

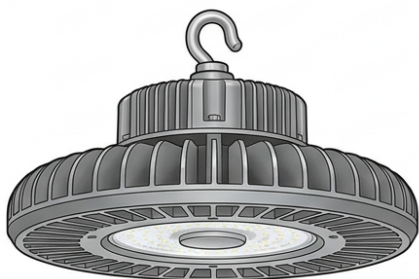
Lighting Masterclass — Commercial Fixtures, Sources & Controls

The lighting deep dive: high-bay to exit signs, the source and driver inside each, color temperature and CRI, the controls the energy code requires, step-by-step installs, emergency testing, and troubleshooting.

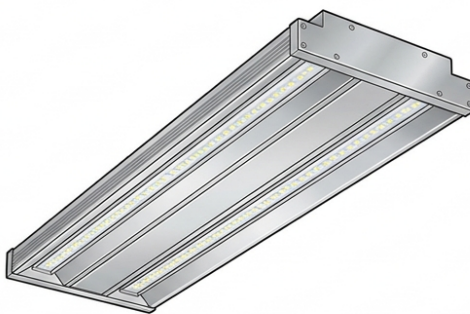
Why a lighting masterclass. Lighting is a large share of commercial electrical work: fixtures, sources, controls, and the energy code that governs them. This module goes deeper than the materials catalog. It covers what each fixture family is and where it is used, the source and driver inside it, color temperature and color rendering, the controls the energy code requires, and how to select a fixture by lumens, mounting height and beam. It then walks step by step through hanging high-bays and troffers, setting a pole, wiring an emergency driver and 0-10 V dimming, testing egress lighting, and troubleshooting what the customer calls in. All NEC numbers are the 2026 edition; where a section moved, the 2023 number is in parentheses.

1 — High-Bay & Low-Bay (the big-ceiling workhorses)

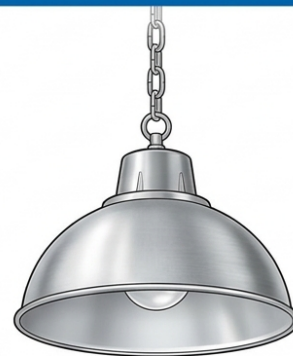
HIGH-BAY & LOW-BAY LIGHTING



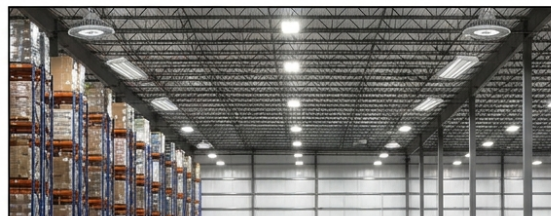
UFO LED high-bay



linear LED high-bay



low-bay
(dome/reflector for 12-20 ft ceilings)



UFO (round) and linear LED high-bays for tall spaces; low-bay domes for moderate ceilings.

Type	Mounting height	Typical LED watt / lumens	Where
UFO LED high-bay	~15-40 ft	100-240 W / 15,000-36,000 lm	Warehouses, manufacturing, gyms; round footprint
Linear LED high-bay	~15-35 ft	110-225 W / 14,000-30,000 lm	Aisles and racking; the long throw follows the rows
Low-bay	~12-20 ft	40-100 W	Lower ceilings, retail back-of-house, shops

- **Beam angle matters with height.** A narrow (60-90°) beam punches light down to the floor from high mounts. A wide (110-120°) beam spreads it for lower ceilings and aisles.
- **Pick by footcandles at the work plane, not by watts.** Section 6 has the IES targets. Higher mounts need more lumens to reach the same footcandles.

Wiring rules for hung fixtures

- A fixture hung on its own support, away from its outlet box, is connected "through metal raceway, nonmetallic raceway, Type MC cable, Type AC cable, Type MI cable, nonmetallic sheathed cable, or by flexible cord as permitted in 410.62(B) or 410.62(C)" (410.24(A)).
- Conductors "within 75 mm (3 in.) of a ballast, LED driver, power supply, or transformer shall have an insulation temperature rating not lower than 90°C" (410.68). THHN/THWN-2 meets this.

Worked example 1: how many 150 W high-bays on one 20 A, 277 V circuit? Lighting is a continuous load, so the circuit is loaded to 80 percent: $16 \text{ A} \times 277 \text{ V} = 4,432 \text{ VA}$. A 150 W high-bay draws about $150 \div 277 = 0.54 \text{ A}$. $16 \div 0.54 =$ about 29 fixtures at steady state. The driver's inrush current often sets a lower limit. Read the "max per breaker" figure on the driver data sheet and use whichever number is smaller.

Step by step: hanging a high-bay

1. Match the fixture to the schedule: type mark, voltage (MVOLT is 120-277 V; HVOLT is 347-480 V), lumens and beam.
2. Lay out the locations from the reflected ceiling plan using a floor-to-ceiling laser.
3. Install the beam clamp or rod, the box and the drop.
4. Hang the fixture, attach the safety cable to the structure, and level it.
5. Wire the whip: hot, neutral and EGC, plus violet and pink if the fixture dims on 0-10 V (Section 7).
6. Energize and verify the voltage at the driver.
7. Test the controls and update the panel directory.

2 — Interior Fixtures

INTERIOR LED FIXTURES



2x4 troffer



2x2 troffer



1x4 troffer



wraparound



strip / industrial



vapor-tight (wet location)



recessed downlight (can)



linear suspended pendant

Recessed troffers (2x4, 2x2, 1x4) for grid ceilings; wraparound, strip, and vapor-tight for utility spaces; downlights and pendants for finish work.

