
Introduction to Lighting Systems and Controls

Course No. ENRG 54

Outline

A. Introduction to fundamentals of lighting

- Lighting terminology
- Physics and principles of lighting
- Units of measurement
- Vision and colors
- Ambient, directional and task lighting
- Over- and under-illuminance

B. Lighting systems

- Components
- Types of lamps
- Ballasts
- Lamp comparison matrix
- Types of lighting luminaires and intensities
- Energy efficiency measures (EEMs)

C. Lighting controls

- Basic concepts of effectiveness of lighting control
- Types and appropriate applications of lighting controls
- Lighting control equations
- Energy efficiency measures (EEMs)

D. Additional EEMs

- De-lamping
- Scotopic lighting
- Task and ambient light levels
- Circadian rhythms

E. Lighting measurements

- Tools
- Data loggers and applications

F. Lighting calculations

- Equation and method of calculating lumens (zonal cavity formula)
- Equation and method of calculating energy savings
- Method of calculating skylight energy savings

G. Lighting standards, codes and regulations

- Underwriters' Laboratory (UL)
- Uniform Building Code (UBC)
- Americans with Disabilities Act (ADA)
- Title 24 applications

H. O&M measures to assure optimal performance

G. Lighting standards, codes and regulations

1. Underwriters' Laboratory (UL)
2. Uniform Building Code (UBC)
3. Americans with Disabilities Act (ADA)
4. Title 24 applications

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Underwriters' Laboratory (UL)

- UL is an independent, non-profit product safety testing and certification organization.
- Testing includes:
 - Risk of fire
 - Electric shock
 - Injury to persons



UL is a global independent safety science company offering expertise across five key strategic businesses: Product Safety, Environment, Life & Health, Verification Services and Knowledge Services. Our breadth, established objectivity and proven history mean we are a symbol of trust and enable us to help provide peace of mind to all.

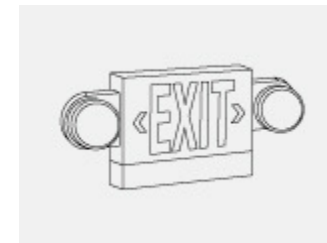
Underwriters' Laboratory (UL)

- UL lighting:

<http://www.ul.com/global/eng/pages/offerings/industries/lighting/>

- Product services

- Lamps and Light Engines
- Luminaires
- Signs and Advertising
- Electronics
- LED Packages and LED Arrays
- Retrofit Kits
- Bases, Holders and Connectors
- Lenses and Optics



G. Lighting standards, codes and regulations

1. Underwriters' Laboratory (UL)
2. Uniform Building Code (UBC)
3. Americans with Disabilities Act (ADA)
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Uniform Building Codes (UBC)

- A national code used mostly in the western states to regulate building standards.
- Was first published in 1927 by the International Council of Building Officials, updated every 3 yrs until 1997.
- Intended to promote public safety and provided standardized requirements for safe construction
- Was replaced in 2000 by the new International Building code (IBC) published by the International Code Council (ICC).

International Building Codes (IBC)

- A model building code developed by International Code Council (ICC).
- Has been adopted throughout most of the US.
- Specifies the minimum acceptable level of safety for buildings.
- California adopted IBC with amendments into California Building Code (CBC)

Reference link: http://www.ccidc.org/code_faq.html

California Building Code (CBC)

- Mandates:
 - Exit lighting requirements
 - Emergency egress lighting
- Usually responsibility of electrical engineers

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Americans with Disabilities Act (ADA)

- Gives civil rights protections to individuals with disabilities that are like those provided to individuals on the basis of race, sex, national origin, and religion.
- Objects projecting from walls with their leading edges between 27" and 80" (685 mm and 2030 mm) above the finished floor (AFF) shall protrude no more than 4" (100mm) into walks, halls, corridors, passageways, or aisles
- ADA web link: <http://www.ada.gov/>

