U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

FEMP FIRST THURSDAY SEMIN@RS

Implementing New and Emerging Lighting Technologies

Instructors: Jeff McCullough, Pacific Northwest National Laboratory
Brian Liebel, The Lighting Partnership

FEMP Expert: Shawn Herrera, Federal Energy Management Program

FEMP Federal Energy Management Program

Core Competencies Addressed in this Seminar

Energy/Sustainability Managers

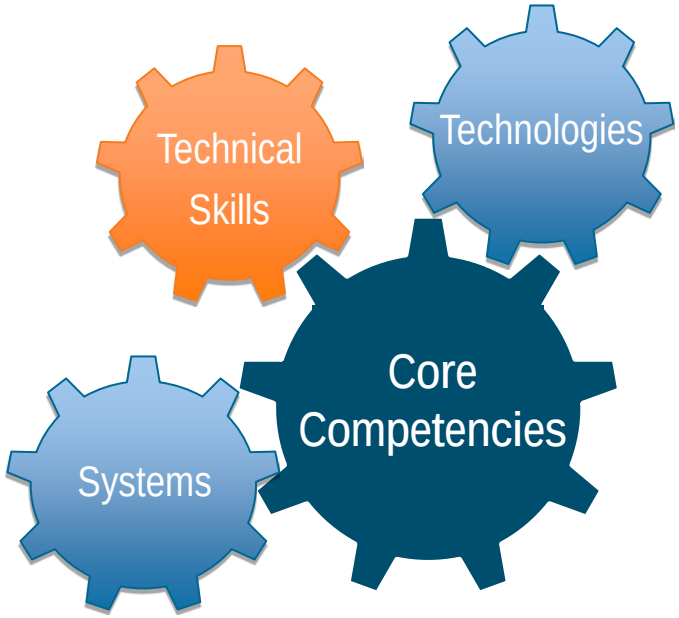
- Industry Trends
- Building Technologies
- Improving Energy Efficiency

Facility Managers

- Industry Trends
- Building Technologies
- Managing Facility Projects

Operating Engineers/Building Technicians

- Lighting Systems
- Adjust/Replace Lighting



Results and Expectations

Implement lighting solution projects that increase energy efficiency in Federal facilities thereby reducing greenhouse gas emissions.

Results and Expectations

1. Select optimal lighting replacement projects based on quality baseline data
2. Review a number of potential lighting technologies and select the best solution for a particular application based on life-cycle costs, design and installation feasibility, and other factors
3. Determine how you will measure project results
4. Locate DOE and industry resources to support decision making processes.

New Lighting Technologies

Overview

- Solid State lighting for exterior applications
- Spectrally enhanced lighting
- Resources to support your decision making

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Solid State Lighting for Exterior Applications

What is Solid State Lighting?

Sources of illumination other than electrical filaments, plasma, or gas

- inorganic semiconductor light emitting diodes (LEDs)
- organic light emitting diodes (OLED)
- polymer light emitting diodes (PLED)

FEMP Exterior SSL Technology Deployment

FEMP developing Federal-wide policy effort

- Example: a collaborative effort between FEMP and USACE to standardize SSL technology for exterior applications
  - Policy
  - Implementation plans
  - Training
  - Qualified Products List
  - Performance Specifications

Parking Structure Facts

- Approximately 110 million spaces
- Low/Medium Fixture Wattage
- Long Daily Operation
- High Energy Use
  - 28.1 TWh/yr
- Infrequent or low occupancy at times
- Daylight and controls potential

Light Source	Portion of Installed Equipment	Number of Lights (000s)
Incandescent	1.6%	600
Halogen	2.2%	800
Fluorescent	45.9%	16,600
Induction	7.4%	2,700
Mercury Vapor	0.1%	44
High Pressure Sodium	23.2%	8,500
Metal Halide	15.3%	5,600
LED	4.1%	1,500
Total	100%	36,400

Cost Type	Median Annual Cost per Space	Part of Total
Cashiering Salaries & Benefits	$184.57	33%
Management Costs	$57.69	10%
Security Costs	$90.65	16%
Utilities	$50.00	9%
Insurance	$13.76	2%
Supplies	$6.61	1%
Routine Maintenance	$37.02	7%
Structural Maintenance	$38.07	7%
Snow Removal	$4.07	1%
Equipment Maintenance	$6.07	1%
Other Expenses	$75.43	13%
Total	$564.03	100%

Unpainted concrete
Embassy Suites, Portland, OR
Source: PNNL

Ceiling & columns painted white
Arizona State University, Tempe, AZ
Source: PNNL

Parking Structure Controls

- Subterranean parking deck
- Directional flow traffic
- Parking for office building
- T12 → HPS → LED
- LED demo
- LED fixtures use occupancy sensors
- LED fixtures Next Generation Luminaire (NGL) winners

Department of Labor Headquarters
Washington, D.C.

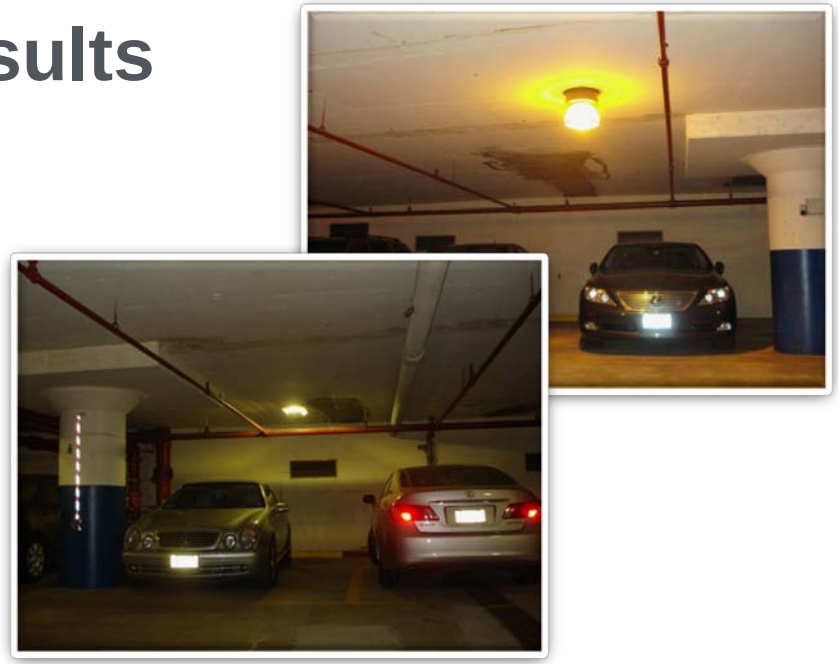
Results

55% savings

- HPS draws 137 W
- LED draws 62 W (high state)

Illuminance

- Average down from HPS to LED
- Minimum up from HPS to LED



Department of Labor Headquarters, Washington, D.C.

