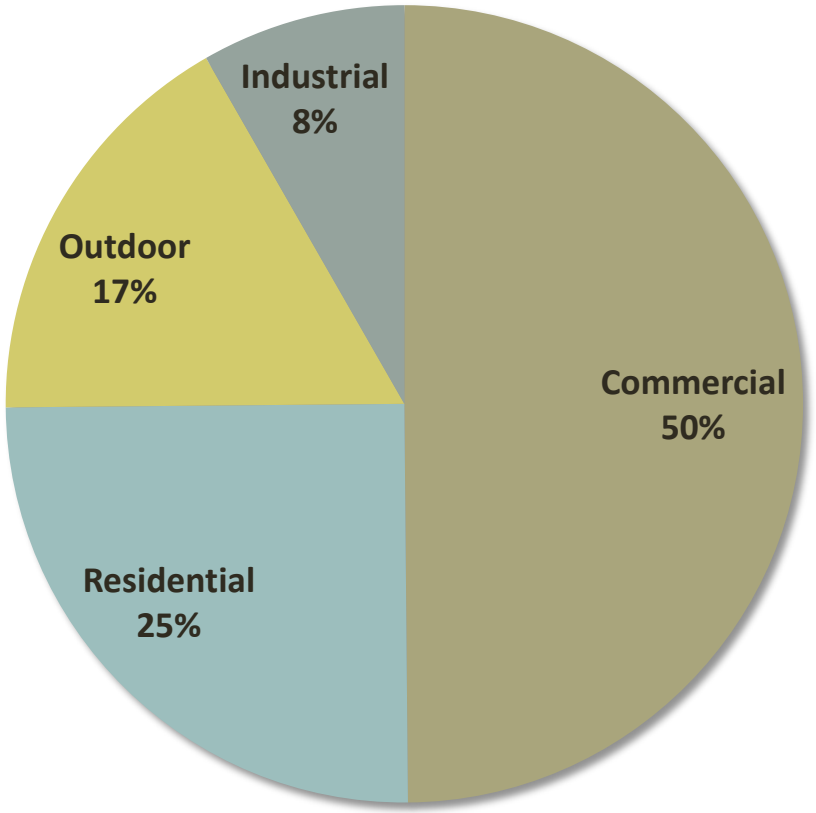
# The Integration of LED Lighting & Advanced Lighting Controls

Peter Schwartz

January 7, 2015

# Lighting Energy Use By Building Sector

- Much effort spent transforming outdoor (HID) lighting to LED
- But most of energy-saving opportunity is in interior fluorescent lighting

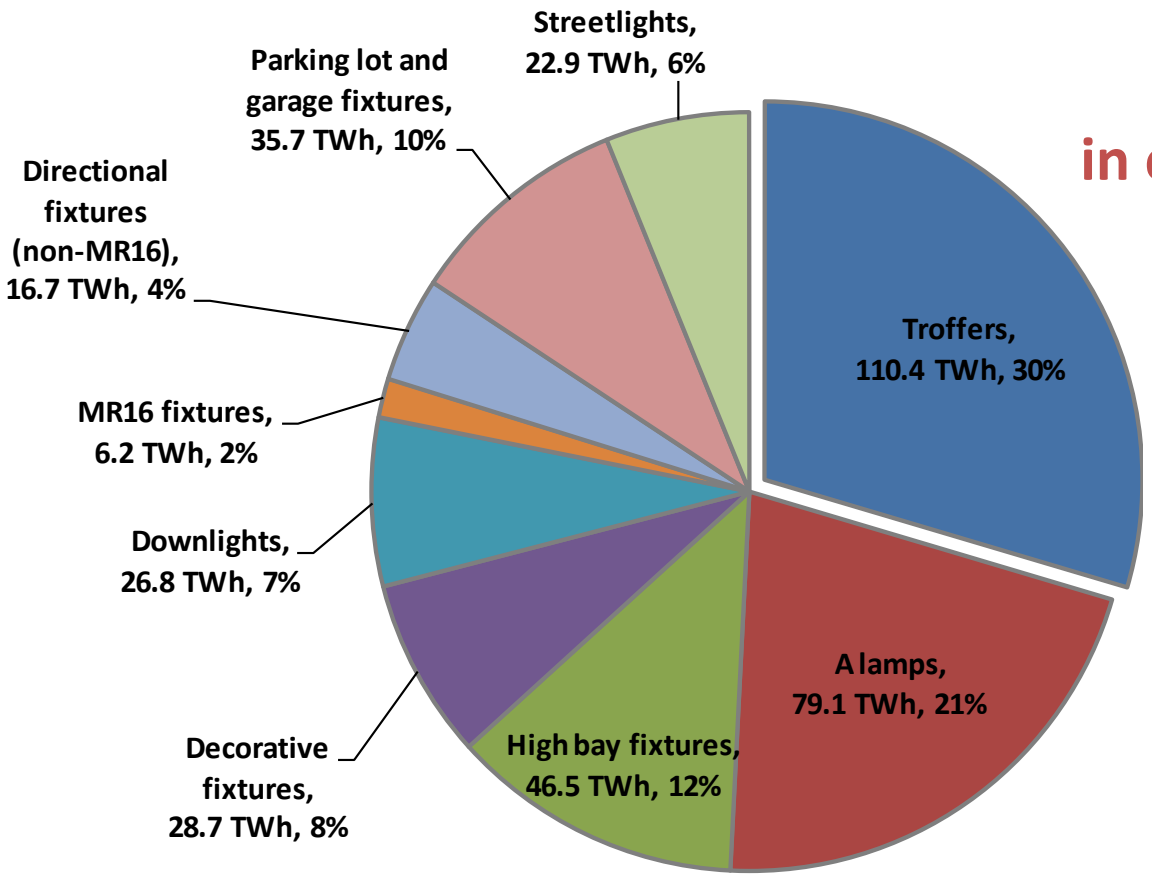



Total: 700 BkWh
Commercial: 350 BkWh
Outdoor: 118 BkWh

***Source: Navigant Consulting, "U.S. Lighting Market Characterization", 2010***

# What If ALL Commercial Lighting Were changed to LED?

**Estimated Annual U.S. Savings Potential (100% LED penetration): 373 TWh**




**$11 Billion in energy savings**

# Shifting Technology Trends in Lighting

| Current Practice | Future Trend | Rationale for Shift |
|---|---|---|
| **Re-Lighting (New Design)** | **Preserve fixture spacing** | **Minimize labor installation costs** |
| Fluorescent lighting (static) | Controllable LED Lighting | Improved dimming range and performance with LEDs |
| Low-voltage control cabling | Wireless connectivity: - ZigBee, WiFi, Zwave, etc | Minimize re-wiring costs |
| Area-based sensors for detecting occupancy and daylight | Integrated sensor package for each luminaire | Reducing commissioning costs and set-up time |
| Separate wireless controller and driver/ballast | Wireless connectivity integrated into driver/ballast | Lower capital and labor costs |

# Commercial Building Partnership Lighting Pilot Sites

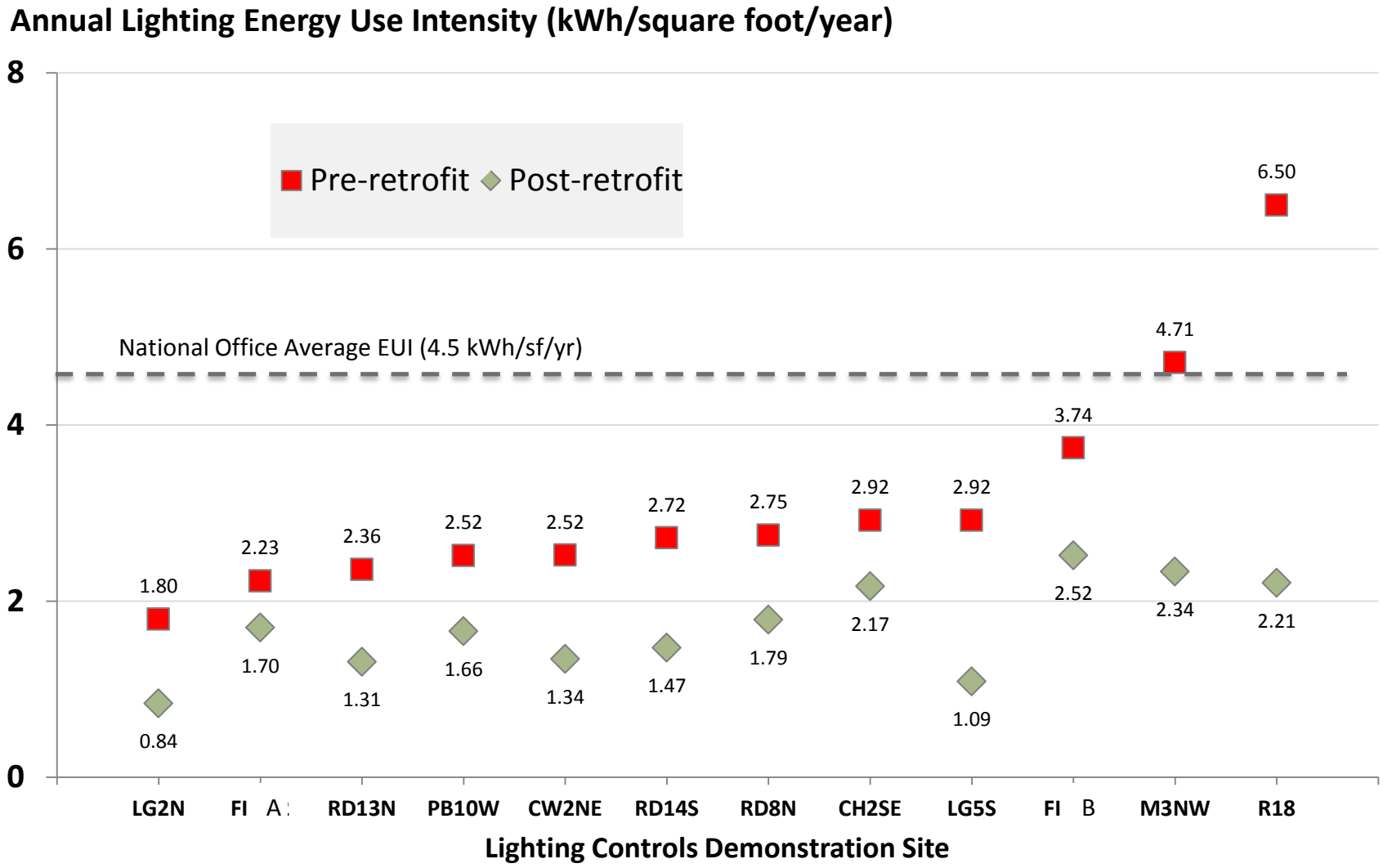
| Site | Agency | Location | Floor Area ($ft^2$) | Pre-Retrofit Metered Area ($ft^2$) | Post-Retrofit Metered Area ($ft^2$) |
|---|---|---|---|---|---|
| Chet Holifield FB (2nd Fl) | Homeland Security | Laguna Niguel, CA | 46,500 | 11,808 | 14,268 |
| Cottage Way FB (2nd Fl) | Bureau of Reclamation | Sacramento, CA | 21,000 | 20,035 | 20,035 |
| Lloyd George FB & Court (2nd Fl) | US Marshals | Las Vegas, NV | 17,500 | | |
| Lloyd George FB & Court (5th Fl) | US Attorneys | Las Vegas, NV | 15,500 | | |
| Matsui FB (3rd Fl) | Bankruptcy Courts | Sacramento, CA | 13,500 | | |
| Philip Burton FB (10th Fl) | Antitrust | San Francisco, CA | 23,500 | | |
| Ron Dellums FB (8th Fl) | Coast Guard | Oakland, CA | 18,500 | 13,746 | 11,920 |
| Ron Dellums FB (13th Fl) | Veteran's Association | Oakland, CA | 15,000 | 5,725 | 3,963 |
| Ron Dellums FB (14th Fl) | Internal Revenue Service | Oakland, CA | 8,000 | 7,885 | 7,225 |
| Roybal FB (18th Fl) | Drug Enforcement Agency | Los Angeles, CA | 25,500 | 24,641 | 22,199 |
| | | | 204,500 | | |

*Assuming leveraging ~ 15:1, > 3 million ft2 of office space is being measured*

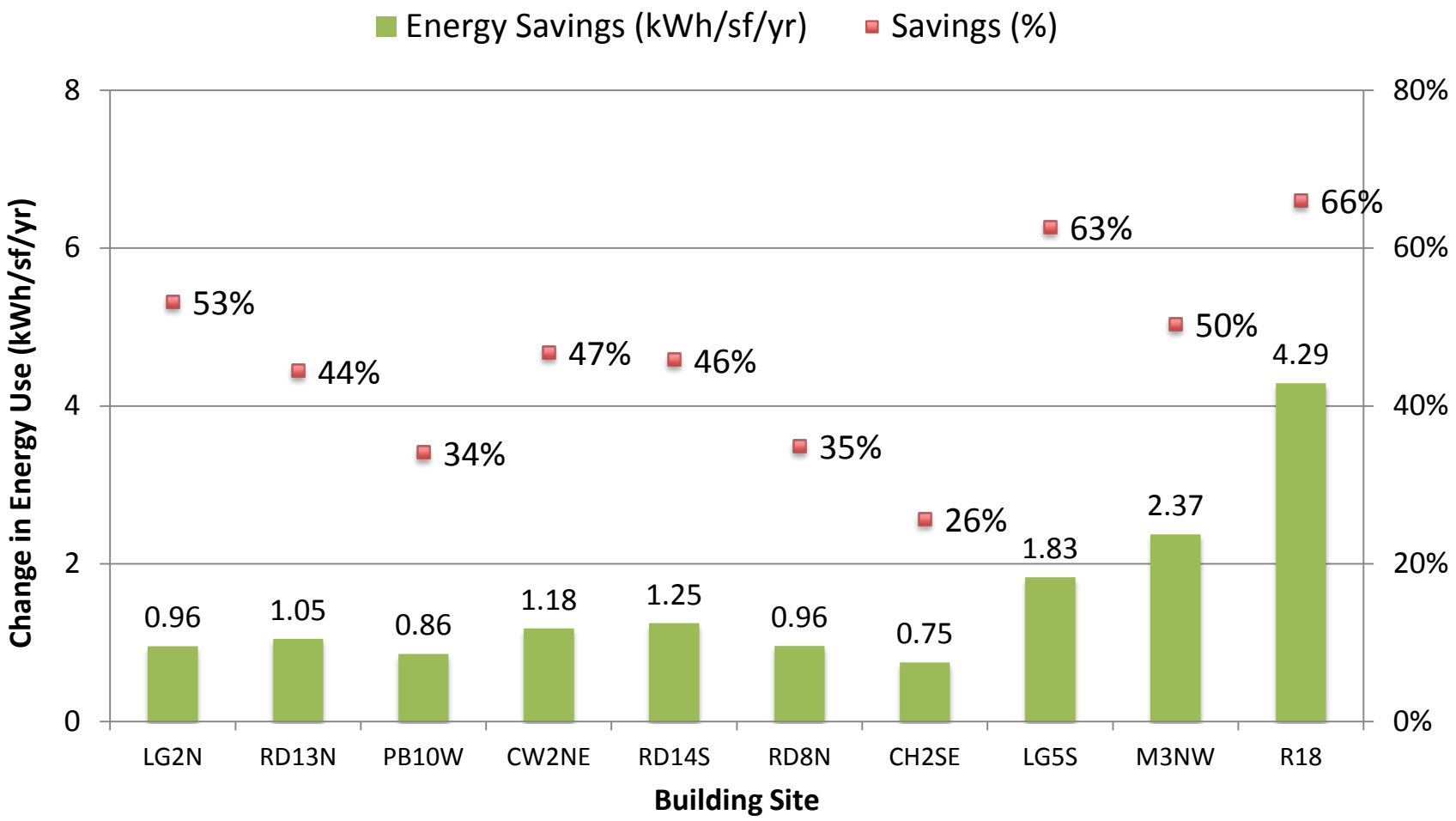
# Determining a Building's Energy Footprint

- Energy Use Intensity (EUI) is a measure of energy density for installed lighting:
  - **Is used in most building energy simulation programs**
  - **Units: Kilowatt-hrs per square foot per year (kWh/ft$^2$/year)**
  - **In Britain, LENI (Lighting Energy Numerical Index) uses kWh/m$^2$/year instead**

