BUILDINGS ENERGY EFFICIENCY CONSORTIUM

U.S. - CHINA CLEAN ENERGY RESEARCH CENTER (CERC-BEE)

YEAR 4 JOINT ANNUAL MEETING

Berkeley California

Panel 3: Building Envelope Advanced Window Technologies

Eleanor Lee, LBNL, Li Zhengrong, Tongji University

Robert Licht, Saint-Gobain, Neil Sbar, Sage Electrochromics, Robert Nachtrieb, Lutron Electronics, Inc., John Mansheim, 3M

Luo Duo, Zhuhai Singye Green Building Technology Co., Ltd.; Shasha Liu, Saint-Gobain

Presented By

Eleanor Lee, Lawrence Berkeley National Laboratory

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Purpose and Objectives

Overall Project Objective

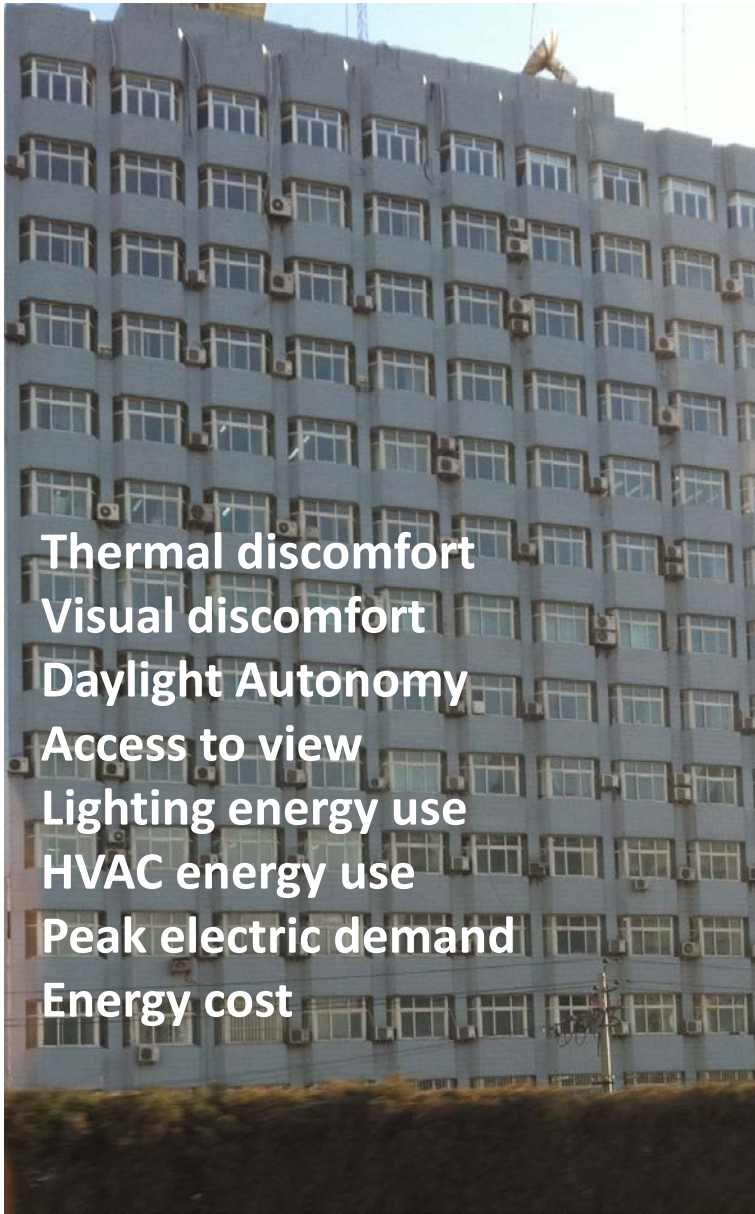
- To identify, develop, and promote the use of energy-efficient window and shading technologies that are pragmatic, cost effective, and can be broadly and rapidly deployed in residential and commercial buildings throughout China and the US.

Year 4 Research Objectives

- **Field Test:** Support dynamic fenestration controls R&D via physical testing in the LBNL Advanced Windows Testbed.
- **Broaden Value Proposition within Whole Building/ Grid Context:** Explore the integration of dynamic fenestration technologies within the whole building, microgrid, and grid context to determine if such strategies can improve cost-effectiveness and applicability in US and China markets.
- **Market Transfer:** Measure energy savings and human factor impacts of advanced fenestration technologies in the SGRS and China demonstration sites. Identify market opportunities and barriers to widespread adoption in the US and China.

Task 1.1, Test A
Field Test of Automated Shading

- **Objectives**
  - Evaluate the latest Lutron automated shading technology and fabric selection process for glare mitigation, daylight autonomy, and views
- **Approach**
  - Evaluate default control settings then modify to achieve optimal performance
  - Compare tradeoffs and performance between conservative and optimal roller shade fabrics
- **Status of Year 4 Milestones**
  - √ Task 1.1, Test A: Field test completed 6/1/14
  - Field test will be extended to Q4 to evaluate winter solstice performance

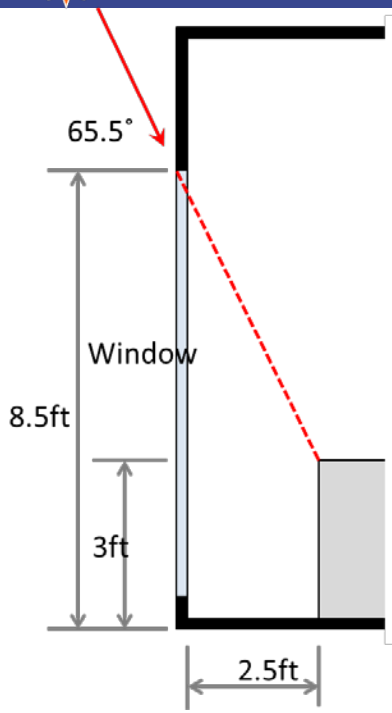


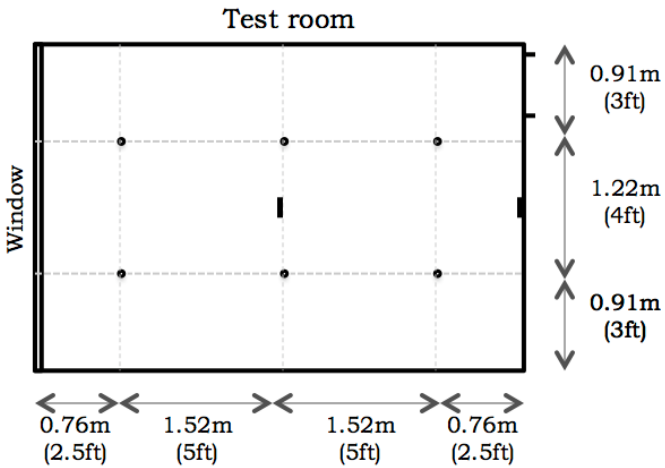
Automated shading field test in the LBNL Advanced Windows Testbed

