatter the light within the interior

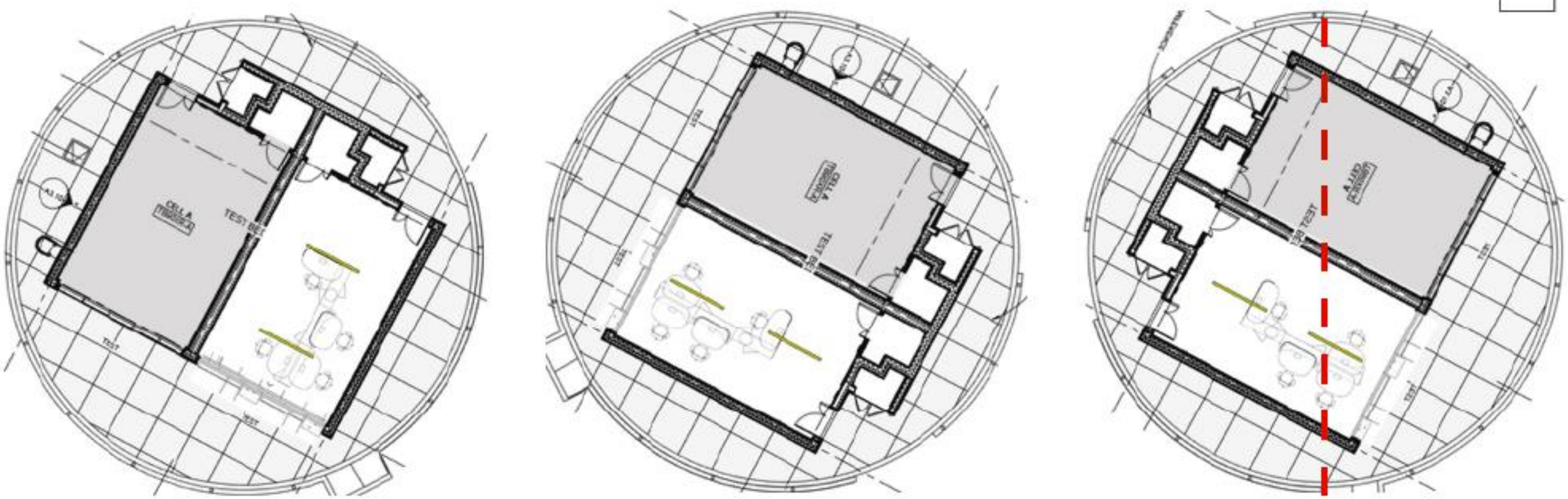
Test Procedure

- Testing three facade orientations: South, West, and East

East Facing (testing) Orientation

242° (28° South of West)





South Facade Orientation

208° (28° West of South)

West Facade Orientation

298° (28° North of West)

East Facade (B35) Orientation

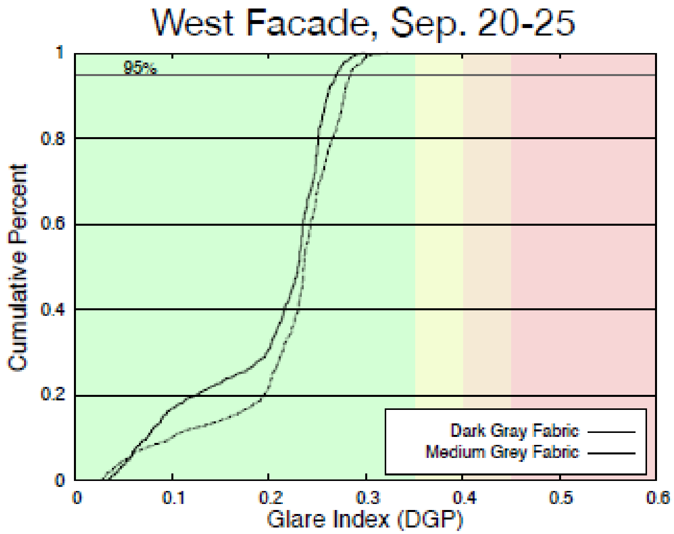
118° (28° South of East)

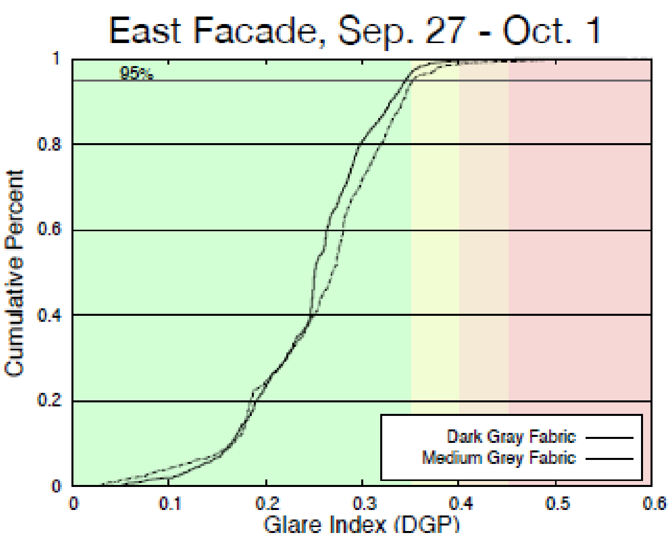
http://eta-publications.lbl.gov/sites/default/files/lbnl-1005151.pdf

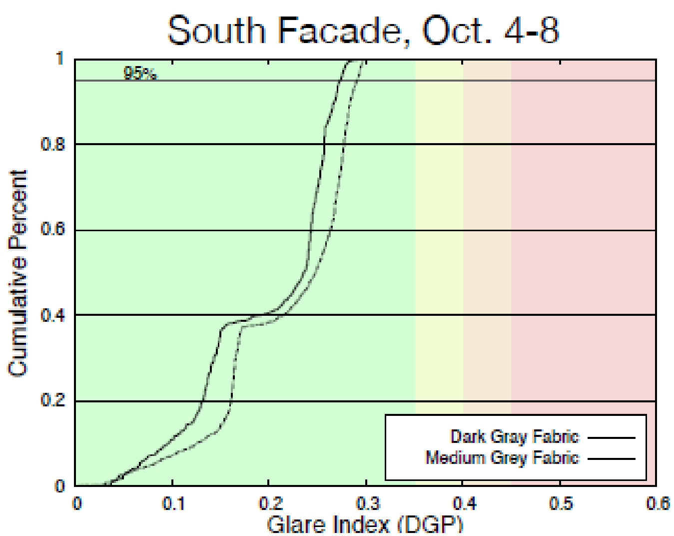
1570: Shadow Grey

1563: Grey

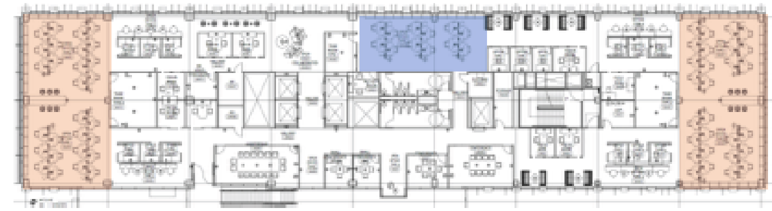
FACADE	SHADE COLOR	95% LIMIT	TOP 5% BAND	CLASS
WEST	Light	0.285	0.299	A
	Dark	0.270	0.283	A
EAST	Light	0.353	0.406	B
	Dark	0.345	0.375	A
SOUTH	Light	0.292	0.301	A
	Dark	0.274	0.289	A

