RESOURCE INNOVATION INSTITUTE

Efficient Yields
Best practices on energy, water efficiency, and productivity

Greenhouse Optimization - Aligning Your Systems with Your Surroundings

In partnership with

3C-REN
TRI-COUNTY REGIONAL ENERGY NETWORK
SAN LUIS OBISPO • SANTA BARBARA • VENTURA

December 2, 2021

Agenda

About RII	1:30 pm PT
Introductions & Purpose	1:35 pm
Controls & Automation in Greenhouses	1:45 pm
Building Envelope & Shading Devices	2:00 pm
Greenhouse Lighting Controls & Automation	2:20 pm
Environmental Controls Avoiding Microclimates	2:40 pm
Efficiency Program Examples	3:00 pm
Q&A	3:15 pm

SECTION 01

WELCOME & ABOUT RII

ABOUT US

About RII

- Objective, data-driven non-profit
- Founded 2016 in Portland, Oregon
- Expertise in climate policy, utility programs, green building certification, sustainable business, construction & indoor cultivation
- In 2020, received 3-year grant from USDA to develop KPIs, standards & building rating system for CEA





ABOUT RII

What We Do / Our Mission

We measure, verify & celebrate the world's most efficient agricultural ideas.

Measure

Efficiency & Productivity

- Key Performance Indicators
- Benchmarks
- Baselines

Verify

Best Practices & Standards

- Training
- Policies
- Utility Programs

Celebrate

Leadership Recognition

- Verification
- Case Studies
- Certification

ABOUT RII

Our Network

ABOUT RII

Technical Advisory Council

Multi-disciplinary body who aggregates knowledge to support producers and other stakeholders with objective and peer-reviewed data and curriculum on benchmarking resource efficiency

- **Guides** development of standards
- **Shapes** tools and resources to support best practices
- **Advocates** for informed policies, incentives and regulations

HVAC - Lighting - Utility - Water
Policy - Data - Controls - Emissions
Facility Design & Construction

ABOUT RII

PowerScore Benchmarking

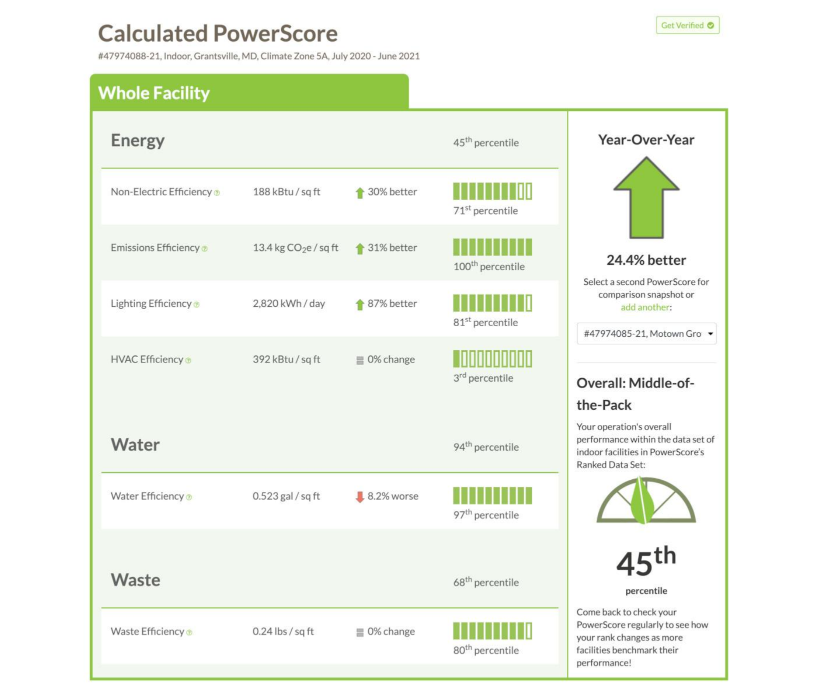
Specialized Key Performance Indicators

- Performance Snapshots
  - Year-over-year energy, water, and emissions rankings
  - Third-party data verification
- PowerScore Comply in select jurisdictions
- Access PowerScore Pro as an RII member
  - Enhanced portfolio management
  - Dashboard reports
  - Filters
  - Access Ranked Data Set

Competitive business insights

- Get ahead of compliance
- Assess portfolios of facilities to continuously improve
- Prioritize capital projects
- Forecast KPIs for new facilities and retrofits

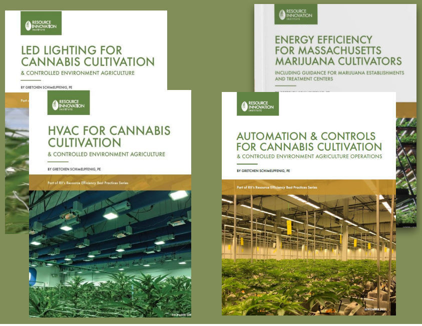
PowerScore



ABOUT RII

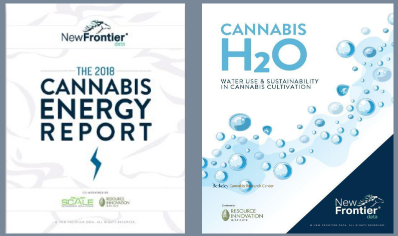
Informing Audiences with Peer-Reviewed Publications

Best Practices Guides
for Producers



Primers
for Governments & Utilities

Collaborative Reports
on Resource Usage



Intelligence Insights
for Members

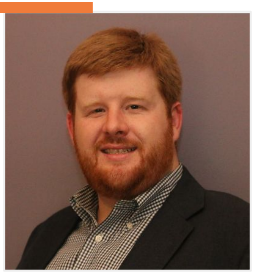
SECTION 02

INTRODUCTIONS & PURPOSE

Today’s Speakers

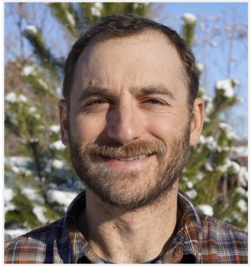
Gretchen Schimelpfenig

RESOURCE INNOVATION INSTITUTE



Kyle Edmiston

svensson



Josh Holleb

CERES GREENHOUSE SOLUTIONS®

Marc Paynter

ARGUS® CONTROLS

Karl Johnson

EnSave

3C-REN: Tri-County Regional Energy Network

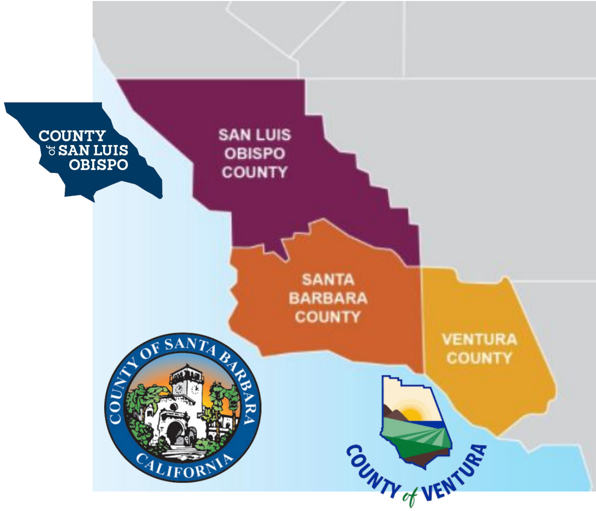
Three counties working together to improve energy efficiency in the region with free programs:

- Energy Code Connect
  - Building professionals
  - Makes the Energy Code easy to follow
- Building Performance Training
  - Current and prospective building professionals
  - Helps workers thrive in an evolving industry
- Home Energy Savings
  - Homeowners and renters
  - Improves home comfort and safety
- Upcoming Courses

3C REN

TRI-COUNTY REGIONAL ENERGY NETWORK

SAN LUIS OBISPO • SANTA BARBARA • VENTURA



Purpose of Today’s Workshop

- Help cannabis producers improve the efficiency of their operations with environmental control systems
- Convey scientific insights directly to producers and finding the best ways to translate them in the context of a local ecosystem
- Help government agencies and energy efficiency programs achieve their climate goals through knowledge sharing
- Encourage cultivators to take advantage of 3C-REN resources to support compliance with County energy conservation plans

3C-REN

TRI-COUNTY REGIONAL ENERGY NETWORK

SAN LUIS OBISPO • SANTA BARBARA • VENTURA

Access Your Tri-County Virtual Classroom

Access the virtual classroom to continue learning

Free guidance on efficient cannabis cultivation

All live workshops are available for on-demand viewing!

- Recordings of live workshops
- Tip Clips
- Downloadable resources
- 3C-REN tools

Create an account at
ResourceInnovation.org/Tri-County

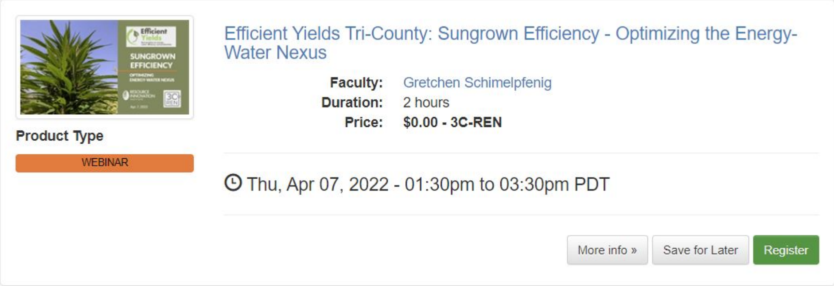
Register for the Workshop Series

Access the virtual classroom to continue learning

Free guidance on efficient cannabis cultivation

All live workshops are available for on-demand viewing!

- Feb 3, 2022
  - Indoor Optimization - HVAC & Lighting Best Practices
- Apr 7, 2022
  - Sungrown Efficiency - Optimizing the Energy-Water Nexus



Efficient Yields

Best practices on energy, water efficiency, and productivity

INDOOR OPTIMIZATION

HVAC AND LIGHTING BEST PRACTICES

RESOURCE INNOVATION INSTITUTE

3C-REN

Feb. 3, 2022

Efficient Yields

Best practices on energy, water efficiency, and productivity

SUNGROWN EFFICIENCY

OPTIMIZING ENERGY-WATER NEXUS

RESOURCE INNOVATION INSTITUTE

3C-REN

Apr. 7, 2022

SECTION 02

CONTROLS & AUTOMATION IN GREENHOUSES

Managing Energy with Controls

Sources of Energy Use

Cultivation operations may use:

Electricity

- Electricity for horticultural lighting
- Electricity for HVAC processes
- Electricity for motors:
  - Pumping water
  - Actuating greenhouse vents
  - Running fans

Fuel (natural gas, propane)

- Fuel for heating processes
- Fuel for combined heat and power (CHP)