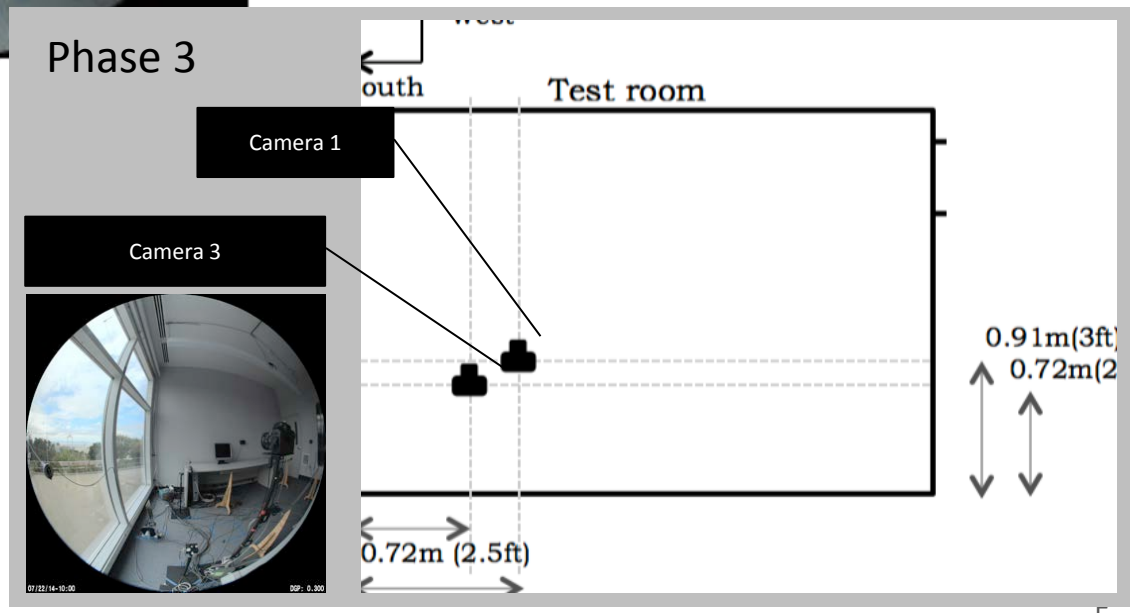
Lutron mullion sensor

Windows face due south (38° latitude)

Automated Controls & Testbed Set-Up

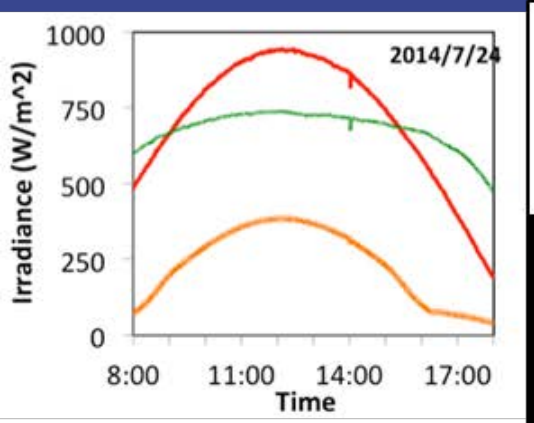






Open-loop, heuristic controls (above):
Limit depth of sun penetration
Reduce sky glare (Tvis-glass=0.60)

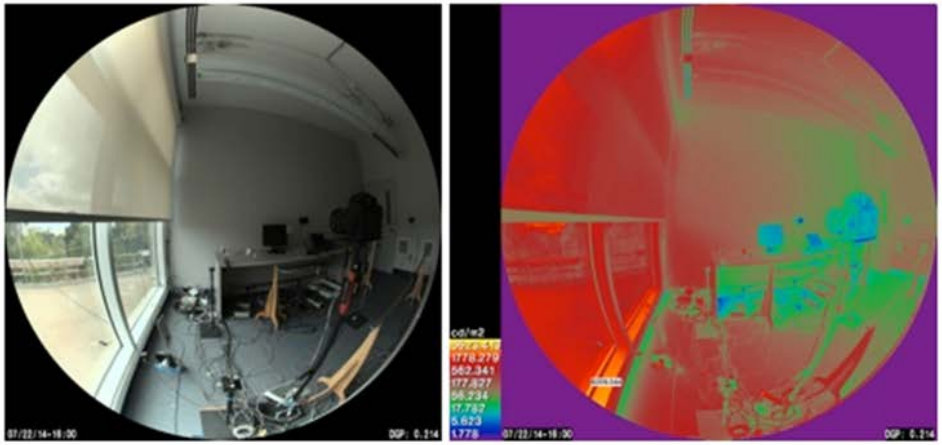
Performance evaluation (right):
Workplane illuminance, view, discomfort glare using high dynamic range imaging