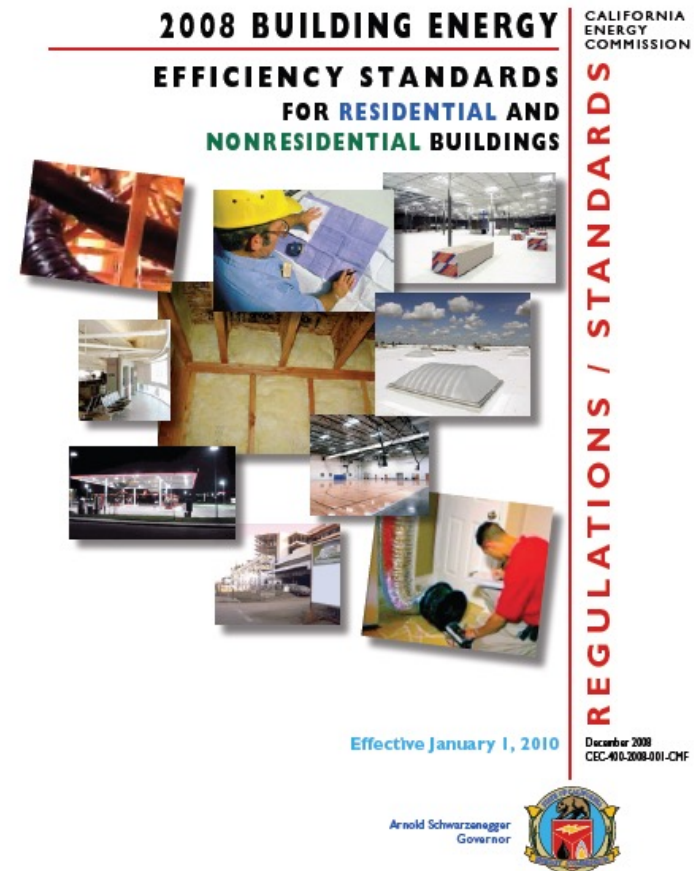
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Title 24

- Mandatory requirements
- Prescriptive requirements
- Exterior lighting regulations
- California Energy commission:
<http://www.energy.ca.gov/>

Title 24 2008:
<http://www.energy.ca.gov/title24/008standards/index.html>



Title 24 – Outline of Lighting Requirements

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

Title 24 – Allowed Lighting Power Densities (LPD)

TABLE 146-E COMPLETE BUILDING METHOD LIGHTING POWER DENSITY VALUES (WATTS/FT²)

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/FT²)

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

Title 24 – Lighting Power Adjustment Factors

TABLE 146-C LIGHTING POWER ADJUSTMENT FACTORS

TYPE OF CONTROL		TYPE OF SPACE	FACTOR
Multi-level occupant sensor (see Note 2) combined with multi-level circuitry and switching in accordance with Section 146(a)2D		Any space \leq 250 square feet enclosed by floor-to-ceiling partitions; any size classroom, corridor, conference or waiting room.	0.20
Multi-level occupant sensor (see Note 2) that reduces lighting power at least 50% when no persons are present. May be a switching or dimming (see Note 3) system.		Hallways of hotels/motels, multi-family, dormitory, and senior housing	0.25
		Commercial and Industrial Storage stack areas (max. 2 aisles per sensor)	0.15
		Library Stacks (maximum 2 aisles per sensor)	0.15
Dimming system	Manual	Hotels/motels, restaurants, auditoriums, theaters	0.10
	Multiscene programmable	Hotels/motels, restaurants, auditoriums, theaters	0.20
Demand responsive lighting control that reduces lighting power consumption in response to a demand response signal. (See Note 1)		All building types	0.05
Manual dimming of dimmable electronic ballasts. (see Note 3)		All building types	0.10
Demand responsive lighting control that reduces lighting power consumption in response to a demand response signal when used in combination with manual dimming of dimmable electronic ballasts (see Note 1 and 3).		All building types	0.15
Combined controls	Multi-level occupant sensor (see Note 2) combined with multi-level circuitry and switching in accordance with Section 146(a)2D combined with automatic multi-level daylighting controls	Any space \leq 250 square feet within a daylit area and enclosed by floor-to-ceiling partitions, any size classroom, corridor, conference or waiting room. The PAF may be added to the daylighting control credit	0.10
	Manual dimming of dimmable electronic ballasts (see Note 3) when used in combination with a multi-level occupant sensor (see Note 2) combined with multi-level circuitry and switching in accordance with Section 146(a)2D.	Any space \leq 250 square feet enclosed by floor-to-ceiling partitions; any size classroom, corridor, conference or waiting room	0.25

Title 24 – Lighting Power Adjustment Factors

Automatic multi-level daylighting controls (See Note 1)	Total primary sidelit daylight areas less than 2,500 ft ² in an enclosed space and all secondary sidelit areas. (see Note 4)		Effective Aperture			
		General Lighting Power Density (W/ft ²)	>10% and ≤20%	>20% and ≤35%	>35% and ≤65%	> 65%
		All	0.12	0.20	0.25	0.30
	Total skylit daylight areas in an enclosed space less than 2,500 square feet, and where glazing material or diffuser has ASTM D1003 haze measurement greater than 90%		Effective Aperture			
		General Lighting Power Density (W/ft ²)	0.6% ≤ EA < 1%	1% ≤ EA < 1.4%	1.4% ≤ EA < 1.8%	1.8% ≤ EA
		LPD < 0.7	0.24	0.30	0.32	0.34
		0.7 ≤ LPD < 1.0	0.18	0.26	0.30	0.32
		1.0 ≤ LPD < 1.4	0.12	0.22	0.26	0.28
		1.4 ≤ LPD	0.08	0.20	0.24	0.28