LED and Controls!

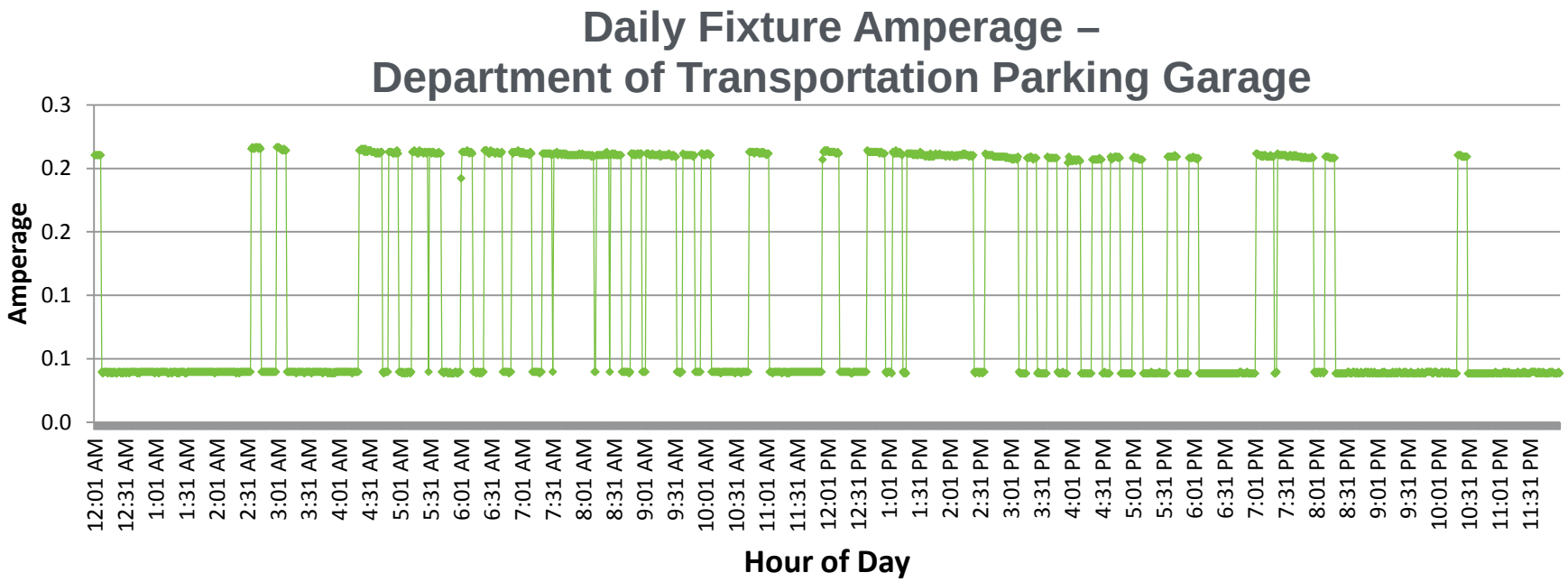
- Bi-level lighting appropriate for garage, parking lots, pedestrian areas
- Motion sensors to reduce lighting levels when not in use

Key Factors for Deployment

Metric	Federal Energy Savings	Cost Effectiveness	Probability of Success	Weighted Score
Weighting	50%	30%	20%	100%
Bi Level Garage / Parking Lot / Pedestrian Lighting Value	0.9	4.0	5.0	53

Army Planning Wide Spread Deployment

Army Exterior SSL Policy Announcement


Daily Fixture Amperage –
Department of Transportation Parking Garage
Amperage
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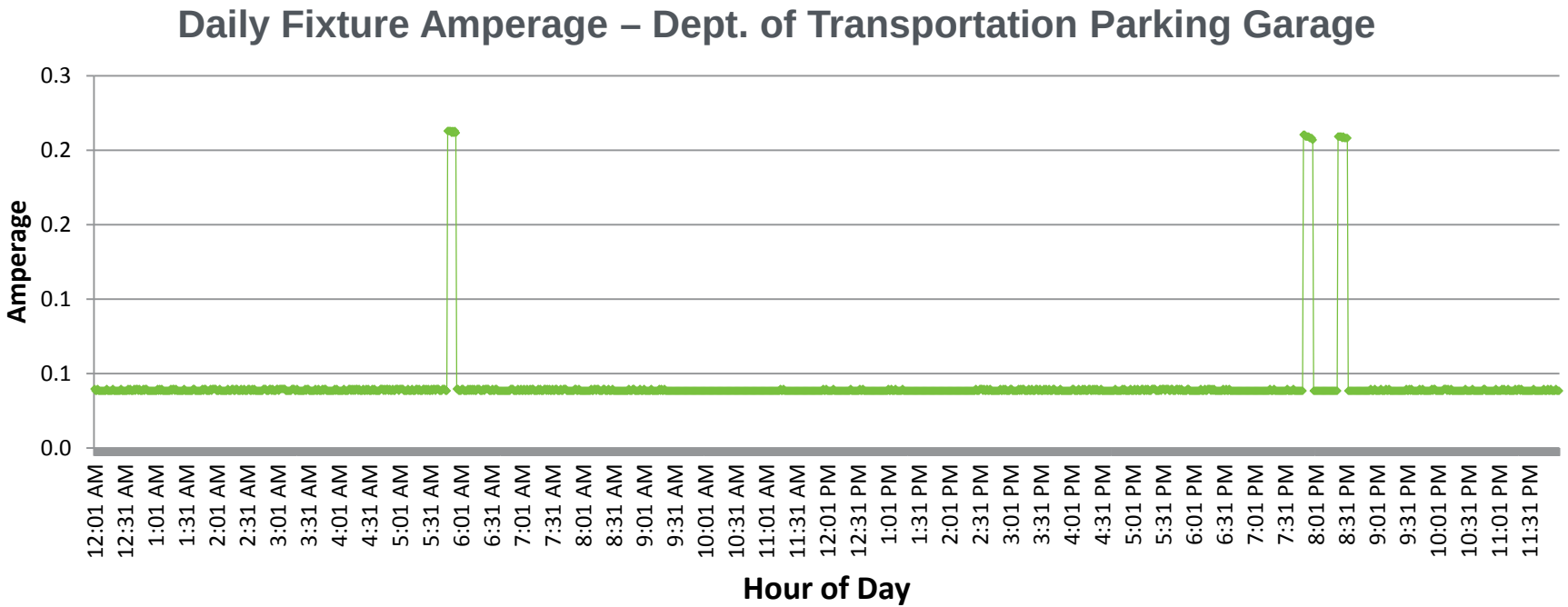
Hour of Day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Hour of Day

Results

- Operating profile
  - Operating in high state ≈30% of time
  - Operating in low state ≈70% of time
- Time out of sensor affects savings
- One way traffic affects usage

LED on left / HPS on right
Department of Labor Headquarters
Washington, D.C.