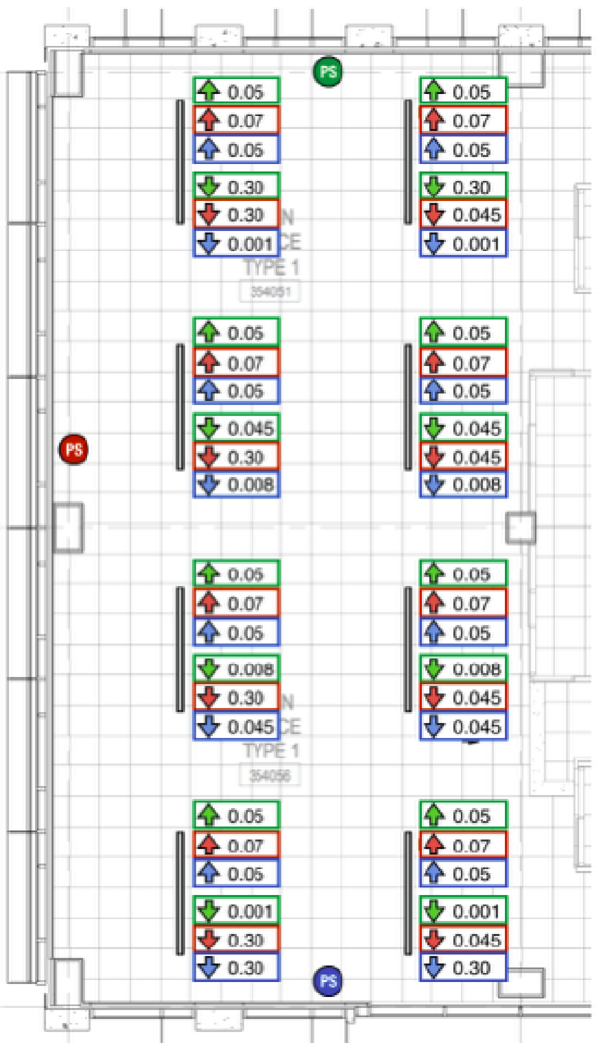






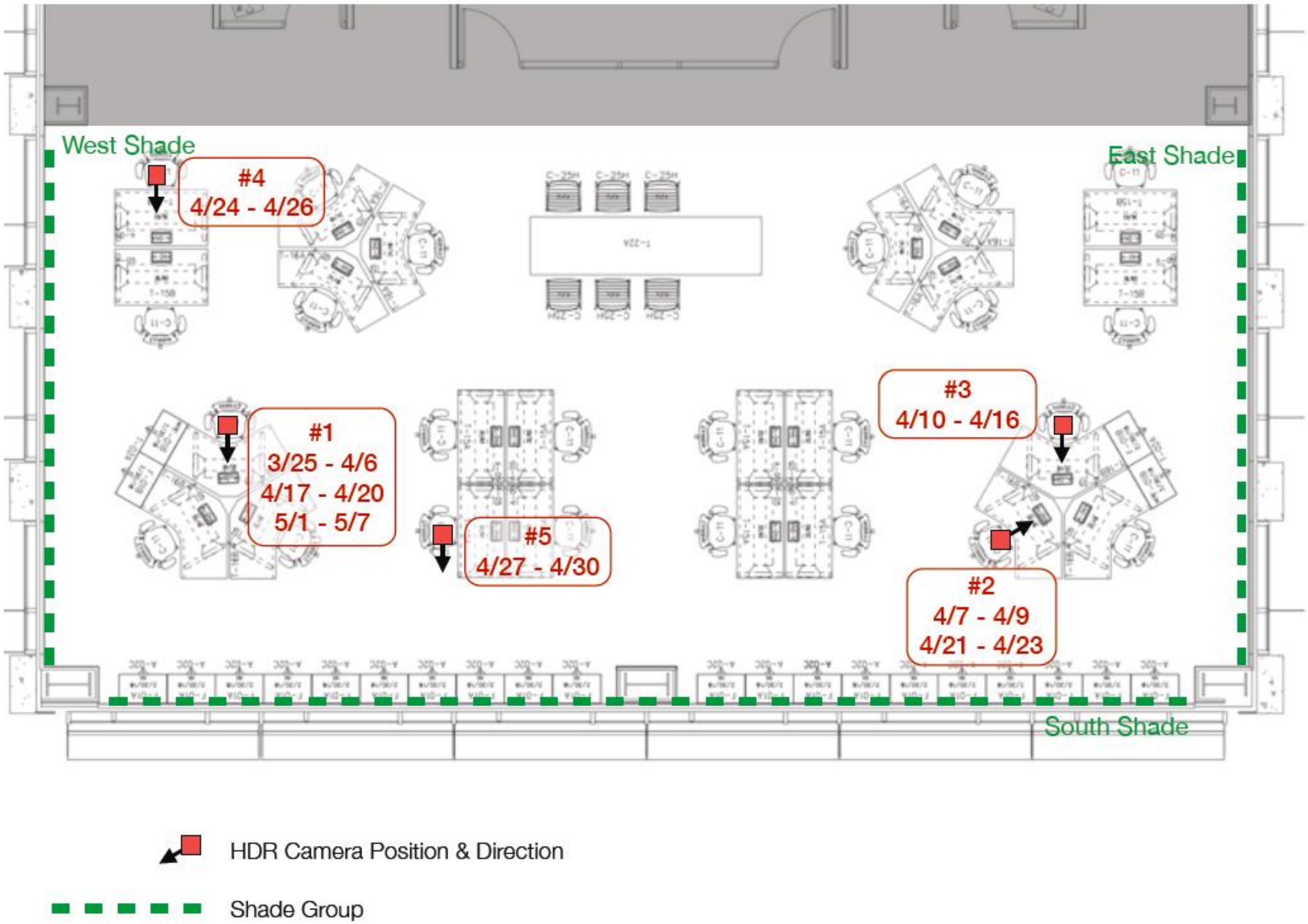
Recommendations





- We provide starting point dependency values based on FLEXLAB
- Lighting in the building ends should be influenced by three photocells, one at each facade.

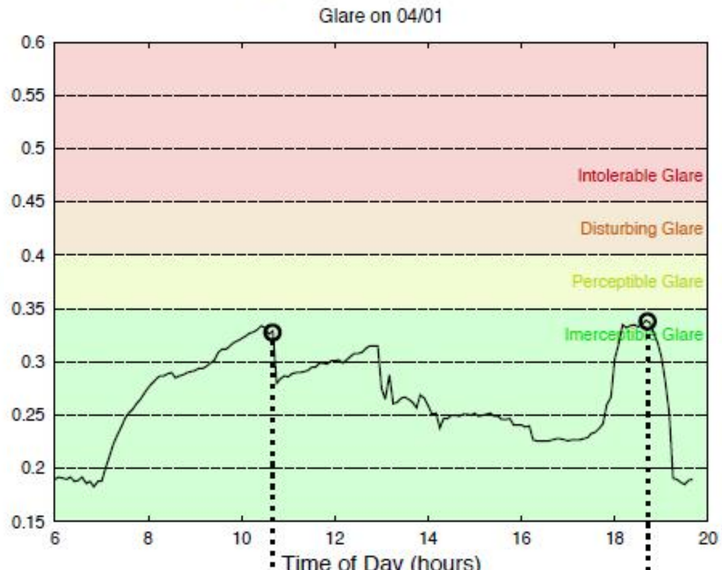
Glare | HDR Camera Locations, **South Area**



http://eta-publications.lbl.gov/sites/default/files/genentech_burn-in.pdf

Glare | **South #1** 3/25-4/3, 4/14-4/20 & 5/1-5/7

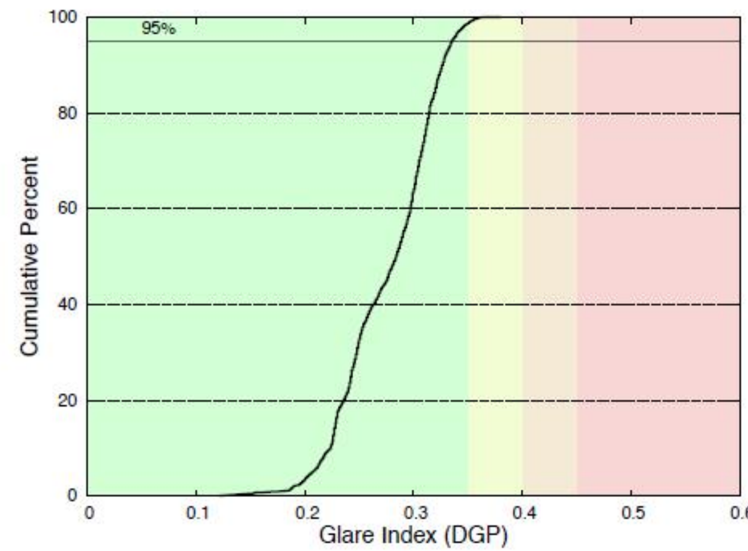
Daily Glare Plot for April 1, 2015



10:40

18:40

Cumulative DGP 3/25-4/3, 4/14-4/20 & 5/1-5/7



Cumulative DGP Statistics, Position #1, South Area

95% DGP Threshold	0.335
Average DGP within top 5% band	0.346
Comfort Class Rating	A

Case study #3: Retrofit construction – Living Lab investigation of LED + automated shading controls

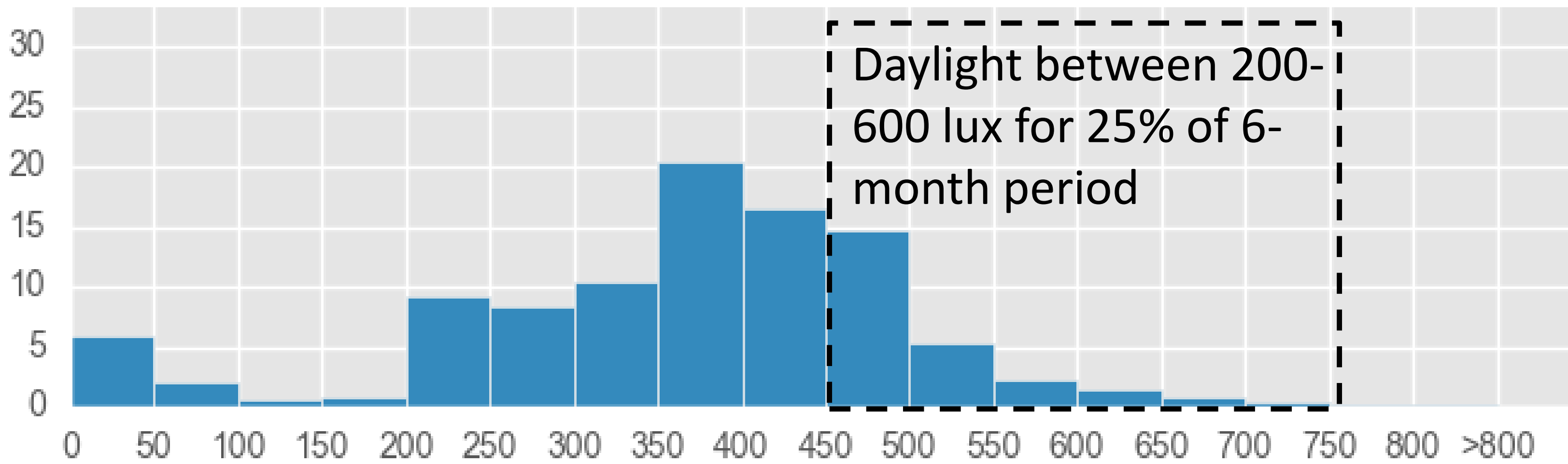
Demonstration site: 2.14 Mft^2, 43-story office building, 90.1-1999 compliant, LEED Gold certification, occupied in 2009

https://facades.lbl.gov/nyclivinglab
http://eta-publications.lbl.gov/sites/default/files/nyc-living-lab-final-report.pdf


Daylight-controlled dimmable lighting
Linear diffuser parallel to window
Thermostat
Automated roller shades
UFAD swirl diffuser
Open plan work area

