RESOURCE INNOVATION INSTITUTE

AUTOMATION & CONTROLS FOR CANNABIS CULTIVATION

& CONTROLLED ENVIRONMENT AGRICULTURE OPERATIONS

BY GRETCHEN SCHIMELPFENIG, PE

Part of RII's Resource Efficiency Best Practices Series

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A report from Resource Innovation Institute

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Available online at: www.ResourceInnovation.org/Resources

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OVERVIEW

As a cultivator operating in a constantly evolving industry, **you may feel like it is hard to know who to trust.** The horticultural market has changed a lot, technology has advanced, and so have the technical terms used to describe everything. It can be hard to navigate the purchasing process when planning a facility and challenging to understand how to integrate hardware and software solutions.

We are here to help. As an objective, data-driven non-profit organization, Resource Innovation Institute measures, verifies and celebrates the world's most efficient agricultural ideas. Our peer reviewed Best Practices Guides are a way of helping growers like you understand the most resource-efficient technologies and how to use them to boost your bottom line.

The operational changes necessary for an efficient cannabis production facility may be detailed, but **it does not have to be a mystery.** Our membership is composed of subject matter experts with the knowledge to help you build and operate the most high-performance and cost-effective facility for cultivating plant life in controlled environments.

You may be looking for a **source of reliable third-party information,** motivated to reduce overhead for your business, or have goals for a more resource-efficient facility. Whatever the reason, when you are considering a decision related to the systems used in your facility, we hope you lay the groundwork with the insights offered in Resource Innovation Institute's Best Practices Guides.

PHOTO: COURTESY OF SOLAR THERAPEUTICS

PURPOSE

Manually operating lighting, HVAC, and watering equipment can be intuitive, but designing, installing, commissioning, and operating automation and control systems for cultivation applications efficiently and effectively requires specialized expertise.

The purpose of this Automation & Controls Best Practices Guide is to support you, the producer, and your design and construction partners with:

- Speaking the language relevant to controlling and automating environmental control systems in horticultural applications
- Understanding types of control systems optimizing horticultural environments
- Planning for integrated controls approaches in your greenhouse or indoor operation
- Installing and operating successful controls solutions in alignment with your business model
- Using data from control systems to improve productivity and efficiency
- Demonstrating energy savings for utility energy efficiency incentive programs

DEMYSTIFYING TERMS

Throughout this guide, you'll learn key terms related to the systems that control crucial elements to plant growth and development: light, climate and airflow, and water. Cultivation facilities manage them differently, and use different systems to maintain desired conditions. It is important to consider how they are used, why the terms are important to consider, and how the terms may be commonly misunderstood or misapplied.

This guide is intended to serve producers and their partners seeking to optimize controlled environments for cultivating cannabis, including architects, engineers, hardware manufacturers, suppliers, systems integrators, data aggregators, controls contractors, commissioning agents, and utility and efficiency program energy engineers.

The key terms address the topical areas listed below:

- Lighting controls
- Climate and airflow controls
- Water controls
- Hardware and software
- Automation
- Data science

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To learn the language of controls, consult our companion resource to this guide that provides a glossary of key controls terms to expand your vocabulary.

To learn more about HVAC and lighting systems, check out our Best Practices on HVAC and LED Lighting for Cannabis Cultivation & Controlled Environment Agriculture, companion guides to this one that cover HVAC and lighting terms and systems used for cultivation environments. Each guide has a companion resource to demystify the meanings of key terms like PPFD and VPD:

Best Practices on HVAC for Cannabis Cultivation

Best Practices on LED Lighting for Cannabis Cultivation

PHOTO: COURTESY OF PHYRE

CONTROLS FOR CULTIVATION

Grow operations can prioritize using automation to increase precision for fine-tuned production operations. Cultivating cannabis in controlled environments involves supplementing or replacing sunlight, maintaining environmental conditions, and providing water and nutrients, processes which can be performed manually or automated with control systems. Manufacturers of lighting, climate and airflow, and irrigation equipment may install on-board controls configured at the factory, and cultivation facility operators can choose how hardware and software integrates with building-level controls of varying levels of sophistication and operates to optimize plant health.