Challenges

- Pipes and signs affect coverage
- Air handler caused “false positive”* for at least one luminaire
- Columns affect coverage
- Motion sensor triggered when no actual movement

Department of Labor Headquarters, Washington, D.C.

Specification Overview

Energy Conservation

- 0.18 W/sf

Background

1. EPAct 40% Parking Structure LPD: 0.18

2. Parking Structures are covered by EPAct deduction

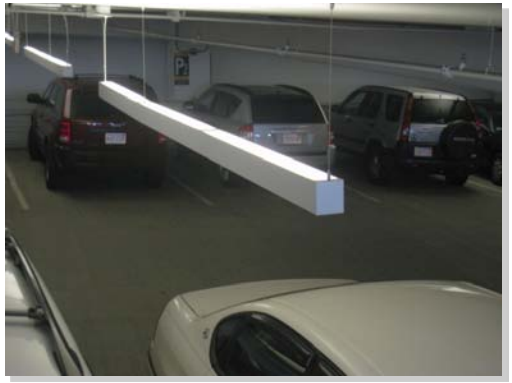
   Internal Revenue Bulletin: 2008-14 Section 6.

Hotel, Cupertino, CA

http://www.irs.gov/irb/2008-14_IRB/ar12.html#d0e4216

Specification Area of Structure	Horizontal[1] Illuminance Requirement	Vertical[2] Illuminance Requirement	Uniformity Max:Min	Uniformity CV
Covered Parking Areas	1.25 (Min)	0.5	7:1	0.38
Ramps (Day)	2.00 (Min)	1.0	10:1	0.41
Ramps (Night)	1.00 (Min)	0.5	10:1	0.41
Vehicle Entry (Day)[3]	50.00 (Min)	25.0	10:1	0.41
Vehicle Entry (Night)	1.25 (Min)	0.5	10:1	0.41
Uncovered (Top Deck)	0.75 (Min)	0.4	10:1	0.41

Specification: Technologies



Fluorescent

Induction

LED

Specification: Daylighting Controls

1. Luminaires within 20’ of perimeter and if wall is 40% open must be controlled with daylight harvesting
2. Luminaires in vehicle exit/entry area turn off additional lighting at night

Photocell requirements

a. 15 – 30 second time delay
b. 10 fc set point for sensor
c. Mounted in an unobscurred location
d. Use relays that are UL 773 or UL 773 A

Electric lighting & daylight
Hotel, Cupertino, CA

Specification: Occupancy Sensor Controls

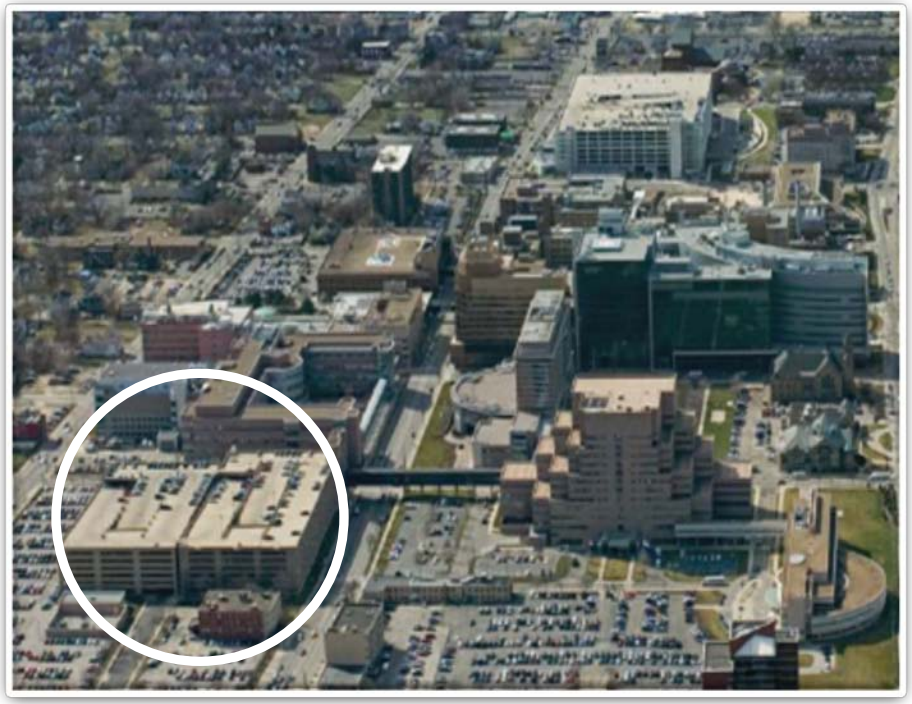
- 1 occ sensor per luminaire, maximum coverage
- Sensors comply with WD 7-2000
- Sensor Type: Infrared or microwave
- Sensors not affected by ambient temperature
- Failsafe feature to fail “on” in event of sensor failure
- Site owner to specify if sensors are on/off or high/low

Control requirements may change

Parking Structures → Low-hanging fruit

- Large footprint, but low equipment density
- High tax incentive with low capital outlay

Natick Collection



Specification in Practice

Cleveland, Ohio

Cleveland Ohio, Hospital Highlights

- ≈1,000,000 sq feet
- 1,500 spaces
- Converted from HPS (top) to LED (bottom)
- 840 fixtures
  - 620 with occupancy sensors
  - 218 with daylight sensors
- Projected 82% energy savings
- Payback: 4.2 years simple payback

Specification in Practice: Washington, DC Metro

- 13,000 HPS luminaires
- 24-hour operation
- 24 parking structures
  - 303,000 – 1,130,000 square feet
- Constructed between 1980 & 2011

- *Offerors are requested to submit a design-build-maintain solution for replacing all HPS fixtures in accordance with the Commercial Building Energy Alliance (CBEA) High Performance Lighting Parking Structure Specification…*

NREL Parking Garage

Computer rendering courtesy of RNL

- 1800 parking spaces
- 1.13 MW PV Arrays
- Daylighting and Controls
- 77W LED Luminaires

Reference	LPD (W/s.f.)	Average Illuminance (foot candles)
NREL Parking Structure	≤ 0.05	≤ 1 fc
CBEA High Efficiency Parking Structure Lighting Specification	0.05-0.18	1-5 fc
ASHRAE 90.1 2007	0.18-0.3	≥ 5 fc

Selecting SSL Exterior Lighting Projects

Applications:

- Parking Lots/Areas
- Parking Garage
- Roadway
- Wall Packs
- Canopies
- Bollards

Benefits:

- Improved uniformity
- White light
- Long life/reduced maintenance costs
- Durability
- Digitally controllable

Evaluating Lighting Technologies

Requires site-specific evaluation:

- Paybacks range from 3 to 20 years
- Conduct life-cycle cost analysis
- Consider non-energy benefits as well

Things to look for:

- 5+ year warranty
- Ask for IES reports
  - LM-79
  - LM-80/TM-21
- Color appropriate for application
- Light distribution and glare

Measurement and Verification

- Wattage reduction calculation can be verified with spot-measurement.
  - For most projects 12 hour/day operation can be assumed
- Occupant/daylight control schemes require metering
- Illuminance readings taken at t_0 and at pre-defined intervals to track lumen maintenance.