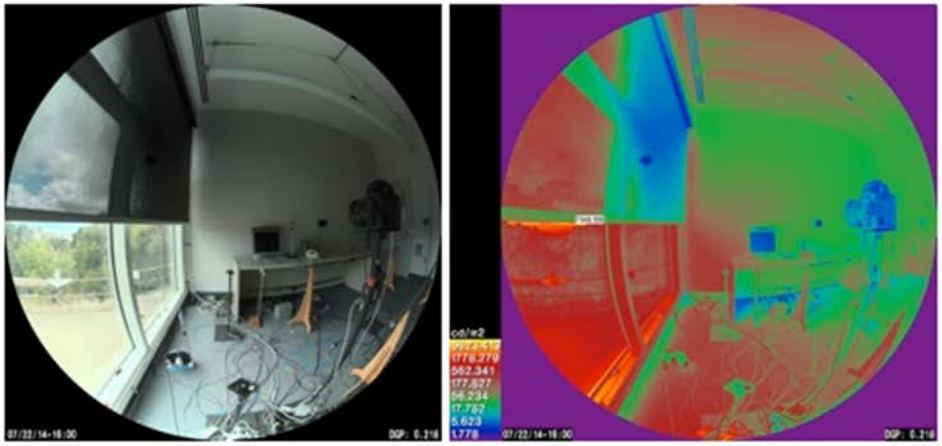
8:00 10:00 12:00 14:00 16:00

DGP_{sky}=0.30-0.35

Lutron 1
July 22, 2014
16:00
White fabric
DGP=0.214

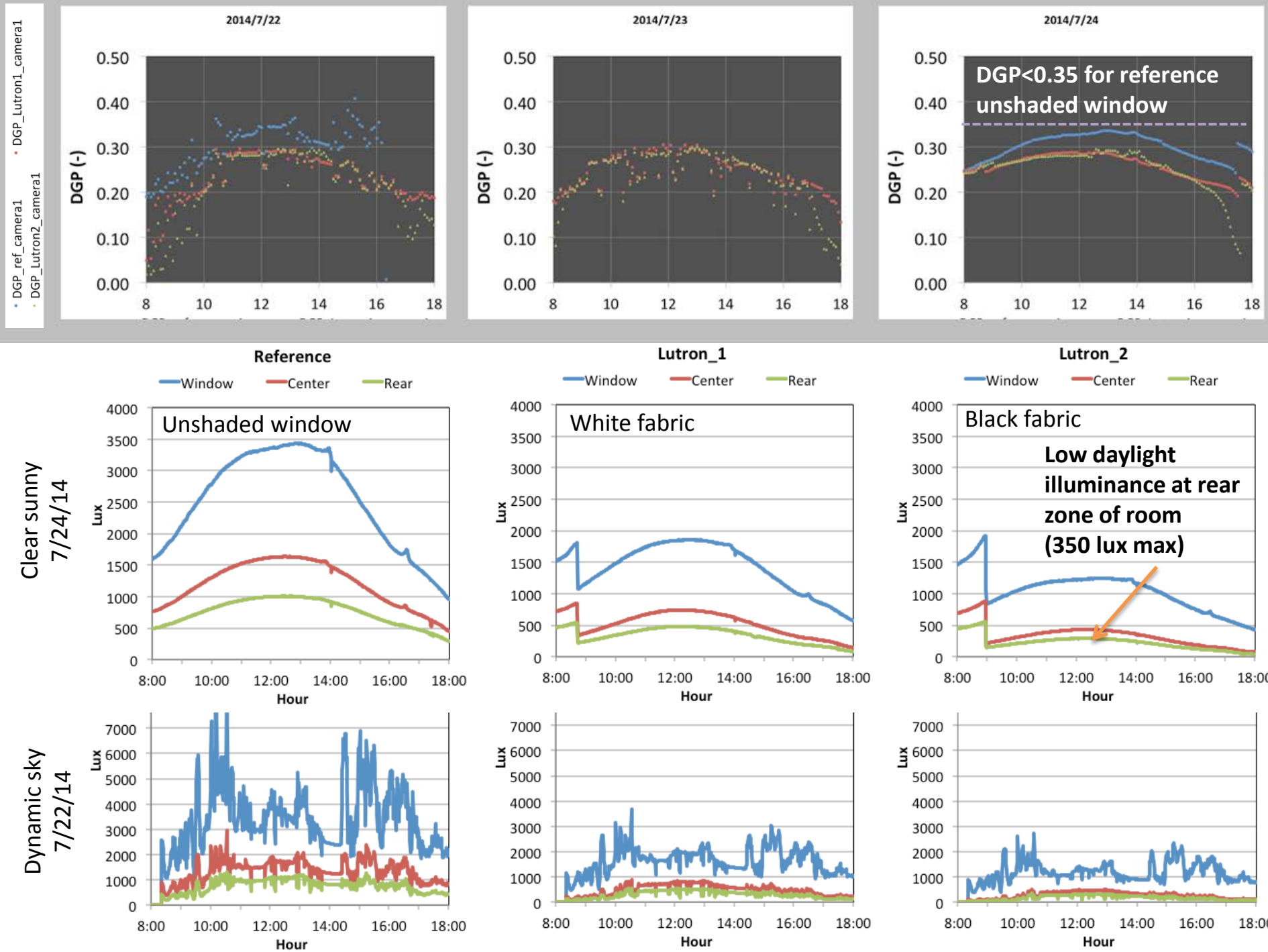


Lutron 2
July 22, 2014
16:00
Black fabric
DGP=0.218



Automatic system controlled sky glare* effectively with a user-designated "visor" position

*Metric: Maximum DGP of 95% of day ≤ 0.35 and average DGP of 5% of day ≤ 0.38


DGP_ref_camera1
DGP_Lutron1_camera1
DGP_Lutron2_camera1
2014/7/22
2014/7/23
2014/7/24
DGP (-)
DGP<0.35 for reference unshaded window
Reference
Lutron_1
Lutron_2
Window
Center
Rear
Unshaded window
White fabric
Black fabric
Low daylight illuminance at rear zone of room (350 lux max)
Clear sunny 7/24/14
Dynamic sky 7/22/14
Lux
Hour

Task 1.1 Test A
Progress, Accomplishments, and Target Outcomes

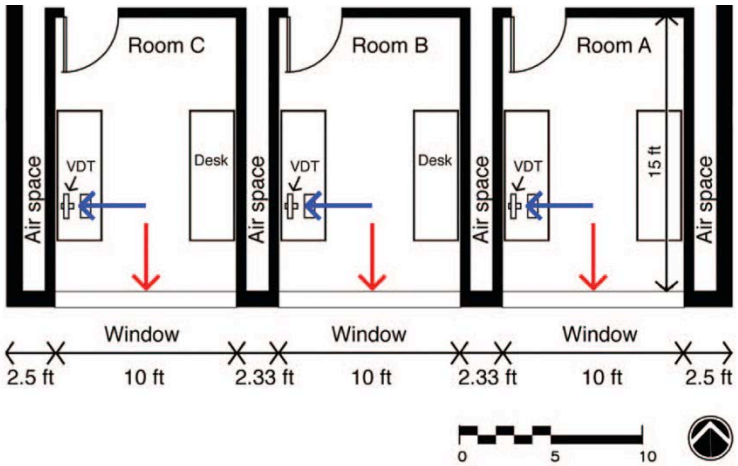
- Outcomes from summer solstice test of automated shades:
  - Default controls performed as intended: automated system controlled sky glare effectively under sunny and dynamic summer sky conditions
  - Daylight illuminance and glare well managed with white fabric; illuminance lowered significantly with black fabric but discomfort glare (DGP) was also lowered by 0.03-0.05.
  - Views out the unobstructed lower area of the window and through the shade fabric
  - Direct sun control and glare from direct sun not yet evaluated (summer sun angles are too high)
- Next steps
  - Winter solstice tests critical for evaluation of direct sun glare control
  - Continue to evaluate trade-offs between glare and daylight illuminance as a function of control settings and fabric choice
  - Lutron exploring possible inclusion in China demonstration projects