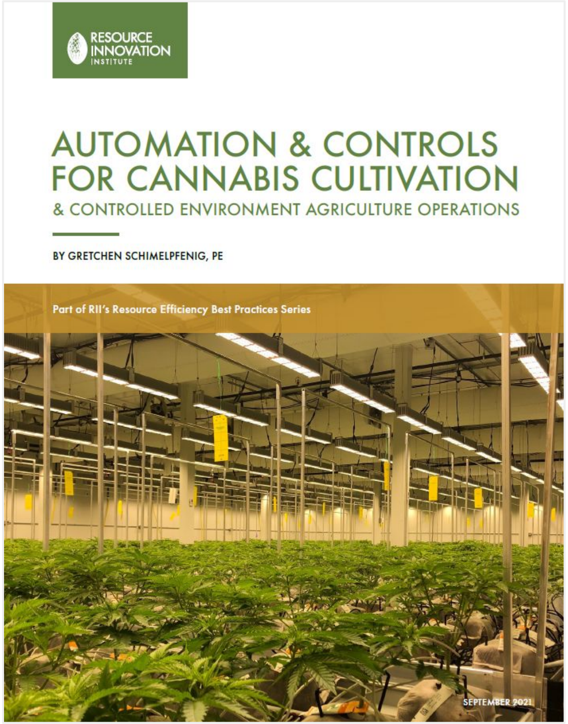
Image credit: TSRgrow

Download the Controls Best Practices Guide

Brand-agnostic information for producers

Free guidance on lighting, HVAC, and water controls

- Speak the language relevant to controlling and automating environmental control systems in horticultural applications
- Understand types of control systems optimizing horticultural environments
- Plan for integrated controls approaches in greenhouses and indoor operations
- Install and operating successful controls solutions in alignment with business models
- Use data from control systems to improve productivity and efficiency
- Demonstrate energy savings for utility energy efficiency incentive programs



DOWNLOAD NOW

Start Your Journey to Automation

Design Conditions vs. Target Conditions

- Optimize for producing for the entire year
  - Consistent yields
  - Verifiable results

Controls Considerations

- Wired vs wireless control systems
- Sensor placement
- Point of control
- Resolution & accuracy
- Integration
- Maintenance & end of life planning

Fully Integrated Controls

- **Feedback**
  - Reacting to a change
- **Feed forward (integrated)**
  - Acting preemptively and predictively
- **Integration benefits**
  - Reduce wear and tear
  - Improve control
  - Save energy
  - Save water
  - Real time data for troubleshooting

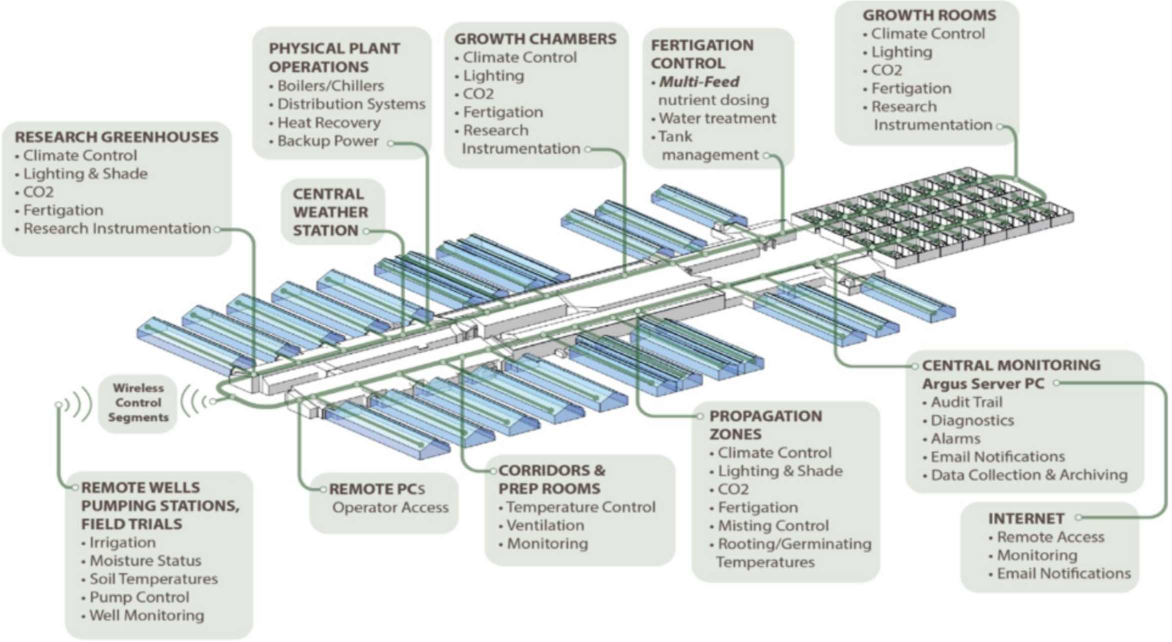


Image credit: Argus Controls

Benefits of Commissioning

Ensure Mission-Critical Systems Perform Optimally

- Improve maintenance procedures
- Save staff time
- Reduce operations & maintenance expenses
- Save energy: 3% and 12% for industrial facilities
- Verify systems respond as expected
- Validate resource efficiency
- Resolve problems before product at risk
- Avoid expensive fixes requiring shutdowns in operation

CANNABIS BUSINESS TIMES

Reduce Expenses by Commissioning Your Cannabis Facility

READ MORE

Design-Phase Commissioning

Third-Party Review of Project Design Docs

- Review Owner's Project Requirements (OPR) including target setpoints, standard operating procedures, failure conditions
- Assist design team with creating Basis of Design (BOD)
- Develop a commissioning plan
- Perform design review of drawings
- Review equipment submittals
- Identify issues & suggest adjustments

Design-Phase Commissioning

Early Engagement to Plan Controls

- Design for annual production
  - All seasons and consistent production
- Analyze supplemental lighting needs
- Understand interactive effects on systems:
  - Power
  - HVAC and humidity management
  - Water
- Plan your controls system responses to conditions outside of target ranges

	Average Daily DLI	Delivered Avg DLI	Required DLI
Month	Hagerstown, MD		
January	14.6	10.22	36.78
February	20.6	14.42	32.58
March	28.7	20.09	26.91
April	35.4	24.78	22.22
May	41.4	28.98	18.02
June	44.1	30.87	16.13
July	43.5	30.45	16.55
August	39.1	27.37	19.63
September	31.2	21.84	25.16
October	23.2	16.24	30.76
November	16.1	11.27	35.73
December	13.2	9.24	37.76

Construction-Phase Commissioning

Performance Testing to Validate Controls

- Multistage process involving several project team members:
  - Construction manager
  - Controls contractor
  - Commissioning agent
- Create prefunctional checklists and functional performance tests and work with controls contractors to witness and record all functional tests
- Identify issues in the field and issue reports recommending resolutions
- Create staff training agendas
- Produce a final commissioning report
- Ensure that Contractors have provided operations and maintenance (O&M) manuals

SECTION 05

BUILDING ENVELOPE & SHADING DEVICES

Greenhouse Climate Control Approaches

Passive Climate Control

Ventilated greenhouses can use low-energy solutions like roof vents to release hot, humid air.

Passive solutions can manage climatic conditions in greenhouses, but actual environmental conditions can range widely.

Active Climate Control

Ventilated greenhouses can be actively ventilated using ventilation fans to cool and dehumidify growing spaces.

Well-sealed greenhouses can achieve target environmental conditions by using fans, evaporative cooling walls, refrigerant-based cooling and dehumidification equipment, and mechanical heating systems.

Greenhouse Envelope

Ventilated greenhouses use plastic or glass coverings which are hard to completely seal.

Greenhouses with insulated and tightly sealed envelopes can more actively control climate and achieve target environmental conditions.

https://www.greenhousegrower.com/technology/optimizing-systems-for-cannabis-greenhouses/

Different Greenhouse Techniques

Ventilated Greenhouses

- Can utilize building envelope for HVAC & dehumidification
- Can use ventilation to control temperature and humidity
- Might use mechanical climate control equipment

Sealed Greenhouses

- Hybrid building envelope of opaque and transparent walls
- Well-insulated and tightly sealed envelope
- Must use mechanical climate control equipment

Upcoming Greenhouse Code Changes

Read the Final CASE Report

Greenhouse Envelope Standards

- *Opaque* walls and opaque roof assemblies must meet the existing mandatory insulation requirements in Section 120.7.
- *Non-opaque* wall assemblies must have a combined **U-factor of 0.7** or less
- *Non-opaque* roof assemblies must have a combined **U-factor of 0.7** or less
- Exempts greenhouses from existing prescriptive building envelope requirements for window wall ratio, skylight roof ratio, and daylighting requirements for large enclosed spaces
- Applies to:
  - Newly constructed greenhouses and to greenhouses being converted from unconditioned to conditioned
  - Additions to conditioned greenhouses

Greenhouse Envelope Performance

Read the Final CASE Report

Insulation

- Greenhouse buildings are constructed in many different ways, and to describe them, it is useful to understand some building system terms.
- Thermal envelopes are sometimes referred to as a building's skin, or shell; you can think of them like your greenhouse's coat in the winter and sunscreen in the summer. Weatherization describes activities you can do to improve thermal envelopes.
- Weatherization activities include insulating , which minimize unwanted heat losses and gains, and air sealing, which reduces the infiltration of outside air.
- Insulation is rated using R-value (a higher value is better) or the U-value (the inverse of R-value, where a lower value is better).

Greenhouse Envelope Performance

Read the Final CASE Report

Greenhouse Coverings

- Popular covering types include rigid plastic, film plastic, and glass
- Each can vary in cost, durability, light transmission, and insulation
- Insulative qualities depend on the type and the thickness
- Rigid plastic products like polycarbonate, acrylic, and fiberglass are popular as they can feature multiple layers of walls which trap air for lower U-value
    - Single wall polycarbonate will not comply
- Film plastic is attractive due to its low cost, but provides no insulation
    - Will not comply without double layers of film and an air gap
- Glass has varying insulation ratings
    - Single pane will not comply

Greenhouse Envelope Performance

Read the Final CASE Report

Insulative Qualities of Coverings

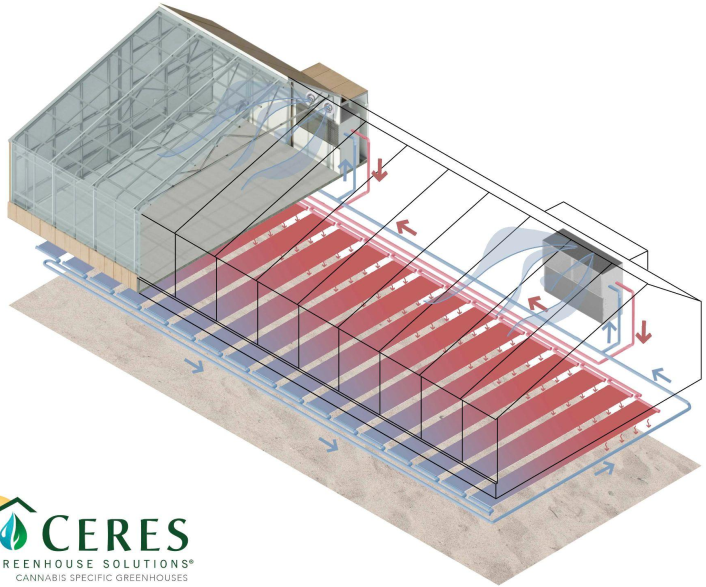
Covering Type	U-Factor	Cost / Square Foot ($USD/sf)	Useful Life (Years)
Polycarbonate, Five Wall, 25 mm	0.31	$8.00	10 -15
Polycarbonate, Triple Wall, 8 mm	0.50	$4.00	10 -15
Double-Pane Storm Windows	0.50	$6.00	25+
Polyethylene film, Double, with IR	0.50	$0.25	3 - 4
Polycarbonate, Double Wall, 10 mm	0.53	$2.50	15
Acrylic, Double	0.56	$2.66	30+
Polycarbonate, Double Wall, 6 mm	0.65	$1.54	10 -15
Polycarbonate, Double Wall, 4 mm	0.70	$1.50	10 -15
Glass, Double Pane	0.70	$6.00	25+
Polyethylene film, Double	0.70	$0.18	3 -4

Sealed Greenhouses

Finely Tuned Environmental Conditions

- Sealed greenhouses are more capable of achieving target environmental conditions because they are **less sensitive to ambient conditions** due to less outdoor air infiltration and have **better thermal performance** than ventilated greenhouses.

