California Public Interest Energy Research (PIER)

U.S. Department of Energy

High Performance Building Facade Solutions

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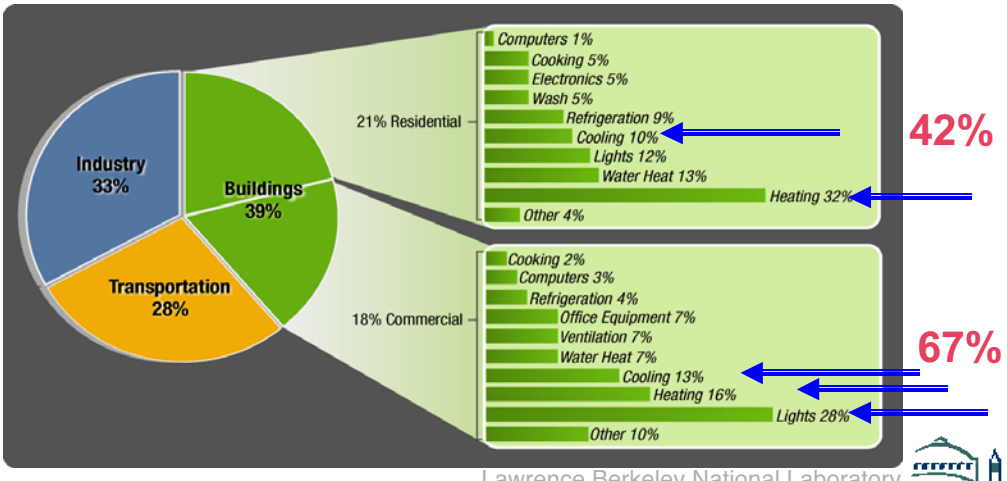
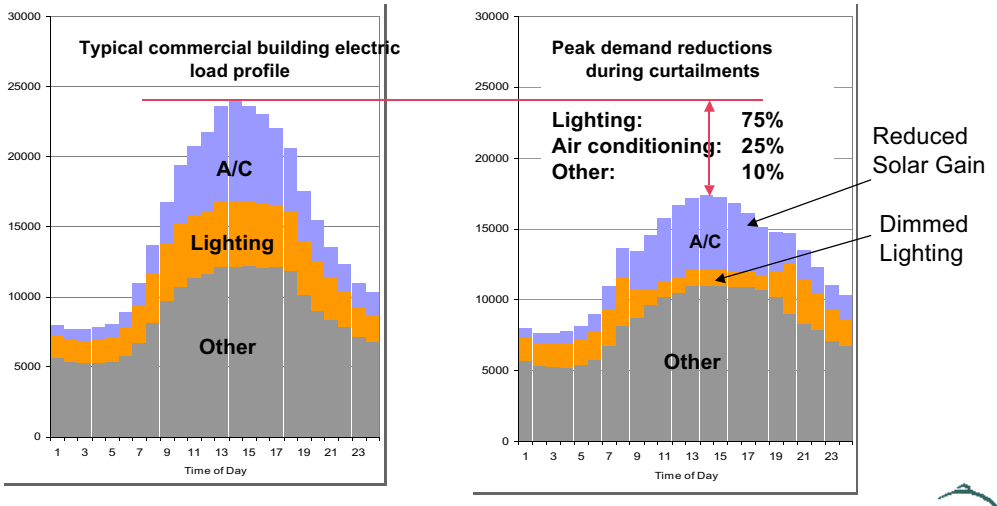
Fenestration Impacts on Building End Use Energy Consumption

Buildings consume 39% of total U.S. energy
• 71% of electricity and 54% of natural gas



Energy/Demand Management Potentials with Active Façades+ Daylighting Controls



Strategy Portfolio for Getting to "Very Low Energy" or "Zero Net Energy" Buildings

Market Forces

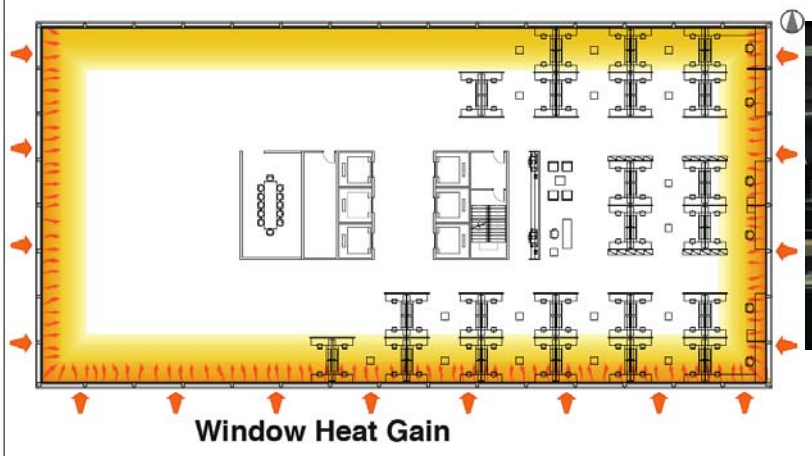
Feedback

- Deployment: (5-30% savings)
  - Identify what works and deploy it widely
  - Applies to all buildings: new and existing
  - Mandatory programs: codes and standards
  - Voluntary programs: incentives
- Demonstrate Emerging Solutions (20-60% savings)
  - Find underutilized, unproven technologies and systems
  - R&D to improve, optimize; make them mainstream
- R&D --> Breakthrough Innovations (50-80% savings plus on-site renewable power)
  - New, more effective, high performance, integrated systems options
  - Technology, Systems, Process
  - Lower costs, lower risk

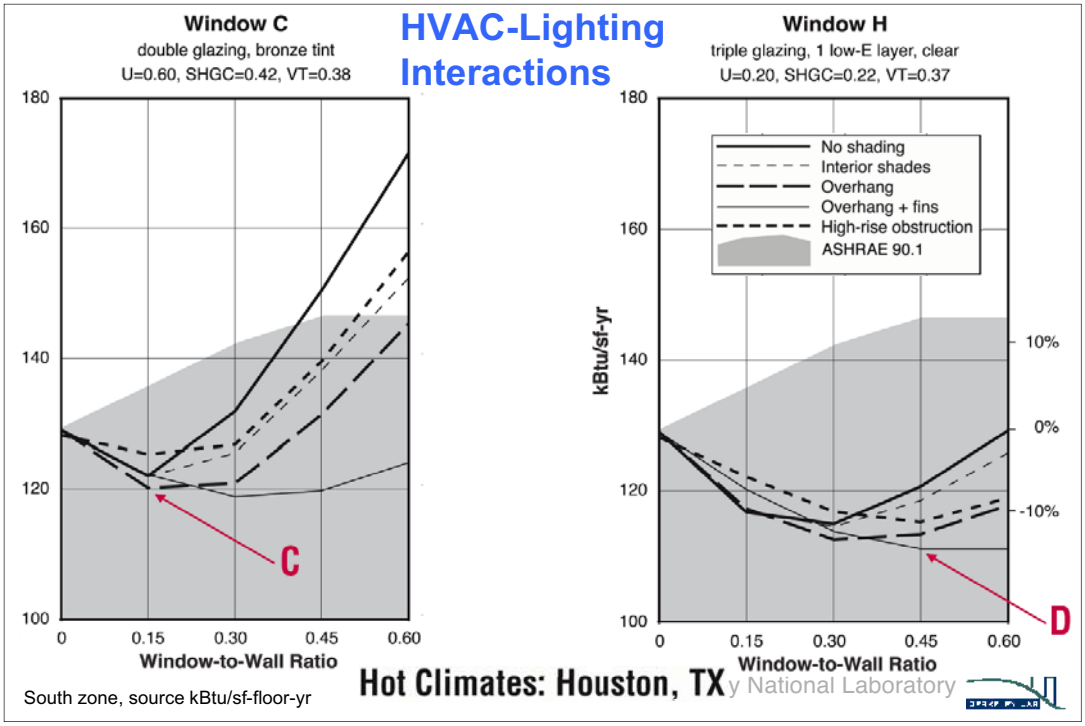
Potential Solutions
(split between KISS + responsive)

- Hi-R facades
  - Aerogel
  - Vacuum glazings
  - Superwindows (R6+)
- Solar control
  - Ceramic fritted glass
  - Exterior metal scrims, fixed overhangs, fins
  - Automated exterior shades
- Daylight redirection/ lighting quality
- Automated, intelligent facades
  - Real-time Façade-HVAC-Lighting systems optimization
  - Daylight + view ↔ SHG + visual comfort/ performance
  - Low-energy cooling strategies
    - Night-time ventilation + chilled ceilings
    - Double-envelope facades
  - Demand response
- Photovoltaic-integrated facades for on-site renewable energy

0% savings: Code baseline: Low-SHGC windows and with manually-operated shades and lighting



HVAC-Lighting Interactions



South zone, source kBtu/sf-floor-yr

Hot Climates: Houston, TX

Next-generation Energy Codes Perspective: No need for daylighting?