Daylight

17.2 feet from window

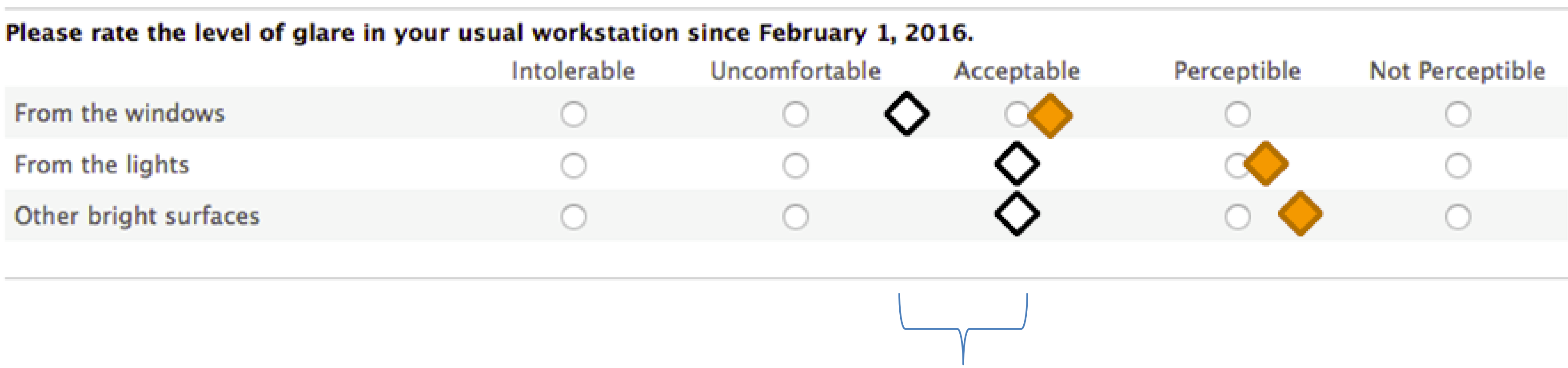


Daylight illuminance levels exceeded 200-300 lux for 47%, 38%, and 25% of the monitored period at the three zone depths of 2.5, 9.9, and 17.2 ft from the window.

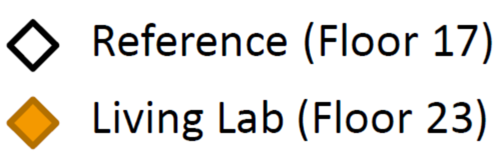
Visual Comfort

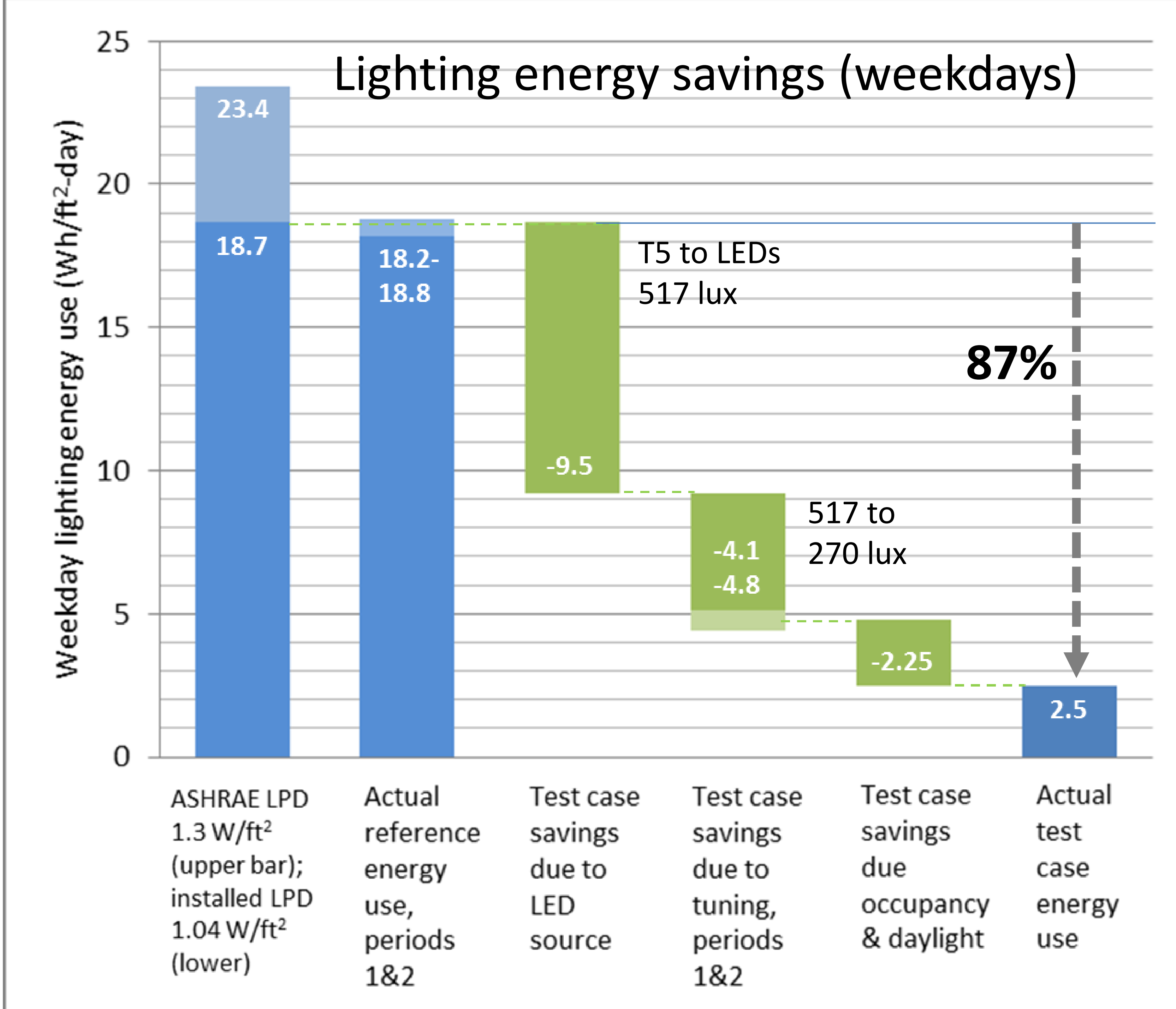
Time-lapsed HDR images on equinox and solstice days, 7AM-7PM

Visual comfort



Survey responses: reference n=2-8; test n=4-30 subjects
Occupant responses were within 2.5-3.1 on average, where 3.0=“acceptable” glare levels





Lighting energy savings (weekdays)
Weekday lighting energy use (Wh/ft²-day)
25
20
15
10
5
0
23.4
18.7
18.2-
18.8
-9.5
T5 to LEDs
517 lux
-4.1
-4.8
517 to
270 lux
-2.25
2.5
87%
ASHRAE LPD 1.3 W/ft² (upper bar); installed LPD 1.04 W/ft² (lower)
Actual reference energy use, periods 1&2
Test case savings due to LED source
Test case savings due to tuning, periods 1&2
Test case savings due occupancy & daylight
Actual test case energy use

What defines high-performance?

Thermal comfort

Visual comfort

Natural daylight

Outdoor views

+1% increased occupancy rate?

+1% increased productivity?

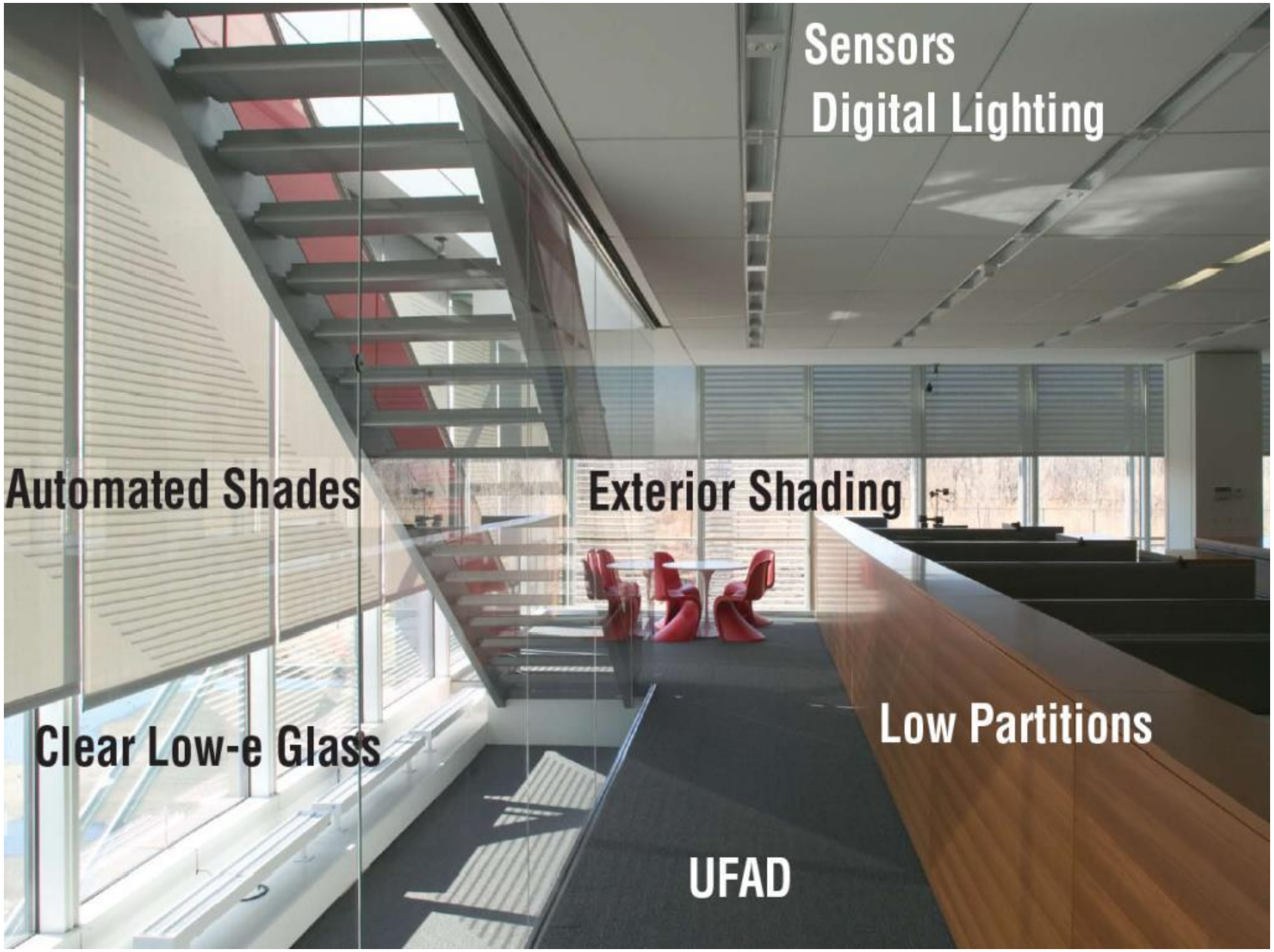
Sustainable

Energy efficient

“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.