Controls hardware and software designers and manufacturers have solutions purpose-built for cannabis cultivation that have gained the lessons learned from diverse commercial and industrial applications. Sensing equipment is now more specialized for horticultural facilities, lower-cost, more widely available, and more durable than ever before. *Environmental control systems* gather and monitor data from sensors and report on grow room conditions and system operation so HVAC, lighting, and irrigation systems can maintain target environmental conditions like light intensity, room temperature, and watering rate.

Integrated control systems with fault detection optimize conditions for cultivation in your facility, which is crucial for growing healthy plants and achieving expected yields. With integration, automation is possible and offers opportunities to improve productivity and reduce labor costs. Give staff more time with plants and data by eliminating having your employees turning dials, flipping switches, and managing schedules. Analytics software can review *trend data*, flag issues, and recommend resolutions to solve problems before they become emergencies.

Automation allows growers to balance productivity and efficiency. Today's United States cannabis market presents a very diverse policy landscape. Producers in younger markets may use controls to maximize yield, while others in mature cannabis markets— with decreasing wholesale prices—plan for competition by reducing operating expenses. Increased demand for products and cost compression in cannabis markets have led to new

PHOTO: COURTESY OF SIGNIFY

attitudes about efficient and optimized control systems. Growers are increasingly considering resource efficiency and productivity to rise above the competition by reducing operations and maintenance costs through using high-performance systems and controls approaches.

Poor control of lighting, HVAC, and water management systems limits your competitive edge and can result in crop loss and plant quality issues. Optimizing control of environmental control systems for crop steering can reduce energy and operating costs while increasing yields per square foot. In the U.S., capital expenditures for high performance indoor cannabis cultivation operations range $250 - 300 per gross square foot. Growers can use passive and active strategies to manage and supplement sunlight, maintain environmental conditions, and provide water and nutrients to plants. Controls hardware and software solutions for controlling these mission-critical systems can add to the first costs of a buildout. Control system upgrades can pay for themselves by freeing up growers to scout for pests and diseases that may have gone unnoticed, which can prevent crop loss and increase your facility's productivity.

With wholesale prices in mature cannabis markets decreasing, automating environmental control systems represents profit potential. Various types of business costs, including human resources and rent, never decrease. In contrast, a number of factors can be significant drivers toward profitability, including lower resource consumption, increased product yield, and improved quality.

Increased demand for products and cost compression in cannabis markets have led to new attitudes about efficient and optimized controls systems. Growers consider resource efficiency and productivity to rise above the competition by reducing operations and maintenance costs through using efficient systems and controls approaches. For example, high performance facilities with integrated control of HVAC, lighting, and water management systems can reduce operating costs by 15%[1] over traditional approaches like manual control and data tracking. Active energy management practices offer a systematic structure that can generate savings of up to 30%[2].

Understand the root causes of controls issues to reduce on-farm labor requirements, increase agricultural yields, maximize resource efficiency, and mitigate risks. In some regions, standards and regulations for energy performance have emerged, and cultivators everywhere can benefit from understanding how smart controls can be a tool for their facility's compliance and operational success.

In the following sections, you will learn how control of key facility building systems affect your plants and support productivity, profitability and optimized conditions for plant growth and development. Understanding the terms used to describe your indoor grow environment requires a slight learning curve, but is essential if you want to ask informed questions, make informed business decisions, and achieve a resource-efficient and high-performance operation.

PowerScore

Resource Innovation Institute's PowerScore resource benchmarking platform benchmarks energy, water, and emissions key performance indicators for controlled environment agriculture operations. The PowerScore platform accepts facility information in a variety of ways. To learn more about different cultivation approaches and how your facility performs compared to growers like you, visit resourceinnovation.org/powerscore. Cannabis growers can receive competitive performance benchmarks comparing facility KPIs to the average of the cannabis Ranked Data Set at cannabispowerscore.org.