# Measured Lighting Energy Use at 12 Demonstration Sites Before & After Lighting Controls Installation



# Energy Savings at 10 GSA Demonstration Sites



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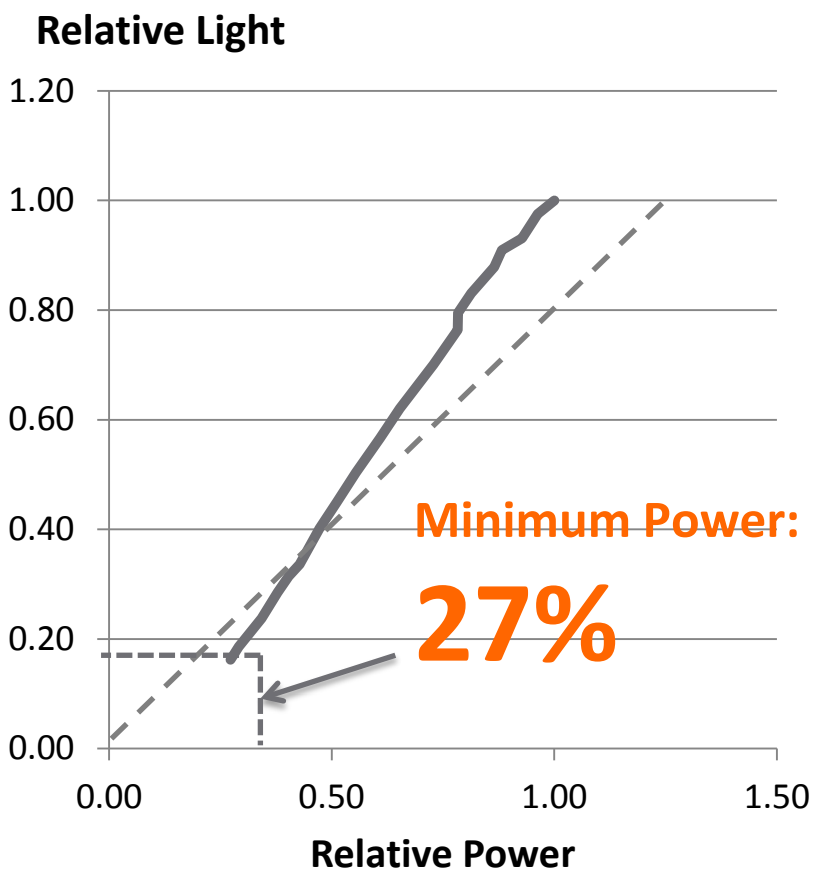
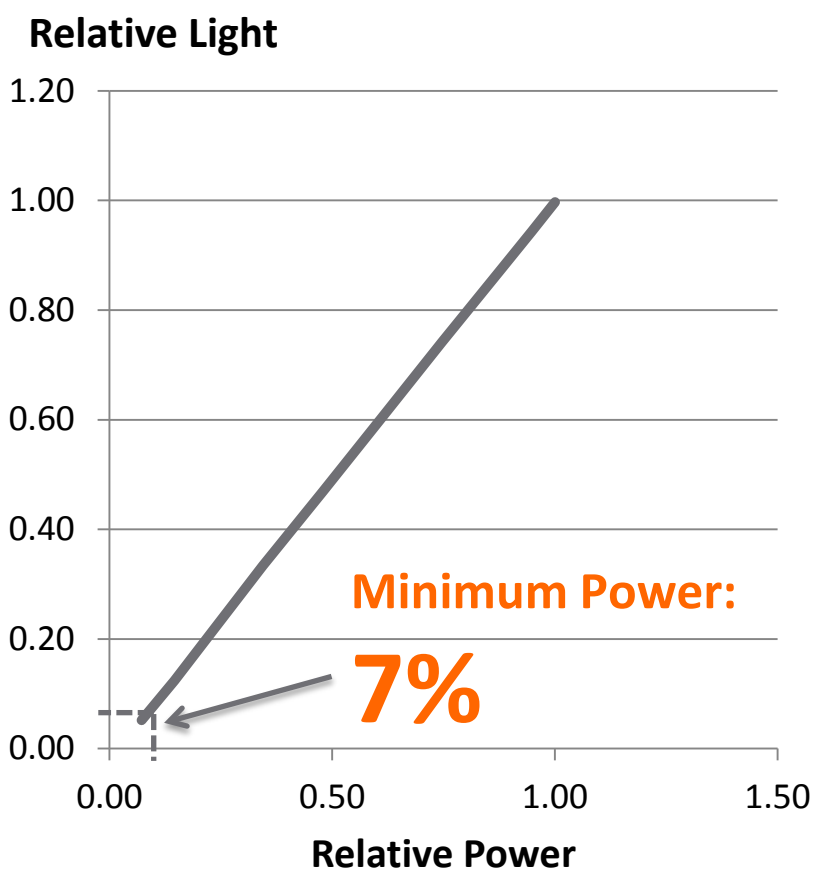
# Fluorescent & LED Dimming Compared

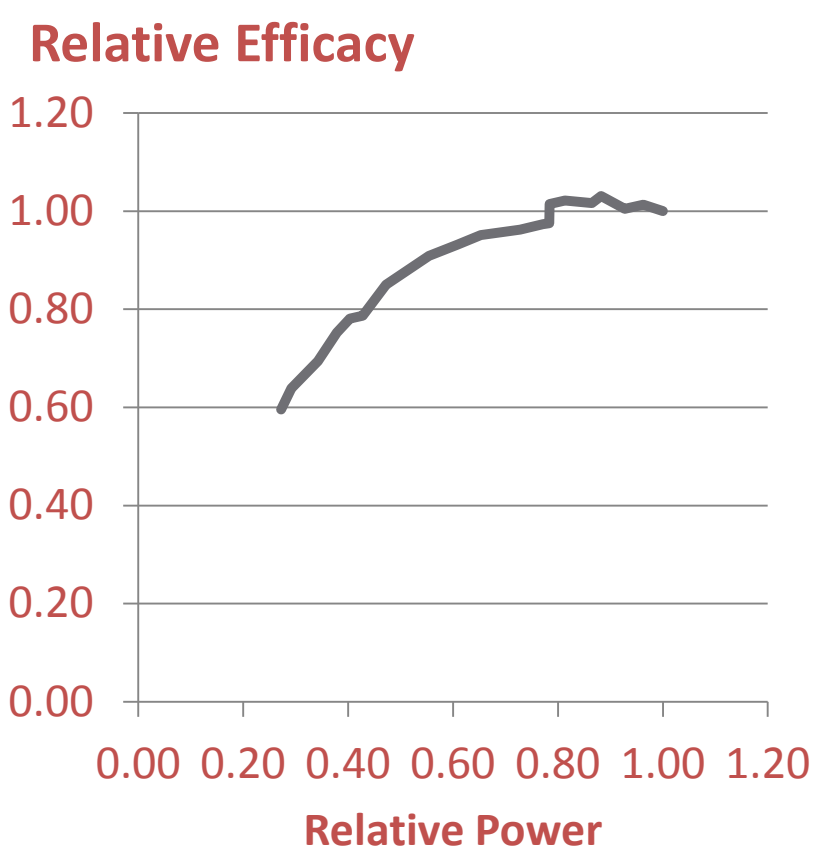
## Fluorescent

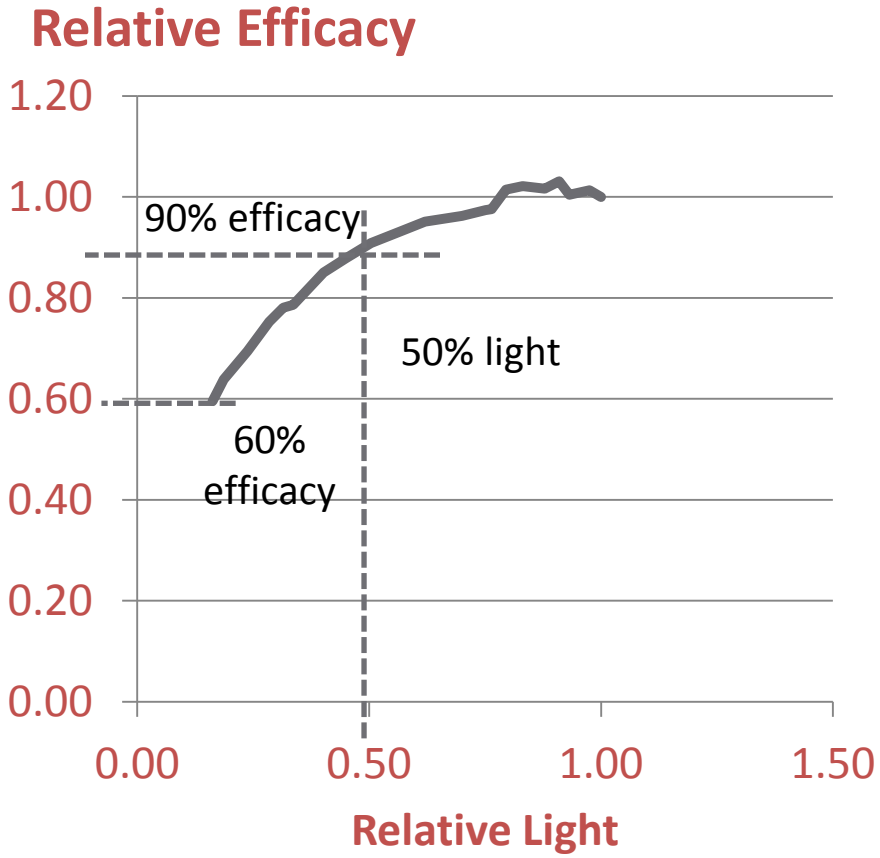



## LED



# Fluorescent Lighting Efficacy Changes with Dimming



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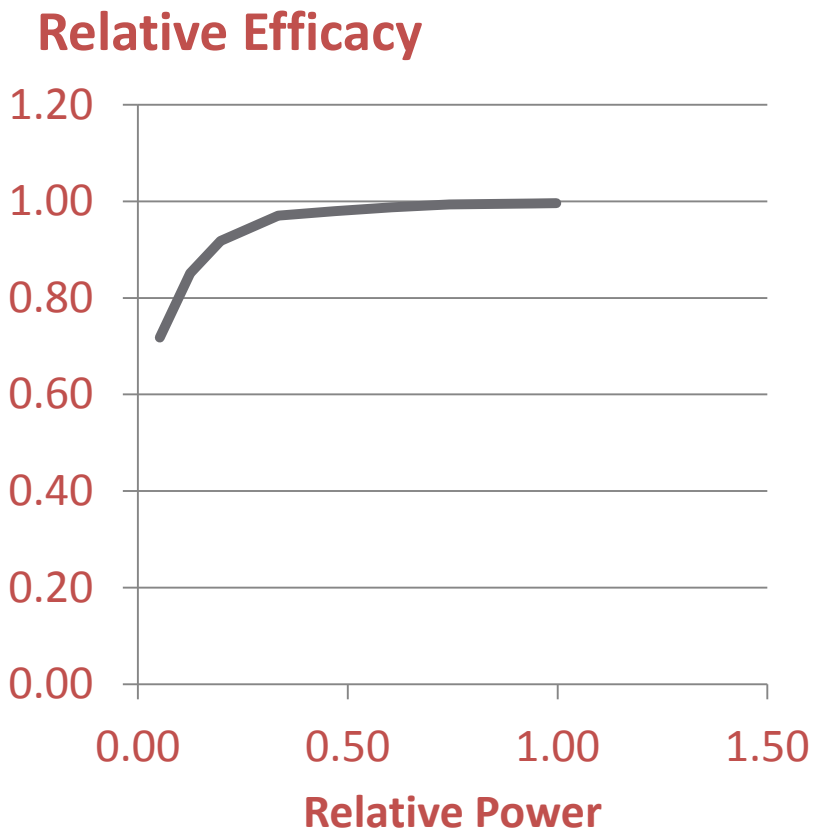
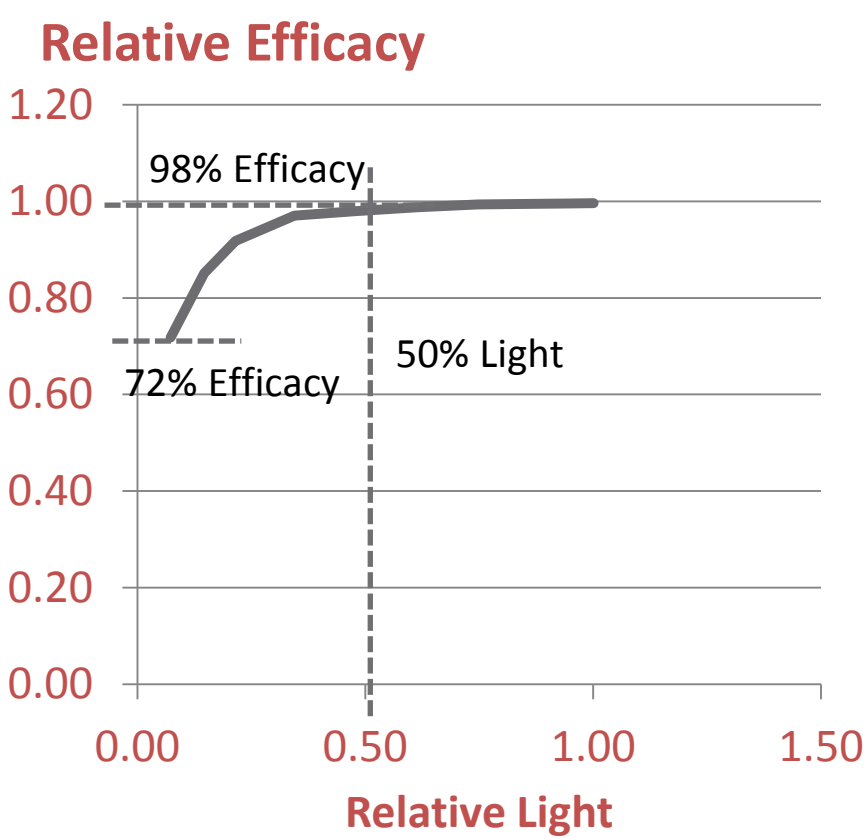
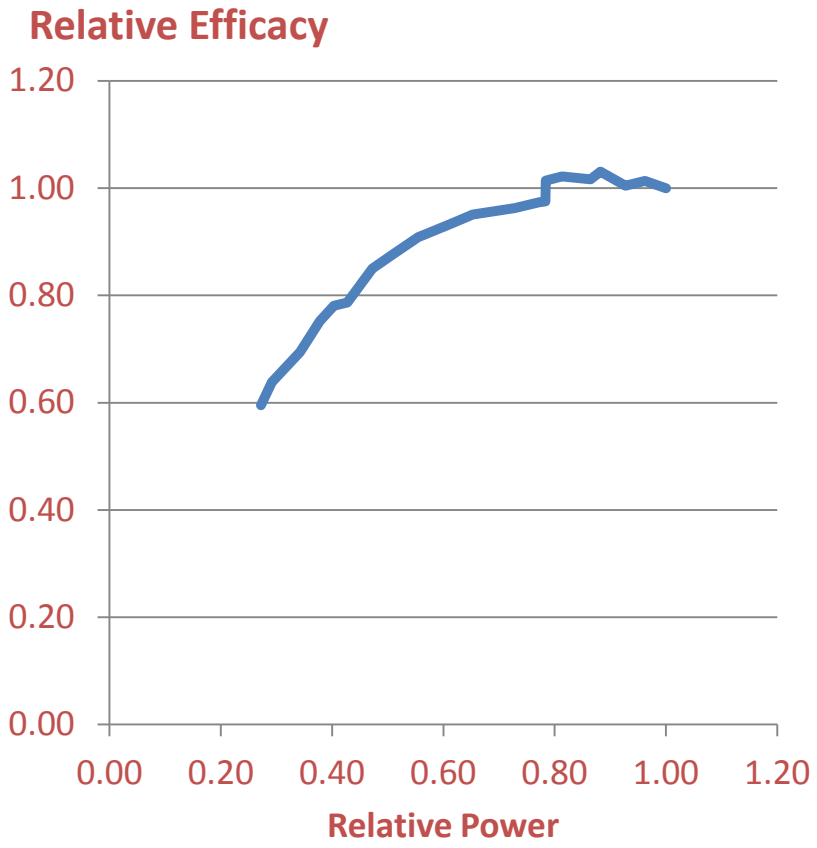