- **Troffers** drop into a suspended grid ceiling. They are the standard office and retail fixture; 2x4 is the most common.
- **Wraparound and strip** fixtures are surface-mounted utility lights for back rooms, stairs and garages.
- **Vapor-tight** fixtures are gasketed for wet or washdown areas (parking decks, food processing, car washes). Wet-location luminaires "shall be marked as suitable for wet locations" (410.10(A)).
- **Recessed downlights (cans)** and **pendants** are for accent lighting and finished spaces. A non-IC recessed fixture keeps ½ in. from combustibles, and insulation stays at least 3 in. away unless the fixture is Type IC (410.116(A)/(B)). Do not reach other boxes through a recessed fixture's opening (410.118).
- **Track lighting** may not go in wet or damp locations, concealed, through walls, or "Less than 1.5 m (5 ft) above the finished floor except where protected" (410.150(C)).

Supporting a lay-in troffer: what the code says and what it doesn't

410.36(B) has two parts. The ceiling framing members "shall be securely attached to the building structure," and luminaires "shall be securely fastened to the ceiling framing member by mechanical means such as bolts, screws, or rivets. Listed clips identified for use with the type of ceiling framing member(s) and luminaire(s) shall also be permitted." That is all 410.36(B) requires. It does not itself require hanger wires from the troffer to the structure.

Hanger wires come from three other places. The manufacturer may call for them; Lithonia's CPX instructions say "Following local codes, attach the luminaire to the building structure using proper hanger wire to support the luminaire in at least two opposite corners." Seismic rules may require them; in Seismic Design Categories D through F, USG SC2493 and ASTM E580 call for the following. The local inspector (AHJ) may require them. Follow the strictest one that applies to your job.

Fixture weight	Slack safety wires (SDC D-F)
Under 10 lb	One 12-gauge wire, housing to structure
10 to 55 lb	Two 12-gauge wires
56 lb and over	Independently supported from the structure

Never hang wiring on the ceiling grid. 300.13(B)(1) (300.11(B) in 2023): "Wiring shall not be secured to or supported by the ceiling grid system, including the ceiling support wires." Independent support wires for wiring are allowed by 300.13(B)(2) if they are "installed in addition to the ceiling grid support wires," are "distinguishable by color, tagging, or other means," and are secured at both ends.

Step by step: installing a troffer (Lithonia GTL and Stack Switch instructions)

1. Inspect the fixture and check the label voltage against the circuit. A 120 V driver on 277 V fails.
2. Set it in the 15/16 in. grid.
3. Bend the T-bar clips at all four corners. Lithonia: "Refrain from bending the T-Grid clips multiple times."
4. Add hanger or slack wires through the clip holes as the specification, seismic rules or the AHJ require.
5. Open the access plate, connect the whip and the EGC, and close the plate.

Fixture whips

- 410.117(C): taps run to "an outlet box placed at least 300 mm (1 ft) from the luminaire ... in suitable raceway or Type AC or MC cable of at least 450 mm (18 in.) but not more than 1.8 m (6 ft) in length."
- MC (330.30(D)(2)) and AC (320.30(D)(3)) may run unsupported "not more than 1.8 m (6 ft) ... from the last point of cable support" to the fixture in an accessible ceiling. FMC uses the 348.30(A) exceptions and LFMC the 350.30(A) exceptions.

The fixture disconnect (410.71)

Indoors in other than dwellings, linear fixtures with double-ended lamps and drivers or ballasts serviced in place need a disconnect, internal or external to each fixture, with guarded line-side terminals. If an existing fixture has none, it must be added "at the time a ballast or LED driver is added or replaced." Exception 2 exempts emergency luminaires covered by 700.16.

3 — Exterior / Site Lighting

EXTERIOR / SITE LIGHTING



wall pack



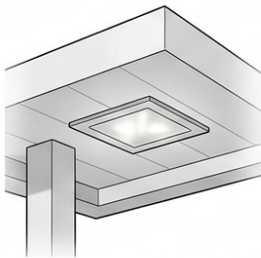
full-cutoff
wall pack



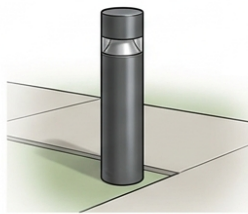
shoebox / area
light on a pole



flood light



canopy light
(gas station style)



bollard



parking-lot
pole light

Wall packs (and full-cutoff for dark-sky/glare control), shoebox/area lights on poles, floods, canopy lights, bollards.

- **Full-cutoff** fixtures throw no light above horizontal. Many dark-sky ordinances require them, and they control glare.
- **Shoebox and area lights on poles** light parking lots. **Canopy** lights go under gas-station and drive-through soffits. **Bollards** light walkways at low level.
- Exterior lighting usually pairs with a **photocell** (dusk-to-dawn) and often a contactor for the lot circuit.
- **480 V lot lighting.** 210.6(D)(1) allows up to 1000 V between conductors for pole luminaires mounted at least 22 ft high in parking lots and similar outdoor areas.
- **Energy code.** IECC 2021 C405.2.7 requires exterior lights to turn off in daylight and to reduce by at least 30 percent from midnight to 6 AM. That takes a photocell plus an astronomical time clock or network control.

Poles (410.30(B))

- A handhole "not less than 50 mm × 100 mm (2 in. × 4 in.)" with a wet-location cover. No handhole is needed on poles 8 ft or shorter with no splice inside, or 20 ft or shorter with a hinged base.
- Metal poles need a grounding terminal reachable from the handhole. A hinged base is bonded to the pole.
- Raceways and EGCs are bonded per 250.118 and 250.122.

