



TITLE 24, PART 6

2028 CODE CYCLE

Controlled Environment Horticulture: Daylight Responsive Controls for Greenhouses

Codes and Standards Enhancement (CASE) Proposal

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A STATEWIDE UTILITY PROGRAM

Review of Proposed Code Change

New Daylight Responsive Controls Requirement for Greenhouses with at least 40 kW of Supplemental Lighting

New Construction & Alterations, All Climate Zones

Two compliance options:

- **Option 1:** Timeclock + Photosynthetic Active Radiation (PAR) Sensor-Based Control
On/off or dimming based on PAR sensor readings of Photosynthetic Photon Flux Density (PPFD)
- **Option 2:** Daily Light Integral (DLI) Control
Adjusts lighting to meet the daily cumulative PPFD target

To ensure the proper functionality of the required controls, an **acceptance test protocol** for use by **field technicians** at the time of installation is being considered.

Clarifying Control Requirements for Indoor Grow Spaces

Minor code updates to improve clarity around how lighting controls must be used in indoor grow operations.

See Title24stakeholders.com for CASE Report, proposal description, justification, draft code language, and requested data

Benefits of the Proposed Change

Significant Energy Savings & Demand Reduction

- Delivers an estimated **9–26% energy savings** depending on the climate zone and crop.
- Reduces over-lighting, lowers cooling loads, and **eases grid demand** during peak hours.
- **Potential for longer luminaire lifespan** due to reduced operating hours and lower LED drive currents while dimmed

Improved Crop Quality & Consistency

- Supports the **optimal daily light delivery** for crops
- Improves yield predictability and grower control

Flexibility for Growers

Two compliance options are offered:

1. Timeclock + PAR Sensor (**lower first cost**)
2. Daily Light Integral (DLI) (**greater energy savings and performance**)

Background Information: How Energy is Saved

Reduces Over-Lighting

- Automatically dims or turns off lights when sunlight provides enough PPFD.
- Limits total number of hours lights are on or dimmed.
- Adjusts to cloud cover and seasonal changes, avoiding wasted energy.

Minimizes Cooling Loads

- Lower lighting intensity reduces heat gain/cooling load in greenhouses.
- Cuts cooling or ventilation energy use.



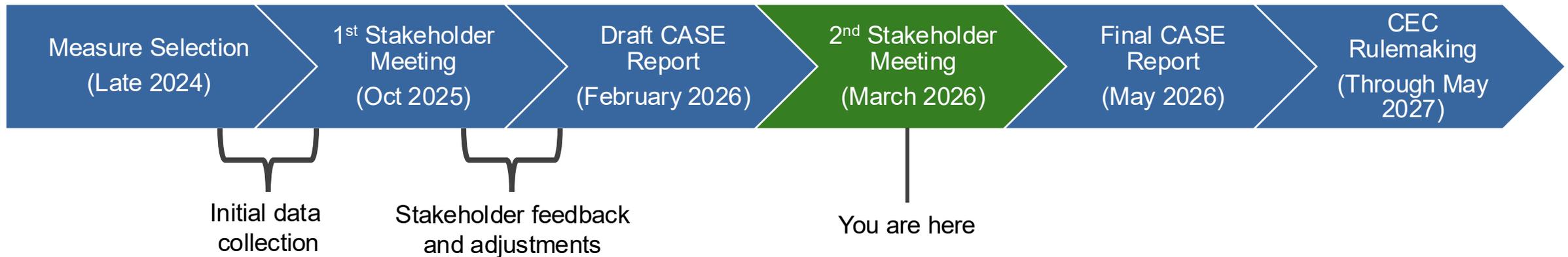
What's New Since Our Last Stakeholder Meeting?

New / Updated

- ✓ Market Share
- ✓ Incremental First & Maintenance Costs
- ✓ Cost-Effectiveness Results & Benefit-to-Cost Ratio
- ✓ Statewide Energy & Energy Cost Savings

Still Under Consideration

- Collecting implementation challenges for technology
- Verifying estimated useful life based on stakeholder experience
- Collecting feedback on acceptance testing protocol



Poll

Based on your experience, approximately what share of larger greenhouses (>40 kW of connected horticultural lighting) use sensor-based lighting controls?