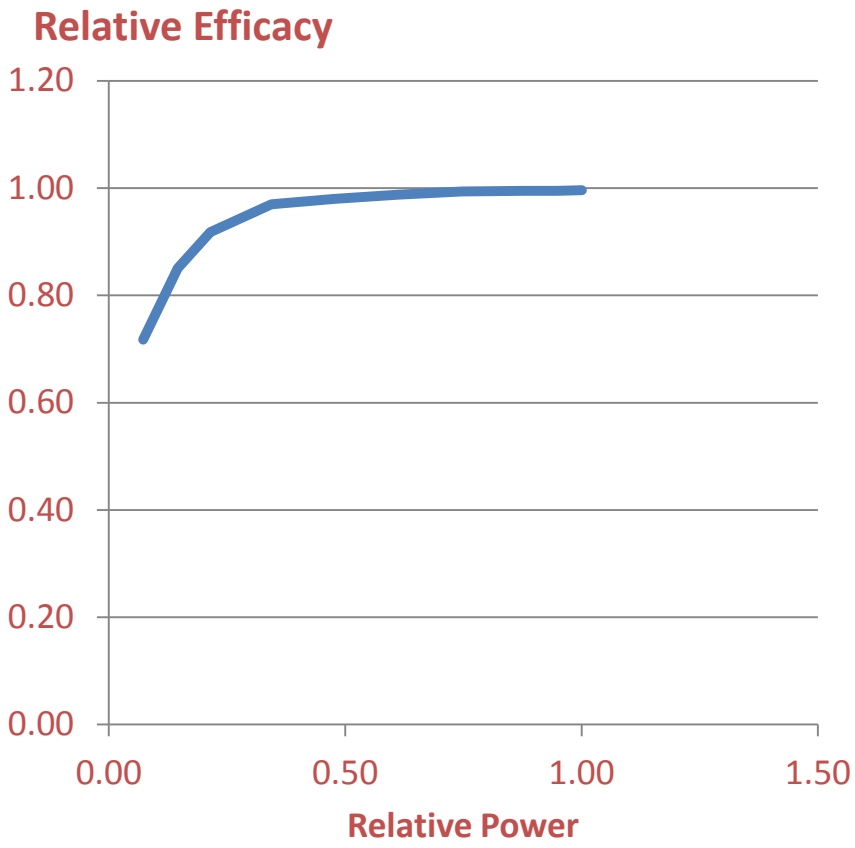



# Relative Efficacies of LED & Fluorescent Compared

## Fluorescent




## LED



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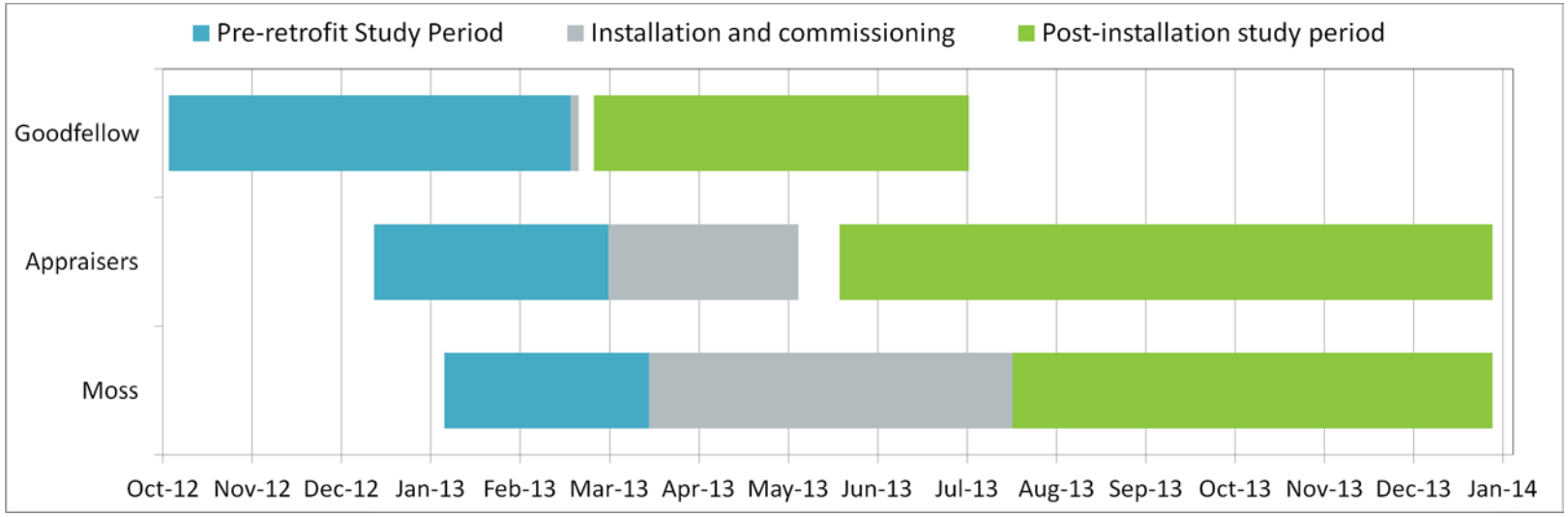
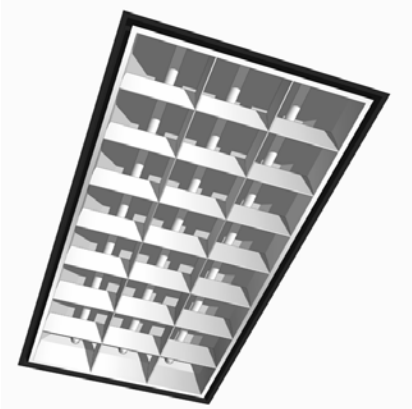
# Demonstration Site Characteristics & Study Schedules

| Building | Test Site Area ($ft^2$) | Space Types | LED Luminaire | Wireless Controls | Original Lighting |
|---|---|---|---|---|---|
| Goodfellow Bldg<br>St. Louis MI | 6,100 | 78% Open Office<br>22% Private Office/Break | X | | 84 2x4<br>3-lamp<br>parabolic |
| Appraiser's Office Bldg<br>San Francisco CA | 6,800 | 74% Open Office<br>6% Private Offices<br>20% Other | X | X | 84 2x4<br>3-lamp<br>parabolic |
| Moss Bldg<br>Sacramento CA | 31,400 | 65% Open Office<br>35% Private Offices, other | | X | ~320 mixed<br>2x4,2x2&1x4 |



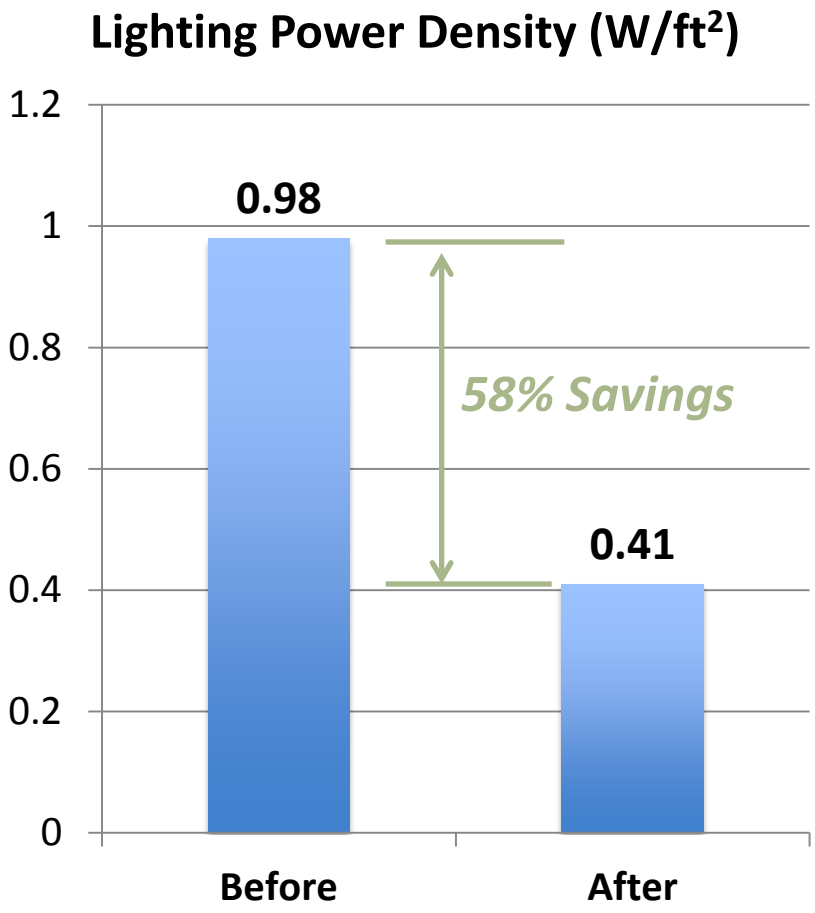
# Goodfellow Building:

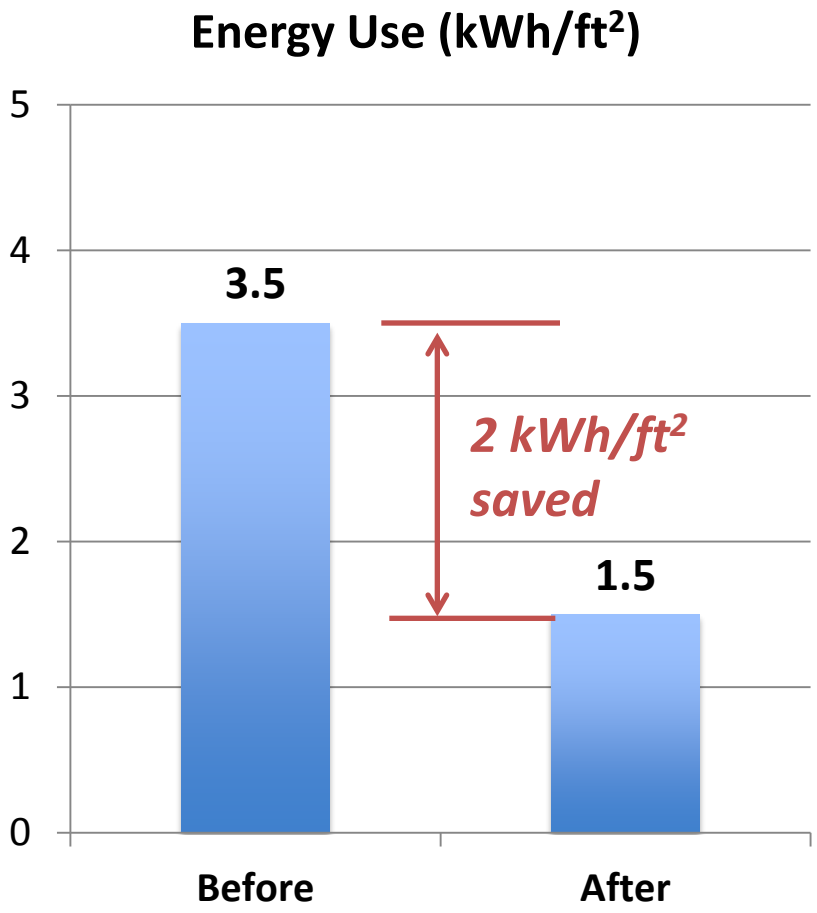
## *Fluorescent to LED without added controls*



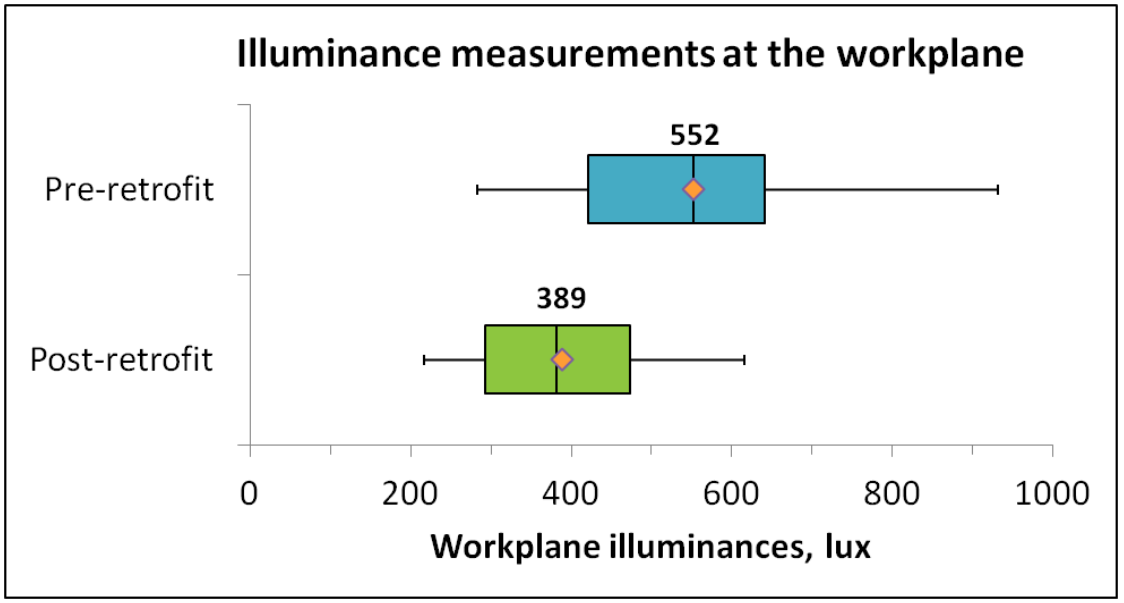

**78% Open Office**
**22% Private Office/Break**

# Goodfellow Building:
# *Power & Energy Savings*



# Goodfellow Building:
# *Changes in Light Levels*

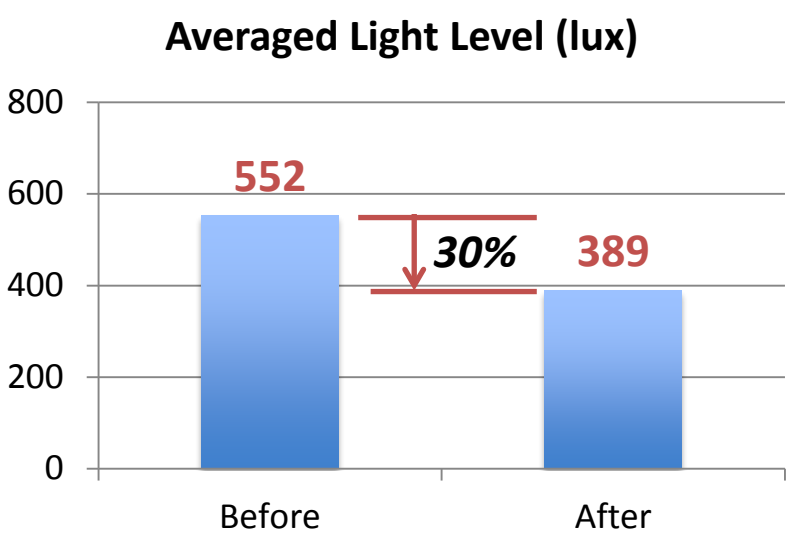


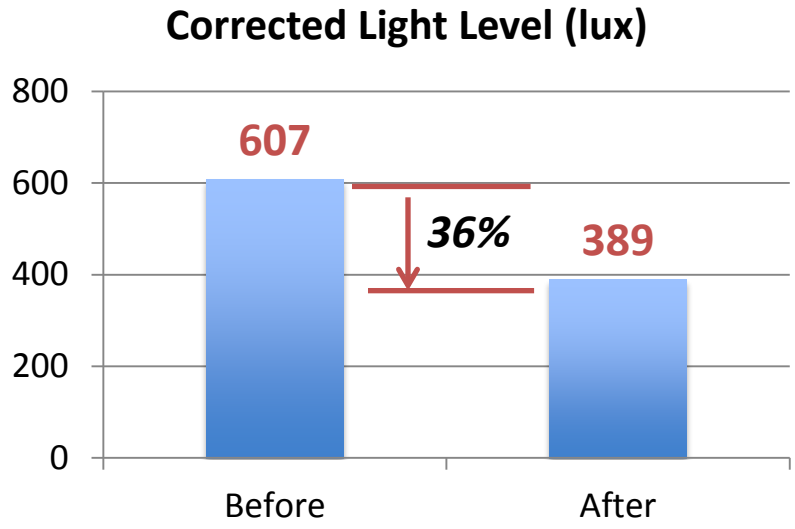

LED retrofits maintained acceptable light levels

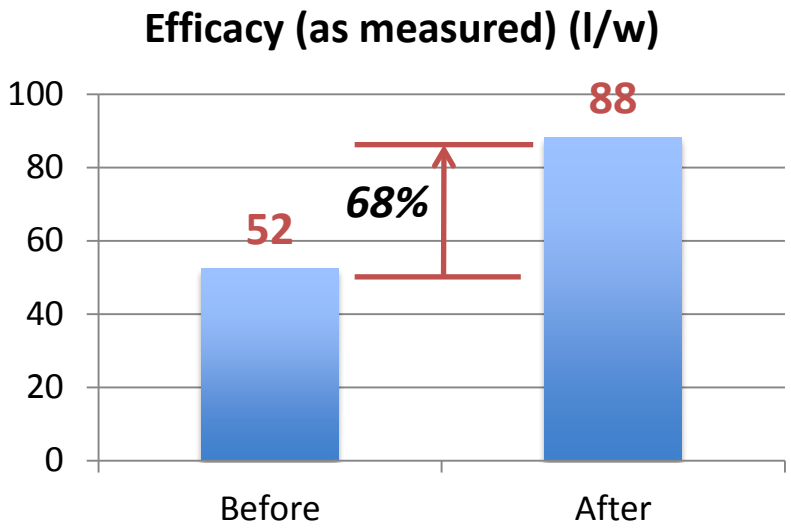
P-100 Acceptable light levels ≥ 323 lux

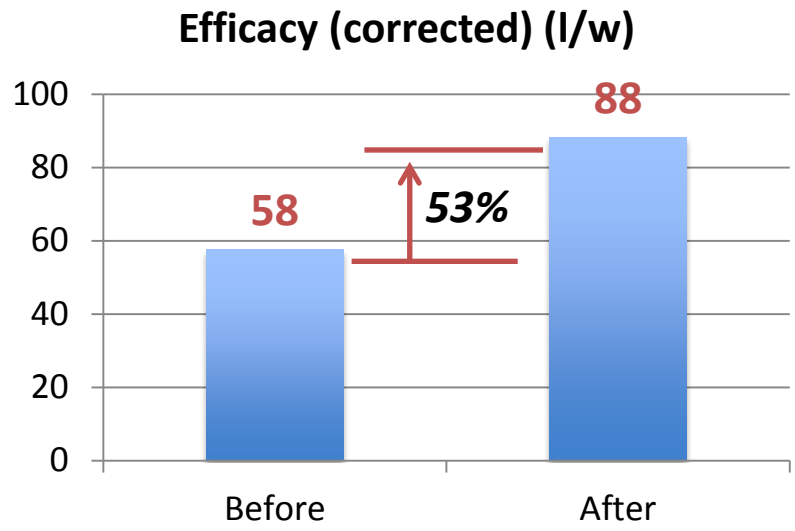
Light levels measured using spectroradiometer located at key workstation locations

