CLTC
CALIFORNIA LIGHTING TECHNOLOGY CENTER

UCDAVIS
UNIVERSITY OF CALIFORNIA

BEST
Building Efficiency for a Sustainable Tomorrow

Visit at UC Davis

January 7, 2016

Energy Efficient Lighting & Daylighting

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Co-Director, California Lighting Technology Center
University of California, Davis

RESEARCH **INNOVATION** **PARTNERSHIP**

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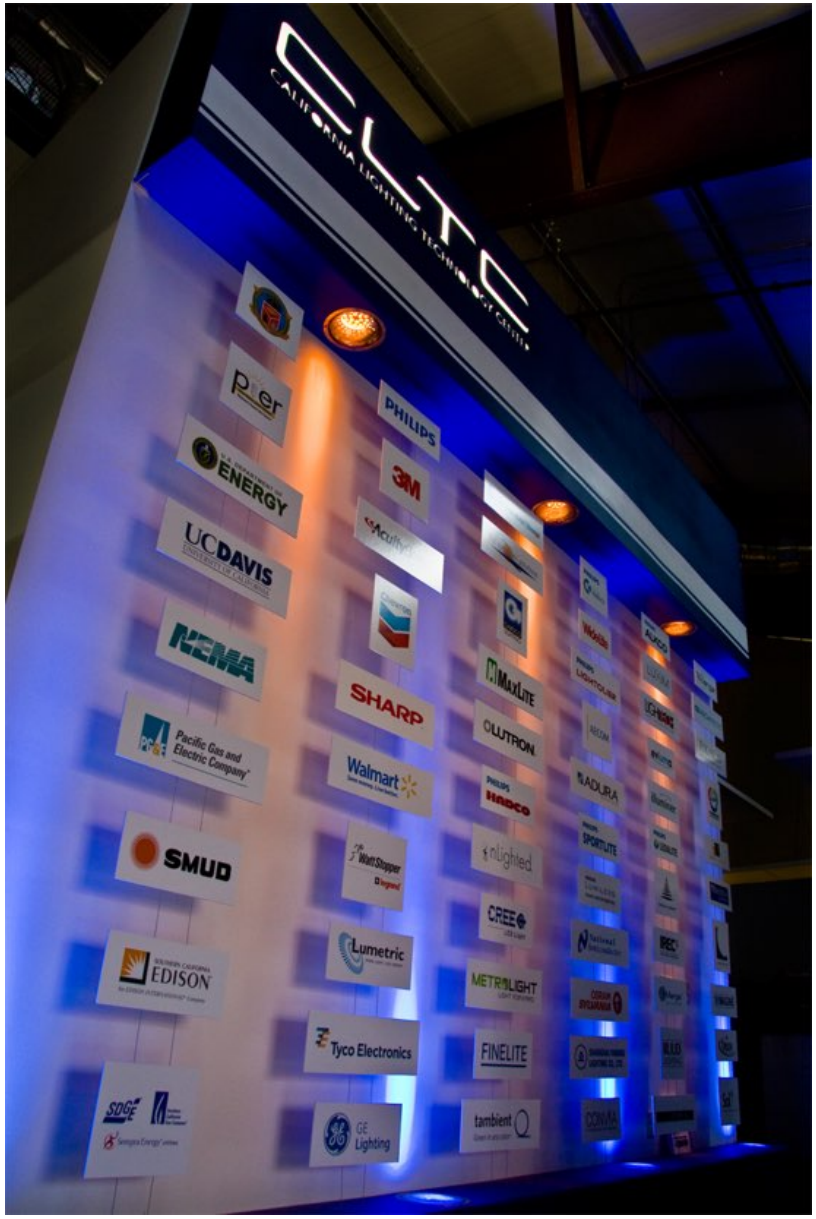
Presentation Outline

- **About CLTC**
- **CA Driving Forces for Energy Efficiency**
  - Energy Codes vs. Best Practices
- **Fundamental Lighting Design Strategy**
  - **S**pectral **P**ower **D**istribution
  - **C**andle **P**ower **D**istribution
  - **Controls**
    - Lighting
    - Daylighting
    - Integrated controls
- **Smart Luminaires, Windows & Skylights**

CLTC Establishment (2002 - 2003)



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University of California, Davis

pier
PUBLIC INTEREST ENERGY RESEARCH
"Research Powers the Future"

California Energy Commission

NEMA

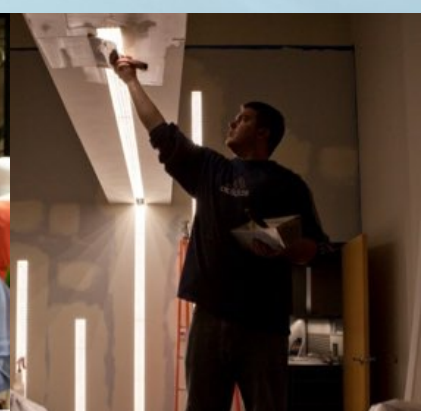
National Electrical Manufacturers Association

US Department of Energy

CLTC Mission & Activities

- **To stimulate, facilitate & accelerate the development, application & commercialization of energy-efficient lighting and daylighting technologies.**
- **Mission-driven Activities**
  - Research & Development
  - Field Testing & Demonstration
  - Outreach, Education & Training
- **In partnership with utilities, manufacturers, end users, builders, designers, researchers, academicians, and governmental agencies**



FOUNDING ORGANIZATIONS

UC DAVIS UNIVERSITY OF CALIFORNIA

pier PUBLIC INTEREST ENERGY RESEARCH "Research Powers the Future"

NEMA

CLTC CALIFORNIA LIGHTING TECHNOLOGY CENTER

UTILITIES

Pacific Gas and Electric Company

Southern California Edison An EDISON INTERNATIONAL Company

SDGE Sempra Energy utilities

SMUD

LA DWP Los Angeles Department of Water & Power

City of Roseville California Roseville Electric

Silicon Valley Power City of Santa Clara

BC hydro

MANUFACTURERS

AcuityBrands

full spectrum solutions

KONICA MINOLTA

OSRAM SYLVANIA

SORAA Simply Perfect Light

Chevron

EVERLAST LIGHTING

LEOTEK LITE-ON GROUP

PHILIPS

SWITCH

COOPER Lighting

GE Lighting

lumenetix

PRIDE INDUSTRIES

Universal Lighting Technologies

CREE

HONDA The Power of Dreams

LUNERA

QUALCOMM

VELUX Skylights

enlighted

INTERMATIC Providing a brighter solution.

LUTRON

Rambus Bringing invention to market

eMerge ALLIANCE

JADE SKY TECHNOLOGIES

LUXIM

sensity

VENTURE

FINELITE

KENALL

Microsoft

SHARP

WattStopper

LARGE END-USERS

DGS Department of General Services BUILDING GREEN · BUYING GREEN · WORKING GREEN

The University of California 1868

CSU The California State University WORKING FOR CALIFORNIA

LACCD

National Park Service

Forest Service US Department of Agriculture

Walmart Save money. Live better.

California Global Warming Solutions Act (AB 32)

Air Resource Board (ARB)

Signed 2006

Reduce **greenhouse gas emissions** **to 1990** levels by **2020**

- **12% reduction *from current* emissions levels**
- **30% reduction *from projected* business-as-usual levels**
- **Annual reduction of 4 tons of CO_2 per capita**
  - From 14 tons to 10 tons by 2020

Huffman Bill (AB 1109)

