

---

# Introduction to Commercial Building Audits

Course No. ENRG 50

---

## Outline

### A. Introduction to concept of commercial building energy auditing

1. Why energy efficiency (EE) is important
2. Energy use and waste in commercial building operations
3. Prioritizing energy efficiency over renewable energy generation

### B. Ordinances, policies and standards governing commercial building audits

1. San Francisco Existing Commercial Buildings Performance Ordinance
2. State of California energy goals
3. ASHRAE standards, including Building Energy Assessment Professional (BEAP)
4. Other audit standards

### C. Three ASHRAE audit levels

1. Preliminary energy use analysis
2. Level 1, Walk-through analysis
3. Level 2, Intermediate, energy survey and energy analysis
4. Level 3, Detailed analysis of capital-intensive modifications

### D. Developing the scope of work in a commercial building audit

1. Objectives of the audit, including needed data and

resources

2. Assessment management
3. Responsibilities of audit team members

### E. Elements in preliminary analysis of building performance data

1. Engineering and architectural document review
2. Geographical and climatic review
3. Review and analysis of current energy use and costs
4. Benchmarking procedures

### F. Factors in on-site building assessment

1. Common safety hazards and field safety techniques
2. Occupant interviews and assessment of building operations
3. Building envelope
4. Electrical systems
5. HVAC&R systems
6. Lighting systems and use
7. Miscellaneous other energy use systems
8. Domestic water systems and use
9. Indoor environmental quality

### G. Analysis of data collected

1. Identify opportunities for efficiency improvement
2. Calculate value of efficiency improvements and return on investment
3. Prioritize options based on client criteria

### H. Audit completion activities

1. Prepare and present written report
2. Assist with development of implementation plan

## F. Factors in on-site building assessment

1. Common safety hazards and field safety techniques
2. Occupant interviews and assessment of building operations
3. Building envelope
4. Electrical systems
5. HVAC&R systems
- 6. Lighting systems and use**
7. Miscellaneous other energy use systems
8. Domestic water systems and use
9. Indoor environmental quality

# Lighting systems and use

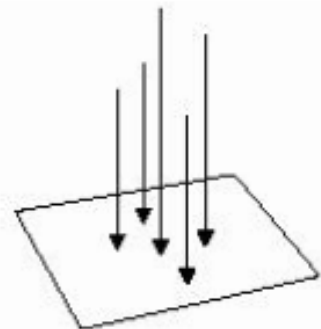
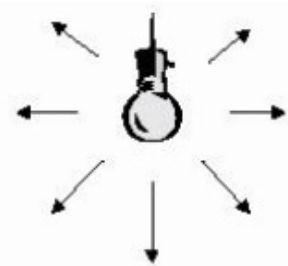
---

- Lighting terminology
- Units of measurement
- Lighting systems
- Type of Lamps
- Lighting controls
- Lighting EEMs
- Tools and measurement
- Lighting standards, codes and regulations

# Lighting terminology

---

- Luminous flux
  - Total amount of light emitted by a source
  - Measured in **lumens**
- Illuminance
  - The density of light on a surface
  - Measured in **lumens per ft<sup>2</sup> (footcandles or fcd)**
  - Also in SI: **lumens per meter<sup>2</sup> (lux)**
  - 1 fcd  $\approx$  10 lux



# Lighting terminology

---

- Power

- The rate energy is transferred, used, or transformed
- Measured in **joule per second (J/s)**, or **watt**

$$P = I \cdot V$$

P : the power (watts)

V : the voltage drop (volts)

I : the current through (amperes)

- Efficacy

- A measure of lamp/ballast performance
- Measured in lumen/watt

$$Efficacy = \frac{Light\ Output}{Power\ Input}$$

# Lighting terminology

---

- Lighting power density (LPD)
  - A measure of the power intensity of lighting system
  - Measured in **watts/sf<sup>2</sup>**
  - Energy code provides limits by space use or building type

$$LPD = \frac{\text{Lighting Power}}{\text{The area of a room}}$$

# Lighting terminology

---

- Lamp life
  - Total operating time that ½ of test set remains burning
- Lamp lumen depreciation (LLD)
  - Describes the decrease in output of a lamp during its life
- Correlated color temperature (CCT)
  - describes the color appearance of white light source
  - is a measurement of coolness or warmness of a light source
- Color rendering index (CRI)
  - A measure of how well a light source renders colors comparing to a reference source
  - 0-100 point scale

# Units of measurement

- Lumen (lm) : SI unit of luminous flux

-  $1 \text{ lm} = 1 \text{ cd} \cdot \text{sr}$

- Foot-candle (fc or fcd): Lumen per  $\text{ft}^2$   
vs. lux (lx): lumen per  $\text{m}^2$