# Changes in Light Level & Workplane Efficacy

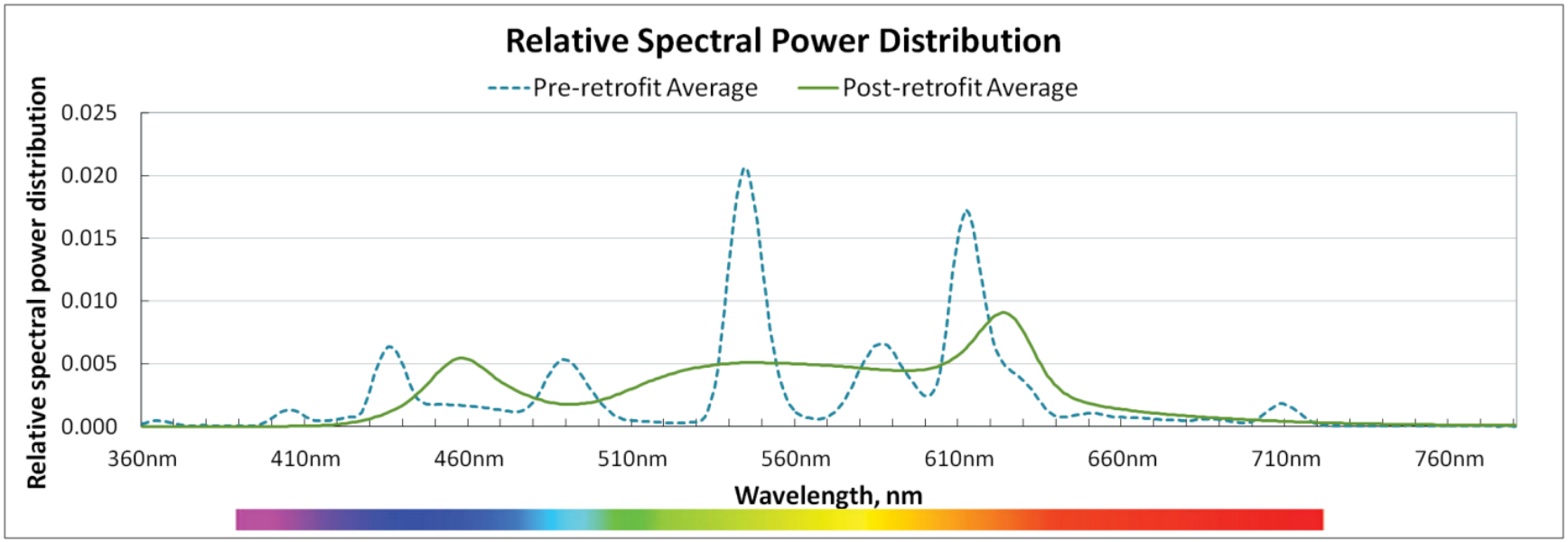


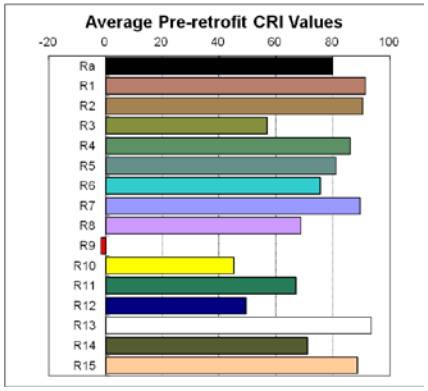



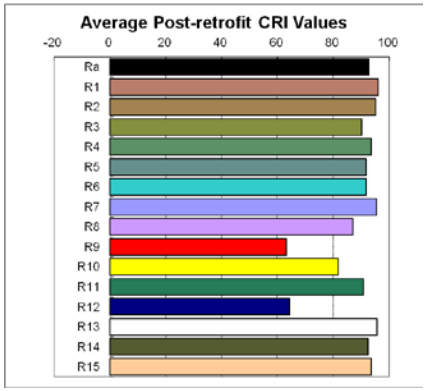
# Measured Changes in Spectral Power Distribution & CRI




| | Ra | R9 |
|---|---|---|
| Pre-retrofit | 80 | -2 |
| Post-retrofit | 93 | 63 |

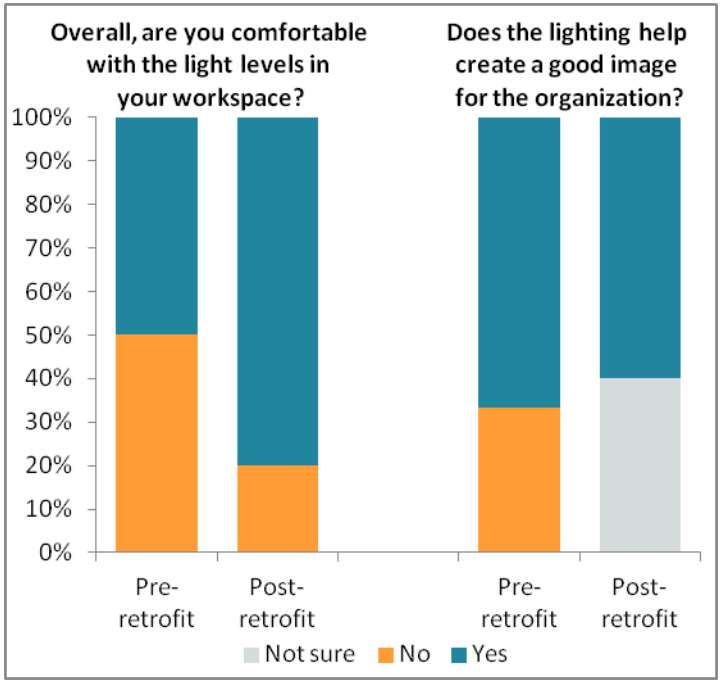


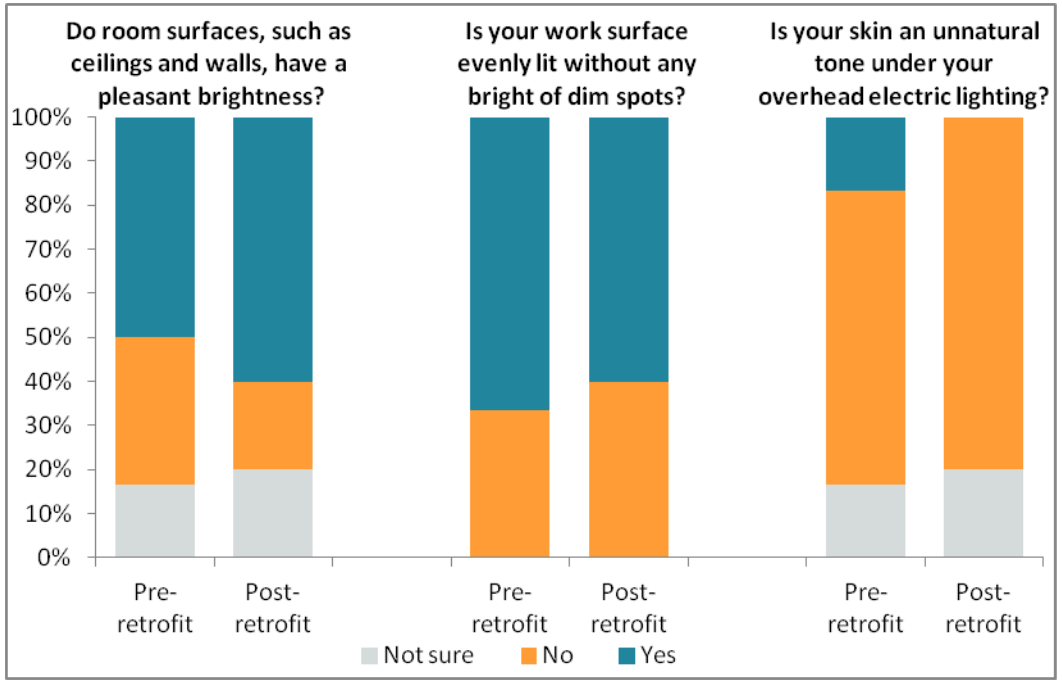

Fluorescent CRI




LED CRI

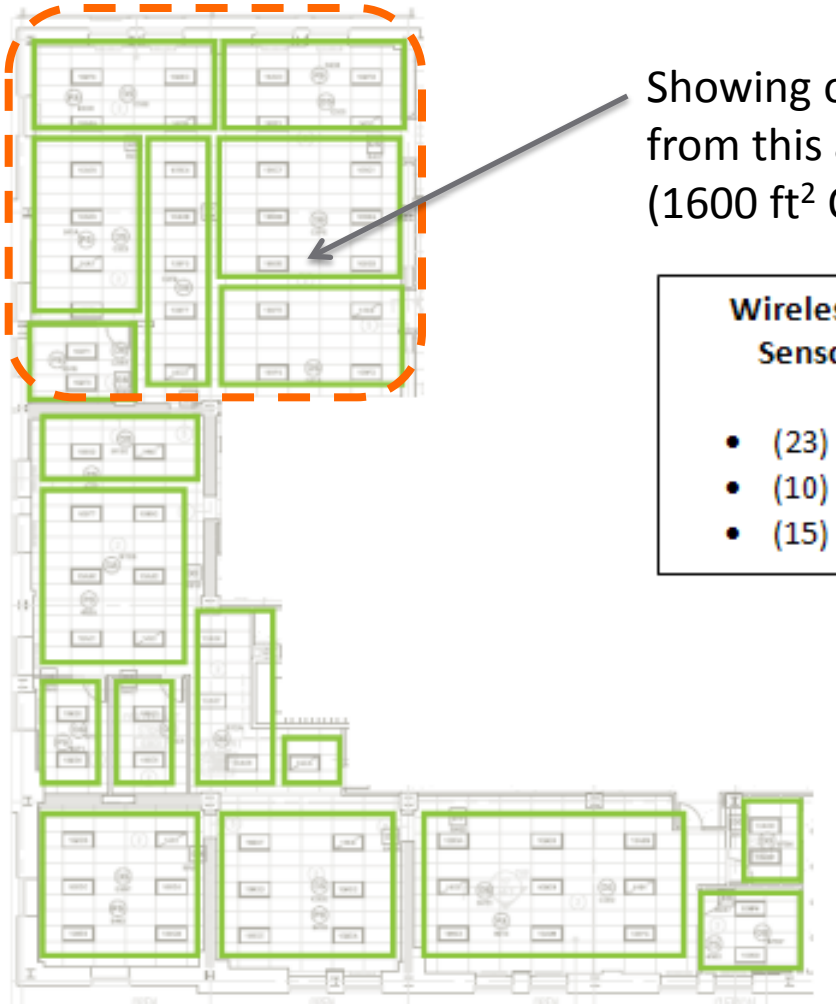
# Occupant Satisfaction Survey




Though not statistically significant, LED luminaires appeared to provide greater occupant satisfaction

# Appraiser's Building:
# *LED Luminaires with Wireless Controls*

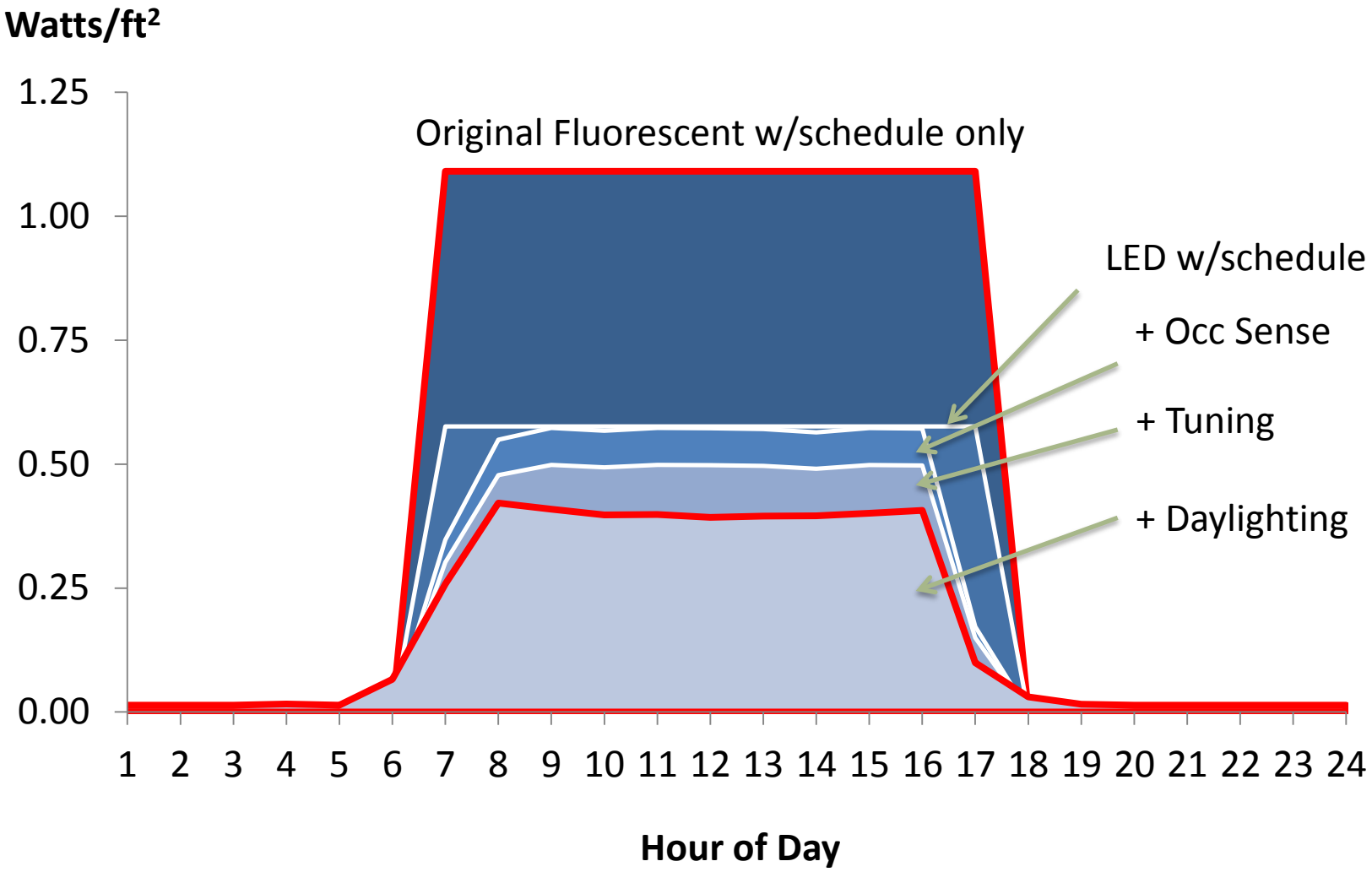


Showing one month's results
from this area only
(1600 ft$^2$ Open Office Area)