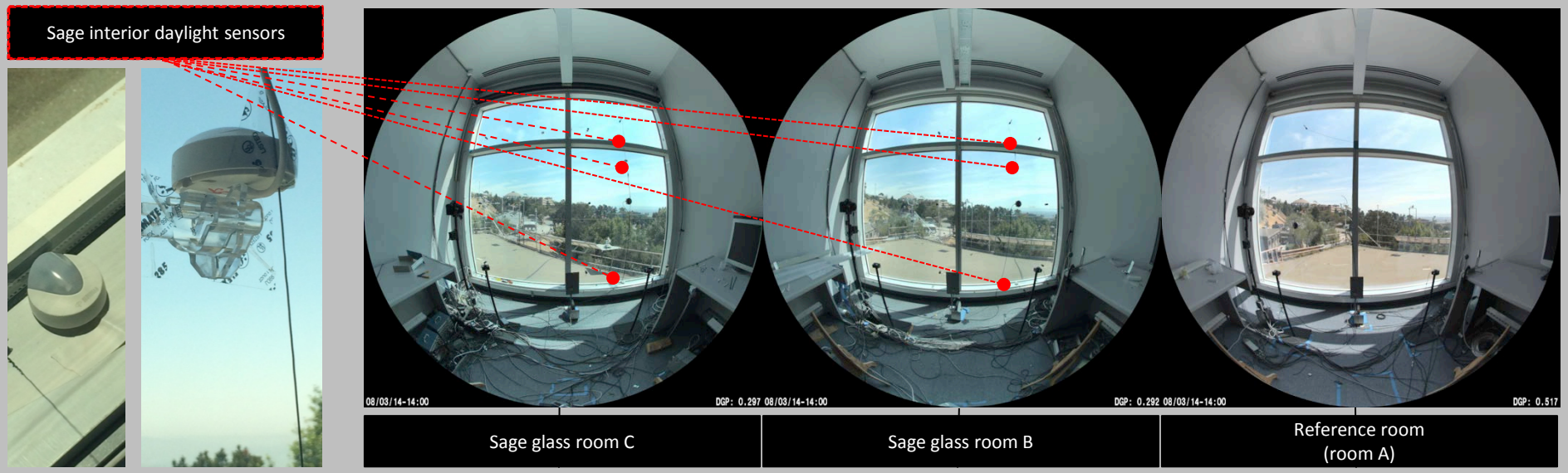
Task 1.1, Test B
Field Test of Automated Electrochromic Windows

- **Objectives**
  - Evaluate the latest Sage Electrochromic (EC) technology for glare mitigation, daylight autonomy, and views in support of SGRS demo
  - Develop then field test a proof-of-concept optimized demand-supply side control of dynamic fenestration and microgrid resources
- **Approach**
  - Evaluate EC technology with default control settings
  - Implement microgrid and evaluate performance of optimized control relative to EC heuristic controls
- **Status of Year 4 Milestones**
  - √ Task 1.1, Test B: EC controls operational, monitoring initiated 6/30/14
  - √ Task 2.1: Set up of optimization software framework completed, 5/14/14

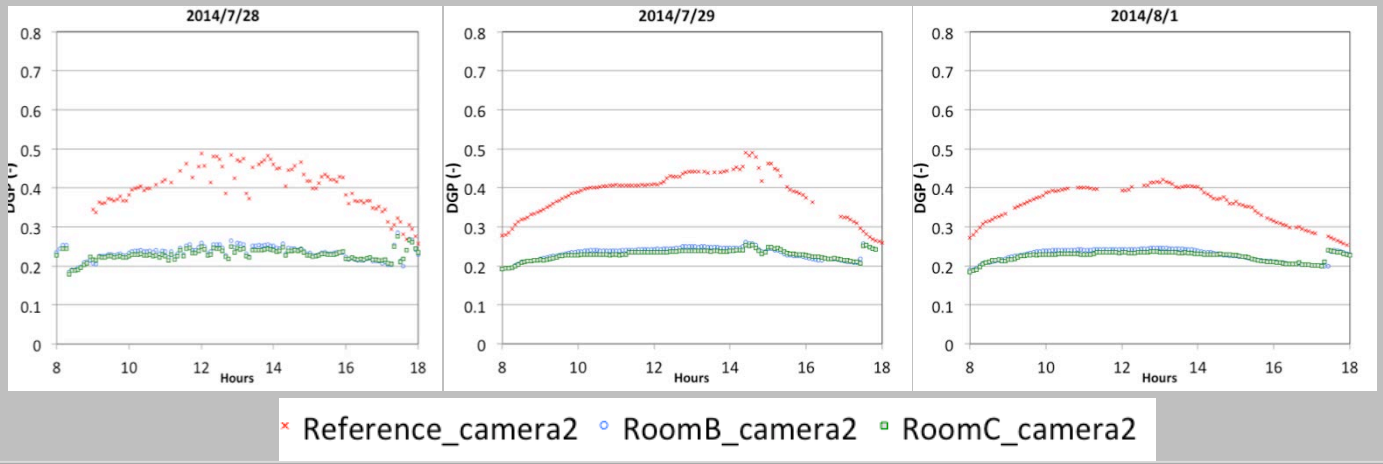
Testbed exterior with EC windows (above)

Electrochromic Window Field Test



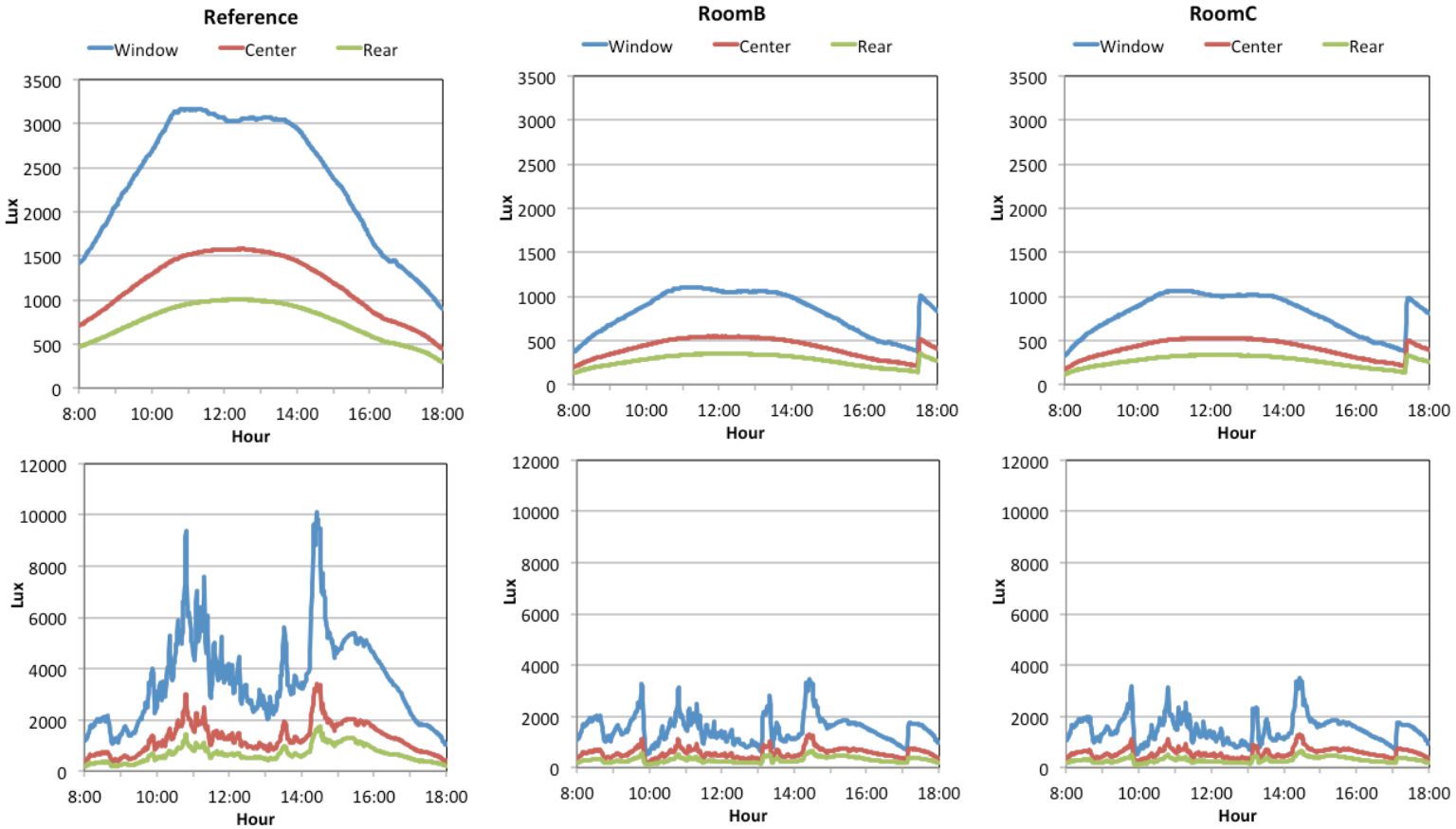


Glare well controlled with EC windows but daylight illuminance levels very low in rear of room