- Prescriptive measures (ASHRAE 90.1, 189, Title-24)
  - Reduce maximum window-to-wall area ratio < 0.30
  - Decrease prescribed SHGC and U-factor
  - Projection factors for attached exterior shading
- Lighting controls
  - Decreased installed LPD
  - Occupancy-based, scheduling, setpoint tuning controls
  - Lower the setpoint for ambient lighting
  - LED task lighting at 7-9 W
  - Annual lighting energy use with controls:
    - 1.65 kWh/sf-yr with occupancy controls
    - 1.2 kWh/sf-yr with occupancy and daylighting
    - Approx 0.3 W/sf equivalent LPD
- **IEQ? View, brightness, health, productivity → People want windows**

Life-Cycle Owner Costs in Perspective

% of 30-year Total Owner Cost

- **Design Fees:** **<1%**
- **Construction:** **4%**
- **Annual operations:** **12%**
- **Staff Salaries** **84%**

Empire State Building goes green, one window at a time

Enlarge By Robert Deutsch, USA TODAY

Jakob Kozcinski cleans the glass of one of the 6,514 Empire State Building windows before film is applied between layers to make it more energy-efficient.

By Rick Hampson, USA TODAY

NEW YORK — You want to ask him: How many do you break?

That's because Anthony Concepcion does windows — lots of windows.

He's working at the Empire State Building. As part of an effort to become certifiably green, the office tower is removing, retrofitting and replacing each of its 6,514 double-hung, dual-pane windows. That's 26,056 panes of glass.

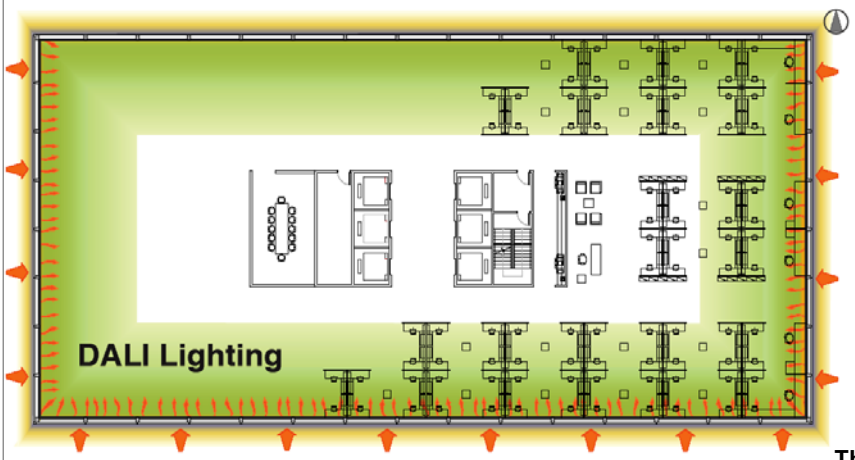
PHOTOS: Empire State Building goes green

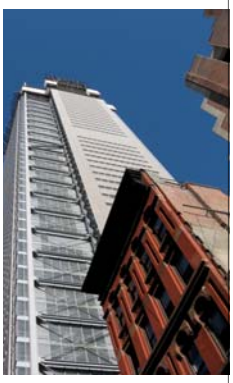
"It's a lot of glass," says Concepcion, 39, work crew supervisor for the contractor, Serious Materials of Sunnyvale, Calif. "It's all part of going green."

The building, for four decades the world's tallest and still the tallest in New York, is spending $13 million on windows, insulation and other upgrades to cut energy use by 38% and save about $4.4 million a year.

Never has a structure so old and so tall gone so green. "It's the

20% savings: Automated interior shades + DALI dimmable lighting systems

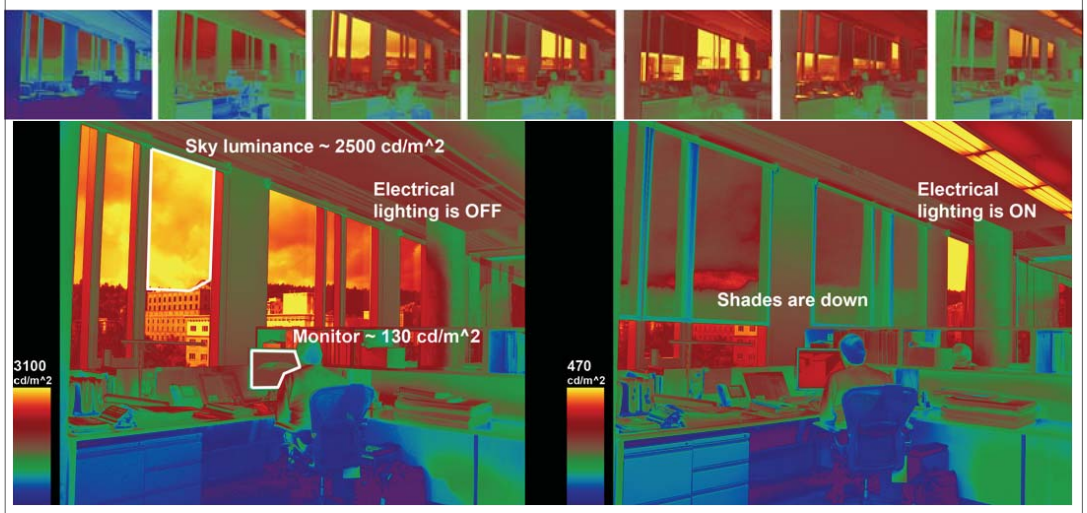




The New York Times Headquarters

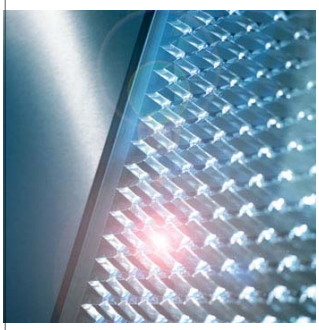
Automated Shades

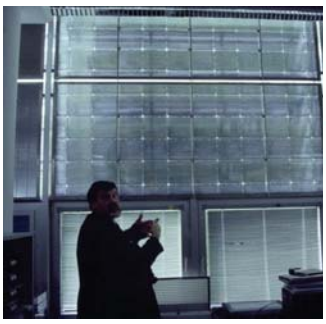
Daylight "efficient" shading

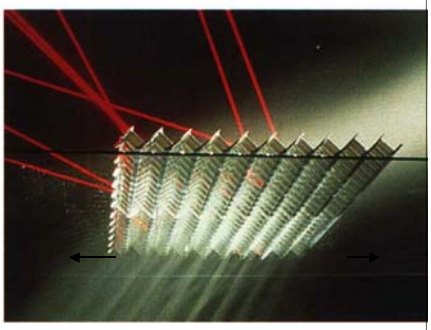


Kyle Konis, UCB/ LBNL

Complex Fenestration Systems (CFS)



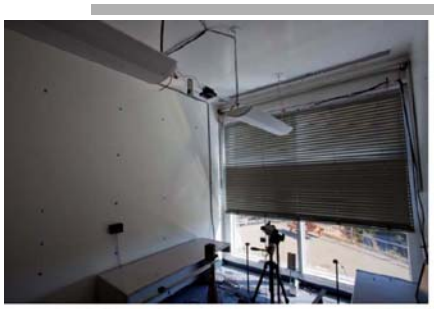


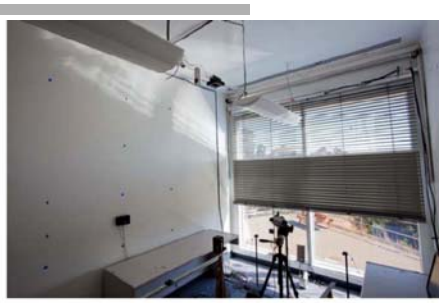


Source: St. Gobain/ Eckelt DLS
COOLSHADE HR 32/9

South **North**

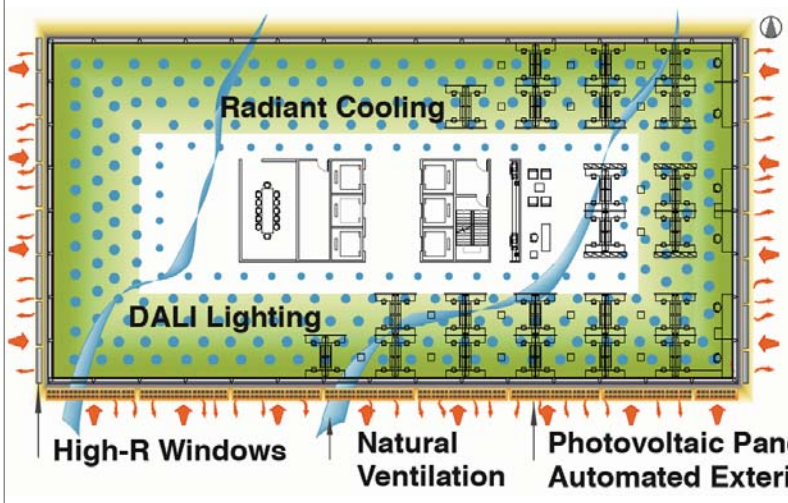
Sunlight-redirecting blinds





30-50% savings: Integrated facades and low-energy cooling

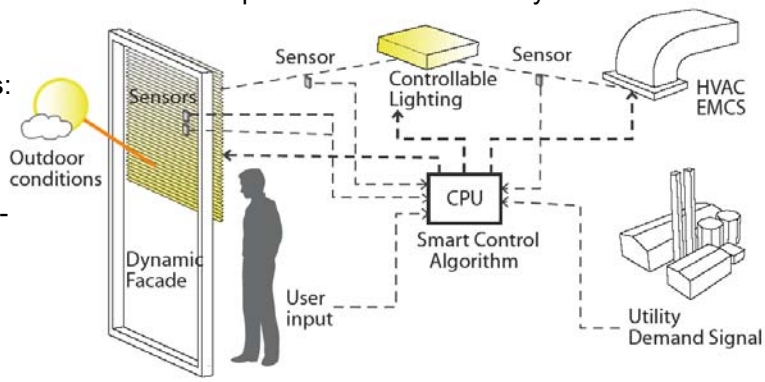
Nord LB, Hannover



Definition of a "Smart", "Dynamic" 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