(Choose one)

- a) Less than 50%
- b) 50-70%
- c) Greater than 70%
- d) Not sure

Daylight Responsive Controls: Current Market Share

Market share: percentage of buildings that already use the proposed technology or design practice (at or above the proposed stringency level)

New
Construction,
Additions &
Alterations

~60-83%

Sources: 2025 Cannabis Business Times Survey, November 2025
CalNEXT Smart Controls for Data-Driven Indoor Agriculture Field Evaluation, October 2025

Technical Considerations

PAR-Sensor Controls

- Can react (dim/turn off lights) in response to instantaneous PPFD
- **Offer simple, low-cost, easy integration**
- Require **strategic positioning above the canopy** to avoid shading or reflection errors
- Need **periodic cleaning and calibration** to maintain accuracy
- They are best for smaller operations and less light-sensitive crops

DLI Controls

- Manage cumulative daily light (Daily Light Integral)
- Are higher cost and more complex but offer **superior crop consistency & energy savings**
- Require sensors + software
- They are best for high-value crops (cannabis, ornamentals) and variable sunlight regions

Poll

Based on your experience, what challenges would greenhouse operators have with sensor-based lighting controls?

(Choose all that apply)

- a) Lack of familiarity with the operation of the systems
- b) Integration with existing lighting systems
- c) Positioning sensors appropriately and calibrating the system based on location
- d) Calibrating at appropriate intervals
- e) None

Energy Modeling Methodology

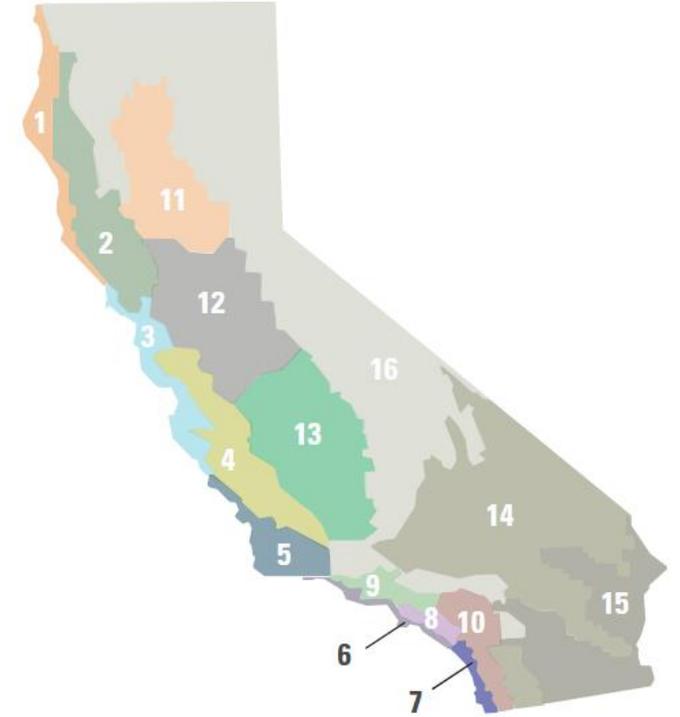
Savings Calculation Approach

Compare greenhouse lighting energy use between:

- **Baseline:** Timeclock only – **lights on 100% power for the full crop-specific photoperiod**
- **Proposed:**
 - Control Option 1: Timeclock + PAR sensor-based control with dimming and on/off (**turns off if dimming setting is below 10%**)
- **Not used:** Control Option 2: DLI responsive control

Modeling Approach

- Savings vary by sunlight availability, so **all 16 California climate zones** will be modeled individually
- Custom **spreadsheet-based 8760 methodology** (CBECC & EnergyPlus do not currently model greenhouses, including Option 1 and 2 controls)
- Simulate hourly light availability as GHI from the **most recently available typical meteorological year (TMY) weather files multiplied by 46% (amount within PAR band), and light transmittance of 50%.**
- **Use crop-specific target DLI (17–43 mol/m²/day) and crop-specific lighting system assumptions to model annual lighting energy use for baseline vs. proposed case**



Energy Modeling Assumptions

Simulated using the following prototypical buildings and climate zones:

Prototypical Buildings

Building Types Included

- **Greenhouses** with supplemental lighting meeting proposed ≥ 2.5 $\mu\text{mol/J}$ PPE

Crops Modeled

- **Cannabis**
- **Tomatoes** (vine crops)
- **Greens** (e.g., herbs, microgreens)

Climate Zones

- Energy savings modeled separately for **all 16 CA climate** zones, reflecting differences in:
 - Regional daylight availability
 - Hourly PAR / solar radiation variability

Energy Modeling Assumptions, cont.