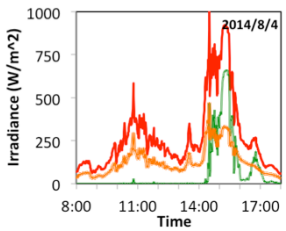
Clear sky 8/1/14

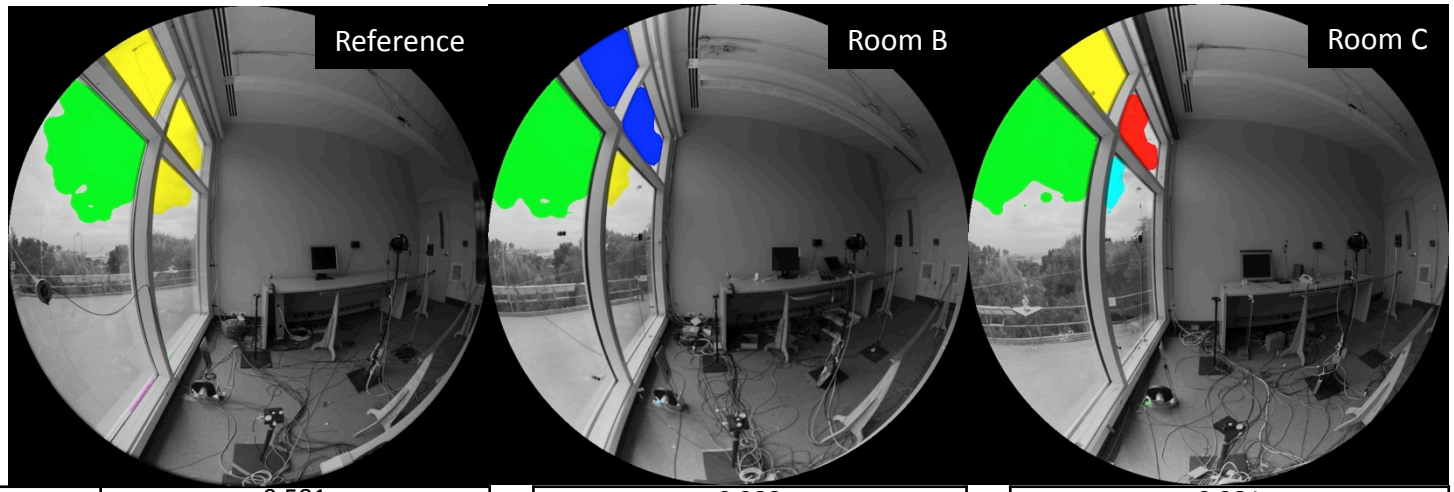
Overcast sky 8/4/14



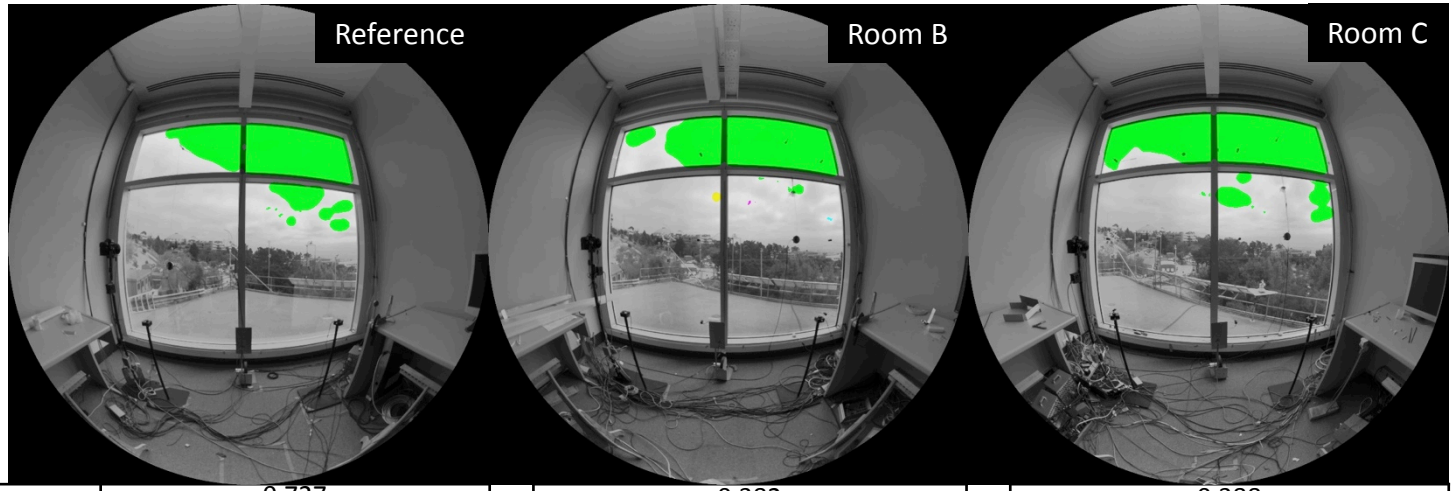
Results

DGP Overcast sky: August 4, 2014, 14:25



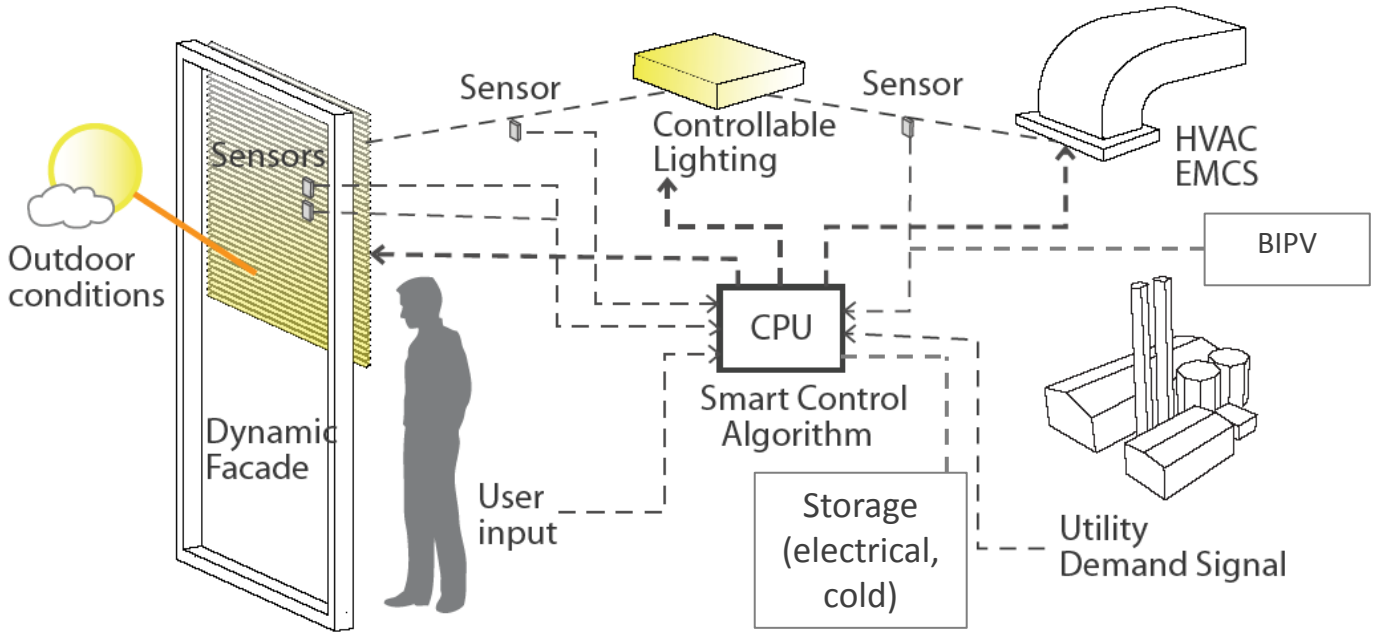


	Reference	Room B	Room C
Max DGP	0.581	0.288	0.281
Max Luminance (W/m^2)	51905	29452	29416
Luminance of Largest glare source (W/m^2)	23134	8794	7496
Percent area of largeset glare source	5.21%	5.22%	5.53%



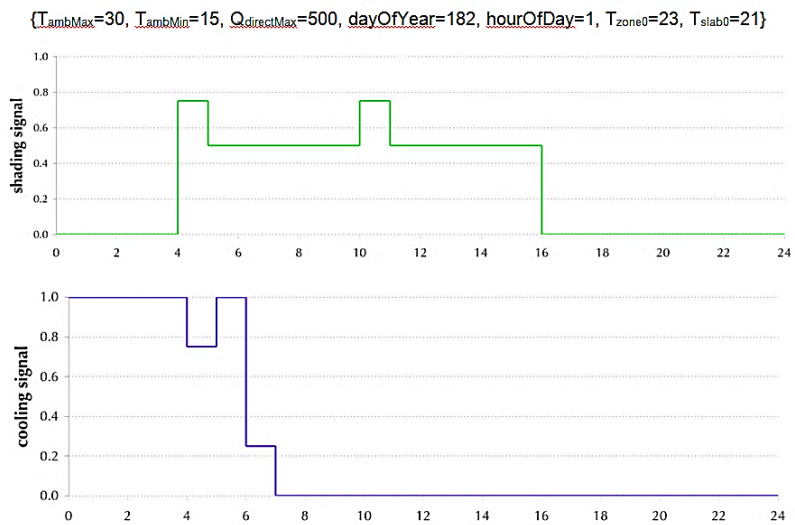
	Reference	Room B	Room C
Max DGP	0.727	0.382	0.388
Max Luminance (W/m^2)	30443	15309	15190
Luminance of Largest glare source (W/m^2)	14633	6613	6571