Signed 2007

Reduce average statewide lighting energy consumption by 2018

- **Indoor Residential Lighting**

  not less than **50%** from the 2007 levels

- **Indoor Commercial Lighting**

  not less than **25%** from the 2007 levels

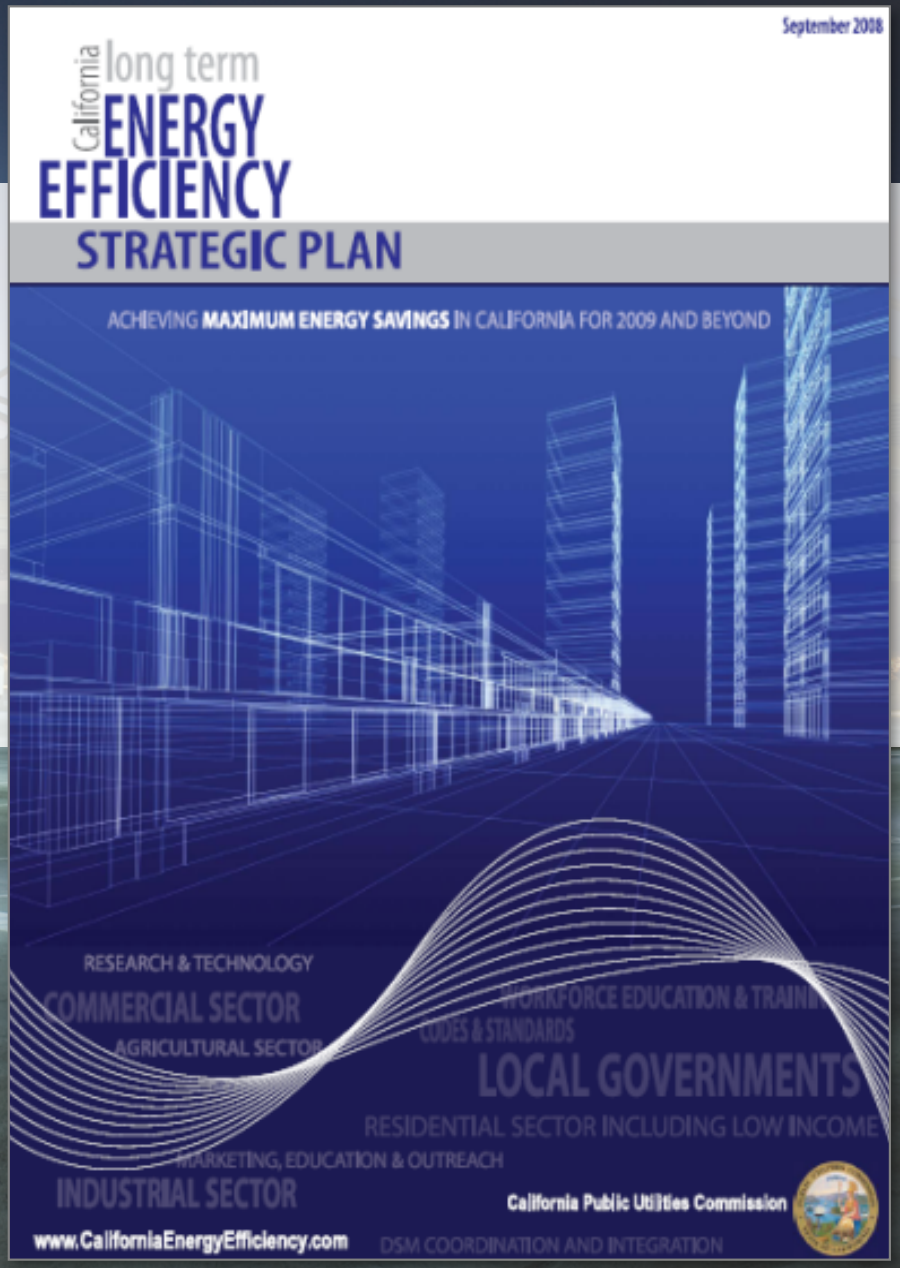
- **Outdoor Lighting**

  not less than **25%** from the 2007 levels

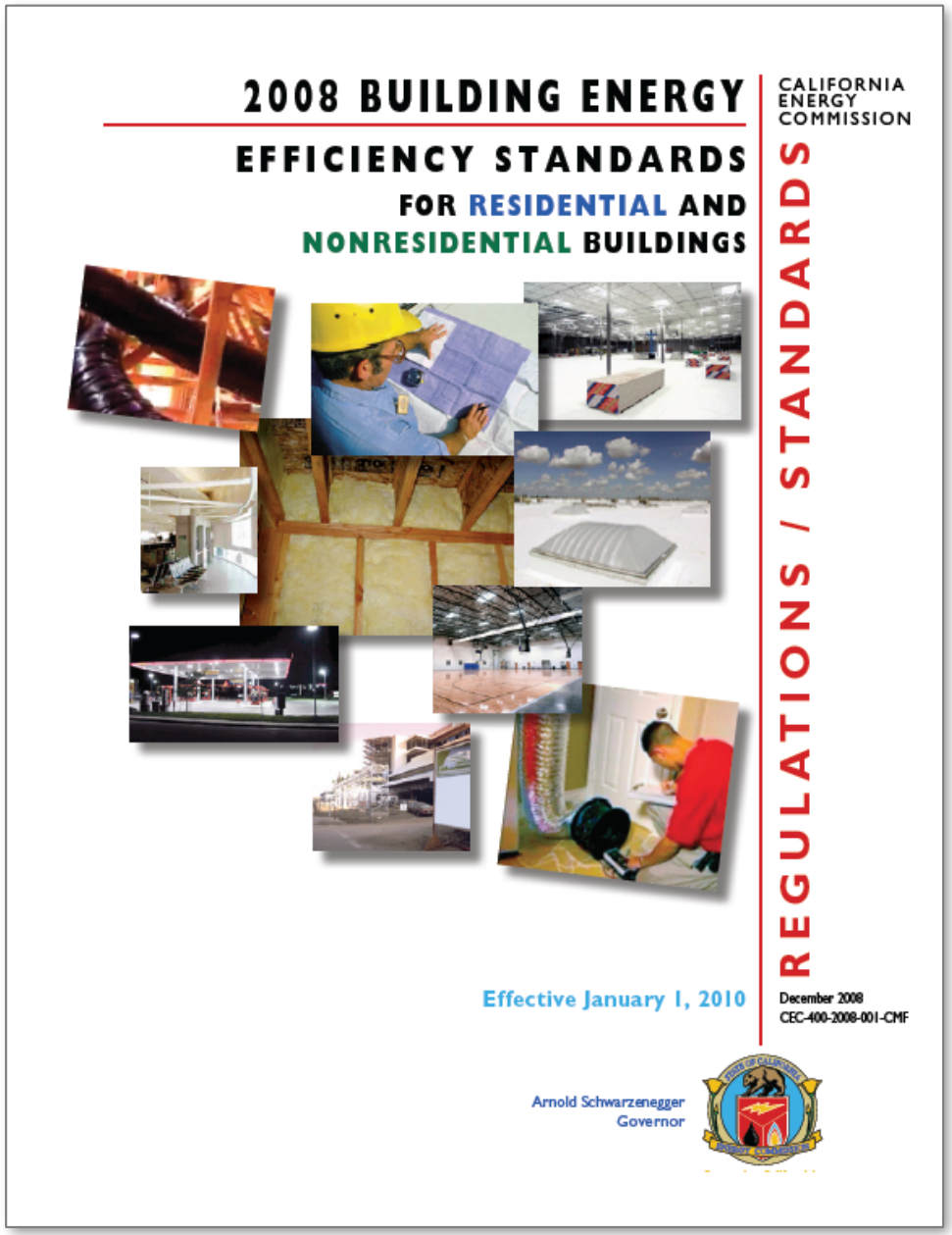
California's Strategic Lighting Plan

September 23, 2012

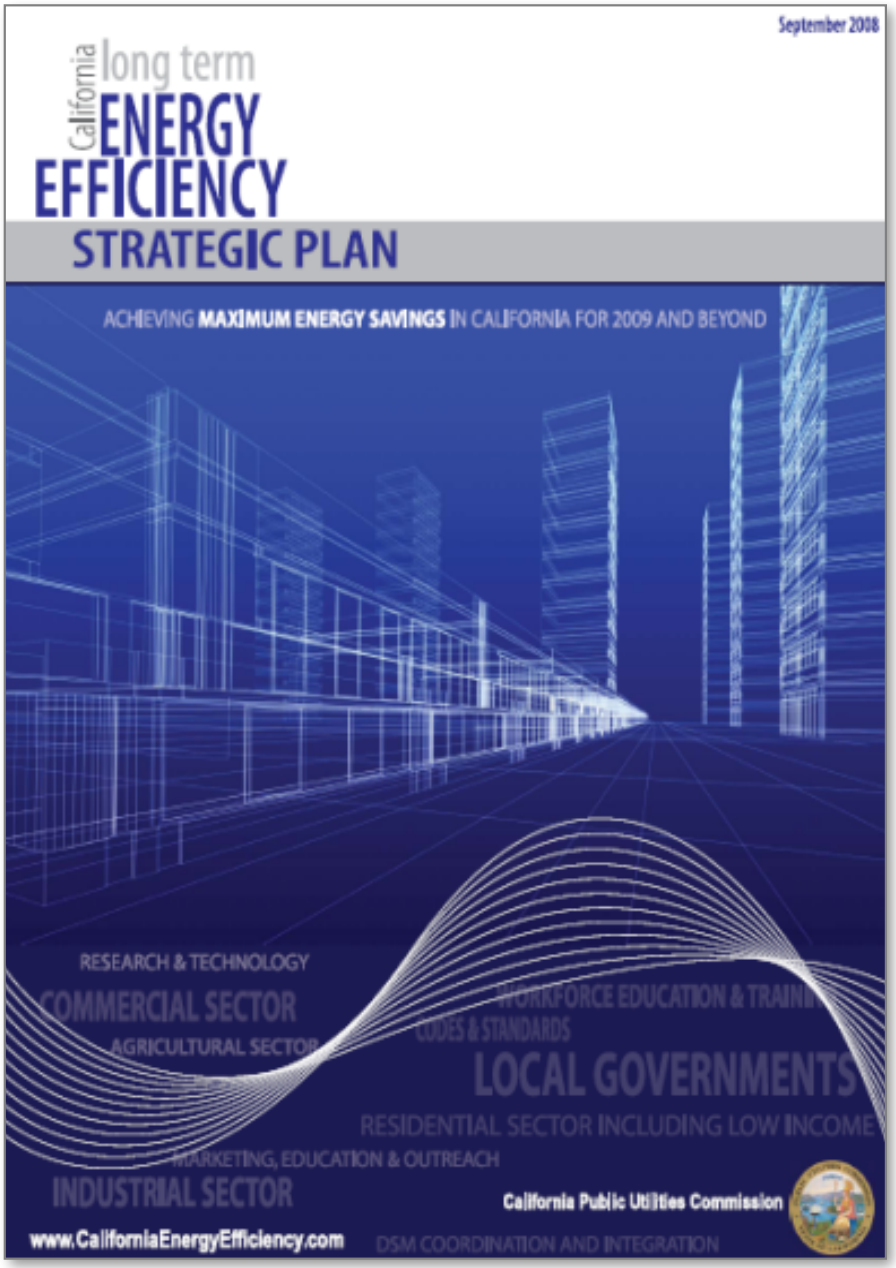
60–80% statewide reduction in electrical lighting energy consumption by 2020



Standard Practice…



Best Practice!



CALGreen Code

Assembly Bill introduced on February 2, 2009

Zero Net Energy (ZNE) standards for buildings starting in 2020

Effective January 2011

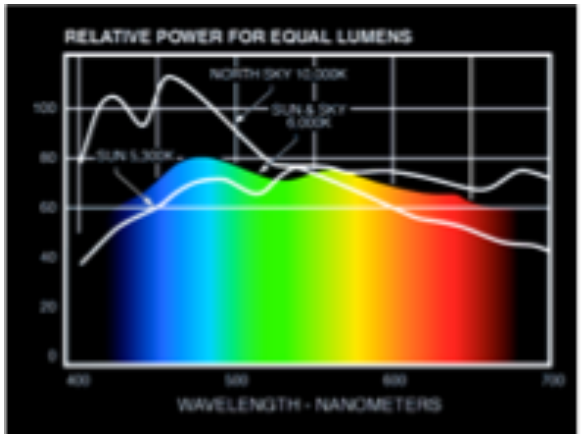
The Fundamental Lighting Design Strategy

Right Light → ***Spectral Power Distribution***

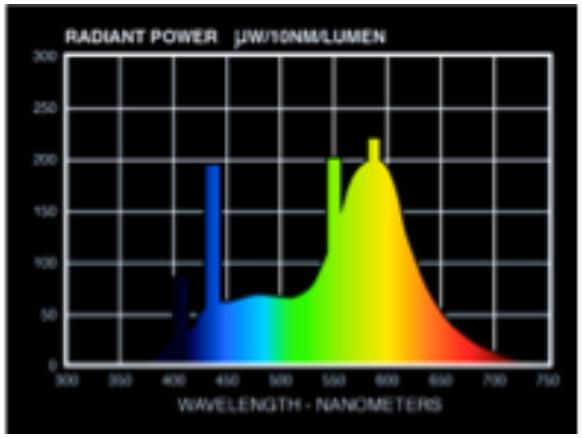
Right Place → ***Candle Power Distribution***