- Cultivars in traditional greenhouses experience wide temperature variation across cultivation spaces:
  - +/- 10 degrees F variance from target temperatures and +/- 10% from the target RH
  - +/- 7 degrees F temperature differences between the intake and fan (exhaust) ends of the same greenhouse bay



CERES
GREENHOUSE SOLUTIONS®
CANNABIS SPECIFIC GREENHOUSES

RESOURCE INNOVATION INSTITUTE

TIP CLIP:

Building Envelope: Sealing & Insulating

With Josh Holleb Ceres Greenhouse Solutions

External & Internal Equipment

External Building Envelope: Vents

- Materials selection has huge impact on building performance
  - Finding the best ratio of insulation to glazing
- Natural ventilation to allow heat to escape and fresh air inside

Internal Building Envelope: Thermal Curtains

- Insulation and management of solar conditions

Fans

- Active ventilation & circulation to optimize airflow

Cooling & Heating

- Active processes to reduce or increase temperature

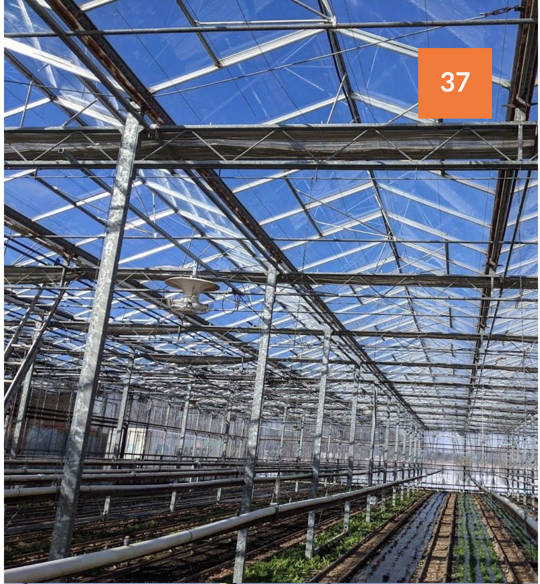
External Building Envelope: Vents

Ridge Vents

- Hot air inside the greenhouse escapes through roof opening
- Manually operated or automatically controlled

Side Wall Curtains

- Rigid plastic rolled up via crank, or opens from the top and drops down
- Manually operated



External Building Envelope: Vents

Side Wall Vents

- Rigid vents operated via rack and pinion systems
- Covered with rigid or film plastic for longer life
- 2 - 3X more expensive than side wall curtains
- Provide a much tighter seal to hold in heat
- Manually operated or automated

Shade and Thermal Curtains

Climate Curtains

- Some curtains both shade and insulate, some do one or the other
  - Open-weave curtains may not insulate
  - Transparent thermal curtains may not shade
- Screens can:
  - Manage solar radiation
  - Reduce heat loss at night and in colder months
  - Protect plants on sunny and hot days
  - Save energy on both heating and cooling
  - Reduce utility bills
- Manually operated or automatically controlled

Right Climate for Growth

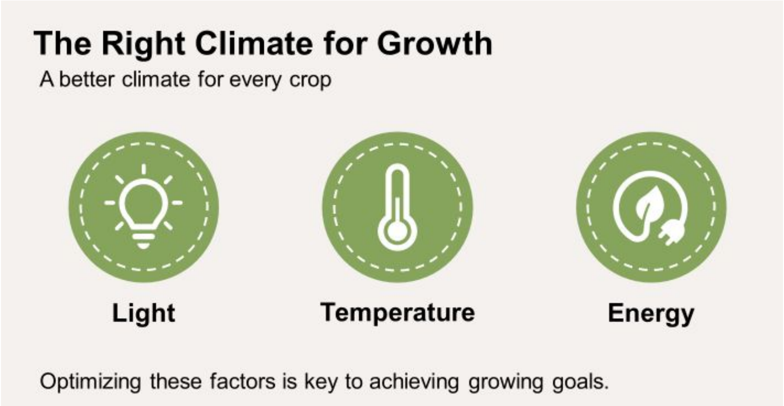


Figure credit: Ludvig Svensson

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TIP CLIP:

Shading Devices

With Kyle Edmiston Svensson

Different Screens for Different Goals

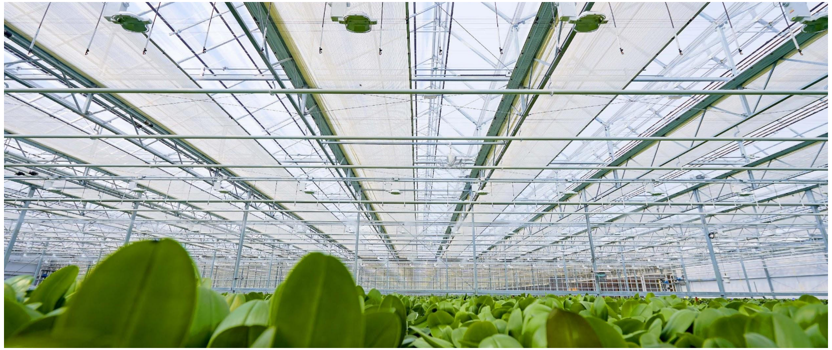


Figure credit: Ludvig Svensson

Diffusion: Even Temperature & Lighting

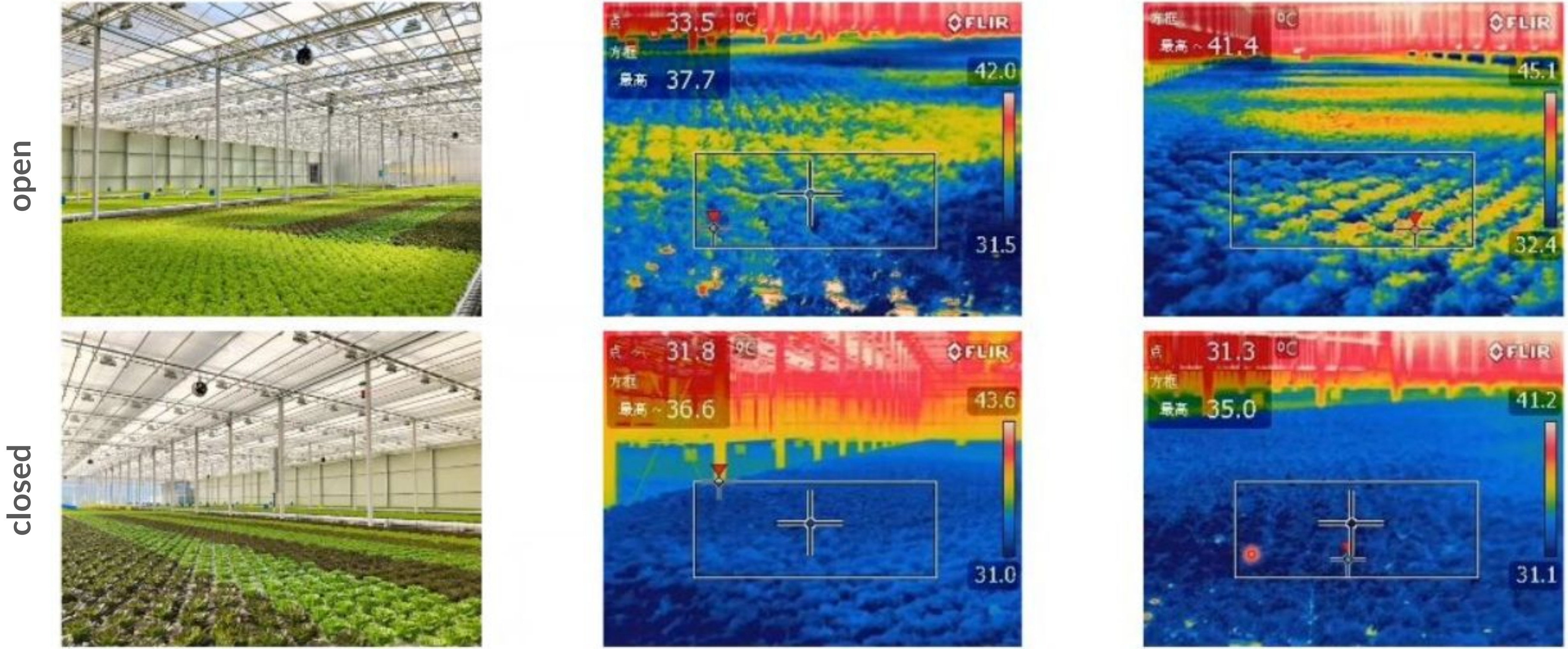


Figure credit: Ludvig Svensson

Other Light Deprivation Considerations

Rollup Screens & Side Walls

Figure credit: Ludvig Svensson

Light Traps

Moisture Management in Screens

- Reduces risk of diseases
  - Powdery mildew
- Gray mold
  - Other fungal diseases
- Helps prevent humidity level extremes and condensation formation on the screen
- Humidity control is vital during flowering

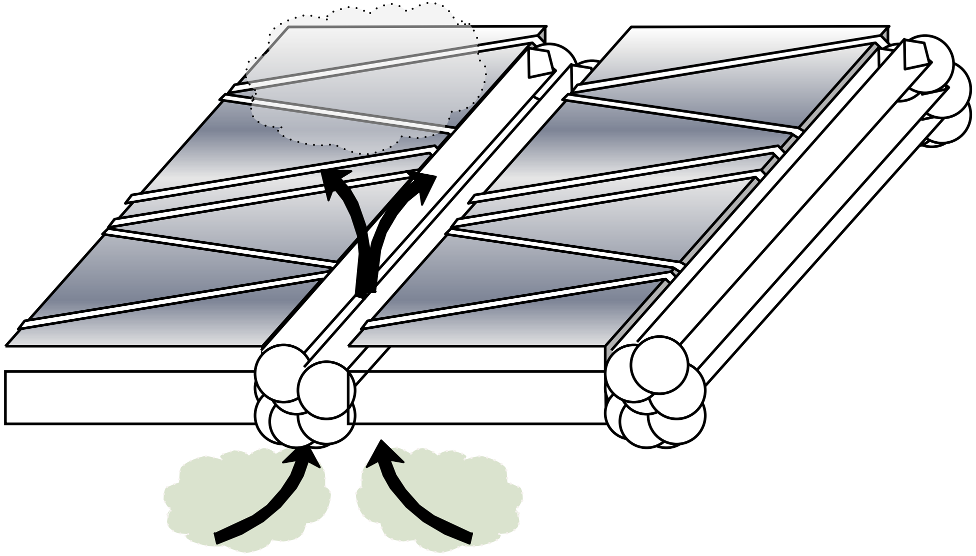


Figure credit: Ludvig Svensson

Diffusion: Even Temperature & Lighting

ANNUAL SUMMARY			
Scenario names	No screen	Blackout only	Blackout & Energy Screen
Screen 1	-	)BSCURA_10070_FR_WB+BV	BSCURA_10070_FR_WB+BV
Screen 2	-	-	HARMONY_2047_FR
Screen 3	-	-	-
Vertical 1	-	OBSCURA_10070_R_FR_W	OBSCURA_10070_R_FR_W
Vertical 2	-	-	-
Energy consumpt. (m3 gas)	575 480	489 455	339 601
m3 gas/m²	58.13	49.44	34.30
Energy expenditure	374 062	318 145	220 741
US Dollars/m²	37.8	32.1	22.3
Energy saving (%)	-	15%	41%
Investment	-	148 500	188 100
US Dollars/m²	-	15.00	19.00
Return on investment (year)	-	2.7	1.2