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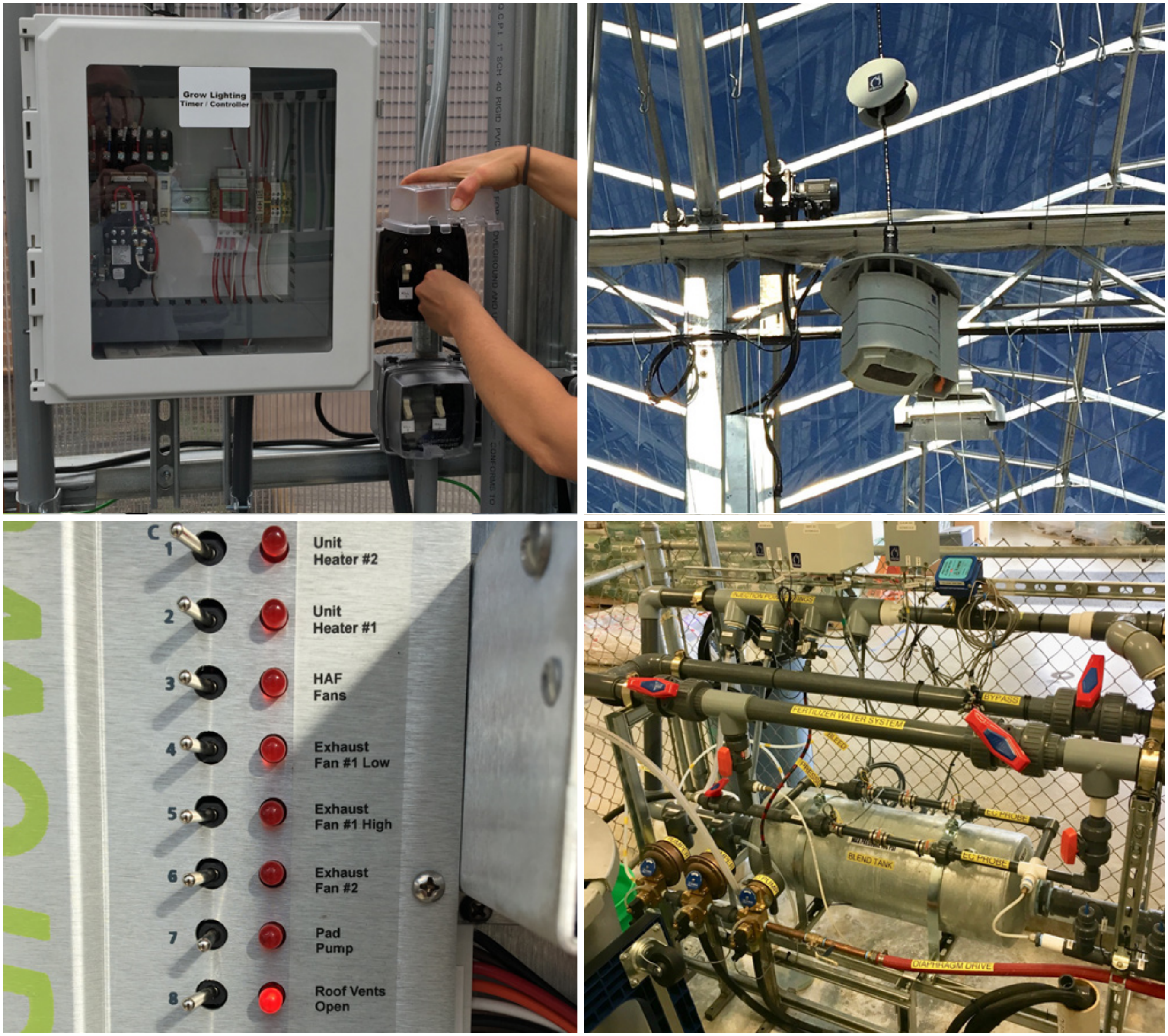
Cultivators may use simple or sophisticated systems, and sometimes system choice correlates with facility size, market, and final product. Smaller facilities may use basic room control, hand mix their nutrients, and manage environmental conditions separately. Medium-sized production facilities may use some automation equipment, but primarily control equipment by hand. Larger cultivation operations are more likely to be fully integrated automation systems centralized at a headend controller to completely manage all light, climate and airflow, and water processes. Innovative and competitive growers connect control systems to monitor, communicate, and automate.

You may encounter different types of controls being used for various cultivation applications. The collage of images on the following page is a small sample of a wide variety of technologies on the market today.

[1] Smart Buildings: Using Smart Technology to Save Energy in Existing Buildings, American Council for an Energy Efficient Economy, 2017

[2] Making Permanent Savings through Active Energy Efficiency, Schneider Electric, 2011



PHOTOS FROM TOP: BANNER IMAGES COURTESY OF ROB EDDY

HOW CANNABIS CULTIVATORS USE CONTROLS

Cultivators can conduct the activities of major building systems differently depending on their kind of cultivation operation and building systems. Some may integrate their building system controls, orchestrating their building systems in concert with each other.