Step by step: setting a pole on an anchor-bolt base (Acuity and Techlight pole guides)

1. Build the foundation the engineer designed for the soil and wind load. Do not substitute a different base.
2. Set the anchor bolts in the factory template, plumb and evenly spaced. Vibrate the concrete and let it cure fully.
3. Stub the conduit up inside the bolt circle.
4. On each bolt stack a leveling nut and washer, then the base plate, then a washer and top nut. Leave a ventilation gap under the plate. Do not set the plate directly on the concrete.
5. Plumb the pole on two faces. On a tapered pole, read both sides and split the difference.
6. Grout under the plate is optional and needs a weep tube; Techlight advises against grouting.
7. Pull the wire, install the in-line fuses, bond the pole, and fit the handhole and base covers.

In-line fuses at the pole base (Eaton Bussmann HEB, data sheet 2127)

HEB breakaway fuse holders are rated 600 V and up to 30 A. Torque the screw terminal to 35 lb-in and the coupling nut to 10–20 lb-in. With boots installed, size the fuse at 200 percent or more of the RMS load current. The neutral gets an NNB dummy link instead of a fuse.

4 — Exit & Emergency Lighting (life safety)

EXIT & EMERGENCY LIGHTING



EXIT sign
(red letters)



**combo EXIT +
emergency
heads**



**emergency
bug-eye
(twin-head)**



**emergency
LED driver /
battery backup**



**exterior
emergency
wall pack
with battery**

Exit signs, combo exit/emergency heads, bug-eye emergency units, and the emergency battery/driver behind them.

This is life safety. Egress lighting and exit signs must stay lit when normal power fails, through an integral battery, a central inverter, or a generator on the emergency system. NEC Article 700 and the life-safety and building codes govern it. Test it, record the test, and replace dead batteries.

The NEC 2026 rules

Rule	Section
Emergency power available within the time required, "not to exceed 10 seconds"	700.12
Batteries carry the load "for a minimum period of 1½ hours" without the voltage falling below 87½ percent (the 90-minute rule)	700.12(B)(4)
Battery-equipped emergency luminaires: listed, fixed in place (cord up to 3 ft allowed)	700.12(G)
Feed: "The same branch circuit as that serving the normal lighting in the area and connected ahead of any local switches"; or a monitored circuit; or a separate circuit with a lock-on breaker. Identify the circuit at the panel.	700.12(G)
Failure of one source "cannot leave in total darkness" any required space	700.16(B)
With HID-only normal lighting, emergency lighting stays on until normal light is restored	700.16(C)

Step by step: wiring an emergency LED driver (Signify Bodine BSL10T3 instructions)

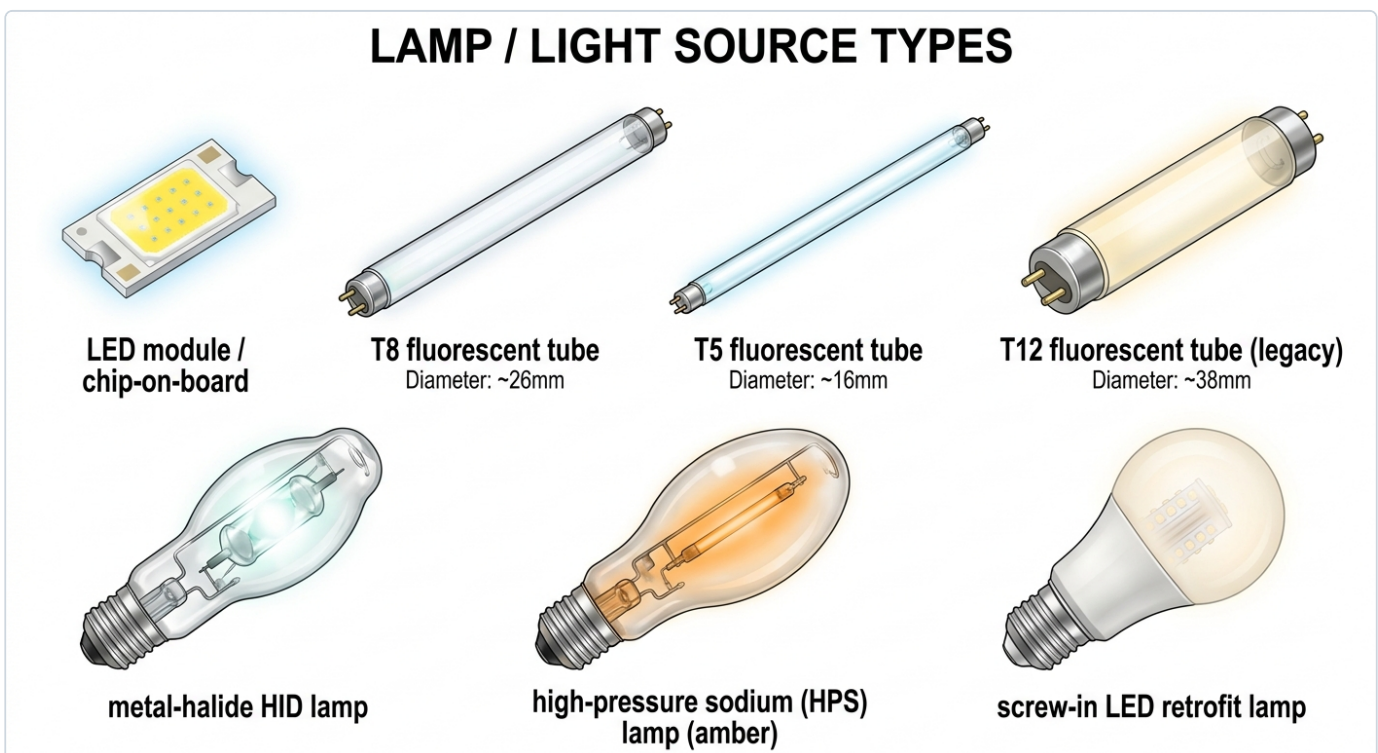
1. De-energize every supply to the fixture and verify dead.
2. Mount the emergency (EM) driver in the fixture.
3. Land an **unswitched hot** on the EM driver, taken ahead of the switch or occupancy sensor.
Bodine: "The emergency driver must be fed from the same branch circuit as the AC driver." The unswitched hot is how the EM driver knows normal power is gone; on the switched leg it would come on every time someone turned the lights off.
4. Land the switched hot on the normal (AC) driver, the EM output to the LED load, then the neutral and the ground. The unit "must be grounded."
5. Mount the illuminated test switch through a ½ in. hole and apply the PUSH TO TEST and CHARGING INDICATOR labels.
6. Apply the label "This Unit Has More Than One Power Connection Point."
7. Energize. The charge light should come on. Let it charge 1 hour before a short test and 24 hours before a 90-minute test.
8. Turn the room lights off at the switch: the EM fixture goes dark with the room and the charge light stays lit. Then open the breaker: the EM fixture lights on battery.
9. For mounting heights above 7.17 ft, measure the emergency illuminance in place.