Figure credit: Ludvig Svensson

Diffusion: Even Temperature & Lighting

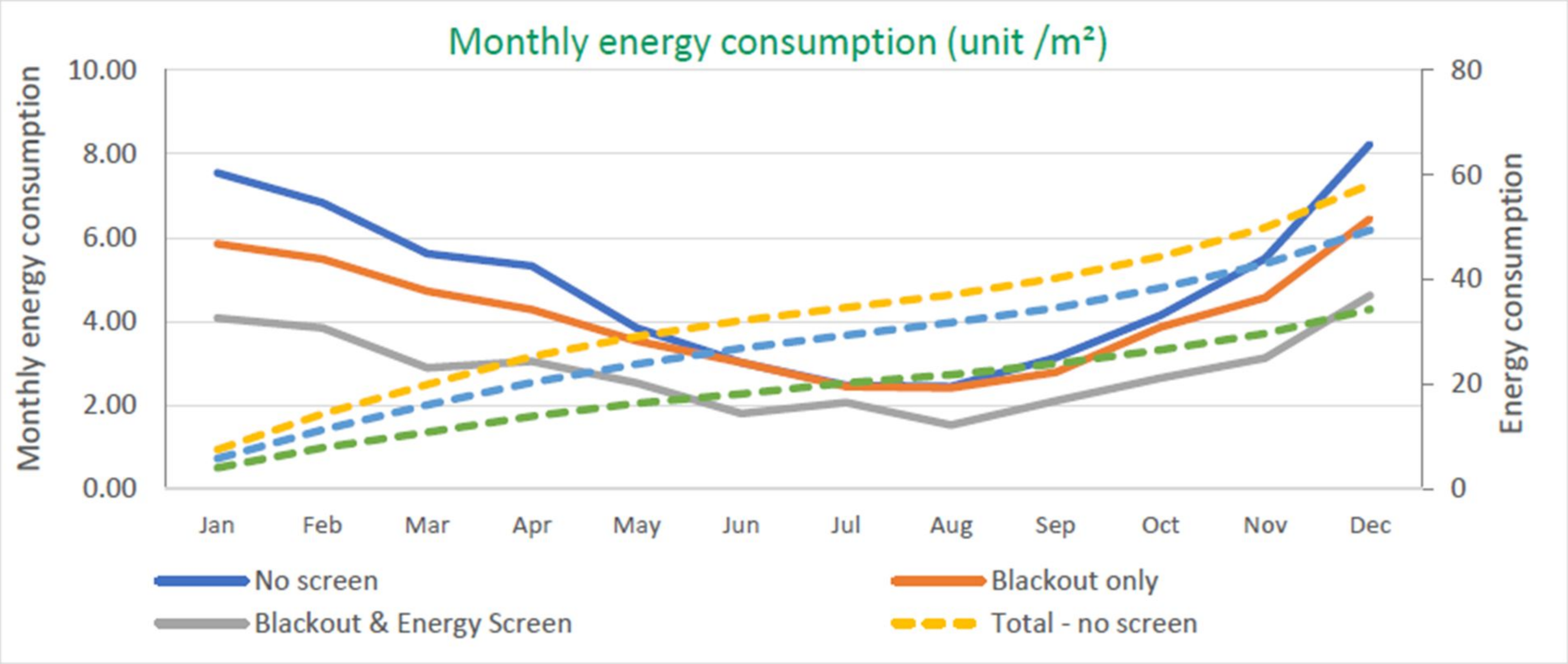
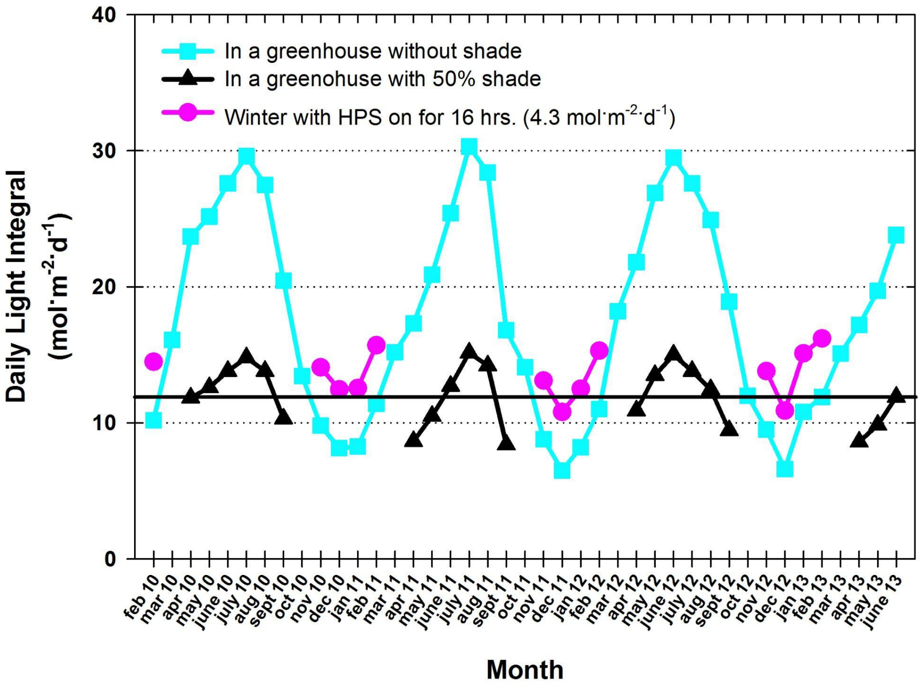


Figure credit: Ludvig Svensson

Shade Curtains to Maintain DLI Targets



R.G. Lopez, 2013

Blackout Screens: Energy Loss

- Heat, humidity can build up under normal blackout screens increased by:
  - Supplemental lights
  - Pipe temperature
  - Climate
- Common Solution: Gapping Screens
- Common Issues:
  - Difficult to manage
  - Light abatement regulations becoming common
- Solution: Active dehumidification with vertical air movement

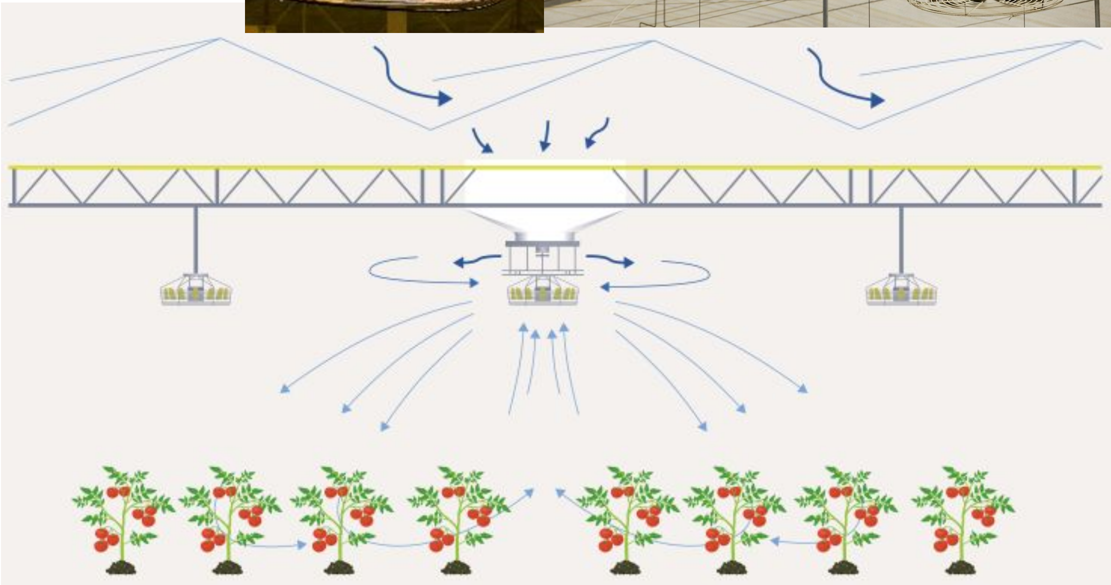
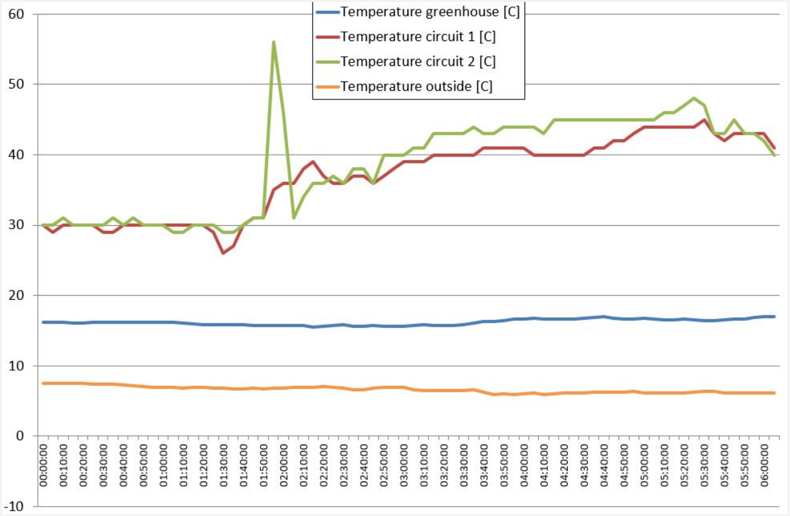
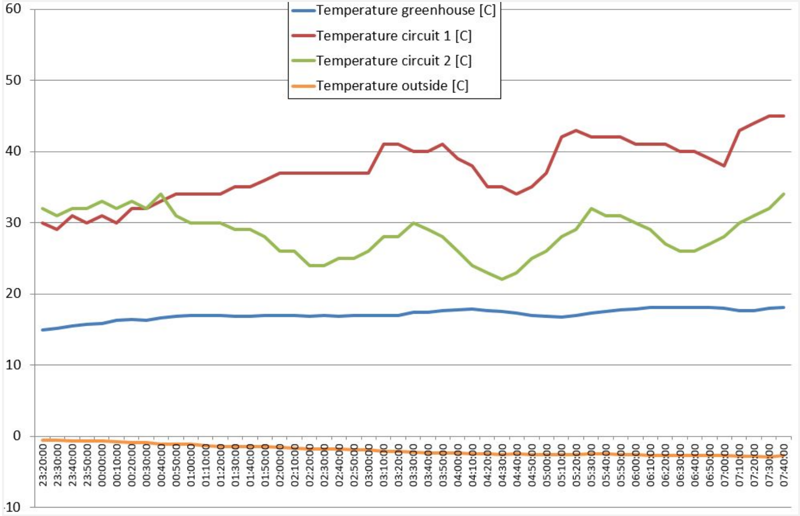


