



TITLE 24, PART 6

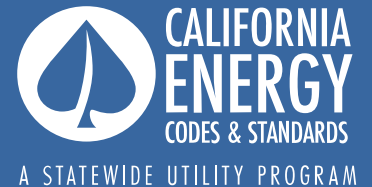
2028 CODE CYCLE

Controlled Environment Horticulture: Daylight Responsive Controls for Greenhouses

Codes and Standards Enhancement (CASE) Proposal

Nicole Hathaway
2050 Partners

September 24, 2025



Proposal Description

- Code Change Proposal
- Benefits
- Background Information



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 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 proposal description,
justification, draft code
language, and requested data

Proposed Definitions

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.

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:

What is Option 1?

Option 1: Timeclock + PAR Sensor-Based Control

On/off or dimming based on PAR sensor levels

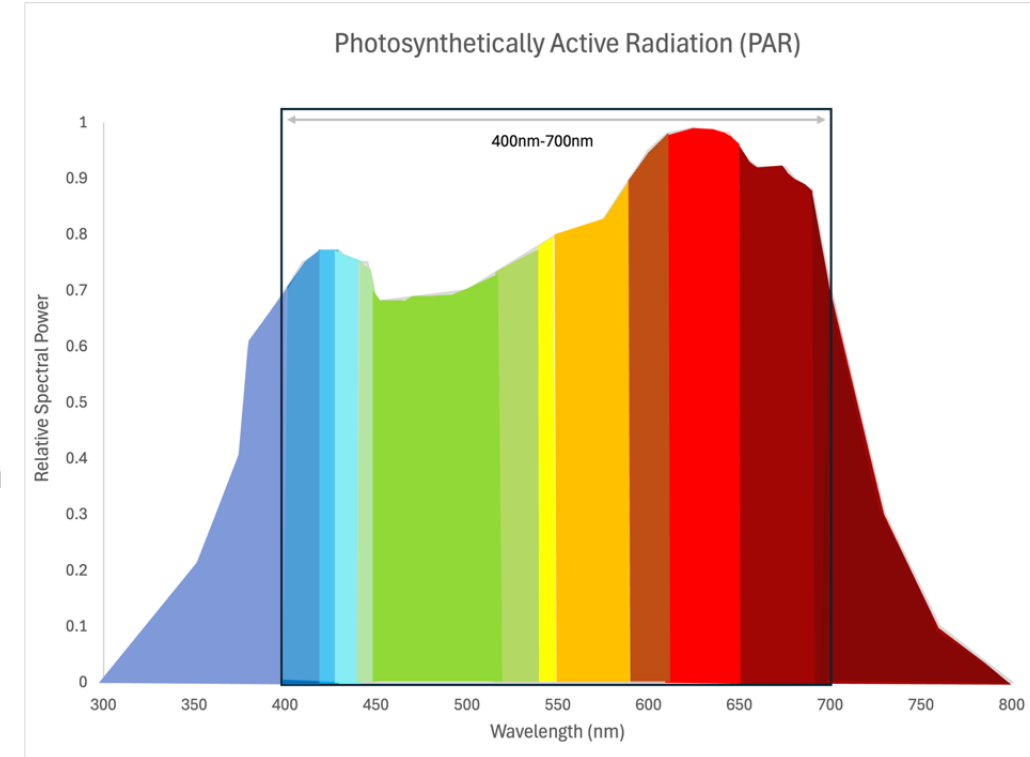
Dimmable LEDs: Enable control systems to precisely deliver photons as needed. (Industry standard practice)

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.



Background Information:

What is Option 2?

Option 2: Daily Light Integral (DLI) Control

Adjusts lighting output to meet the daily cumulative PPFD target

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

PAR sensors: Measure PPFD in $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ (also referred to as quantum sensors).

Control platform:

- Software/hardware integration to adjust lighting throughout the day.
- Integrates real-time + forecasted DLI.
- Sends continuous dimming/shut-off commands to meet daily cumulative PPFD target.