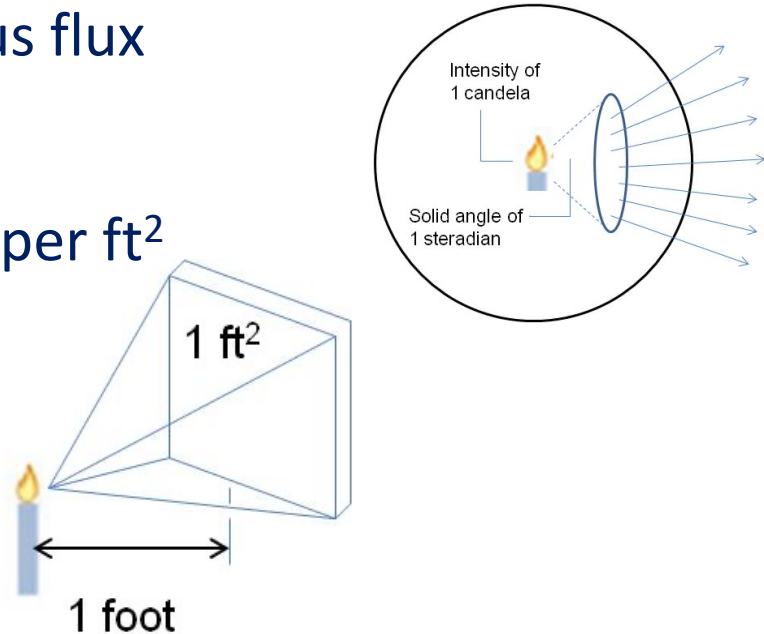
-  $1 \text{ fcd} = 10 \text{ lux}$

- Power: Wattage

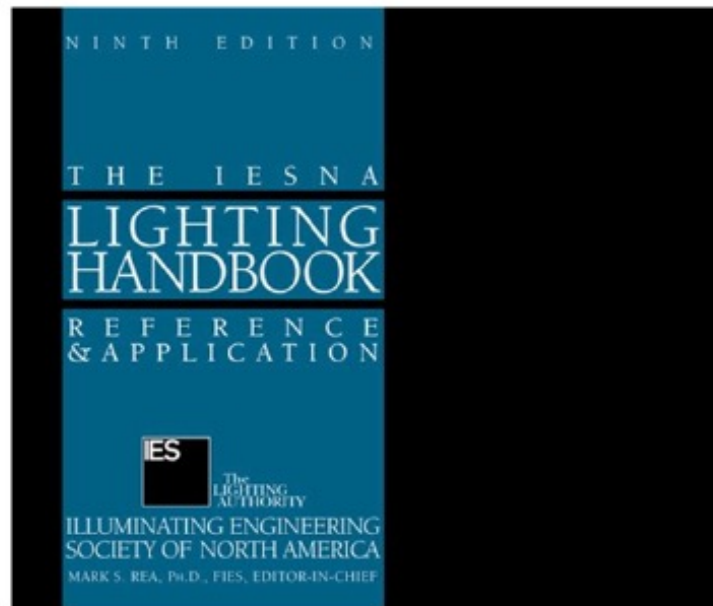


- Energy: kWh

-  $\text{kWh} = \text{Watts} * \text{Time (hrs)}/1000$



# Lighting design guide



*Orientation and simple visual tasks.* Visual performance is largely unimportant. These tasks are found in public spaces where reading and visual inspection are only occasionally performed. Higher levels are recommended for tasks where visual performance is occasionally important.

A	Public spaces	30 lx (3 fc)
B	Simple orientation for short visits	50 lx (5 fc)
C	Working spaces where simple visual tasks are performed	100 lx (10 fc)

*Common visual tasks.* Visual performance is important. These tasks are found in commercial, industrial and residential applications. Recommended illuminance levels differ because of the characteristics of the visual task being illuminated. Higher levels are recommended for visual tasks with critical elements of low contrast or small size.

D	Performance of visual tasks of high contrast and large size	300 lx (30 fc)
E	Performance of visual tasks of high contrast and small size, or visual tasks of low contrast and large size	500 lx (50 fc)
F	Performance of visual tasks of low contrast and small size	1000 lx (100 fc)

*Special visual tasks.* Visual performance is of critical importance. These tasks are very specialized, including those with very small or very low contrast critical elements. Recommended illuminance levels should be achieved with supplementary task lighting. Higher recommended levels are often achieved by moving the light source closer to the task.

G	Performance of visual tasks near threshold	3000 to 10,000 lx (300 to 1000 fc)
---	--	---------------------------------------

# Lighting systems

---

- Lighting components:
  - Luminaire: a complete lighting unit, including lamps, ballast/power drive, reflector, diffuser/lens/louver, other accessories
  - Lamp
  - Ballast
  - Reflector
  - Diffuser lens or louver



# Ballast

---

- Power regulator required for all discharge lamps: HID and fluorescent
- Preheat the electrodes (for rapid start lamps) to make it easier to start the arc
- Apply high voltage to start the arc
- Limits current in an electric circuit
- Types:
  - Electromagnetic (magnetic)
  - Electronic

Frontierlighting.com



# Ballast

---

- a. Electro-magnetic (magnetic) ballast
  - Made of wire coiled to create a magnetic field
  - Secondary freq. = primary frequency (60Hz)
- b. Electronic ballast
  - Up to 40% efficiency improvement over magnetic ballasts
  - Secondary freq. 20000-40000Hz
  - No ballast “hum”
  - Can drive up to 4 lamps/ballast
  - High Power Factor
  - Light weight
  - No flicker

