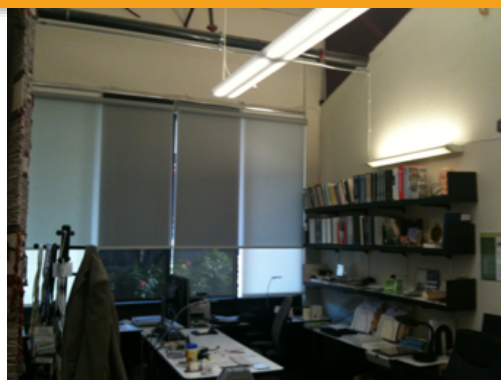
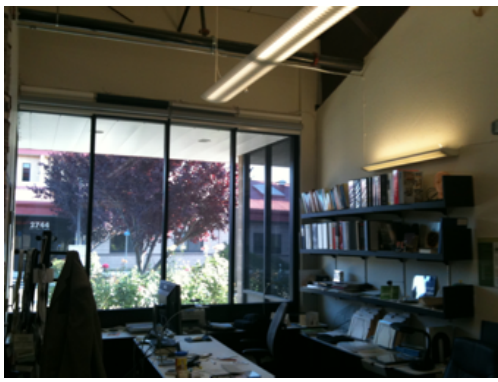
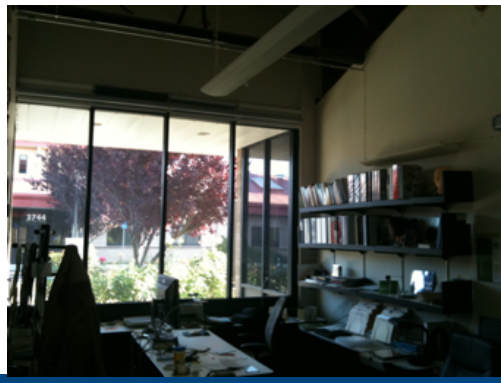
CLTC
CALIFORNIA LIGHTING TECHNOLOGY CENTER

UCDAVIS
UNIVERSITY OF CALIFORNIA







SSLNet Smart Sustainable Lighting Conference

August 19, 2014, University of Toronto, Mississauga Campus

Integration of Adaptive Lighting & Daylighting

Konstantinos Papamichael, Ph.D.
Professor, Department of Design
Co-Director, California Lighting Technology Center
University of California, Davis

RESEARCH **INNOVATION** **PARTNERSHIP**

633 Pena Drive, Davis, CA, 95618 | cltc.ucdavis.edu | PH: 530-747-3838, FAX:530-747-3812

The Fundamental Lighting Design Strategy

Provide

Right Light → *Spectral Power Distribution*

Where → *Candle Power Distribution*

& When → *Environmental Conditions*

Needed

Offers the Most Energy Efficient Lighting

Adaptive Electric Lighting Systems

- Automatically adjust their light output…
- …based on environmental conditions…
- …to optimize space & building performance

Adaptive Electric Lighting Systems

- **Automatically adjust their light output…**
  - Candle Power Distribution (SPD) - *total flux & spatial distribution*
  - Spectral Power Distribution (SPD) - *CCT & CRI*
  - …
- **…based on environmental conditions…**

- **…to optimize space & building performance**

Adaptive Electric Lighting Systems

- **Automatically adjust their light output…**
  - Candle Power Distribution (SPD) - *total flux & spatial distribution*
  - Spectral Power Distribution (SPD) - *CCT & CRI*
  - …
- **…based on environmental conditions…**
  - Occupancy / Vacancy
  - **Daylight Availability**
  - Demand Response Signals
  - …
- **…to optimize space & building performance**

Adaptive Electric Lighting Systems

- **Automatically adjust their light output…**
  - Candle Power Distribution (SPD) - *total flux & spatial distribution*
  - Spectral Power Distribution (SPD) - *CCT & CRI*
  - …
- **…based on environmental conditions…**
  - Occupancy / Vacancy
  - **Daylight Availability**
  - Demand Response Signals
  - …
- **…to optimize space & building performance**
  - Maximize Comfort
  - Minimize Energy Requirements
  - Minimize Peak Electricity Demand
  - …

Simple Adaptive Lighting Control Strategy

During Occupancy
Focus on Comfort

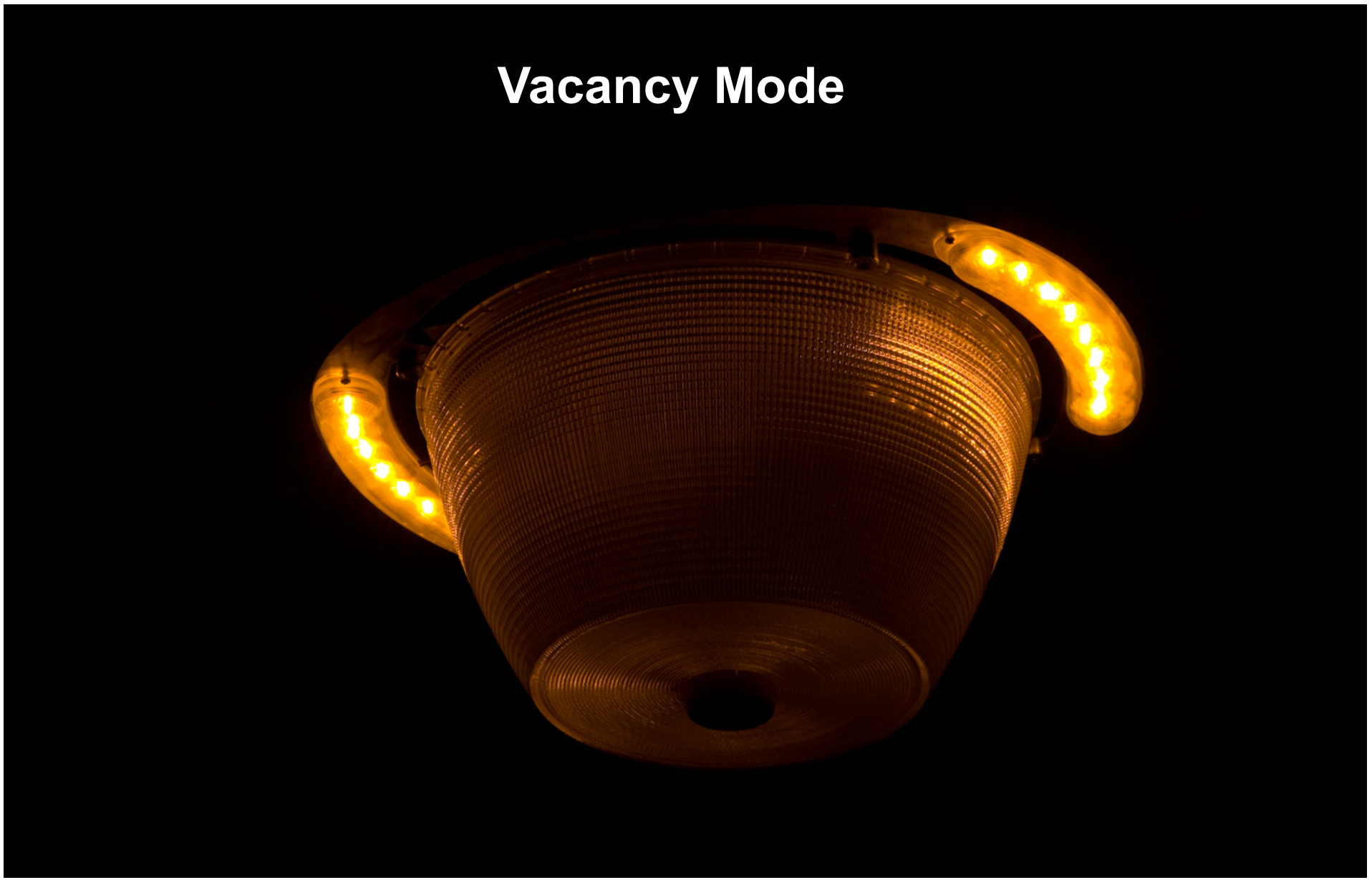
During Vacancy
Focus on Energy Efficiency

Adaptive Outdoor Lighting – Circa 2005

- **Amber LED** (2W) & **CFL** Light Sources
- **Photo** sensor: both light sources off during daytime
- **Occupancy** sensor: LED during vacancy and CFL during occupancy

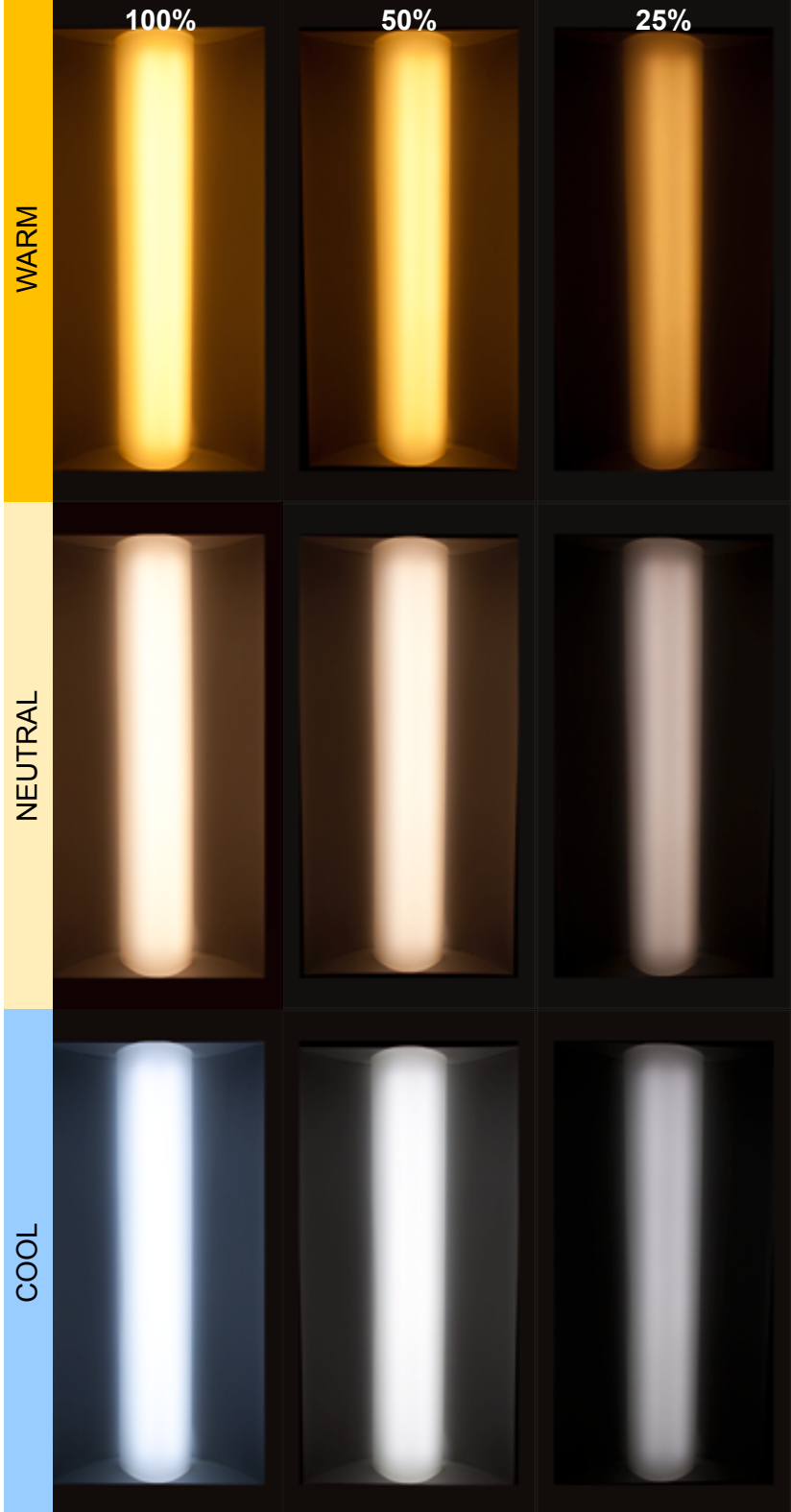
Dual Source Bi-level Luminaire

Dual Source Bi-level Luminaire



Spectrally Tunable Lighting

- **Research & Development**
  - Technology
  - Human Factor
- **Multiple Applications**
  - Office spaces
  - Assisted living
  - Hospitals
  - Hotels

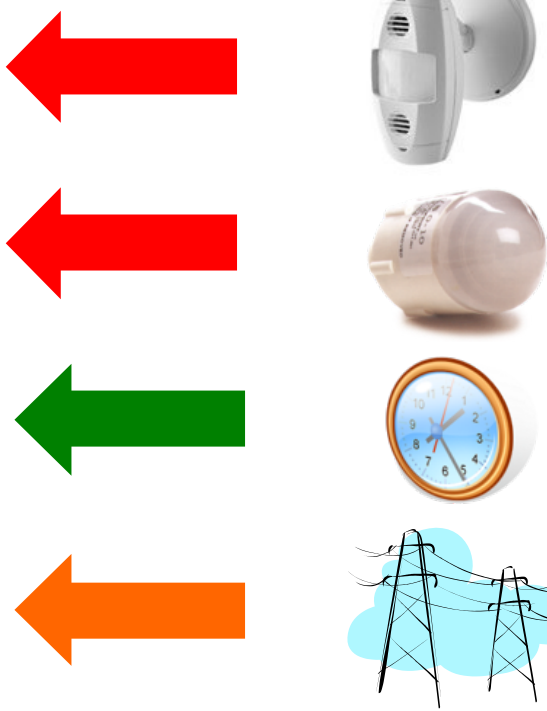


Key Electric Lighting Control Strategies

Automated Controls

Key Challenge

- High-end Tuning
- Occupancy/Vacancy!
- Daylight Harvesting!
- Scheduling
- Demand Response!
- Manual Control(!)