There are many ways to grow cannabis, and in this guide we find common ground by speaking to a few of the more common methods of operations cultivating cannabis in North America. The images and **Table 1** on the following page describes the three major methods of growing and the ways operations may find value in and make use of lighting, climate and airflow, and water controls systems.

Table 1: Benefits of Controls Systems for Cannabis Cultivators

	 **Indoor Single Tier**	 **Indoor With Vertical Racking**	 **Greenhouse Single Tier**
Data Value Proposition	Control systems can continuously monitor intra-canopy conditions throughout a sea of green.	Control systems can continuously monitor multi-tiered racks and automatically respond.	Control systems can improve maintenance of target environmental conditions.
Common Control System Priorities	Prioritize control of environmental control systems for increased precision.	Prioritize integration of environmental control systems for centralized control.	Prioritize response to outdoor environmental conditions and solar exposure.
Common Lighting System Control Approaches Dehumidification System	Sole-source lighting equipment can be controlled on a schedule, and dimmed manually.	Sole-source lighting equipment can be controlled with automated scheduling, dimming, and spectral tuning controls through a centralized environmental control system.	Approaches for supplemental lighting controls may account for solar exposure and *daily light integral*. Supplemental lighting equipment can be controlled with automated scheduling, dimming, and spectral tuning controls through standalone or a centralized greenhouse controls system.
Common Climate and Airflow Control System Approaches	Distributed HVAC equipment can be controlled independently, and may be integrated through a centralized environmental control system.	Central plant and distributed HVAC equipment can be controlled through a centralized environmental control system.	Roof vents, thermal curtains, and distributed HVAC equipment can be controlled independently or integrated through a centralized environmental control system to coordinate staging of equipment.
Common Water Control System Approaches	Water management systems can be separately controlled and may be automated to a certain extent.	Water management systems are integrated and automated.	Water management systems can be managed independently or integrated into a greenhouse control system.

CHART PHOTOS: COURTESY OF FLUENCE BY OSRAM (LEFT), SOLAR THERAPEUTICS (CENTER), AND CERES GREENHOUSE SOLUTIONS (RIGHT)
BOTTOM PHOTO: COURTESY OF GRO IQ / INFISENSE

DESCRIBING CONTROL SYSTEMS FOR CULTIVATION OPERATIONS

Plants and their surrounding environment need to work in harmony for optimized growth. Integrated systems in your facility coordinate their performance to optimize plant production and increase yields.

To understand what control systems are most important for growing cannabis, approach the topic from the plant's perspective. **Figure 1** below describes the production journey of cannabis plants, and at each stage of plant growth and during processing, controls parameters need to be adjusted to maintain optimal bud for final sale.

Figure 1: Cannabis Cultivation and Post-Harvest Processes

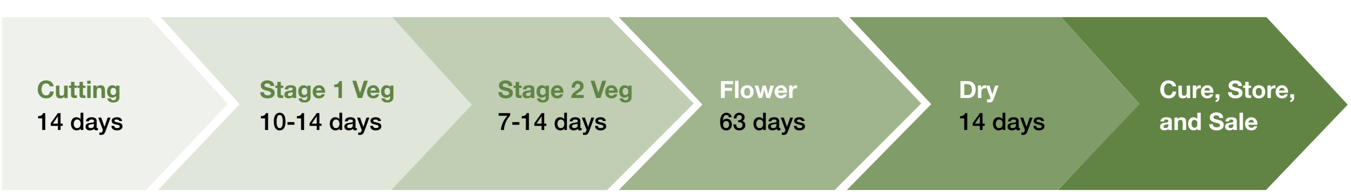


PHOTO: COURTESY OF SOLAR THERAPEUTICS; CHART: COURTESY OF ZARTARIAN ENGINEERING

In all cannabis grow environments, plants are arranged in a canopy, horizontally distributed at a planting density. In racking systems, plants can be vertically distributed in tiers. The distribution and density of a grow environment will influence the ways building systems maintain optimal conditions for plants.