EEM opportunities to  
replace magnetic  
ballast by electronic  
ballast

# Lamp: lighting source

---

- Incandescent
- Halogen
- Fluorescent
- High Intensity Discharge
  - Metal halide
  - Mercury vapor
  - High Pressure Sodium
  - Low Pressure Sodium
- Induction lamps
- Light Emitting diodes (LEDs)
- Neon



# Type of lamps: Comparison Matrix

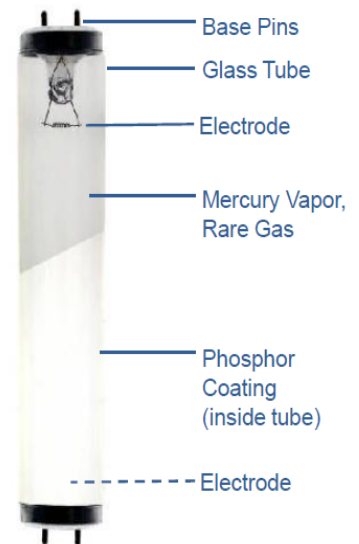
Lamps	Source Type	Efficacy (lm/W)	Lamp Life (rated hrs)	Color Temp. <sup>1</sup>	CRI	Dimm-able <sup>2</sup>	Volt. Sen- sitive <sup>2</sup>	T. Sen- sitive <sup>2</sup>
Incandescent	Point	6-24	750-2000	W	100	Y	Y	N
Halogen	Point	8-35	2000-6000	W	100	Y	Y	N
Fluorescent	Linear	60-100	7500-30,000	WMC	50-98	Y	N	Y
CFL	Area	28-84	10,000-20,000	WMC	82-86	S	N	Y
Metal Halide	Point	50-110	6000-20,000	WM	65-92	S	N	N
Mercury Vapor	Point	30-65	16,000-24,000	WMC	15-40	S	Y	N
High Pressure Sodium	Point	50-120	16,000-24,000	W	25	N	N	N
Low Pressure Sodium	Point	60-150	12,000-18,000	W	5	N	N	N
Induction	Area	60-80	100,000	WM	80	N	N	N
White LEDs	Projec- tion	27-92	50,000- 100,000	WMC	75	Y	N	Y

1: W (Warm), M (Mid-range), C (Cool); 2: Y (Yes), S (Special cases), N (No)

# Type of lamps

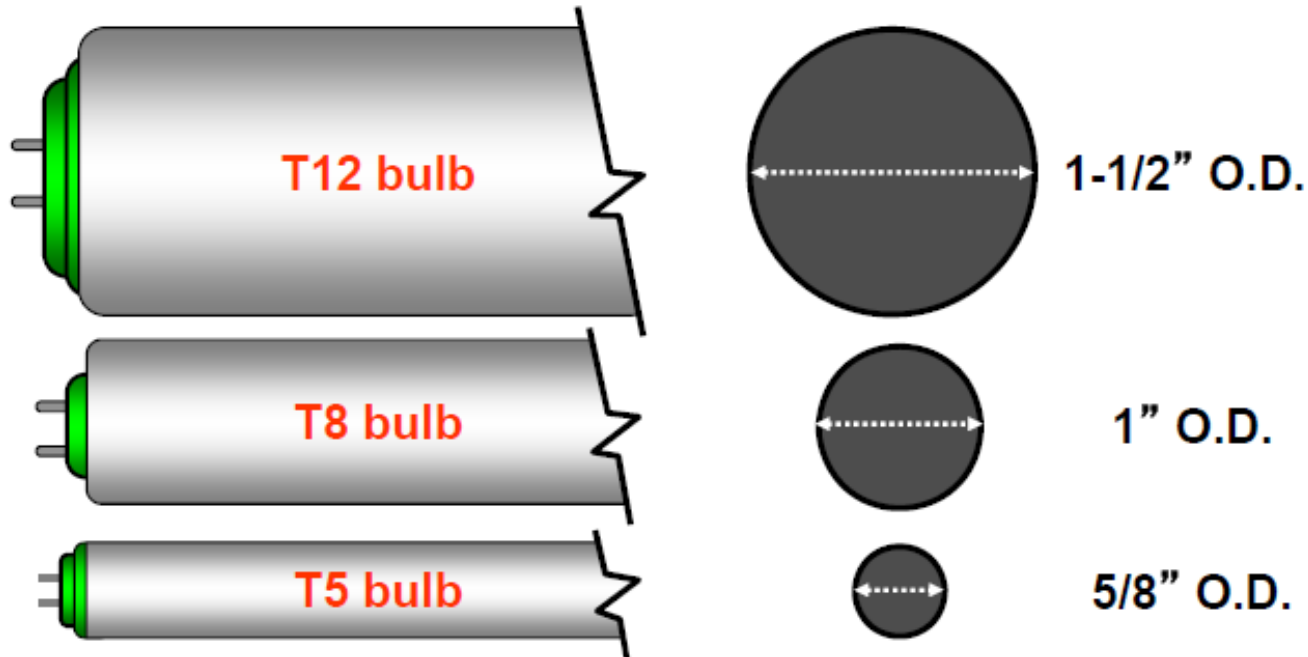
---

- Incandescent: w/ filament; need to be replaced
- Halogen: a type of incandescent; EEM opportunities
- Fluorescent:
  - Mercury vapor arc stream emits UV energy, phosphors convert UV into visible light
  - requires a ballast to regulate the current through the lamp
  - Fluorescent tube lamp
  - Compact Fluorescent Lamp (CFL)
  - high efficacy/long life/high CRI