Right Time → ***Environmental Conditions***

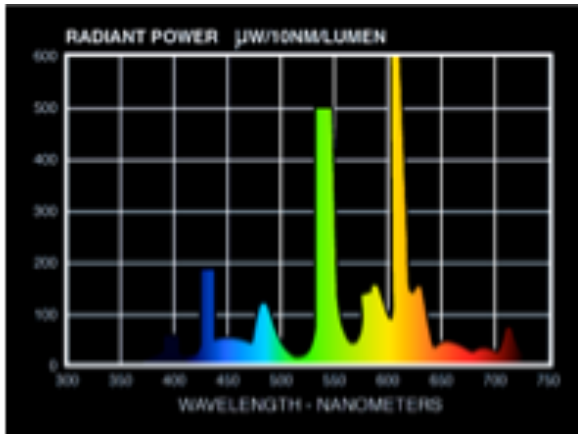
Spectral Power Distributions



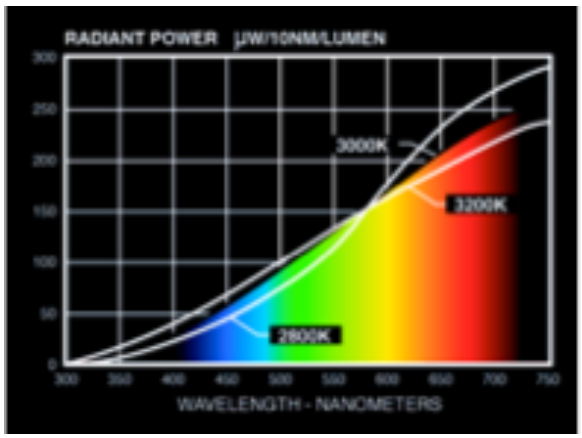
Daylight



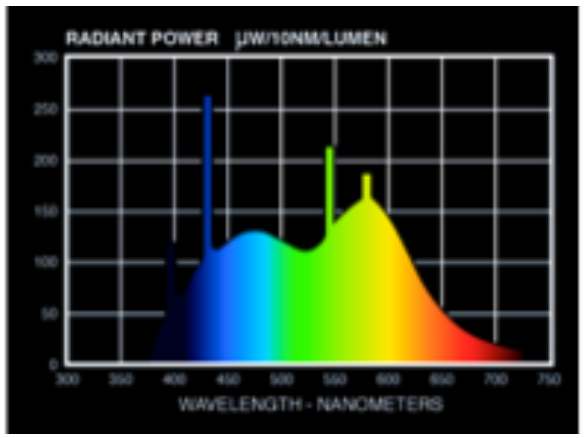
Cool White Fluorescent



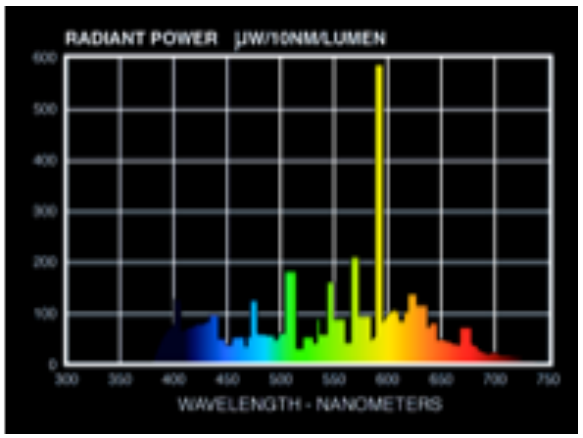
Tri-Phosphor 3500K



Incandescent

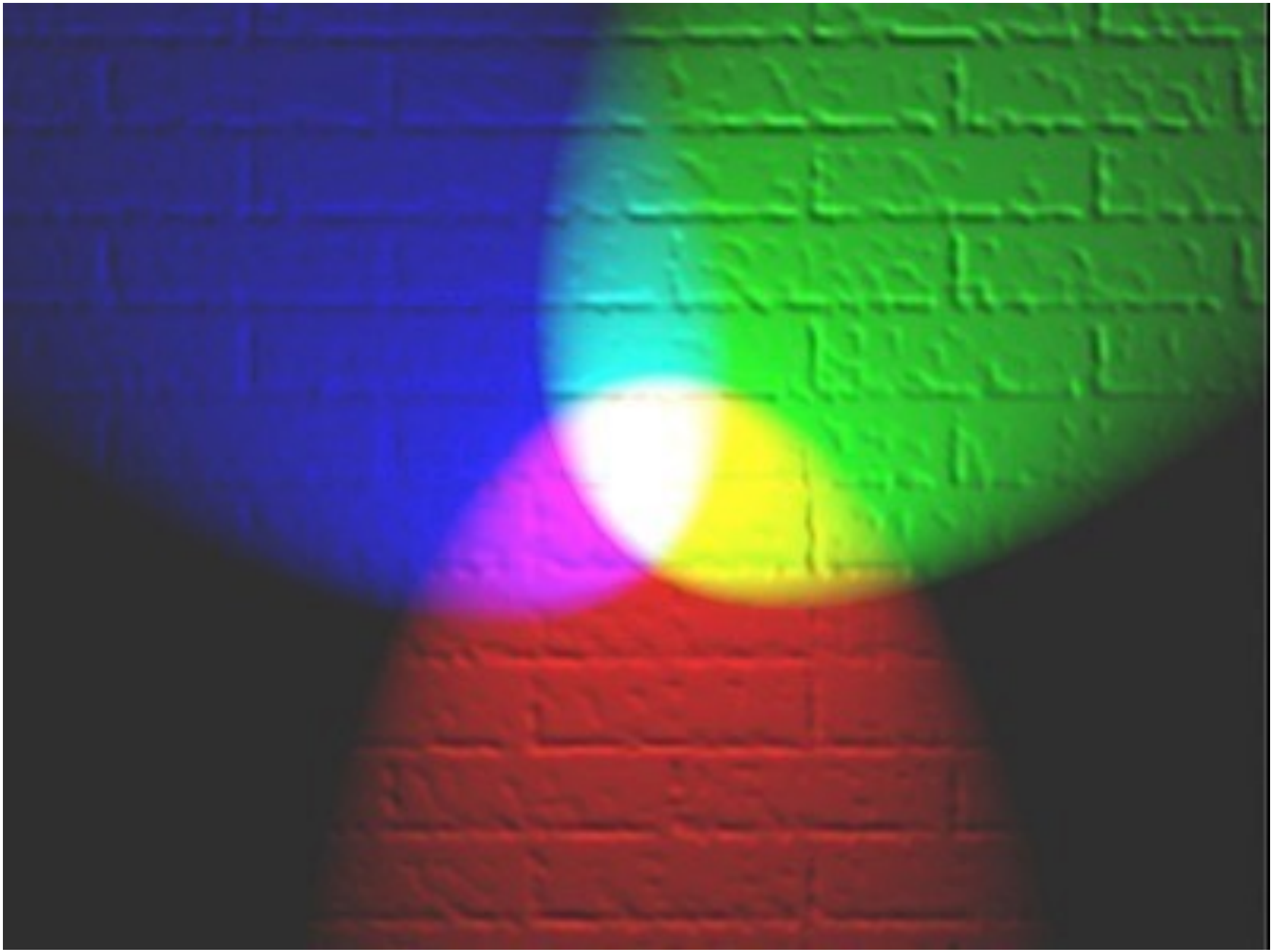


Daylight Fluorescent

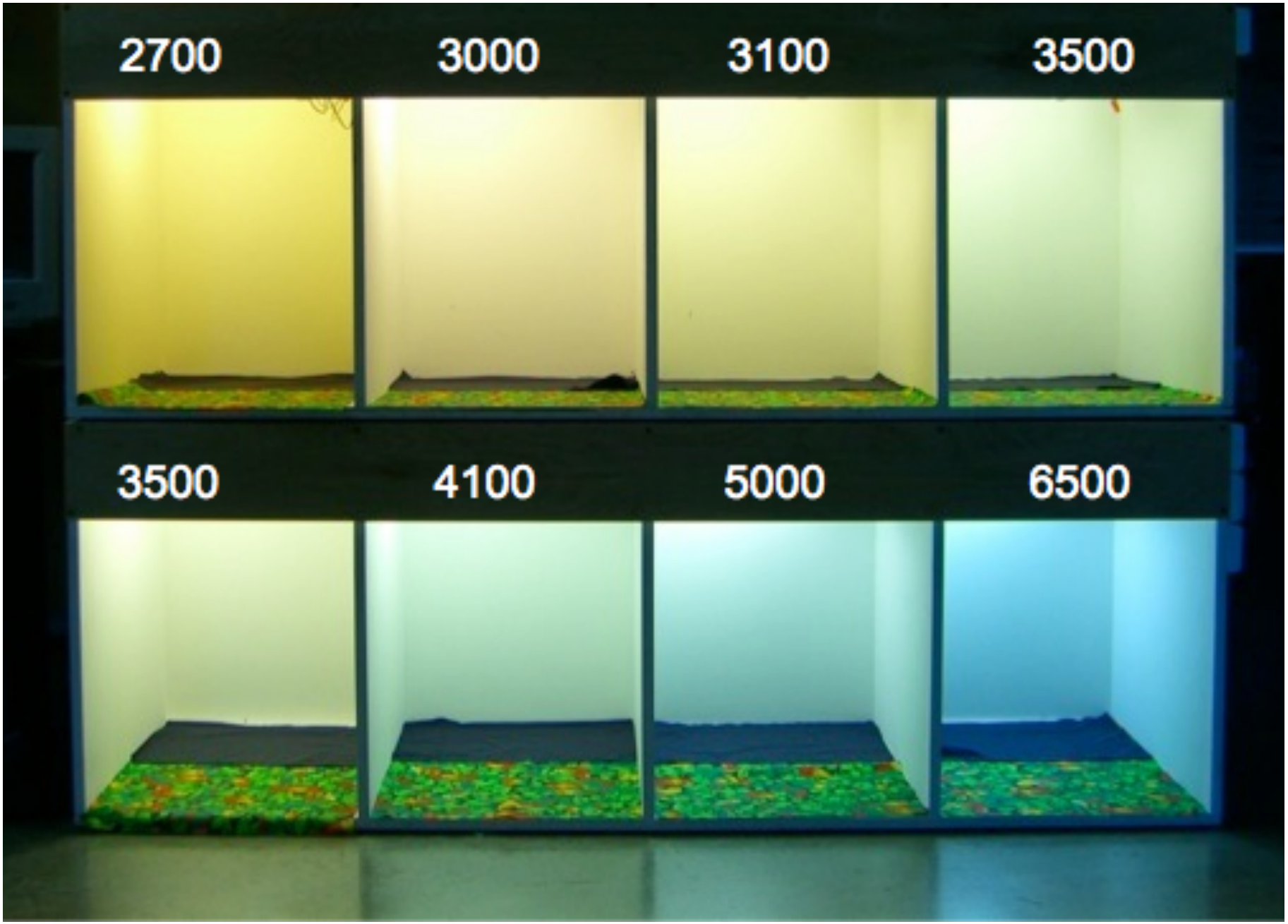


Metal Halide

Perception of White Light

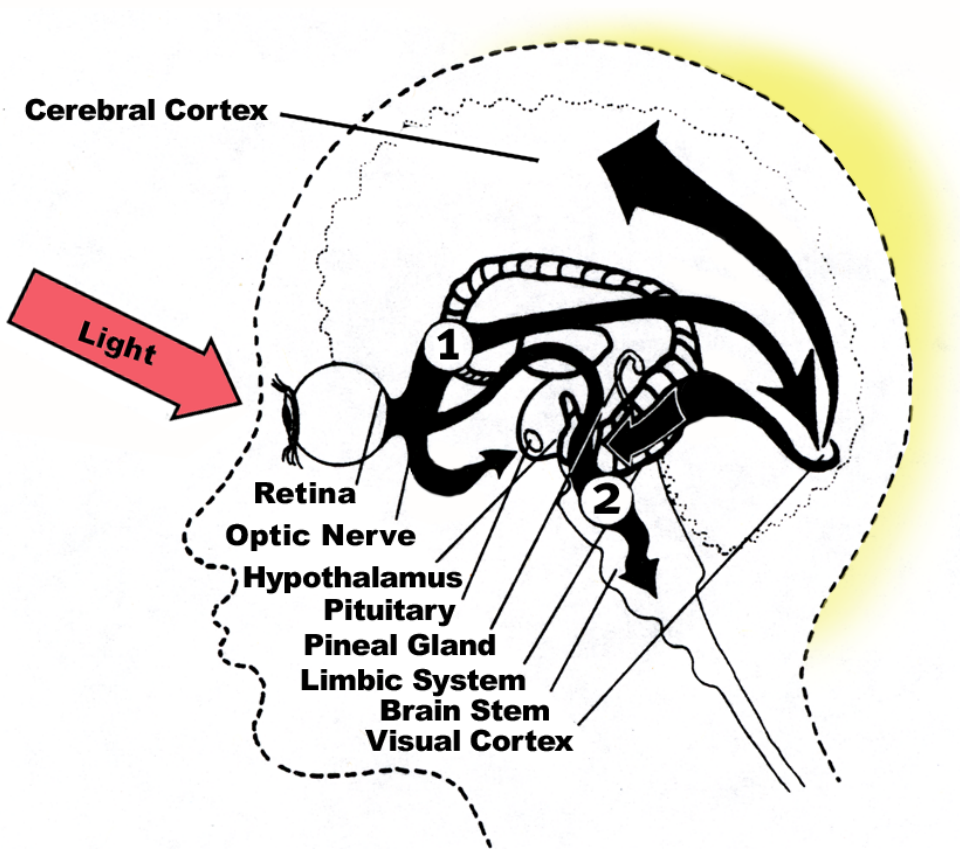


CFL Correlated Color Temperature



Visual & Circadian Pathways

1. **Visual Pathway**
   - Light stimulates the cerebral cortex for vision & perception
2. **Circadian Pathway**
   - Light causes messages along a biological pathway (Hypothalamus, Pituitary, Pineal Gland) that are used to regulate the body's autonomic nervous and endocrine systems



Human Evolution - Sunrise

Human Evolution - Daytime

Human Evolution - Sunset

Evolution - Night

Evolution - Light at Night

Evolution - Light at Night

American Medical Association - June 2012

Light Pollution: Adverse Health Effects of Nighttime Lighting

*Report 4 of the Council on Science and Public Health (A-12) of the **American Medical Association***

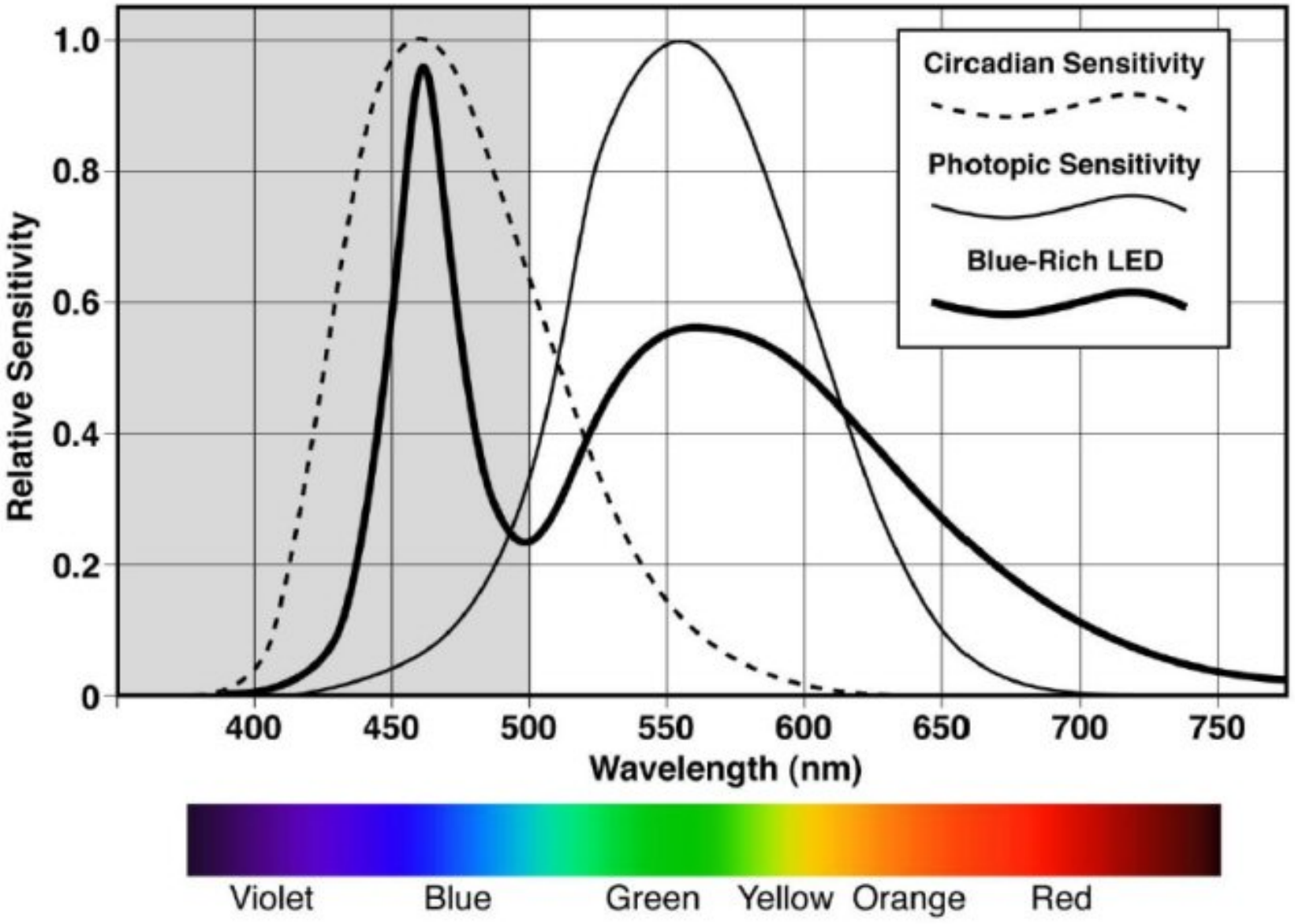
Biological adaptation to the sun has evolved over billions of years.

The **power to artificially override the natural cycle** of light and dark is a **recent event** and represents a **man-made self-experiment on the effects of exposure to increasingly bright light during the night** as human societies acquire technology and expand industry.

Among the latter (health effects) are potential **carcinogenic effects** related to melatonin suppression, especially **breast cancer**. Other diseases that may be exacerbated by circadian disruption include **obesity, diabetes, depression** and **mood disorders**, and **reproductive problems.**

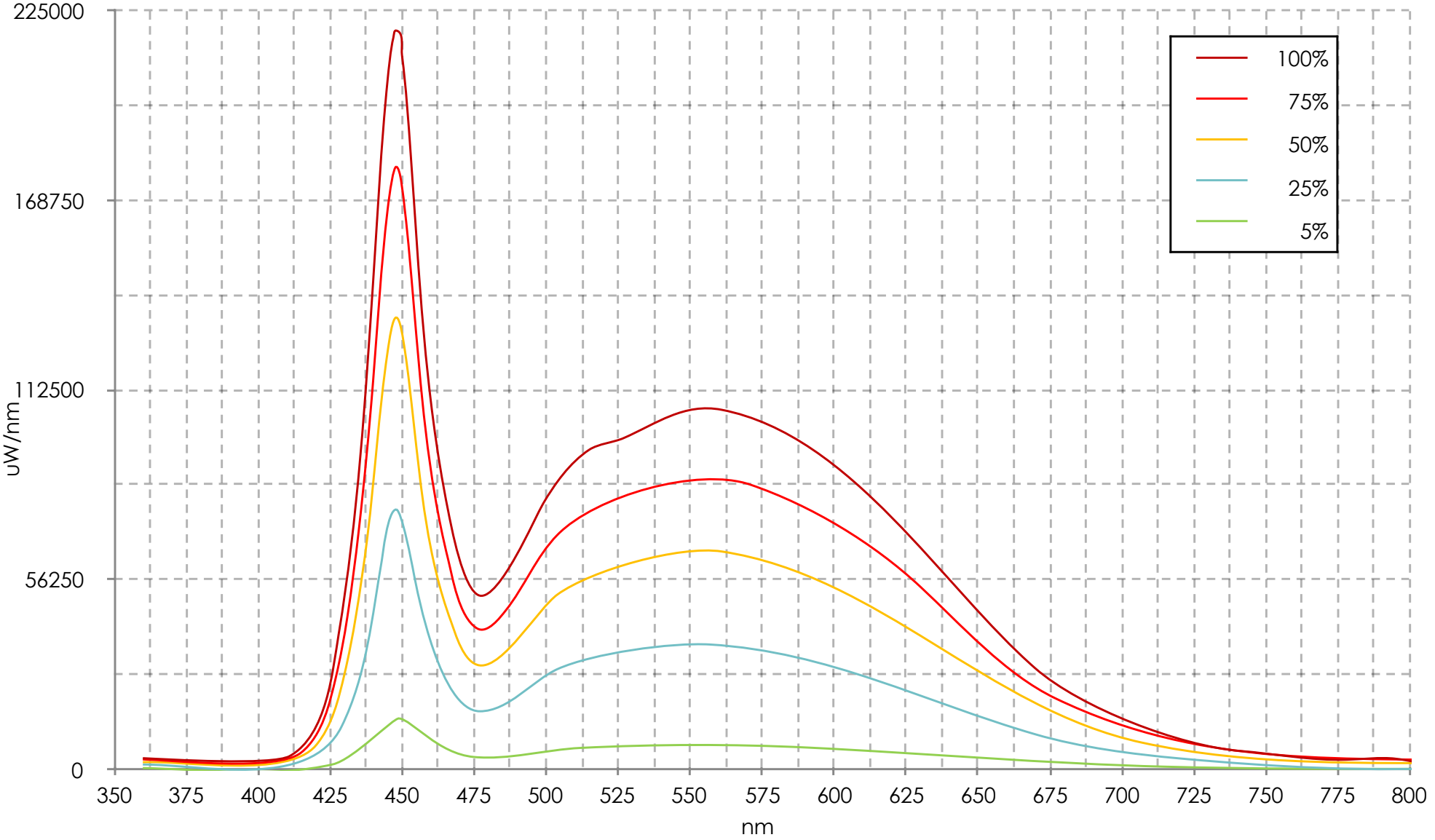
Due to the nearly ubiquitous exposure to light at inappropriate times relative to endogenous circadian rhythms, a need exists for further multidisciplinary research on occupational and environmental exposure to light -at-night, the risk of cancer, and effects on various chronic diseases.