What Is Happening

Easy

What To Do

Energy Savings Opportunity

Energy Savings Opportunity

Energy Savings Opportunity

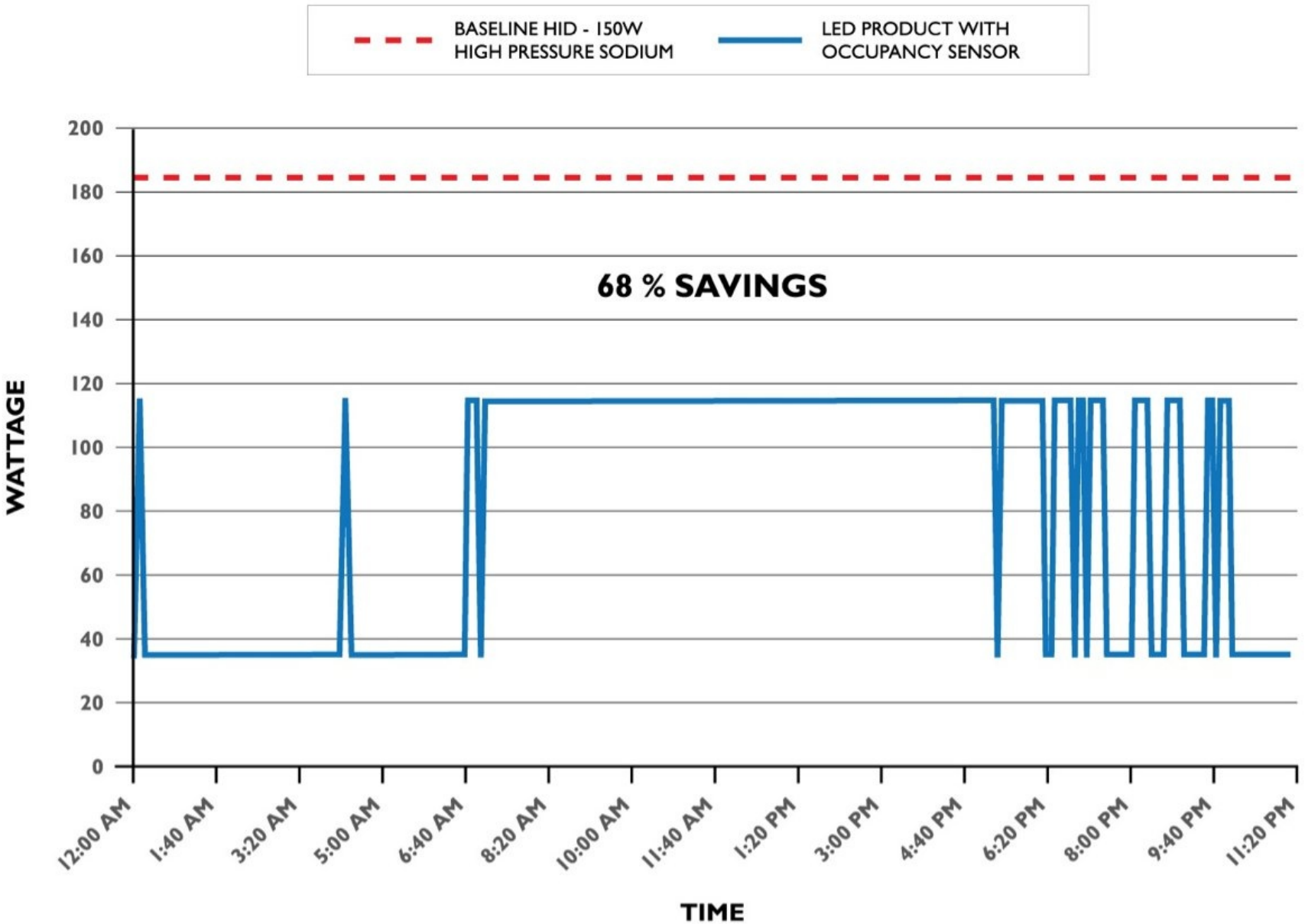
Energy Savings Opportunity

Occupancy-based bi-level parking lighting

one of our largest outdoor opportunities for energy savings

60% average savings

Occupancy-based Bi-level Parking Lighting

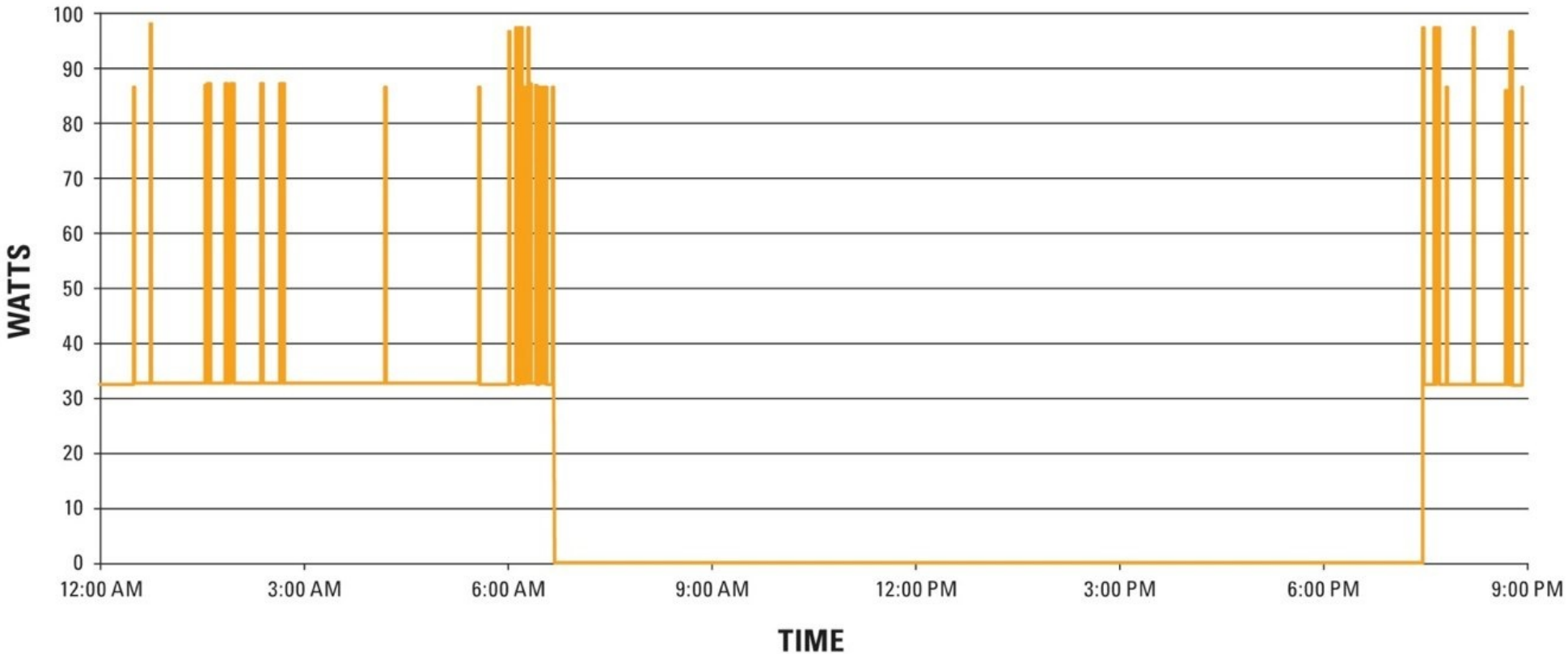


Bi-Level LED Bollards

Arcade Creek park
California Department of Public Health

Bollards operate in low mode 85% of the time

Occupancy-based Bi-level Pathway Lighting

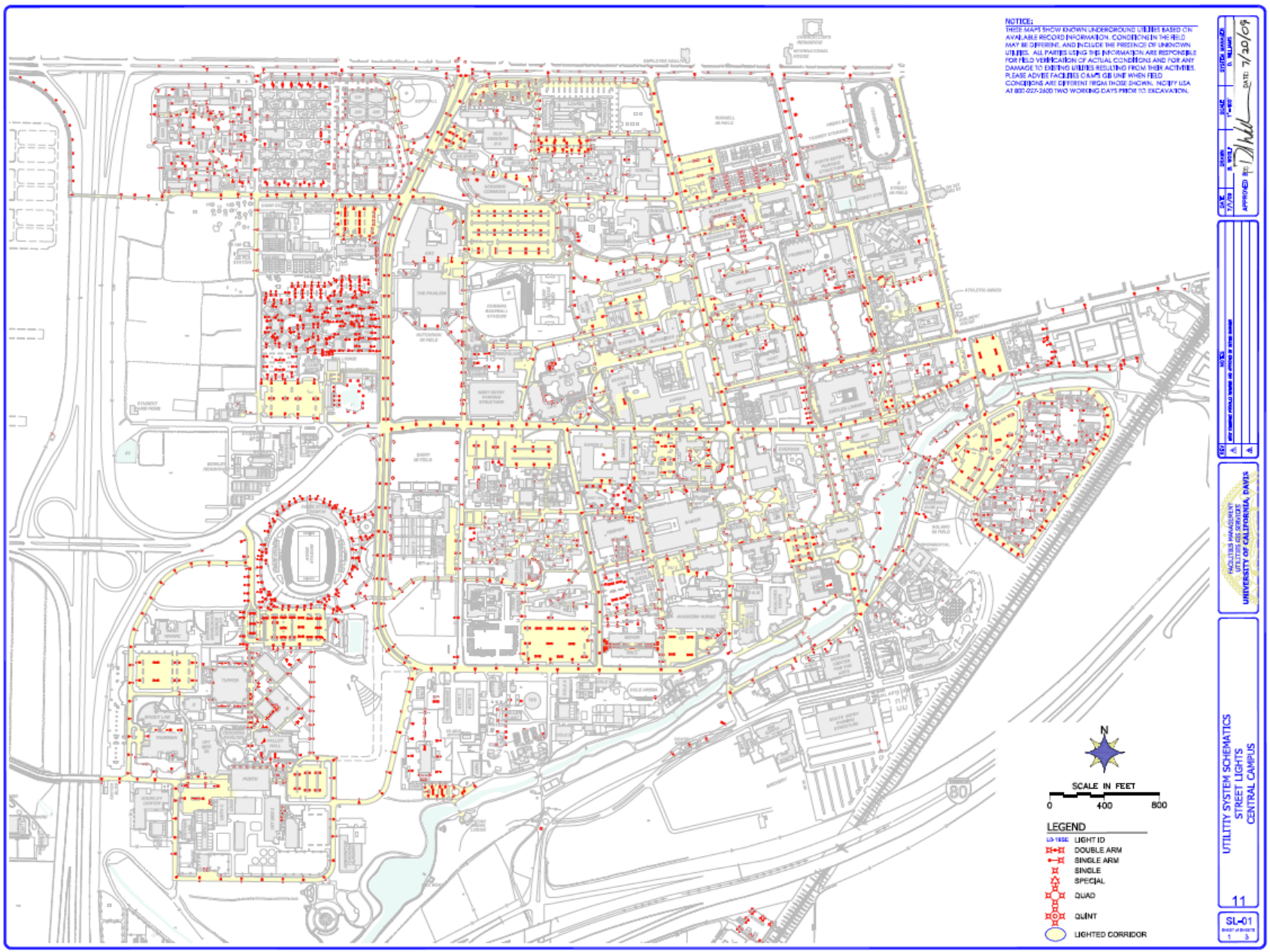


Pathway luminaires, April 24, 2012

60% energy savings compared to continuous full output

UC Davis Campus Today

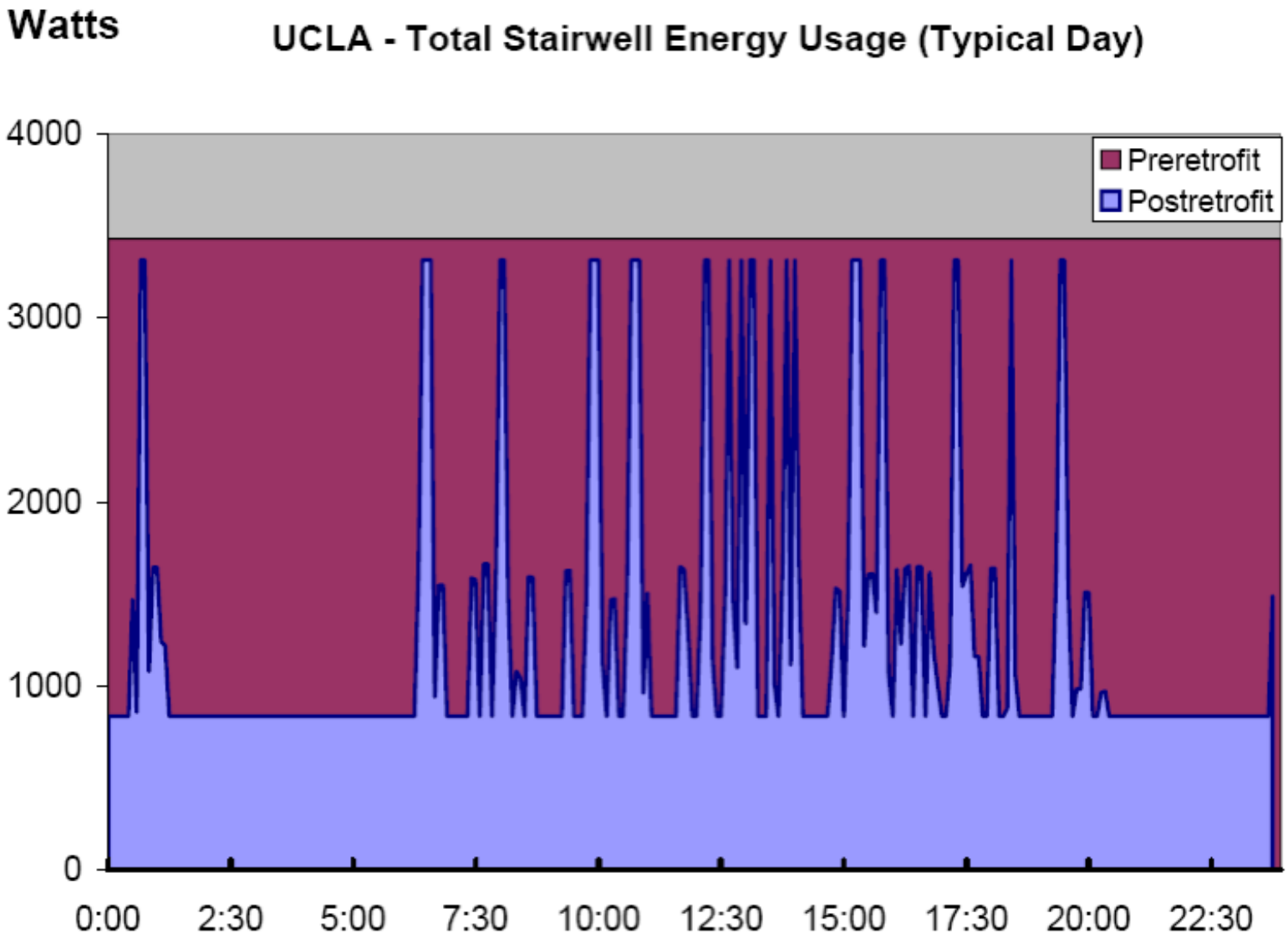
~1,600 Networked Occupancy-Based Bi-Level Outdoor Luminaires