## Fluorescent: tube

---



Example: **F32T8/835**

F = fluorescent

32 = 32 lamp watts

T = tubular bulb shape

8 =  $\frac{8}{8}$ " diameter (1")

/ = separator

8 = CRI in the 80s

35 = apparent color temperature = 3500° Kelvin

# Type of lamps

---

- HID: High-intensity discharge lamp, electrical gas-discharge lamp
  - Metal halide
  - Mercury vapor
  - High pressure sodium
  - Low pressure sodium
- applications:
  - Street lights
  - Exterior lighting of buildings
  - Warehouse lighting
  - High-bay retail

Metal Halide (PS)



Mercury Vapor



High Pressure Sodium



Low Pressure Sodium



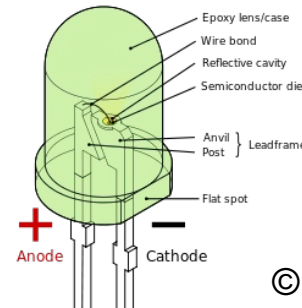
# Type of lamps

## LED (Lighting emitting diodes)

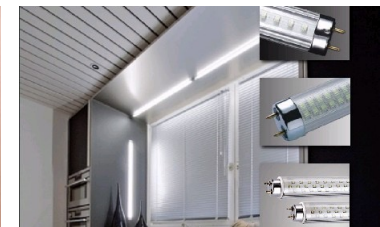
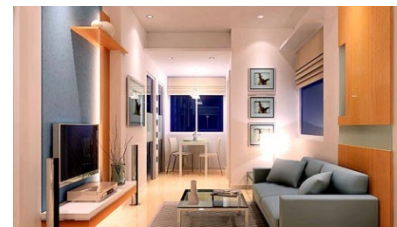
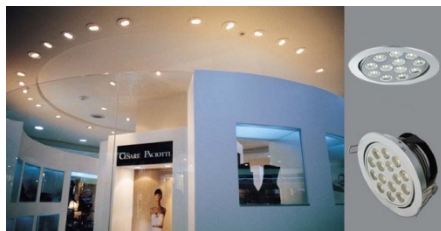
- High brightness
- Low energy consumption
- Long life time
- Need heat management

### Applications:

- indoors/outdoors
- Exit signs, safety lights
- Traffic lights/street lamps
- Advertising
- General lighting



© wikipedia



# Lighting controls

---

## Types and appropriate applications of lighting controls

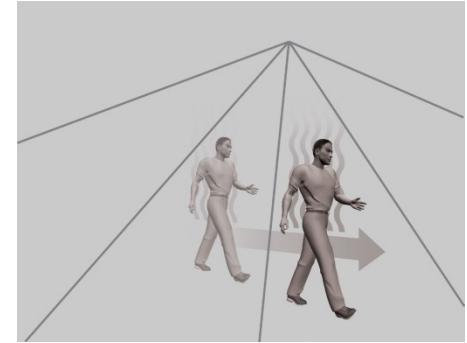
- a. Manual Switches
- b. Schedule controls or sweeps (building automation systems)
- c. Timers and time clocks
- d. Infrared and ultrasonic occupancy sensors
- e. Manual dimmers
- f. Daylight controls or Photosensors
- g. Bi-level switching

## Occupancy sensors

## Qualify for PG&E Incentive

- Types:

- Passive infrared (PIR): a line of sight beam that reacts to heated motion across a field of view
- Ultrasonic (US): a reflective wave form that reacts to disturbances in return wave form.
- Dual Tech (DT): combines both PIR and US sensing technologies in one device.



leviton.com



## Occupancy sensors: Wall switches

---

PIR



DT



[leviton.com](http://leviton.com)

## Energy saving equation

---

**Power** = The Rate of Consumption kilowatts kW

**Time** = The Duration of Consumption

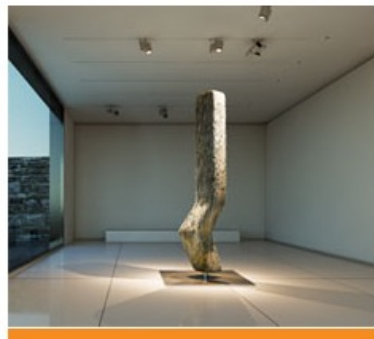
**Energy = Power X Time**

= Total Consumption in Kilowatt hours kWh

Control strategy: regulate the rate of consumption (**power**),  
or the duration of consumption (**time**), or both.