Blue-rich LED & Circadian Sensitivity



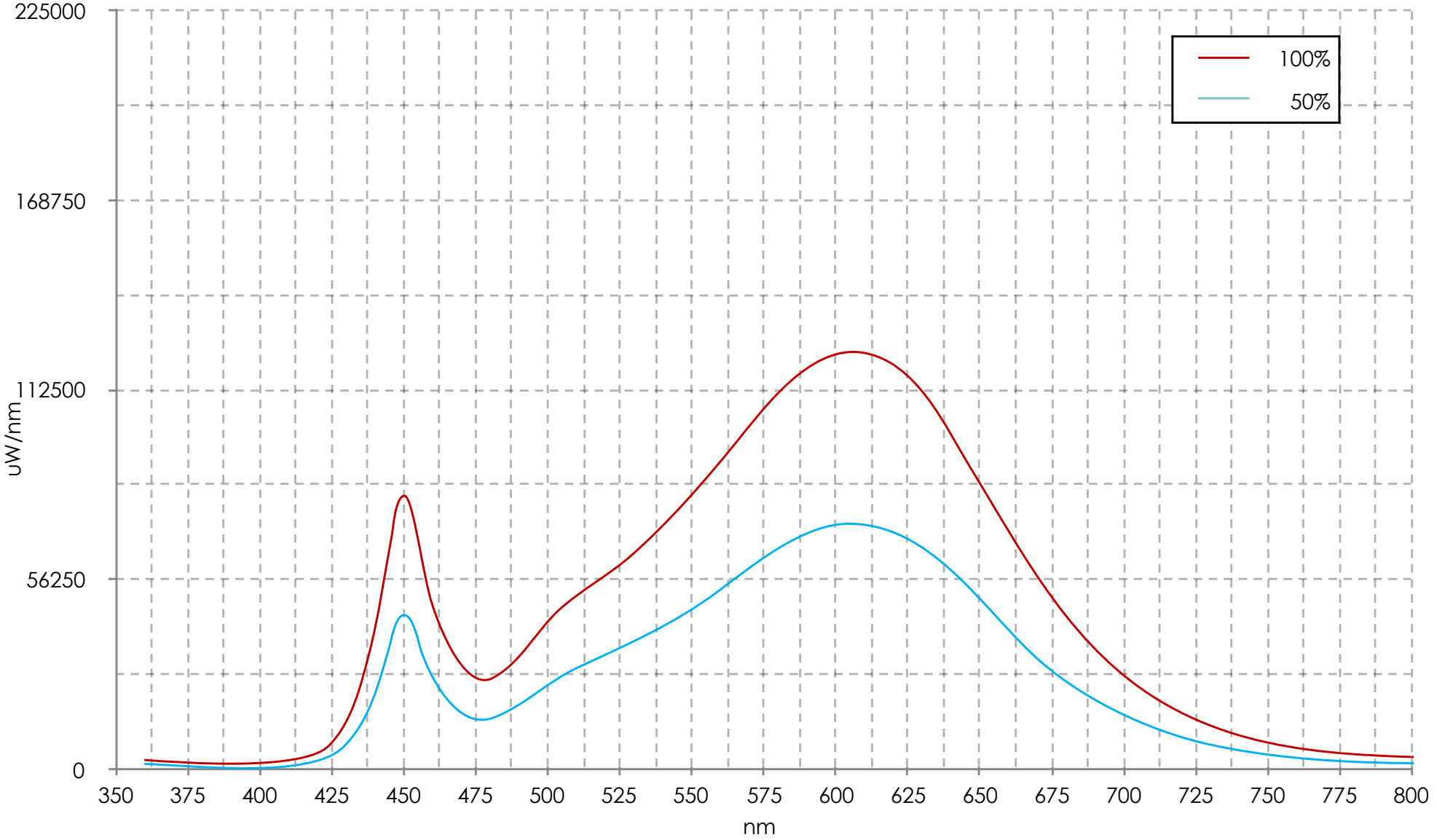
6500K CCT

Spectral Power Distribution



3000K CCT

Spectral Power Distribution



Spectrally Tunable Lighting

Two LED sources dimmed individually…

Low CCT (2,700K)

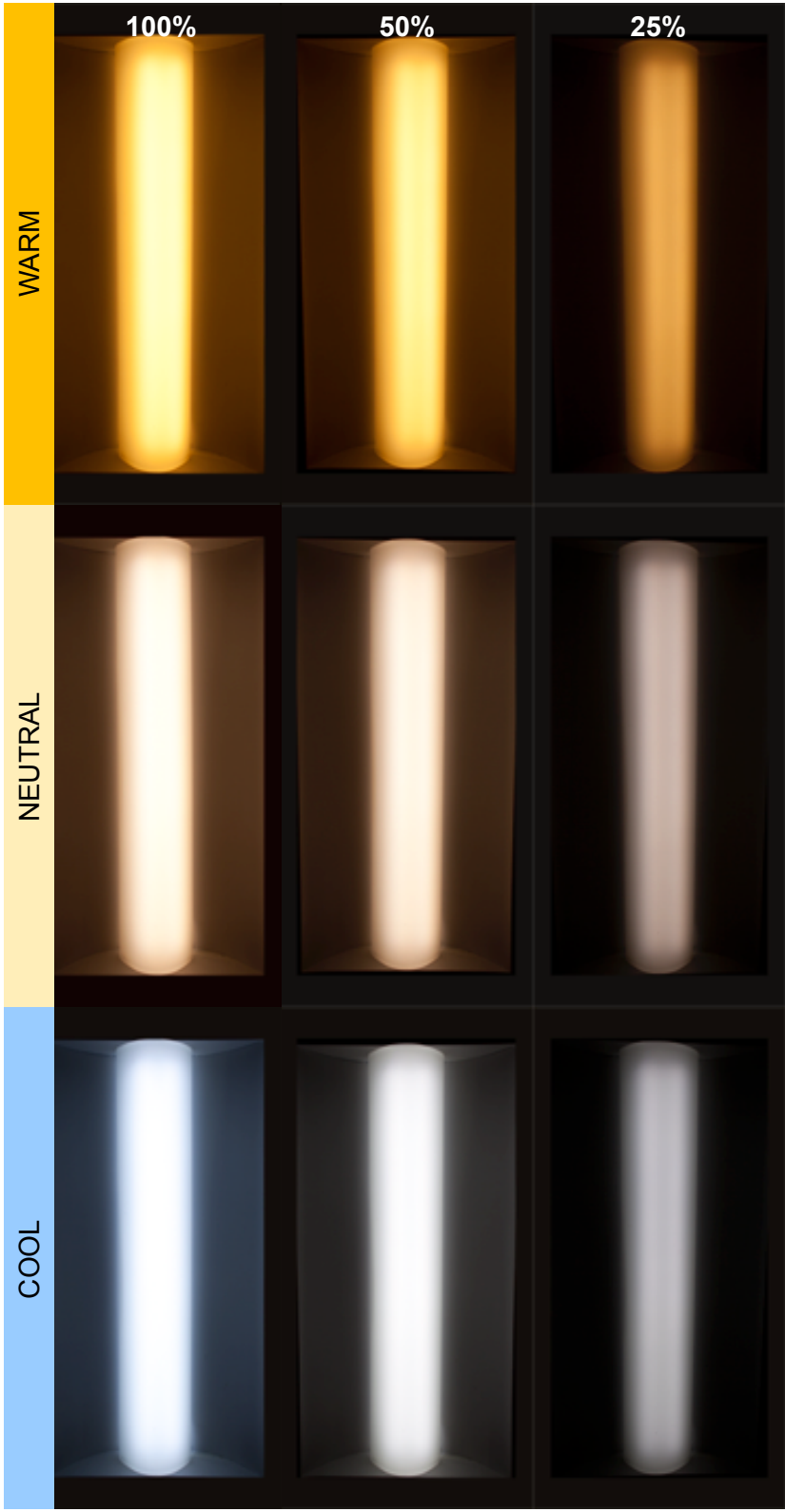
High CCT (6,000K)

…can produce the whole range of CCTs…

From low (2,700K) to high (6,000K)

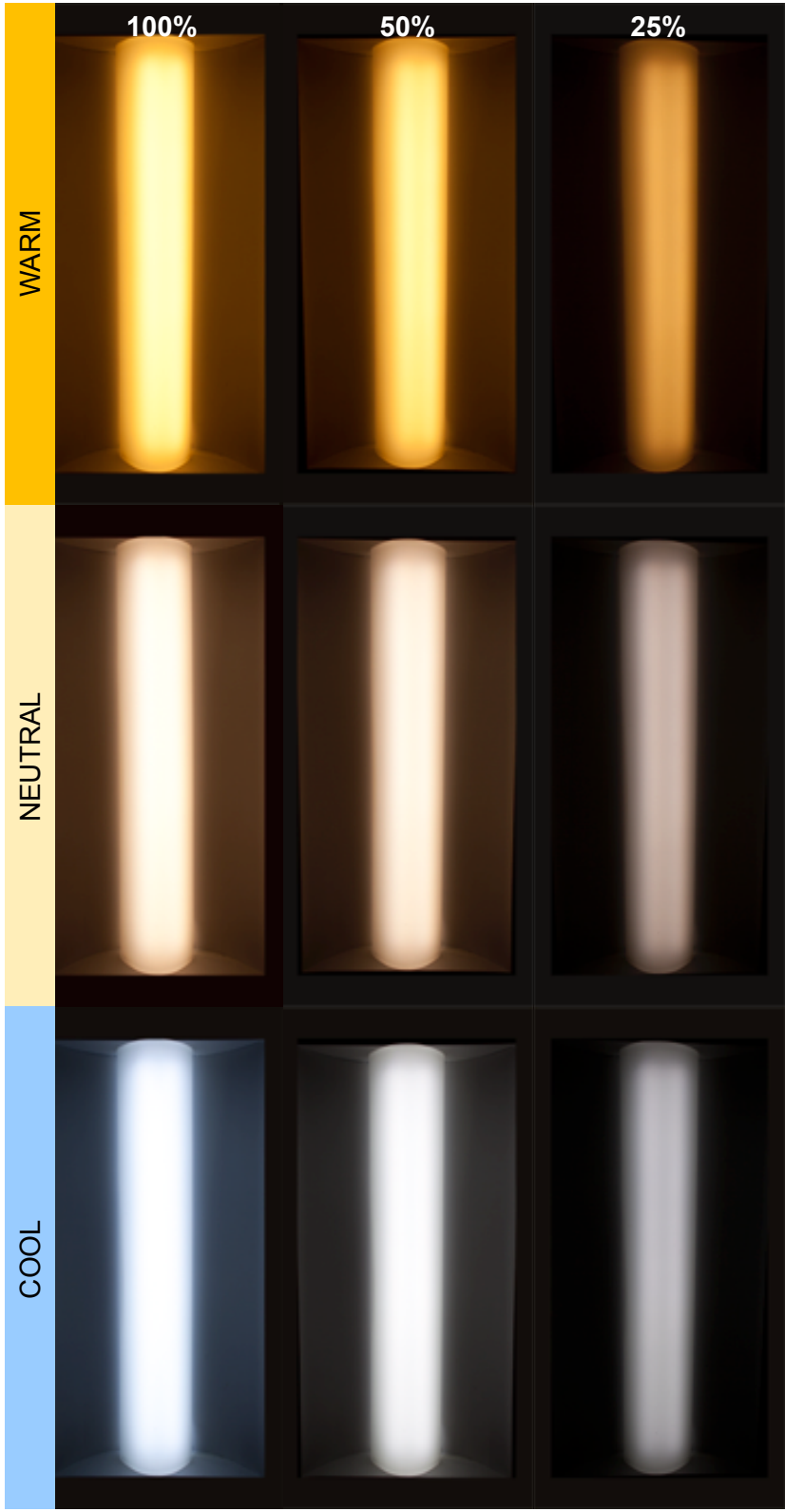
…along the whole dimming range

From 0% to 100% output (50% each)



Spectrally Tunable Lighting

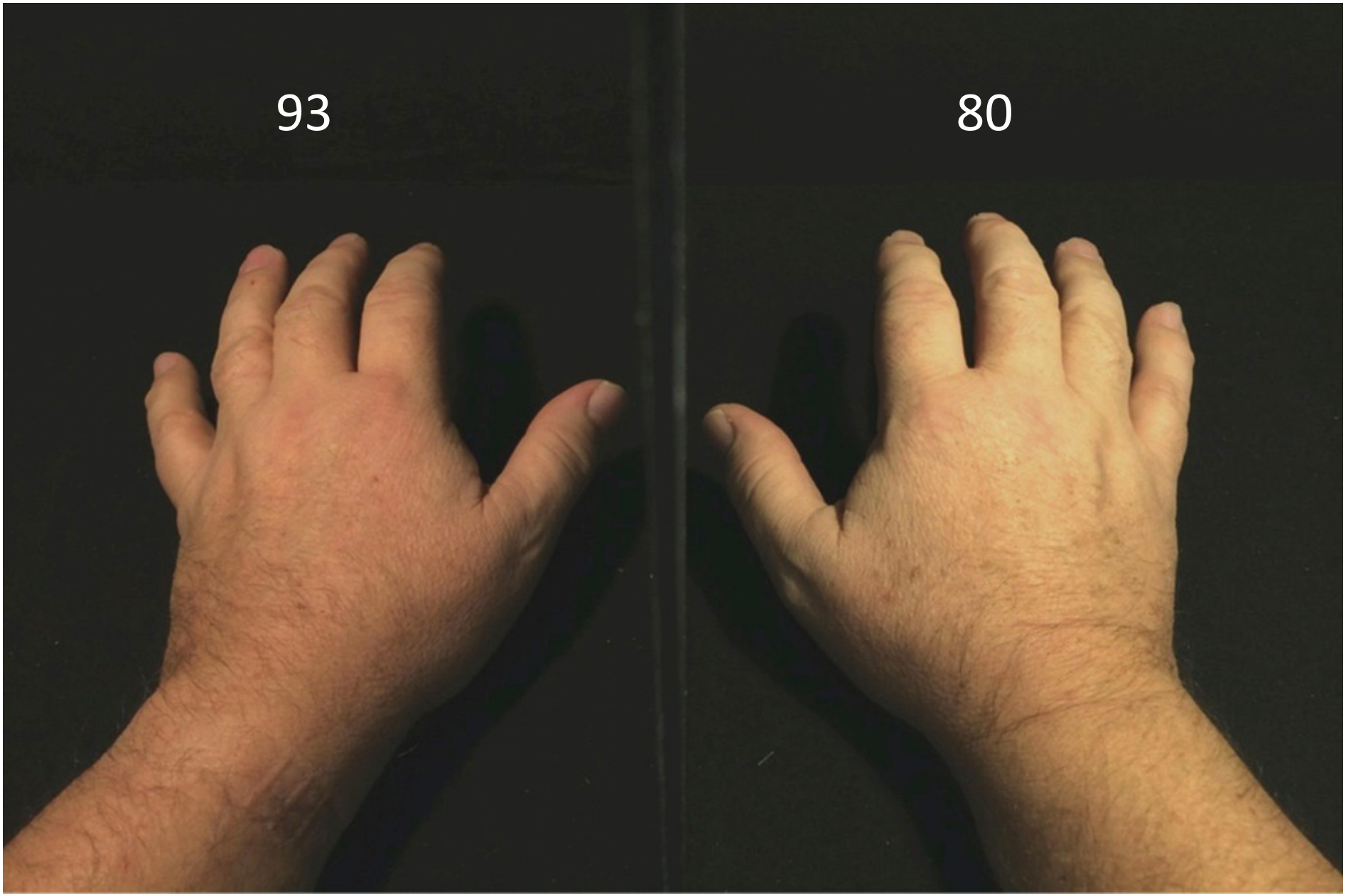
- **Research & Development**
  - Technology
  - Human Factors
- **Multiple Applications**
  - Office spaces
  - Assisted living
  - Hospitals
  - Hotels
  - …



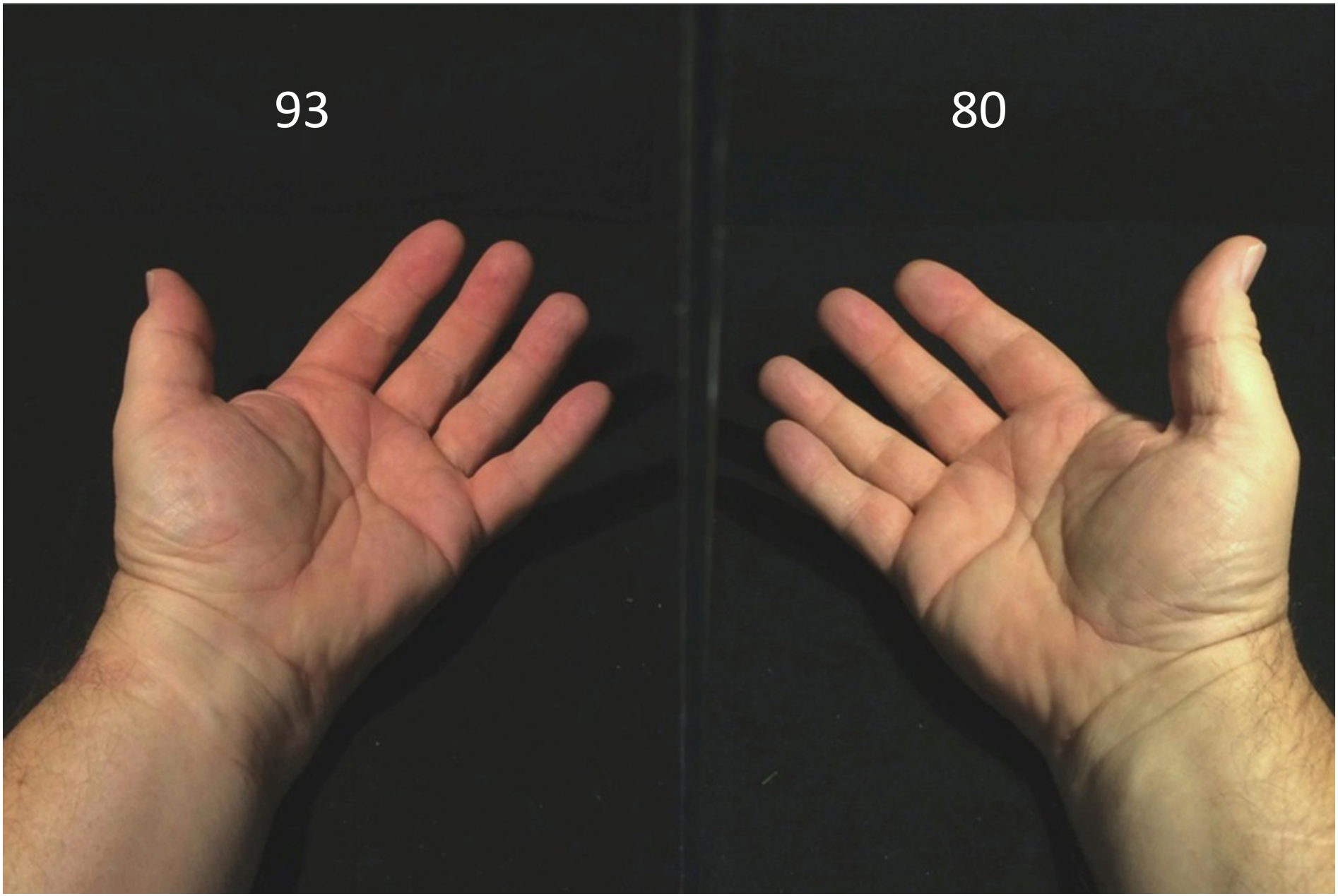
Color Rendering is Most Important!