Testing and records (NFPA 101, 7.9.3.1.1)

Test	How often	Duration
Functional test	"at 30-day intervals"	"not less than 30 seconds"
Full test	Annually	"not less than 1-1/2 hours if ... battery powered"
Exit signs	Visual check at 30 days or less	Confirm lit
Self-diagnostic units	Monthly visual check	Plus the annual 90-minute test

"Written records ... shall be kept by the owner." When you test, write the date, the result and your name on the owner's log.

5 — Light Sources (what's inside)



LED has replaced nearly everything; you still meet legacy fluorescent (T8/T5/T12) and HID (metal-halide, HPS).

- **LED** is the standard now: highest efficacy (lumens per watt), long life, instant-on, dimmable, no mercury.
- **Fluorescent:** T8 (1 in.) is still common, T5 (5/8 in.) is in newer and high-output fixtures, and T12 (1½ in.) is legacy and phased out, so retrofit it to LED. All contain mercury; recycle the lamps.
- **HID:** metal-halide (bluish-white) and high-pressure sodium (amber) in old high-bay and site lighting. They warm up and restrike slowly and their ballasts fail; they are the main LED retrofit target.

LED drivers

The driver turns line voltage into the DC the LEDs need. A **constant-current (CC)** driver holds a fixed current (for example 1050 mA) over a voltage window (for example 30–54 V). If the LED string's total forward voltage falls outside that window, the driver shuts down or "hiccups" (blinks on and off). A **constant-voltage (CV)** driver holds 12 or 24 V for LED tape that has resistors on board. Mixing them destroys parts: tape on a CC driver burns the tape, and a CC array on a CV supply runs away thermally.

Retrofits and listing

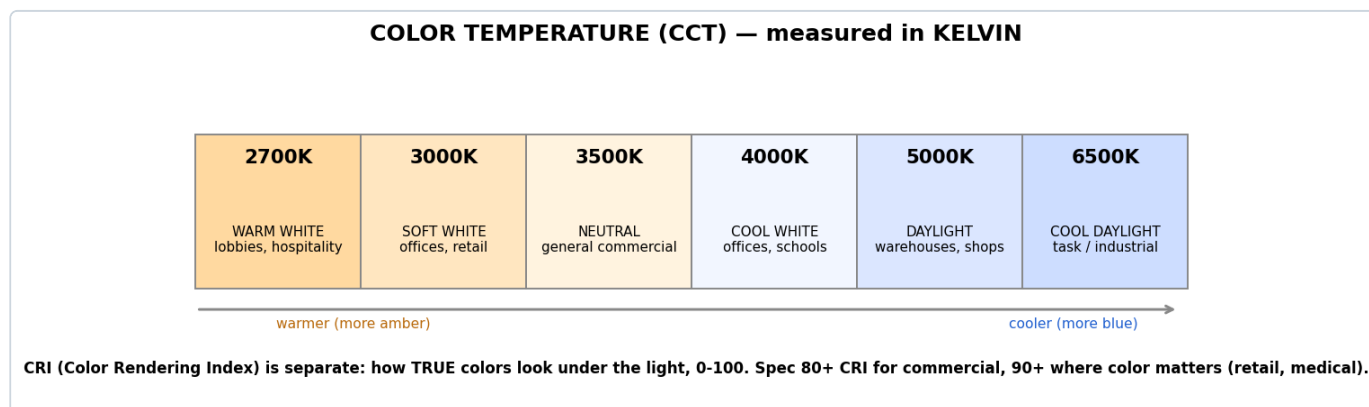
- "All luminaires, lampholders, lighting systems, and retrofit kits shall be listed" (410.2).
- New in 2026, 410.3(B): reconditioned luminaires, lampholders, ballasts, LED drivers, lamps and retrofit kits may not be installed.
- Listed retrofit kits are allowed on 277 V circuits (210.6(C)(8)).

Type B (ballast-bypass) LED tubes put line voltage on the sockets. Single-ended tubes need non-shunted sockets; Satco's instructions say "do not use this retrofit kit in luminaires employing shunted bi-pin lamp holders," and installers "should cut existing lamp holder leads away ... and make new electrical connections." Double-ended tubes are "not hot until both ends are installed." The fixture gets a field label because the listing moves to the kit (UL 1598C). The next person to change a lamp must know this fixture no longer has a ballast.