Prototype: Greenhouse

Photosynthetic Photon Flux Density ($\mu\text{Mol}/\text{m}^2/\text{s}$)

Building Type	Cannabis Flower	Cannabis Vegetative	Cannabis Clone	Leafy Greens	Tomatoes
Target	600	400	200	200	350
Supplemental	400	267	133	133	233

Lighting System Design Parameters

	Cannabis Flower	Cannabis Vegetative	Cannabis Clone	Leafy Greens	Tomatoes
Canopy Area per Luminaire (ft^2)	20	24	10	58	56
Photoperiod (hours per day)	12	18	24	18	12
Mounting Height Above Canopy	24"	24"	24"	24"	24"
Target DLI ($\text{mol}/\text{m}^2/\text{day}$)	43.2	38.9	N/A	14	16



Standard Design

1. 2.5 PPE ($\mu\text{Mol}/\text{J}$)
2. Title 24 2025



Proposed Design

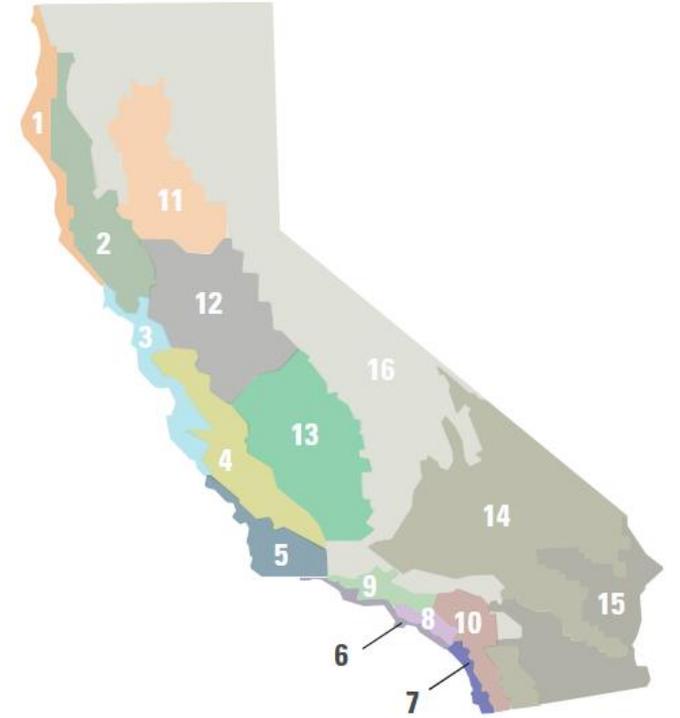
1. 2.5 PPE ($\mu\text{Mol}/\text{J}$)
2. Lighting use reduction due to DRC (%)

Energy Savings Analysis: Daylight Responsive Controls Algorithm

- Determine daylight at canopy
- Compare daylight with crop-specific PPFD threshold
- Translate light shortfall to a dimming command
 - If there is no shortfall, lights are turned off.
 - If the required output is below the driver's minimum of 10%, hold at 10%.
 - If required output is between 10% and 99%, dim accordingly.
 - If required output exceeds full power, cap at full power.
- Calculate fixture output and power hourly.

First-Year Per-Unit Energy Savings

- **Energy savings:** 25 to 45 kWh per year per canopy square foot
- **Electric demand reductions:** 0.001 to 0.002 kW per canopy square foot
- **No natural gas savings** are associated with the proposed measure



First Year Electricity Savings (kWh) Per Canopy Square Foot by Climate Zone (CZ) - Daylight Responsive Controls

Prototype	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16
Greenhouse Cannabis	31.41	36.63	37.38	40.99	40.55	41.14	40.34	40.85	41.75	41.62	36.63	38.46	40.27	43.27	43.06	37.51
Greenhouse Leafy Greens	24.70	26.36	26.71	27.83	27.74	27.80	27.58	27.68	27.90	27.84	26.17	27.06	27.50	28.34	28.30	26.73
Greenhouse Tomatoes	36.37	40.11	40.87	43.67	43.47	43.84	43.35	43.64	44.21	44.11	40.10	41.82	43.16	45.34	45.30	41.04

What are your thoughts on the energy savings modeling or assumptions?

(You may share support, concerns, or general comments.)