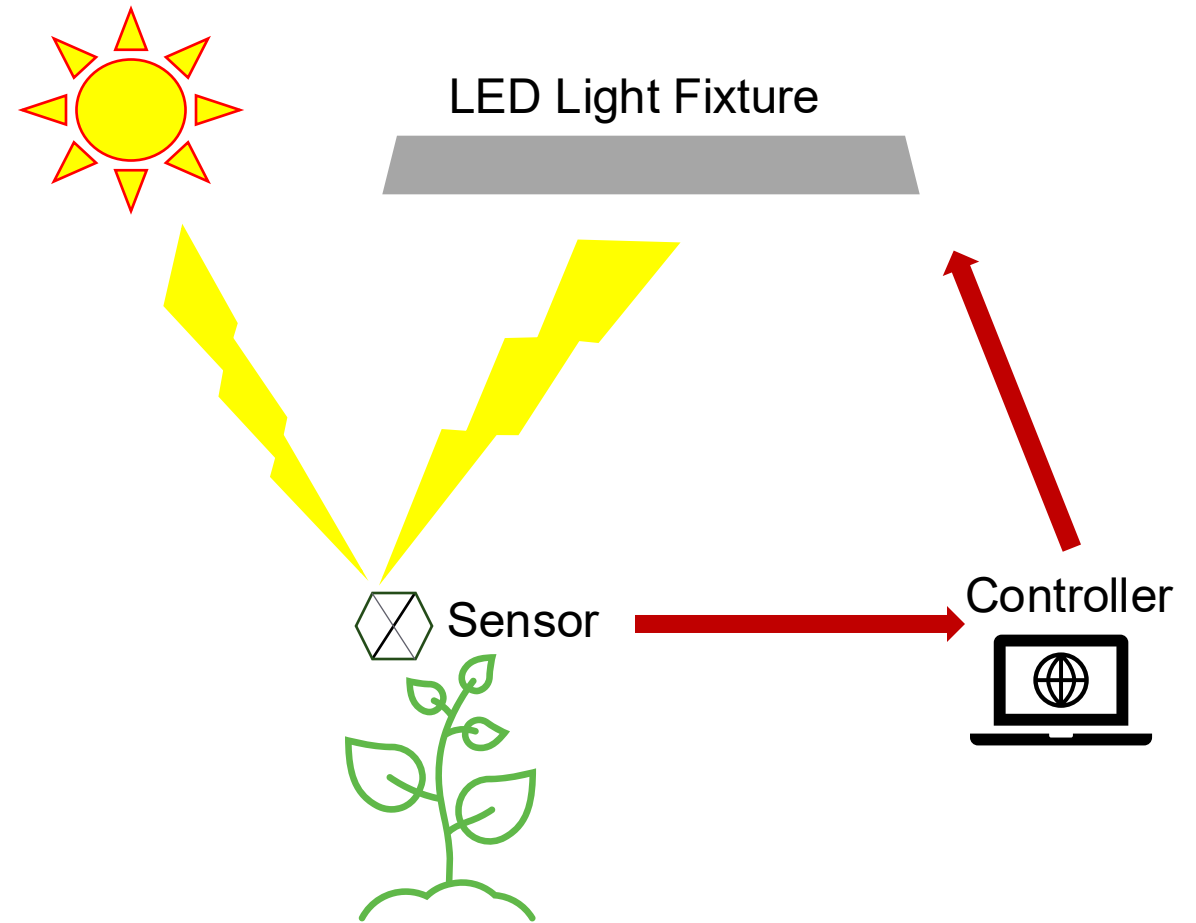


Image modeled after figure from Greenhouse Product News

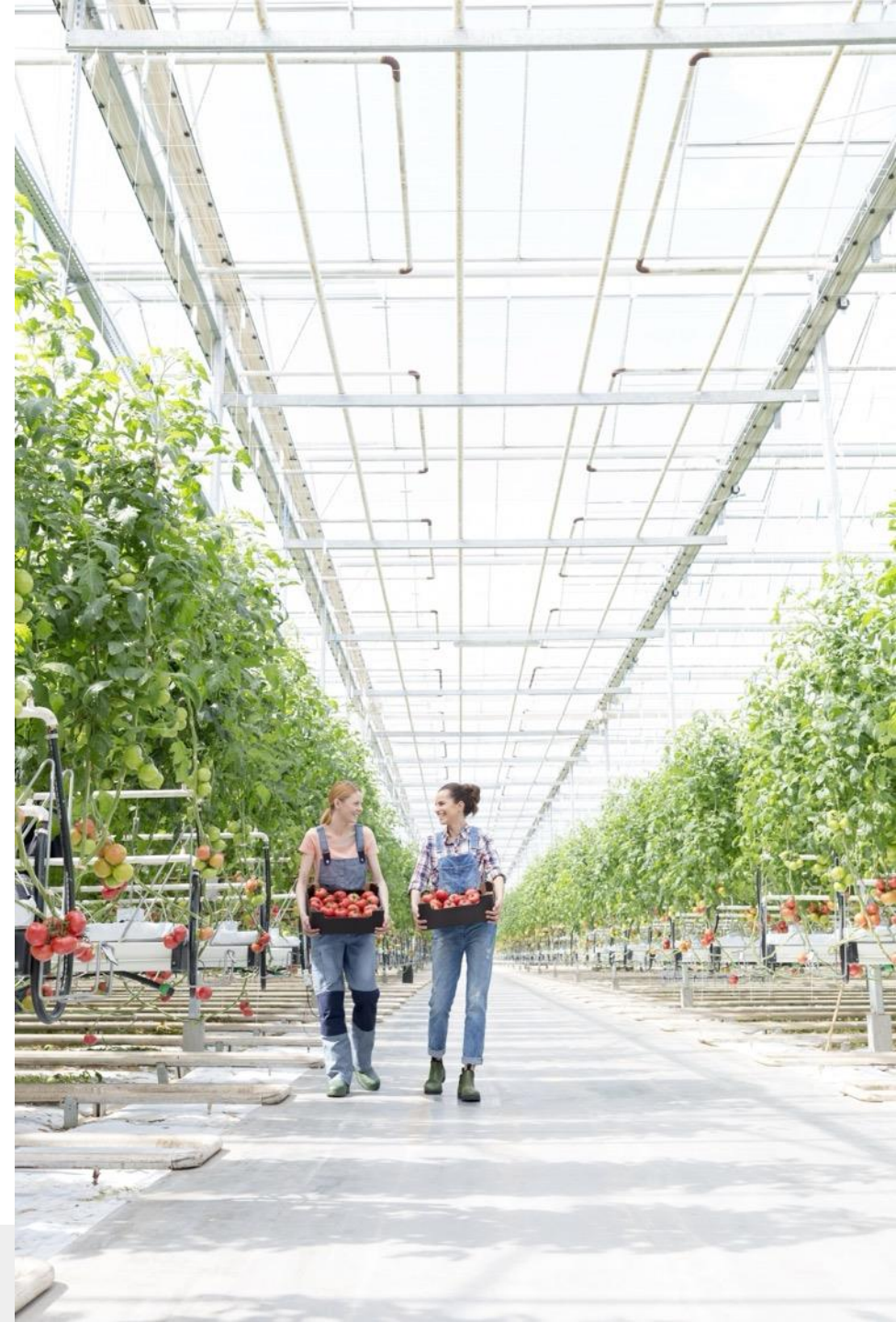
Background Information: How Energy is Saved

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



Marked-up Code Language

See [Title24stakeholders.com](https://title24stakeholders.com) for marked-up code language

Title 24, Part 1

- No changes

Title 24, Part 6

- Section 100.1
- Section 120.6(h)

Reference Appendices

- NA7



Market and Technical Considerations

- Current Conditions and Trends
- Potential Barriers and Solutions
- Technical feasibility

Poll

What percentage of new greenhouse construction in California (≥ 40 kW horticultural lighting) do you think currently installs daylight-responsive lighting controls (PAR-based sensors or DLI)?