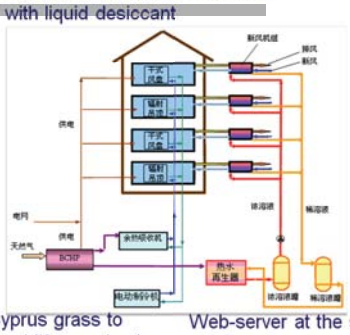
Control algorithms: Accepts input from sensors or computations then determines how to position the operable façade components

Façade as HVAC + Lighting System

Active facade for natural ventilation

Micro-mirror to redirect sunlight

Decentralized dehumidification with liquid desiccant



Phase change material to increase thermal storage

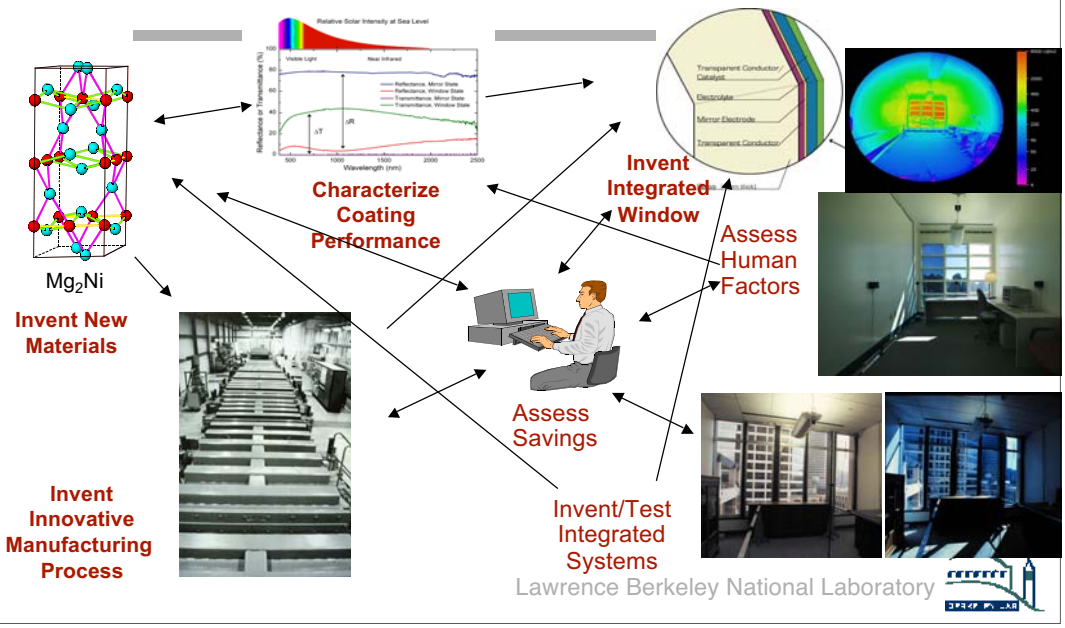
Cyprus grass to humidify supply air

Web-server at the size of 25 cents

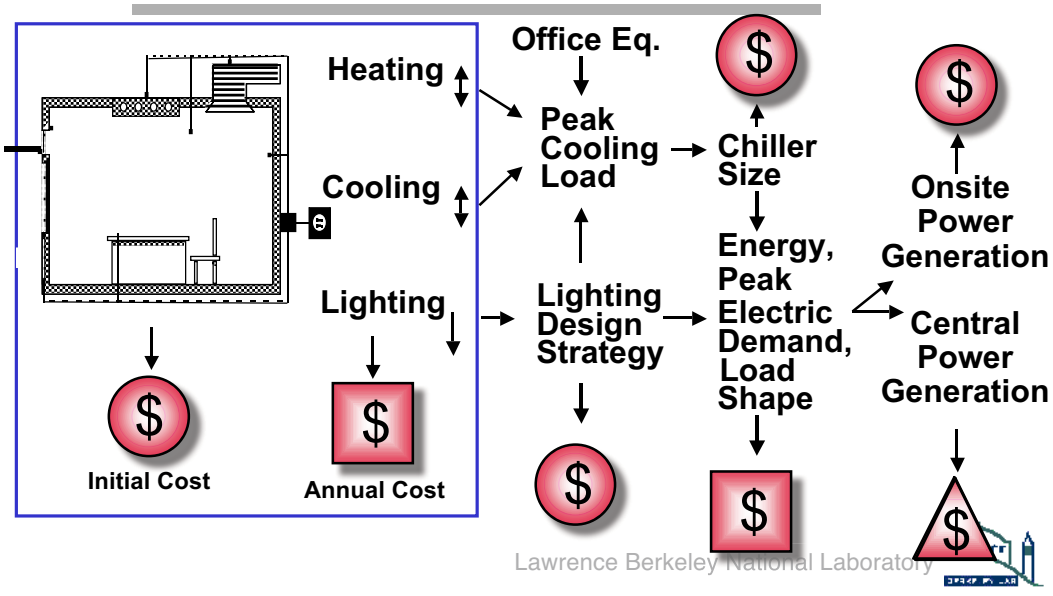
High-Performance Facades Research Portfolio

	Technical Strategies	Simulation Tools	Systems Engineering	Market Transfer
Deployment (20% savings)	Integrated Envelope and Lighting Controls	Commercial Fenestration Design Tool (COMFEN)	Industry Partnerships	Codes and Standards, Rebates/ Incentives
Emerging Solutions (40-50% savings)	Non-selective filters	Complex Fenestration (CFS) Modeling Tools	Bench-scale Tests: IR Chamber, Material Science Lab, Lighting Lab	NFRC Rating and Labeling, CMA Tools
	Angular-selective filters	IGDB/ CFS Database	Windows Testbed Facility	Design Assistance/ Design Guides
	Super-insulating Windows	Window 6-7	Energy Use/ Peak Demand/ HVAC Downsizing	UCBerkeley UCDavis
	Daylight-redirecting systems	CFS/ Radiance	Human comfort, acceptance, satisfaction	DOE Commercial Buildings Initiative: National Accounts, GSA
	Low-cost, intelligent facades	CFS/ EnergyPlus	Systems Engineering: Improve, optimize	Monitored Studies and Post-Occupancy Evaluations
			Specifications, Commissioning	
R&D Breakthroughs (50-75% savings)	Whole-building intelligent facades	iFACade: Virtual Testbed Façade-Lighting-HVAC Controls	ZEB National User Facilities	San Francisco Federal Building
				New York Times Headquarters

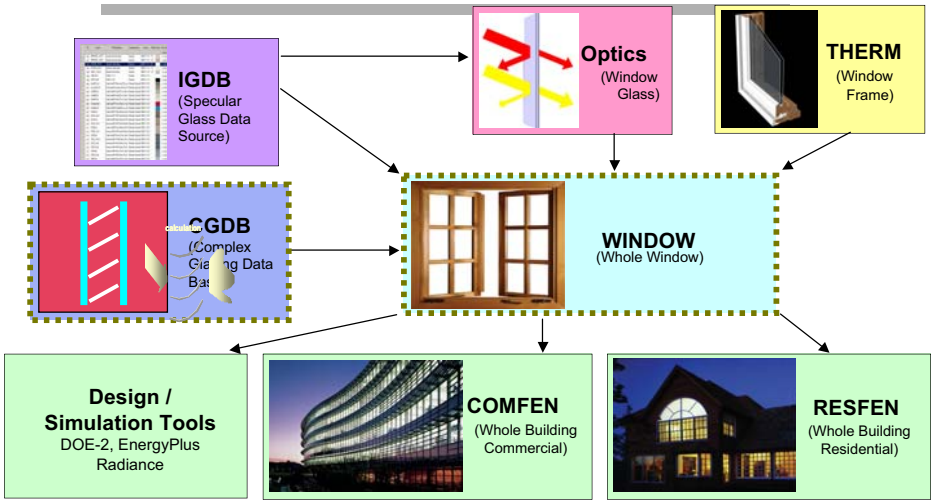
Integrated R&D Strategy for New Systems
(Needed to guide R&D for maximum success in markets)