Step by step: Type B tube retrofit

1. Lock out the circuit and verify dead.
2. Pull the lamps and remove the ballast.
3. Identify the socket type (shunted or non-shunted) and replace the sockets if the kit requires it.
4. Wire per the kit: single-ended has line and neutral at one end; double-ended has line at one end and neutral at the other.
5. Apply the retrofit label.
6. Install the tubes and test.
7. Add the 410.71 disconnect if the fixture lacks one.

6 — Color Temperature & CRI



CCT (Kelvin) sets how warm or cool the light looks; CRI sets how true colors render under it.

Correlated color temperature (CCT)

CCT, in kelvin (K), is the temperature of a glowing black body whose color "most closely matches the color of the light source" (DOE LED Color Characteristics fact sheet). Lower kelvin looks warmer (yellow), higher looks cooler (blue-white). CCT "characterizes the color of the emitted light, not the color of illuminated objects"; that is what CRI is for. Within a product family, "Higher-CCT LED sources tend to be more efficacious," so a 5000 K version of a fixture usually puts out a few more lumens per watt than the 3000 K version.

CCT	Look	Typical use (Orion IES/CCT reference)
2700–3500 K	Warm	Hospitality settings: restaurants, hotels
4100–5000 K	Neutral to cool	Office environments
5000 K and up	Cool	Distribution centers, warehouses

Always install the CCT listed on the fixture schedule; do not mix CCTs in one room.

Color rendering index (CRI)

CRI (written Ra) compares how 8 test colors look under the source with how they look under a reference source of the same CCT. 100 means identical. DOE's grading: "70s ... acceptable for interior ... 80s ... good (specification grade) ... 90s excellent." CRI does not tell you which way colors shift, only how much.

CRI	Grade (DOE)	Where you see it
70-79	Acceptable for interior	Warehouses, parking
80-89	Good (specification grade)	Most commercial interiors
90+	Excellent	Retail, healthcare, anywhere color matters

R9 is the score for saturated red, and it is not part of the 8-color average. It matters for skin tones, meat and produce. An "R9 score greater than 0 is generally considered acceptable"; ENERGY STAR lamps require CRI 80 or more and R9 above 0. A 3000 K, CRI 85 T8 measured R9 = 2, so a good CRI does not guarantee good reds.

TM-30: the newer metric

- **Rf** (fidelity, 0–100) works like CRI but uses 99 color samples instead of 8. The IES recommends replacing CRI with Rf.
- **Rg** (gamut) tells you which way colors shift. 100 is neutral; above 100 colors look more saturated, below 100 duller. The usual range is about 60 to 140.
- **Rf,h1** (the red hue fidelity) tracks R9.
- Two lamps with the same CRI can look different. In DOE's example, three "CRI 80" sources all measured Rf 75 but Rg 80, 100 and 120: one dull, one neutral, one oversaturated.

Light units

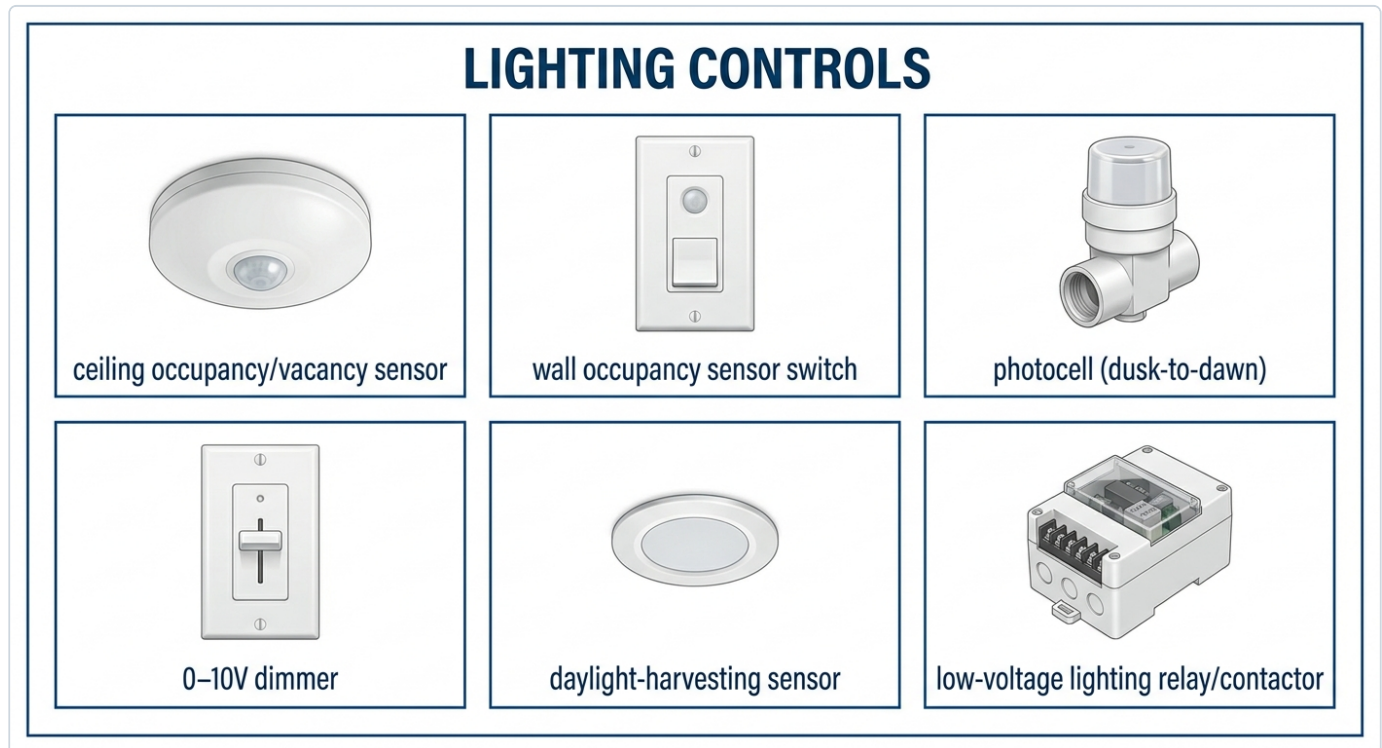
Unit	Meaning
Lumen (lm)	Total light output of the source
Efficacy (lm/W)	Lumens per watt; how efficient the fixture is
Footcandle (fc)	Lumens per square foot landing on a surface; what a light meter reads in the US
Lux (lx)	Lumens per square meter; 1 fc = about 10.76 lux