Figure credit: Ludvig Svensson

Vertical Air Movement Energy Savings Potential



Screen in **open** position



Screen in **closed** position

Figure credit: Ludvig Svensson

Increase Fabric Longevity with Programming

Envelope/Shade/Thermal Curtain In Warm Climate Field Example

New Mexico Project

- 5725 ft elevation
- Opaque insulated E/W/N walls and N roof
- Shade curtain with 36% shade and 47% heat retention
- “It was 20 degrees last night and with no heat at all it didn’t drop below 65 degrees in the greenhouse overnight”

Dive Deeper into Greenhouse Controls

The Carbon Emission Impacts of Greenhouse Cannabis Cultivation

CANNABIS BUSINESS TIMES

READ MORE

Optimizing Systems for Cannabis Greenhouses

GREENHOUSE GROWER

READ MORE

Articles co-authored by RII with members of our Technical Advisory Council Working Groups

SECTION 06

LIGHTING CONTROLS & AUTOMATION

Lighting Controls: Value Proposition

Dial in the number one nutrient for plants

Provide with granularity:

- Proper light levels
- Optimal spectra for cultivars
- Preferred photoperiod by stage of development
- Desired DLI to empower plant growth

Provide plants with the exact intensity and quantity of light while minimizing energy consumption and lowering bills

Figure credit: Signify

RESOURCE
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TIP CLIP:

Greenhouse Lighting Controls & Automation Best Practices: LED

With Colin Brice
Signify

Lighting Efficacy and Controls

Read the Final CASE Report

Greenhouse Growing, Horticultural Lighting

In a building with CEH spaces and with more than 40 kW of aggregate horticultural lighting load, the electric lighting systems used for plant growth and plant maintenance shall meet the following requirements:

1. Luminaires shall have a photosynthetic photon efficacy of at least *1.7 micromoles per joule* rated in accordance with ANSI / ASABE S640 for wavelengths from 400 to 700 nanometers.

2. Time-switch lighting controls shall be installed and comply with Section 110.9(b)1, Section 130.4(a)4, and applicable sections of NA7.6.2.

3. Multilevel lighting controls shall be installed and comply with Section 130.1(b).

Designing Lighting Controls Systems

Planning Lighting Controls

- Facility location
- Crop being grown
- Growing seasons
- Cost vs. performance
- Perpetual harvest
- Maximizing production
- Balancing efficiency

Provide plants with the exact intensity and quantity of light while minimizing energy consumption and lowering bills

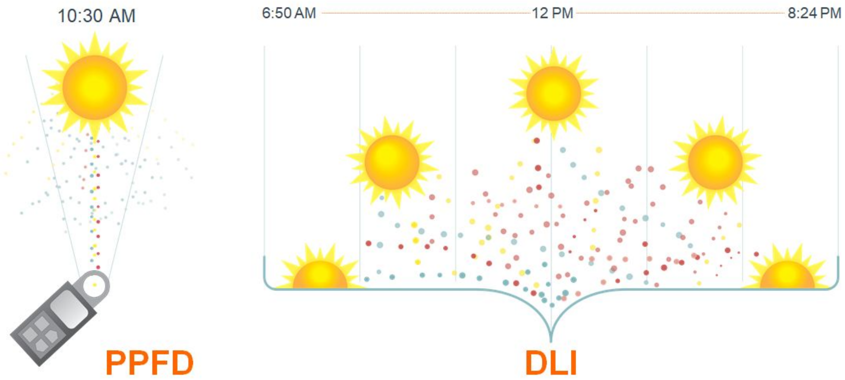
Specify Control Parameters

Target Ranges for Best Outcomes for Plants

- PPFD
- DLI

Determine the information sensors will use to modulate equipment output to meet thresholds

PPFD vs. DLI



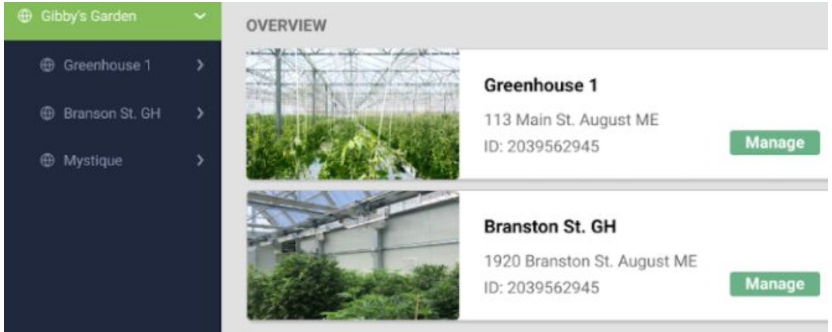


Figure credit: Fluence (top), TSRgrow (bottom)

Designing Lighting Controls

Power and Light Planning

- Pre-install design, mapping, PPFD
- Configuration vs commissioning
- Post-install verification

Fixture Layout

Flower House	9							
	Cabinet	TGHV #	Modules #	Junction Boxes/Module	Junction Box/Module Code	TG-1000HVR Fixtures/module	TG-1000HVR Power/Fixtures (W)	Power/Module (W)
Itemized	RA01	1	1	1	RA01,1-1	3	1000	3000
			2	1	RA01,1-2	3	1000	3000
			3	1	RA01,1-3	3	1000	3000
			4	1	RA01,1-4	3	1000	3000
			5	1	RA01,1-5	3	1000	3000
			6	1	RA01,1-6	3	1000	3000
						3	1000	3000
						3	1000	3000
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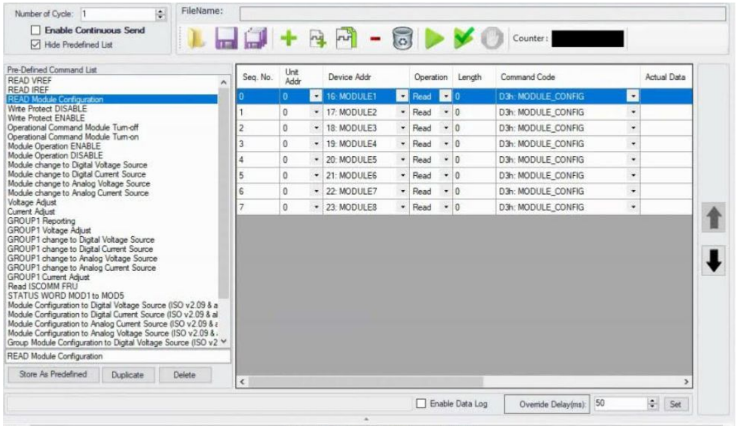
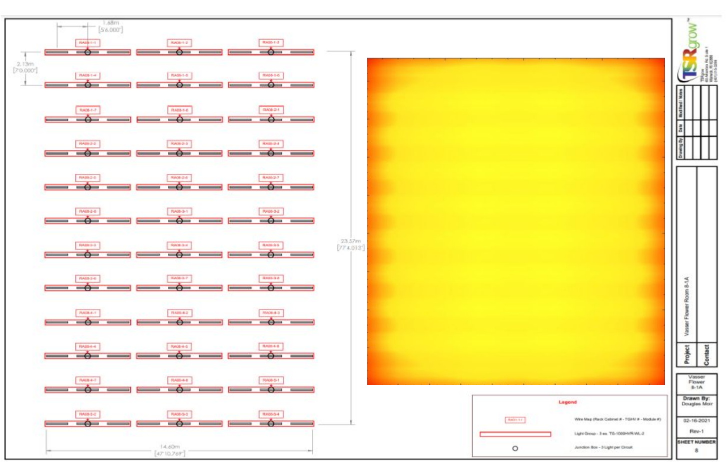




Lighting Controls: Recipes for Cannabis Steering

Gather data to support lighting controls incentives

Table 4: Lighting Controls for Cannabis Steering by Stage of Plant Growth[6]

Lighting Controls	Vegetative	Flowering	Ranges of Controls Values
PPFD	Lower	Higher	300 - 1500+ µmols/m²/s
DLI	Less	More	20 - 42 moles/m²/day
Spectral Treatments (R:B ratio)	Higher	Lower	7 - 15%; higher blue for shorter plants
Far Red Treatments	More	Less	Used to manage shade avoidance

Figure data source: Signify

Systems to Control: Lighting

Sensors and their integration

- New construction or existing
- Wireless vs. wired
- Determine zones
- Controlling vs monitoring
- Key points to monitor

Lighting Controls Strategies

Scheduling

- Adjust photoperiod

Dimming

- Modulate light intensity by zone of control
  - Daily
  - By stage of plant growth

Spectral Tuning

- Modulate photon output from wavelength ranges

Understand energy savings potential of strategies and data needed to validate performance

Table 3: Lighting Controls Parameters Measured by Cannabis Cultivators

Lighting Data Collected[5]	Percentage of Growers Collecting, 2020
Light intensity (PPFD)	55%
Spectral quality	33%

Credit: Cannabis Business Times (top, figure data source), ERS (bottom)

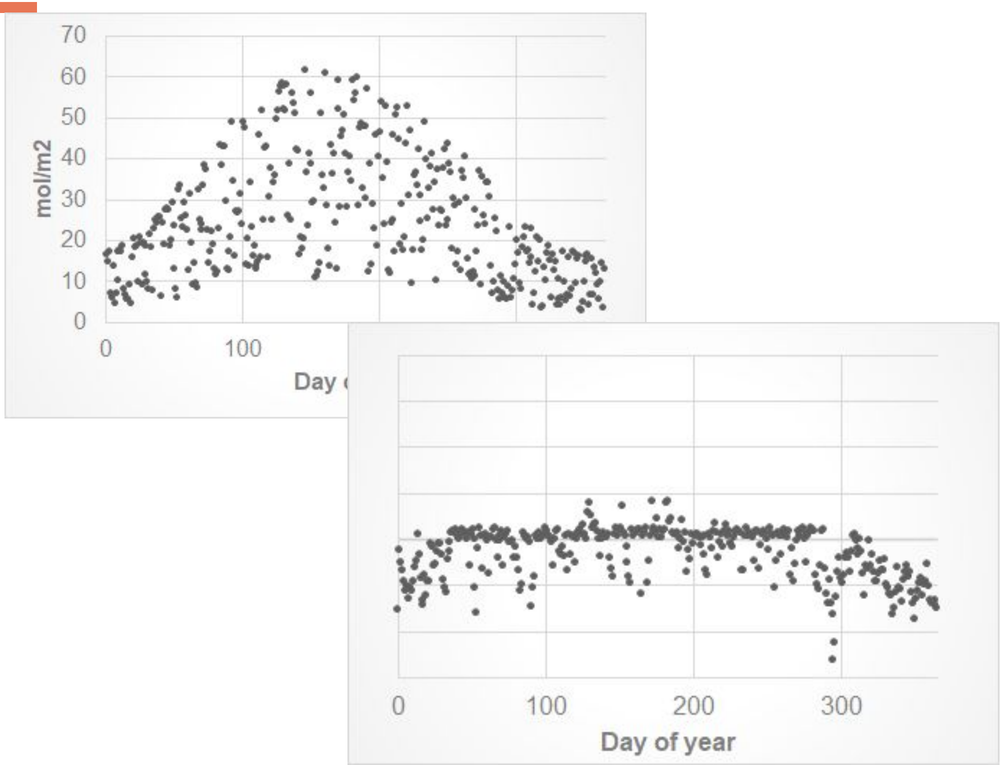
Dimming Controls to Meet DLI Targets

Daylighting Controls for Greenhouses

- **Dimming**
  - Thresholds
  - Response rates

Maintain light levels to the canopy

Avoid under-lighting or over-lighting



Energy Savings from DLI Controls

Academic greenhouse bserved 30% energy savings from using controllers to operate lights off sunlight intensity compared to operating off timers