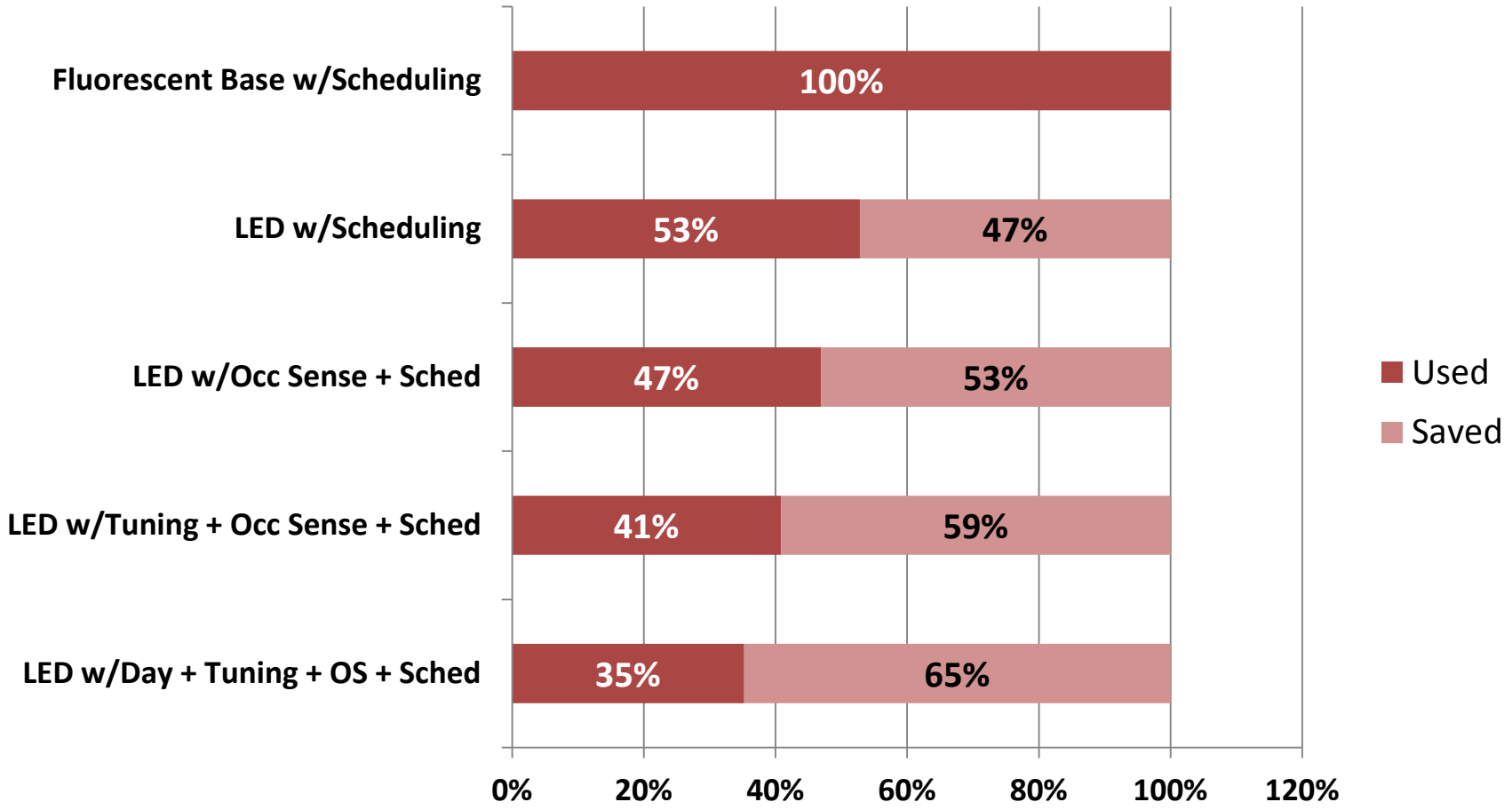
**Wireless Lighting System**
**Sensors and Switches**

- (23) Occupancy sensors
- (10) Photosensors
- (15) Dimmer switches

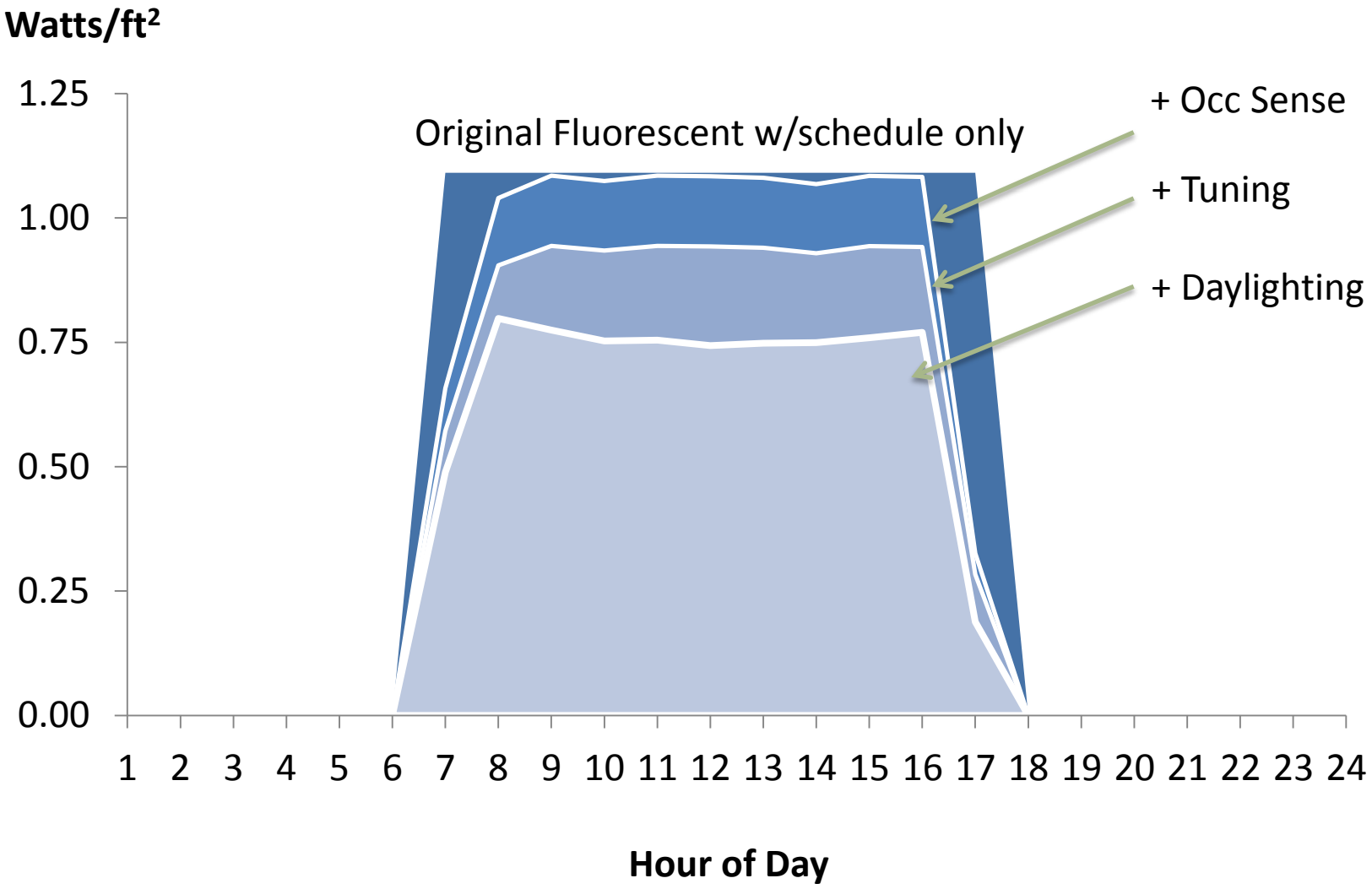
# Estimating How Much is Saved By Each Additional Control Strategy



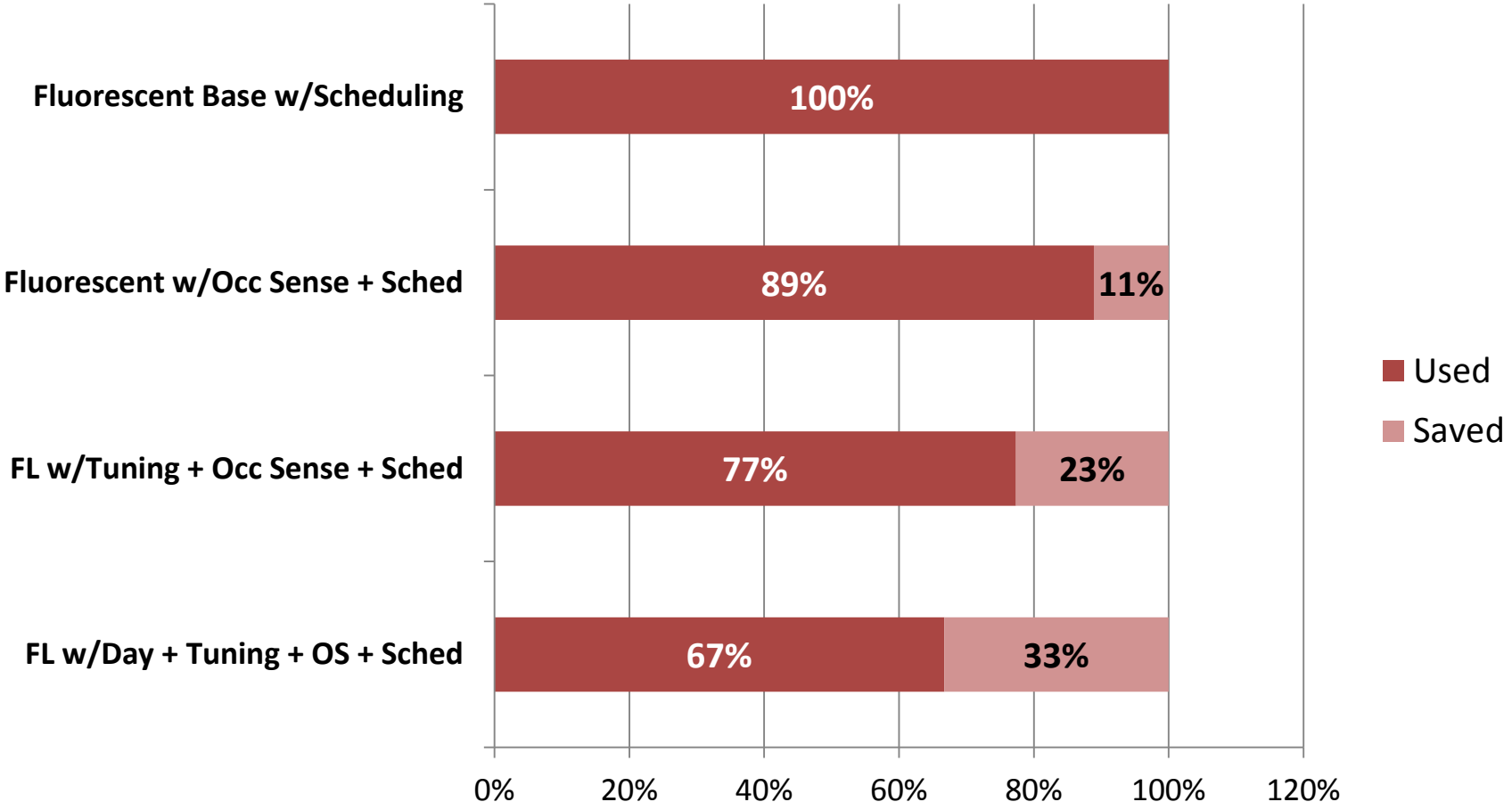
# Fluorescent to Controllable LED



# Simulating the Lighting Controls Savings if the Lighting Were *Not* Changed to LED



# Fluorescent to Controllable Fluorescent



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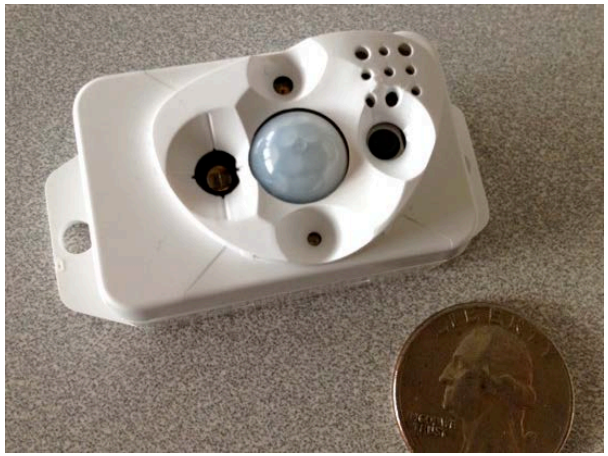
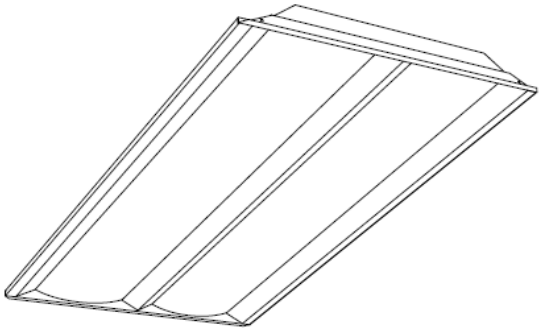
# Examples of Integrated Sensors for Individual Luminaires

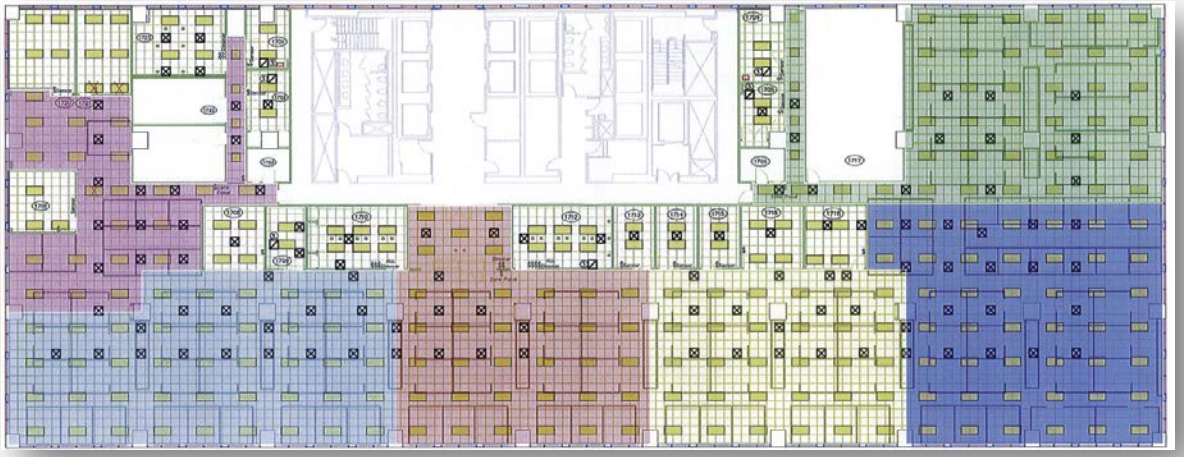
# LED Fixtures with Integrated Controls




- **Higher efficacy**: More lumens / watt, reducing lighting power and improving lighting service
- **Tuning**: Maximum fixture power set to default "medium" level (88% of maximum rated output)
- **Grouping and occupancy sensing**:
  - Fixtures organized in large zones (groups) that operate in concert (via on-board wireless communication)
  - When any fixture in group senses occupants, all fixtures in group turn on to "background" level
  - Fixtures above occupants brighten to "medium" level
- **Daylight harvesting**: reduces electric light levels based on available daylight

# Deployed in Two Federal Buildings

- **Metcalfe LED fixture grouping**



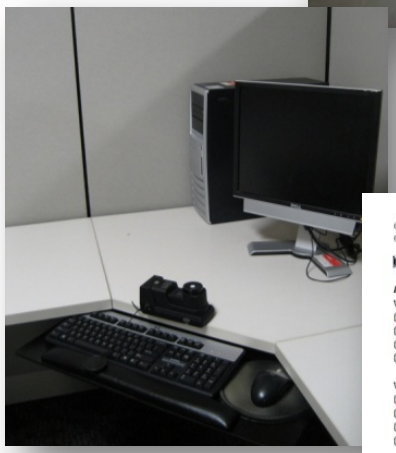
- Study Area ~ 19,750 ft$^2$
- 270 2’x 4’ 3 lamp parabolic troffers
- Large open office area with 9 private offices
- 2 conference rooms, 2 break rooms reception, storage areas, copy rooms, etc.