See Gateway Reports:

www1.eere.energy.gov/buildings/ssl/gatewaydemos_results.html

FEMP Resources

- Street/Roadway lighting
- Parking Structure lighting
- General Resources
- Design Light Consortium
  - Qualifying Products List

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FEDERAL ENERGY MANAGEMENT PROGRAM

A FEMP Outdoor SSL Initiative

Resources for Outdoor SSL Applications

LED lighting installed in the parking garage of the Frances Perkins Building, U.S. Department of Labor headquarters, Washington, D.C.

Outdoor Solid-State Lighting in the Federal Sector

The Federal Energy Management Program (FEMP) is encouraging Federal agencies to accelerate the thoughtful application of outdoor solid-state lighting luminaires. The FEMP Outdoor SSL Initiative offers a unique opportunity for the Federal sector to lead a large-scale implementation effort focused on an SSL application that is ripe for near-term implementation through a process that recognizes the technology's potential, as well as its challenges. This initiative is intended to help Federal energy managers overcome the widespread misinformation they are encountering, learn about this technology and its unique attributes, and provide the tools needed to make good decisions that result in cost-effective energy savings and good-quality lighting.

As part of this initiative, FEMP will leverage existing SSL outdoor tools and materials, and will develop new ones as needed to meet the unique needs of Federal agencies. This paper provides an overview of existing outdoor SSL resources developed by the US Department of Energy's SSL Program and other Federal initiatives including:

- SSL Street/Roadway Lighting
- SSL Site (Parking Lot/Garage) Lighting
- General SSL Resources

Street/Roadway Lighting

A variety of resources are available for facility managers interested in pursuing SSL street and roadway lighting, including DOE SSL GATEWAY demonstration project results, a Find Target Efficacy Calculator, and DOE CALiPER test results.

Municipal Solid-State Street Lighting Consortium Fact Sheet – The Consortium shares technical information and experiences related to LED street and area lighting demonstrations. The Consortium also serves as an objective resource for evaluating new products on the market intended for street and area lighting applications.
http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/consortium_fs.pdf

DOE SSL GATEWAY Demonstration Project Results – DOE GATEWAY demonstrations showcase high-performance LED products for general illumination in a variety of commercial and residential applications. Demonstration results provide real-world experience and data on state-of-the-art solid-state lighting (SSL) product performance and cost-effectiveness. The following studies have been completed on Street/Roadway lighting:

- ***LED Roadway Lighting: Palo Alto, California***
  Assessment of energy, economic, and performance impacts of replacing high-pressure sodium street lights with LED and induction street lights.
  http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/gateway_palo-alto.pdf

According to the U.S. Department of energy, no other lighting technology offers as much potential to save energy and enhance the quality of our building environments, contributing to our nation's energy and climate change solutions.
http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/dec2010_guidedmarket_factsheet.pdf

- ***LED Street Lighting: Lyn Loop, Portland, OR***
  Analysis of the energy and performance impacts of replacing eight high-pressure sodium street lights on one residential street with LED luminaires.
  http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/gateway_lyn-loop.pdf
- ***LED Roadway Lighting: I-5W Bridge***
  Analysis of Phase 1 results, completed in September 2008. Phase 2 involves long-term monitoring to evaluate lumen depreciation, physical effects, and performance impacts over time.
  http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/gateway_i-5w-bridge.pdf

Spectrally Enhanced Lighting (SEL)

What is Spectrally Enhanced Lighting (SEL)?

- Design method for interior lighting applications where **visual acuity** is important
- Not for outdoor lighting

SEL Ranked High for Technology Deployment

- Designs are simple lamp/ballast retrofits that result in 20-30% energy savings
- Requires no special controls or equipment
- Paybacks are typically
  - 3-4 years on T8 retrofits
  - 1 year for T12 retrofits

SEL Office Lighting Retrofit

Before

After

Washington DC Navy Office Building

Before

After

Orinda City Hall: New Construction

LEED Gold

Lamp Nomenclature

835 Lamp

78-85 CRI

CRI: scale from 0-100: How well the lamp renders color

3500K Correlated Color Temperature

CCT Scale

(6500-8000K)