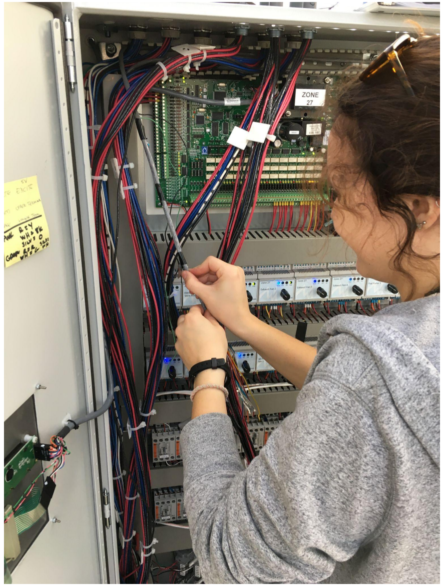


Figure credit: Rob Eddy

Feed-Forward Controls for Lighting

Lighting Benefits from Predictive Controls

- Predictive controls and cost-effectiveness
  - Weather
  - Peak demand
  - Shade control integration
  - Photoperiods
  - DLI

Map Your Controls and Responses

  - Zones
  - Dimming
  - Response rates
  - Ambient conditions and interactive effects

Commissioning Lighting Controls

Advanced Lighting Systems

- Verification of installation
- Remote monitoring
- Integrated startup and commissioning
- Reporting and metrics and verification

Target Setpoints

- Zones
- Ranges
- Choosing control values
- Set points that are sustainable year round

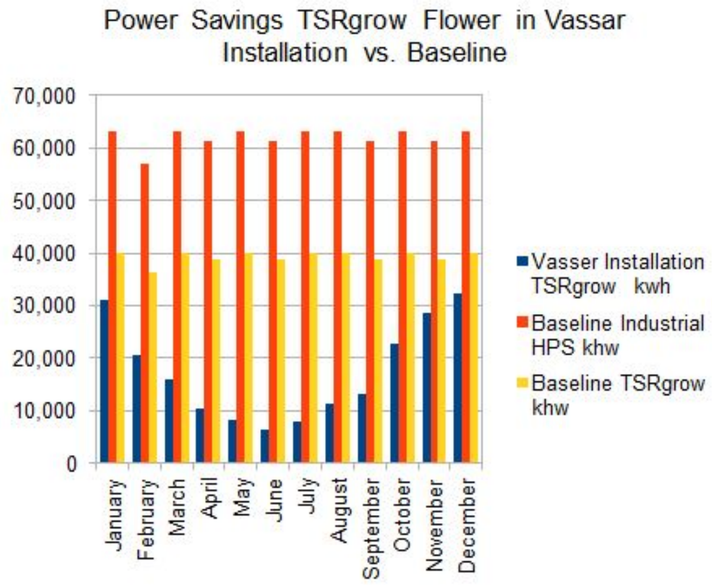
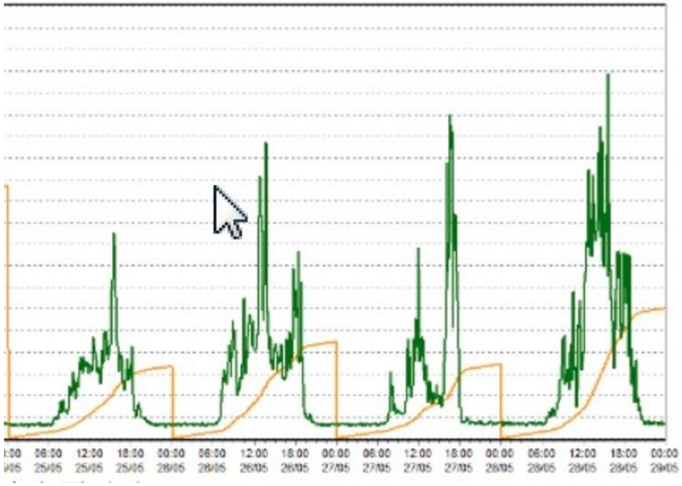


Figure credit: TSRgrow

Tweaking Lighting Response Rates

Applying a data filter to light sensors reducing cycling of equipment



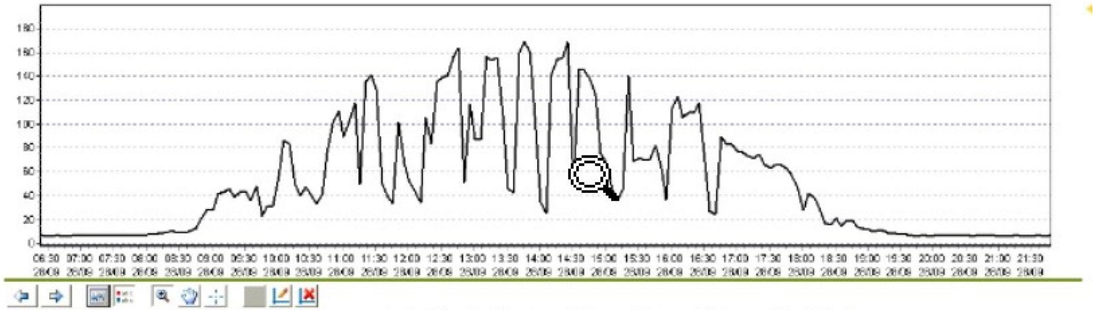


Figure credit: Rob Eddy

Lighting and Environmental Controls

Lighting Interactive Effects

- Ambient conditions can affect demand for lighting (schedule and intensity)
  - Greenhouses have dynamic temperature, humidity, CO_2

Systems Affected by Lighting

- HVAC and humidity management
- Fertigation
- Curtain controls

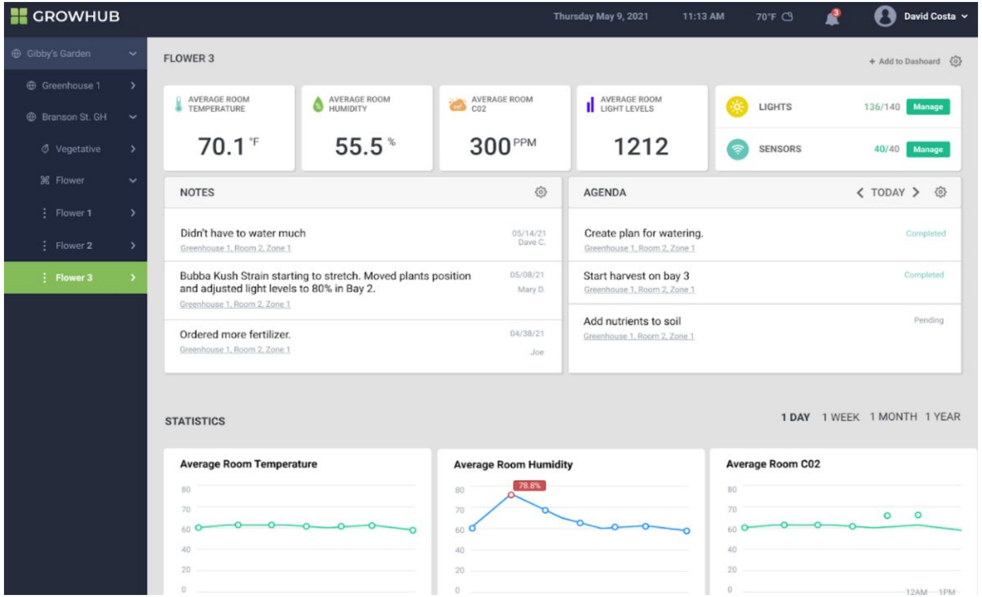


Figure credit: TSRgrow

Dive Deeper into Lighting Controls

The Right Light

CANNABIS BUSINESS TIMES

READ MORE

How Manipulating Light Treatments Affects Plant Expression

CANNABIS BUSINESS TIMES

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How LED Light Recipes and Controls Can Improve Quality and Yield for Cannabis Producers

cannabis science and technology
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SECTION 07

ENVIRONMENTAL CONTROLS AVOIDING MICROCLIMATES

Greenhouse Climate Control Approaches

Active Climate Control

Ventilated greenhouses can be actively ventilated using ventilation fans to cool and dehumidify growing spaces.

Well-sealed greenhouses can achieve target environmental conditions by using fans, evaporative cooling walls, refrigerant-based cooling and dehumidification equipment, and mechanical heating systems.

Passive Climate Control

Ventilated greenhouses can use low-energy solutions like roof vents to release hot, humid air.

Passive solutions can manage climatic conditions in greenhouses, but actual environmental conditions can range widely.

Greenhouse Envelope

Ventilated greenhouses use plastic or glass coverings which are hard to completely seal.

Greenhouses with insulated and tightly sealed envelopes can more actively control climate and achieve target environmental conditions.

https://www.greenhousegrower.com/technology/optimizing-systems-for-cannabis-greenhouses/

HVAC Controls: Value Proposition

Optimize environmental conditions for plants

- Proper temperature (space, relative & leaf), humidity, airflow, CO2 levels
- Optimal plant growth, control mold, mildew and other pests
- ROI plus visibility of data to create a more stable operation

Reduce operating costs while maximizing efficiency and productivity

Figure credit: Microclimates

HVACD for Controlled Environment Agriculture

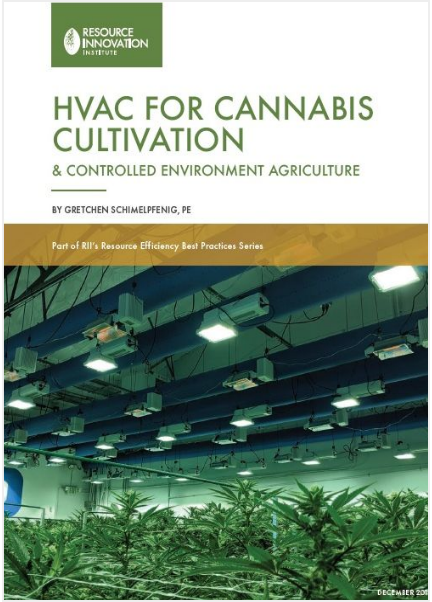
Demystifying Key Terms

- Cultivation
- Energy & Power
- Environmental Conditions
- General HVAC
- Energy Efficiency
- Construction
- Cultivation Key Performance Indicators (KPIs)

Key Concepts

Understand HVAC options

Learn tips for optimizing design, installing equipment, and operating HVAC systems effectively



DOWNLOAD NOW

HVAC Controls: Recipes for Cannabis Steering

Table 7: Climate & Airflow Controls for Cannabis Steering by Stage of Plant Growth[8]