- a. Less than 10%
- b. 10–25%
- c. 26–50%
- d. 51–75%
- e. More than 75%
- f. Not sure

Poll

What percentage of greenhouse alterations in California (≥ 40 kW horticultural lighting) do you think currently install daylight-responsive lighting controls (PAR-based sensors or DLI)?

- a. Less than 10%
- b. 10–25%
- c. 26–50%
- d. 51–75%
- e. More than 75%
- f. Not sure

Current Market Conditions

- **16 million ft² of greenhouse space in California** is estimated to have 40 kW+ horticultural lighting load, representing **~2,000–5,000 greenhouses**.
- **~30%** of these greenhouses are *assumed* to **use supplemental electric lighting**.
- This equates to an estimated annual **~44 GWh** of CEH lighting use in greenhouses.
- PAR-based sensor and DLI systems are both **widely available** from several manufacturers/distributors.
- Daylight-responsive controls **adoption is growing**:
 - A 2024 Cannabis Business Times survey found **75% of growers use dimming technology**, and **91% of those use a control system**.

Sources:

Kunczynski, Zyg and Kyle Booth. Energy Solutions. [Greenhouse Lighting Controls](#). CalNEXT Final Report. March 2023.

2024 State of the Cannabis Lighting Market: [Research Results](#)

Market Barriers and Solutions

Market Barriers

1. Higher upfront costs for DLI control systems (sensors, software, integration).
2. Limited awareness of daylight-responsive controls.



Potential Solutions

1. Provide a compliance pathway for simpler, cost-effective PAR-based controls as an alternative to full DLI controls.
2. Develop Compliance Manual language to increase familiarity with PAR and DLI control strategies.

Current Market Share (Estimated)