Case study #4: Persistence of savings – Post-occupancy evaluation 5 years later



https://facades.lbl.gov/newyorktimes/nyt_post-occupancy.html
http://eta-publications.lbl.gov/sites/default/files/lbnl-6023e.pdf

Frequency of manual override of automated shades
(600,000 ft^2 installation)

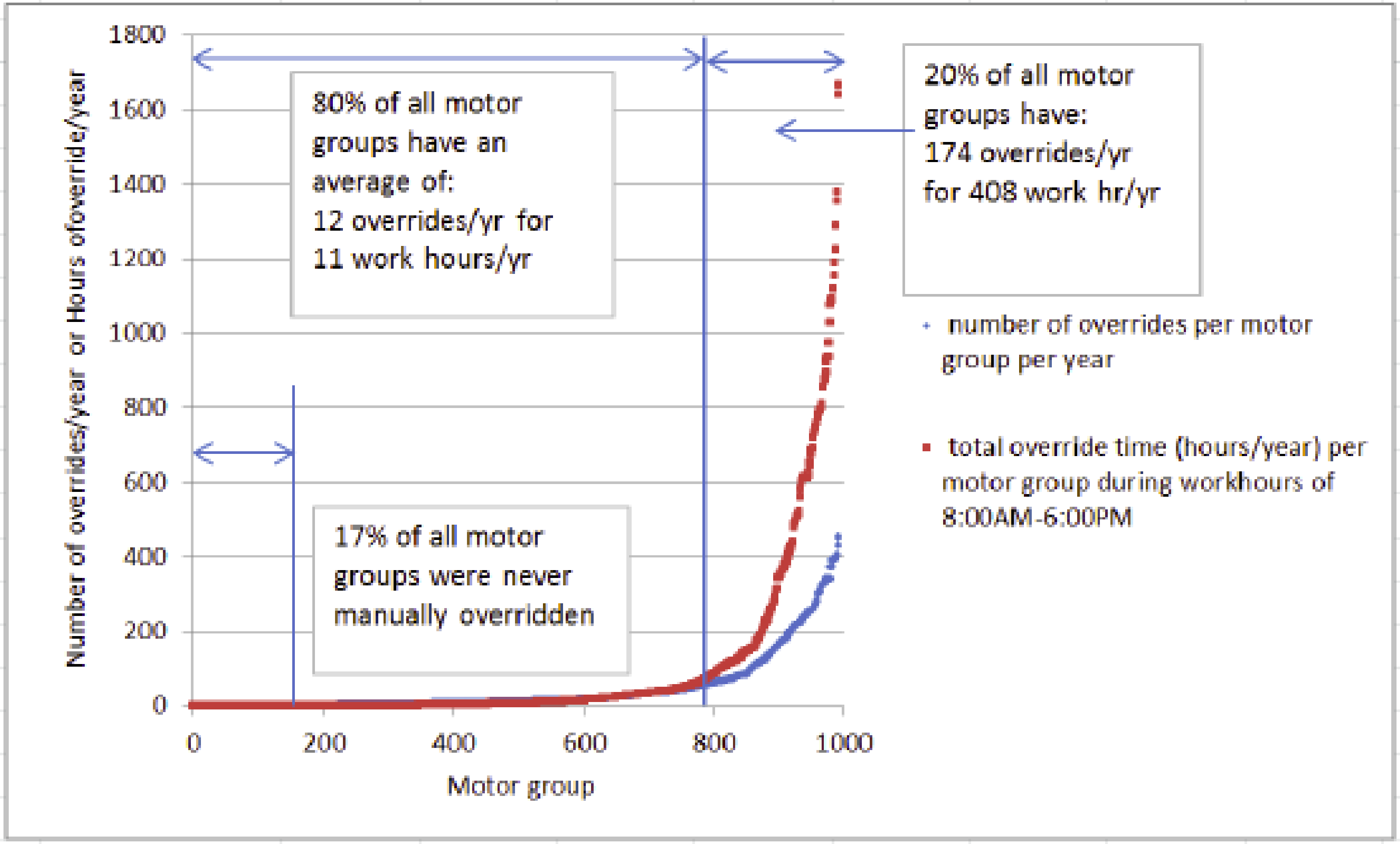
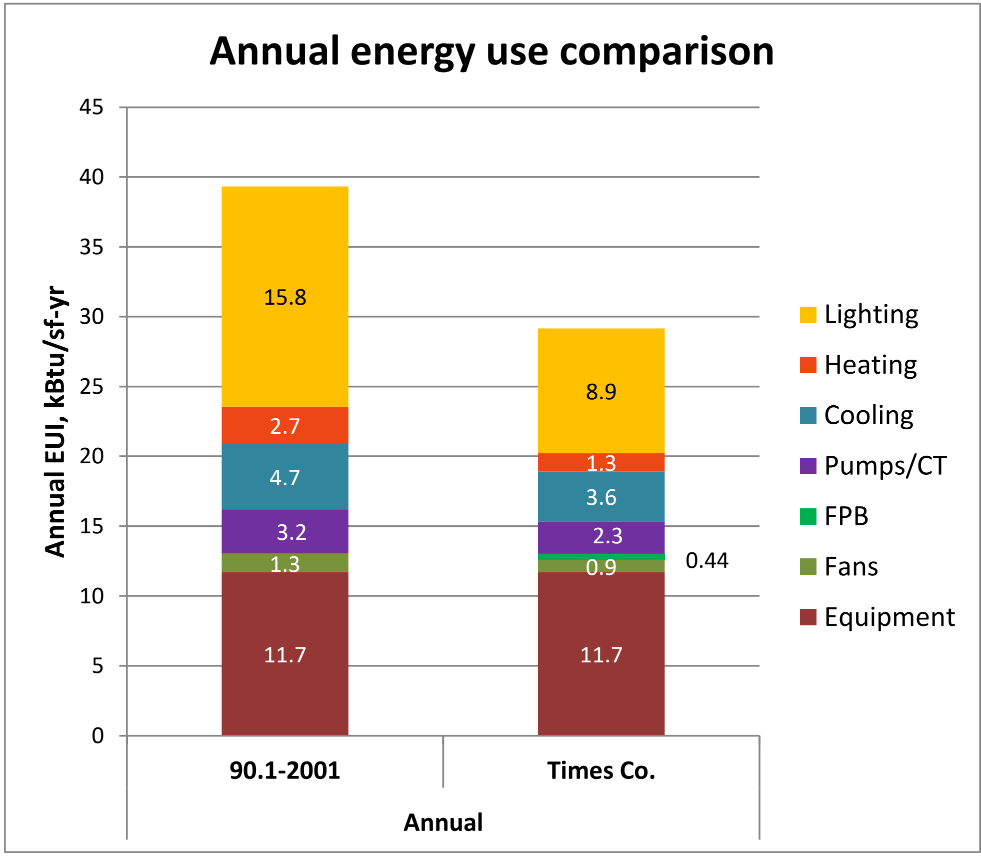


Figure 15. Distribution of the number of manual overrides per motor group for all motor groups on all floors during work hours (8:00 AM to 6:00 PM) on weekdays for one year.

Energy and demand savings (20th floor)

- Site Electricity
  - 8.16 kWh/ft²-yr use
  - 2.58 kWh/ft²-yr savings
  - **43% lighting savings**
  - **23% cooling savings** (despite larger WWR)
- Site Heating
  - 1.31 kBtu/ft²-yr use
  - **51% savings**
- Peak electricity demand
  - 2.65 W/ft² use
  - 1.08 W/ft² savings (22%)
  - **628 kW reduction total**
  - 0.49 W/ft² lighting reductions during summer



Outcome of occupant surveys – occupants who understood the basis for energy efficiency measures were more likely to be satisfied with the measures