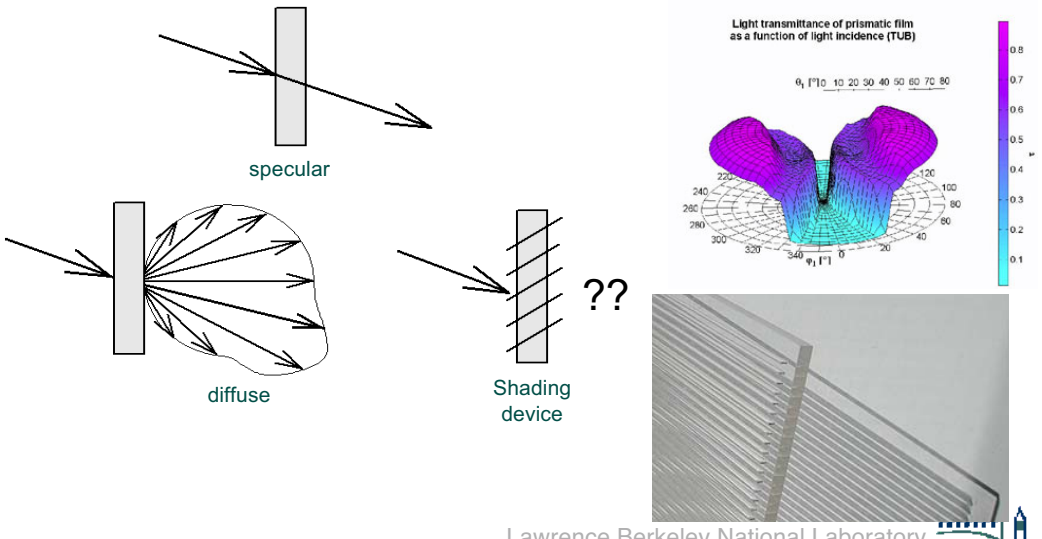
System Integration: Cost Tradeoffs



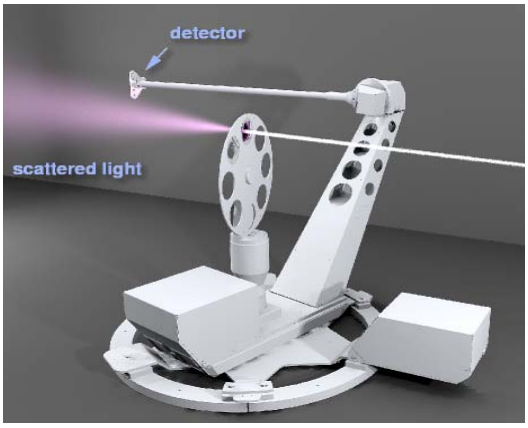
Software Tools Overview



Background: Optics of Glazing and Shading Layer types



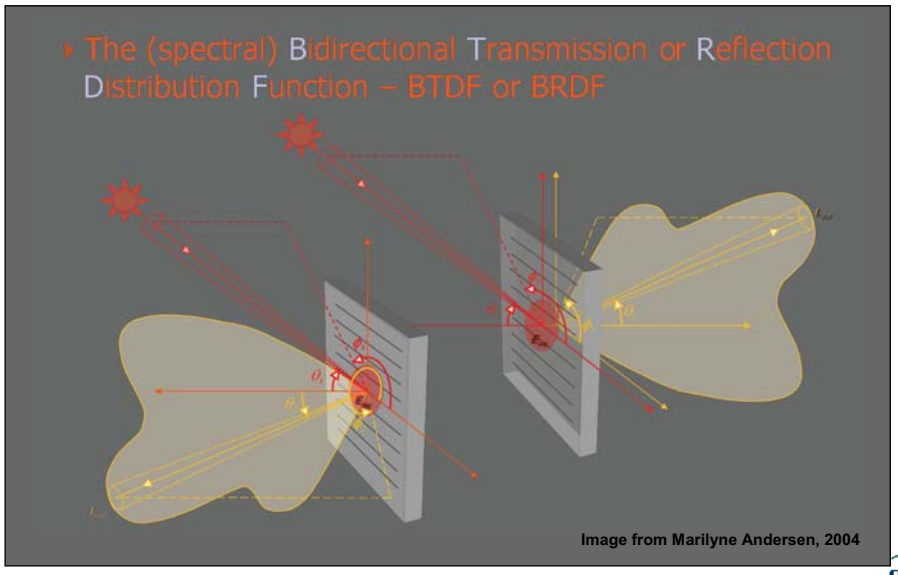
Scanning radiometer



Hemispherical measurement, RGB and SOL spectrum

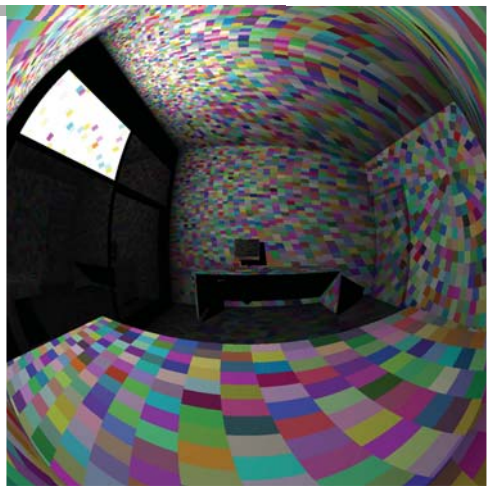
Definition: BRDFs and BTDFs

bi-directional reflectance and transmittance functions



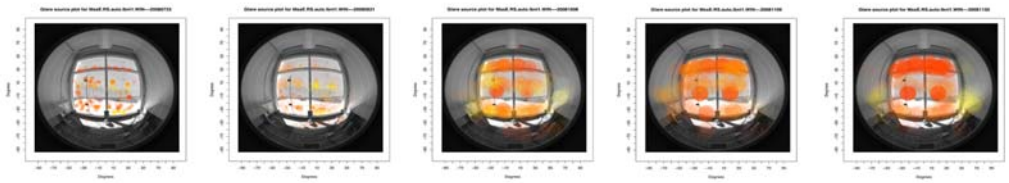
Basis Angle Projections

Klems basis projection



2° basis projection

Diagnostics: Glare Source Composites

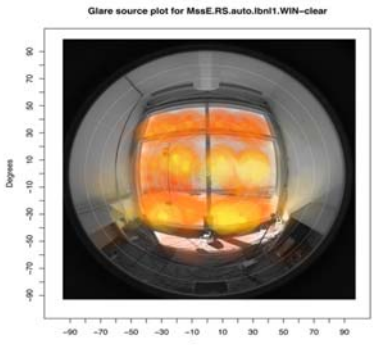


07.23 08.21 10.08 11.09 11.30

Daily Composites…

Glare Source	Dx	Dy	Dz	Steradians	Luminance (cd/m^2)	Indirect Illuminance (lux)
1	0.88	0.30	-0.37	0.27	2771	1143
2	0.82	-0.37	-0.13	0.45	1799	
3	0.18	-0.96	-0.20	0.01	1432	
4	0.82	0.54	-0.21	0.00	3582	
5	0.96	0.18	0.20	0.14	2940	
6	0.92	0.38	0.11	0.02	3180	
7	0.89	0.45	-0.01	0.02	2506	
8	0.85	0.44	0.30	0.02	2070	
9	0.83	0.51	0.21	0.02	2762	
10	0.85	0.53	-0.01	0.02	2463	
11	0.79	0.61	-0.08	0.02	2370	
12	0.77	0.60	0.23	0.02	2791	
13	0.76	0.64	0.08	0.02	2708	
14	0.75	0.47	0.47	0.02	1226	
15	0.84	-0.06	0.55	0.00	1295	