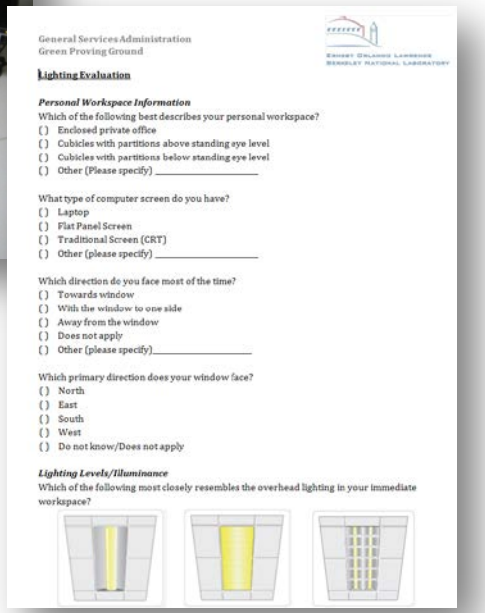
- **Summit LED fixture grouping**


- Total Area ~ 12,900 ft$^2$
- 150 recessed 2’x4’ 2 lamp troffers
- Open office areas, 2 private offices, 2 conference rooms, 1 copy room, 1 break room

# Our Measurement Suite

- Measure lighting power and energy usage
  - Lighting power density (LPD), W/ft$^2$
  - Energy use intensity (EUI), kWh/ft$^2$/year
- Measure light levels and characteristics
  - Illuminance (foot-candles)
  - Color rendering index (CRI)
  - Spectral power distribution (SPD)
  - Color Temperature (CCT)
- Determine occupant satisfaction through administration of surveys





General Services Administration
Green Proving Ground

Lighting Evaluation

*Personal Workspace Information*

Which of the following best describes your personal workspace?
( ) Enclosed private office
( ) Cubicles with partitions above standing eye level
( ) Cubicles with partitions below standing eye level
( ) Other (Please specify) _____

What type of computer screen do you have?
( ) Laptop
( ) Flat Panel Screen
( ) Traditional Screen (CRT)
( ) Other (please specify) _____

Which direction do you face most of the time?
( ) Towards window
( ) With the window to one side
( ) Away from the window
( ) Does not apply
( ) Other (please specify)_____

Which primary direction does your window face?
( ) North
( ) East
( ) South
( ) West
( ) Do not know/Does not apply

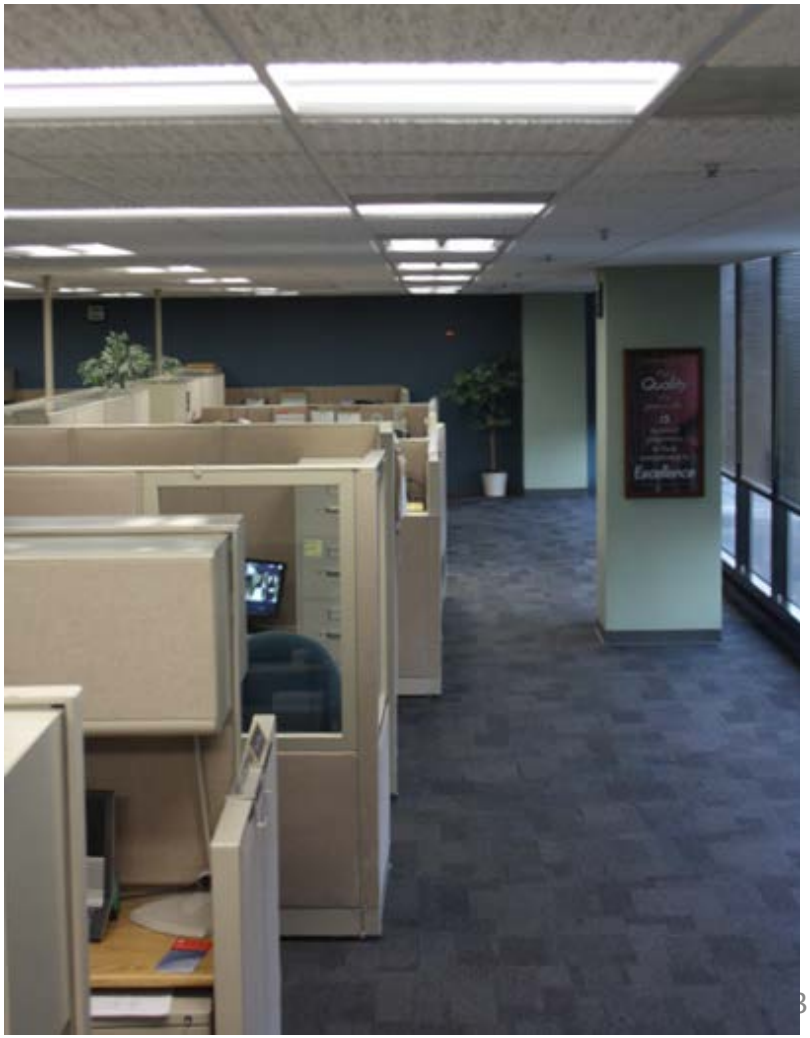
*Lighting Levels/Illuminance*

Which of the following most closely resembles the overhead lighting in your immediate workspace?

# Before & After Lighting (Metcalfe Building)

*Note the many randomly failed lamps before the new lighting was installed*

# Before & After Lighting (Summit Building)



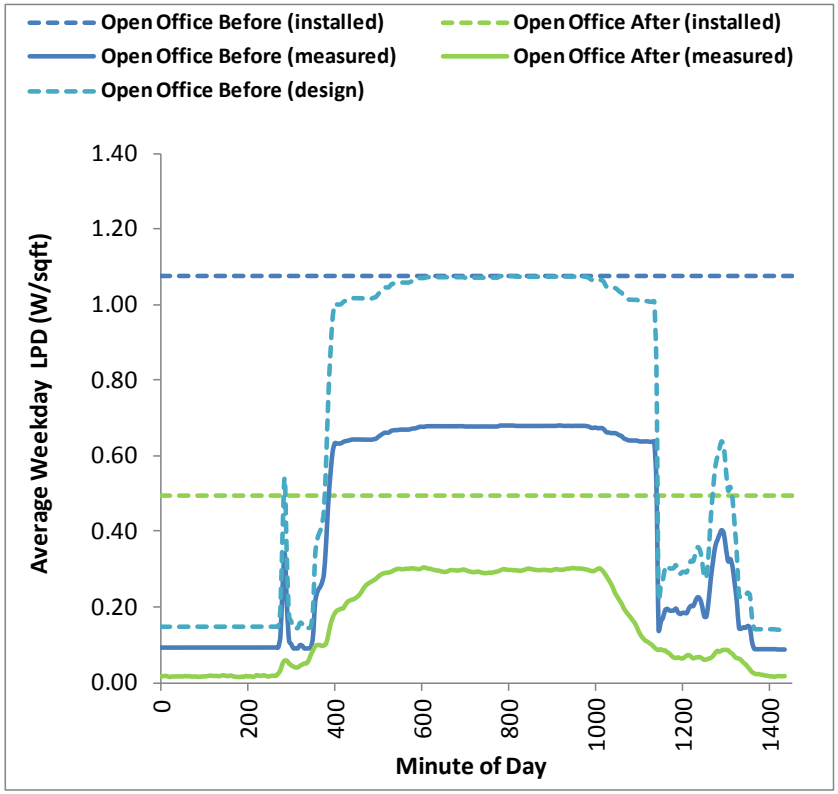
# Measured Changes in Lighting Power Density

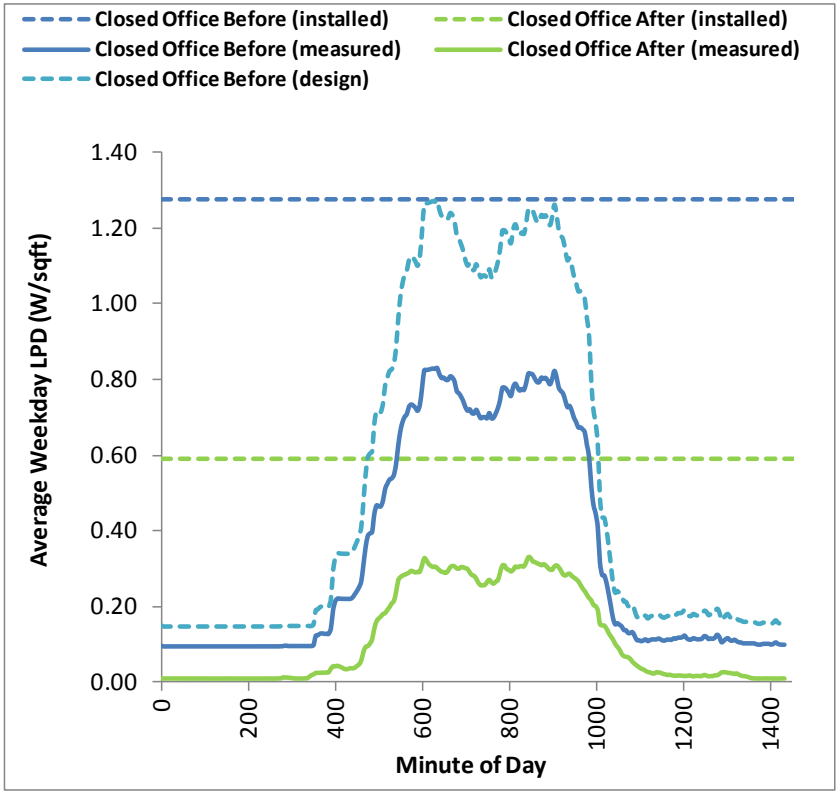
| | Metcalfe W/ft² | Metcalfe savings | Summit W/ft² | Summit savings |
|---|---|---|---|---|
| Pre-retrofit | 1.09 | -- | 0.66 | -- |
| Post-retrofit (full power) | 0.59 | **46%** | 0.52 | **21%** |
| Post-retrofit (tuned, medium power) | 0.50 | **54%** | 0.44 | **33%** |

Measured LPD at Metcalfe much lower (0.71) due to lamp outages

*Total fixture counts remained nearly the same at each location

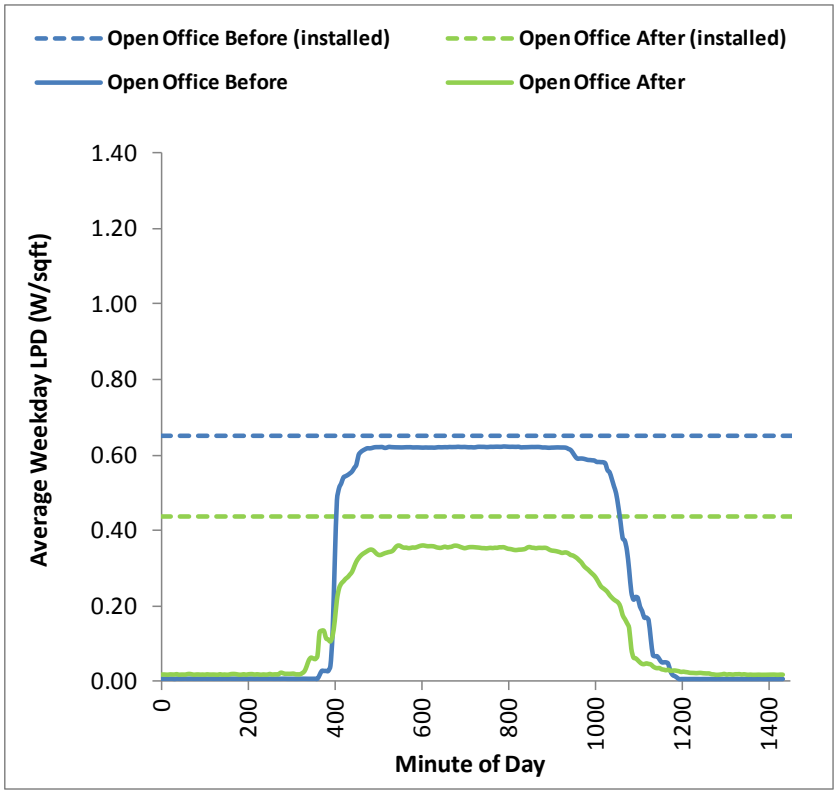
# Preliminary Energy Results: Metcalfe

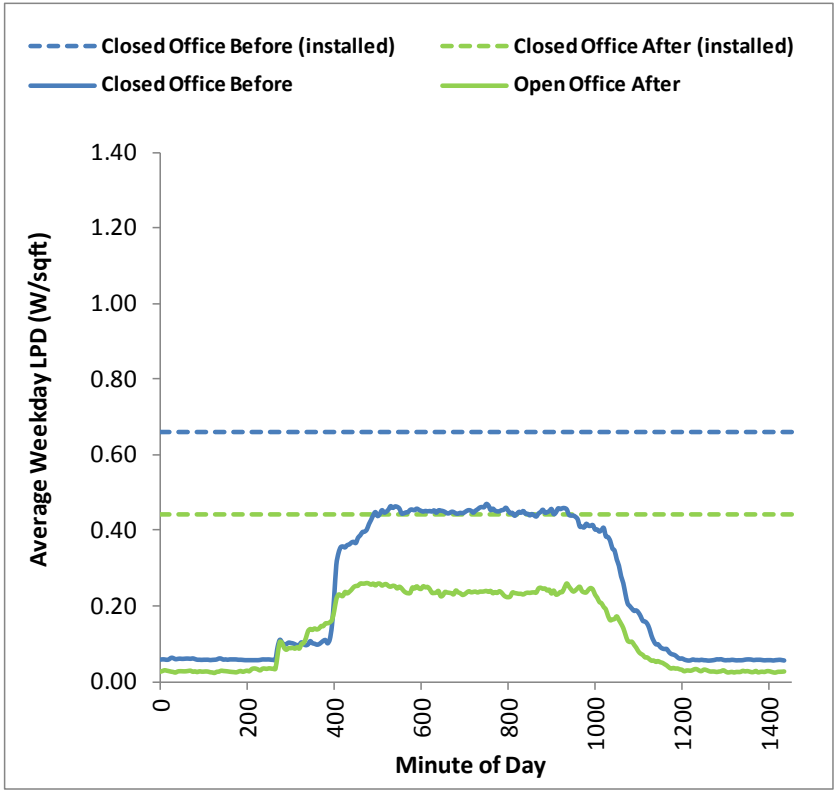



- Below average pre-retrofit energy consumption
  - Measured baseline EUI: 2.57 kWh/ft$^2$/yr
  - 'Design' baseline EUI: 4.03 kWh/ft$^2$/yr (with all fluorescent lamps working)
- Very low post-retrofit energy consumption
  - Post-retrofit EUI: 0.98 kWh/ft$^2$/yr
  - **62% savings**, and 76% relative to design