Climate Controls	Vegetative	Flowering	Ranges of Controls Values
Day-Night Temperature Difference	Smaller	Larger	0 - 9 degrees F
Afternoon Temperature Increase	None or small	Larger	0 - 5.5 degrees F
Start Time for Heating System	Earlier	Later	4 hours before sunrise to sunrise
Night-Day Temperature Increase	Higher	Lower	1 - 4.5 degrees F
Start Time for Day-Night Temperature Decrease	Earlier	Later	2 hours before to 2 hours after sunset
Speed of Day - Night Temperature Decrease	Slower	Faster	0 - 7 degrees F per hour
Average Daily Setpoint Temperature	Lower	Higher	68 - 82 degrees F
Vapor Pressure Deficit Target	Lower	Higher	0.8 - 1.5 kPa
Ventilation for Temperature Control	More	Less	Used for temperature control
CO_2 Enrichment	More	Less	350 - 1500 ppm
Energy Screen	Close	Open	Used to manage plant stress

Figure data source: Signify

Greenhouse HVAC Controls

VPD Controls

- Target ranges vary by stage of plant growth
- Dial in energy-efficient VPD setpoint ranges

Airflow Controls

- Sizing for cultivation can range from 10 to 20 ACH, with some cases as high as 30 - 40 ACH
- Reduce supply air volume setpoint during dark periods

Understand energy savings potential of strategies and data needed to validate performance

Table 5: Climate and Airflow Controls Parameters Measured by Cannabis Cultivators

Climate and Airflow Data Collected[7]	Percentage of Growers Collecting, 2020
Space Temperature	85%
Relative humidity	72%
CO2 concentration	66%
Leaf temperature	31%
Air speed	19%

Table 6: VPD Targets for Cannabis Cultivation

Cannabis Growth Stage	Target VPD Range (kPa)
Flower/Bloom/Mother	1.0 - 1.5
Vegetative	0.8 - 1.1
Clone/Seedling	0 - 0.2

Figure data source: Cannabis Business Times

Traditional Greenhouse HVAC Systems

Figure credit: Gretchen Schimelpfenig, University of Vermont

High-Performance Greenhouse HVAC Systems

Figure credit: Ceres Greenhouse Solutions

High-Performance HVAC System Data

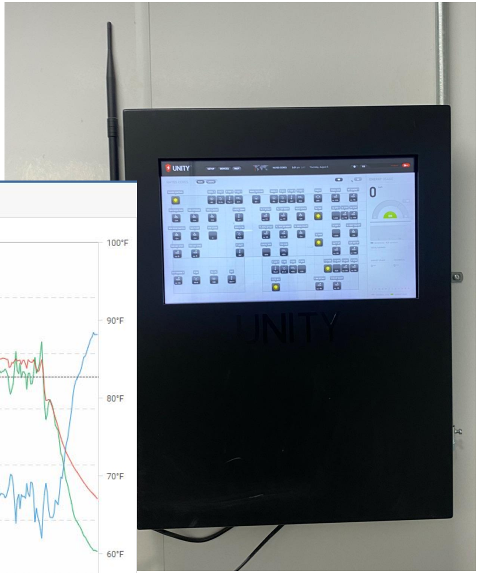


Figure credit: Ceres Greenhouse Solutions

High-Performance HVAC System Data

All Sites | Select | < | May-2021 | > | Rules | Options

All Sites | Something From The Farm

Equip	Cooling Elec Cost	Cooling Energy Use	Cooling Equipment Runtime	Heater BTU	Heater Elec Cost	Heater Energy Use	Heater Propane Cost	Heater Propane Use	Heater Runtime
Something From The Farm Circ Fans	$25.11	279kWh	7.49day						
Something From The Farm EF01_24in	$8.48	94.26kWh	9.56day						
Something From The Farm EF02_24in_LouverC	$6.35	70.61kWh	6.23day						
Something From The Farm EF03_36in	$0.50	5.606kWh	9.46hr						
Something From The Farm EF04_36in	$2.39	26.56kWh	1.87day						
Something From The Farm GAHT Fan A	$11.18	124kWh	4.36day						
Something From The Farm GAHT Fan B	$18.10	201kWh	6.81day						
Something From The Farm Heater A				384,071h_BTU	$0.31	3.486kWh	$13.12	5.247gal	6hr
Something From The Farm Heater B									
Something From The Farm LouverA&B			11.23day						
Something From The Farm Wet Wall Door	$1.90	21.14kWh	4.99day						
Something From The Farm Wet Wall Pump	$2.66	29.5kWh	12.97hr						

Figure credit: Ceres Greenhouse Solutions

Mechanical Cooling Equipment

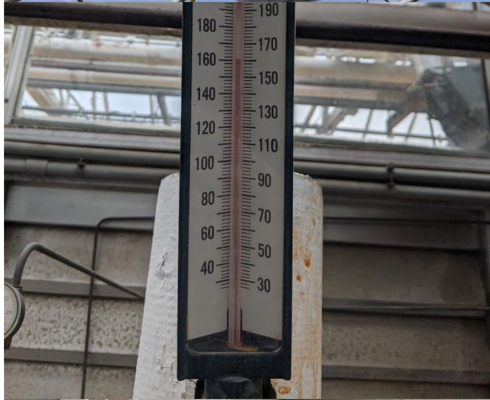
Cooling

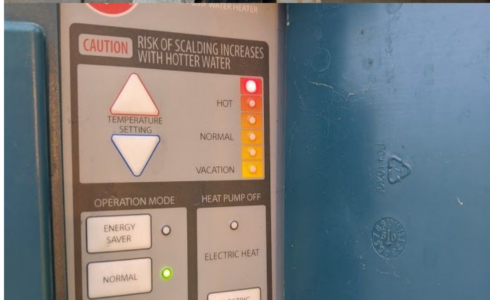
- Cooling equipment to maintain target environmental setpoints
  - Evaporative systems:
    - Pads and fans (P&F)
    - High-pressure fog (HPF)
  - Refrigerant-based cooling systems
    - Direct expansion (DX)
    - Heat pump equipment
- Often automatically controlled
  - Can be staged on after passive ventilation strategies

Mechanical Heating Equipment

Heating

- Radiant systems to maintain target environmental setpoints
  - Associated pumps
- Unit heaters
- Heat pump equipment
- Sizing heating equipment for CEA
  - Winter / night conditions
    - Depend on cultivar
    - Affected by supplemental lighting
  - Determine design conditions for winter / night
- Temperature controls for hydronic and ducted systems





Climate & Airflow Controls

Climate & Airflow

- Mapping your facility
- Use the environment to your advantage
  - Consider advanced in-ground designs for heat capture/re-use/recirculation and cooling

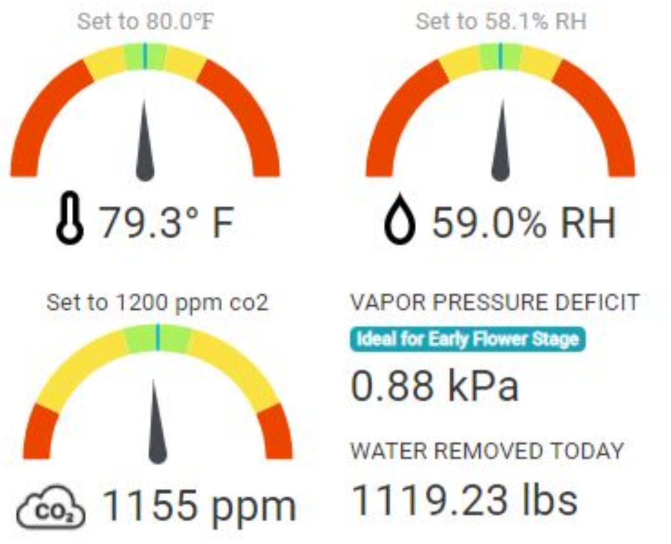
Monitor and Measure to Control

- Sensors throughout facility
  - At all levels and in the ground
- Feed-forward predictive control
  - Reacts to environmental influences before they are reported by sensors

HVAC Controls: Interactive Effects

Respond to light and water

- Orchestrate your envelope HVAC controls to call and respond to daily and seasonal solar variation and your supplemental lighting controls
- When the sun sets, humidity spikes, and control strategies give envelope and HVAC equipment more time to ramp up and respond
- Likewise, plant stage of growth and timing of watering events can demand more of your HVAC system



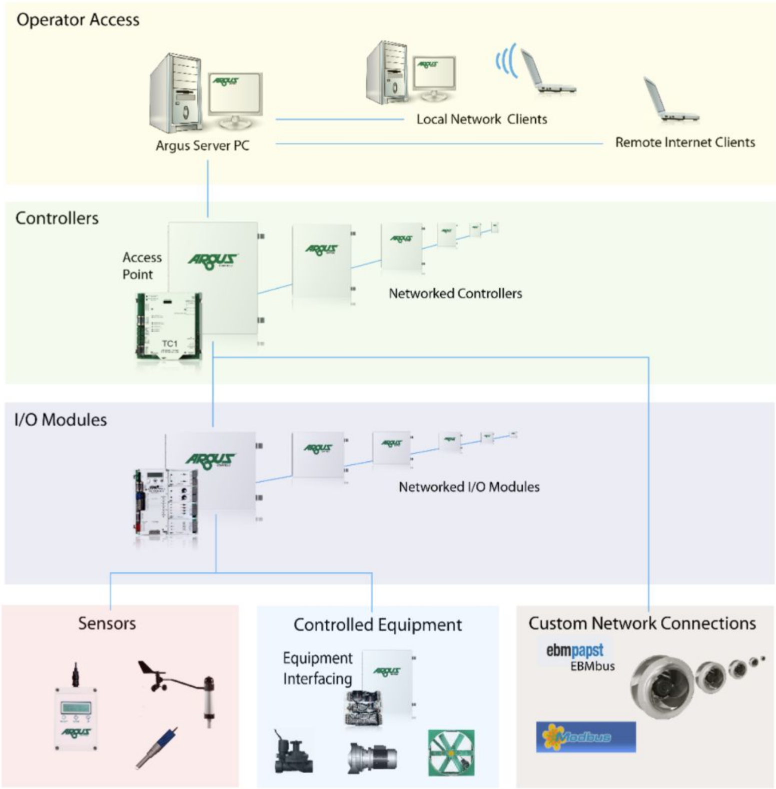
HVAC equipment should monitor both lighting and irrigation controls activities for faster response times and happier plants

Figure credit: Inspire Transpiration Solutions

Integrated Greenhouse Controls

Intelligent Cooling with Feed-Forward Controls

- Feedback alone can cause poor control and wasted energy
- Using feed-forward integrated controls, HVAC controls can preemptively anticipate weather conditions to improve control and save energy.
- Hardware communicates with software to inform systems of actual conditions in the greenhouse
- Environmental controls orchestrate which system should respond:
    - Vents, curtains, fans, active cooling



HVAC Controls: VPD Controls

Maintain efficient VPD targets

- There is not a target VPD that is appropriate for all cultivars, environments, or cultivation methods
- Consider acceptable VPD ranges by stage of plant growth

Dial in HVAC system automation to tailor VPD to specific cultivars, systems, and facility configurations