# Advanced Lighting guidelines

CONTROL STRATEGY	EXAMPLES	AVERAGE SAVINGS
Institutional Tuning	High-end trim dimming (ballast tuning), task tuning, lumen maintenance, provision of controls for areas/groups of occupants	36%
Personal Tuning	Dimmers, wireless switches, bi-level switches, computer based controls (for personal offices, workstation-specific lighting, classrooms)	31%
Daylighting	Photosensors	28%
Occupancy	Occupancy sensors, time clocks, EMS	24%
Multiple Strategies	Any combination of the above	38%



# Lighting EEMs

---

- Lamp replacement
  - Replace inefficient lamps with efficient lamps
  - Replace **incandescent** lamps with CFL or LED
  - Replace **T12** lamps with T8, T5 or T5/HO
  - Replace **mercury vapor lamps** with MH or other sources
- Ballast replacement
  - Replace magnetic ballast with electronic ballast :
  - For fluorescent lamps, 10-25% efficiency improvement
- Lighting controls
- Other EEMs

## Ballast replacement

---

Replace magnetic ballast with electronic ballast :

- for fluorescent lamps, 10-25% efficiency improvement
- for HID lamps, lower ballast losses and light

depreciation, meaning lamps produce more light over their entire lifespan.

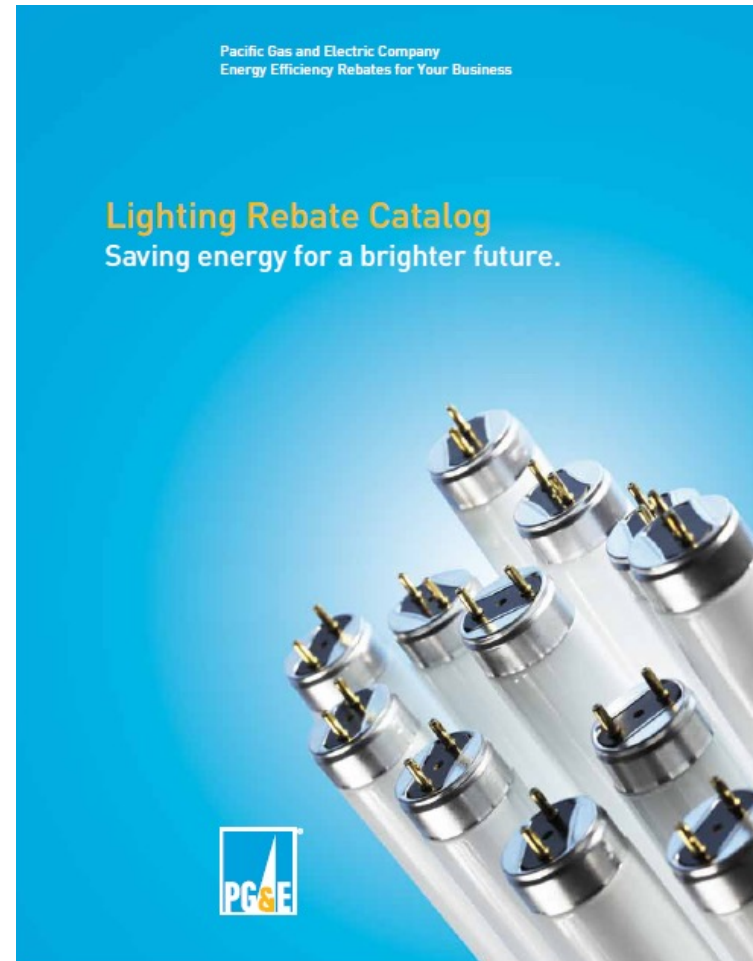


Frontierlighting.com

# PG&E lighting rebates

---

[http://www.pge.com/includes/docs/pdfs/mybusiness/energysavingsrebates/incentivesbyindustry/lighting\\_catalog\\_final.pdf](http://www.pge.com/includes/docs/pdfs/mybusiness/energysavingsrebates/incentivesbyindustry/lighting_catalog_final.pdf)



# Tools and measurement

---

## Tools:

- Flicker checker  
spin to check the type of ballast: magnetic/electronic  
alternative: discriminator



- Illuminance meter  
for "incident" light level (fcd or lux)
- Luminance meter  
reading reflected or transmitted "brightness" in (cd/m<sup>2</sup>)