RADIANCE Findglare output x 144 images



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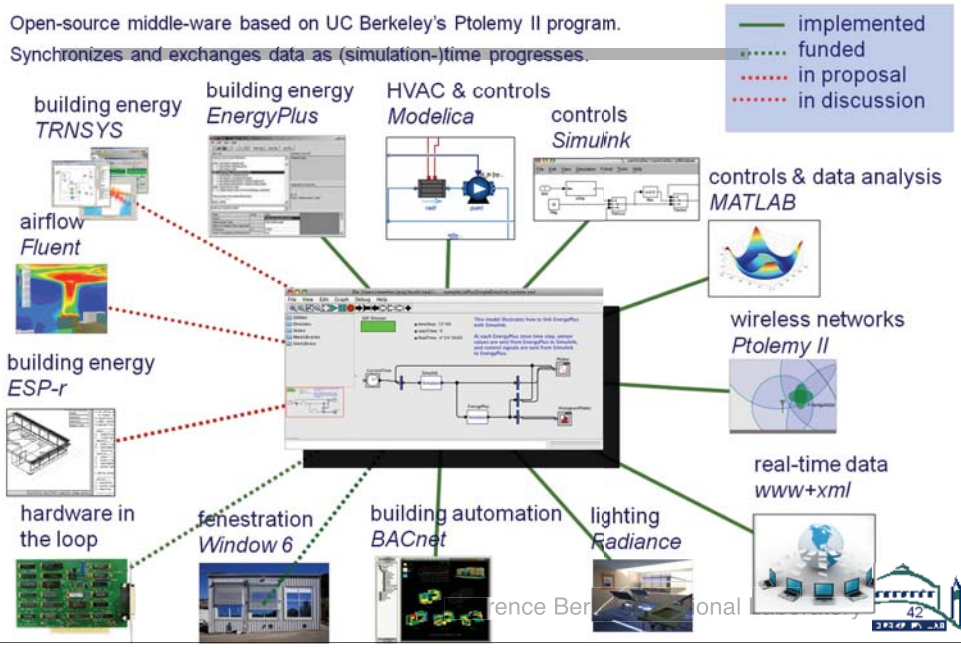
Test Condition

Solstice to solstice composite, N = 14 days (clear)

Lawrence Berkeley National Laboratory

Building controls virtual testbed (BCVTB)

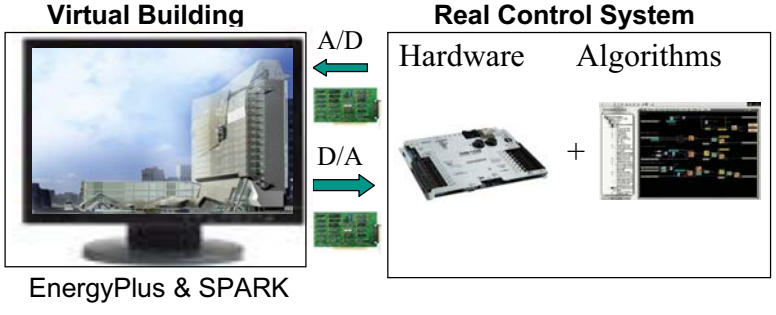
27



Control System Testing Using Design Simulations

28

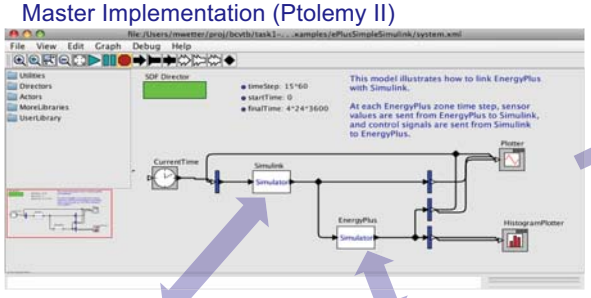
- Test control system using design simulation:
  - Real-time EnergyPlus → Hardware interface → Control hardware from the building
  - Does the control program produce the expected performance?



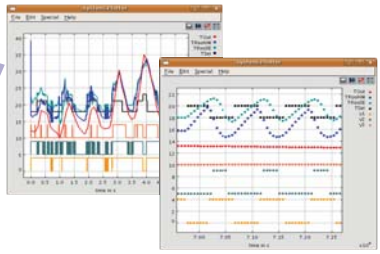
Natural Ventilation in SF Fed. Bldg. 29

All software modules reusable without code modification

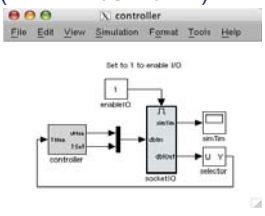
Master Implementation (Ptolemy II)



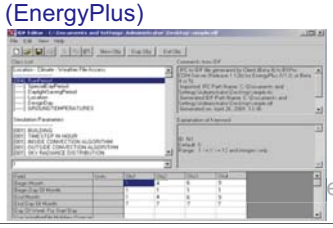
Real-time output (Ptolemy II)



Controls algorithm (MATLAB/Simulink)



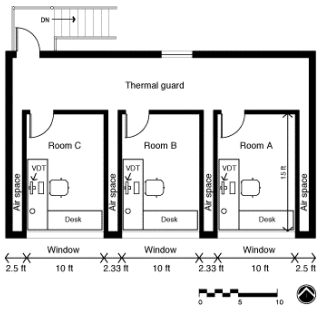
Building temperatures and airflow (EnergyPlus)



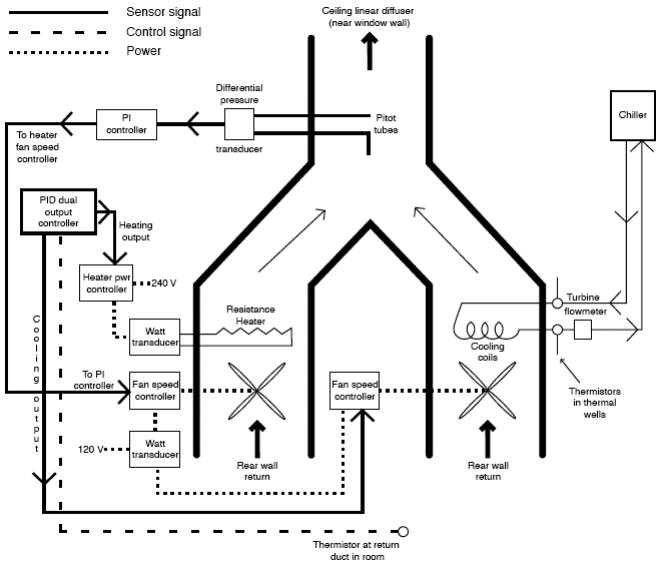
eley National Laboratory

LBNL Windows Testbed 30

Lawrence Berkeley National Laboratory

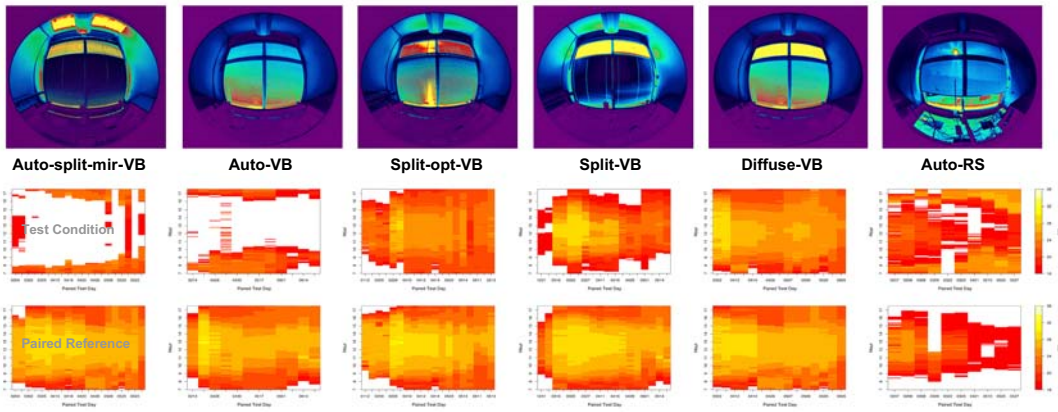


LBNL Windows Testbed



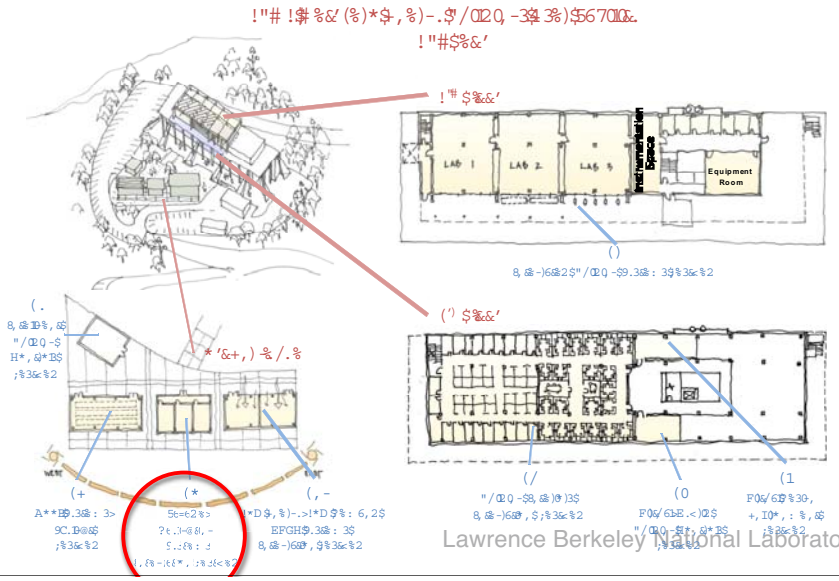
DGI Summary for 6 Test Conditions

(Window View)