NOTES FOR TABLE 146-C:

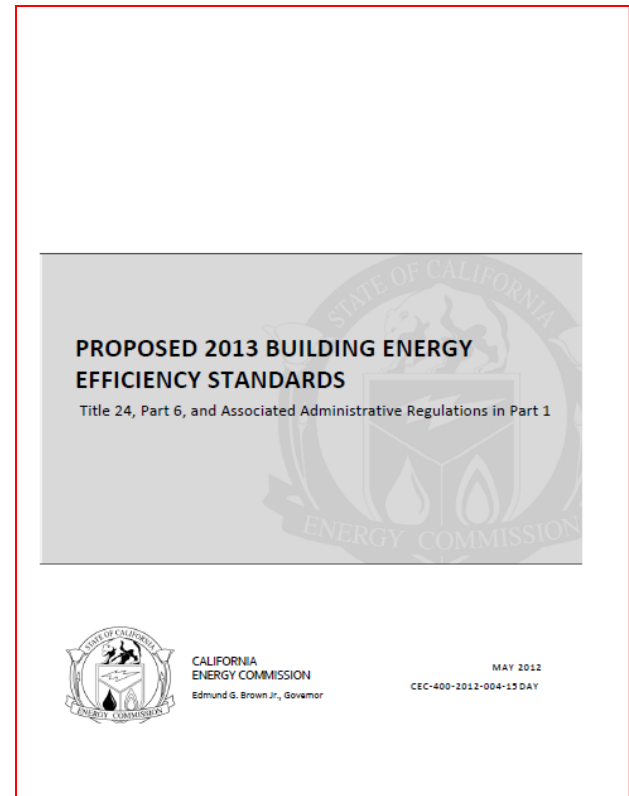
1. PAFs shall not be available for lighting controls required by Title 24, Part 6.
2. To qualify for the PAF the multi-level occupant sensor shall comply with the applicable requirements of Section 119.
3. To qualify for the PAF all dimming ballasts for T5 and T8 linear fluorescent lamps shall be electronic and shall be certified to the Commission with a minimum RSE in accordance with Table 146-D.
4. If the primary sidelit daylight area and the secondary sidelit daylight area are controlled together, the PAF is determined based on the secondary sidelit effective aperture for both the primary sidelit daylight area and the secondary sidelit daylight area.

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



Title 24 2013 Key Requirements

- Reductions in Area Category LPDs

	2008 T24	2013 T24
Open office (>250sf)	0.9 W/sf	0.75 W/sf
Private office (<250sf)	1.1 W/sf	1.0 W/sf
Retail	1.6 W/sf	1.2 W/sf with adders: <ul style="list-style-type: none">- 0.3 W/sf for accent, display and feature lighting (must be adjustable or directional luminaires)- 0.2 W/sf for decorative lighting

Title 24 2013 Key Requirements

- New power adjustment factors for occupancy sensor control in open offices:
 - 0.2 for 250-500 sf per sensor (4 people)
 - 0.3 for 125-250 sf per sensor (2 people)
 - 0.4 for <125 sf per sensor (1 person)