Several horticultural processes require systems that can be controlled to optimize plant growth and development:

- **Light:** horticultural lighting systems used sole-source or to supplement solar radiation
- **Climate & Airflow:** mechanical systems to move and circulate air and manage conditions of the air including moisture and temperature
- **Water:** circulation systems to treat, *fertigate*, and process water used in the facility

Throughout this guide, best practices will be recommended for monitoring, control, and automation with these three major system types.

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To dive deeper, read more articles on HVAC, lighting, and water controls published by RII to share best practices with cannabis growers:

The Right Light - Cannabis Business Times

Cannabis H2O: Water Use and Sustainability in Cultivation

How Manipulating Light Treatments Affects Plant Expression - Cannabis Business Times

Empowering Plants with Environmental Controls Systems - Greenhouse Grower

Rooting for Recapture and Reuse - Cannabis Science & Technology

Fine-Tune Environmental Controls to Drive Your Competitive Edge - Cannabis Business Times

Integrate Environmental Controls For Better Cannabis Production - Cannabis Business Times

PHOTOS FROM TOP: COURTESY ANDEN AND GRODAN

PHOTO: COURTESY OF SIGNIFY

AUTOMATE YOUR LIGHTING SYSTEMS

Light is the #1 growth input for plants, and impacts development along with genetics, fertigation, and environmental conditions. Horticultural lighting controls manage operation of light fixtures that drive growth of your plant performers. Controls are stage directors that automate lighting schedules and modulate light levels.

OPTIMIZE YOUR LIGHTING CONTROLS DESIGN

Lighting control systems can be designed to manage the lighting schedule (photoperiod), light intensity (PPFD), total accumulations of light over single day periods (DLI), and spectral quality of the light fixtures used for supplemental or sole-source lighting in a cannabis grow environment.

Select Sole Source or Supplemental - When growing indoors, electric light is the *sole source* of light, while greenhouses can integrate *supplemental* lighting solutions with sunlight. Controls for greenhouse supplemental lighting systems should respond to inputs like solar radiation because of the variation in natural light conditions. *Daily light integrals* (DLI) can vary from 2 to 50 mols/m^2/day after taking into account light losses through greenhouse transmission surfaces. *When growing indoors, the operational schedule and intensity of sole source lighting solutions acutely influence environmental conditions that affect plant transpiration such as temperature and relative humidity. In greenhouses, these conditions are also significantly impacted by changing solar conditions.*

Specify Spectra - Spectrum impacts plant growth and development, energy use, and temperature control strategies. LEDs are the only type of grow light that has customizable *spectral quantum distribution*; manufacturers can provide unique light recipes targeting specific plant responses. Some LED fixtures can be spectrally tuned to adjust light quality throughout the day, during different stages of plant growth, or for different cultivars. *Spectral tuning* modulates the output of diodes like red and blue to affect photomorphogenic qualities. These qualities include biomass production and *phytochemical responses like secondary metabolite production. Spectrally tuning lighting systems affects energy consumption and can be an energy efficiency strategy incentivized by utilities and program administrators.*

Schedule Photoperiods - Design your daily lighting schedules and establish how light is used over the course of harvest cycles. **Table 2** below summarizes typical DLI targets and photoperiods for cannabis cultivators and can guide you as you decide what is right for your plants in your location. Think about how energy will be used daily and throughout the year. *Greenhouse operations can establish target DLI and how it will be achieved with available sunlight and supplemental electric light. Consider balancing flowering rooms in indoor environments to reduce electric demand and utility bills.*

Table 2: Lighting Schedules and DLI Targets for Cannabis Cultivation

Cannabis Growth Stage	Average DLI Target for Cannabis (Moles/Square Meter/Day)	Example Sole-Source Daily Lighting Hours (Indoor)	Example Supplemental Daily Lighting Hours[3] (Greenhouse)
Flower/Bloom	25 - 50	12	North: 6 - 8 hours South: 5 - 6 hours
Vegetative	20 - 40	18 - 24[4]	North: 4 - 6 hours South: 1 - 3 hours
Clone/Seedling	15 - 20	14 - 24	North: 0 - 2 hours South: Not needed
Mother	20 - 40	18	North: 4 - 6 hours South: 1 - 3 hours