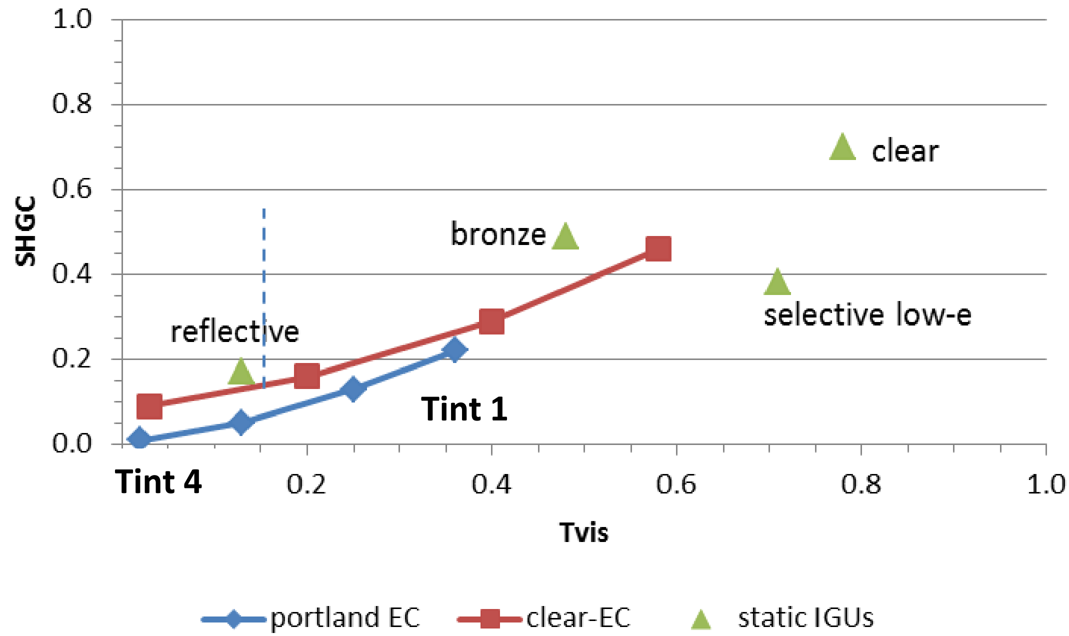
http://eta-publications.lbl.gov/sites/default/files/nyt-lbl-occu-satisfaction.pdf

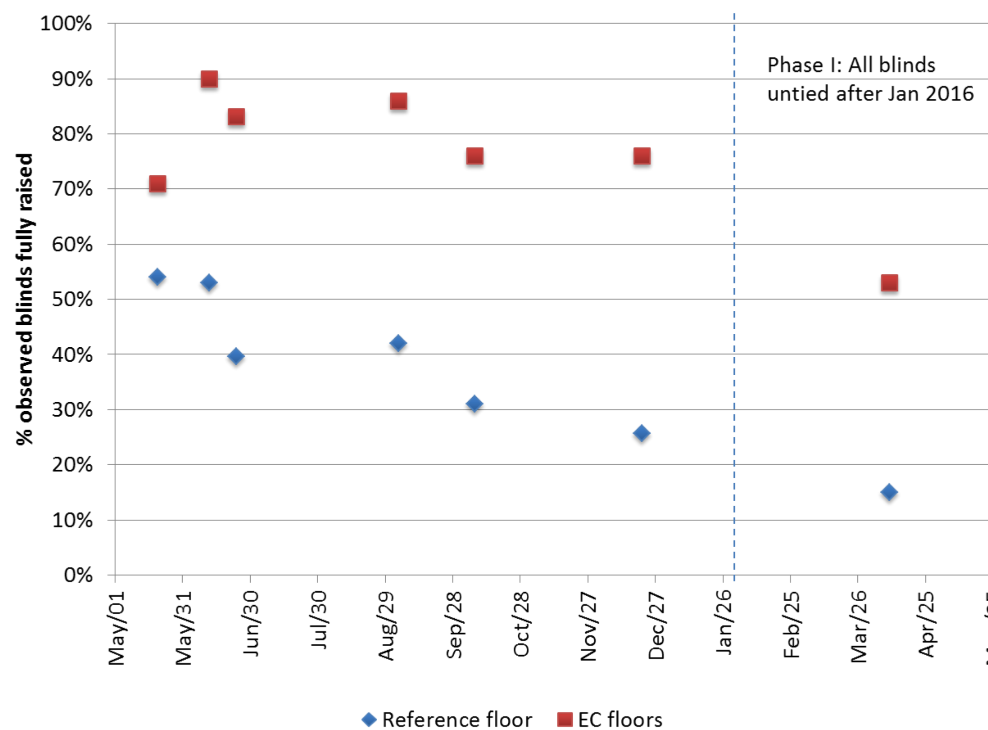
Case study #5: Retrofit with switchable electrochromic windows

http://eta-publications.lbl.gov/sites/default/files/gpg-portland-lee.pdf
https://www.gsa.gov/governmentwide-initiatives/sustainability/emerging-building-technologies/published-findings/building-envelope/

Monitored outcomes

- 36% annual lighting energy savings due to daylight
- 57% reduction in weekend VAV cooling load when in setback mode with tinted EC
- 85% and 92% of occupants preferred EC windows over existing windows in Phases I&II, respectively.
- 40% more blinds fully raised in EC area compared to original windows in private offices





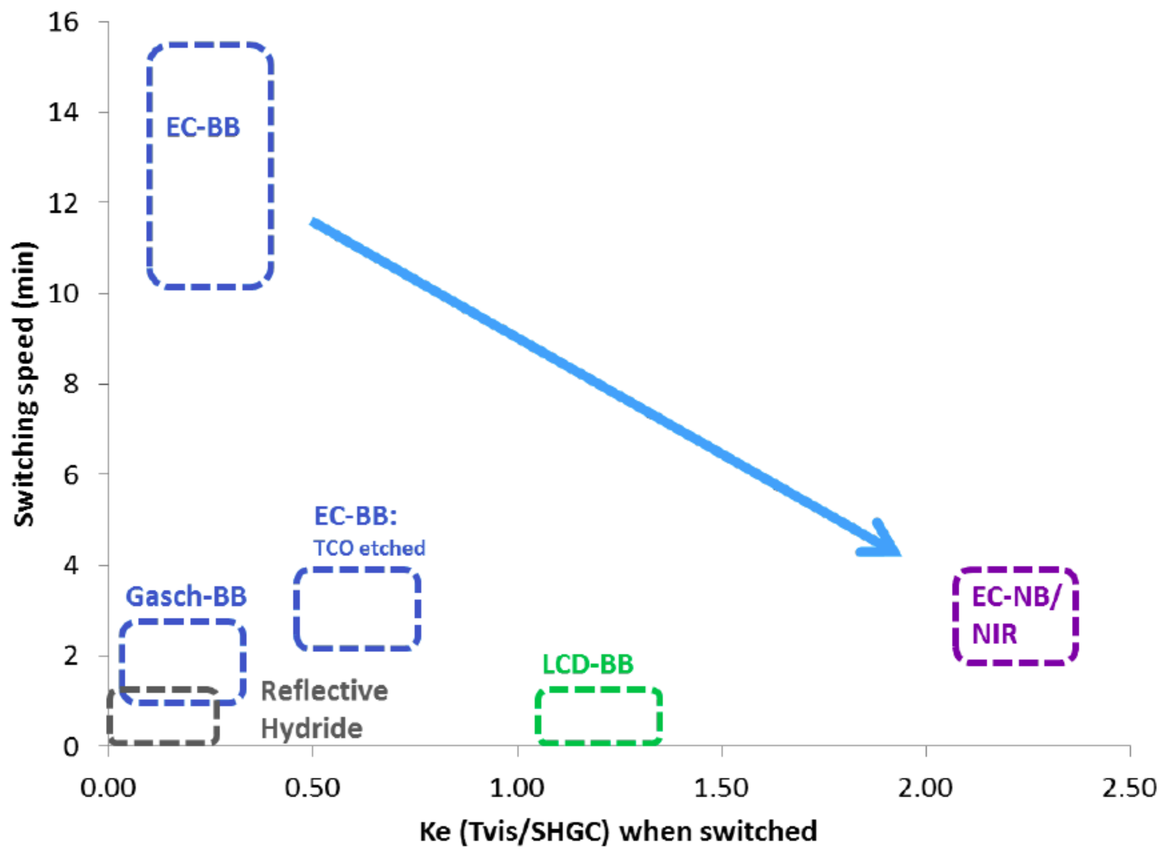
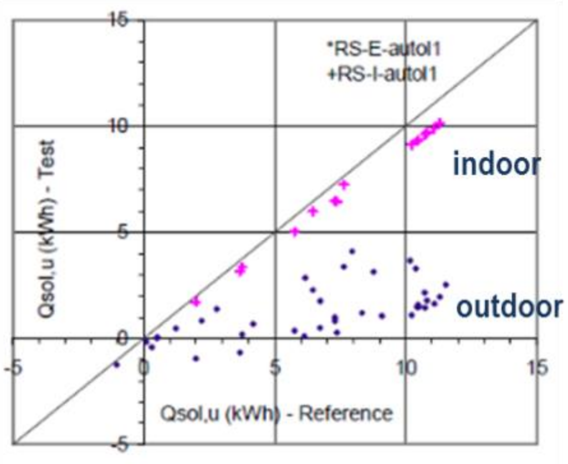


Figure 7. Suggested direction of material science R&D for dynamic glazing materials. An ideal switchable chromogenic glazing would have fast switching, narrowband near-infrared properties with Tvis>0.50 when clear/ bleached. Note: EC=electrochromic, Gasch=gasochromic, BB=broadband, NB=narrowband.

http://eta-publications.lbl.gov/sites/default/files/ch6.3-innovative_glazing_lbnl_2001193_eslee.pdf