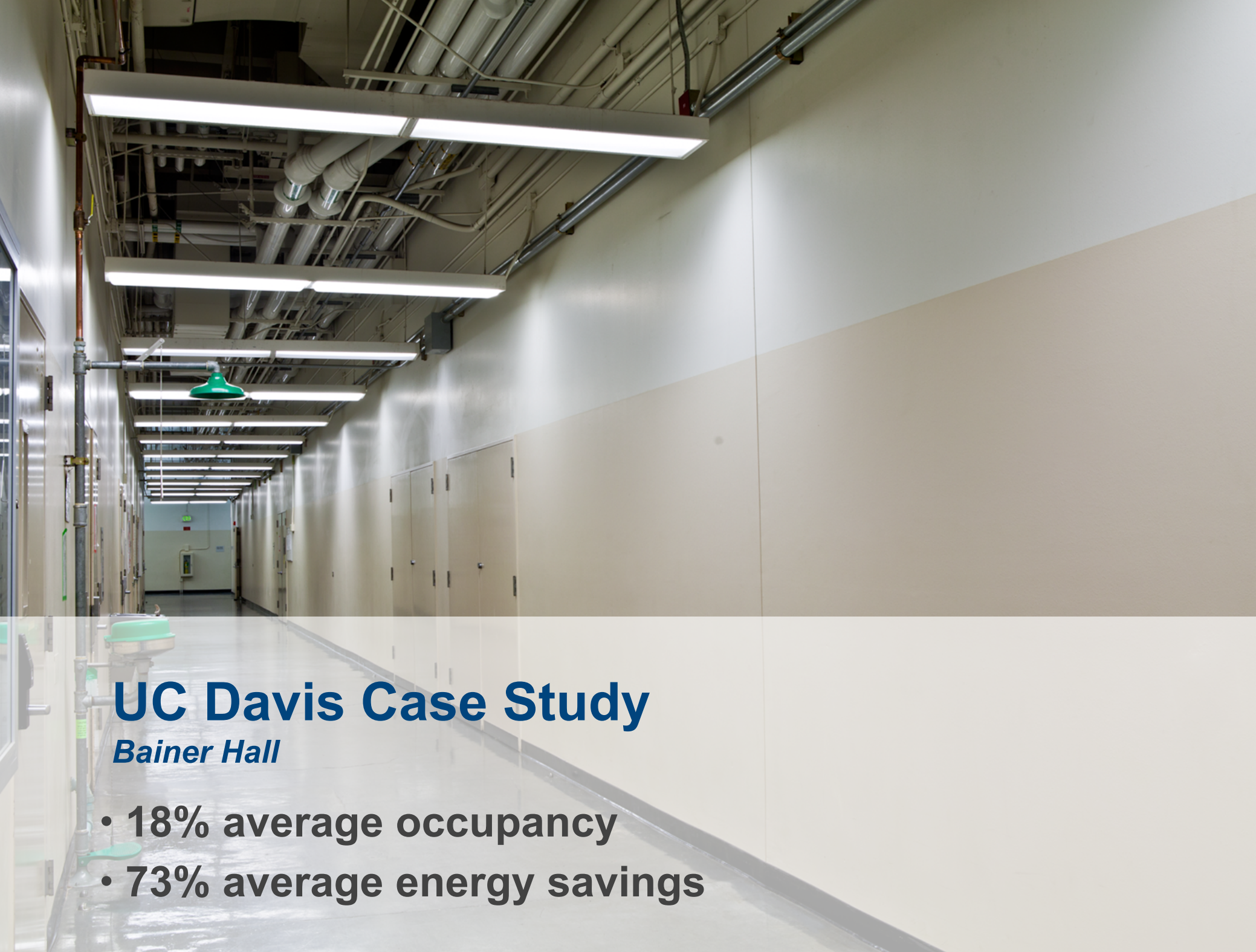


Adaptive Street Lighting - 2nd Street, Davis, CA

- Predictive controls RD&D
- Microwave sensors can sense speed of motion
- Can differentiate among automobiles, bicycles and pedestrians
- Full power from one to three light posts ahead of motion detection

Stairwell Occupancy-Based Bi-Level Controls





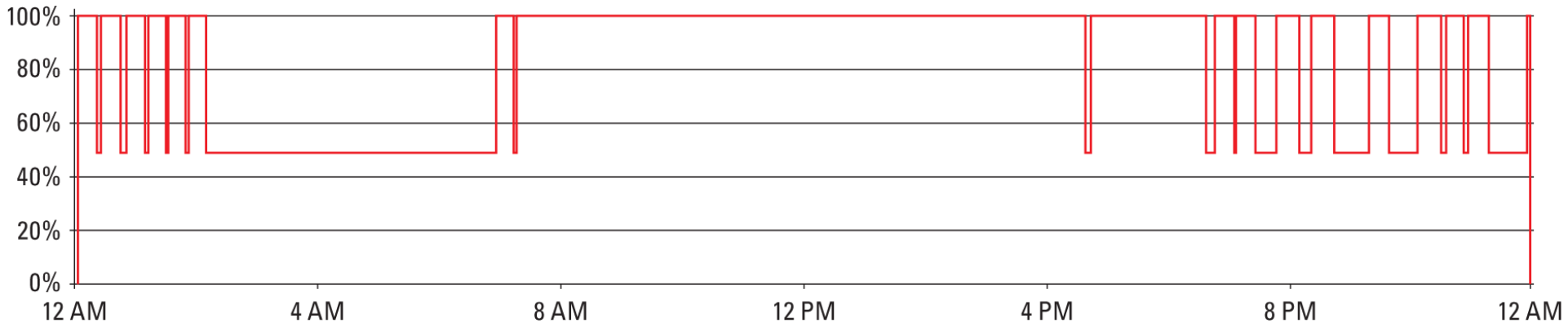
UC Davis Case Study

Bainer Hall

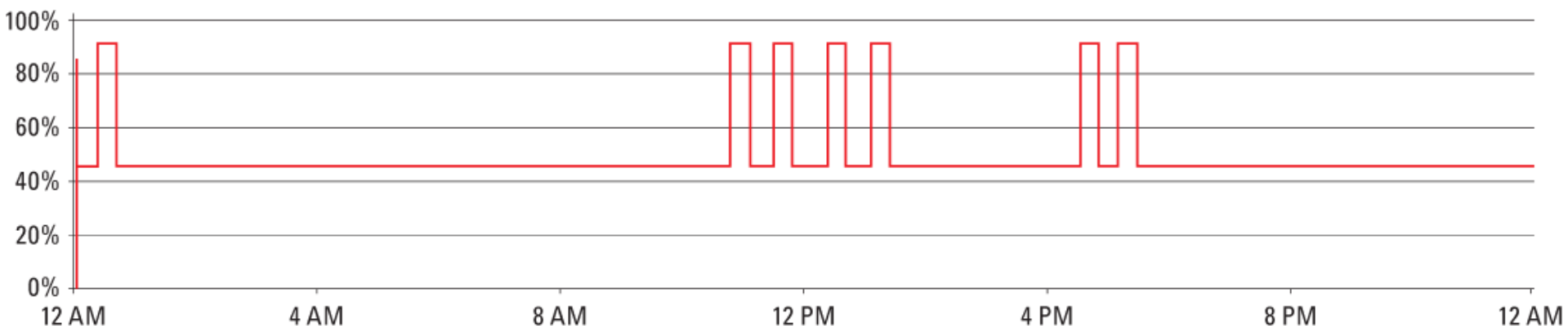
- 18% average occupancy
- 73% average energy savings

Corridor Occupancy-Based Bi-level Control
Bainer Hall, UC Davis

Weekday



Weekend



UC Santa Barbara Corridors Study

- Occupancy rates for 50 corridors across 11 buildings on UCSB campus
- Occupancy ranged from 2.6% to 25.9%
- Average occupancy of 10.2% across all buildings
- 12.3% corridor occupancy in first floors, 8.9% elsewhere

Daylight Harvesting Strategy

- **Reduce electric lighting based on available daylight**
- **Among most promising energy efficiency strategies**
  - Significant **energy savings**
    - Lighting
    - Cooling
  - Significant **peak demand reduction**
    - Daylight availability coincides with peak demand



Energy Savings Opportunity

Energy Savings Opportunity

Energy Savings Opportunity

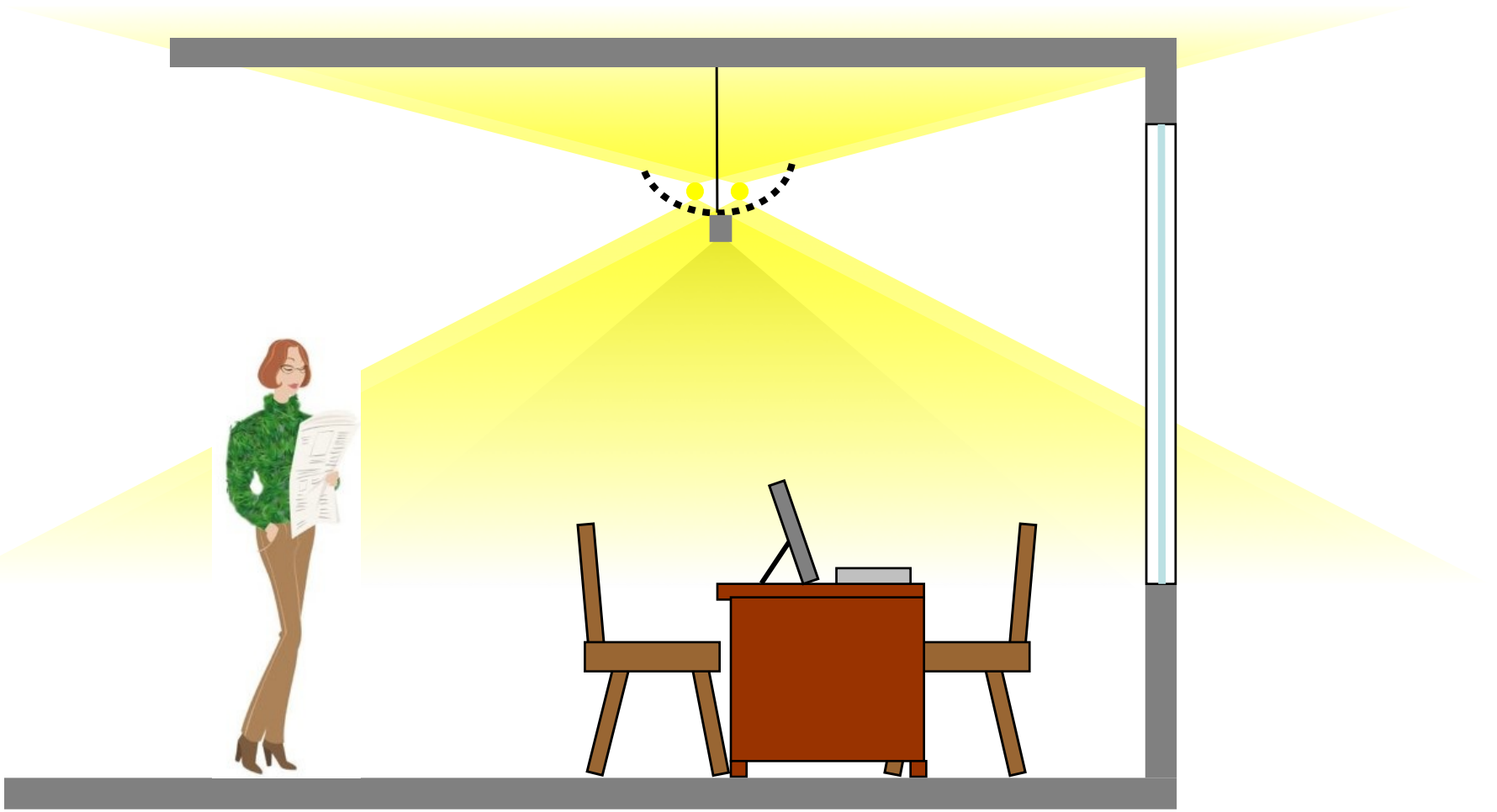
Barriers to Wide-Spread Applications

- **Reliability**
  - **Over dimming** of electric lighting
    - Occupant complaints, lost employee productivity
  - **Under dimming** of electric lighting
    - Lost energy savings
- **Cost Effectiveness**
  - **Component** costs – **low**
  - **Commissioning** costs – **high**
  - **Re-commissioning** costs – **higher**
  - **Lost employee productivity** costs – **highest**
    - 1 hr employ cost = 1 yr electric lighting savings
  - **Energy**
    - Ineffective controls → significant penalties

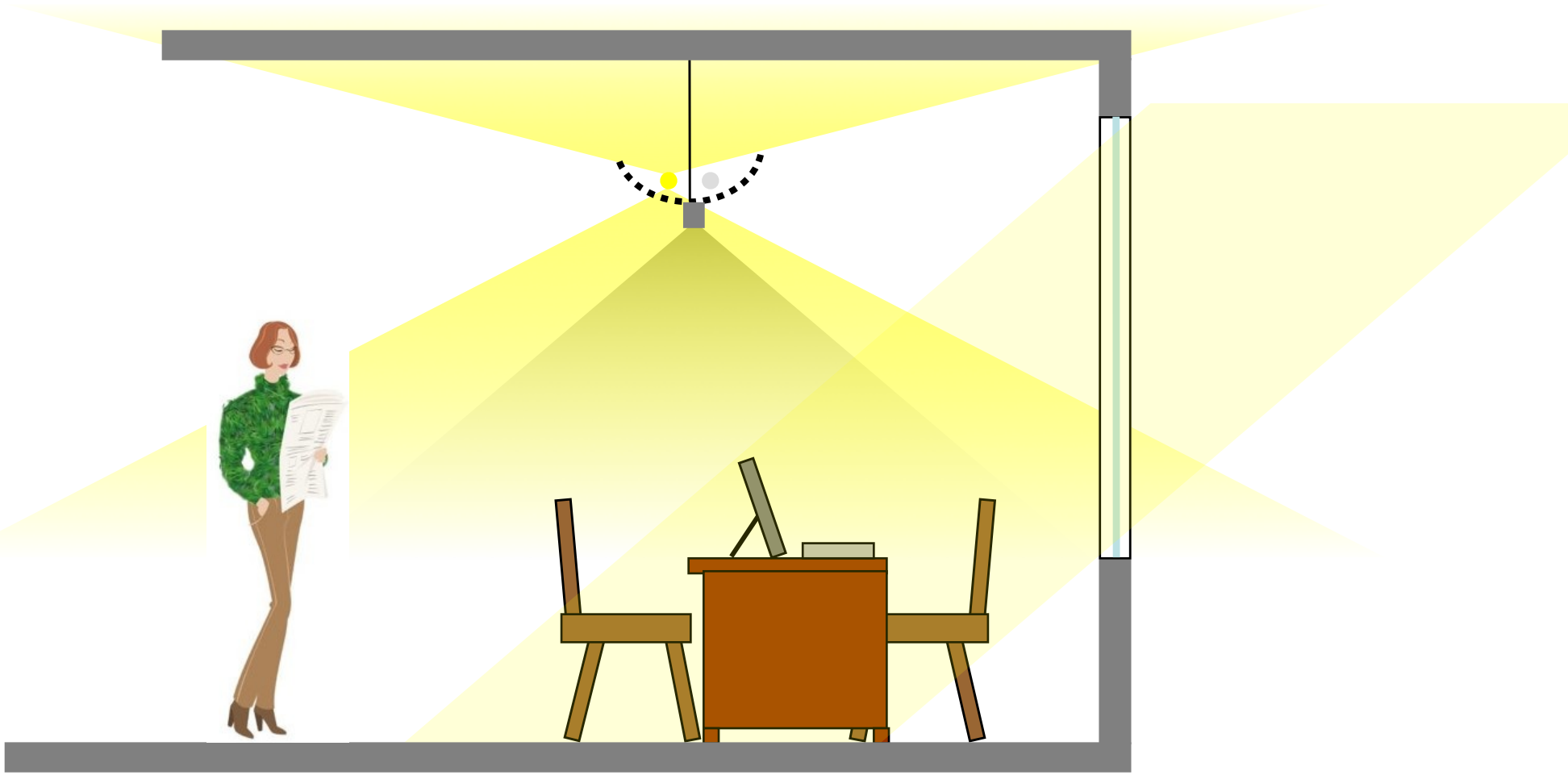
New, Market Driven Technologies

… we need a simplified, inexpensive daylight harvesting control system that turns off half of the lights in areas with plenty of daylight, such as next to windows and under skylights …