- **Human vision evolved with full spectrum radiators**
- **“Natural color experience is a basic human right”**
  - Prof. Lorne Whitehead, Ph.D., University of British Columbia
- **CRI measures distortion from what we evolved with**
  - Daylight (high CCT)
  - Incandescent (low CCT)
- **Incandescent & Daylight CRI is 100 (by definition)**
  - 80 CRI (Energy Star) is twice as bad as 90 (CA Quality Spec)

Color Rendering Index

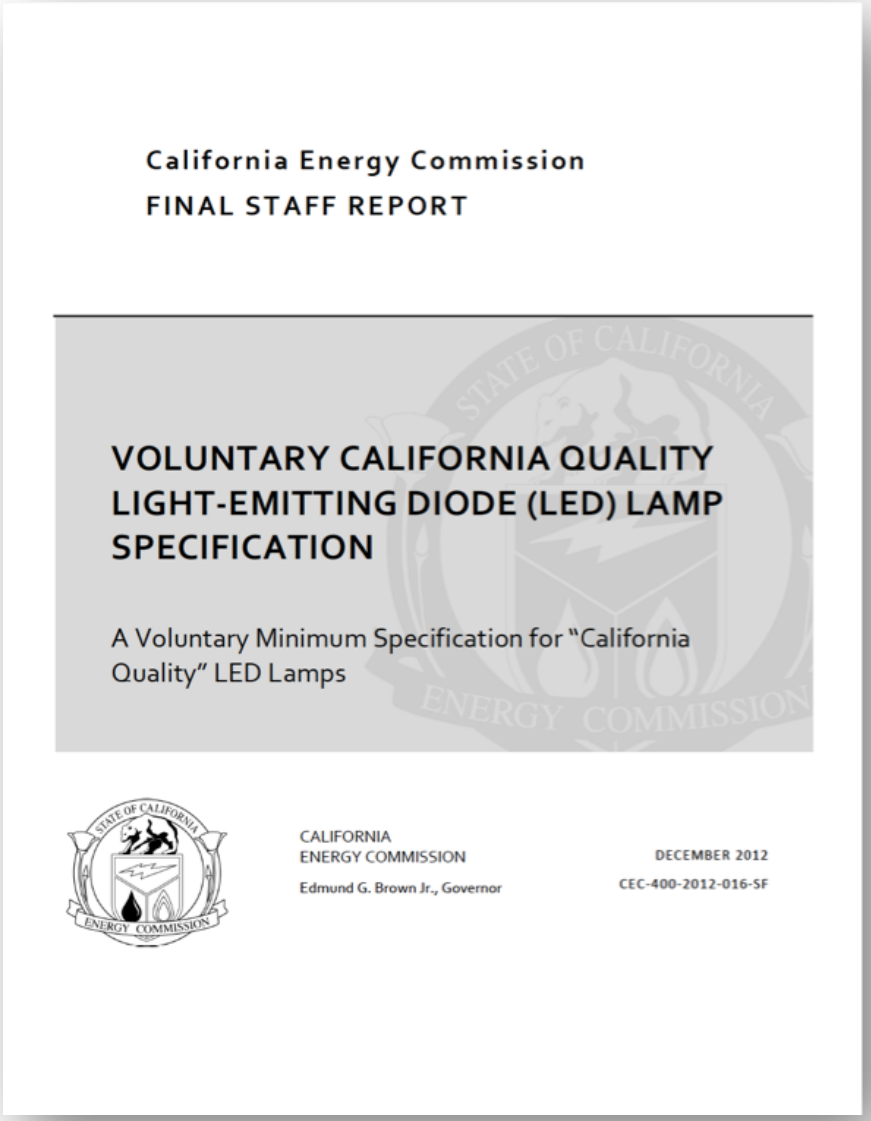


Color Rendering Index



CA LED Lighting Quality Specification

- Energy Star Plus approach
- Quality focused
- Attached to rebates

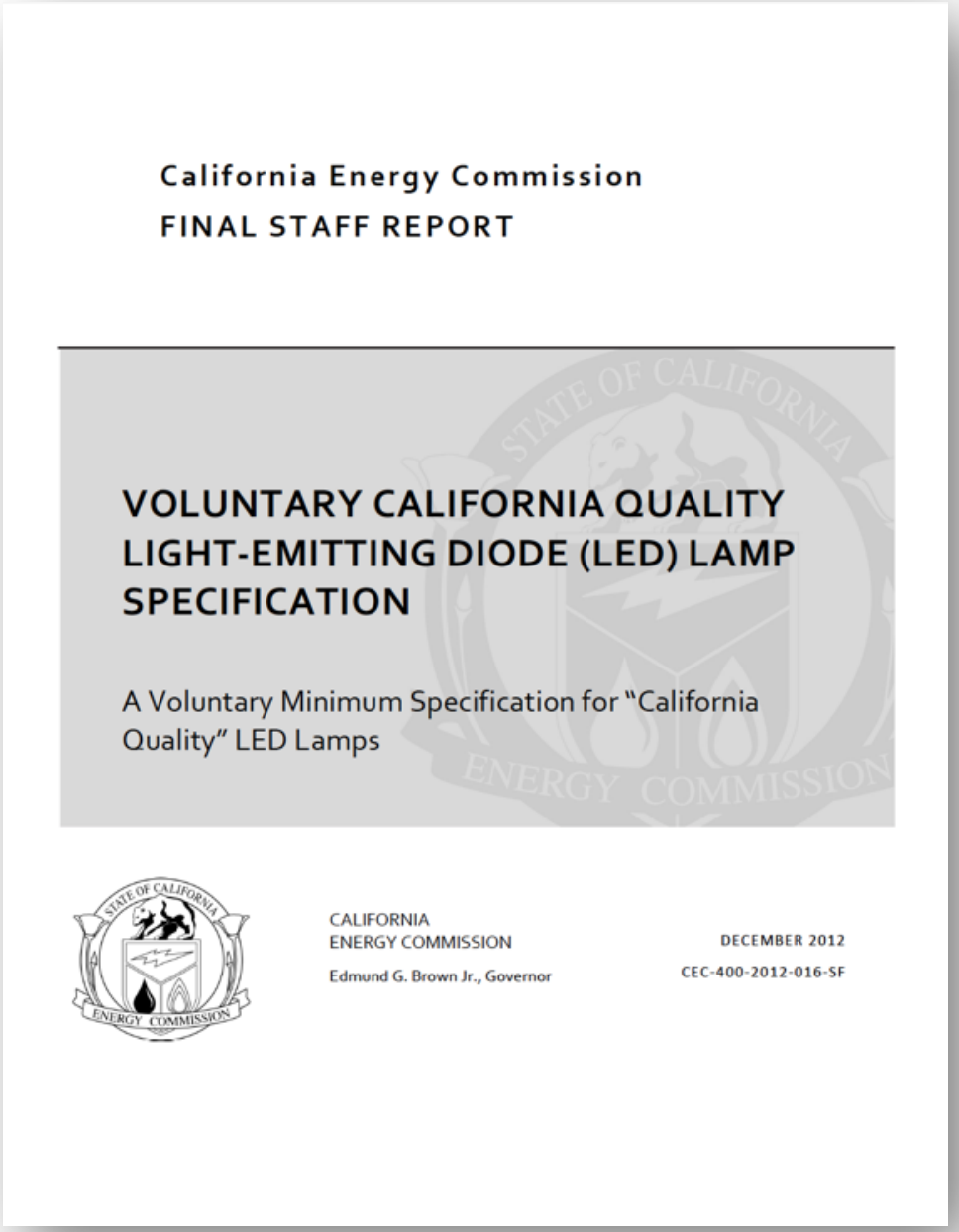


CA LED Lighting Quality Specification

- **Light Output Characteristics**
  - CCT
  - CRI
  - Consistency
  - Candlepower
- **Operational Characteristics**
  - Dimming
  - Flicker
  - Noise
  - Longevity

CA Lighting Quality Standard

- "Energy Star Plus"
- Quality focused
- Attached to rebates



CA Lighting Quality Standard

- **Light Output Characteristics**
  - CCT
  - CRI
  - Consistency
  - Candlepower
- **Operational Characteristics**
  - Dimming
  - Flicker
  - Longevity
  - …

The Fundamental Lighting Design Strategy

Right Light → ***Spectral Power Distribution***

Right Place → ***Candle Power Distribution***

Right Time → ***Environmental Conditions***

Adaptive Lighting is Automated Implementation

Adaptive (a.k.a. Smart) 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 (CPD) - *total & directional output*
  - 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 & Wellbeing
  - Minimize Energy Requirements
  - Minimize Peak Electricity Demand
  - …

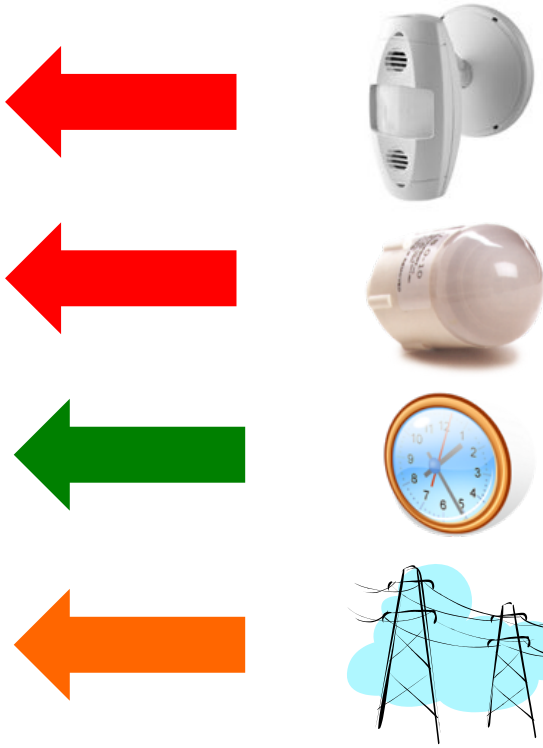
Adaptive Outdoor Lighting – Circa 2005

- **Two light sources** - LED (2W) & CFL
- **One Photo sensor** - Both light sources off during daytime
- **One Occupancy sensor** - LED on during vacancy & CFL on during occupancy

Key Electric Lighting Control Strategies

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

Automated Controls



Key Challenge

What Is Happening

Easy

What To Do

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
  - …

Energy Savings Opportunity

Energy Savings Opportunity

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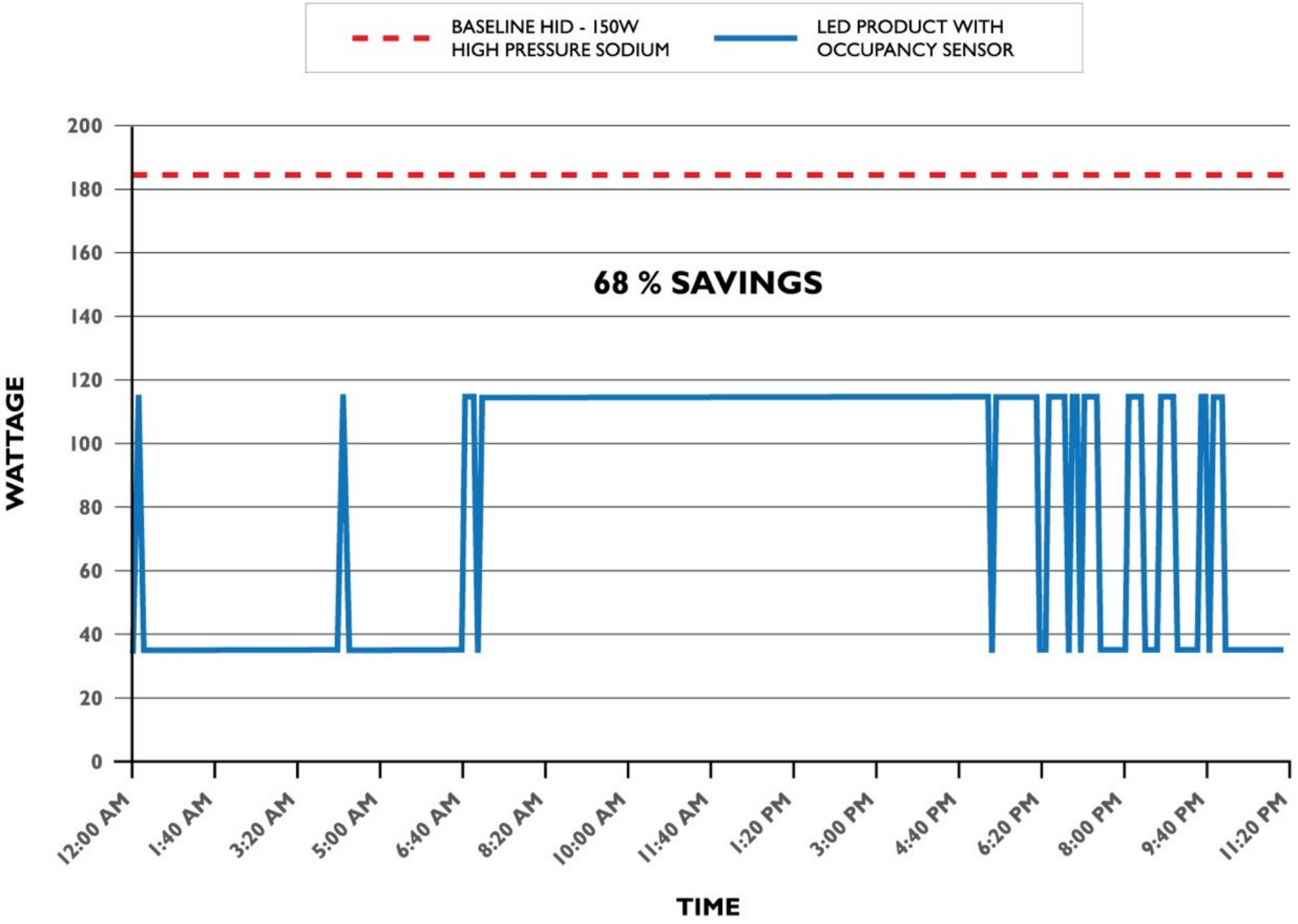
Energy Savings Opportunity