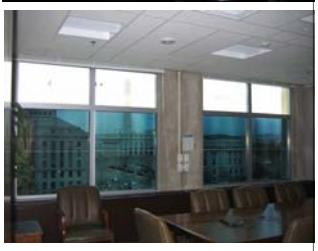
DGI of 16:20 = Just Acceptable, 20:24 = Just Uncomfortable, 24:28 = Just Intolerable, 28:32 = Intolerable

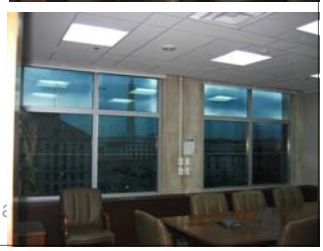
LBNL User Facility Elements 6-8 New Testbeds



Pilot Demonstration

- Conference Room Setting in Washington DC (West-facing)
- 41x50-inch EC windows, SHGC=0.40-0.08, Tv=0.52-0.03, U=0.347 Btu/h-°F-ft²
- Electrochromic Window Controls:
  - On-off window tinting
  - Seasonal solar control when unoccupied (tinted during summer, bleached during winter)
  - Lower windows tinted based on 20,000 lux threshold vertical illuminance
  - Upper windows tinted based on 30,000 lux threshold
  - Manual override
- Lighting controls:
  - DALI dimmable ballasts
  - Architectural scenes, occupancy, daylight controls
- Monitoring underway





New San Francisco Federal Building: A Naturally Ventilated Office Tower

- **Shallow plan for daylighting and cross-flow ventilation**
- **Open plan perimeter offices have no mechanical cooling or ventilation**
- **Exposed 8-inch ceiling slab acts as thermal flywheel**
- **Automatically-controlled windows provide fresh air and night flush**
- **Occupant-operated windows provide local control**
- Work supported by the California Energy Commission, the General Services Administration and the Federal Energy Management Program.
- Images courtesy of Morphosis and Arup

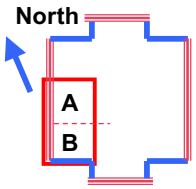
The New York Times Headquarters, New York, NY

- 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?

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 potential

- 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



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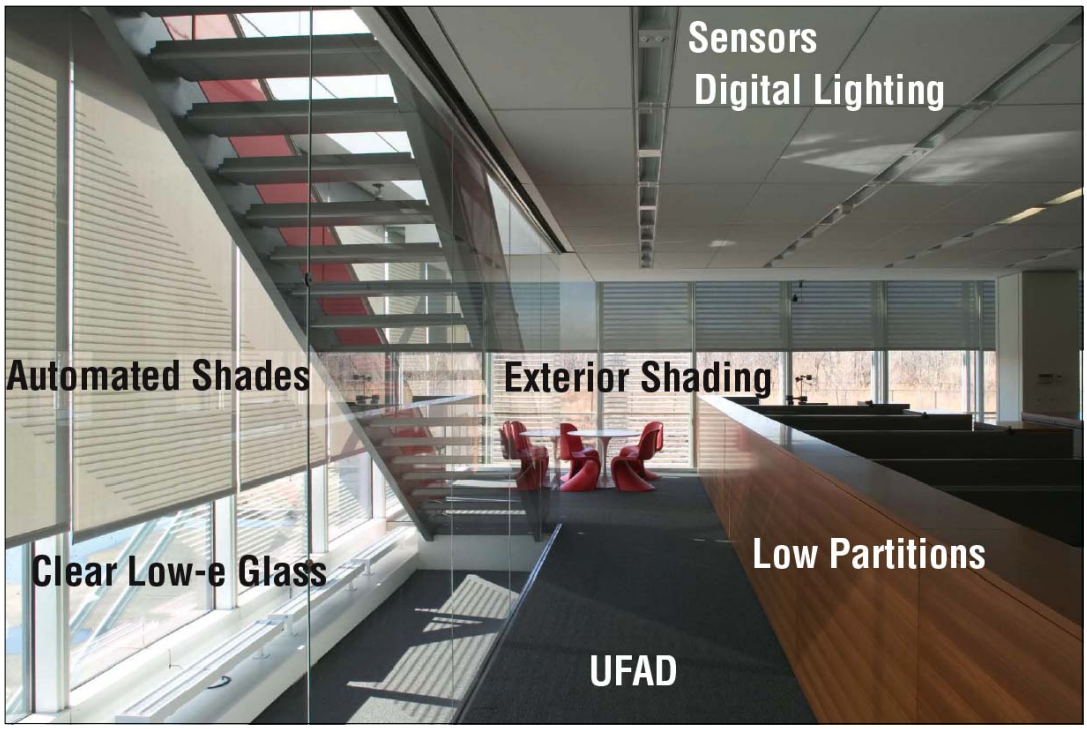
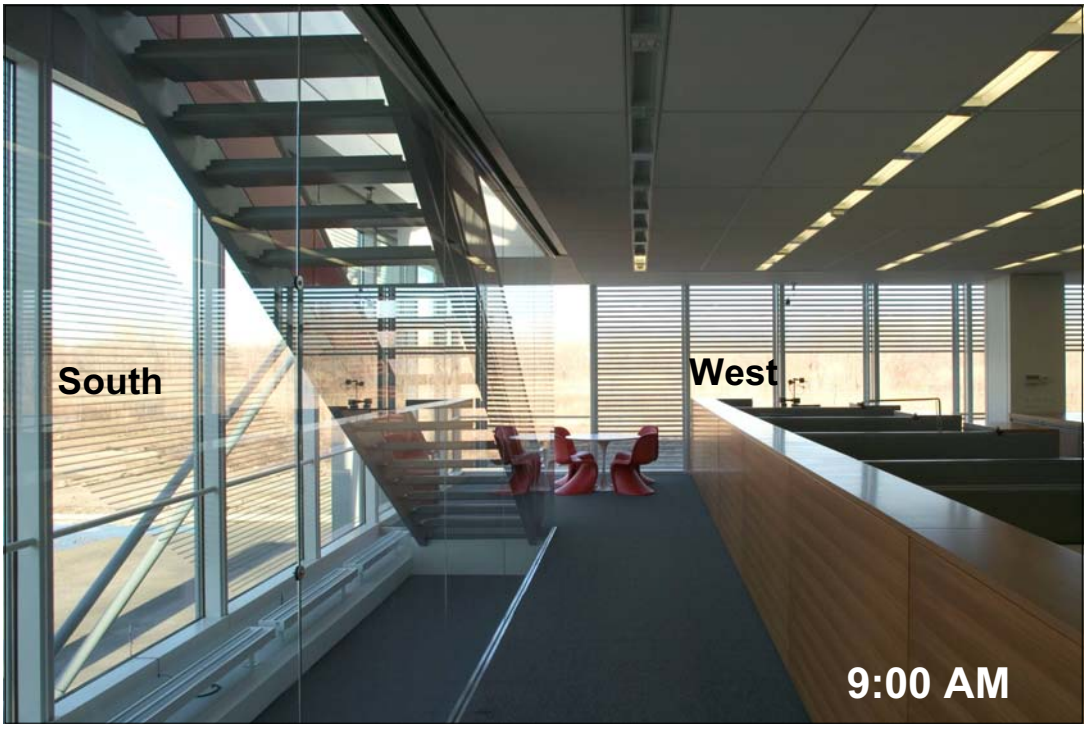
Mock-up Instrumentation