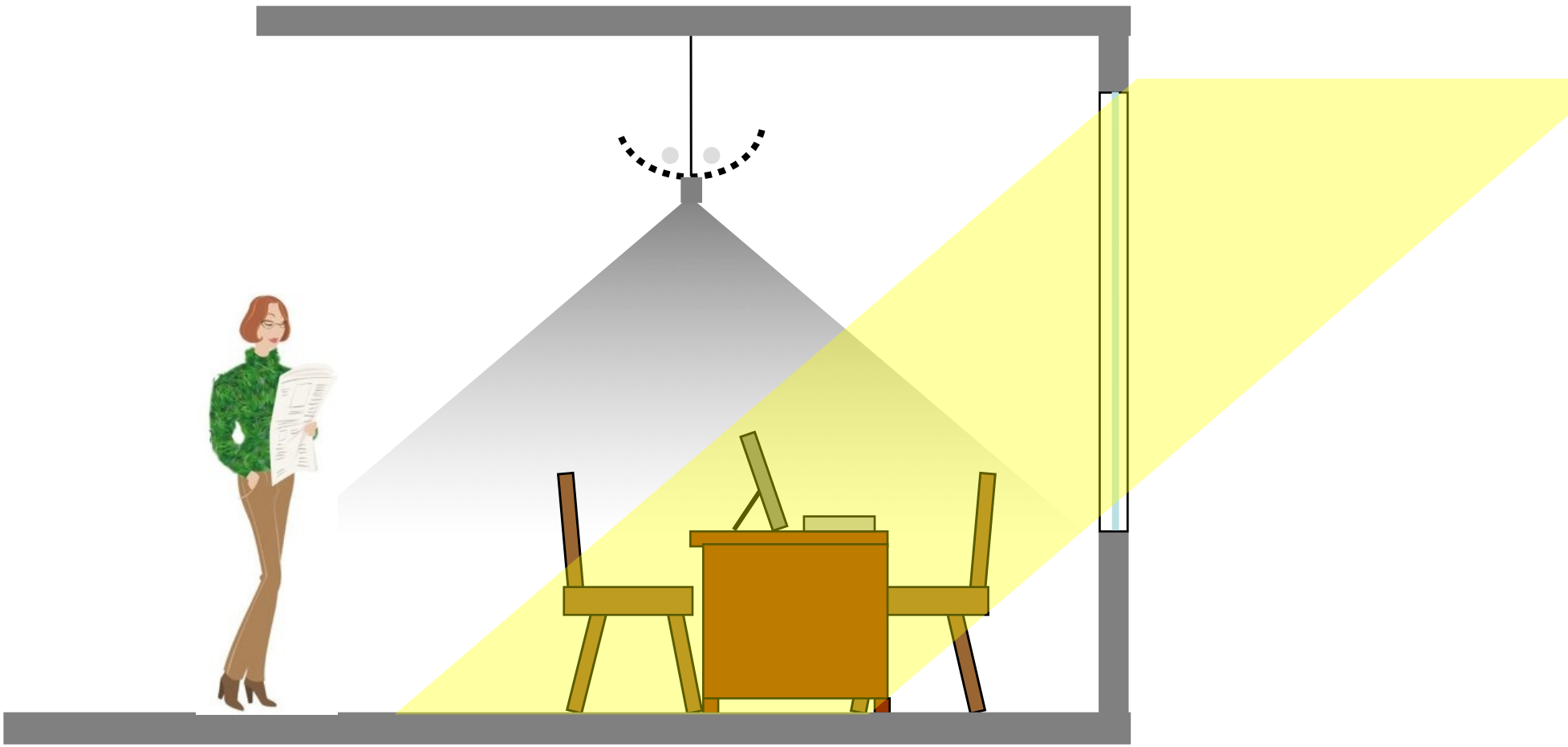
Not enough daylight: 100% lighting



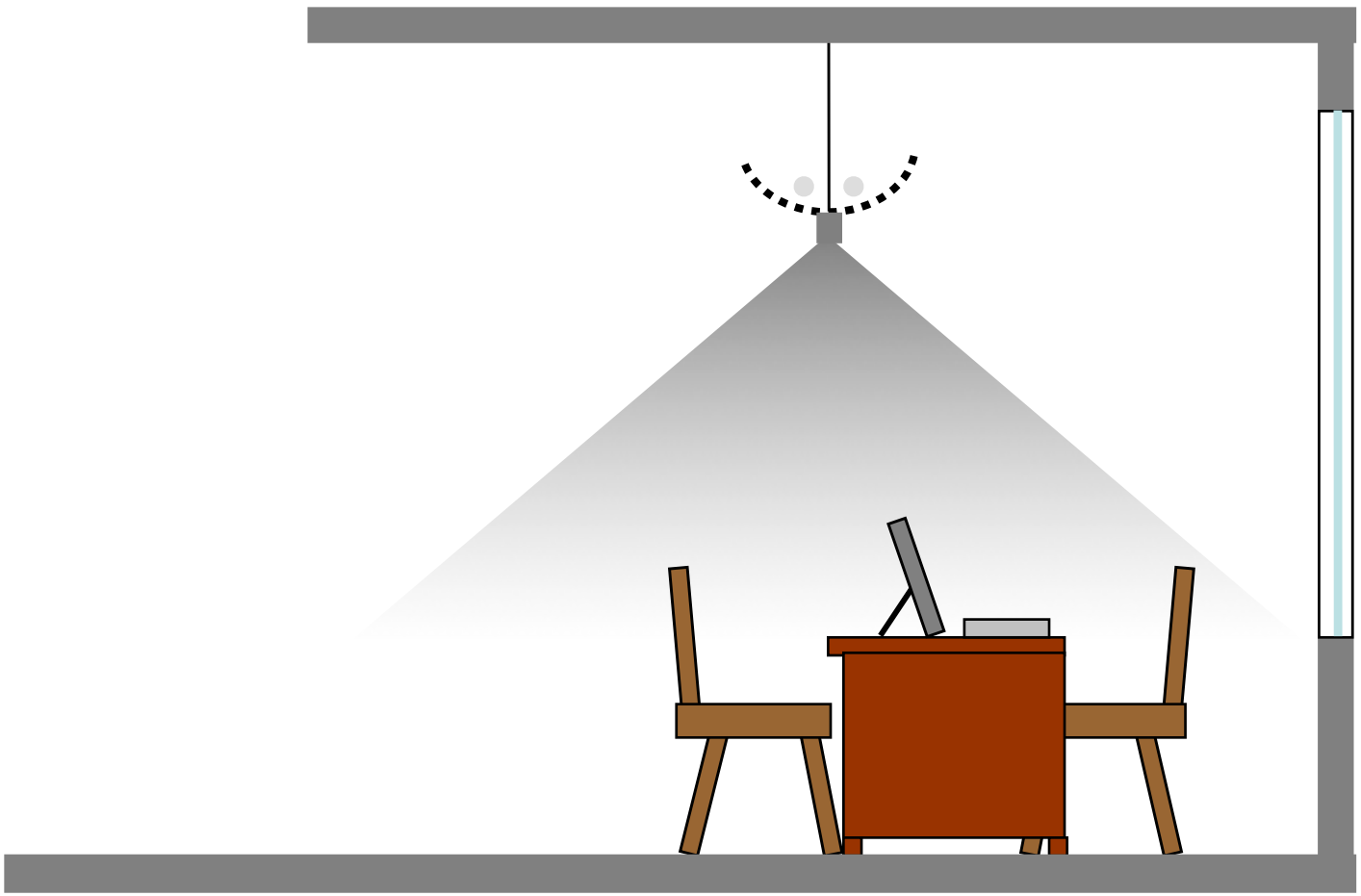
“Enough” daylight: 50% lighting



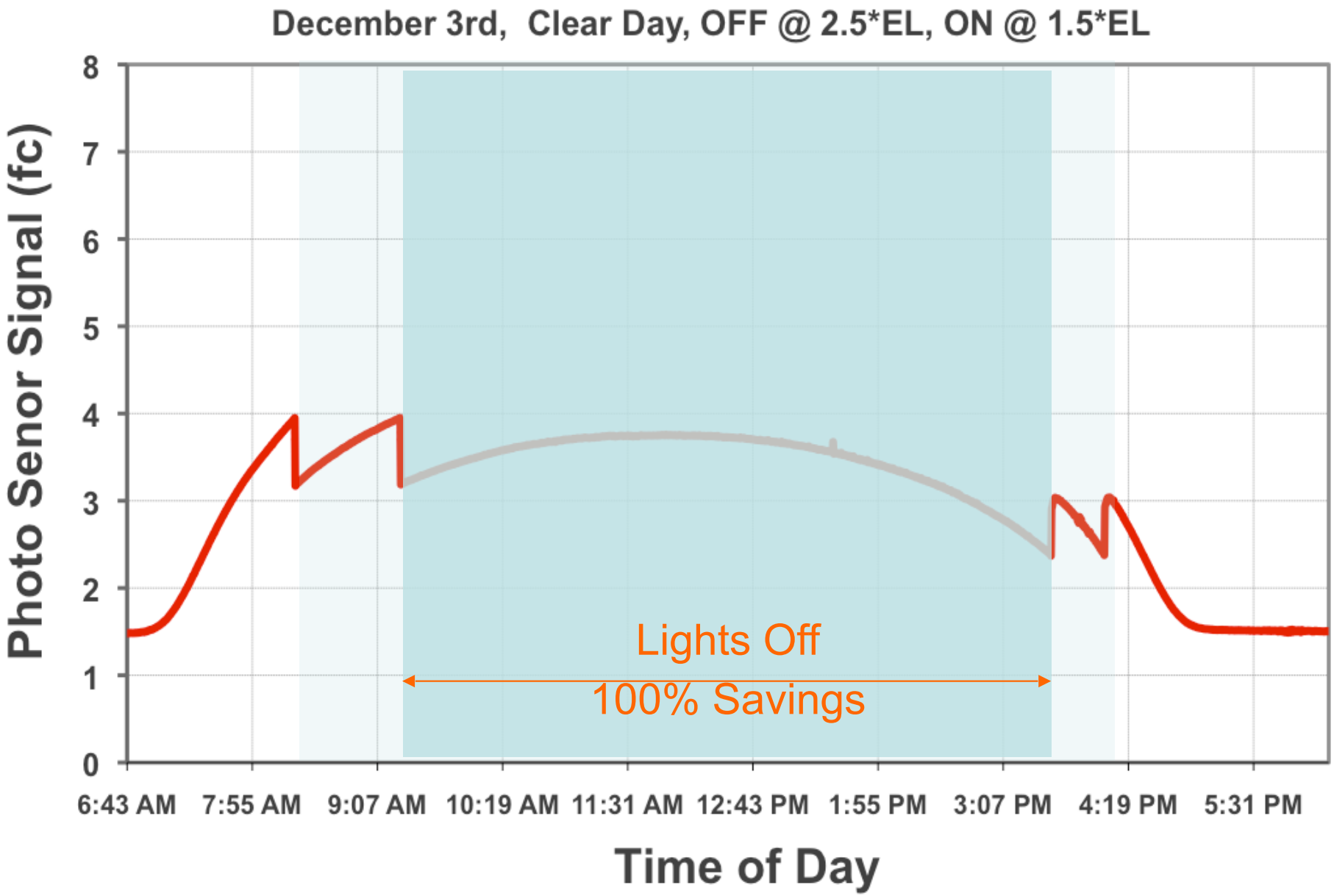
Even more daylight: 0% lighting



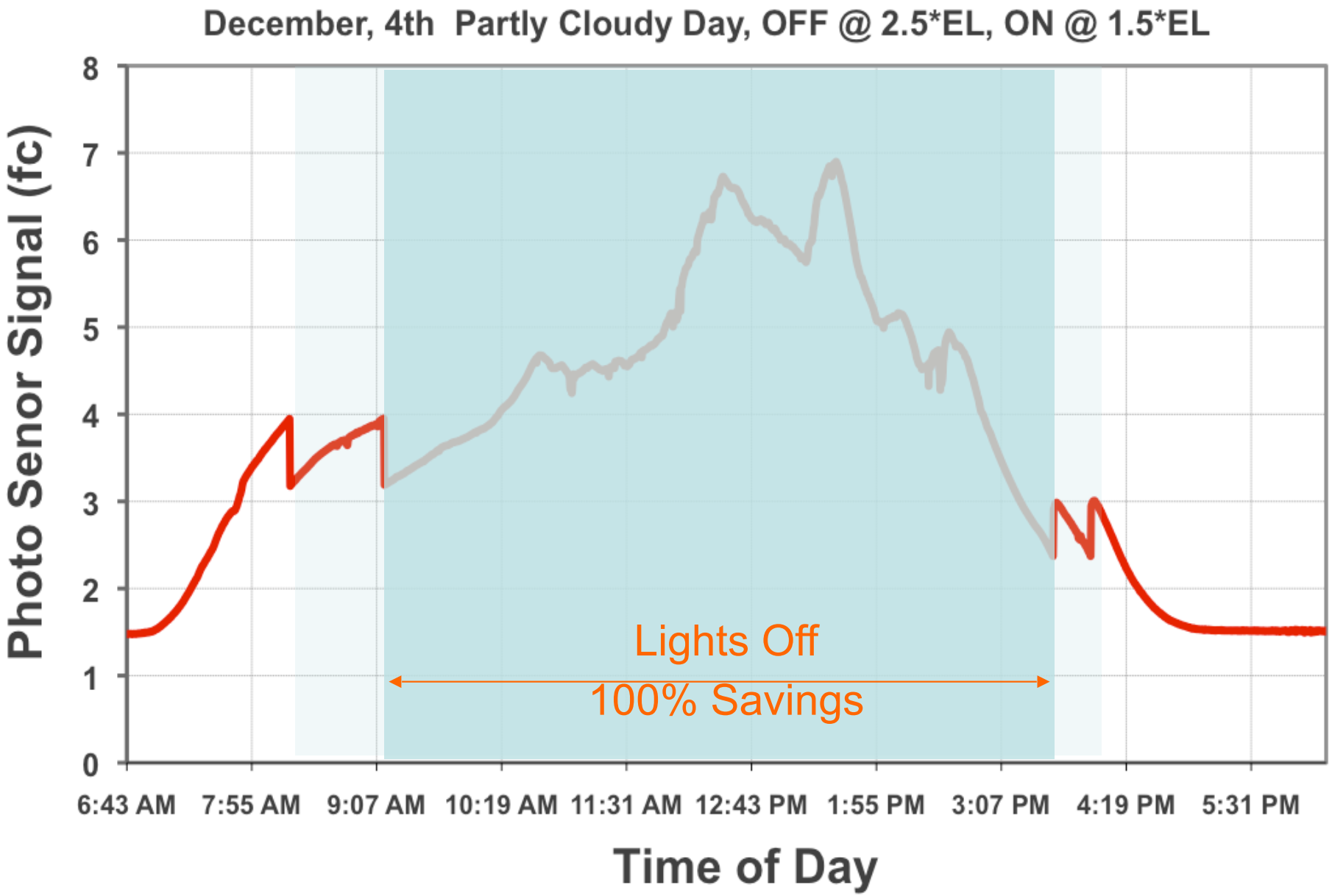
No occupants: 0% lighting



Bi-Level Switching



Bi-Level Switching



Commercialization

- On/Off Switching based on available daylight
- Automatic, continuous calibration
- Adjustable set points
- Adjustable time delay

From the Lab…

… To the Marketplace

WattStopper

legrand®

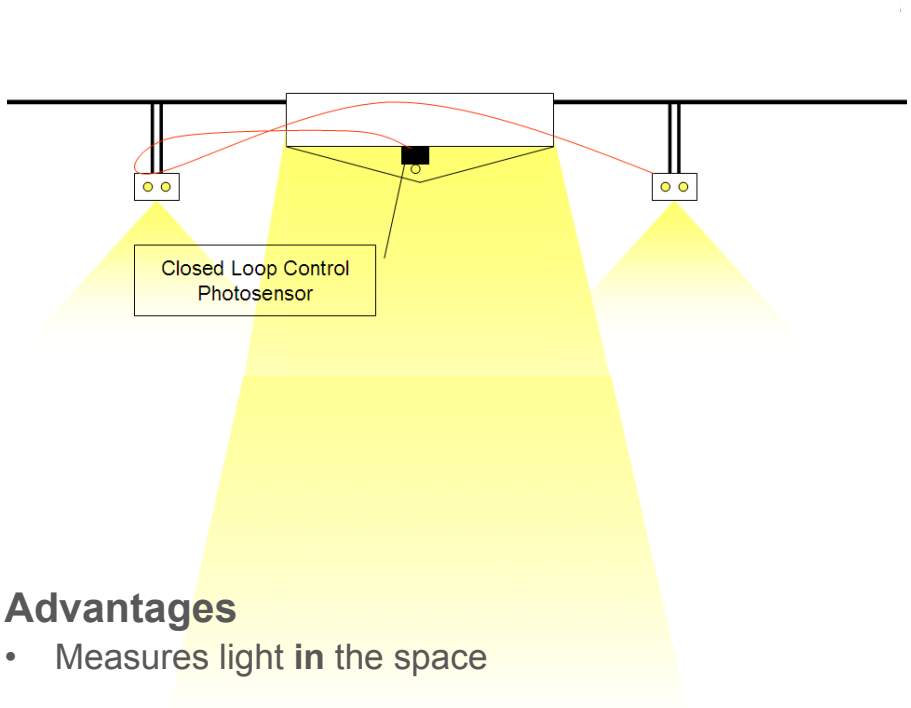
New, Market Driven Technologies

… we need a simplified, inexpensive daylight harvesting control system that turns off half of the lights in areas with plenty of daylight, such as next to windows and under skylights …