Case study #6: Operable, coplanar exterior shading

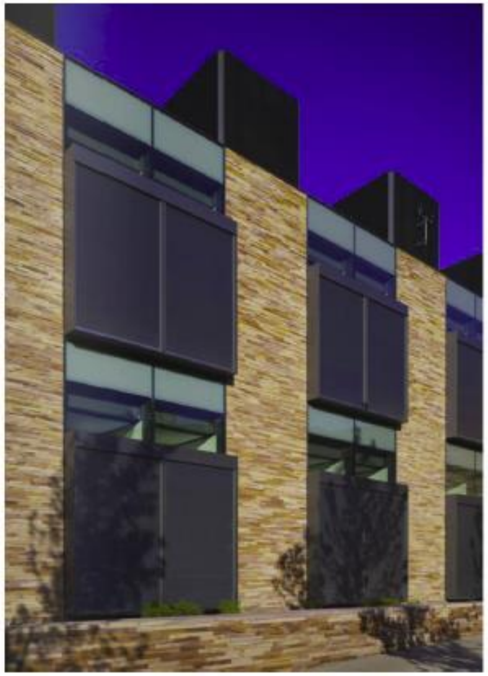
Between 6 types of exterior shades:
78-94% reduction in window heat gains
-25% to 36% reduction in lighting energy use
2-32% of day with glare



compared to low-e glazing with indoor shade

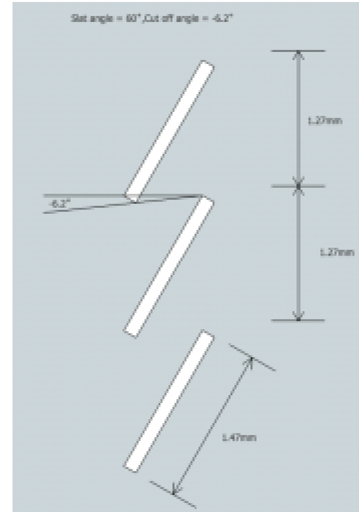
E.S. Lee et al., High Performance Building Façade Solutions, Final project report, California Energy Commission, CEC 500-06-041 (2009), Table 6.
https://facades.lbl.gov/sites/default/files/lbnl-4583e.pdf

Case study #7: Non-operable, coplanar exterior shading

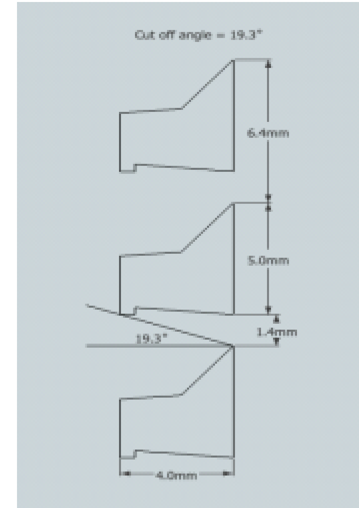


Hilton Foundation, Agoura Hills
Stainless steel roller shade (shd 6)
(picture: ZGF architects)

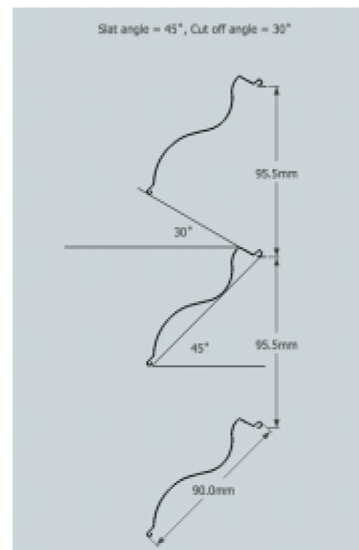
Li Ka Shing, UC Berkeley campus
Aluminum louvers above window
Aluminum louvers in shutters (shd 8)
(picture: ZGF architects)



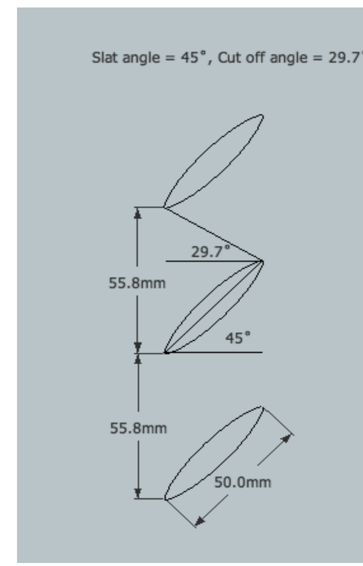
shd 5



shd 6



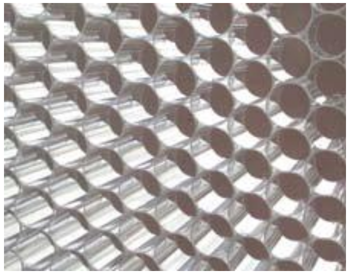
shd 7



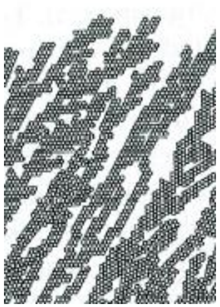
shd 8

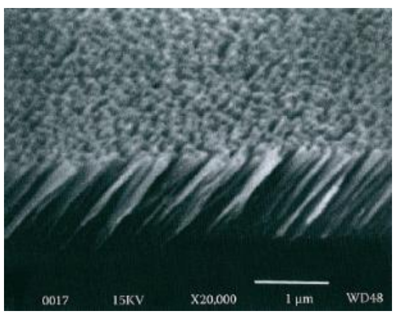
http://eta-publications.lbl.gov/sites/default/files/lbnl1005092.pdf

Case study #6: Fixed, angular selective, between-pane shading

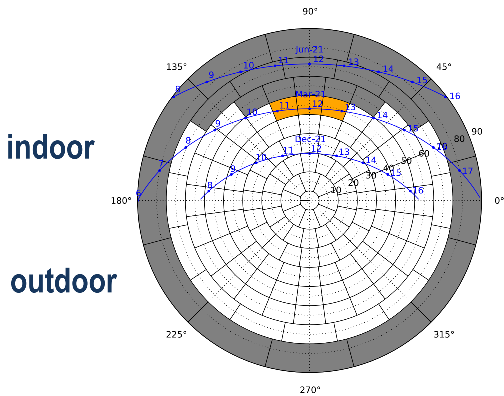


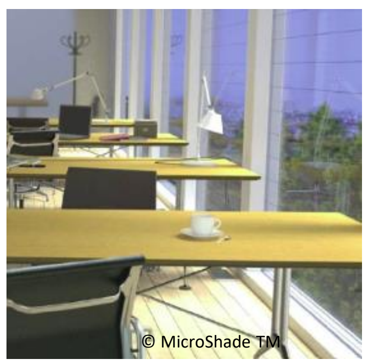
© Panelite





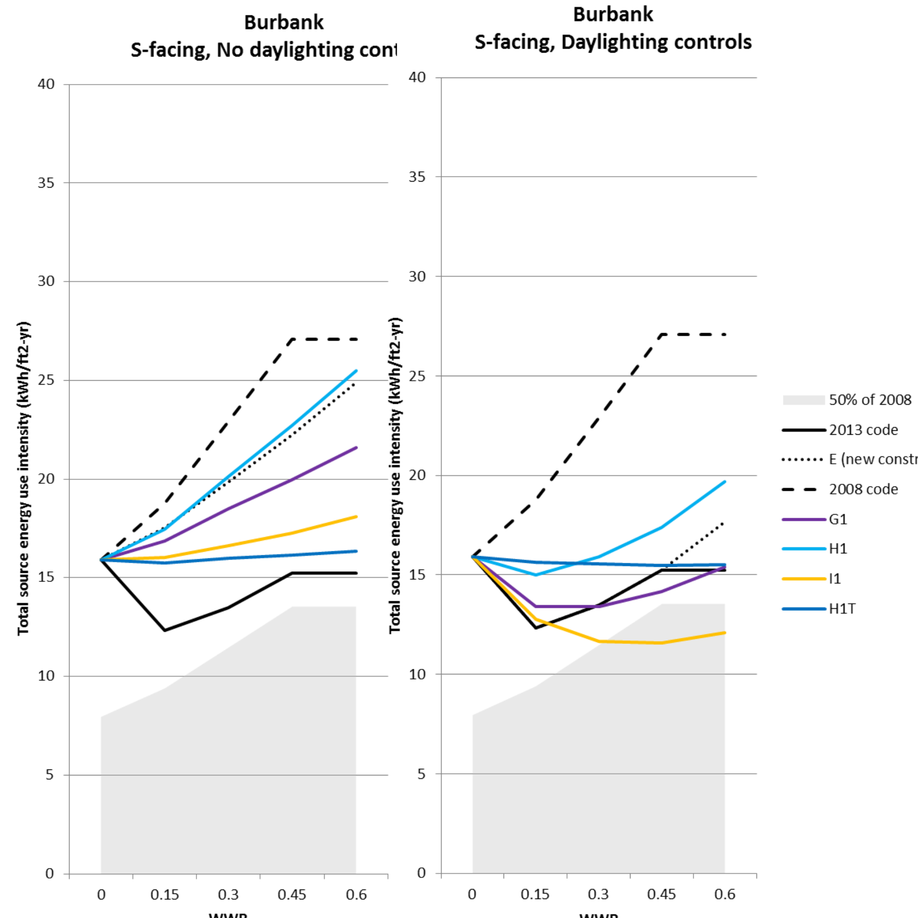
Inclined columnar nanostructures (MJ. Brett, *J.Mater.Sci* 24(1989); GW Mbise et al. *J.Phys.D: Appl. Phys.* 30(1997))





2 angular selective shading system (G1) with outdoor view (solar cut-off angles in image above)

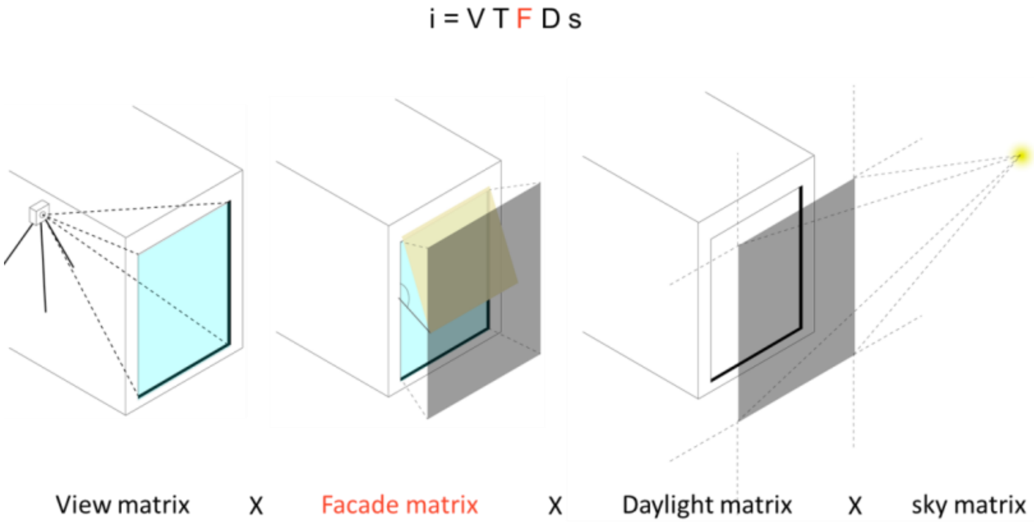
Between-pane shading systems with daylighting: 32-55% savings compared to Title 24 2008