IES recommended light levels (IES Handbook, 10th edition, via Orion)

These are maintained average horizontal footcandles. The low end of each range assumes most users are under 25; the high end assumes most are over 65.

Space	Average fc	Range
Office desk, open or private	40	30–50
Conference table	30	15–60
Corridor, stairs	5	2.5–10
Warehouse, bulky items or large labels	10	5–20
Warehouse, small items	30	15–60
Shipping dock	10	5–20
Fine assembly	100	50–200
Parking, suburban / urban	1 / 1.5	0.5–2 / 0.75–3
Parking, covered	5	—
Gas station canopy	12.5	10–15

7 — Lighting Controls (the energy code drives these)



Occupancy/vacancy sensors, photocells, 0-10V dimmers, daylight sensors, and lighting relays/contactors.

- **Occupancy and vacancy sensors** turn lights off when a space is empty. Occupancy sensors turn on automatically; vacancy sensors need a manual "on." The energy codes (IECC, ASHRAE 90.1) require them in many room types.
- **Daylight harvesting** dims fixtures near windows and skylights as daylight rises.
- **0-10 V dimming** is the common commercial LED method: two low-voltage control wires to the driver.
- **Photocells** switch exterior lighting dusk to dawn. **Lighting contactors and relays** switch big lighting loads from a low-voltage signal (time clock, building automation system, photocell).

0-10 V: how it works and how to wire it

0-10 V is a "sink" system under ANSI C137.1 and IEC 60929 Annex E. The driver supplies about 10 V on its control leads, and the dimmer pulls that voltage down. Leads open (or 10 V) means full light; leads shorted (0 V) means minimum or off.

Wire	Color	Note
Dim +	Violet	Positive
Dim -	Pink	Gray on drivers made before January 1, 2022

- Polarity matters. ETC: "Crossing the positive and negative wires ... will result in ... flickering or not dimming."

- Count drivers. Each driver sources about 0.5 mA (up to 2 mA). A controller that can sink 30 mA could in theory take 60 drivers at 0.5 mA; Acuity's Pathway guide says to keep it to 30 or fewer.
- Color of field control wire (410.69): it "shall not be of a color reserved for the grounded ... or the equipment grounding conductor." Gray is allowed only if re-identified with a color other than white, gray or green. A gray field-installed dim wire must be re-marked.

Other dimming systems

- **DALI** (IEC 62386): a two-wire digital bus at about 16 V with up to 250 mA total supply; 64 control gear and 64 control devices, 16 groups, up to 300 m. It is not polarity sensitive.
- **Phase-cut (forward-phase) dimmers** on LED: NEMA SSL 7A covers compatibility, but Lutron notes it "defines only basic dimming criteria." Some dimmers need a neutral and about 10 percent low-end trim. Use the dimmer maker's compatibility list.

Step by step: occupancy sensor with a power pack (Wattstopper UT-300 / BZ pack)

1. Mount the BZ power pack (120/277 V input, 20 A relay).
2. Wire the Class 2 side: RED +24 VDC, BLACK common, BLUE control.
3. One pack powers up to 5 UT-300 sensors.
4. Place ultrasonic sensors at least 4 ft from supply air ducts and at least 6 ft from horizontal discharge.
5. Set manual-ON (vacancy) or auto-ON with the DIP switches.
6. Test. If the lights won't go off, pull the BLUE wire and check the pack's input and its 24 VDC output. If 24 VDC reaches the sensor and it still fails, replace the sensor.

Switches and the neutral

- 406.30(C) (404.2(C) in 2023): the grounded conductor "shall be installed at the location where switches control lighting loads." Sensors and electronic switches need it.
- 406.46 (404.14 in 2023): a general-use snap switch may control LED driver loads "not exceeding 20 amperes and not exceeding the ampere rating of the switch at the voltage applied." On 277 V circuits, use 277 V-rated devices.

IECC 2021 C405 control requirements

Requirement	Value
Occupant sensor shutoff	Within 20 minutes of vacancy; turn on manually or automatically to no more than 50%
Open-office zones	600 ft ² or less each; reduce at least 80% when vacant
Time-switch override	2 hours or less; 5,000 ft ² or less per override
Manual light reduction	At least 50%
Daylight control required	Sidelit primary zone over 150 W, total sidelit over 300 W, or toplit over 150 W; dim to 15% or less, may shut off
Exterior	Off in daylight; reduce 30% midnight to 6 AM (C405.2.7)
Functional testing	Before final (C408.3.1)

ASHRAE 90.1 is an alternate compliance path. Which code applies is set by the state and the AHJ.

8 — Selecting a Fixture

The numbers that decide it

- **Lumens, not watts.** Watts is energy used; lumens is light produced. Compare efficacy (lm/W) to judge efficiency.
- **Footcandles at the work plane** are the design target. Use the IES table in Section 6.
- **Mounting height and beam angle** set how the lumens land. A higher mount or a narrower task needs more lumens.
- **CCT** for the look, **CRI 80+** for general commercial and **90+** where color matters.
- **Lighting load** is calculated and added to the panel and feeder (NEC 2020 120.42; 220.12 in 2023). It is a continuous load, so the breaker must be at least 125 percent of it (210.20(A)).