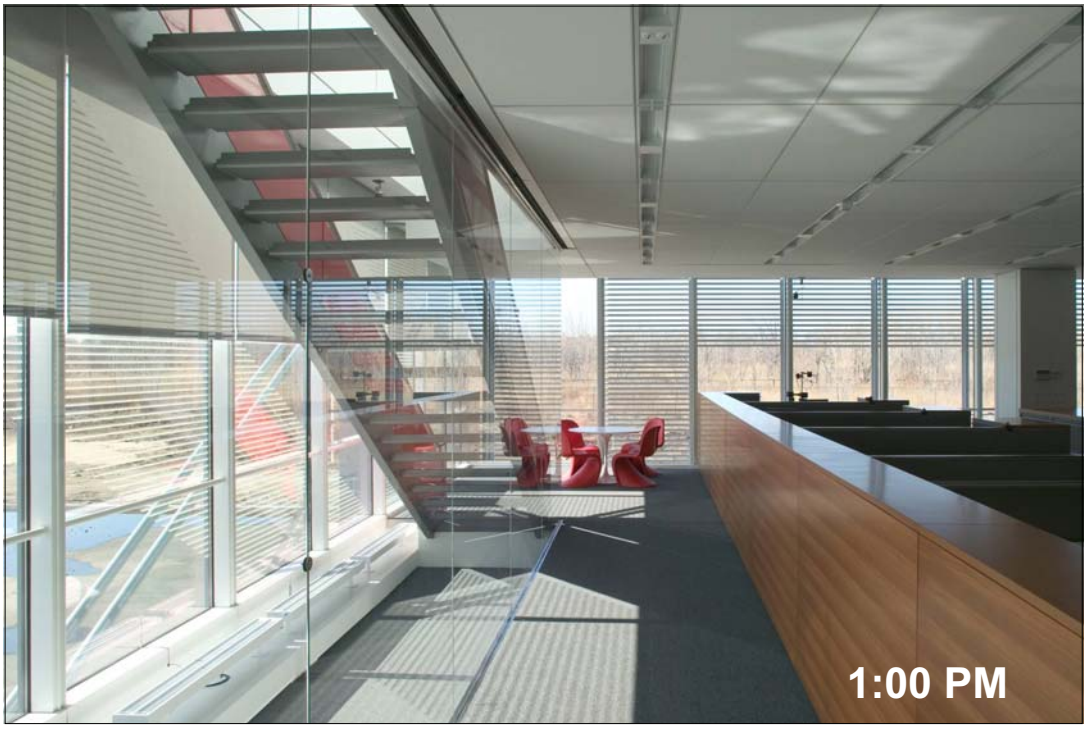
Illuminance sensors

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


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


South
West
9:00 AM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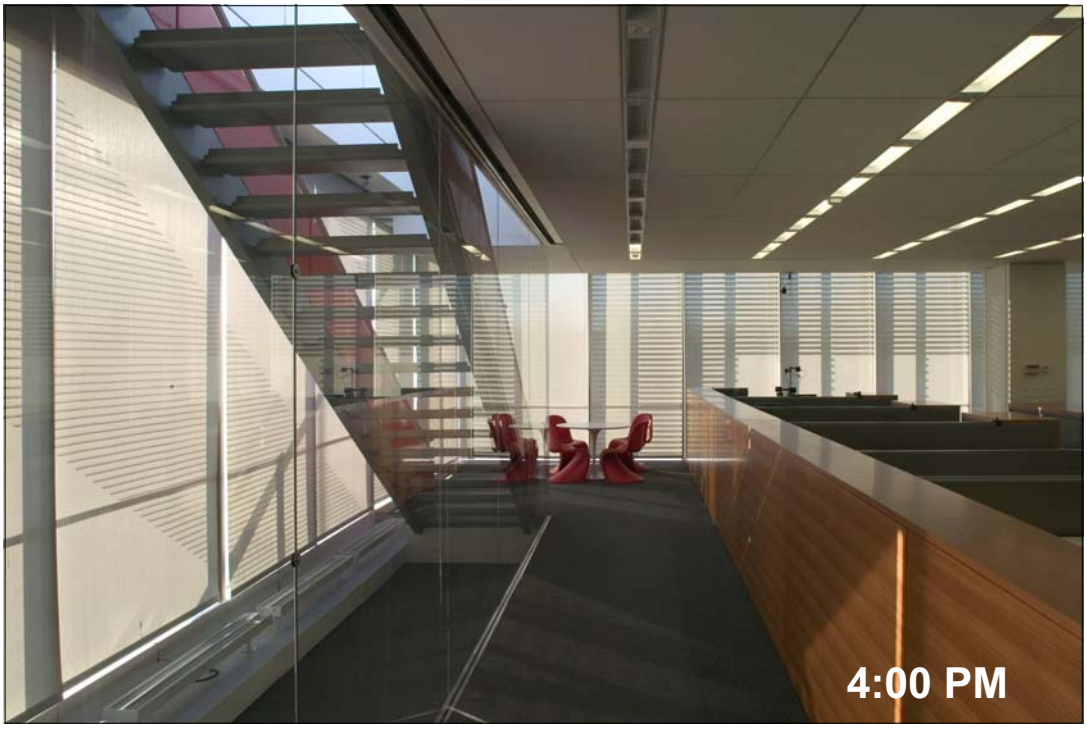
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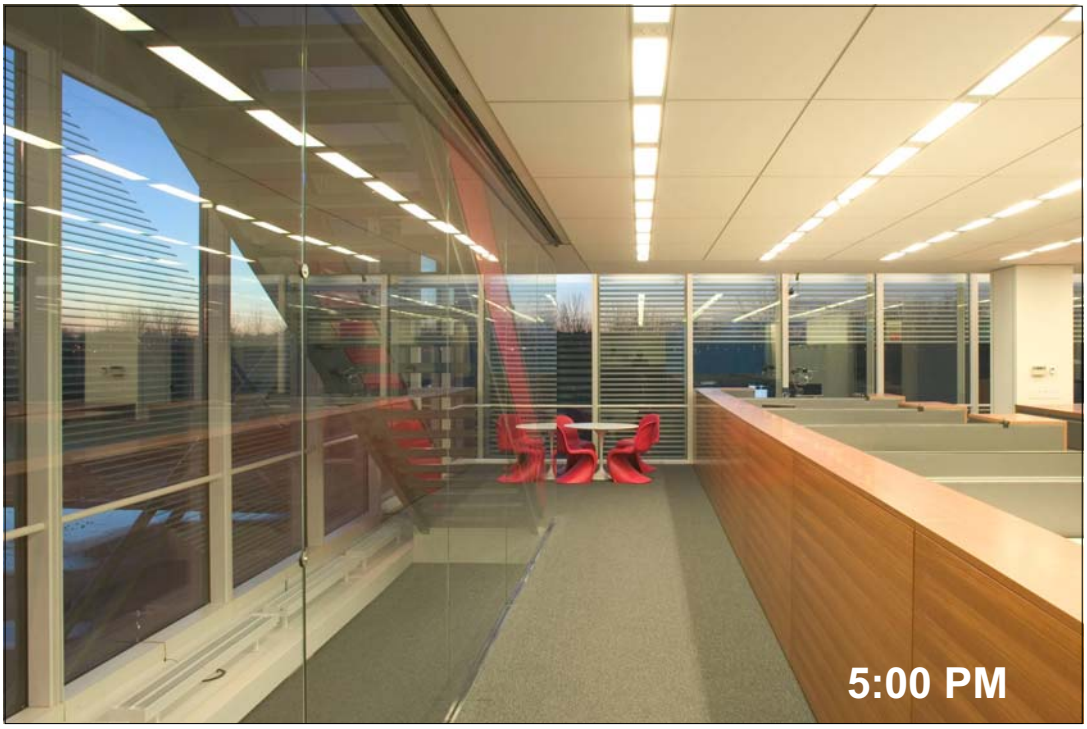
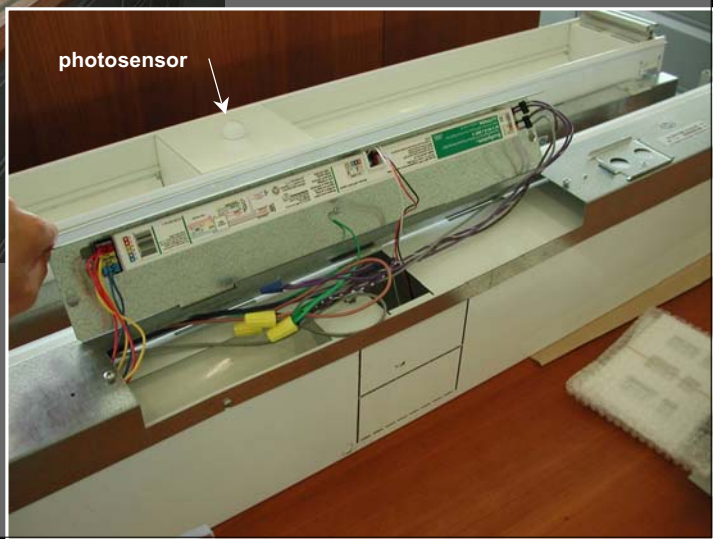
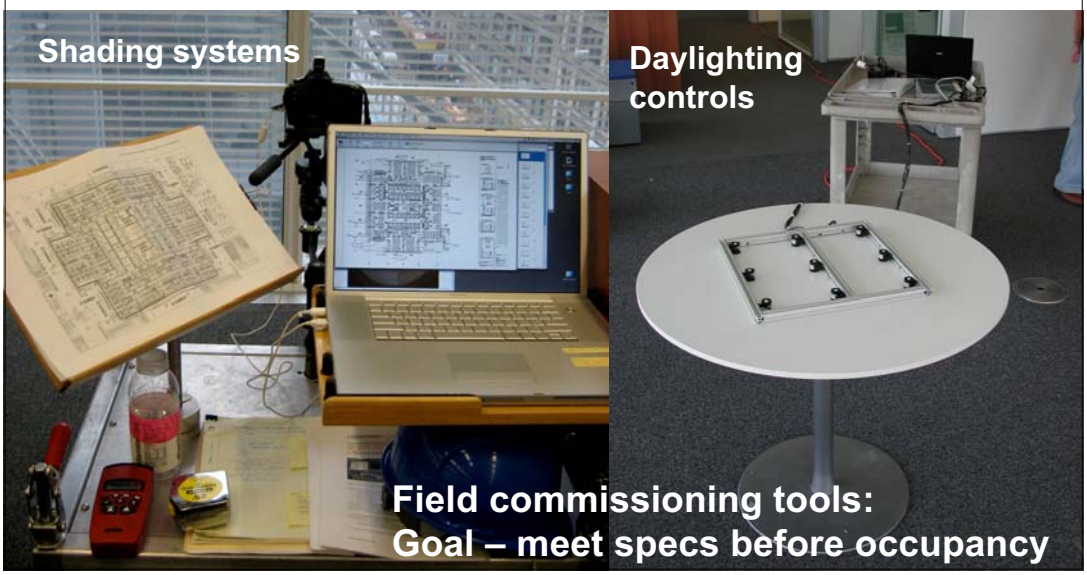