Determine Zones - Light fixtures are typically installed on a grid with similar directionality. Decide how many *zones* of what size you need based on your plant population. Greenhouses benefit from at least three zones to account for shading from side walls that varies over the course of the day. *Design cultivation rooms with multiple dimmers to create different zones of light intensity in areas to correspond to batches of strains and optimize light levels specifically for cultivars.*

Understand Target Flux Density Levels - Target *photosynthetic photon flux density* (PPFD) impacts productivity and efficiency; higher targets can increase biomass production but also increase energy consumption. Establish the ways electric lighting will serve plant growth and development by understanding the ranges of light intensity desired by stage of plant growth. Determine how PPFD will be maintained: manually or automatically. Growers can use mobile mounting racks to move lights or employ lighting control systems to automatically modulate PPFD. *Adjusting light fixture height while employing dimming controls can reduce lighting energy use by up to 25%. However, moving lights can affect consistency and uniformity of the PPFD across and through the canopy which influences your plant canopy's transpiration rate and growth. Hardware and software solutions can maintain uniform PPFD by changing input power to light fixtures to adjust light output.*

Consider Greenhouse DLI Targets - DLI-based controls can offer between 20 - 40% in energy savings when used to optimize lighting system operation in greenhouses. Set automatic response controls (auto-response on/off control or dimming) to modulate light out based on available sunlight. *Assess target DLI, select response setpoints optimized for your cultivation facility, and ensure measurements are taken inside the greenhouse or are converted to account for transmissivity of greenhouse coverings.*

[3] The number of hours for supplemental lighting varies with location, transmittance of greenhouse covering, lighting technology efficacy, target DLI, and seasonal variation in solar radiation. Recommended hours of supplemental light for greenhouses were calculated by analyzing four locations in North America (Northern: Chicago, IL and Sudbury, ON Southern San Diego, CA and Tampa, FL) using Signify's HortiView software which has a 10-year average of mol/m^2 for all 52 weeks of the year for locations across the globe. Average PPFD targets for each cannabis growth stage were used from ranges reported by the Fluence Cannabis Cultivation Guide, and an assumed maximum usable light intensity (PPFD) of 750 µmol/m^2/sec (for flowering vegetative, and mother stages) and 400 µmol/m^2/sec (for clone and seedling stages) for greenhouse supplemental lighting were applied for each of the four locations in a spreadsheet calculator for every week of the year. DLIs were reduced by 33% to account for average losses through glazing and superstructure for an "inside DLI" received by plant canopy. The DLI received from the Sun inside the greenhouse was subtracted from the average value of the DLI target range for that cannabis growth stage to provide an average number of daily hours of supplemental lighting. This analysis was corroborated with a more general approach of dividing the U.S. Daily Light Integral Map into northern (N) and southern (S) halves, estimating average light across the year in those halves, and using the same calculation method.

[4] Some growers light vegetating plants for 24 hours a day with no dark period.

? **To choose a target DLI, determine the maximum PPFD inside your greenhouse and use that as a setpoint in µmol/m²/ sec (or convert to W/m² by dividing by 2.1 for sunlight).** DLI setpoints for lighting controls systems should be set at the target DLI value (ex. 45 mols/m²/day) in seasons where DLIs from the Sun are below target values. Conversely, DLI setpoints should be set slightly below DLI target values in seasons where DLI from the Sun is expected to exceed target values, unless shading systems are used and integrated for measurement-based response to prevent exceeding target DLI.

Dim Down to What - Some lighting systems may have issues with *total harmonic distortion* below 50% output, and many cannot dim below 20%. LEDs offer more *granularity* of light levels compared to high-intensity discharge lighting solutions and can modulate from 1 - 100% output. As LEDs dim, light fixture *photosynthetic photon efficacy* (PPE) can increase, saving energy. *As a portion of total system cost, it is relatively easy and inexpensive to break up rooms into zones and dim with LEDs. Manage demand and save money on utility bills using dimming controls. Tweak light levels to find the sweet spot of maximum productivity with minimum resource consumption. Utility energy efficiency programs can offer financial incentives for dimming.*

PURCHASE LIGHTING CONTROLS EQUIPMENT

Once you document the requirements of your lighting controls system, select hardware to suit your needs.