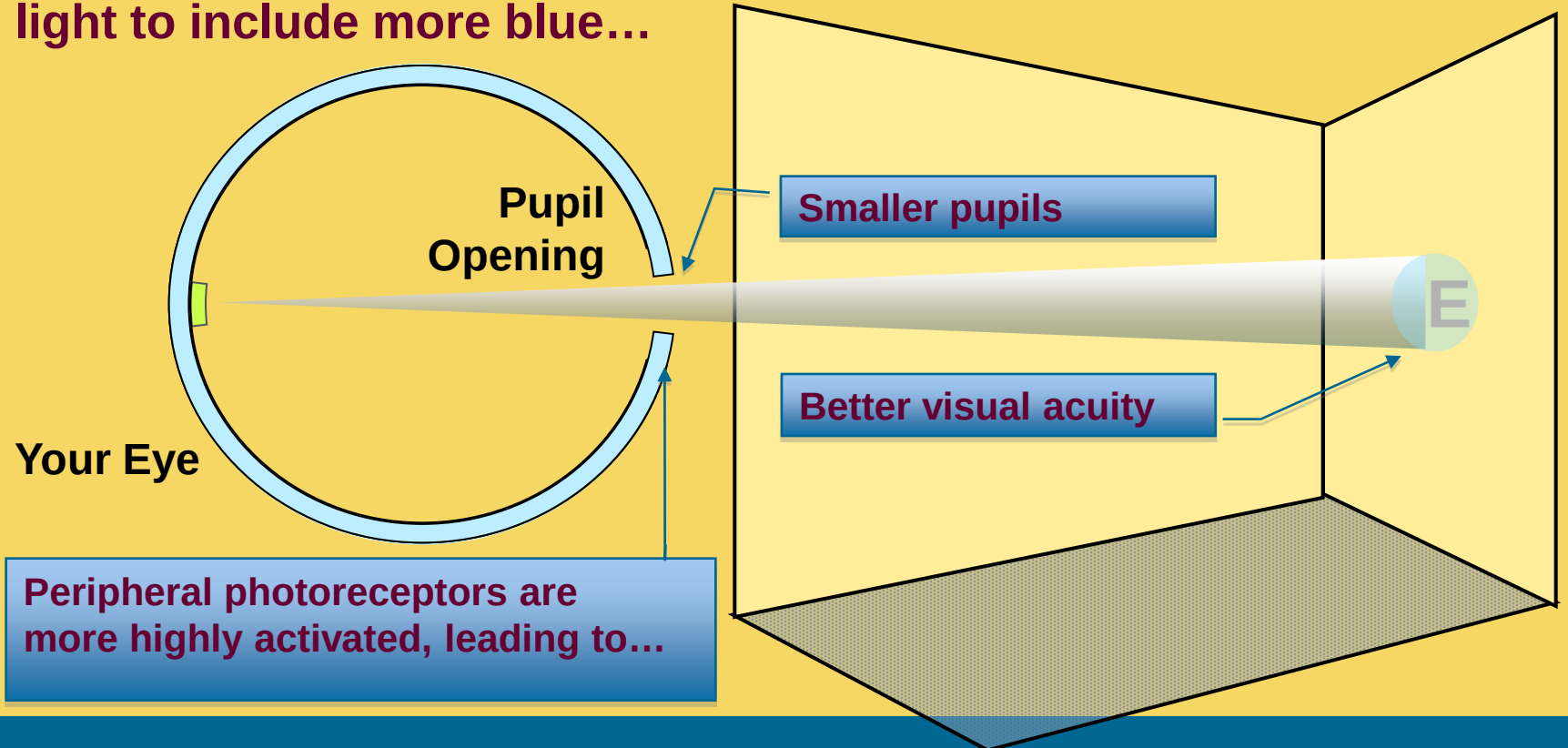
(2700-3500K)

There's More to Light than What We Measure

Using higher CCT lamps with spectra more like daylight

- Makes eye's pupil smaller
- Improve visual acuity
- Affects Circadian Rhythm

By changing the spectrum of light to include more blue…



The Analogy: What Happens When…

we increase light levels?

we increase the color temperature (but not the light level)?

- Pupils get smaller
- Spaces seem brighter
- **We see more clearly**

Light Source

Shift Spectrum - Use Higher CCT

Same Light Level

Smaller Pupils

Increased Visual Acuity

No Energy Savings

Reduce Light Level

Same Pupil Size

Same Visual Acuity

Save Energy

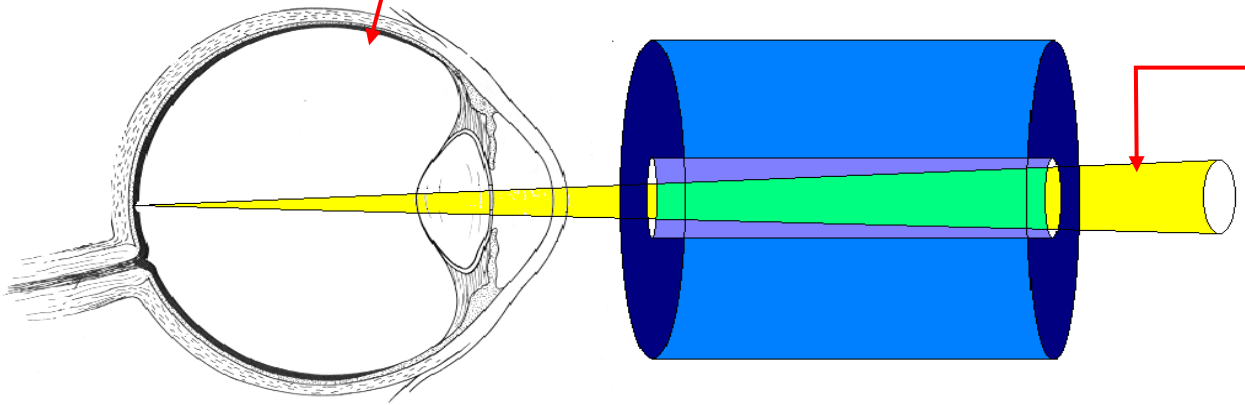
IESNA Illuminance Levels

- ***Category D (P): 300 lx***
  - ***High contrast, large size***
- ***Category E (R): 500 lx***
  - ***High contrast, small size***
  - ***Low contrast, large size***
- ***Category F (T): 1000 lx***
  - ***Low contrast, small size***

- IES recommendations are “Photopic” and do not consider spectrum
- What does this mean to lighting design?

Standard Lighting Measurement - Photopic

This ignores the influence of the peripheral photoreceptors that take in lighting from the rest of the real Field of View



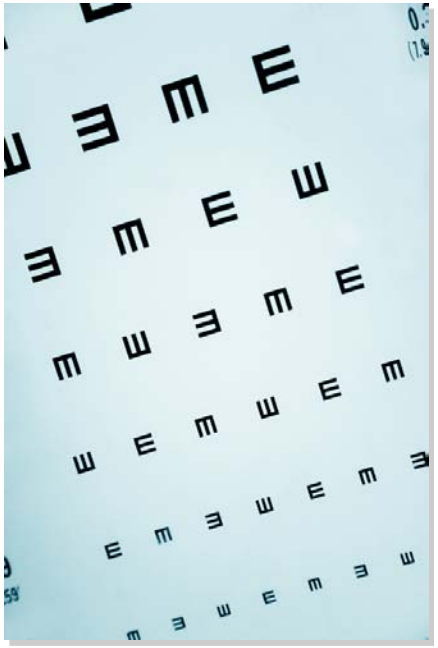
2º Field of View

This is less than 1/10 of 1% of the natural Field of View!