Occupancy-based bi-level parking lighting

one of our largest outdoor opportunities for energy savings

Occupancy-based Bi-level Parking Lighting

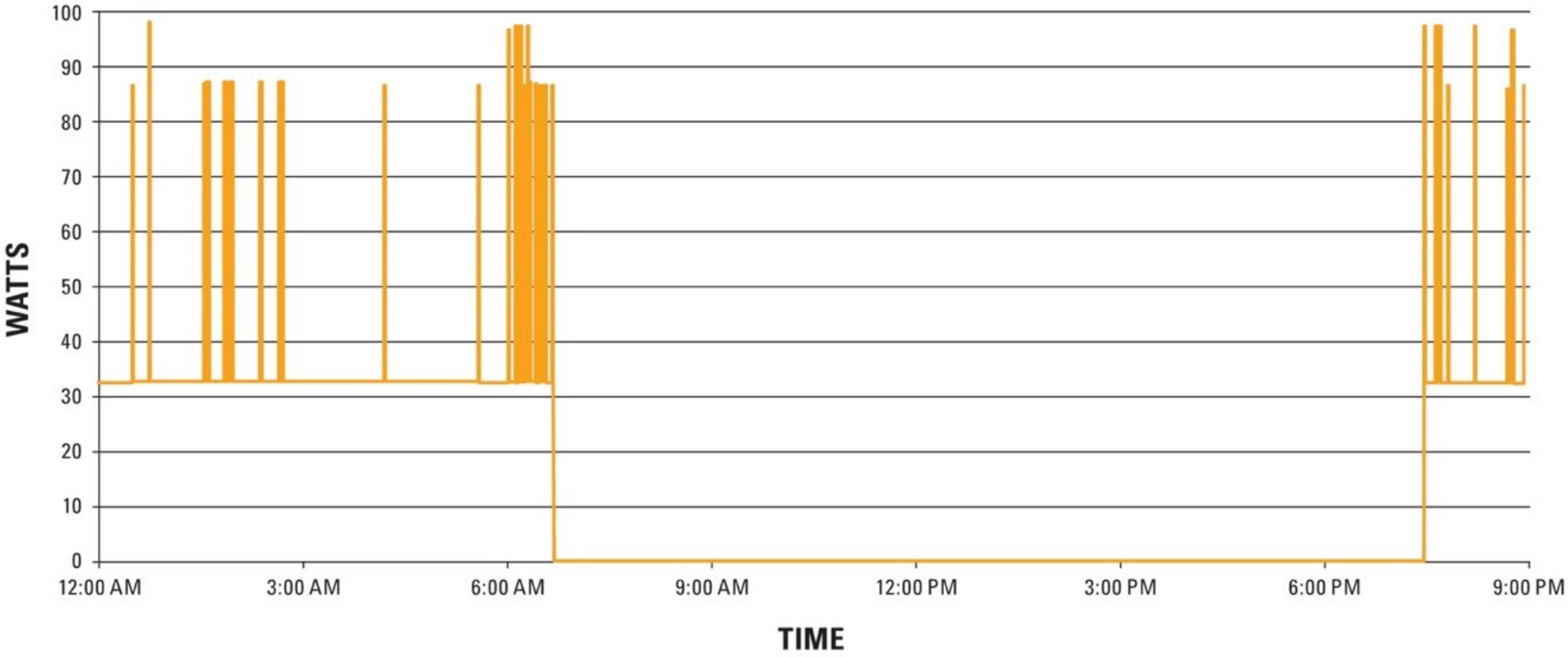


Bi-Level LED Bollards

Arcade Creek park
California Department of Public Health

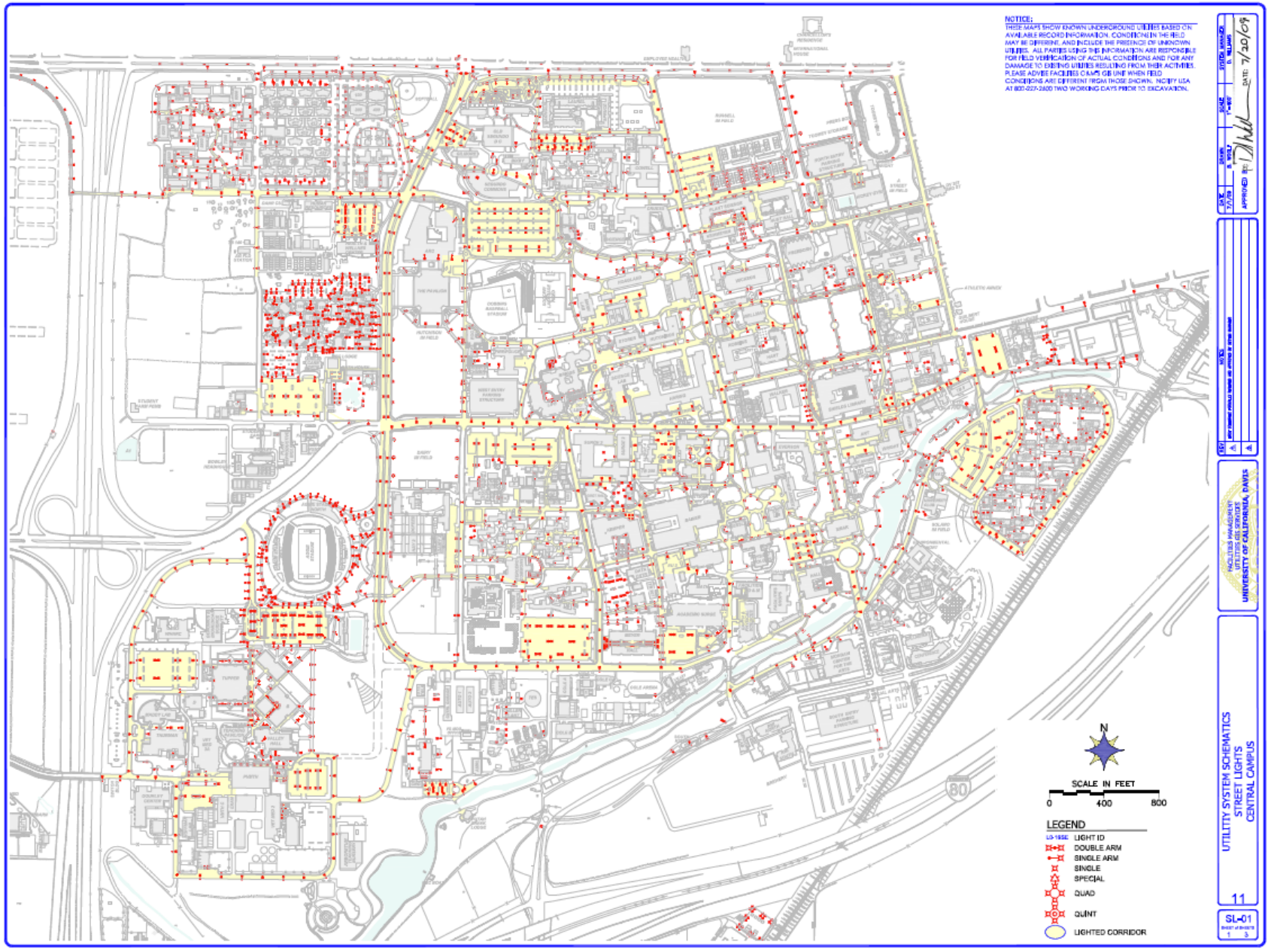
Bollards operate in low mode 85% of the time

Occupancy-based Bi-level Pathway Lighting



UC Davis Campus Today

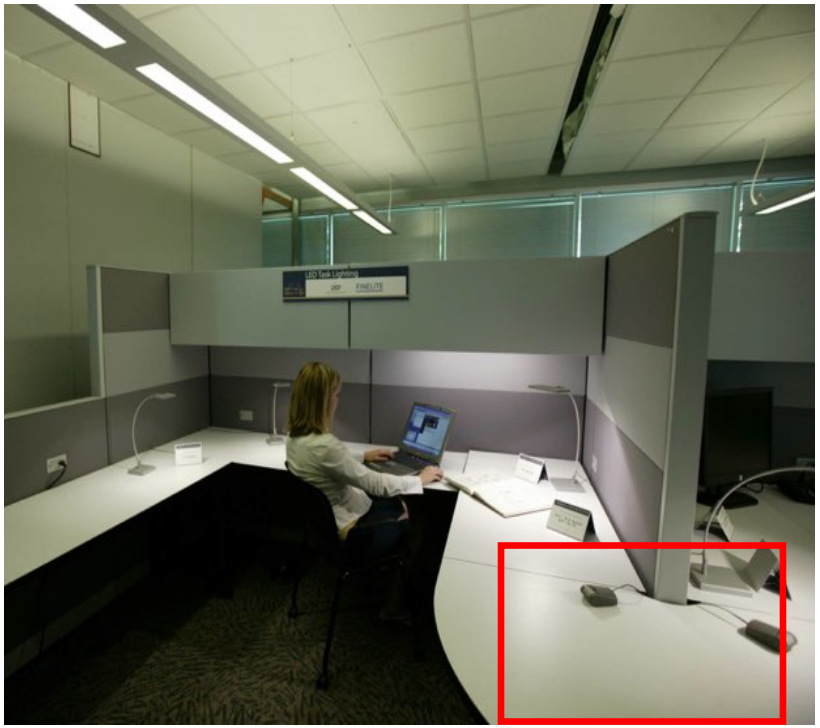
~1,600 Networked Occupancy-Based Bi-Level Outdoor Luminaires



Adaptive Street Lighting - 2nd Street, Davis

Task Ambient Lighting Strategy

- Low overhead ambient lighting
- High quality task lighting (desktop, under-cabinet)
- Total power: 0.5W/ft^2
- Occupancy control on task lighting



Adaptive Stairwell Lighting

Typically illuminated continuously

Low rate of occupancy

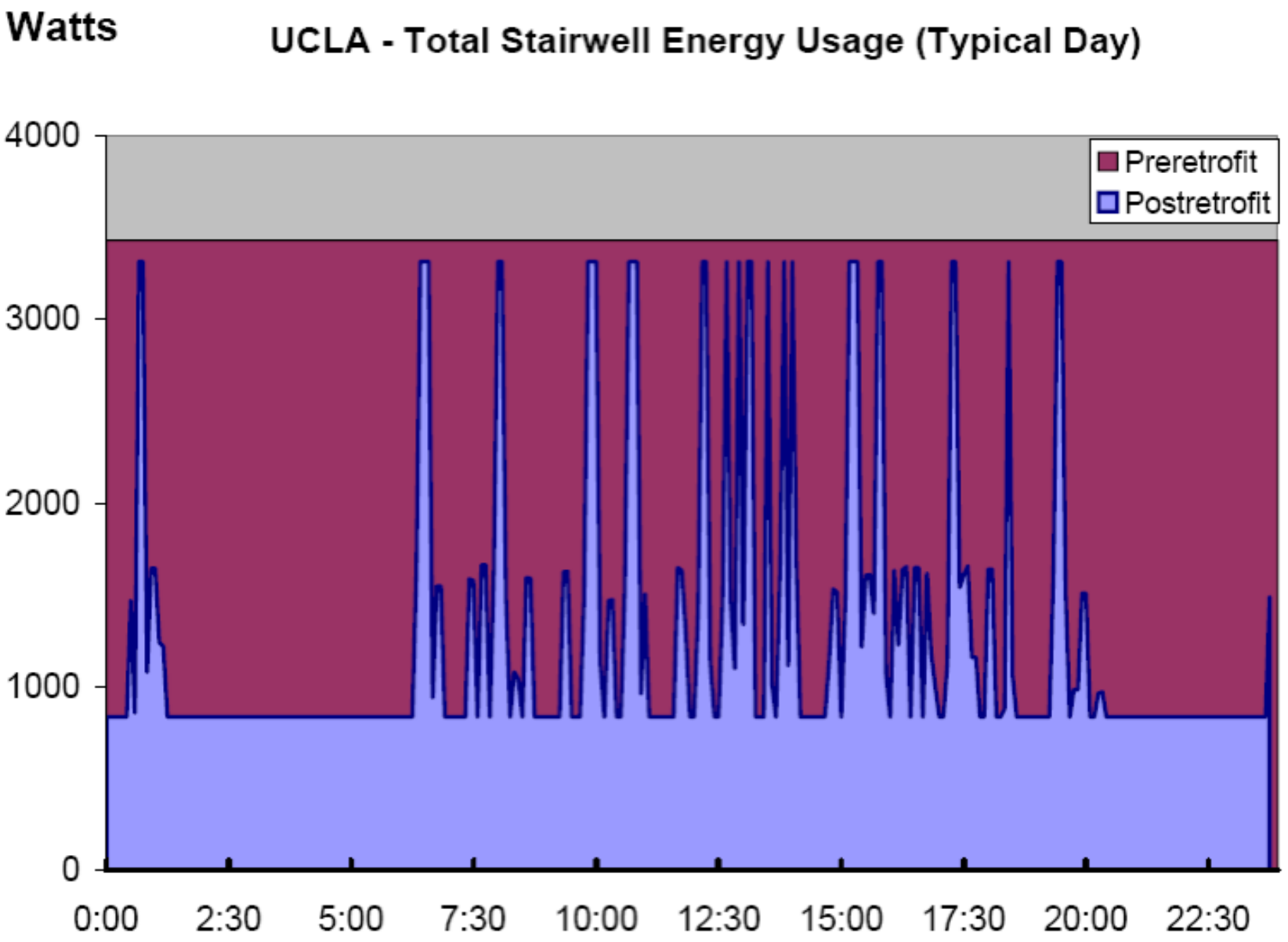
Integrated sensors or added control components