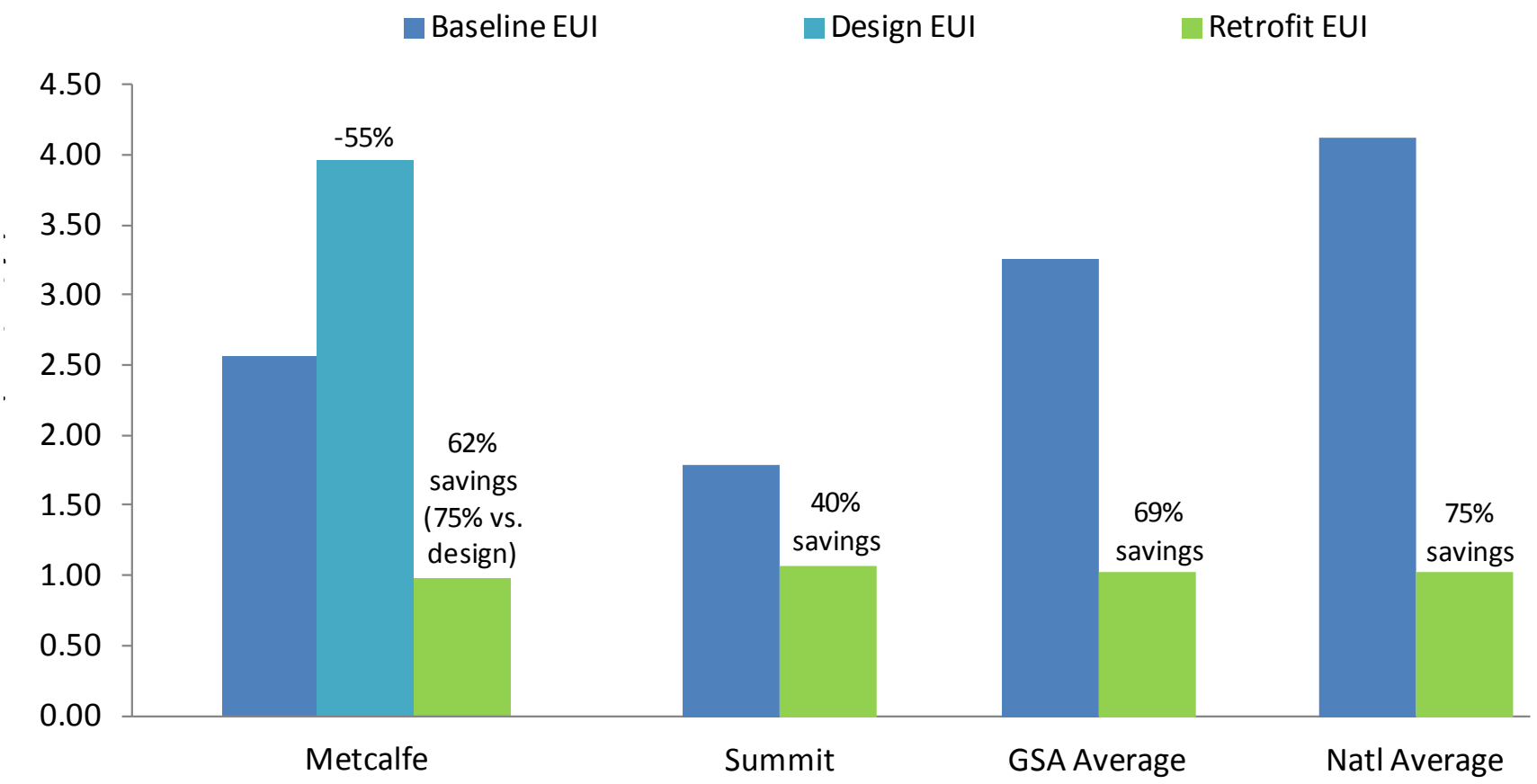
# Preliminary Energy Results: Summit



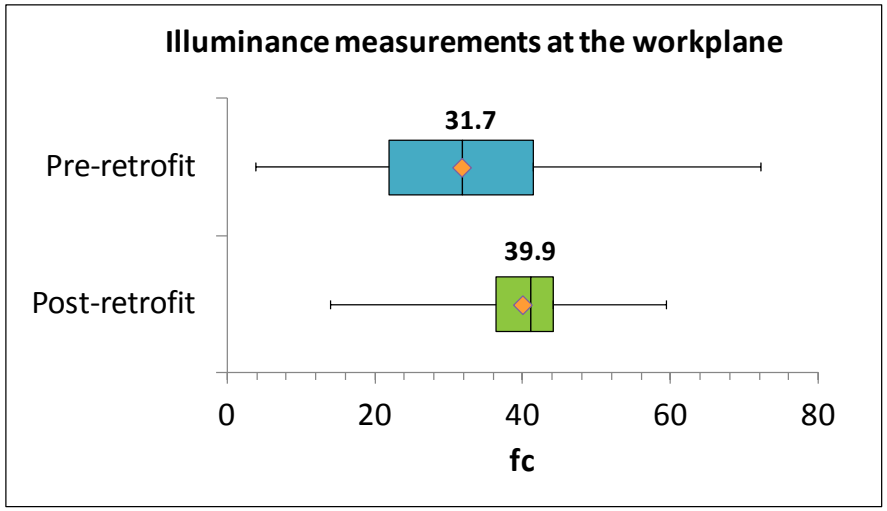

- Low pre-retrofit energy consumption
  - Measured baseline EUI: 1.84 kWh/ft$^2$/yr
- Very low post-retrofit energy consumption
  - Post-retrofit EUI: 1.09 kWh/ft$^2$/yr
  - **41% savings**

# Preliminary Energy Savings Results



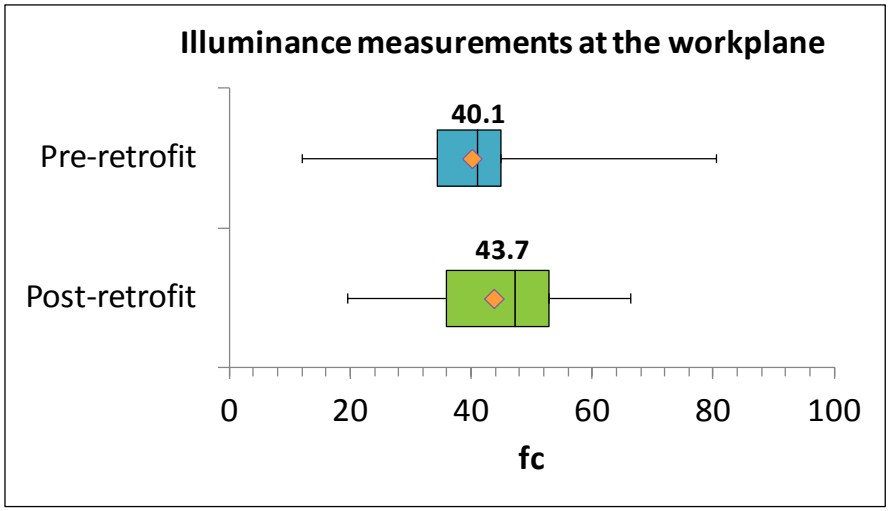
# Before and After Light Levels at Both Sites

## Metcalfe



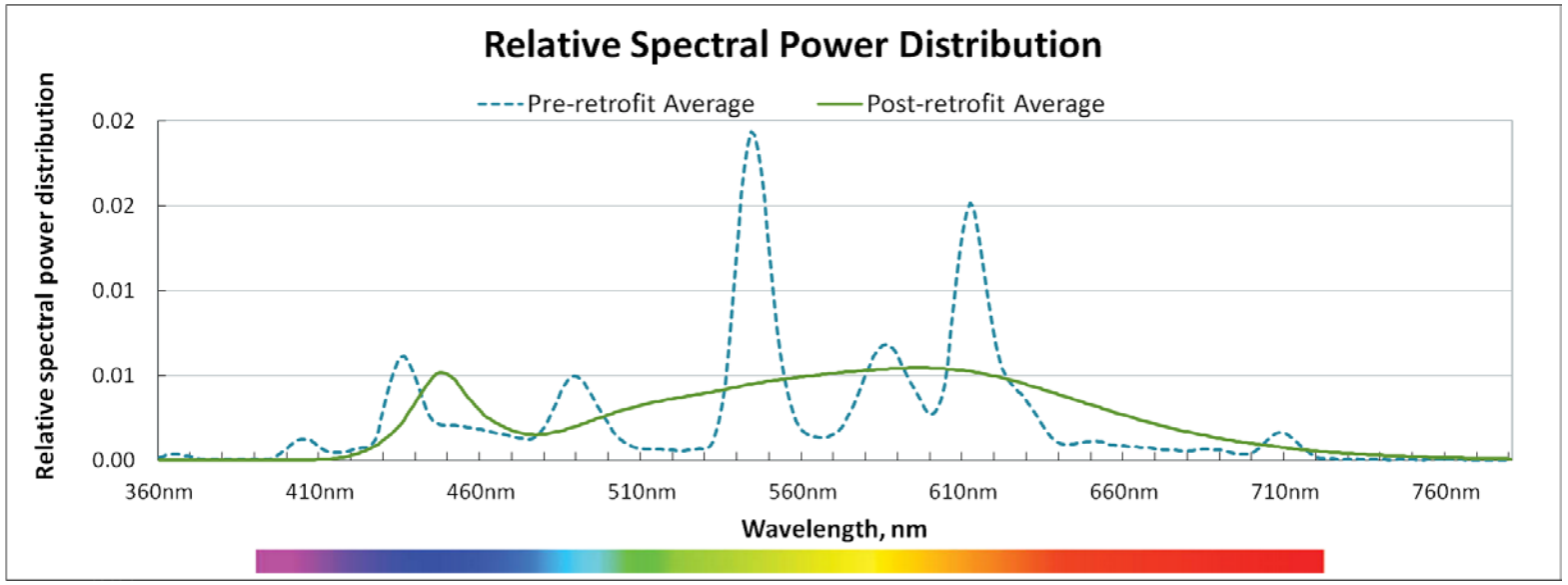

| Stage | CRI | R9 |
|---|---|---|
| Pre-retrofit | 77 | -14 |
| Post-retrofit | 83 | 17 |

## Summit




| Stage | CRI | R9 |
|---|---|---|
| Pre-retrofit | 81 | 2.8 |
| Post-retrofit | 83 | 14 |

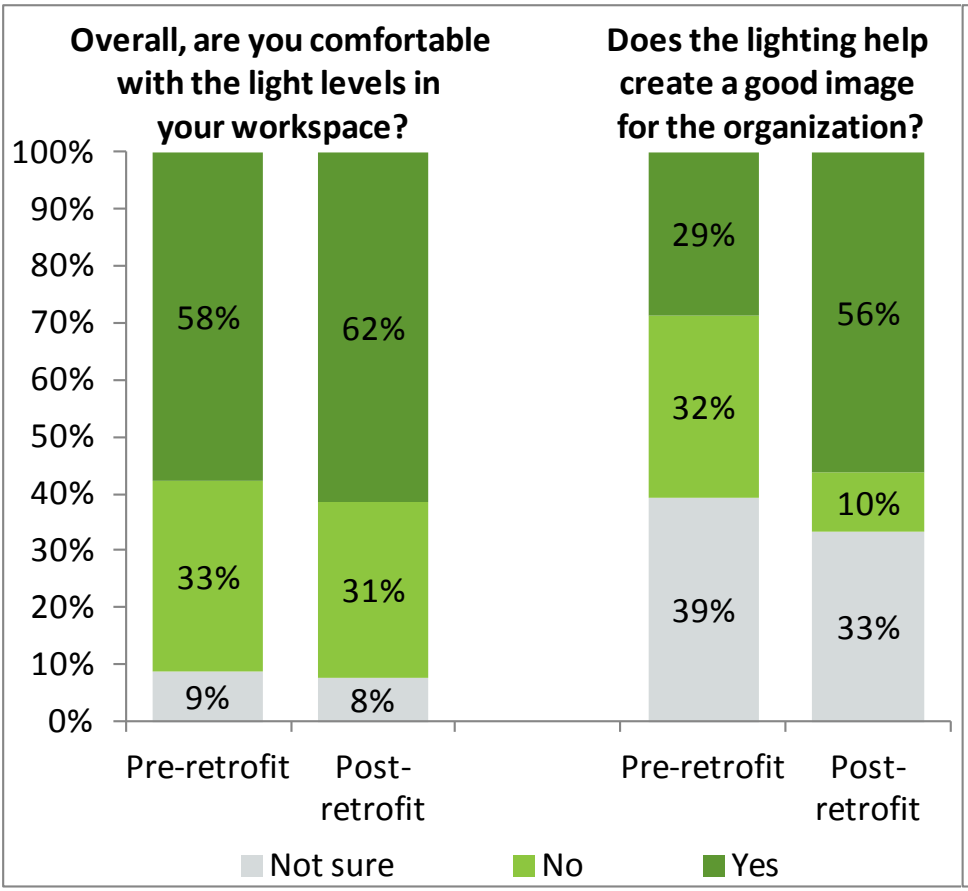
# Measured Changes in Color Quality



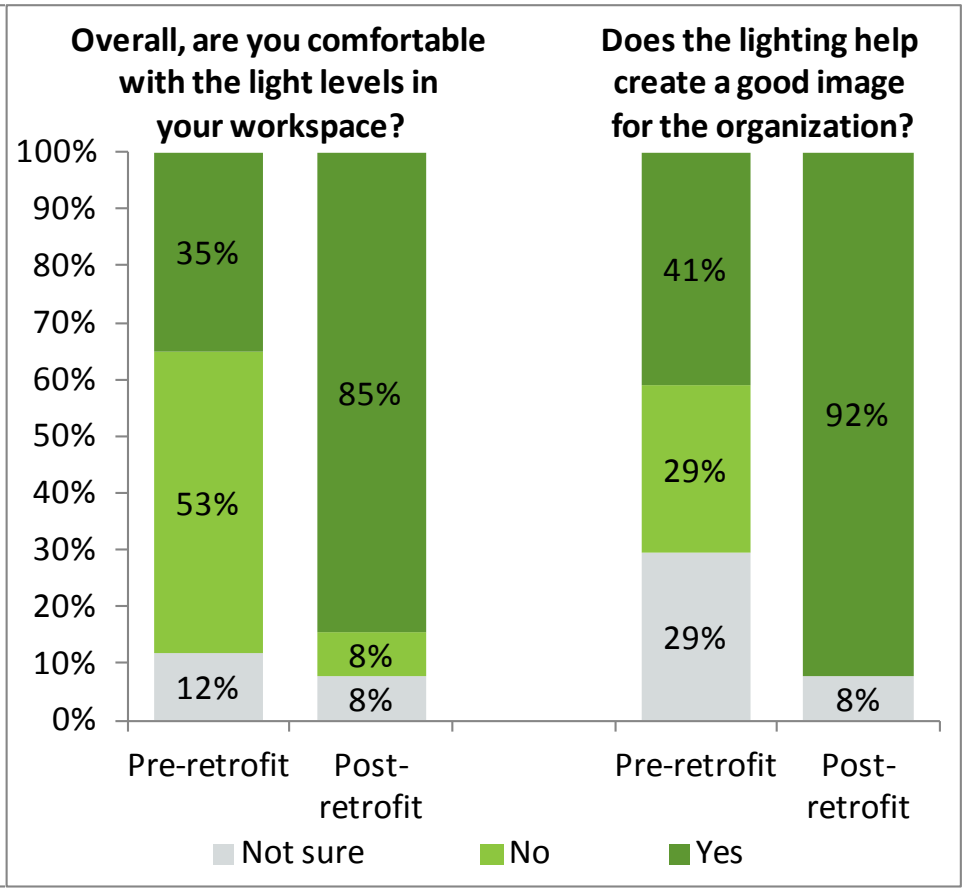

- Color temperature and spectral power distribution results similar at both locations
  - CCT Pre ~3800K
  - CCT Post ~3900K