3 annual source energy use for angle-selective shade (G1, H1, I1, H1T) compared to Title 24 2008 & 2013 code

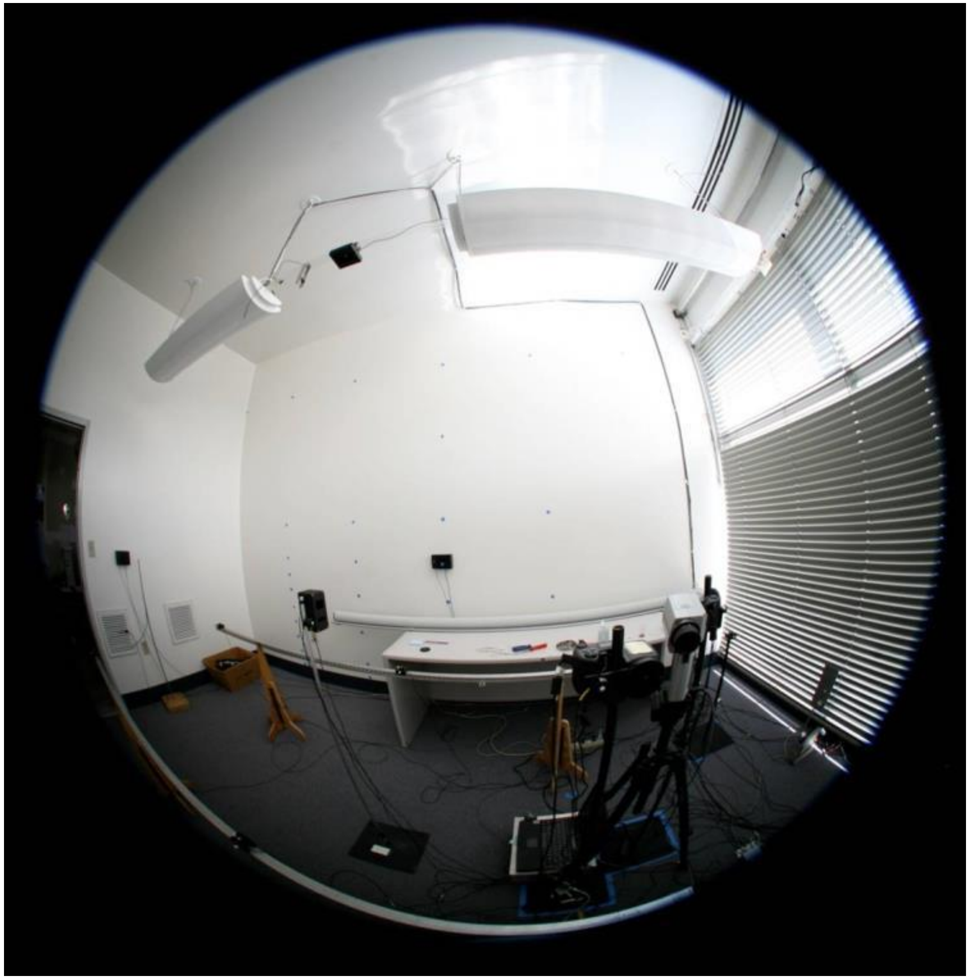
https://facades.lbl.gov/between-pane-shading

Case study #9: Non-coplanar shading systems



http://eta-publications.lbl.gov/sites/default/files/ncp_lbnl-final_lee_0.pdf

Case study #10: Daylight redirecting systems
Passive optical light shelves, prismatic films, dynamic metamaterials

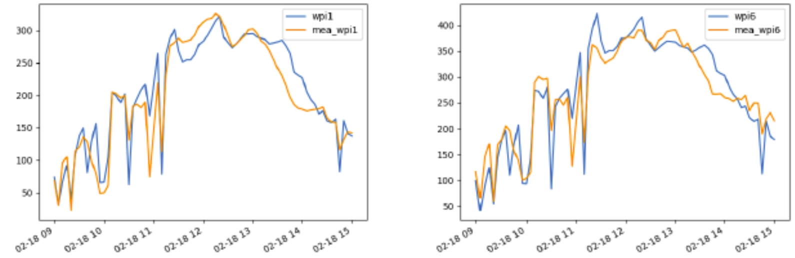


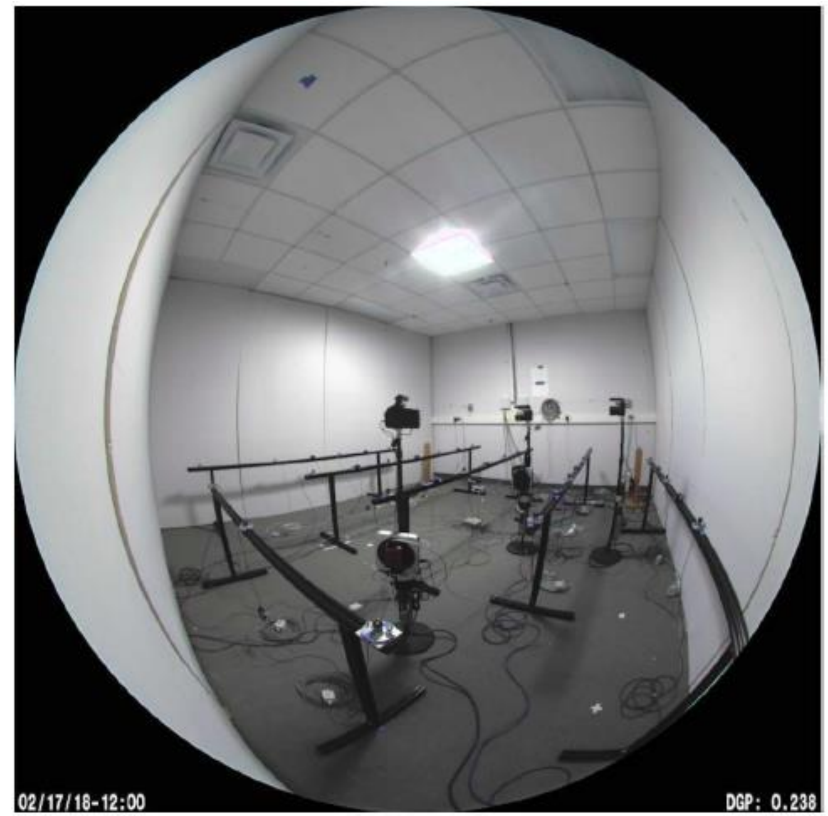
https://facades.lbl.gov/optical-light-shelves
https://facades.lbl.gov/dynamic-metamaterials
http://eta-publications.lbl.gov/sites/default/files/lbnl-2001167.pdf
http://eta-publications.lbl.gov/sites/default/files/lbnl-2001051.pdf
http://eta-publications.lbl.gov/sites/default/files/lbnl-187135.pdf
http://eta-publications.lbl.gov/sites/default/files/lbnl_dual-zone_shades_lbnl2001196.pdf
http://eta-publications.lbl.gov/sites/default/files/passive_optical_light_shelf.pdf

Case study #11: Tubular daylighting devices

Validation of matrix algebraic methods of modeling TDDS in FLEXLAB

Figure 5.16: Simulated and Measured Workplane Illuminance at Two Representative Sensor Locations, Test Day February 18, 2018