… we need a daylight harvesting system that reliably dims electric lights based on available daylight indoors …

Traditional Daylight Sensing Strategies

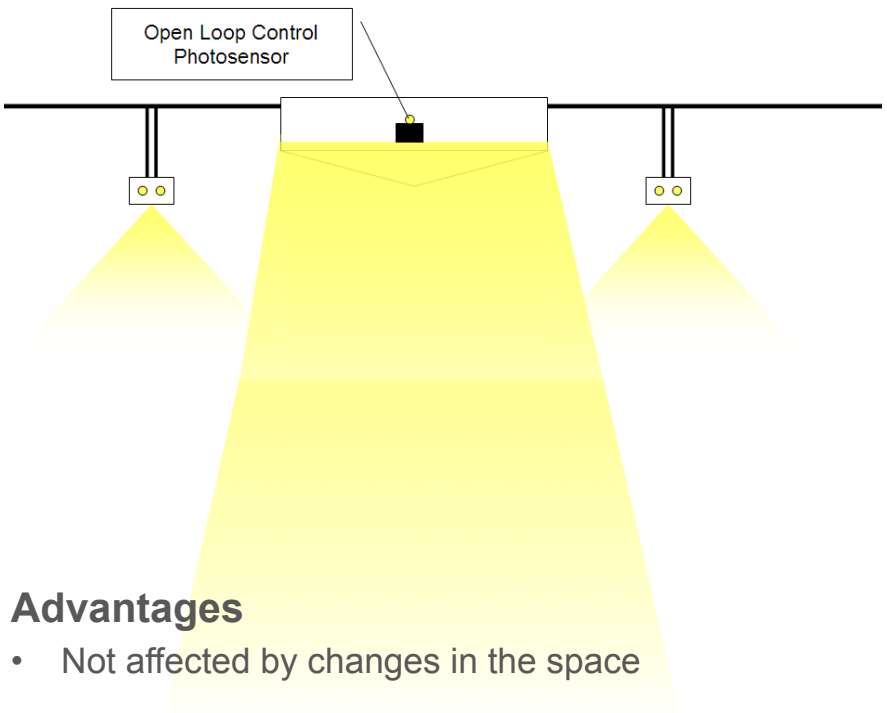
Closed Loop Sensing
Affected by electric lighting



Advantages
- Measures light **in** the space

Disadvantages
- Requires re-calibration for long-term changes (geometry and reflectance of interior surfaces)
- Cannot differentiate between:
  - Daylight changes (fluctuations in daylight levels)
  - Short-term space changes (moving occupants/ objects)

Closed Loop Sensing
Not affected by electric lighting

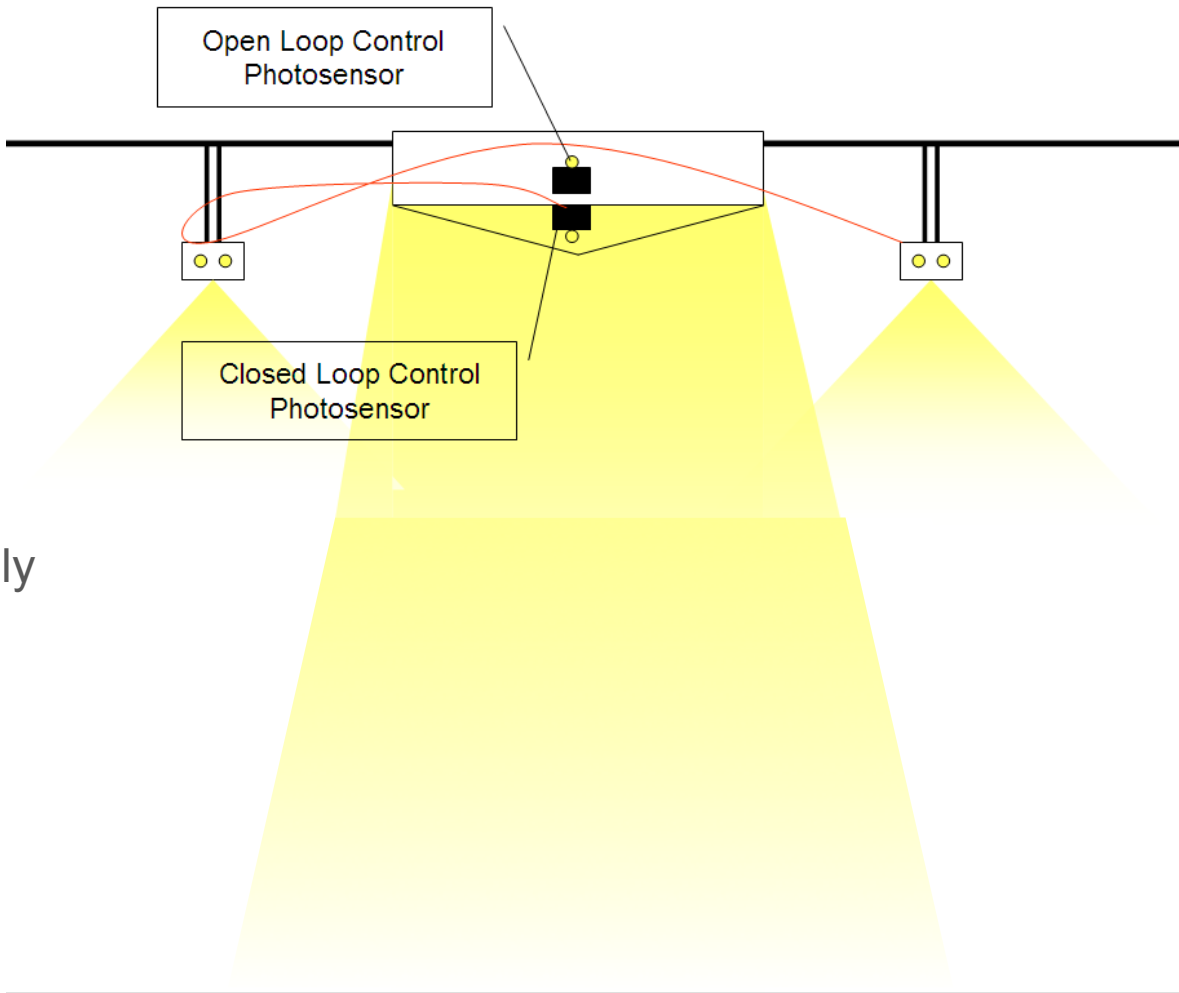


Advantages
- Not affected by changes in the space

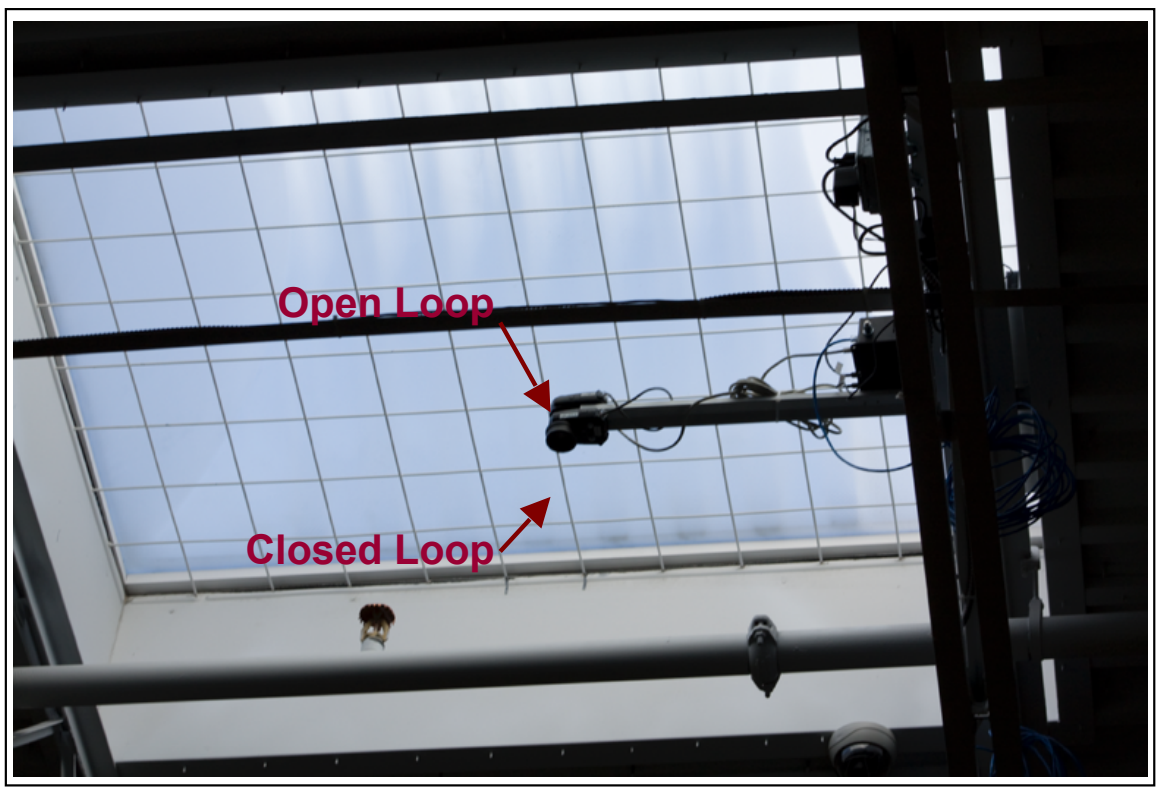
Disadvantages
- Requires commissioning
- Not an accurate indicator of daylight levels in the space