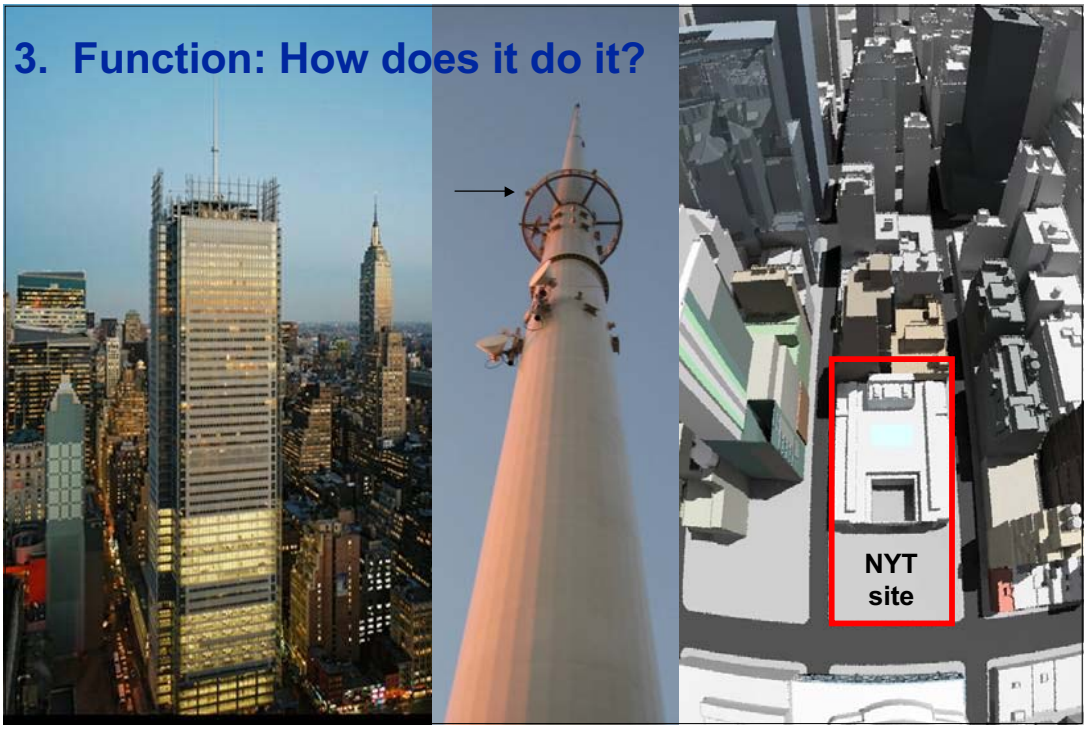


Simplify wiring and cabling to reduce install costs

5. Include commissioning and verification in the specifications

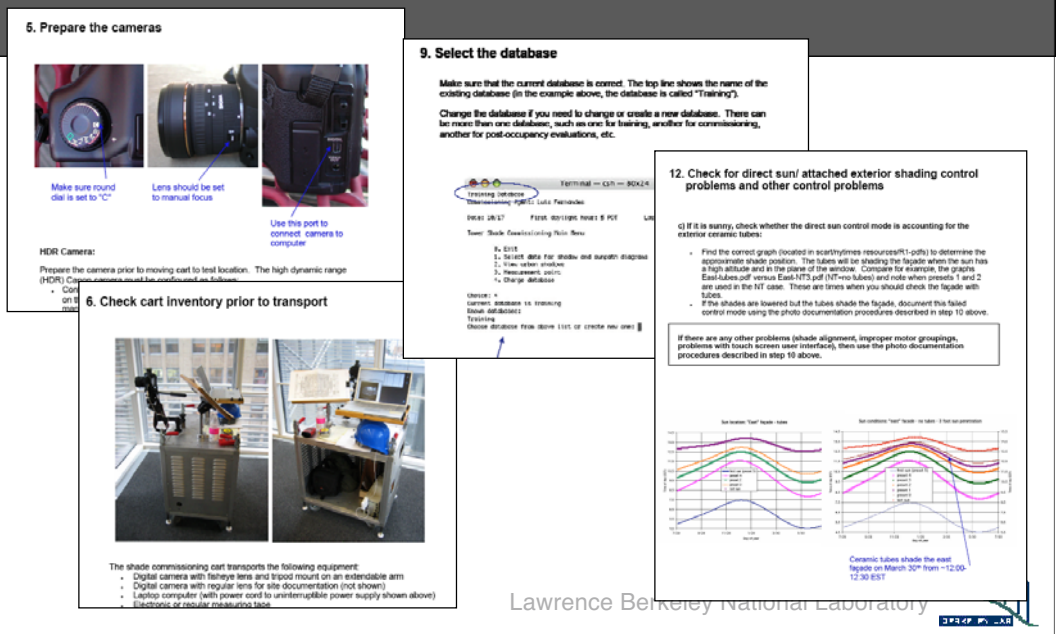


3. Function: How does it do it?



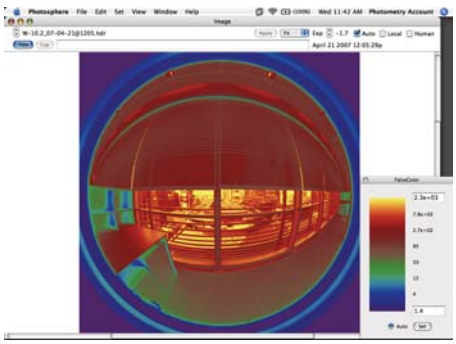
LBNL shade commissioning cart at The New York Times Headquarters Building

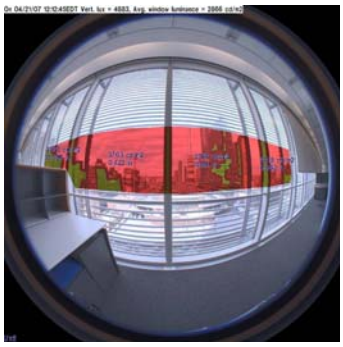
Step-by-step How-to Guide

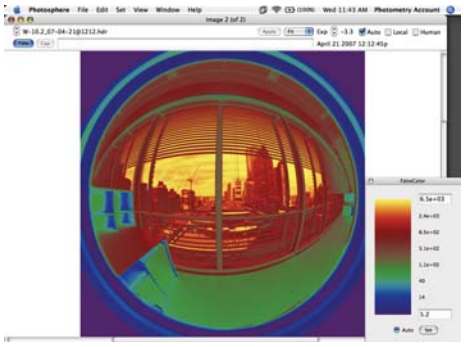


Auto mode:

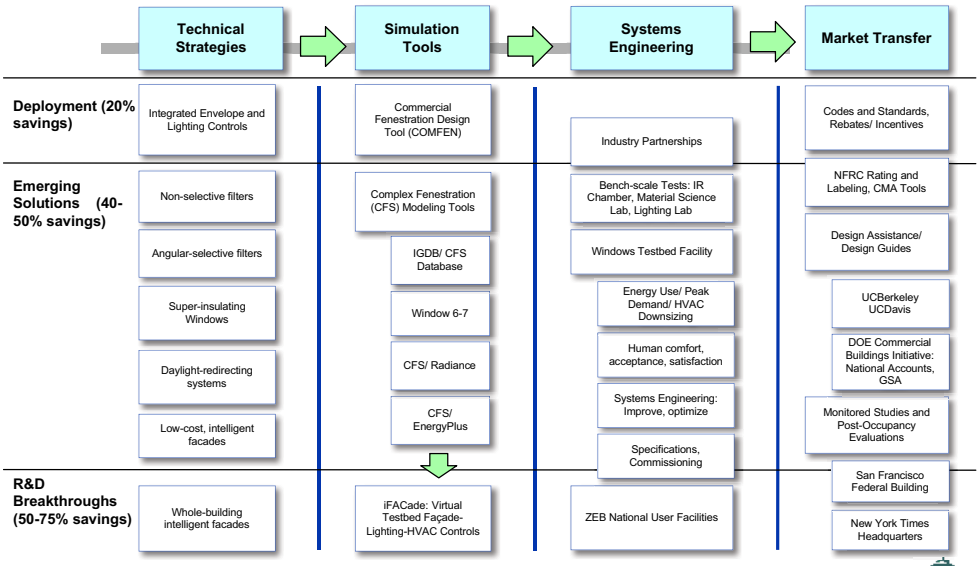
Override mode:







High-Performance Facades Research Portfolio



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More Info:

Window 6
http://windows.lbl.gov/software/window/6

High performance commercial building facades
http://lowenergyfacades.lbl.gov

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Public Interest Energy Research (PIER)