Percent area of largeset glare source	5.24%	4.78%	6.25%

Optimized demand-supply side control of dynamic facades and microgrid sources

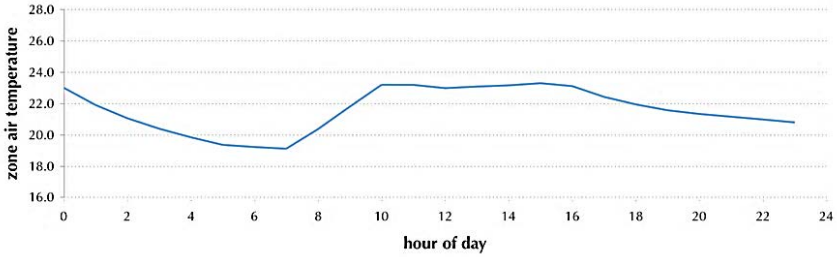


- **Software approach**
  - Radiance + Modelica to generate HVAC, lighting, and comfort database for each window state and grid of conditions (weather parameters, day of year, etc.)
  - DERCAM-Operations weighs cost tradeoffs between cooling and lighting end uses within comfort constraints → generates 7-day schedule based on weather forecast → actuates fenestration and control sources (PV, battery, grid on 24 Vdc network) in real time in testbed