Science of SEL

When you have a full field of view:

- Six separate vision studies from school children to older adults
- Spectrum affects visual acuity
- Higher CCT, better visual acuity

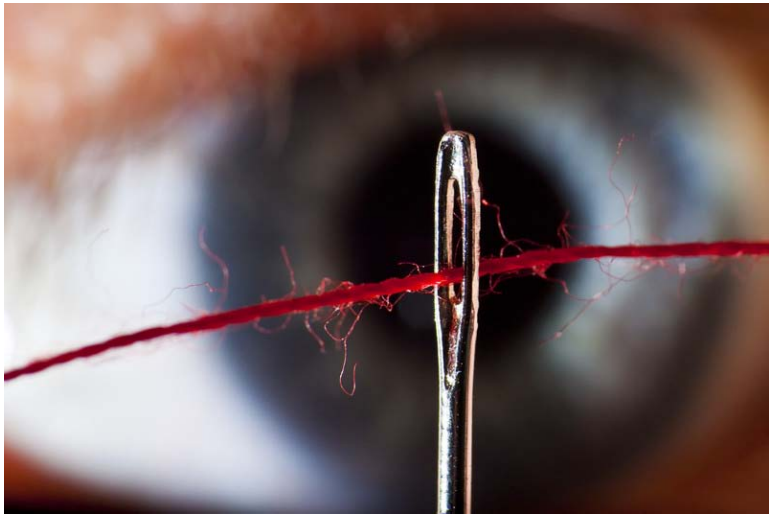


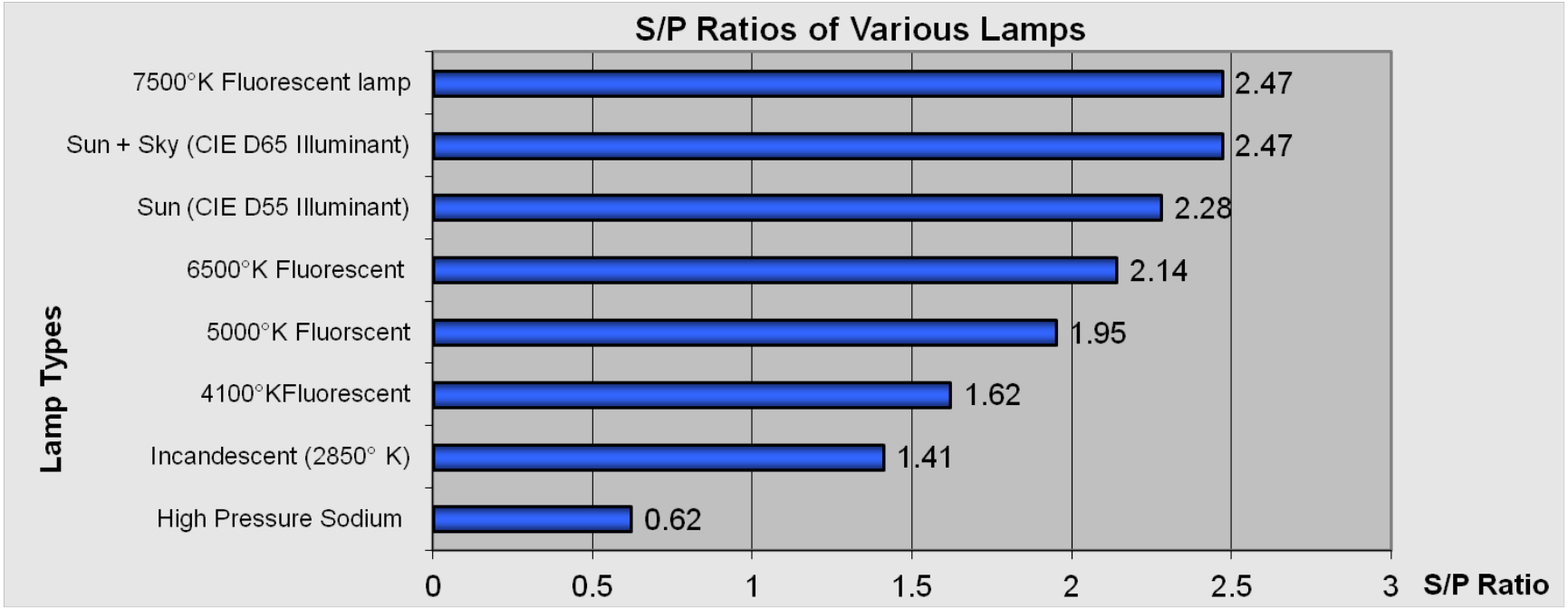
Science of SEL

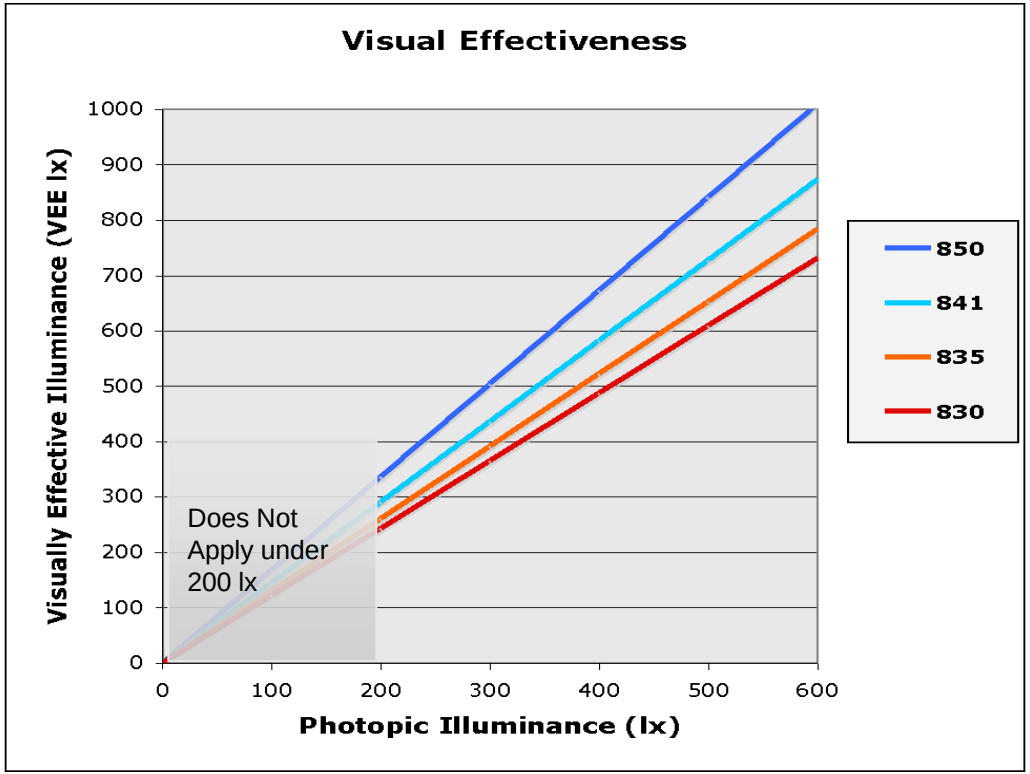
Increased visual acuity due to smaller pupil sizes, driven by recently discovered non-visual peripheral photoreceptors

Science of SEL

Empirically derived formulas using the S/P value account for the peripheral photoreceptor effect on visual acuity and are the basis of SEL