Incremental Cost Framework

Prototype(s): Greenhouse



Baseline

First Cost

1. Lighting Control Costs (Timeclock only)
 - Control hardware, wiring, and lighting control software/firmware (if needed)
2. Installation
 - Control panel mounting, low-voltage wiring or networking

30-Year Maintenance Costs

1. Equipment Replacement (as needed)
2. Regular Maintenance
 - Seasonal timeclock adjustments
 - Minor calibration & troubleshooting



Proposed

First Cost of PAR Sensors with Dimming Controller

1. Lighting Control Costs
 - PAR sensors
 - Control hardware, wiring, and lighting control software
2. Installation
 - Sensor placement, control wiring, fixture integration, calibration/commissioning, networking

30-Year Maintenance Costs

1. Equipment Replacement
2. Regular Maintenance
 - Sensor cleaning & calibration

Incremental Costs per 40kW Lighting Zone

First Costs:

	Baseline Timeclock On/Off)	Proposed (PAR + Dimming)	Incremental Cost
Hardware cost	\$63	\$1284	\$1221
Installation cost	\$167	\$445	\$278
Total First Cost	\$230	\$1729	\$1499

Maintenance Cost Assumptions:

- Effective Use Life of eight years assumed for time clocks, PAR sensors, and dimming controllers, based on DEER
- Full replacement of each system every eight years, at the same hardware and installation cost as initial installation
- Regular maintenance costs assumed to be the same for baseline and proposed cases

Poll

Based on your experience in the market, is the proposed incremental first cost (\$1499) accurate?

- a) Much too high
- b) A little too high
- c) Accurate
- d) A little too low
- e) Much too low
- f) Not sure

Poll

Based on your experience in the market, is the EUL of eight years for time clocks, dimming controllers, and PAR sensors accurate?

- a) Accurate for all three pieces of hardware
- b) Accurate for some, but not all pieces of hardware
- c) Not accurate for any
- d) Not sure

30-Year Cost-Effectiveness Summary Per Canopy Square Foot

New Construction & Additions

Prototype	Benefits: LSC Savings + Other PV Savings (2029 PV\$)	Costs: Total Incremental PV Costs (2029 PV\$)	Benefit-to- Cost Ratio
Greenhouse Cannabis	\$231.54	\$4.16	56
Greenhouse Leafy Greens	\$172.97	\$0.83	208
Greenhouse Tomatoes	\$257.77	\$1.46	177

Alterations

Prototype	Benefits: LSC Savings + Other PV Savings (2029 PV\$)	Costs: Total Incremental PV Costs (2029 PV\$)	Benefit-to- Cost Ratio
Greenhouse Cannabis	\$237.80	\$4.16	57
Greenhouse Leafy Greens	\$175.34	\$0.83	211
Greenhouse Tomatoes	\$263.34	\$1.46	181

Statewide Energy Savings Assumptions

Metric	Assumption	Source
Market Size	40.2 million SF of CEH facilities estimated statewide, with 2.1 million SF of projected annual new construction.	2029 CEC Construction Forecast
Facility Type Breakdown	68% of statewide CEH square footage is greenhouse 32% is indoor grow facilities	2029 CEC Construction Forecast
Greenhouse Applicability	70% of greenhouse square footage has connected horticultural lighting load \geq 40 kW and is therefore subject to the proposed lighting measure.	2025 Title 24 Controlled Environment Horticulture Final CASE Report
Crop Mix	40% Tomatoes / Flowers / Vine Crops 30% Cannabis 30% Leafy Greens / Herbs / Microgreens	2025 Title 24 Controlled Environment Horticulture Final CASE Report
Turnover Rate	Lighting controls have an estimated useful life (EUL) of 8 years, resulting in approximately 12.5% annual turnover of applicable greenhouse square footage for this measure.	CPUC DEER (Database for Energy Efficient Resources)

Total First-Year Energy Savings by Crop (Statewide)

Crop Type	Construction Type	First-Year Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First -Year Natural Gas Savings (Million Therms)	First-Year Source Energy Savings (Million kBtu)	30-Year Present Valued LSC Savings (Million 2029 PV\$)
Cannabis	New Construction & Additions	2.89	0.13	N/A	0.82	\$17.21
	Alterations	10.25	0.46	N/A	2.95	\$61.02
Greens	New Construction & Additions	3.10	0.17	N/A	1.38	\$19.78
	Alterations	10.83	0.58	N/A	4.91	\$69.22
Tomatoes	New Construction & Additions	6.42	0.32	N/A	2.25	\$39.30
	Alterations	22.58	1.12	N/A	8.08	\$138.62
All	Total	56.08	2.78	N/A	20.39	\$345.16

What are your thoughts on the statewide energy savings impacts assumptions?

(You may share support, concerns, or general comments.)