Title 24 – Multi-level control requirements

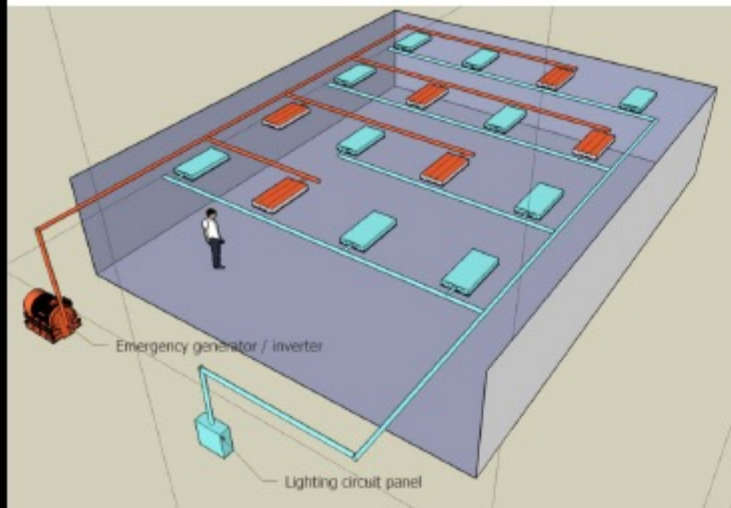
Luminaire Type	Minimum Required Control Steps (percent of full rated power ¹)				Uniform level of illuminance shall be achieved by:
Line-voltage sockets except GU-24	Continuous dimming 10-100 percent				
Low-voltage incandescent systems					
LED luminaires and LED source systems					
GU-24 rated for LED	Continuous dimming 20-100 percent				
GU-24 sockets rated for fluorescent > 20 watts					
Pin-based compact fluorescent > 20 watts					
GU-24 sockets rated for fluorescent ≤ 20 watts	Minimum one step between 30-70 percent				Stepped dimming; or continuous dimming; or switching alternate lamps in a luminaire
Pin-based compact fluorescent ≤ 20 watts ²					
Linear fluorescent and U-bent fluorescent ≤ 13 watts					
Linear fluorescent and U-bent fluorescent > 13 watts	Minimum one step in each range:				Stepped dimming; or continuous dimming; or switching alternate lamps in each luminaire, having a minimum of 4 lamps per luminaire, illuminating the same area and in the same manner
	20-40 %	50-70 %	80-85 %	100 %	
Track Lighting	Minimum one step between 30 – 70 percent				Step dimming; or continuous dimming; or separately switching circuits in multi-circuit track with a minimum of two circuits.
HID > 20 watts	Minimum one step between 50 - 70 percent				Stepped dimming; or continuous dimming; or switching alternate lamps in each luminaire, having a minimum of 2 lamps per luminaire, illuminating the same area and in the same manner.
Induction > 25 watts					
Other light sources					

Title 24 2013 Key Requirements

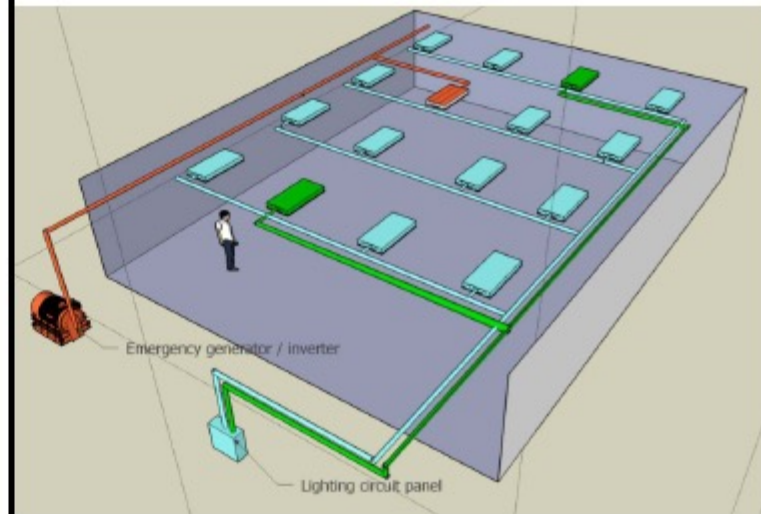
- Allowance for 24/7 lighting for building security has been removed (130.1(a) and 130.1(c)).
- allowance for egress lighting have mostly been removed
 - 0.2 W/sf is excepted from the Area Control requirements, along designated egress routes (130.1(a)). (previous code was 0.3W/sf)
 - 0.05 W/sf is excepted from the Shut-Off Control requirements, along designated egress routes in offices only. Other building types have no allowance. (130.1(c)).(previous code was 0.3 W/sf)