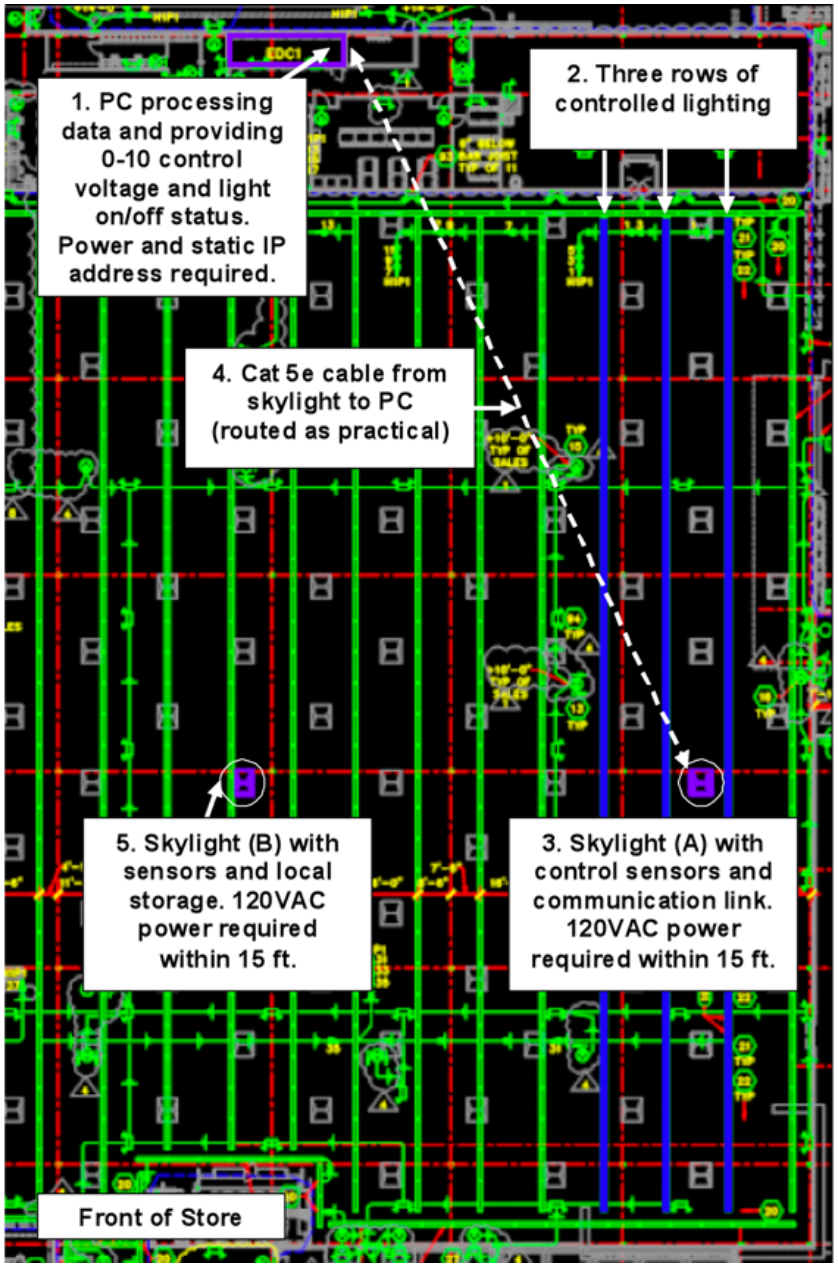
Dual Loop Daylight Sensing

- **Measures light in and out of the space**
- **Automatic closed-loop calibration**
  - Based on electric light levels
  - No need for commissioning
- **Continuous closed-loop re-calibration**
  - Closed loop sensor automatically adjusts to interior changes
  - No need for re-commissioning
- **Dual sensor logic**
  - Differentiates daylight changes from changes to interior reflectance values
  - Offers reliable operation



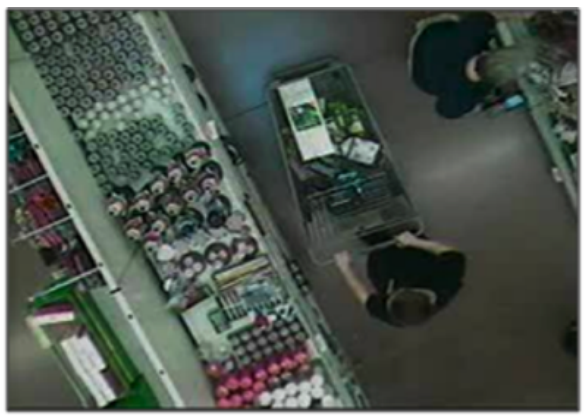
Field Testing
West Sacramento Wal-Mart Store





Effect of Interior Changes on Sensor Signal

12/25/08: EL = 4.75

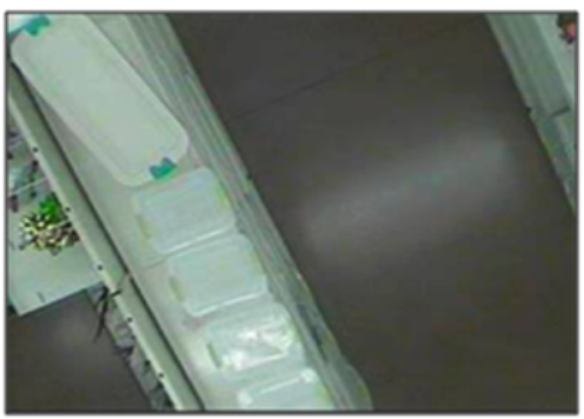


12/26/08: EL = 4.77

12/29/08: EL = 4.94

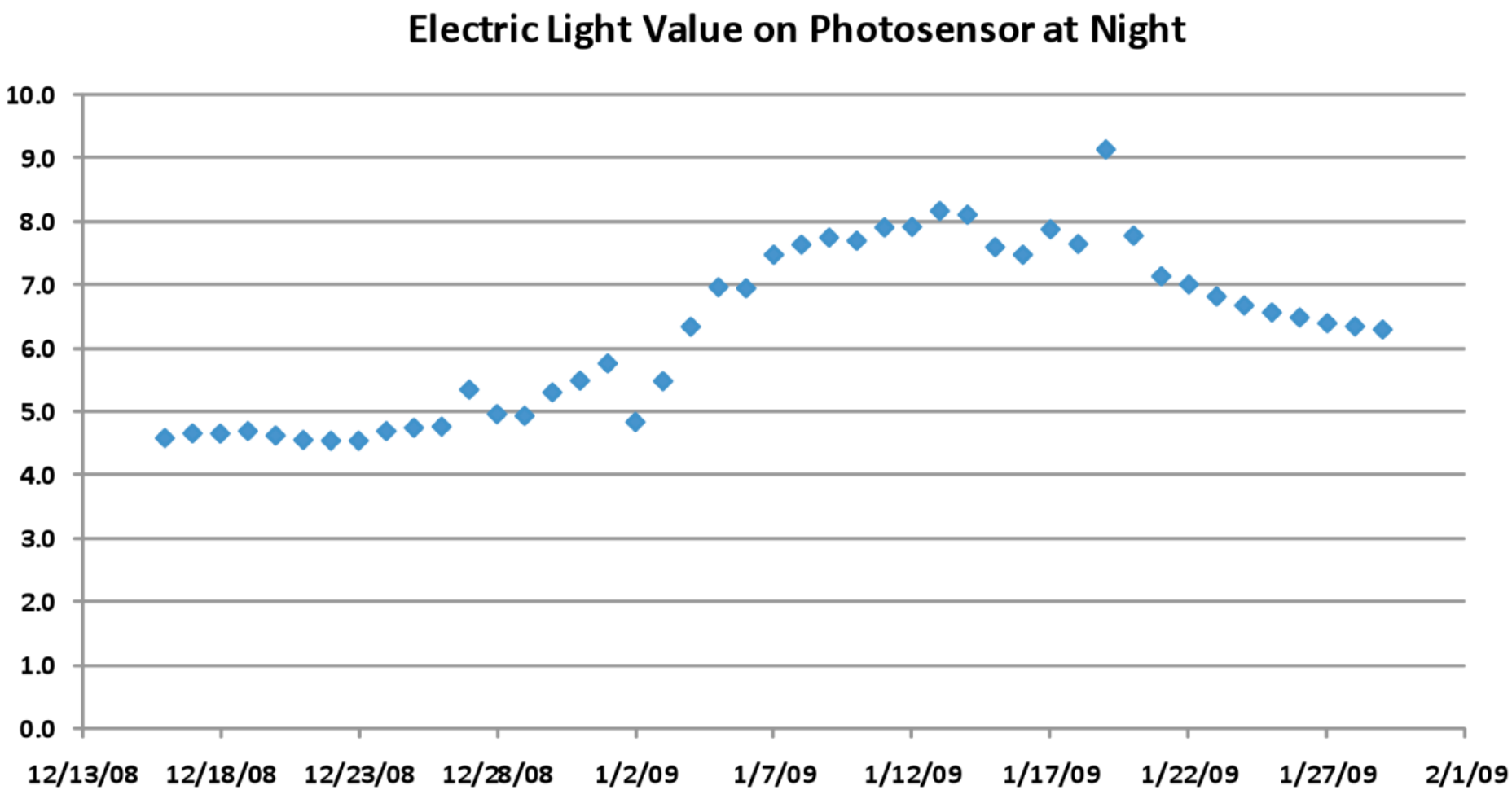
01/01/09: EL = 5.77

01/04/09: EL = 6.34



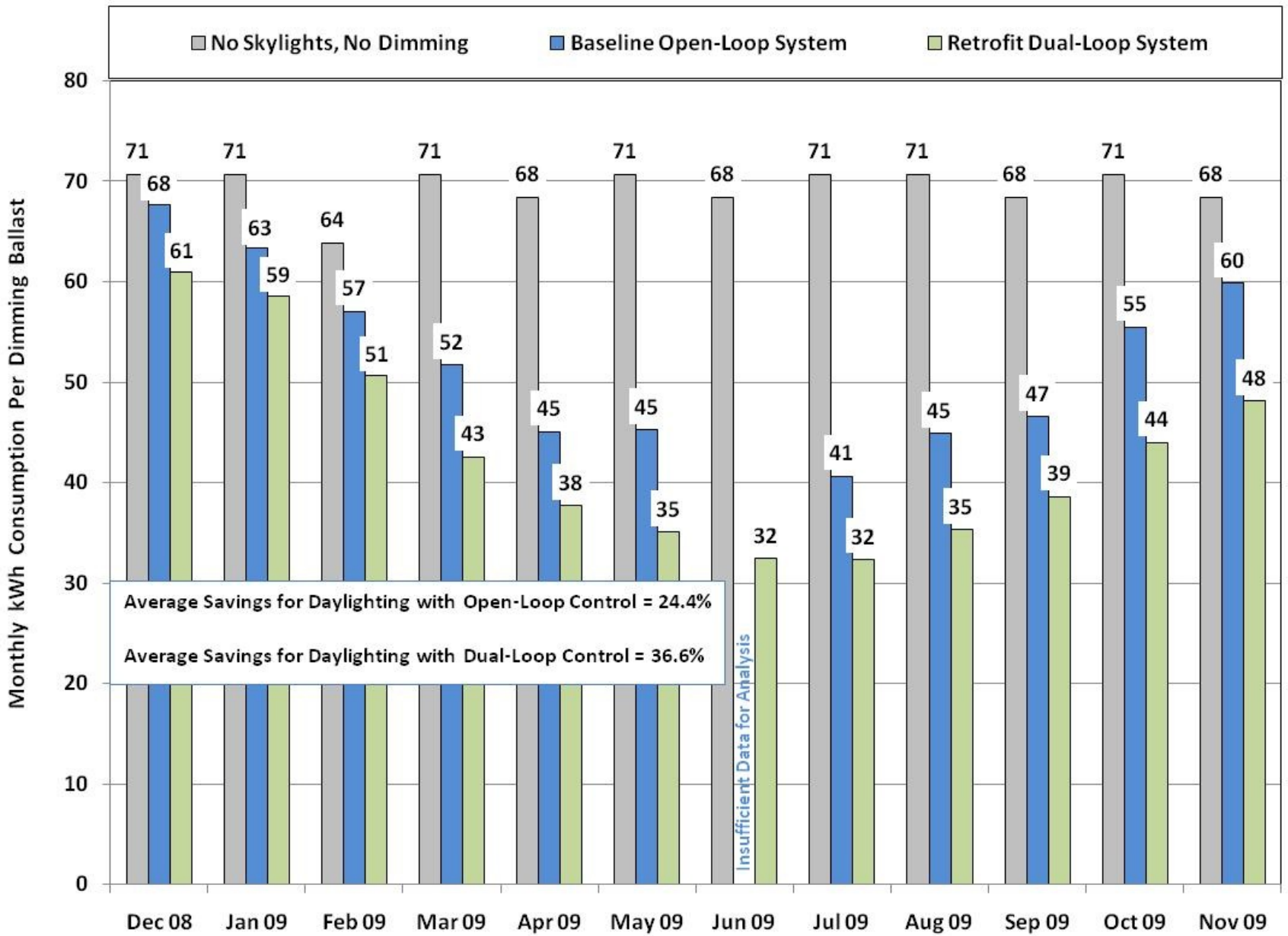
01/05/09: EL = 6.97 (+47%)!