2024 State of the Cannabis Lighting Market: [Research Results](#). Cannabis Business Times.

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

New
Construction
and Additions

20-25%

- PAR-based: 15-20%
- DLI: 4-7%

Alterations

10-15%

- PAR-based: 8-12%
- DLI: 2-3%

Technical Considerations

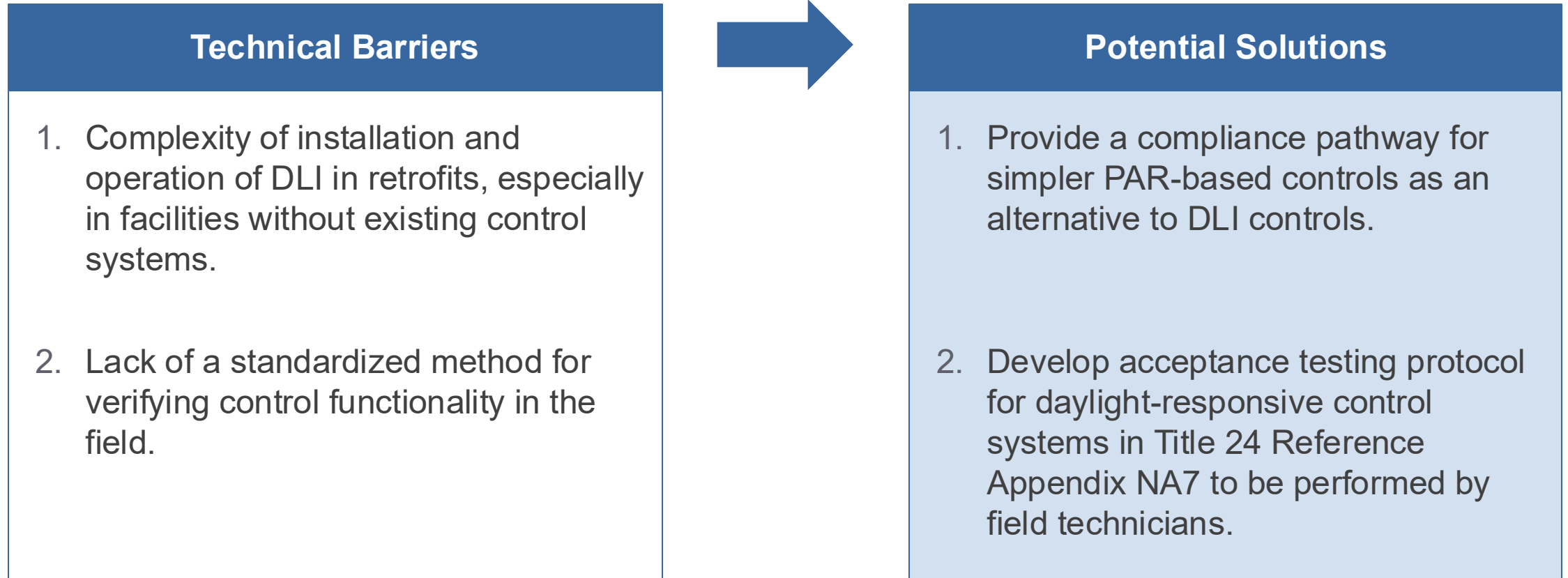
PAR-Sensor Controls

- 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.

Technical Barriers and Solutions



Poll

Based on your experience, which best describes standard dimming practice for horticultural LED lighting?

- a) Lights are not typically dimmed (on/off only)
- b) Lights are dimmed, with low-end dim range ~50% of full output
- c) Lights are dimmed, with low-end dim range ~20% of full output
- d) Lights are dimmed, with low-end dim range ~10% of full output
- e) Other (please specify)

Poll

What—if any—minimum time delay should be included in the code language to ensure persistent energy savings and avoid nuisance fluctuations?

- a) No minimum delay needed
- b) 30 seconds
- c) 1 minute
- d) 5 minutes
- e) 10 minutes
- f) Other (please specify): _____

Poll

In practice, does it make sense to allow a single sensor to serve multiple control zones (40 kW max), even though zones often have different characteristics (e.g., shading, thermal curtains, blackout curtains)?

- a) Yes — a single sensor is often sufficient across multiple zones
- b) Yes — but only if calibration can be configured per zone
- c) No — each zone should have its own sensor
- d) Maybe — depends on facility design or crop type
- e) Other (please specify): _____

Per Unit Energy and Cost Impacts

Methodology and Assumptions

- Energy Savings
- Energy Cost Savings
- Incremental Costs



Energy Modeling Methodology

Savings Calculation Approach

Compare greenhouse lighting energy use between:

- Baseline: Timeclock only
- Control Option 1: Timeclock + PAR sensor-based control
- 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 using **most recently available typical meteorological year (TMY) weather files** and **model annual lighting energy use for baseline vs. proposed case.**
- Inputs include **10-year averaged PAR, glazing properties & transmission factors**, and **crop-specific DLI** (17–43 mol/m²/day).