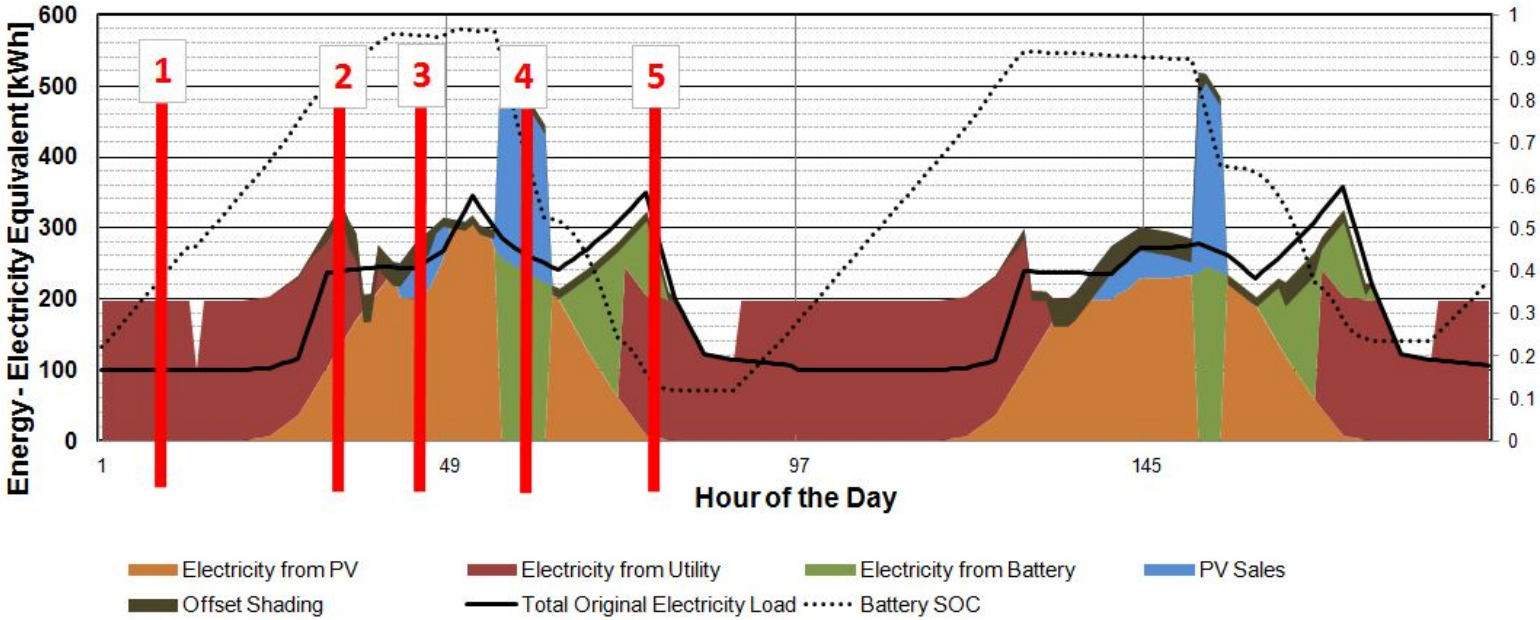
End use loads & source optimization



Demand-side management controls: Pre-cooling strategy integrated with automated exterior shading control



Demand-supply side controls with automated shading, PV, and battery storage



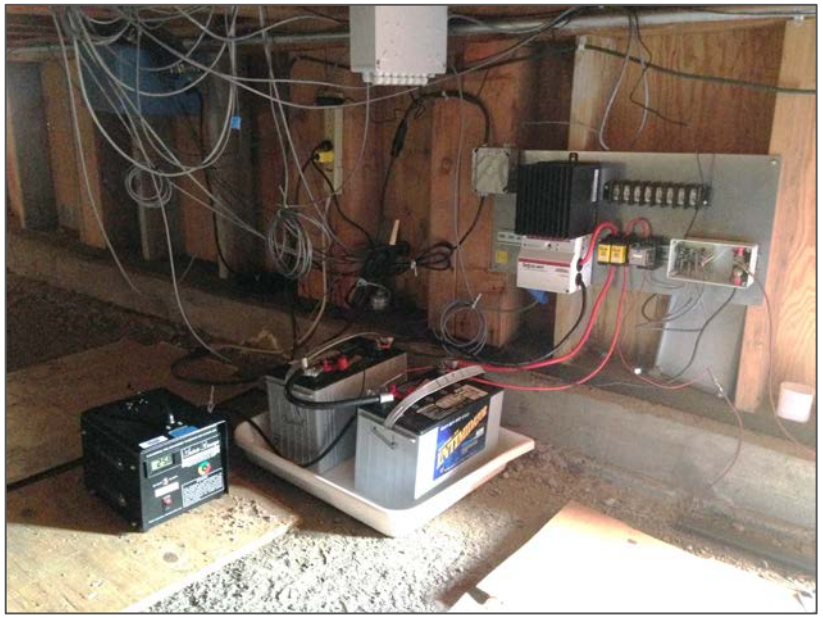
Task 1.1 Test B (Task 3a of D1, D3, E1 Microgrid Project) Progress, Accomplishments, and Target Outcomes

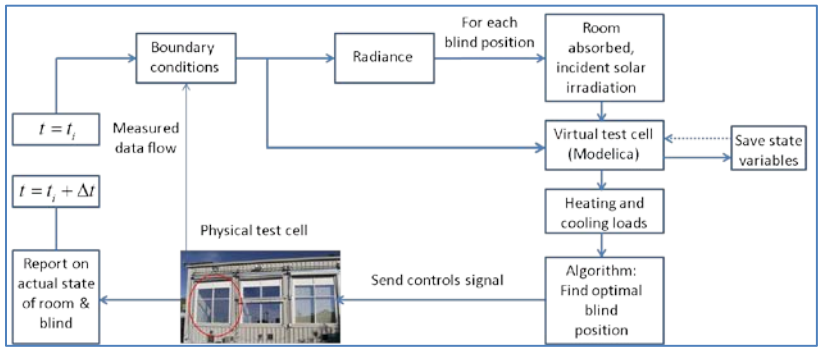
Outcomes:

- Sage default controls performed as intended: automated system controlled sky glare effectively under sunny and dynamic summer sky conditions, however daylight illuminance lowered significantly
- Software framework coupling Modelica-Radiance generated database with DERCAM-Ops for demand-supply side control completed
- Microgrid set up but independent source source control confounded by PV-battery dc network → exploring options for maintaining proper battery state of charge

Next steps

- Sage default: winter solstice tests critical for evaluation of direct sun glare control
- Start-up field test of demand/ supply-side control and evaluate performance





Real-time operation in Advanced Windows Testbed via http interface to physical components (end uses and sources)

Task 1.2. Electrochromic Window Demonstration

Saint-Gobain Research Shanghai Center (SGRS)

Objectives

- Evaluate technical potential and identify market opportunities and barriers to widespread adoption of the electrochromic technology in the U.S. and China

Approach

- Tongji conducting workday and special weekend tests to quantify energy use and comfort impacts
- SGRS & LBNL issuing occupant surveys to evaluate comfort and satisfaction with EC technology

Progress and accomplishments on Year 4 Milestones and Target Outcomes

- √ Task 1.2: Controls operational, monitoring initiated 6/30/14
- √ Surveys: Normal use of conference room (N=21); “Office-based” use of conference room for 1 hour (N=38)

SGRS conference room with south-facing windows

“Office” task survey results where difference between means were statistically-significant at the 99% level

C6) **Light level**

Too Dark		Just Right		Too Bright
1	2	3	4	5

C10) **How did the space feel?**

Space feels gloomy		Neutral		Space feels bright
1	2	3	4	5

C14) **Please rate the level of glare sensation in your workspace during the session.**

Not Perceptible	Perceptible	Acceptable	Uncomfortable	Intolerable
1	2	3	4	5

Electrochromic Room

Reference Room with shades

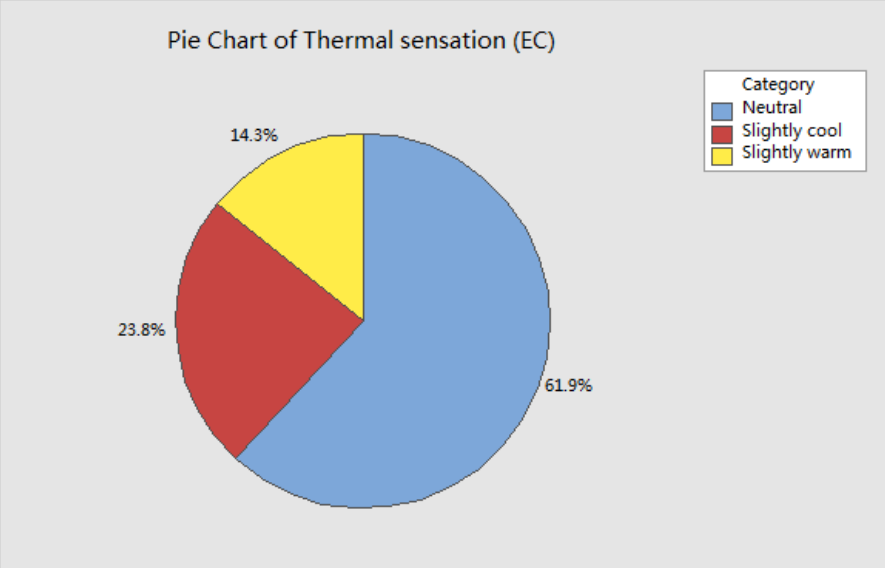
Tasks 1.2: Progress, Accomplishments, and Target Outcomes