Reading the fixture schedule and cut sheet

The schedule on the drawings lists, for each type mark: manufacturer and catalog number, lumens, CCT and CRI, voltage, wattage, mounting, controls, emergency option, and circuit. The cut sheet adds the DLC listing, the IES photometric file, the maximum fixtures per breaker, the ambient temperature rating, and the wet or damp rating. Check all of them before you order.

Lighting load (Table 120.42(A))

Occupancy	VA/ft ²
Office	1.3
Warehouse	1.2
Retail	1.9
Manufacturing facility	2.2
Parking garage	0.3

Where the building is designed to an adopted energy code, 120.42(B) allows the lighting load to be calculated from the energy code values instead.

Worked example 2: the lumen method for a 30 × 40 ft office

The lumen method finds how many fixtures a room needs. It uses the room shape, the fixture's coefficient of utilization (CU, the share of lamp lumens that reach the work plane) and the light loss factor (LLF, for dirt and lamp aging).

Step	Math	Result
Room cavity height (9 ft ceiling, 2.5 ft work plane, recessed fixtures)	$9 - 2.5$	6.5 ft
Room cavity ratio, $RCR = 5 \times h \times (L + W) \div (L \times W)$	$5 \times 6.5 \times 70 \div 1,200$	1.9
CU from the fixture photometry (ceiling 80%, walls 50% reflectance)	Sample troffer table	0.90
LLF = lumen depreciation × dirt depreciation × room surface dirt	$0.85 \times 0.92 \times 0.95$	0.74
Fixtures $N = fc \times area \div (lumens \times CU \times LLF)$, target 40 fc, 4,000 lm troffer	$40 \times 1,200 \div (4,000 \times 0.90 \times 0.74)$	18
Spacing check: spacing criterion (from photometry; 1.2 used here as an example) × mounting height	1.2×6.5	About 7.8 ft max
Layout: $3 \times 6 = 18$ puts rows 10 ft apart, too wide. Use 4×5	About 7.5×8 ft spacing	20 fixtures
Load: 20×33 W	$660 \text{ W} \div 1,200 \text{ ft}^2$; $660 \div 277$	0.55 W/ft ² ; about 2.4 A

On a real job, read CU and the spacing criterion from the fixture's photometric report. The engineer usually does this calculation, but knowing it lets you spot a layout that will come up dark.

Worked example 3: voltage drop on a 277 V lighting home run

The 210.19 informational note recommends no more than 3 percent drop on a branch circuit and 5 percent total. Voltage drop for a single-phase circuit is $VD = 2 \times K \times I \times L \div CM$, with $K = 12.9$ for copper, I in amps, L the one-way length in feet, and CM the conductor's circular mils (Chapter 9, Table 8). Load: 16 A at 250 ft one way on 277 V.

Wire	Math	Drop	Result
12 AWG (6,530 cmil)	$2 \times 12.9 \times 16 \times 250 \div 6,530$	15.8 V	5.7%, fails 3%
10 AWG (10,380 cmil)	Same	9.9 V	3.6%, still over 3%
8 AWG (16,510 cmil)	Same	6.25 V	2.3%, passes

Step by step: running a 277 V lighting circuit

1. Confirm the panel is 480Y/277 V and note the circuit numbers from the drawings.
2. Use a 20 A, 1-pole breaker (12 AWG copper is limited to 20 A by 240.4(D)). A multiwire branch circuit needs a multipole breaker or handle ties so it can "simultaneously disconnect all ungrounded conductors" (210.4(B)).
3. Pull 12 AWG THHN/THWN-2 (larger if voltage drop requires it), with the neutral identified per 200.7.
4. Home-run to the first box, then whips of 6 ft or less to the fixtures.
5. Use 277 V-rated switches and sensors and bring the neutral to the switch box.
6. Torque terminations per 110.14(D) and the device labels.
7. Insulation-test the circuit before energizing.
8. Energize and measure: about 277 V hot to neutral and about 480 V hot to hot between phases.
9. Check every fixture and the dimming, then update the panel directory.

9 — Troubleshooting Lighting

DOE: "LED flicker characteristics are primarily a function of the LED driver." Start at the driver and work out.

Symptom	Likely cause	Check
Fixture dead	No input, open LED string, forward voltage outside the driver window, failed driver	Measure input voltage; bypass the dimmer; measure driver output; swap in a known-good driver
Flicker	Driver PWM, dimmer mismatch, loose neutral, voltage induced on 0-10 V leads	Film it with a phone at 240 fps slow motion; measure for AC on the control leads
Won't dim, or dims backward	Violet and pink swapped, wrong protocol	Check polarity and that the driver and control use the same protocol
Dimmer drops out at the low end	Load below the dimmer's minimum	Raise low-end trim; use a neutral-type dimmer
Driver failed on day one	120 V driver on a 277 V circuit	Read the label before installing
Lights won't turn off	Sensor or power pack	Pull BLUE, check pack input and 24 VDC output
EM fixture comes on with the wall switch off	EM driver fed from the switched leg	Move it to the unswitched hot
EM indicator flashing (Bodine)	2 flashes battery, 3 charging, 4 load changed more than 25%, 5 temperature	For code 3, check the unswitched hot, neutral and ground
Pole light out	Blown in-line fuse	Check HEB fuses in the handhole

For flicker limits, IEEE 1789's low-risk line is percent flicker no more than $0.08 \times$ the flicker frequency, for 90 to 1,250 Hz.