# Occupant Satisfaction Survey: Before and After

## Metcalfe

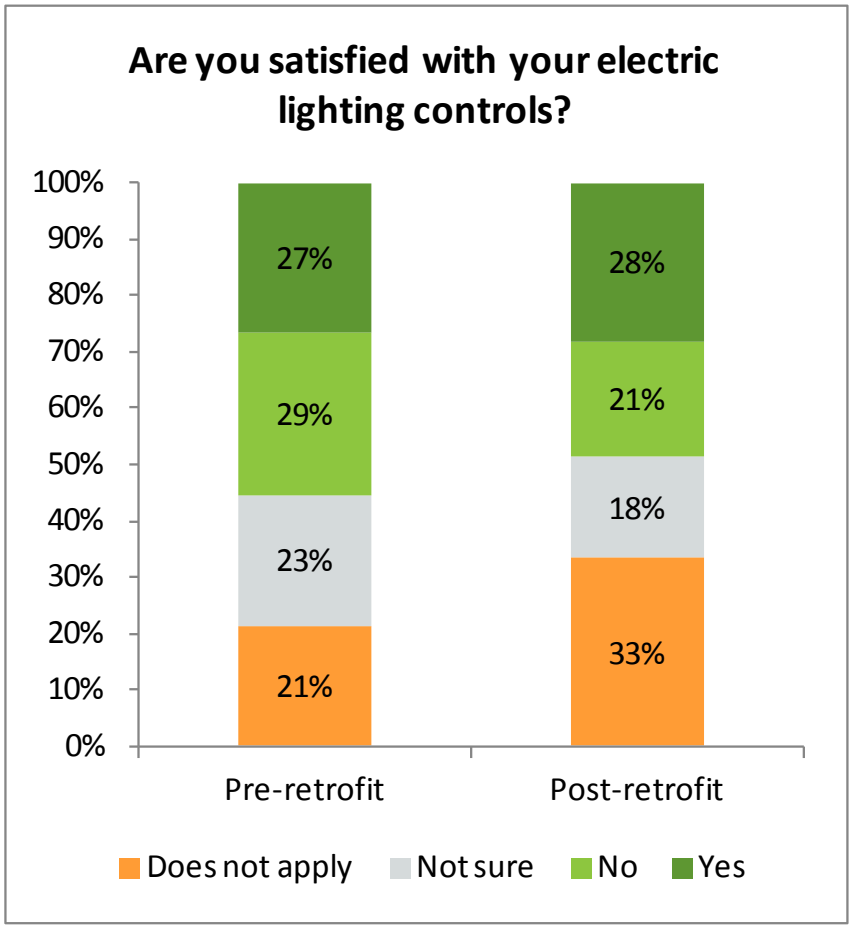



## Summit

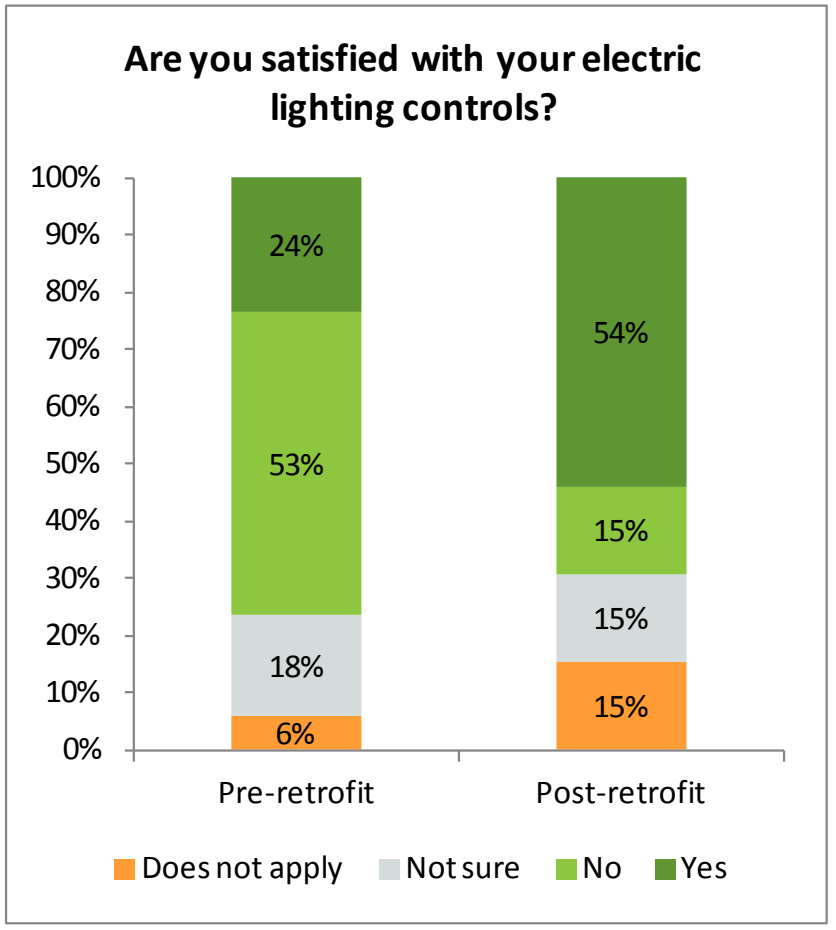


# Occupant Satisfaction Survey: Before and After

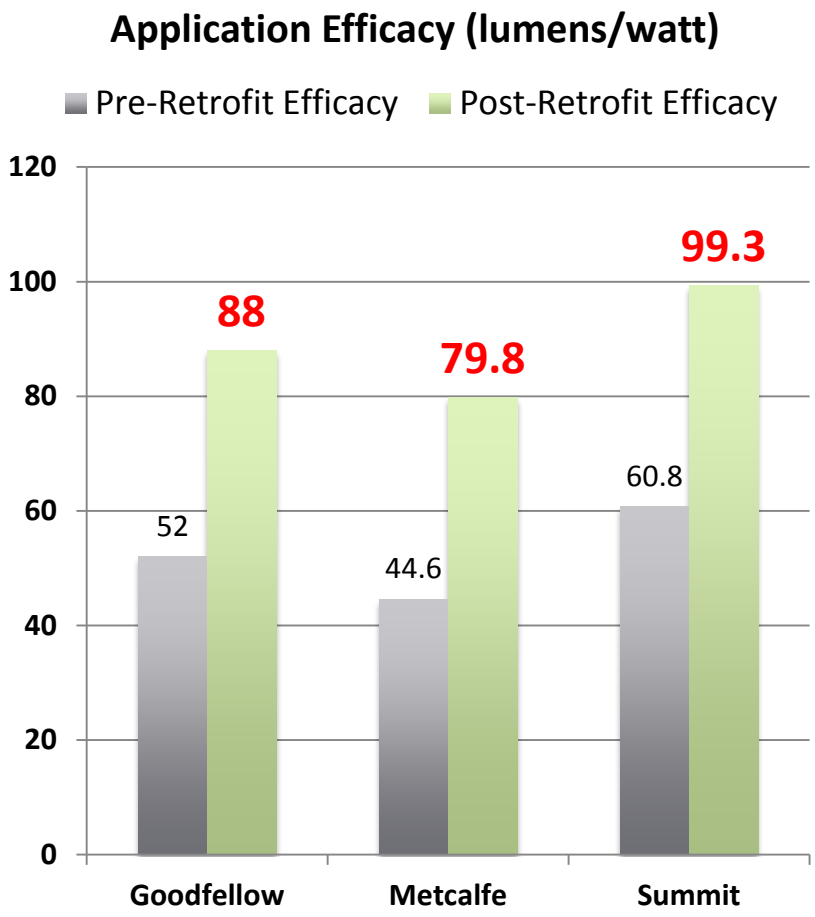
## Metcalfe

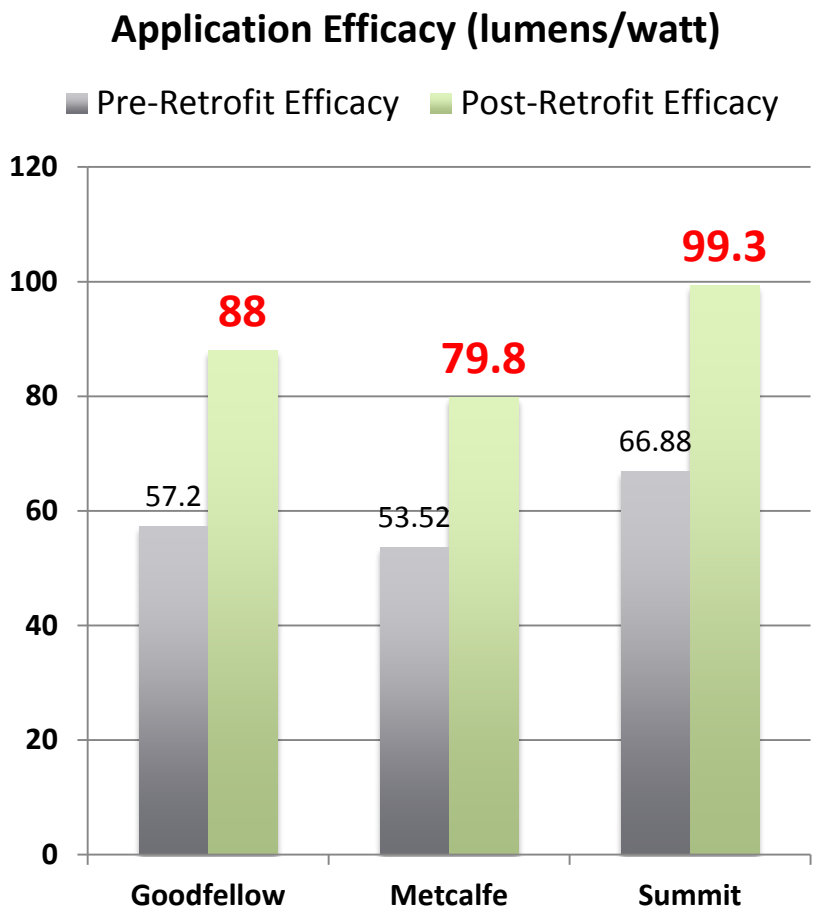



## Summit



# Measured Improvements of Workplane Efficacy (l/w)



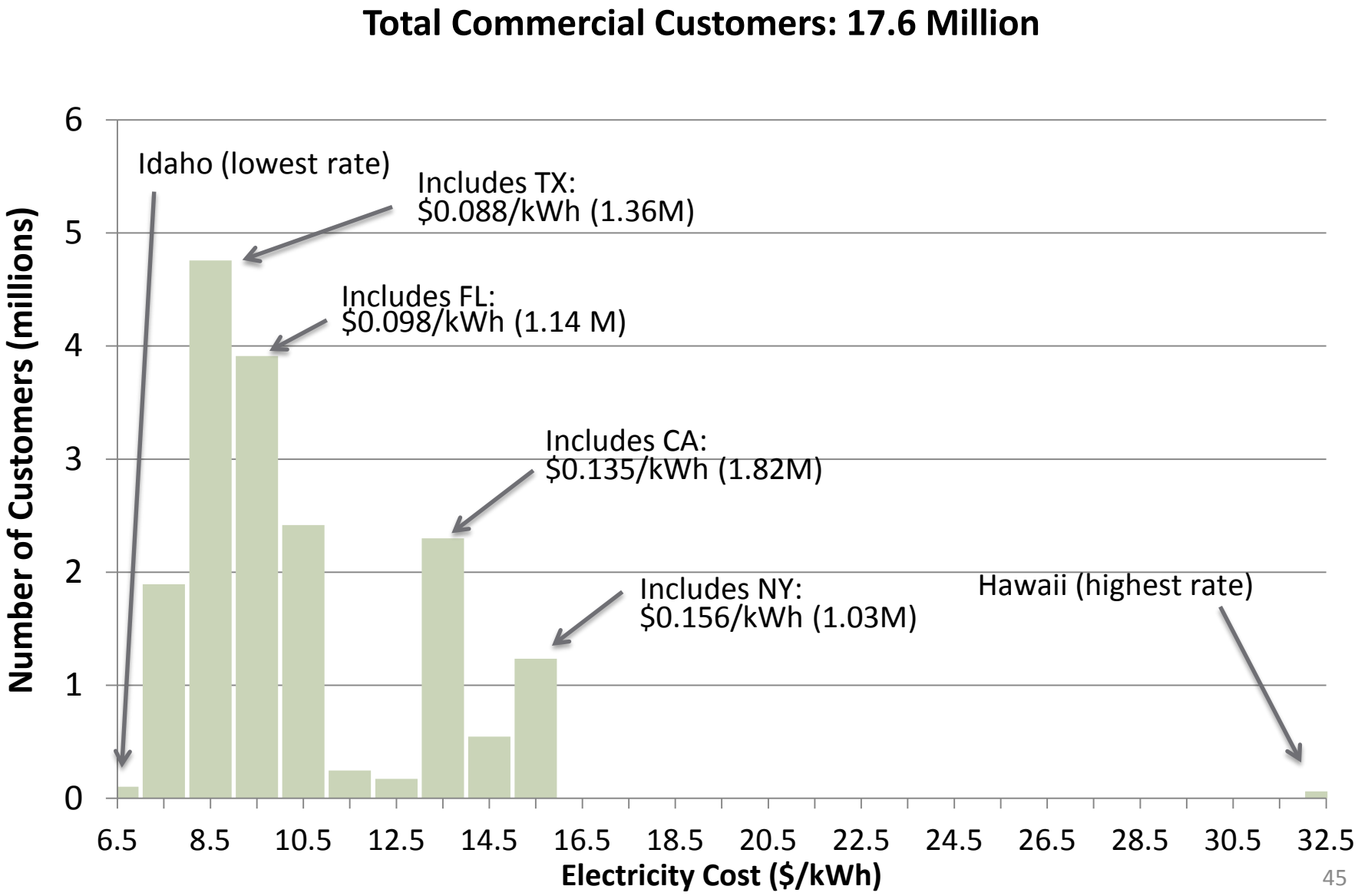



# Shifting Technology Trends in Lighting

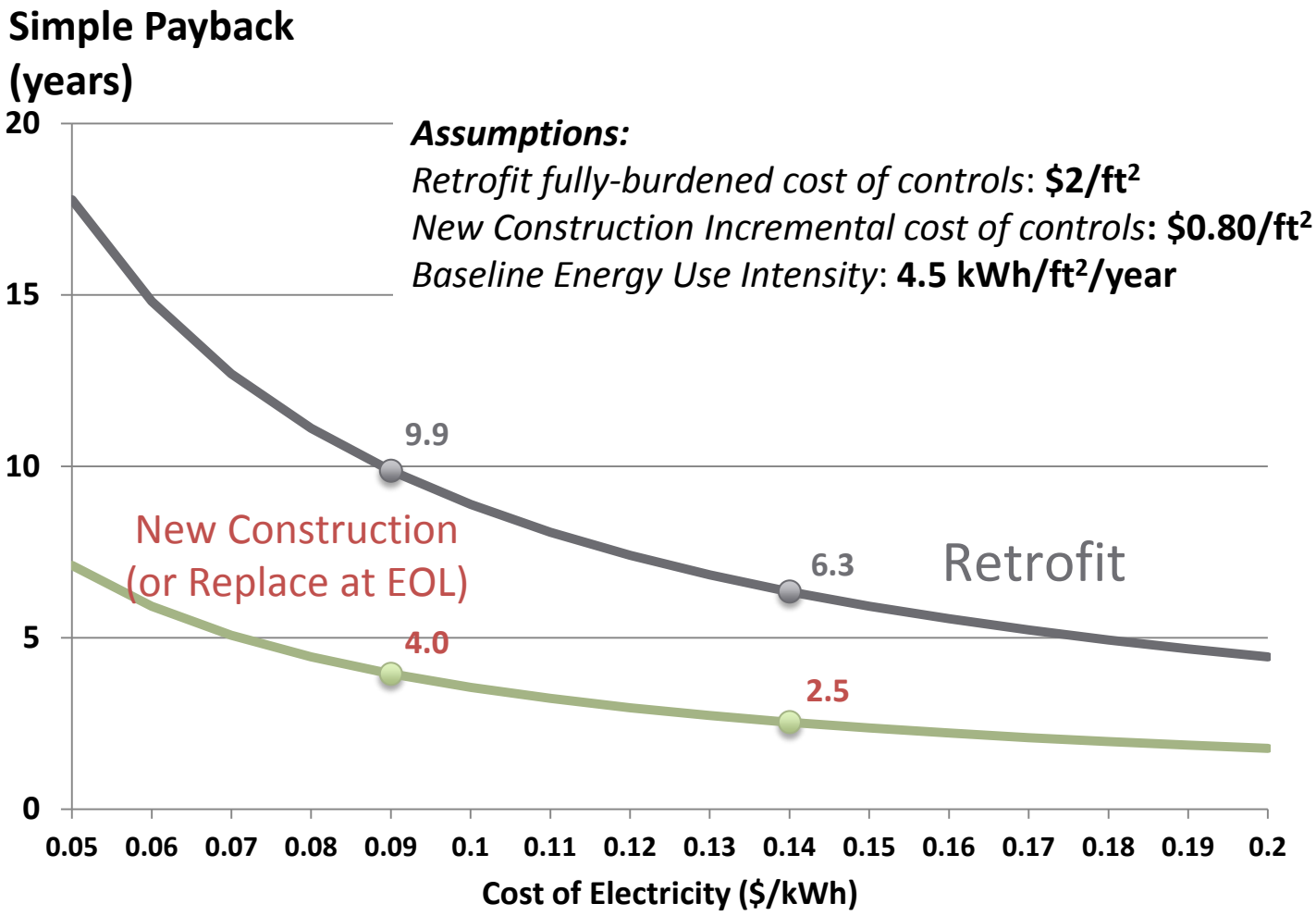
| Current Practice | Future Trend | Rationale for Shift |
|---|---|---|
| Re-Lighting (New Design) | Preserved Fixture Spacing | Minimize labor installation costs |
| Fluorescent lighting (static) | Controllable LED Lighting | Improved dimming range and performance with LEDs |
| Low-voltage control cabling | Wireless connectivity: - ZigBee, WiFi, Zwave, etc | Minimize re-wiring costs |
| Area-based sensors for detecting occupancy and daylight | Integrated sensor package for each luminaire | Reducing commissioning costs and set-up time |
| **Separate wireless controller and driver/ballast** | **Wireless connectivity integrated into driver/ballast** | **Lower capital and labor costs** |

# LED driver with snap-in communications package

# Electricity Costs for US Commercial Customers



# Paybacks for Retrofit & New Construction (or Replacement at End-of-Useful Life)



# Summary Points for Lighting Renovation

- Preserve fixture spacing to reduce first costs
- LEDs are easier & cheaper to control than fluorescent lighting
- Use wireless controls judiciously to avoid unnecessary re-wiring in the ceiling
- Luminaires that incorporate integrated sensors avoid many of the commissioning issues with area-based sensors
- Identify all code compliance issues early in the design process to avoid unexpected expenses that reduce cost-effectiveness

# Summary

- LEDs with wireless controls is clear winner for new construction or major renovation
- For retrofit applications, today's solutions are too expensive by factor of 2X to 3X
  - Labor cost variable and uncertain
- Need fluorescent-based controls solutions (retrofit kits) that cost under $\$2/ft^2$

# Acknowledgements

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Contact:

PMSchwartz@lbl.gov