Occupancy-based control

- 100% during occupancy
- 50% or less during vacancy

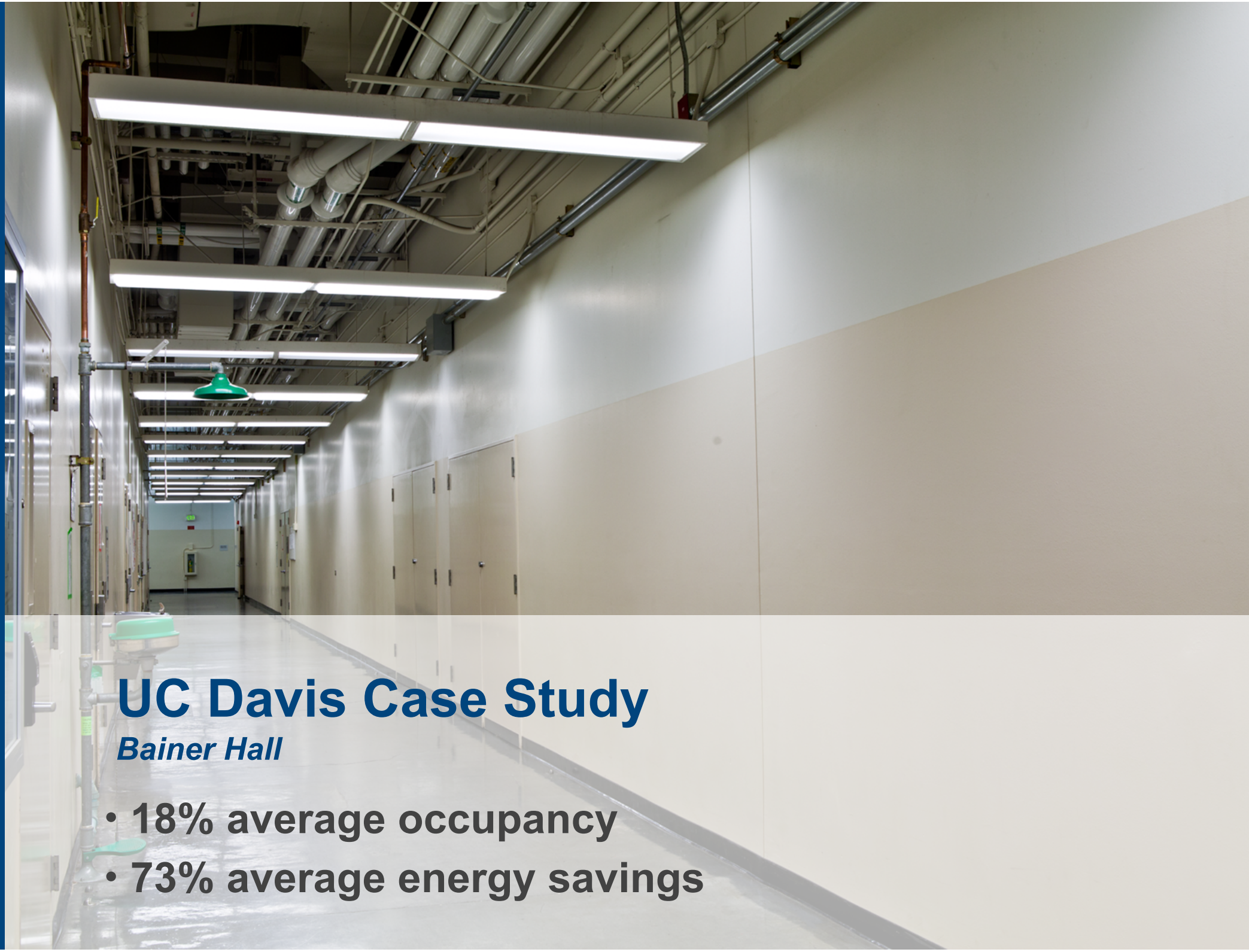
Case studies to date show up to 80% reduction

Stairwell Occupancy-Based Bi-Level Controls



Adaptive Corridor Lighting

- **Typically illuminated continuously**
- **Intermittent occupancy**
- **Occupancy-based control**
  - 100% during occupancy
  - 50% or less during vacancy
- **Case studies to date**
  - Commercial
  - Educational
  - 40-50% savings



UC Davis Case Study

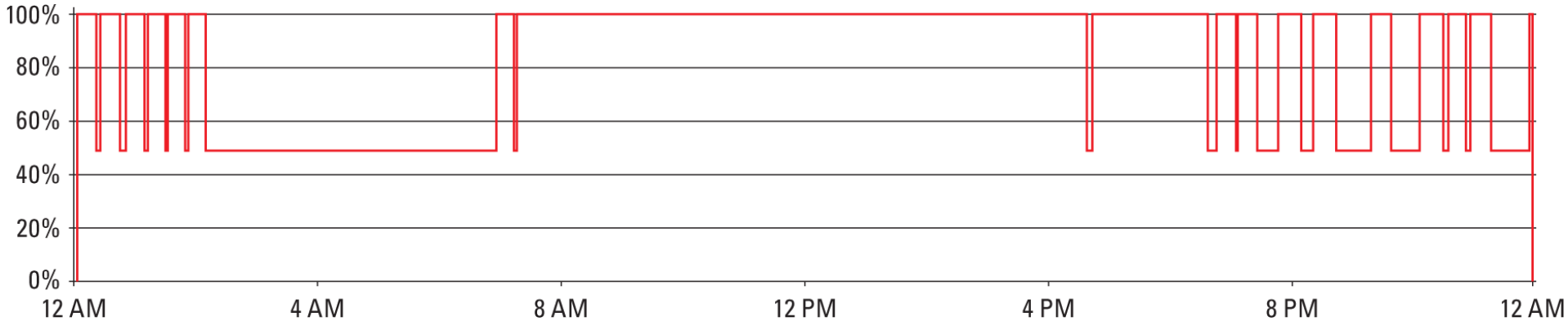
Bainer Hall

- 18% average occupancy
- 73% average energy savings

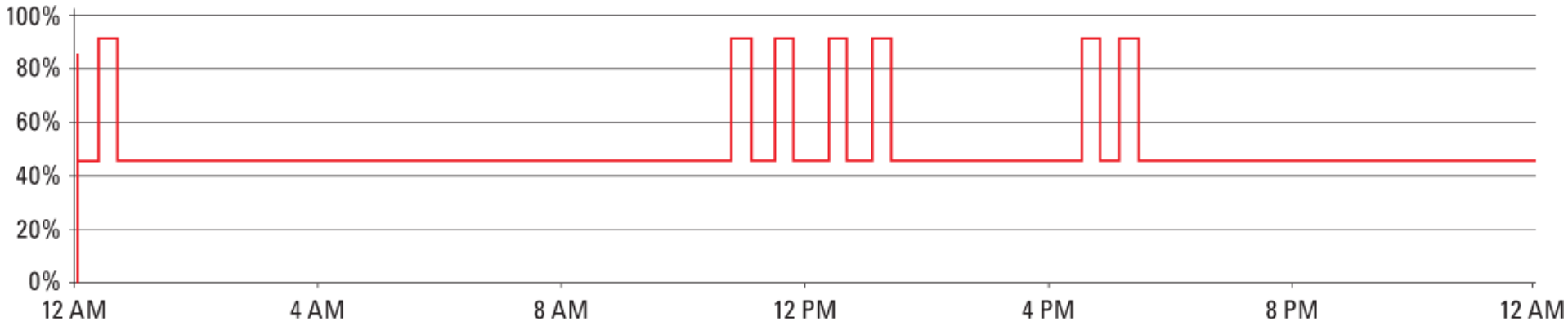
Corridor Occupancy-Based Bi-level Control

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

Electric Lighting Controls for Daylight Harvesting

- **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 Efficiency Opportunity

Energy Efficiency Opportunity

Energy Efficiency Opportunity

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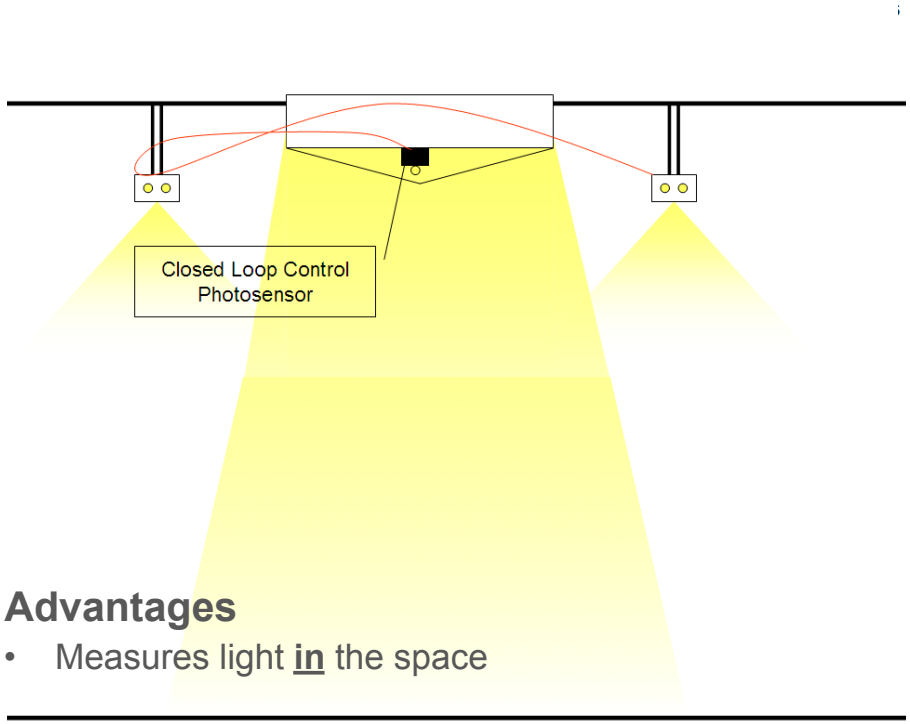
Traditional Daylight Sensing Strategies

Closed Loop Sensing
Affected by electric lighting



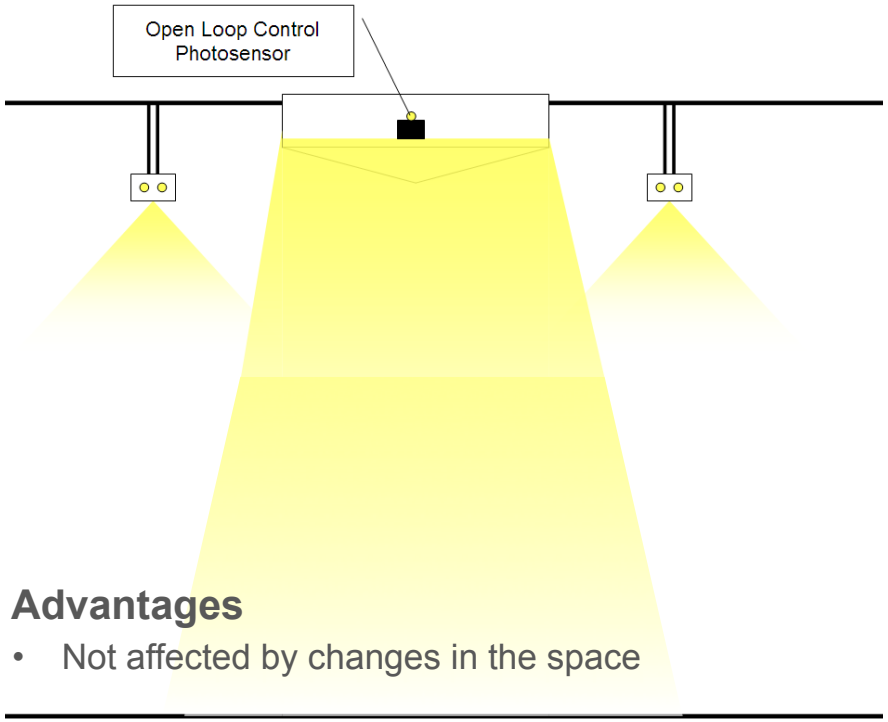
Advantages

- Measures light **in** the space

Disadvantages

- Requires re-calibration after 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)