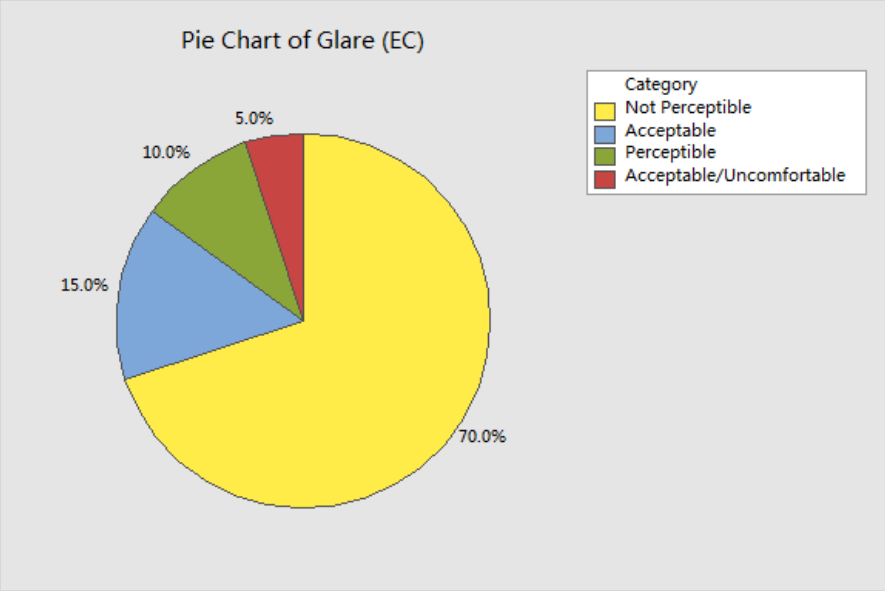
Outcomes:

- SGRS Demonstration underway with two surveys issued to occupants
- Summer subjective survey results are consistent with LBNL measured data in testbed: glare is controlled but indoor illuminance levels are low compared to conventional shaded windows
- Tongji tuning HVAC controls (to lower the 7% difference in heating energy use with low-e window in both rooms)

Next steps

- Re-issue surveys for equinox and winter solstice conditions
- Collaborate with Tongji to extract useful HVAC and lighting energy use data





Key Year 4 Technical Achievement

- Key Year 4 Technical Achievement
  - Automated roller shades have been shown to effectively mitigate sky glare during summer solstice conditions.
  - Automated electrochromic windows have been shown to provide a comfortable, satisfactory, and acceptable work environment to occupants in China during summer solstice conditions.
  - Integrated dynamic façade technologies with whole building/ grid optimization strategies is feasible and will result in lower energy cost and CO_2 emissions if electric source costs differ (e.g., cold storage for cooling; PV for lighting)
- Estimated CO_2/Energy savings
  - Savings of 995 TBtu/year and 100 Mtons of CO_2 emissions in 2025
  - Assumptions: 35% average EUI savings in perimeter zones (based on Year 1 study for Guangzhou and Beijing), perimeter-to-core area ratio of 0.60, market adoption of 50% in 2025, 2 Bm^2-yr floor area of new and retrofit commercial construction

Schedule and Funding

- Schedule of completion for remaining (unmodified) Year 4 Milestones and Target Outcomes, percentage of cumulative unspent DOE funds
  - Task 1.1 Test A: Extended by 6 months to capture winter solstice conditions*
  - Task 1.1 Test B: Added evaluation of Sage default controls after accepting delivery of Sage windows after Go/ No-Go decision point passed*
  - Task 1.1 Test B: Field test of demand/ supply side optimization control system delayed due to implementation challenges; testing to commence in September 2014
  - Task 1.2 SGRS Demo: Milestones on track
  - Task 1.3 Demos: Lutron to discuss use of automated shading in Xingye; Sage and 3M demos with CABR pending possible alternate demonstration site
  - Task 2 Microgrid Integration: Field testing to commence in September 2014
- Percentage of cumulative unspent DOE funds: 33%
- Issues/risks and abatement plans
  - Task 1.1/2 Test B: Risk: Independent source switching c annot be implemented; abatement: use calculations + measured data to determine impact or accept actual battery SOC as limitation.

Appendix 1: Concept Proposal for Project Continuation

- **Task 1. Field testing**: Conduct detailed monitored study of performance tradeoffs with demand/ supply side control of dynamic façade and microgrid sources
- **Task 2. SGRS Demonstration**: Complete monitored evaluation of electrochromic windows in Shanghai office building (end date: March 2015)
- **Task 3. Demonstrations**: Conduct a monitored evaluation of energy performance, occupant impacts, and economics of advanced window and daylighting systems in demonstration commercial buildings in hot/cold and hot regions of China
- **Outcomes and benefits**
  - Improved understanding of occupant response to advanced technologies and impacts on actual building performance in China and the US
  - Improvements to advanced technologies based lessons learned in real world building demonstrations
- **Budget**: $200K

Appendix 1: Budget, Spending, Cost-share

Project Budget: 2010-2014: $645K total, 2014: $130K new + $236K carryover

Variances: Carryover from 2013 due to production delays by Sage Electrochromics; controls R&D at LBNL and M&V of Shanghai demonstration delayed to 2014.

Cost to Date: 2010-2014: $433K, 2014: $154K

Additional Funding: $200K in-kind contribution from Saint-Gobain, Sage Electrochromics, Dow Chemical, Lutron Electronics, and 3M (materials, technical support).

Budget History					
1/1/2010– FY2010-2013 (past)		FY2014 (current)		FY2015 – 12/31/15 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$279K	$50K	$366K	$150K	$200K	$100K

Appendix 1: Project Plan and Schedule

Project Schedule		
Project Start: January 2010		Completed Work
Projected End: December 2015		Active Task (in progress work)
		Milestone/Deliverable (Originally Planned)
		Milestone/Deliverable (Actual)

	FY2013				FY2014				FY2015			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
Q2 Milestone: Initiate Sage and Lutron field tests												
Q3 Milestone: Initiate integrated controls test												
Q3 Milestone: Initiate SGRS demonstration												
Q4 Milestone: Initiate Xingye demonstration												
Current/Future Work												
Q1 Milestone: complete field tests												
Q2 Milestone: complete SGRS demonstration												
Insert more Milestones as needed												