10 — Safety, Mistakes and Inspection

Lighting circuits fool people. Turning off the wall switch does not kill the fixture: the unswitched EM hot, a shared neutral on a multiwire circuit, and 277 V all stay live. Lock out per OSHA 1910.147 and 1910.333(b)(2), then test before you touch every conductor in the fixture, including the EM feed and the neutral.

Common mistakes

Mistake	Rule or reason
Wiring hung on the ceiling grid wires	300.13(B)
Whips longer than 6 ft	410.117(C), 330.30(D)(2)
EM driver fed from the switched leg	700.12(G); Bodine instructions
0-10 V polarity crossed, or a gray control wire not re-identified	Flicker or no dimming; 410.69
Type B tubes in shunted sockets	Satco instructions
No disconnect added when a driver is replaced	410.71
Reconditioned fixtures or drivers installed	410.3(B)
Pole base plate set directly on the concrete	Pole maker instructions
Missing in-line fuses at the pole	Fixture and pole protection
Wrong CCT mixed in one room	Fixture schedule
Controls never commissioned	IECC C408.3.1

Inspection checklist

1. Troffers clipped at all four corners, with hanger or slack wires as the spec, seismic rules or AHJ require.
2. Whips 6 ft or less; 90°C wire within 3 in. of the driver.
3. Fixture voltage matches the label; 277 V devices; neutral at every switch location.
4. Emergency: unswitched hot ahead of controls, labels in place, a witnessed 30-second test, circuit identified at the panel.
5. Exit signs lit.
6. Poles: handhole cover, grounding terminal, bonding, in-line fuses.
7. 0-10 V polarity correct and dimming smooth end to end.
8. Controls test record (IECC C408.3.1).
9. Panel directory updated.

NEC 2026 Checkpoints (2023 number in parentheses where it moved)

- **410.2** listing • **410.3(B)** no reconditioned luminaires, drivers, lamps or kits (new) • **410.10(A)** wet locations • **410.24(A)** connection • **410.30(B)** poles • **410.36(B)** lay-in support.
- **410.68** 90°C conductors • **410.69** control wire colors • **410.71** fixture disconnect • **410.116**, **410.118** recessed • **410.117(C)** 6 ft whips • **410.150(C)** track.
- **300.13(B)** (300.11(B)) wiring above ceilings • **330.30(D)(2)**, **320.30(D)(3)** unsupported cable.
- **406.30(C)** (404.2(C)) neutral at switch • **406.46** (404.14) switch ratings.
- **120.42** (220.12) lighting load • **210.20(A)** 125% continuous • **210.4(B)** multiwire disconnect • **210.6(C)**, **210.6(D)(1)** 277 V and 480 V lighting • **240.4(D)** small conductors.
- **700.12** 10 seconds • **700.12(B)(4)** 90 minutes • **700.12(G)** battery-equipped luminaires • **700.16** emergency illumination.
- Energy: IECC 2021 C405 and C408.3.1, or ASHRAE 90.1, as adopted by the state and AHJ. Life safety: NFPA 101 7.9.3.

Hands-On Field Exercise

- Install a 2x4 troffer in a grid: four clips, hanger wires per the spec, whip of 6 ft or less, EGC landed.
- Wire an EM driver into a troffer from an unswitched hot, then do the switch-off and breaker-open tests and record a 30-second test.
- Wire 0-10 V dimming to three drivers, then cross the violet and pink on one and observe what happens.
- Work the lumen method for a room in the shop and compare your count with the drawing.
- Calculate voltage drop for the longest lighting home run on a current job.
- With a light meter, measure footcandles at desk height in an office and compare with the IES table.
- Set up an occupancy sensor and power pack and run the "lights won't turn off" check.

Sources used in this module (public documents)

- NFPA 70, National Electrical Code 2026 (free read-only access at [nfpa.org](https://www.nfpa.org)): Articles 120, 210, 240, 300, 320, 330, 406, 410, 700.
- NFPA 101, Life Safety Code, 7.9.3 (as reprinted by Big Beam, bigbeam.com, and NFPA Journal, July 2020, [nfpa.org](https://www.nfpa.org)).
- U.S. Department of Energy: LED Color Characteristics fact sheet; TM-30 tutorial (2022) and introduction webinar (2015); flicker fact sheet and postings: [energy.gov](https://www.energy.gov)
- ENERGY STAR integral lamps v1.0 cover letter: energystar.gov
- Orion Lighting, IES Guideline and CCT brochure (IES Handbook 10th edition values): orionlighting.com
- Illumination Pros, lumen method and LED driver articles: illuminationpros.net. Designing Light lumen worksheet: designinglight.com
- Signify Bodine BSL10T3 / BSL06T3 instruction sheet: signify.com

- ETC 0-10 V guide: etcconnect.com. Acuity Brands Pathway 0-10 V best practice and nLight IECC 2021 guides: acuitybrands.com
- DALI Alliance: dali-alliance.org. NEMA SSL 7A: nema.org. Lutron application note 048637: lutron.com
- Leviton 2021 IECC design guide: leviton.com
- Wattstopper UT-300 / BZ power pack installation instructions.
- Lithonia (Acuity) CPX, GTL and Stack Switch instructions; Acuity square straight pole guide; Techlight pole installation: techlightusa.com
- USG SC2493 seismic hanger wire guide: usg.com. ASTM E580: astm.org
- Eaton Bussmann HEB in-line fuse holder data sheet 2127: eaton.com
- Satco S11732 retrofit instructions: satco.com. Regency Supply on Type B tubes and UL listing: regencysupply.com
- OSHA 29 CFR 1910.147 and 1910.333: osha.gov

Next: Legacy Systems Masterclass.