# Tools and measurement

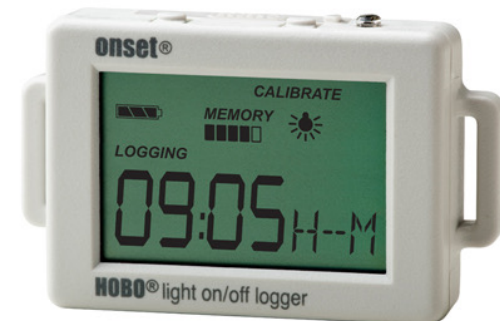
---

## Data loggers and applications:

- Occupancy
- Hours of use
- Multiple channels



<http://www.onsetcomp.com>



# Lighting standards, codes and regulations

---

- Title 24

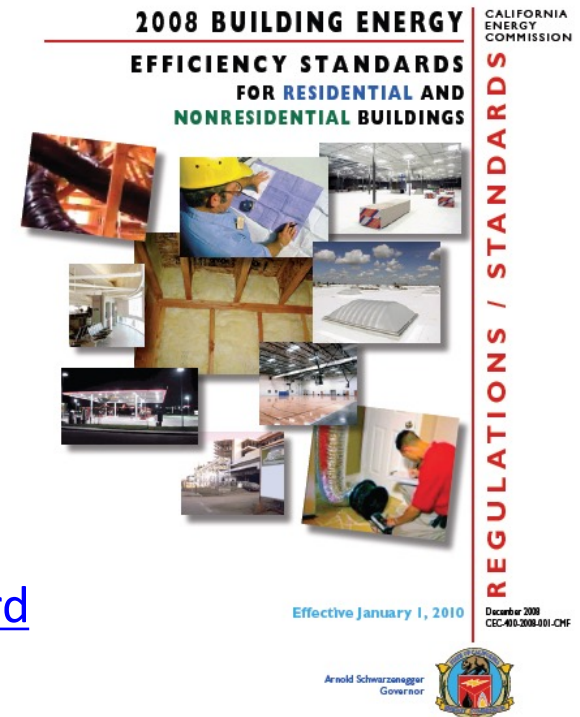
- Mandatory requirements
- Prescriptive requirements
- Exterior lighting regulations

- California Energy commission:

<http://www.energy.ca.gov/>

Title 24 2008:

<http://www.energy.ca.gov/title24/2008standards/index.html>



## Title 24 – Outline of Lighting Requirements

---

Standard	Mandatory Measures	Prescriptive Requirement
Nonresidential	<ul style="list-style-type: none"><li>• Shutoff controls</li><li>• Space control</li><li>• Exit signs</li><li>• Occupant sensors</li><li>• Daylighting controls</li><li>• Special controls</li></ul>	<ul style="list-style-type: none"><li>• Lighting power (whole building and space-by-space allowances)</li><li>• Control credits</li></ul>
Residential	<ul style="list-style-type: none"><li>• Luminaire efficacy</li><li>• controls</li></ul>	<ul style="list-style-type: none"><li>• None</li></ul>

# Title 24 – Allowed Lighting Power Densities (LPD)

---

*TABLE 146-E COMPLETE BUILDING METHOD LIGHTING POWER DENSITY VALUES (WATTS/FT<sup>2</sup>)*

TYPE OF USE	ALLOWED LIGHTING POWER
Auditoriums	1.5
Classroom Building	1.1
Commercial and industrial storage buildings	0.6
Convention centers	1.2
Financial institutions	1.1
General commercial and industrial work buildings	
High bay	1.0
Low bay	1.0
Grocery stores	1.5
Library	1.3
Medical buildings and clinics	1.1
Office buildings	0.85
Parking Garages	0.3
Religious facilities	1.6
Restaurants	1.2
Schools	1.0
Theaters	1.3
All others	0.6

# Title 24 – Allowed Lighting Power Densities (LPD)

TABLE 146-F AREA CATEGORY METHOD - LIGHTING POWER DENSITY VALUES (WATTS/FT<sup>2</sup>)

PRIMARY FUNCTION		ALLOWED LIGHTING POWER (W/ft <sup>2</sup> )	PRIMARY FUNCTION		ALLOWED LIGHTING POWER (W/ft <sup>2</sup> )
Auditorium		1.5 <sup>1</sup>	Laboratory, Scientific		1.4 <sup>4</sup>
Auto Repair		0.9 <sup>2</sup>	Laundry		0.9
Beauty Salon		1.7	Library	Reading areas	1.2
Civic Meeting Place		1.3 <sup>1</sup>		Stacks	1.5
Classrooms, lecture, training, vocational room		1.2	Lobbies	Hotel lobby	1.1 <sup>1</sup>
Commercial and industrial storage (conditioned. & unconditioned.)		0.6		Main entry lobby	1.5 <sup>1</sup>
Commercial and industrial storage (refrigerated)		0.7	Locker/dressing room		0.8
Convention, conference, multipurpose and meeting centers		1.4 <sup>1</sup>	Lounge/recreation		1.1
Corridors, restrooms, stairs, and support areas		0.6	Malls and atria		1.2 <sup>1</sup>
Dining		1.1 <sup>1</sup>	Medical and clinical care		1.2
Electrical, mechanical, telephone rooms		0.7 <sup>2</sup>	Offices	> 250 square feet	0.9
Exercise center, gymnasium		1.0		≤ 250 square feet	1.1
Exhibit, museum		2.0	Parking garage	Parking Area	0.2
Financial transactions		1.2 <sup>1</sup>		Ramps and Entries	0.6
General commercial and industrial work	Low bay	0.9 <sup>2</sup>	Religious worship		1.5 <sup>1</sup>
	High bay	1.0 <sup>2</sup>	Retail merchandise sales, wholesale showrooms		1.6
	Precision	1.2 <sup>3</sup>	Tenant lease space		1.0
Grocery sales		1.6	Theaters	Motion picture	0.9 <sup>1</sup>
Hotel function area		1.5 <sup>1</sup>		Performance	1.4 <sup>1</sup>
Housing, Public and Commons Areas	Multi-family, Dormitory	1.0	Transportation Function		1.2
	Senior Housing	1.5	Waiting area		1.1 <sup>1</sup>
Kitchen, food preparation		1.6	All other		0.6