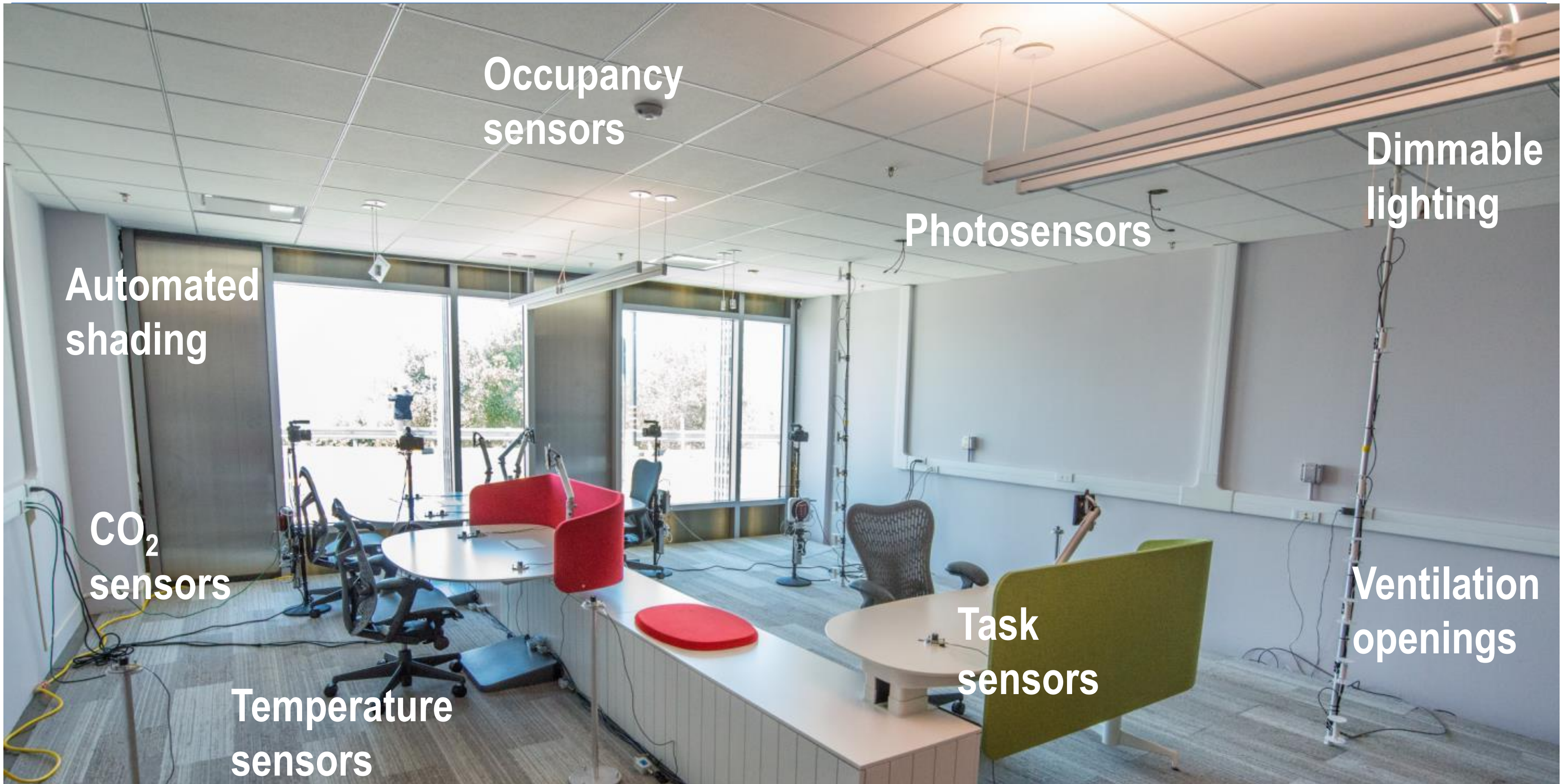




Lee, E. S., et al. 2019. *High-Performance Integrated Window and Façade Solutions for California.* California Energy Commission (to be published).

Case study #13: Smart, integrated systems

Building-to-grid, intelligent controls for advanced façade systems



https://facades.lbl.gov/model-predictive-controls

Lessons Learned

- **Tremendous innovation from the facades sector!**
- Complex optimization problem: all techs have pros and cons → it's what matters most to the client and application (i.e., capital cost, operating cost, maintenance, IEQ)
- Generational or sector shift from bottom-line economics to the happiness + healthiness quotient
- Organizations are getting serious about GHG/ energy-efficiency goals and are pushing the architectural-engineering industry to be serious too (backed by financial penalities)

What's *driving* high-performance today?

Energy efficient

Demand responsive

GHG/ Sustainable

Resiliency

Economic competitiveness

Pressure to lower EUI

Pressure to raise EUI

Comfort

IAQ

Natural daylight

Outdoor views

Health + well-being

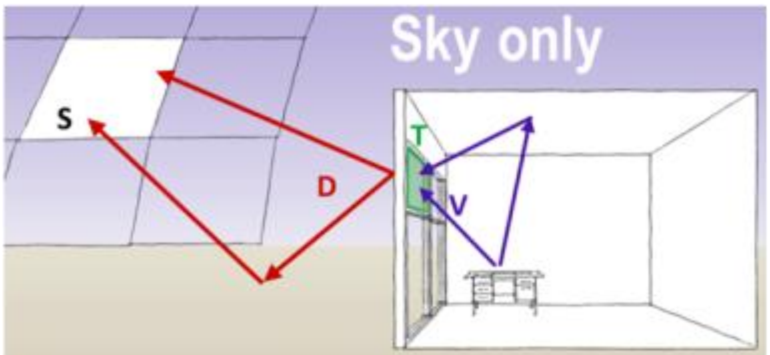
What can we do to help?

Enable industry to make informed decisions

- Validated building physics models (daylight, solar gains, heat transfer)
- Validated human factors models (comfort, IEQ/view, health)
- Certified, standardized product database for plug and play, apples-to-apples analysis (e.g., NFRC, AERC)
- Facility management tools for commissioning, fault diagnostics, and continuous M&V; provide a feedback loop to industry

Model development and validation

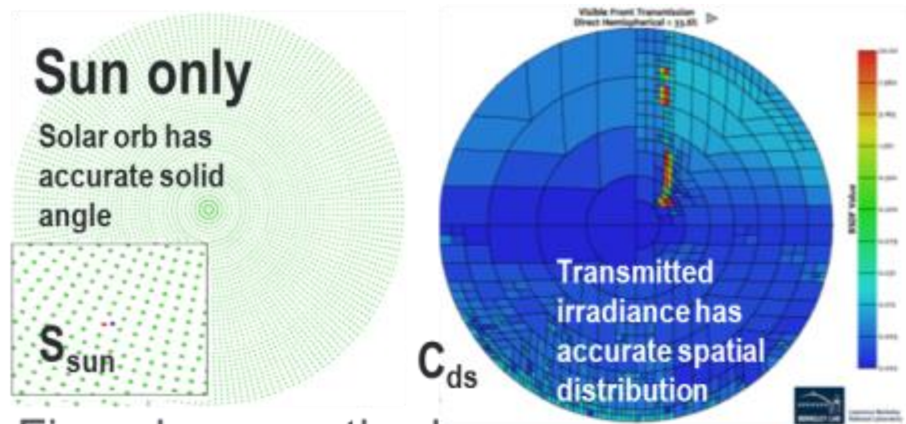
Matrix algebraic methods for speedy annual simulations



Three-phase method

$$I_{3ph} = VTDS$$

+



Five-phase method

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

145xN resolution

http://eta-publications.lbl.gov/sites/default/files/ibpsa_0.pdf
http://eta-publications.lbl.gov/sites/default/files/lbnl-2001102.pdf

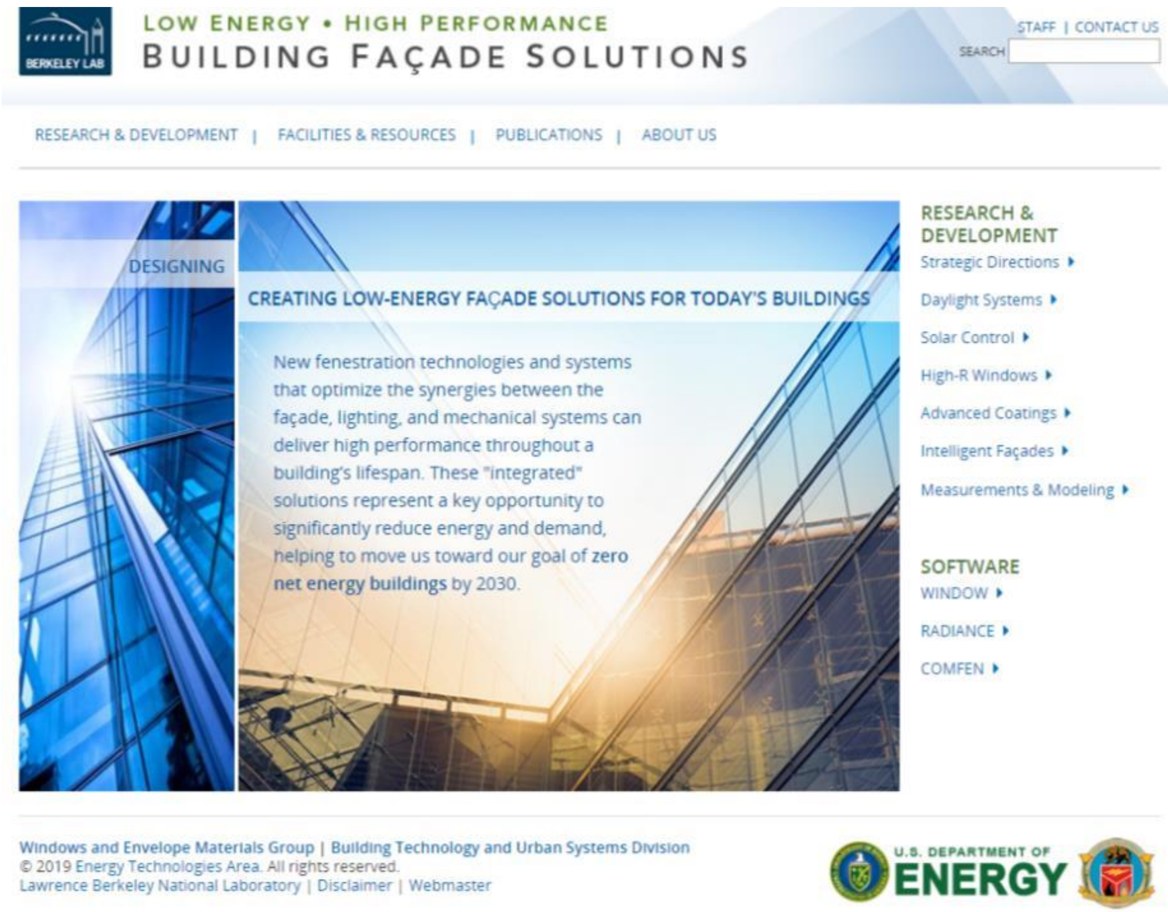
IEA SHC Task 61C and

Attachments Energy Rating Council
AERC

- Define **standard methods for generating product data for complex fenestration systems** in support of modeling daylight and solar radiation impacts in buildings such that **simulated values agree with measured data to within an RMSE<5-10%**.

http://task61.iea-shc.org/meetings
https://www.radiance-online.org/community/workshops/2018-loughborough/presentations/03-HighResBSDFs.pdf

3% openness factor, pearl white roller shade fabric



https://facades.lbl.gov/

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