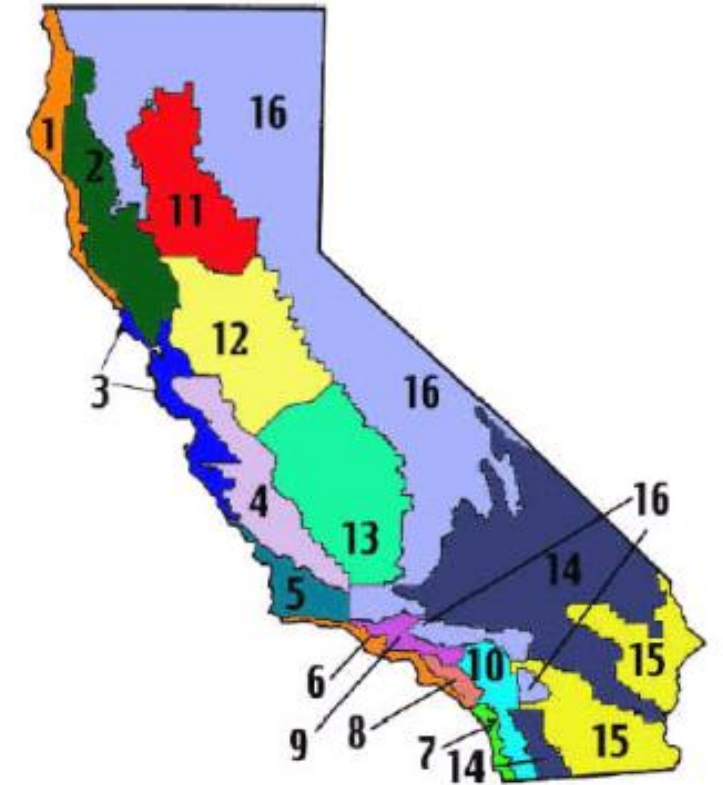


Image Credit: CEC Title 24 Residential Compliance Manual

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

Prototype: Greenhouse

Photosynthetic Photon Flux Density (μMol/m²/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 (ft²)	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 (mol/m²/day)	43.2	38.9	N/A	14	16



Standard Design

- 1. 2.5 PPE (μMol/J)
- 2. Title 24 2025



Proposed Design

- 1. 2.5 PPE (μMol/J)
- 2. Lighting use reduction due to DRC (%)

Incremental Cost Framework

Prototype(s): Greenhouse



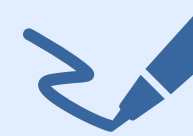
Baseline

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 Each Option (PAR and DLI)

1. Lighting Control Costs by Option
 - PAR sensors
 - Control hardware, wiring, and lighting control software
2. Installation
 - System setup, programming, and calibration (sensor placement, control wiring, fixture integration, & networking)

30-Year Maintenance Costs

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

Approach for Gathering Costs

Direct Outreach to Industry Stakeholders

- Targeted calls and surveys to collect real-world installation, equipment, maintenance, and lifetime costs from **Growers & Facility Owners**.
- Interviews with **Lighting Manufacturers & Distributors** focused on PAR-based sensor solutions, DLI systems, and emerging market trends.
- Data sharing focused on cost info, EUL, maintenance recommendations, especially for facilities installing both HVAC and lighting upgrades, with **HVAC & Controls Vendors**.

Industry Association Engagement

- Partner with groups like **GLASE, RII, ALA, and horticulture equipment associations** to access aggregated pricing data.
- Leverage existing contacts and vendor networks for broader insight.

Approach for Gathering Costs

Surveys + Data Collection

Conduct structured surveys of contractors, integrators, and distributors to gather:

- Control costs (timeclock-only vs. PAR sensor-based + timeclock vs. DLI),
- Installation labor rates (new construction vs. alterations), and
- Commissioning and calibration fees.

Integrated Outreach

- Combine lighting and space conditioning measure outreach whenever possible to increase efficiency and reach.
- Joint surveys and interviews to streamline stakeholder engagement.

Supplemental Baselines

- Use RSMeans or online cost databases as a preliminary benchmark, only if primary data falls short.



Compliance Verification

- Key Aspects of Compliance Verification
- Barriers and Solutions

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

Compliance Barriers and Solutions

Compliance Verification Barriers

1. Limited familiarity of AHJ with CEH daylight-responsive controls.
2. Field technicians will lack experience performing **new** acceptance tests for daylight-responsive controls.
3. Building operators may lack experience with how to use daylight responsive controls.



Potential Solutions

1. NRCC-PRC-E form is designed to make it clear whether the equipment installed meets the code requirements.
2. Develop detailed acceptance test protocols and training materials; conduct pilot testing and gather input from technicians to refine procedures.
3. Handoff between installers and building owner via. NRCA-PRC form.

Poll

Would it be useful to base a field verification protocol on existing manufacturer or installer commissioning practices?

- a) Yes — and we'd be willing to share examples of protocols we use or have seen in practice.
- b) Yes — but we don't have specific protocols to share.
- c) No — commissioning practices are too variable.
- d) Maybe — more research is needed before deciding.
- e) Other (please specify): _____

Nicole Hathaway

2050 Partners

nicolehathaway@2050partners.com

Joe Sullivan

Franklin Energy

jsullivan@franklinenergy.com

Please copy: info@title24stakeholders.com

More information on

CEC's 2028 proceeding website.

We want to hear from you!

Energy and Cost Savings Methodology



Slide NOT shown

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

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%