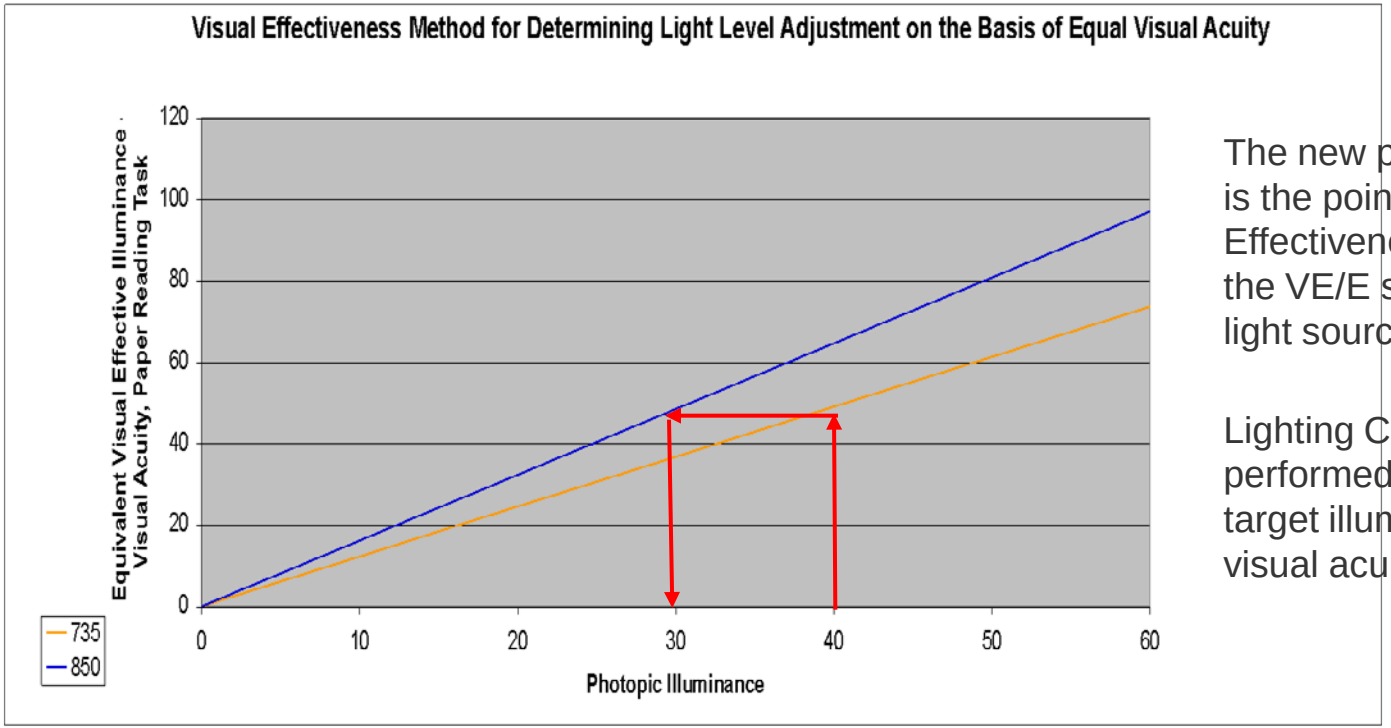



S/P Ratios of Various Lamps
7500°K Fluorescent lamp
Sun + Sky (CIE D65 Illuminant)
Sun (CIE D55 Illuminant)
6500°K Fluorescent
5000°K Fluorscent
4100°KFluorescent
Incandescent (2850° K)
High Pressure Sodium
2.47
2.47
2.28
2.14
1.95
1.62
1.41
0.62
Lamp Types
0
0.5
1
1.5
2
2.5
3
S/P Ratio



For visual acuity, visually effective illuminance (VEE) is

$$VEE = P \times (S/P)^{.78}$$



The new photopic illuminance is the point where the Visual Effectiveness value intersects the VE/E slope of the new light source.

Lighting Calculations can be performed with this as the target illuminance - with equal visual acuity for paper tasks.

SEL Energy Savings from Retrofit Lamp Changes Only

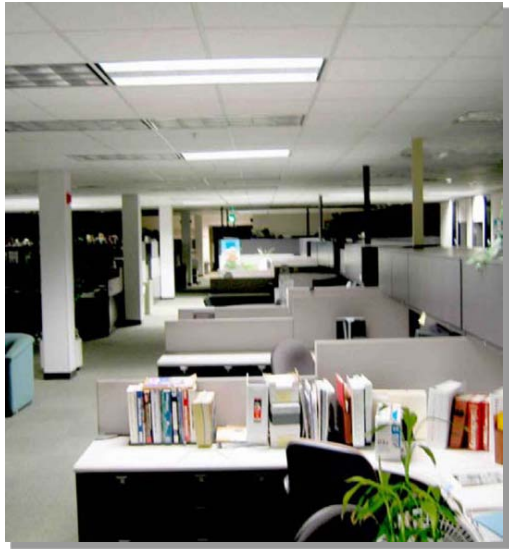
Lamp	Mean Lumens (Catalog)	S/P Value	Equiv. Visual Efficacy	Energy Savings
F32T8 730	2650	1.19	3035	37%
F32T8 735	2650	1.3	3252	32%
F32T8 741	2650	1.56	3749	22%
F32T8 830 3rd	2950	1.29	3598	25%
F32T8 835 3rd	2950	1.41	3857	20%
F32T* 841 3rd	2950	1.62	4298	11%

SEL Energy Savings Retrofits + New Ballasts

Lamp	Ballast Tech	EOL Lumen Maintenance	EOL Efficacy	Energy Savings
F32T8 730	SEIS	90%	82	44%
F32T8 735	SEIS	90%	88	40%
F32T8 741	SEIS	90%	101	30%
F32T8 830 3rd	SEIS	92%	99	32%
F32T8 835 3rd	SEIS	92%	106	27%
F32T* 841 3rd	SEIS	92%	119	18%

Testing SEL in Real Applications

- **2001: 7 buildings; 300,000 sq. feet**
  - Informal study, 850 lamps, No objections to color of lighting even with lowered light levels
- **2004: UCOP Study Occupant Acceptance**
  - Compared 850 vs. 835; Occupant acceptance of 850 under lower light level



DOE Field Study: Economics Validation

- 3 buildings retrofit with 850 lamps & standard ballasts;
- Equal occupant satisfaction

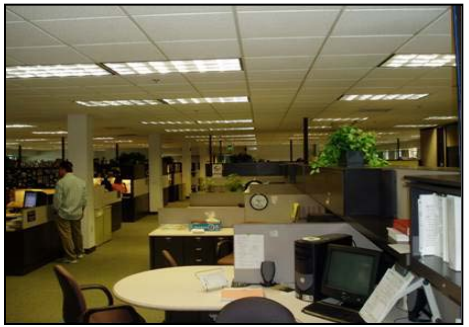
Building A (735, T12)