Night-time Daily Automatic Calibration



Field Test: Energy Savings

24/7 Operation

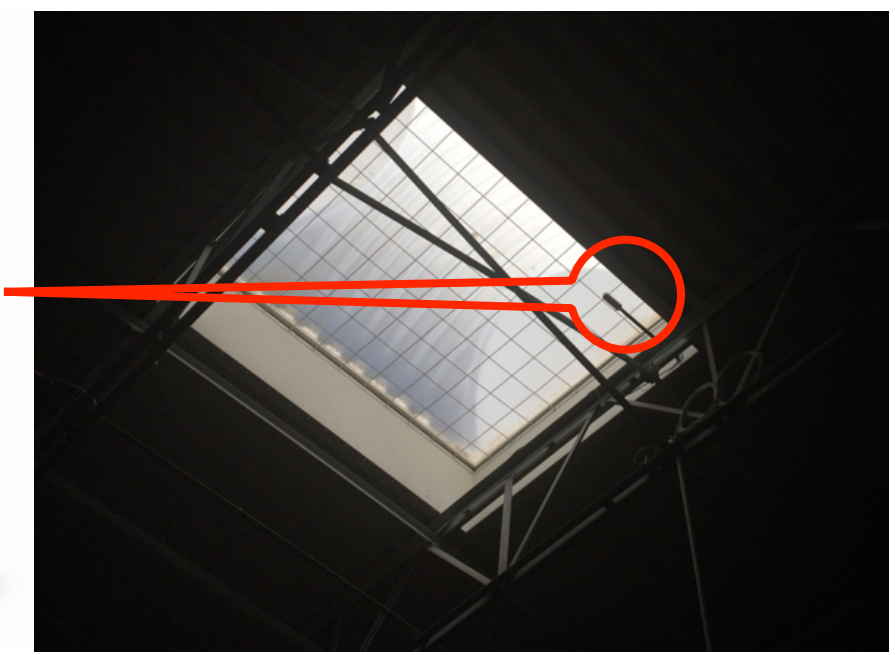


Commercialization

- Dual-Loop photo sensing
- Automatic, continuous calibration of closed loop
- Integrated in the Watt Stopper DLM control system

From the Lab…

… To the Marketplace



Closed Loop

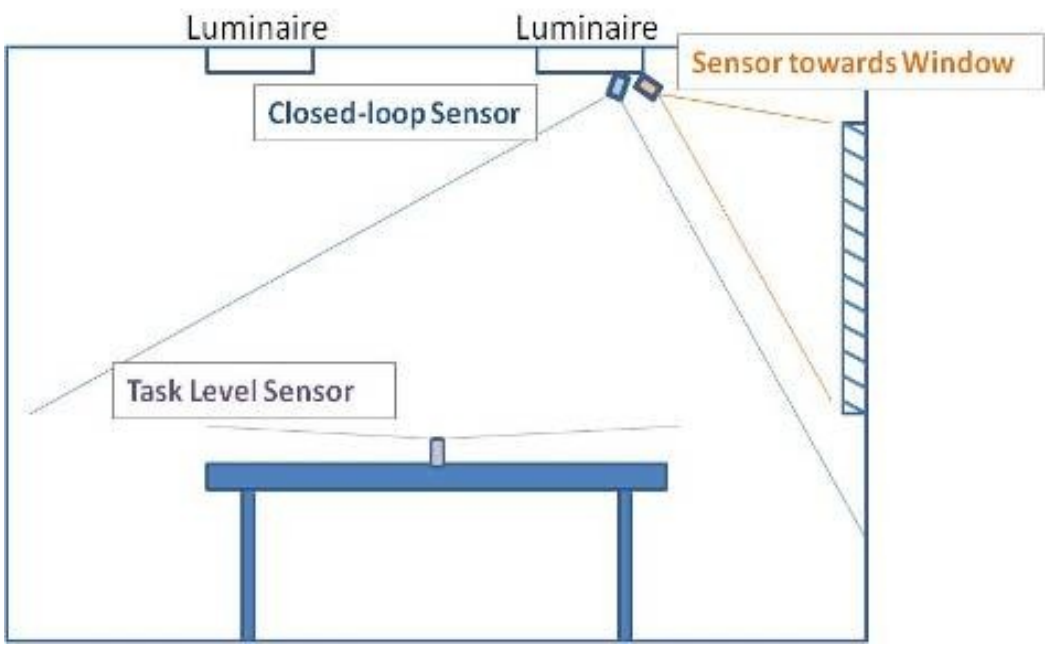
Open Loop

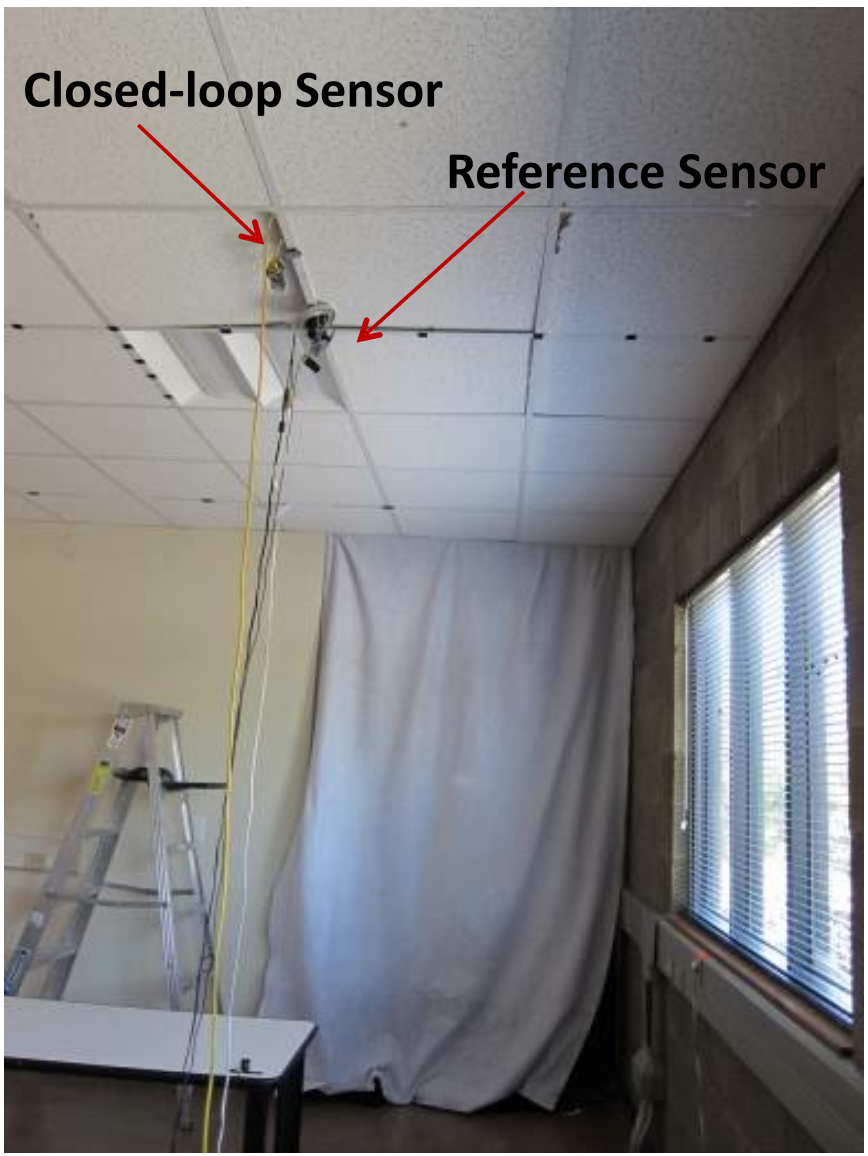
WattStopper

legrand®

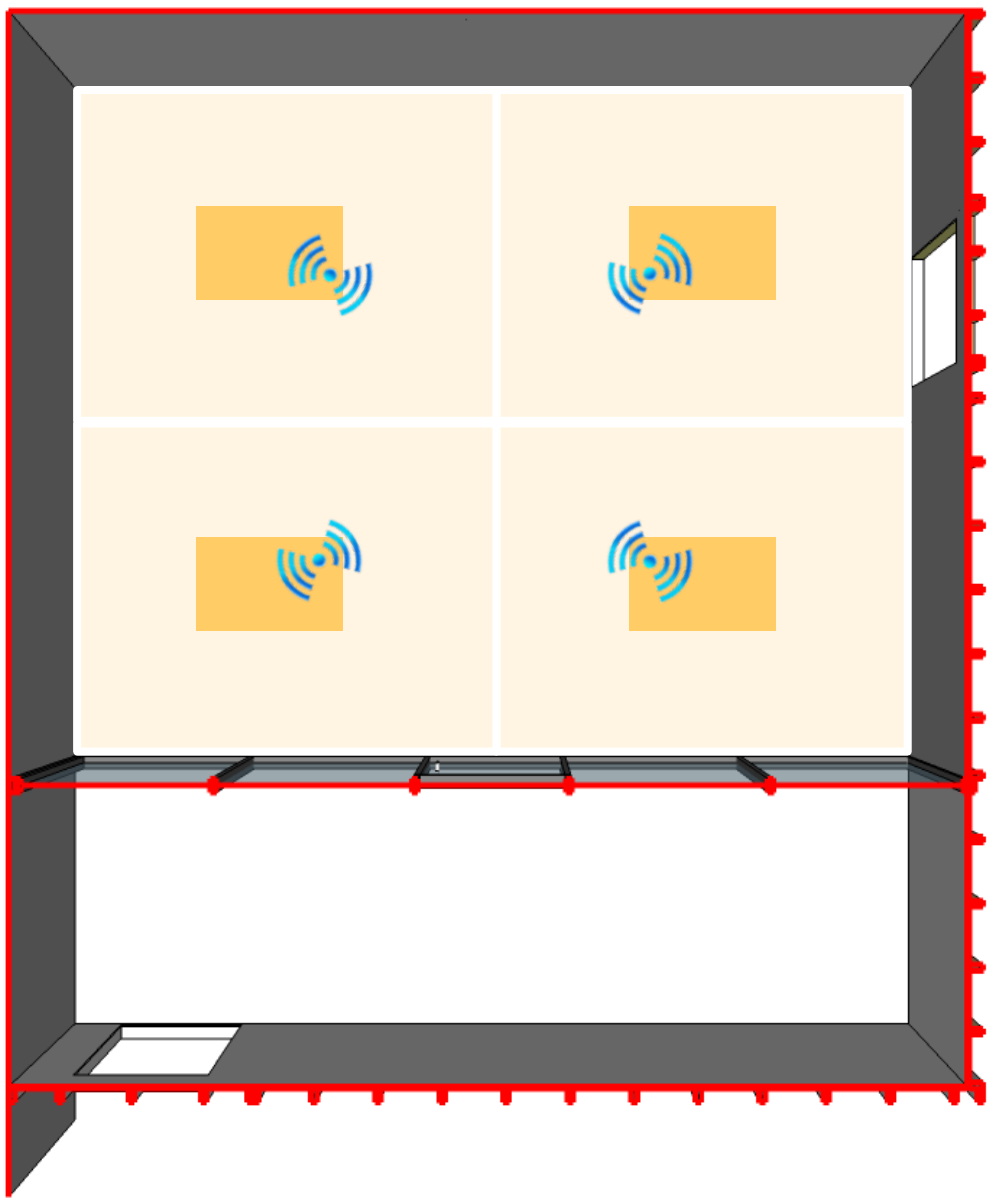
Dual Loop for Window Applications

- It works!
- but requires commissioning for proper placement and field of view of “open loop” (reference) sensor





Redundant Sensing Strategy



You can fool one sensor at a time.

Fooling multiple sensors at the same time in the same way requires special choreography…

Ultra Smart Luminaires

- **One or more light sources**
- **Multiple integrated sensors**
  - Occupancy sensing
  - Photo sensing
  - Temperature sensing
  - …
- **Communications**
  - With other luminaires
  - With utilities
  - …
- **Control logic based on multiple sensor signals**
  - From same luminaire
  - From neighboring luminaires

CLTC Daylight Harvesting Laboratory

- Daylight simulator – new facility with industry support
- Optimize daylight harvesting for comfort and energy efficiency

Ultra-smart Luminaires R&D

Daylight Harvesting Optimization Strategy

- Reduce electric lighting based on available daylight
- After electric lighting is off or at minimum output
- Adjust fenestration transmittance based on
  - HVAC status
  - Potential for glare



Adaptive Daylighting Systems

- **Automatically adjust their light output…**
  - Candle Power Distribution (SPD) - *total flux & spatial distribution*
  - Spectral Power Distribution (SPD) - *color spectrum – CCT, CRI*

- **…based on environmental conditions…**
  - Occupancy / Vacancy
  - **Electric Lighting Status**
  - Demand Response Signals
  - **HVAC Status**
  - …
- **…to optimize space & building performance**
  - Maximize Comfort
  - Minimize Energy Requirements
  - Minimize Peak Electricity Demand
  - …