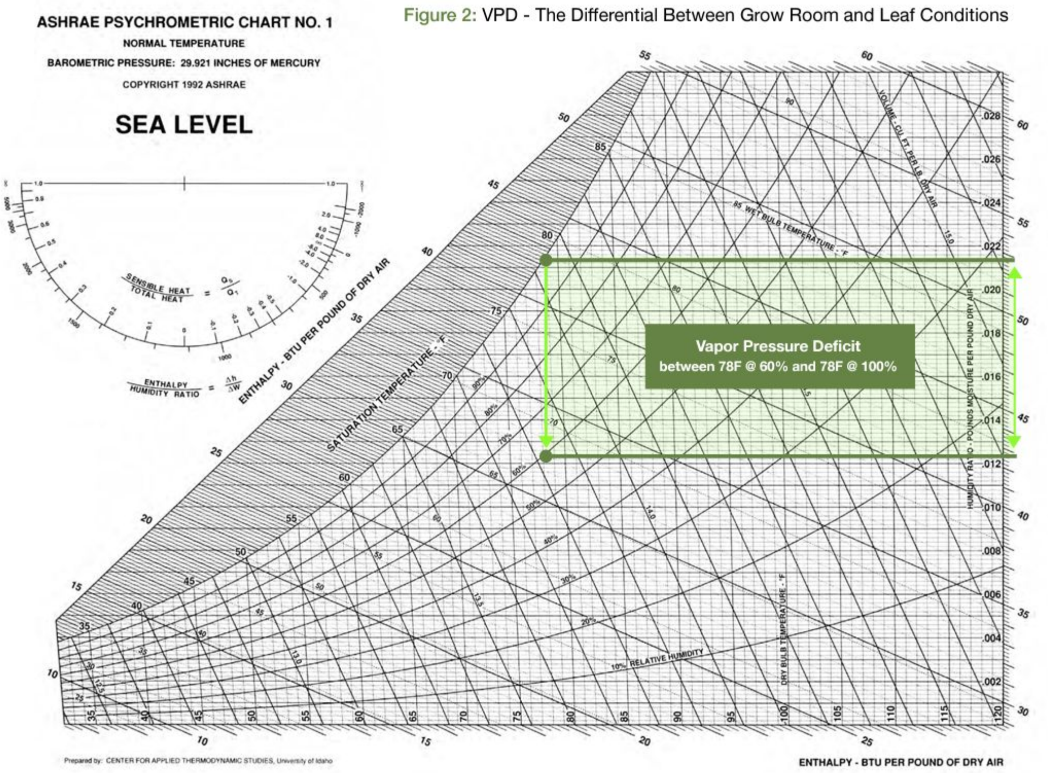


Figure credit: Desert Aire & ASHRAE

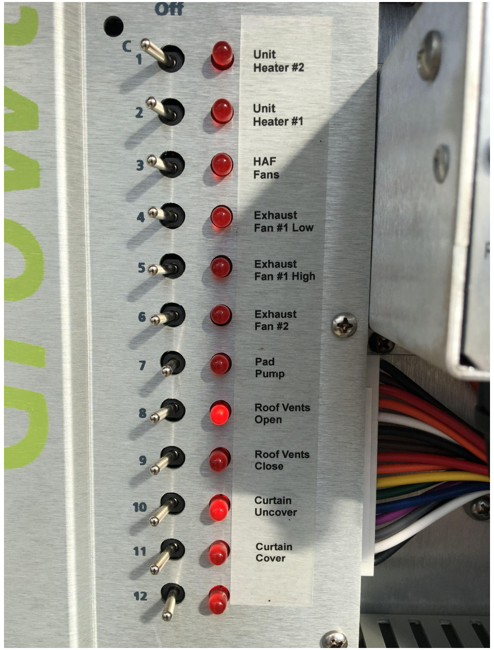
Maintaining Airflow

Ventilation & Circulation Fans

- Using both leeside and windside vents can allow for smaller openings
  - Leeside to reduce temperatures and remove excess humidity
  - Wind side vents can create greater air movement above thermal curtains
- Size ventilation fans properly for your airflow requirements:
  - For hot season growing use 8 CFM per square foot of growing space
  - For cooler season growing use 2 CFM per square foot
- Install circulation fans to satisfy flow rates of 25% of your greenhouse’s volume per minute

Plant Empowerment Concepts for Cannabis

1. Control radiation with thermal curtains
   a. Close energy screens to limit heat emission from plants at night
   b. Open energy screens later in AM and close earlier in PM
2. Determine what equipment serves what purpose
   a. Circulate and ventilate to actively maintain airflow
   b. Improve humidity control with HVACD equipment
3. Document target environmental conditions
   a. Select targets to maintain plant balances
4. Operate HVAC equipment to maintain a uniform climate
   a. Stage equipment to achieve target environmental conditions
5. Monitor VPD, lighting system operation, and energy flows
6. Base irrigation on total energy flows and VPD monitoring



Commissioning Environmental Controls

Monitoring

- You can't manage what you don't measure...but you can't measure what you don't monitor
- Make data to support savings claims

Calibration

- Ensure sensor accuracy so HVAC systems respond to actual environmental conditions
- Configure response times to reduce short-cycling

Commissioning

- Functionally test HVAC sequences of operation to ensure persistent energy savings

Figure credit: Gro iQ / InfiSense

Dive Deeper into Environmental Controls

Empowering Plants with Environmental Controls Systems

GREENHOUSE GROWER

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Avoiding Cannabis Crop Loss in Cultivation

GREENHOUSE GROWER

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Integrated Pest Management for Cannabis Cultivation Monitoring, Identifying, Preventing, and Controlling Pests with HVAC Solutions

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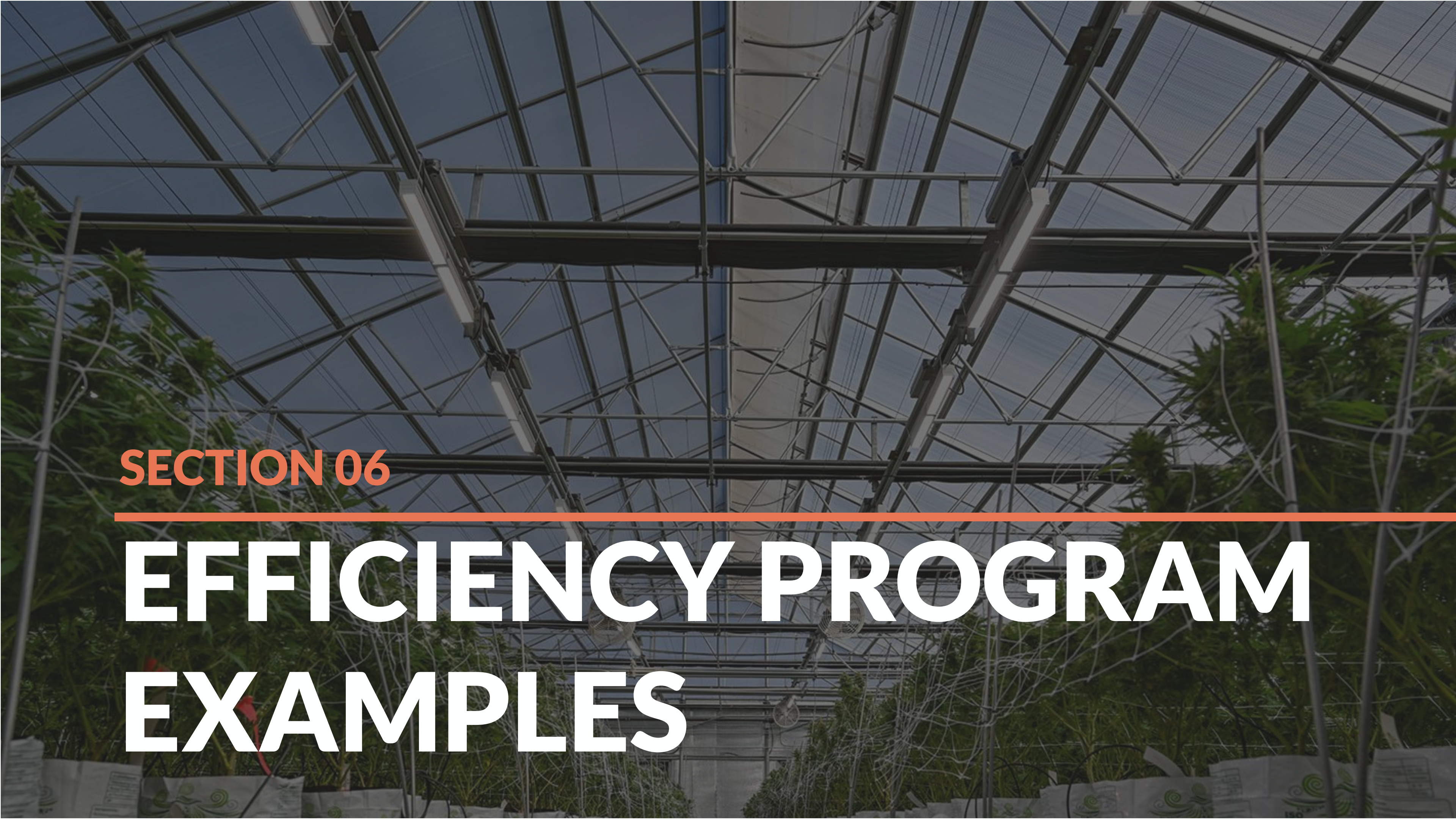

SECTION 06

EFFICIENCY PROGRAM EXAMPLES

Efficiency Utilities Serving Tri-County

Three Regional Utilities with Efficiency Programs

- Utility service territories determine eligibility
- Growers in Tri-County region can benefit from technical assistance and financial incentives
- Incentives reduce the first cost of high-performance technology

SOUTHERN CALIFORNIA EDISON®

PG&E Pacific Gas and Electric Company®

SoCalGas

Cannabis Efficiency Project Landscape

Read customer testimonials at
https://www.socalgas.com/for-your-business/energy-savings/rebate-and-incentive-testimonials

SoCalGas Programs for Producers

Energy Efficiency Programs

- **Agriculture Energy Efficiency Program (AgEE)**
    - New program implemented by ICF, EnSave, and ERI Pacific
    - Financial incentives of up to 50% of the project cost
    - Projects must be installed by the end of 2023
    - Incentives for some projects are available back to June 7th, 2021
    - SoCalGas customers can contact Karl from EnSave at karlj@ensave.com
    - Send general program emails to AgEE@CAEnergyPrograms.com
    - Call 844-523-9981

Visit https://caenergyprograms.com/AgEE

SoCalGas Greenhouse Customer Incentive Examples

Project 1:
Sunnyland Nurseries - Greenhouse

Energy management system

- Saves energy by monitoring climatic changes and automatically adjusting setpoints inside greenhouse
- "Does a better job than I did," notes owner Robert Akashi

Energy Saving Results

4,800 therms per year
Incentives $3,850

Project 2:
Skyline Flowers - Greenhouse

Infrared film

- Saves energy by reducing thermal cooling at night
- "If you're aware of the program and know what it offers, the rebates can be substantial for agriculture businesses"

Energy Saving Results

20,000 therms per year
Incentive $25,000

SoCalGas AgEE Program Offerings for CEA Customers

Energy Efficient Equipment Incentives

- Heat curtains / energy screens: $0.35 - $0.50 per sq. ft.
- Infrared (IR) film: $0.045 - $0.10 per sq. ft.
- Condensing boilers: $6.00 - $10.00 per rated kBtu capacity
- Pipe insulation: $2.50 - $4.00 per linear foot
- Custom projects: $2.50 - $3.00 per first-year therm saved

Other Program Offerings

- Free technical assistance to identify and prioritize greenhouse energy efficiency projects
- Energy audits and facility walkthroughs for large customers
- Direct installation of select measures at low/no cost for growers in disadvantaged communities
- Zero-percent on-bill financing up to $100,000 per meter

All SoCalGas customers qualify for participation. Contact EnSave for more information!

Q & A

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