Field Study (cont)

- **Similar Pre-Retrofit conditions**
  - Parabolic luminaries
  - Mixed private and open offices
  - Mixed daylit and non-daylit areas
  - Over 100 full time workers
- **Differences**
  - Lamp color
  - Lamp and ballast technology
  - Energy savings potential

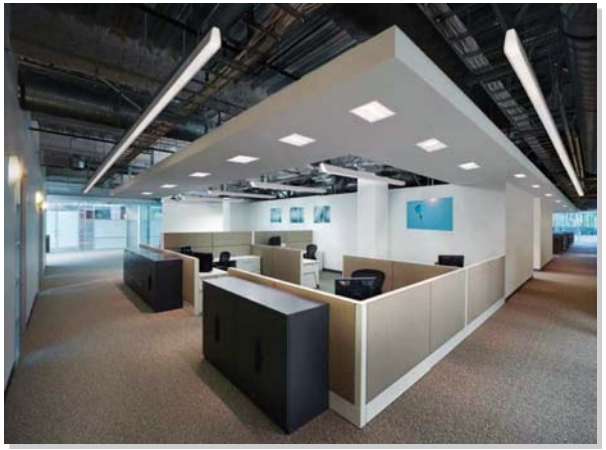
Building B (730, T8)

Building C (741, T8)

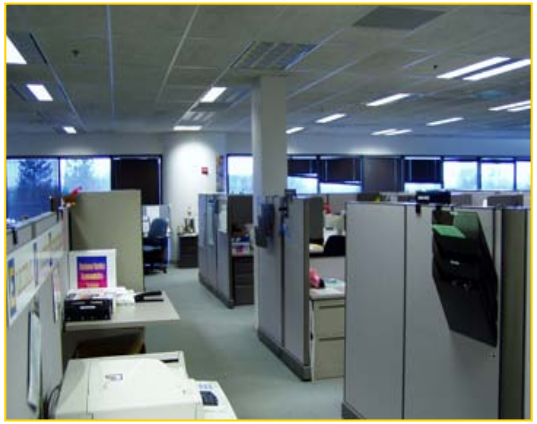


Field Study Findings

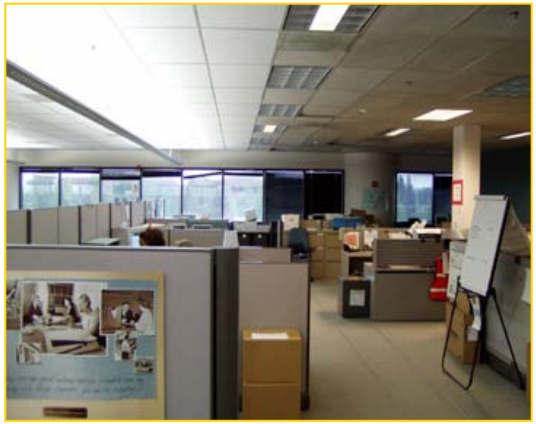
- Nearly 50% energy savings on T12 conversions
- 20% energy savings on T8 conversions
- No increase in task lighting usage
- No difference in occupant satisfaction



Results: Power Density of .5 Watts per Sq. Foot



Before

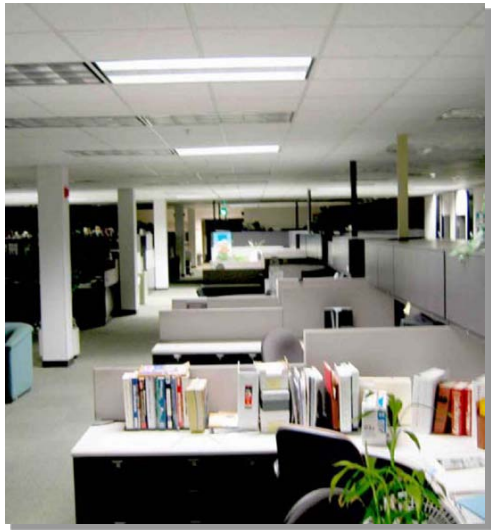


During

After

SEL 850 Lamp and SEL 5000K Lighting Adopted as Standard for Retrofits and New Construction

- Pacific Gas and Electric calls SEL one of their top 5 strategies for energy efficient lighting
- San Diego Unified School District
- Cities of San Diego and Oakland
- Counties of Napa and San Mateo



SEL Lighting in Federal Buildings

- **Port Hueneme**
- **Washington Navy Yard**
- **Navy Techval Program**
- **US Forest Service**

- **Recent NARA project (2011)**
  - surveyed building occupants in sample area and found high level of positive response
  - As a result, they successfully retrofit their entire building

Illuminating Engineering Society (IES)

- Resulting photopic light levels should meet IES minimum recommendations
- IES minimums for interior lighting are not specifically stated
- In general a 30% reduction from IES recommendations is considered a minimum light level

Spectrally Enhanced Lighting Summary

- More like daylight
- More energy efficient
- Easy to implement
- Cost effective for retrofits
- Immediate savings for new construction
- Okay to use as long as it meets IES minimum levels

Selecting SEL Lighting Projects

Applications:

- Offices
- Educational Facilities
- Medical Facilities
- Warehouses
- Correctional Facilities

Interior Lighting Retrofits:

- Any building with T12 fluorescent or HPS lighting
- T8 fluorescent systems that are 10 years old

Evaluating Lighting Technologies

If you have:

- Fluorescent T12 lamps, or T8 systems 10 years old
- High Pressure Sodium hibay/lowbay fixtures

Change to:

- T8 850 Lamps & Extra High Efficiency Ballasts
- Metal Halide or High CCT fluorescent fixtures

Measurement and Verification

- Calculations are generally done on a per-fixture basis:
  (watts per fixture) x (number of fixtures)

- Verification can be done by spot-checking individual fixtures, or by monitoring lighting panels

In Closing

DOE and FEMP Resources

FEMP Exterior SSL

- http://www1.eere.energy.gov/femp/technologies/solid_state_lighting.html

SEL

- http://www1.eere.energy.gov/buildings/spectrally_enhanced.html

- http://www1.eere.energy.gov/femp/technologies/eut_spectral_lighting.html

FEMP Resources

FEMP Exterior SSL Initiative

www.femp.energy.gov/technologies/solid_state_lighting.html

Commercial Building Energy Alliance

www.buildings.energy.gov/alliances/parking_structure_spec.html

www.buildings.energy.gov/alliances/parking_lot_lighting.html

Municipal Solid-State Street Lighting Consortium

www.buildings.energy.gov/ssl/consortium.html

U.S. Department of Energy Solid-State Lighting

www.ssl.energy.gov

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