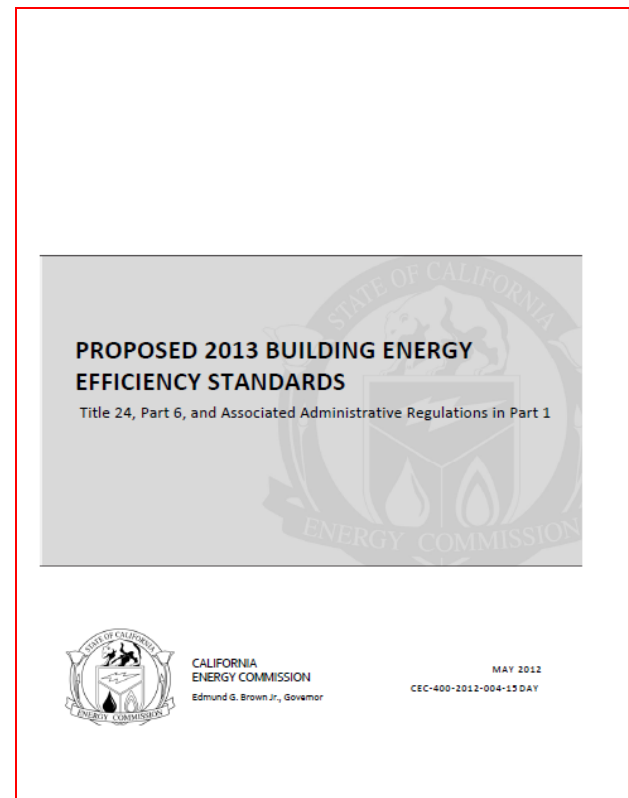
# Title 24 2013

---

- California's building efficiency standards are updated on a 3 year cycle.
- Title 24 2013 takes effect in January 2014.
- Compliance with new Code results in 25% less energy for lighting, heating, cooling, ventilation, and water heating than 2008 Standards.

Web link:

[http://www.energy.ca.gov/title24/2013standards/supporting\\_docs.html](http://www.energy.ca.gov/title24/2013standards/supporting_docs.html)

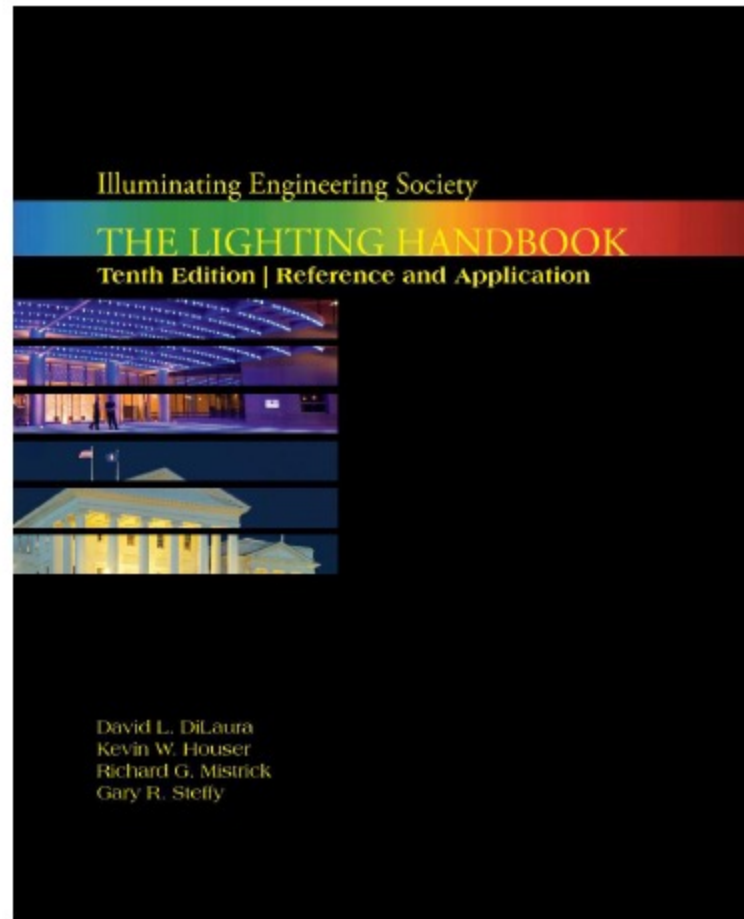


# Lighting design

---

## IES Handbook – 10<sup>th</sup> Edition

- **Industry Recognized Standard**
- 10<sup>th</sup> Edition has a new format
- Organization of information
  - Framework
  - Design
  - Applications
- Illuminance Selection Procedure
  - Return to showing a range of illuminance based on the age of the occupants