Emergency and Egress Control Layers



Title 24 2008

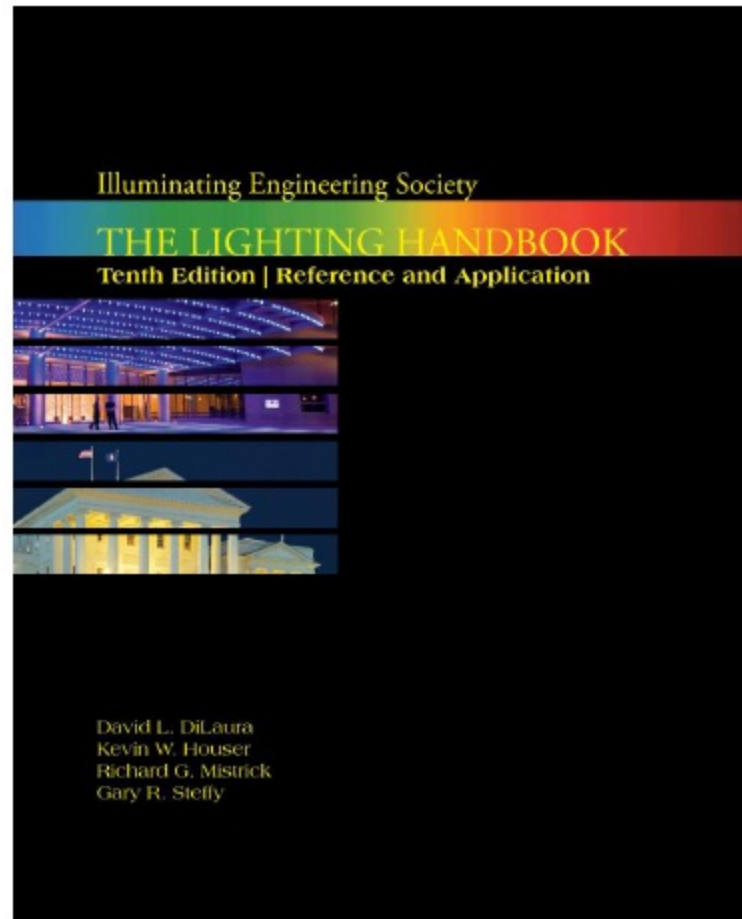


Title 24 2013

Lighting design

IES Handbook – 10th Edition

- **Industry Recognized Standard**
- 10th 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 10TH Ed.
Table 32.2

Applications and Tasks ^a	Notes	Recommended Maintained Illuminance Targets (lux) ^{b,c,d}											
		Horizontal (E _h) Targets						Vertical (E _v) 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
OFFICES	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.												
PARKING	See 26 LIGHTING FOR EXTERIORS												
PEDESTRIAN WAYS	See 26 LIGHTING FOR EXTERIORS												
READING AND WRITING													
• Computer	See READING AND WRITING/VDI Screen and Keyboard												
• Electronic Readers													
• Electronic Ink Devices	E _h and E _v @height of device	P	150	300	600	Avg	N	75	150	300	Avg		
• LCD or LED Devices	E _h and E _v @height of device	N	75	150	300	Avg	K	25	50	100	Avg		
• Facsimile													
• Analog	E _h @2' 6" AFF; E _v @4' AFF ³	R	250	500	1000	Avg	M	50	100	200	Avg		
• Digital	E _h @2' 6" AFF; E _v @4' AFF ³	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 _h @2' 6" AFF; E _v @4' AFF ³	P	150	300	600	Avg	L	37.5	75	150	Avg		
• Red	E _h @2' 6" AFF; E _v @4' AFF ³	R	250	500	1000	Avg	M	50	100	200	Avg		
• Ballpoint/Rollerpoint/Felt-tip													
• Black	E _h @2' 6" AFF; E _v @4' AFF ³	P	150	300	600	Avg	L	37.5	75	150	Avg		
• Red, Green, Blue	E _h @2' 6" AFF; E _v @4' AFF ³	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 _h @2' 6" AFF; E _v @4' AFF ³	R	250	500	1000	Avg	L	37.5	75	150	Avg		
• Specular paper and ink	E _h @2' 6" AFF; E _v @4' AFF ³	R	250	500	1000	Avg	L	37.5	75	150	Avg		
• 8- and 10-pt Font													
• Matte paper and ink	E _h @2' 6" AFF; E _v @4' AFF ³	P	150	300	600	Avg	K	25	50	100	Avg		
• Specular paper and ink	E _h @2' 6" AFF; E _v @4' AFF ³	P	150	300	600	Avg	K	25	50	100	Avg		
• 12-pt Font													
• Matte paper and ink	E _h @2' 6" AFF; E _v @4' AFF ³	O	100	200	400	Avg	K	25	50	100	Avg		
• Specular paper and ink	E _h @2' 6" AFF; E _v @4' AFF ³	O	100	200	400	Avg	K	25	50	100	Avg		

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H. O&M measures to assure optimal performance

H. Operations & Maintenance (O&M) measures to assure optimal performance

1. Make sure occupancy sensors turn lights off after a reasonable period of time
2. Check timer(s) and lighting schedule set-up regularly
3. Override manual controls
4. Daylighting commissioning
5. Educate the end users in proper use of lighting controls
6. Seasonally adjust exterior lighting schedule
7. Re-lamp entire building on a regular schedule

Daylighting commissioning

- Select proper equipment
- Install the sensors at proper place(s)
- Calibrate sensors so they produce the desired control signal
- The light sensor and controller must be adjusted to provide the desired light level at the task location.
- May require professional designer(s) and/or contractor(s)

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

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