Key Aspects of Compliance Verification

Updates to Covered Process Compliance Form NRCC-PRC-E

- Document type of daylight responsive control used

Updates to Covered Process Installation form NRCI-PRC-E

- **Allow building inspectors to confirm control strategies** are documented
- Document make/model of daylight responsive control installed
 - Timeclock
 - PAR Sensor
 - DLI System

Acceptance Test Protocol (Field Verification)

- Ensure the proper functionality of daylight-responsive controls
- **Performed by field technicians at the time of installation**
- Confirm response to changing light levels, dimming behavior, and integration with other systems (if applicable)
- **Add a new NRCA-PRC form**

No Updates to Compliance Software

Key Features of Proposed Acceptance Test Protocol

Considering a Sampling Approach:

- For greenhouses with up to 5 lighting control zones, all control zones shall be tested.
- For greenhouses with more than 5 lighting control zones, sampling may be performed provided at least 25% of lighting control zones are tested and at least 5 lighting control zones are tested.

Acceptance Test Protocol (Field Verification) for PAR Sensor + Dimming

- **Requires a portable lighting illuminance level sensor**
- Tests at full output, no daylight, full daylight, 95% daylight, and 20-95% daylight
- Record lighting illuminance level at grow table surface.
- Confirm that light output is stable with no visible flicker.
- Confirm that only luminaries in the lighting control zone are affected by the zone's PAR sensor reading.

Acceptance Test Protocol (Field Verification) for DLI

- **Requires a portable lighting illuminance level sensor**
- Test illuminance at design DLI setpoint
- Confirm reduction in illuminance when DLI setpoint is reduced.

Poll

If lighting zone sampling for acceptance testing were an allowable compliance option, would it be helpful for greenhouses with many lighting control zones?

- a) Yes, it would significantly reduce compliance burden
- b) Yes, in limited cases only
- c) No, full testing is preferable
- d) Not sure / need more information

What are your thoughts on the proposed acceptance test protocols?

(You may share support, concerns, or general comments.)

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More information on

[CEC's 2028 proceeding website.](#)

**We want to
hear from you!**

Energy and Cost Savings Methodology



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$$\text{Annual Energy Use (GWh)} = \frac{\text{PPFD}}{\text{PPE} \times 10.764} \times \frac{1}{1000} \times \text{FLH} \times \text{Area (ft}^2\text{)} \div 1,000,000 \times \text{Controls Savings \%}$$

Where,

- PPFD = $\mu\text{mol/m}^2/\text{s}$
- PPE = $\mu\text{mol/J}$
- 10.764 = m^2 to ft^2
- FLH = Full Load Hours per Year
- Area = ft^2
- 1000 = W to kW
- 1,000,000 = kWh to GWh
- Controls Savings % Range: 9 to 26%

Proposed Definitions



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PHOTOSYNTHETIC ACTIVE RADIATION (PAR): A unit of measure of radiation relevant to plant growth, falls in the wavelength range of 400-700 nm.

DAILY LIGHT INTEGRAL (DLI): Photosynthetic photon flux density (PPFD) of daylight and electric light integrated over a 24-hour period in units of mol/m²/day.

DAILY LIGHT INTEGRAL (DLI) CONTROL: A lighting control strategy that uses the calculated Daily Light Integral (DLI) of daylight and electric light to adjust supplemental lighting intensity to achieve an optimal DLI target.

PHOTOSYNTHETIC PHOTON FLUX DENSITY (PPFD): Photosynthetic Photon Flux per unit of surface area, expressed in micromoles per square meter per second (μmol/m²/s), as defined by ANSI/ASABE S640.

PAR SENSOR: A device that measures photosynthetic photon flux density (PPFD) in the photosynthetically active radiation (PAR) range of 400 to 700 nanometers, typically expressed in micromoles per square meter per second (μmol/m²/s) and used to monitor light levels for the purpose of managing and controlling CEH lighting systems.

Background Information: What is Option 1?

Option 1: Timeclock + PAR Sensor-Based Control

On/off or dimming based on PAR sensor levels

Dimmable LEDs: Enable control systems to precisely deliver photons as needed. (Industry standard practice)

Timeclock:

- Lights operate based on preset on/off times, often aligned with photoperiod requirements.
 - Occasional reprogramming or seasonal adjustment needed if not an astronomical type.
- Astronomical versions will auto-adjust schedules based on daily sunrise and sunset times year-round.

PAR/Quantum sensors:

- Measure PPFD in $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$.
- Can be used with dimmable fixtures for more granular control.
- Require strategic positioning (sometimes needing multiple sensors) above the canopy to avoid shading or reflection errors.
- Need periodic cleaning and calibration to maintain accuracy.



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