# Lighting design

IES HANDBOOK 10<sup>TH</sup> Ed.  
Table 32.2

Applications and Tasks <sup>a</sup>	Notes	Recommended Maintained Illuminance Targets (lux) <sup>b,c,d</sup>											
		Horizontal (E <sub>h</sub> ) Targets						Vertical (E <sub>v</sub> ) Targets					
		Visual Ages of Observers (years) where at least half are						Visual Ages of Observers (years) where at least half are					
		<25		25-65		>65		<25		25-65		>65	
		Category						Gauge	Category				Gauge
<b>OFFICES</b>	See READING AND WRITING, establish tasks and normalize to illuminance of most important task or most common task; use controls to provide illuminance variability if tasks so demand.												
<b>PARKING</b>	See 26   LIGHTING FOR EXTERIORS												
<b>PEDESTRIAN WAYS</b>	See 26   LIGHTING FOR EXTERIORS												
<b>READING AND WRITING</b>													
• Computer	See READING AND WRITING/VDI Screen and Keyboard												
• Electronic Readers													
• Electronic Ink Devices	E <sub>h</sub> and E <sub>v</sub> @height of device	P	150	300	600	Avg	N	75	150	300	Avg		
• LCD or LED Devices	E <sub>h</sub> and E <sub>v</sub> @height of device	N	75	150	300	Avg	K	25	50	100	Avg		
• Facsimile													
• Analog	E <sub>h</sub> @2' 6" AFF; E <sub>v</sub> @4' AFF <sup>3</sup>	R	250	500	1000	Avg	M	50	100	200	Avg		
• Digital	E <sub>h</sub> @2' 6" AFF; E <sub>v</sub> @4' AFF <sup>3</sup>	P	150	300	600	Avg	L	37.5	75	150	Avg		
• Handwritten Work	Based on fair-to-good penmanship/hand print on white or canary paper												
• Pencil													
• Graphite/HB	E <sub>h</sub> @2' 6" AFF; E <sub>v</sub> @4' AFF <sup>3</sup>	P	150	300	600	Avg	L	37.5	75	150	Avg		
• Red	E <sub>h</sub> @2' 6" AFF; E <sub>v</sub> @4' AFF <sup>3</sup>	R	250	500	1000	Avg	M	50	100	200	Avg		
• Ballpoint/Rollerpoint/Felt-tip													
• Black	E <sub>h</sub> @2' 6" AFF; E <sub>v</sub> @4' AFF <sup>3</sup>	P	150	300	600	Avg	L	37.5	75	150	Avg		
• Red, Green, Blue	E <sub>h</sub> @2' 6" AFF; E <sub>v</sub> @4' AFF <sup>3</sup>	Q	200	400	800	Avg	L	37.5	75	150	Avg		
• Laptop	See READING AND WRITING/VDI Screen and Keyboard												
• Microforms (Projected)		L	37.5	75	150	Avg	I	15	30	60	Avg		
• Print Media	Digital-printing-press-generated, white paper												
• 6-pt Font													
• Matte paper and ink	E <sub>h</sub> @2' 6" AFF; E <sub>v</sub> @4' AFF <sup>3</sup>	R	250	500	1000	Avg	L	37.5	75	150	Avg		
• Specular paper and ink	E <sub>h</sub> @2' 6" AFF; E <sub>v</sub> @4' AFF <sup>3</sup>	R	250	500	1000	Avg	L	37.5	75	150	Avg		
• 8- and 10-pt Font													
• Matte paper and ink	E <sub>h</sub> @2' 6" AFF; E <sub>v</sub> @4' AFF <sup>3</sup>	P	150	300	600	Avg	K	25	50	100	Avg		
• Specular paper and ink	E <sub>h</sub> @2' 6" AFF; E <sub>v</sub> @4' AFF <sup>3</sup>	P	150	300	600	Avg	K	25	50	100	Avg		
• 12-pt Font													
• Matte paper and ink	E <sub>h</sub> @2' 6" AFF; E <sub>v</sub> @4' AFF <sup>3</sup>	O	100	200	400	Avg	K	25	50	100	Avg		
• Specular paper and ink	E <sub>h</sub> @2' 6" AFF; E <sub>v</sub> @4' AFF <sup>3</sup>	O	100	200	400	Avg	K	25	50	100	Avg		

# BEST Center Curricula, Resources & Recordings

## Academic Programs

Georgia Piedmont Technical College - Building Automation Systems

Milwaukee Area Technical College - Sustainable Facilities Operations

Laney College - Commercial HVAC Systems

City College San Francisco - Commercial Building Energy Analysis & Audits

## Professional Development Materials, Presentations & Videos

National Institutes

Building Automation Systems Instructor Workshops

Webinars (e.g., BEST Talks)

## Faculty Profile Videos

## Reports & Case Studies

## Marketing Resources

© 2013-2025 by BEST Center: NSF National Center for Building Technician Education is licensed under Creative Commons Attribution-Non Commercial (CC BY-NC) 4.0 International.

To view a copy of this license, visit <https://creativecommons.org/licenses/by-nc/4.0/>

 CC BY-NC 4.0

# Attribution-NonCommercial 4.0