Open Loop Sensing
Not affected by electric lighting



Advantages

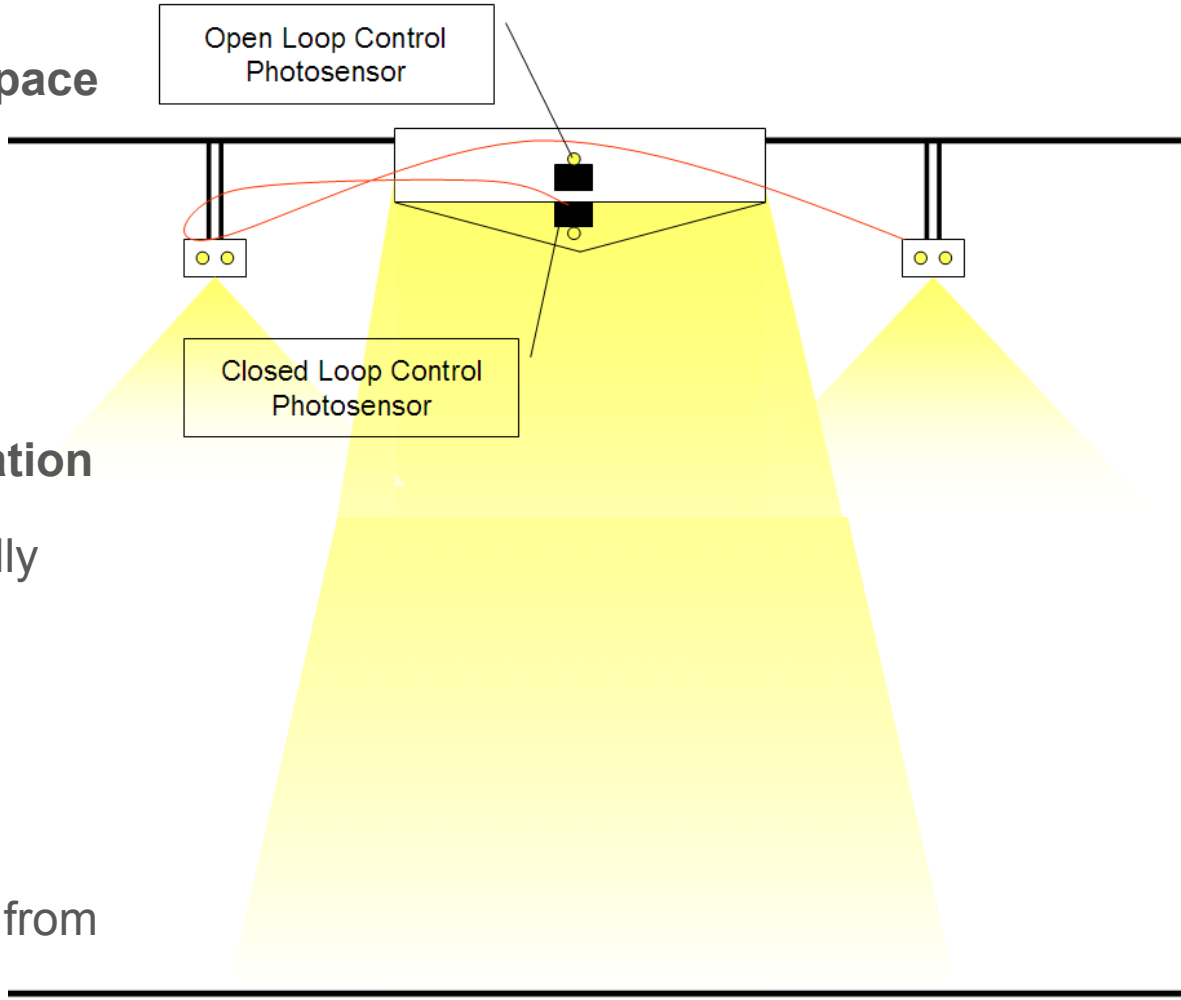
- Not affected by changes in the space

Disadvantages

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

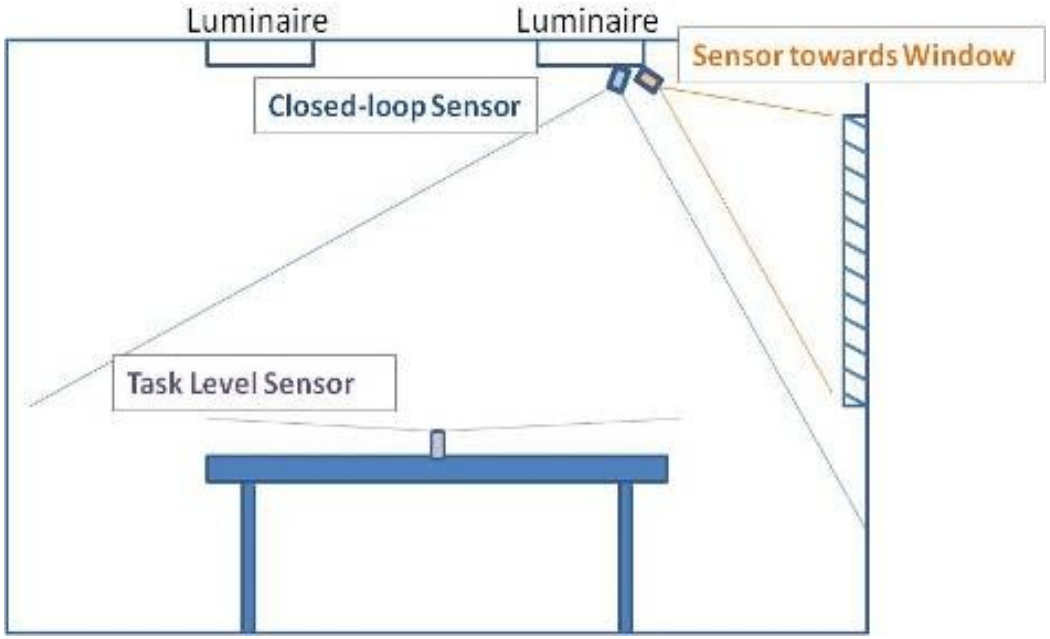
Dual-Loop Daylight Sensing

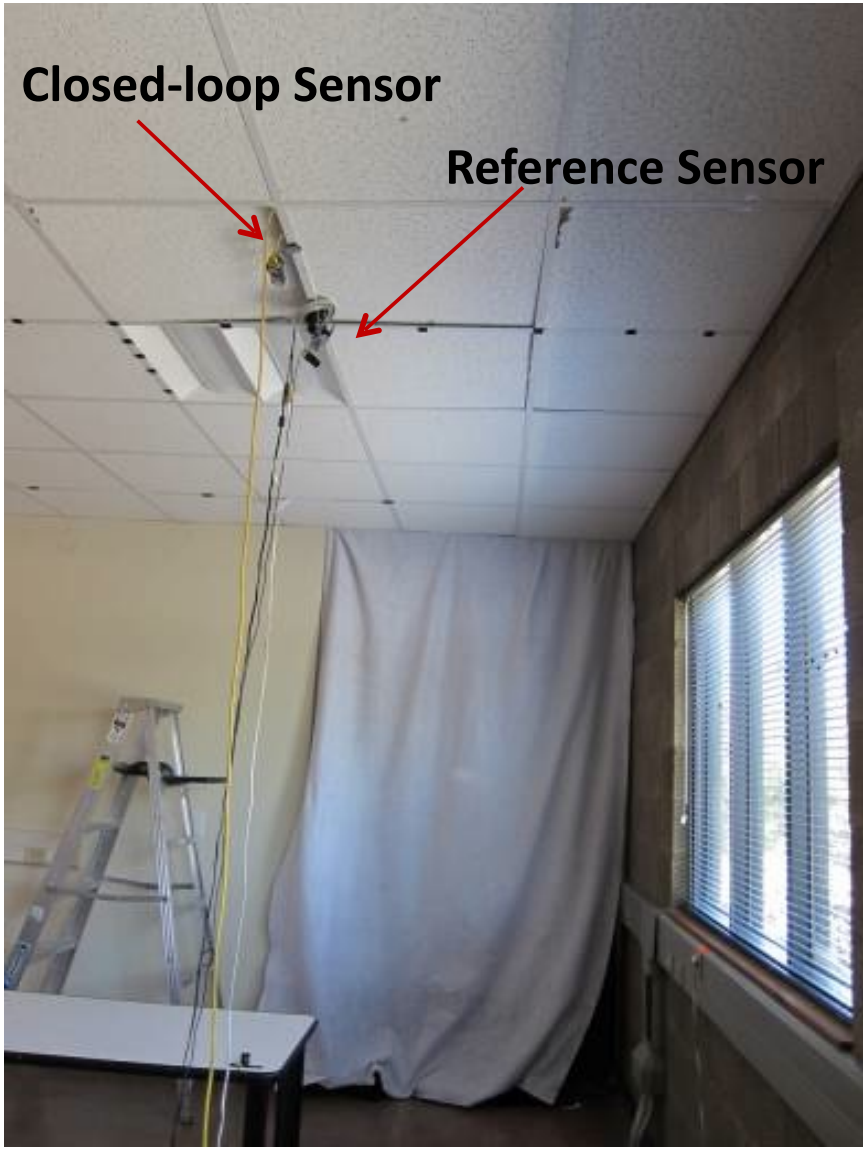
- **Measures light in and out of the space**
- **Automatic closed-loop calibration**
  - Based on electric light levels
  - No need for commissioning
- **Continuous closed-loop re-calibration**
  - Closed loop sensor automatically adjusts to interior changes
  - No need for re-commissioning
- **Dual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



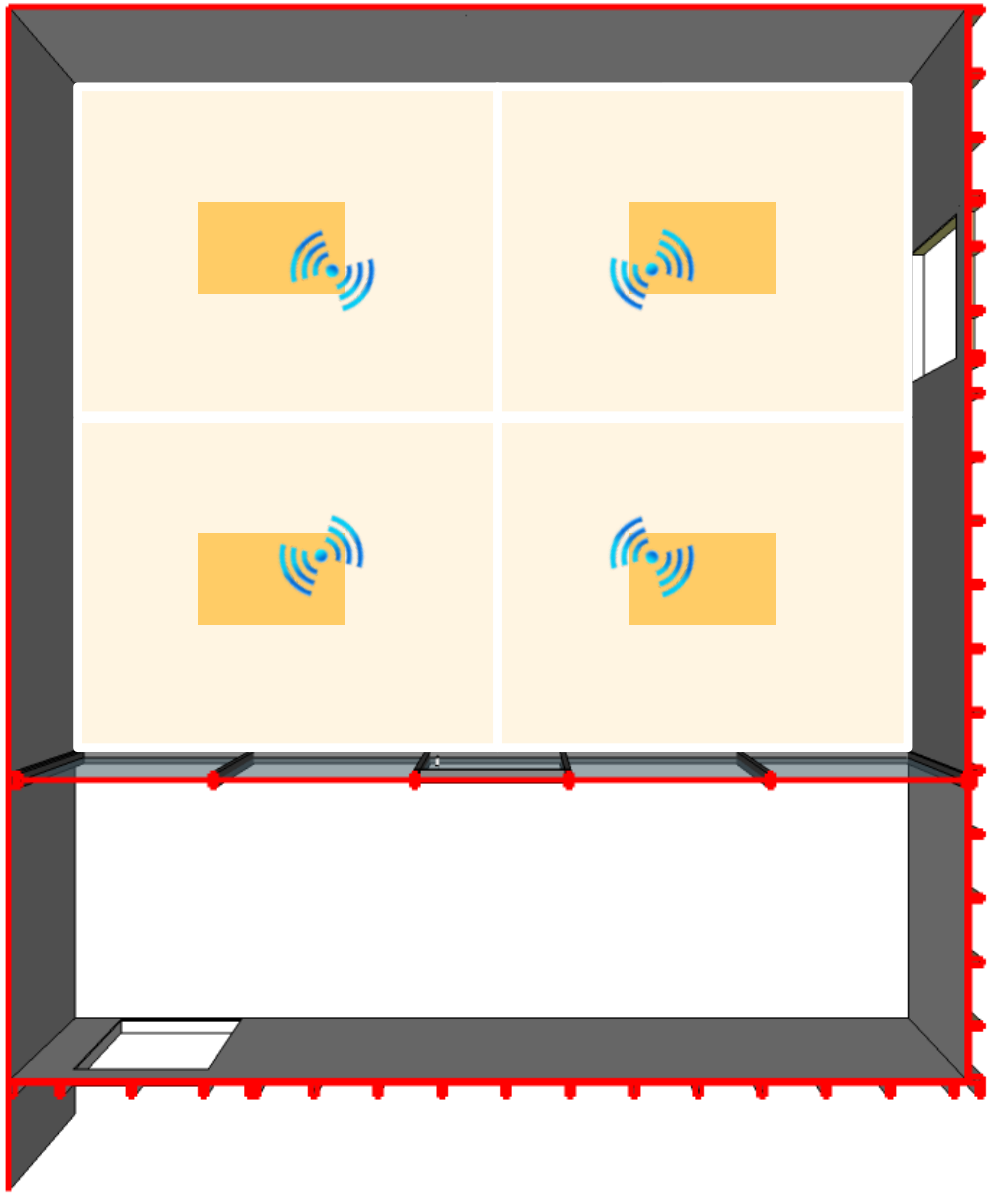
Dual Loop for Window Applications

- **It works!** **…through…**
- **Very Expensive Commissioning**
  - Knowledge & Time
    - Reference Sensor
      - Position
      - Field of View





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…

Daylight Harvesting Optimization Strategy

- **Reduce electric lighting based on available daylight**

  and after electric lighting is off or at minimum output

- **Adjust fenestration transmittance based on**
  - HVAC status
  - Potential for glare

Smart Windows & Skylights

- **Multi-sensor-based automated controls**
  - Occupancy, light, air temperature, etc., indoors & outdoors
- **Multiple performance aspects**
  - Luminous, thermal, ventilation, view, safety, etc.

CLTC Daylight Harvesting Laboratory

Integrated Control Strategy

- During **Occupancy** Focus on **Comfort**

- During **Vacancy** Focus on **Energy Efficiency**

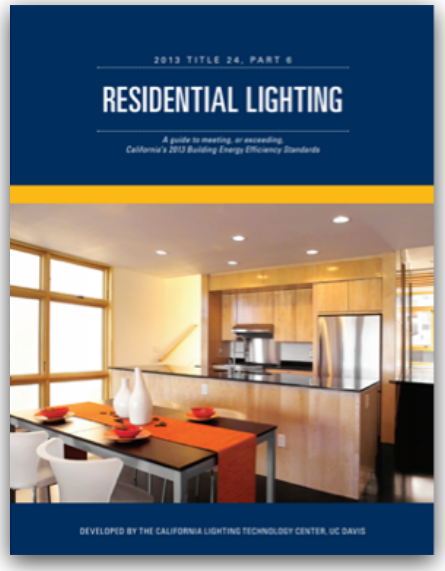
Integrated Control Strategy

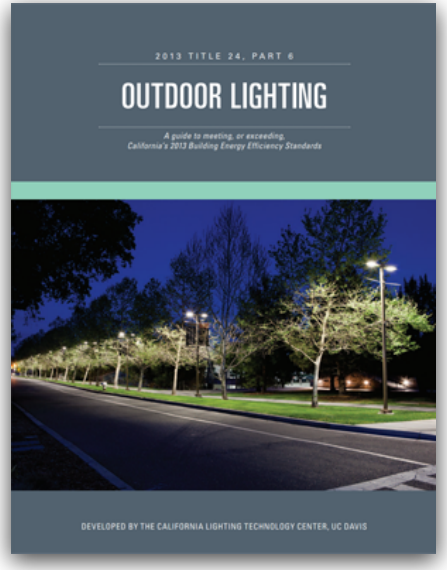
- During **Occupancy** Focus on **Comfort**
  - **Adjust fenestration for daylight penetration**
  - **Adjust electric lighting for daylight contribution**
  - **Adjust HVAC for thermal comfort & indoor air quality**
- During **Vacancy** Focus on **Energy Efficiency**

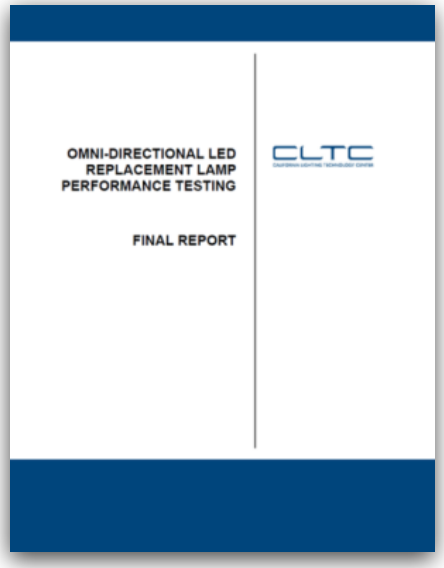
Integrated Control Strategy

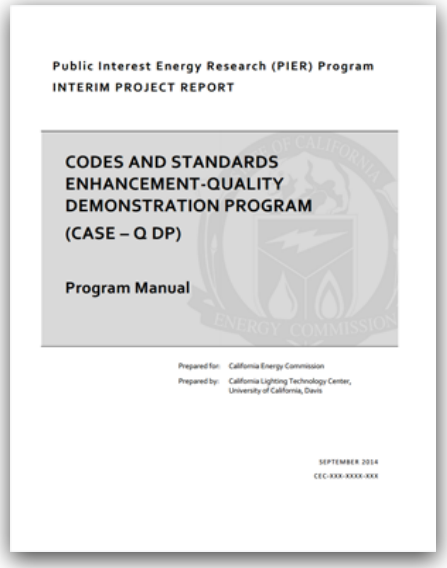
- During **Occupancy** Focus on **Comfort**
  - Adjust fenestration for daylight penetration
  - Adjust electric lighting for daylight contribution
  - Adjust HVAC for thermal comfort & indoor air quality
- During **Vacancy** Focus on **Energy Efficiency**
  - Adjust fenestration for cooling/heating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

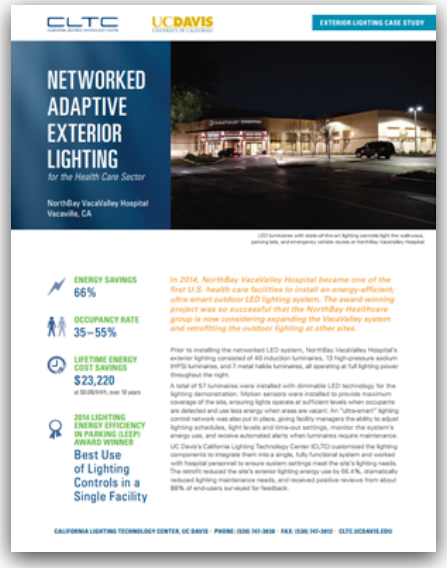
Selected CLTC Publications (links to CLTC web site)











For more information about CLTC's projects, publications, and resources, visit:
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Thank You!

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