Ball State University
Muncie, Indiana

http://sageglass.com/portfolio/siemens/

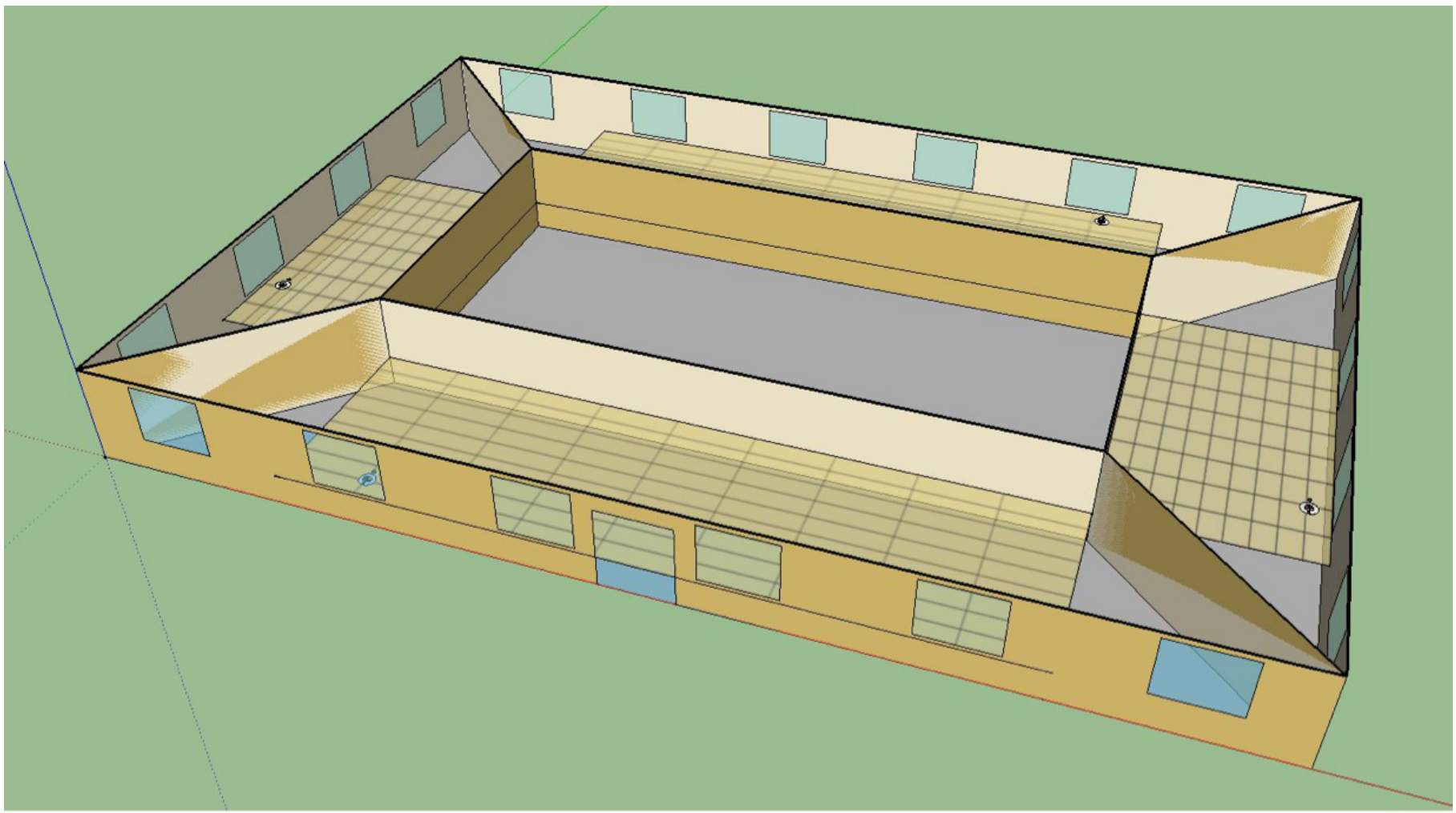
Chabot College
Hayward, California

http://sageglass.com/portfolio/siemens/

Chabot College
Hayward, California

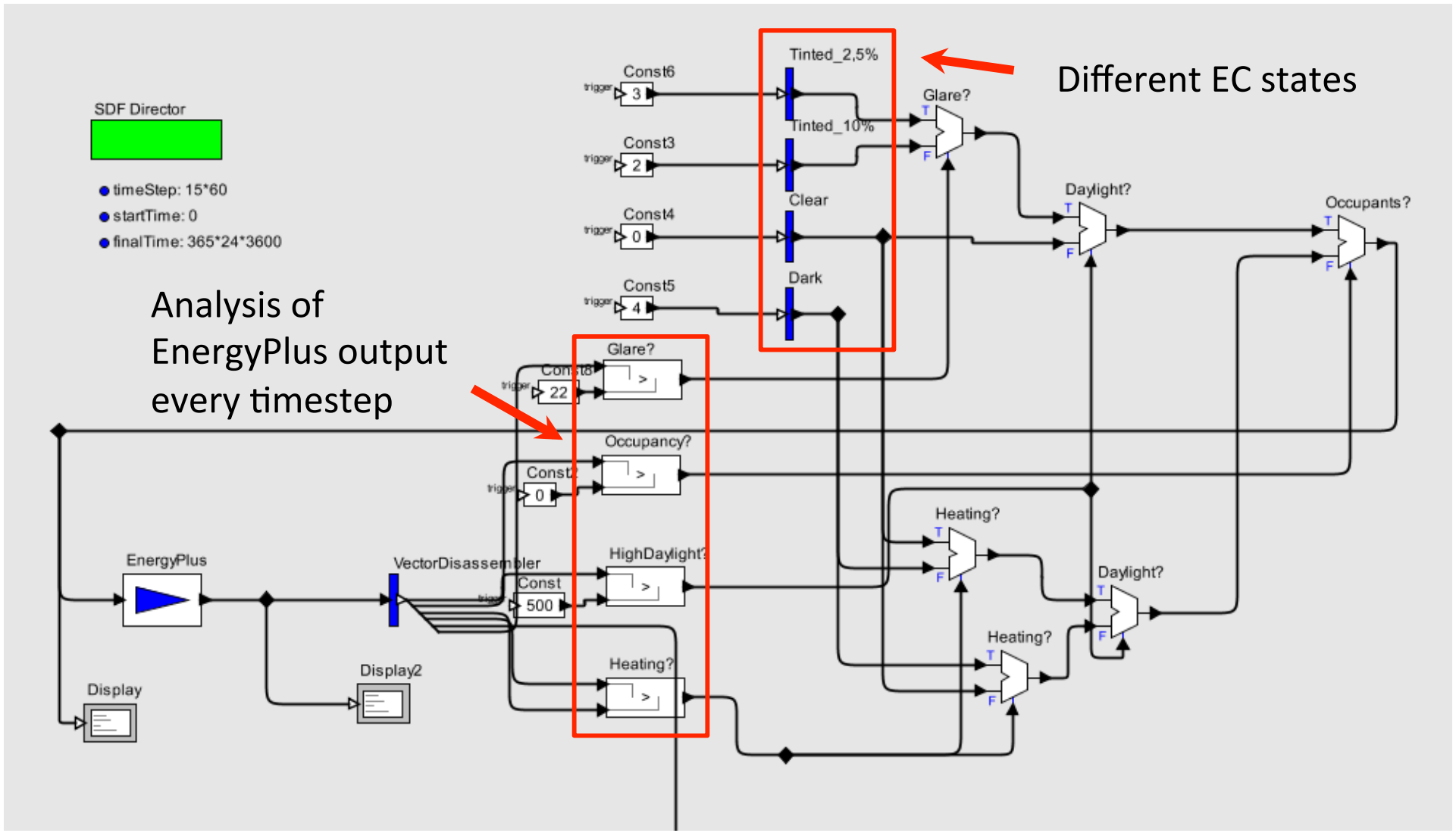
http://sageglass.com/portfolio/siemens/

Daylight Harvesting Optimization Simulation Windows with Electrochromic Glazing DOE - Standard Small Office



BCVTB Controls Simulation Modeling

Released in 2011, **B**uilding **C**ontrol **V**irtual **T**est **B**ed supports different simulation programs simultaneously, calculating parameters at every time step with custom algorithms



DOE Standard, Validated Small Office Model

Phoenix, AZ

#	Lighting Controls?	Fenestration Controls?	Lighting [GJ]		Cooling [GJ]		Heating [GJ]		Total [GJ]	
1	no	no	56.69		59.82		9.04		125.55	
2	yes	no	36.84	-35%	55.79	-7%	10.39	15%	103.02	-18%
3	yes	yes	33.34	-41%	49.98	-16%	11.88	31%	95.20	-24%
4	yes	yes, only summer	33.34	-41%	51.08	-15%	9.27	3%	93.69	-25%
5	yes	yes, 4 states (BCVTB)	33.34	-41%	52.89	-12%	10.72	19%	96.95	-23%

Baltimore, MD

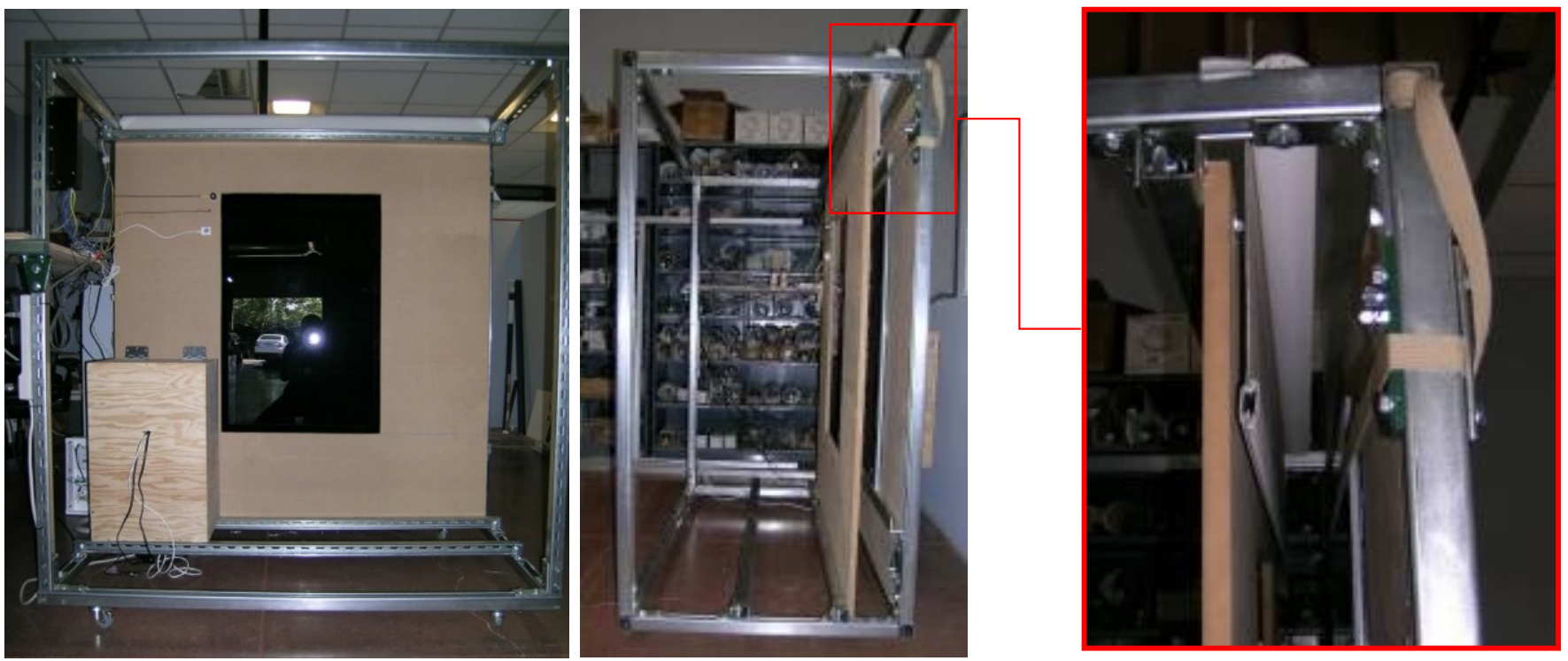
#	Lighting Controls?	Fenestration Controls?	Lighting [GJ]		Cooling [GJ]		Heating [GJ]		Total [GJ]	
1	no	no	56.69		19.79		44.40		120.88	
2	yes	no	35.29	-38%	17.40	-12%	50.90	15%	103.59	-14%
3	yes	yes	33.85	-40%	14.74	-26%	58.16	31%	106.75	-12%
4	yes	yes, only summer	33.85	-40%	15.25	-23%	46.59	5%	95.69	-21%
5	yes	yes, 4 states (BCVTB)	34.32	-39%	15.45	-22%	53.23	20%	103.00	-15%

Minneapolis, MN

#	Lighting Controls?	Fenestration Controls?	Lighting [GJ]		Cooling [GJ]		Heating [GJ]		Total [GJ]	
1	no	no	56.69		12.28		97.07		166.04	
2	yes	no	35.59	-37%	11.03	-10%	106.59	10%	153.21	-8%
3	yes	yes	34.04	-40%	8.71	-29%	117.82	21%	160.57	-3%
4	yes	yes, only summer	34.04	-40%	9.65	-21%	100.14	3%	143.83	-13%
5	yes	yes, 4 states (BCVTB)	37.32	-34%	9.54	-22%	102.02	5%	148.88	-10%

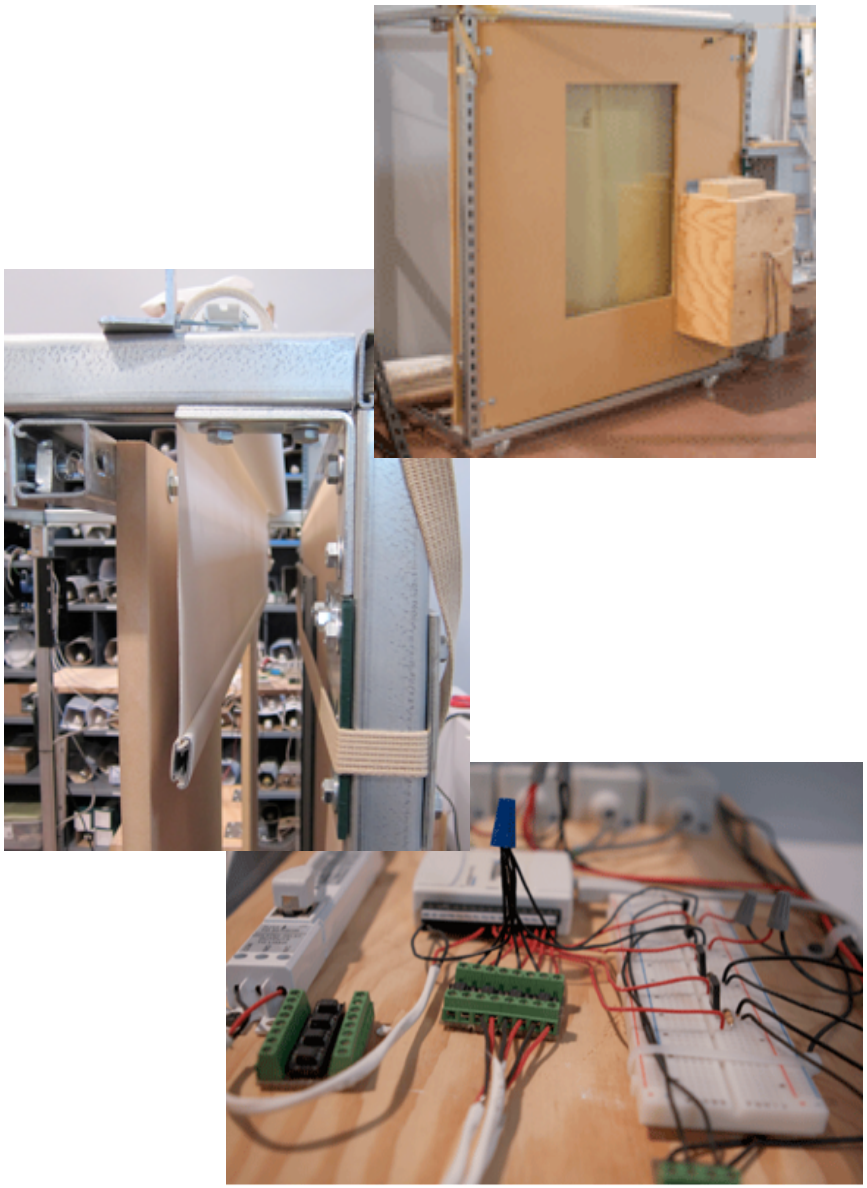
Smart Windows & Skylights

- **Multi-sensor-based automated controls**
  - Occupancy, light, air temperature, wind, etc., in/out
- **Multiple performance aspects**
  - Luminous, thermal, ventilation, view, safety, etc.



Current Laboratory Prototype Work

- **Development of control algorithms**
  - LabView
- **Three dynamic components**
  - Electrochromic glazing
  - Retractable perforated shades
  - Retractable films
- **Five sensors**
  - Indoor occupancy
  - Indoor & outdoor light
  - Indoor & outdoor temperature



Ultra Smart Luminaires, Windows & Skylights

- Integrated sensors (occupancy, light, temperature, …)
- Integrated communications (DR & sensor-based controls)
- Ultra Smart Luminaires
  - Automatic adjustment of electric light CPD & SPD
  - Based on Occupancy, Daylight, DR & Manual(!) signals
- Ultra Smart Windows & Skylights
  - Automatic Adjustment of Daylight CPD SPD & Ventilation
  - Based on Occupancy, Electric Lighting, HVAC & Manual(!) signals

Integrated Control Strategy

- During **Occupancy** Focus on **Comfort**
  - Adjust fenestration for maximum daylight penetration
  - Adjust electric lighting for daylight contribution
  - Adjust HVAC
- During **Vacancy** Focus on **Energy Efficiency**
  - Adjust fenestration for cooling/heating loads
  - Turn electric lighting off or dim down
  - Adjust HVAC

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Thank You!

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