Note Manufacturer Hardware - Manufacturers control light output and spectral quality differently. Some systems can flicker, which can be problematic for plants and human occupants. *Understand how controllers actually modulate light output, as there is not an industry rule for what light intensity output corresponds to what power input (0 - 10 V).*

Consider Wired Solutions - Wired lighting control solutions require no batteries to change and the signal is always at 100%. Depending on the size of the facility, there could be a lot of wiring to do, cables can get in the way, and line boosters may need to be installed for long runs. *Wired lighting controls work well in facilities who cannot or do not want to rely on wireless communication or who have a building structure that adversely affects wireless signals.*

Go Wireless - Get more freedom of installation locations and total number of sensors installed while also being able to place sensors virtually anywhere. Horticultural lighting controls for cannabis cultivation requires connecting a large number of fixtures in various zones. Bluetooth connects to one device at a time and larger zones with thousands of light fixtures may not be possible to control. *WiFi* devices connect to your network but also compete with everything else on your network. *LoRa WAN* is an independent network and has long-range communication capabilities. *It is important to consider what happens when your network goes down or experiences connectivity issues. Lighting systems becoming uncommunicative or unexpectedly turning off can endanger crop vitality.*

Lay Out Sensor Hardware - Some lighting control solutions can measure and report parameters like *photosynthetically active radiation* (PAR), PPFD, and DLI. Other sensor hardware can measure both lighting and environmental parameters. Especially in greenhouses, use *pyranometers* to accurately monitor changing light conditions. Indoors, use handheld or permanently installed light meters to configure and verify light levels. Be aware of new sensors that measure ePAR, which includes far red. *Calibrated lighting systems with dimming controls use integrated light sensing equipment to maintain PPFD. Measuring climate parameters (page 20) is essential in both indoor/greenhouse environments, and conditions can be directly impacted by artificial lighting systems.*

CONFIGURE LIGHTING CONTROLS EQUIPMENT

Get the most out of your hardware by thoughtfully installing and configuring your lighting controls solutions.

Sense Conditions of Your Plants - Ensure accurate PPFD measurements by placing sensors in areas representative of average light intensity. Optimized light plans using wide-beam LED optics often result in up to 20% variations of PPFD values in the lit area due to inherent limitations on fixture placement, total fixture count, and light beam shape. For greenhouses, avoid placing light sensors where they may be shaded by obstructive materials as the sun changes position. ***Table 3*** *on the following page shows that more than half* *of cannabis growers measure PPFD. Validate light levels and account for variation of PPFD values with accuracy by using two or more sensors within each lighting control zone to represent a composite average of light intensities.*

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%

Log Data - Some light sensors can connect to dedicated loggers that allow you to view and record live data on devices like mobile phones via apps. You can also connect sensing equipment to your environmental control system so it reports to a front-end interface and historical records can be stored on a hard drive or in the cloud. The more often sensors take readings, the more data your system has to retain. Local loggers can be limited by their storage capacity. *Consider how frequently your sensors should record data and where that data should be logged.*

Choose Response Rates - Understand how often you would like greenhouse lighting control systems to respond with what degree of *sensitivity*. Discuss with your controls contractor how to use weighting functions to limit how much an input changes a parameter in a given amount of time to avoid ramping light intensity up and down every time a cloud passes. *Set time delays on PAR readings so greenhouse shade curtains and light fixtures do not cycle too much.*

Commission Lighting SOPs - For indoor environments, consider how lights should automatically respond if HVAC systems go down, as heat output from lights can be used as a tool in emergencies. Test how light deprivation, shade curtain, energy screens, and lighting control systems respond in greenhouses and how systems should operate when temperatures get too hot or too cold. *Run your lighting system through functional performance tests to ensure schedules, flux targets, and dimming sequences of operation are implemented as expected.*

PHOTO: COURTESY OF FLUENCE BY OSRAM

OPERATE LIGHTING CONTROLS EQUIPMENT

Synthesize efficiency and productivity by modulating lighting systems thoughtfully to maximize yields and minimize energy consumption.

Dial In Flux Density - *Dimming* controls are relatively inexpensive compared to light fixture costs, and offer granular control of light levels. Dimming controls modulate light output to maintain PPFD at the plant canopy as it grows taller and save energy by using less power for lighting. In indoor vertical environments, dimming is often necessary to allow certain cannabis cultivars to grow closer to the lights than specified from the light plan. Balance productivity with efficiency by ramping down light output when plants are small, and raising light output as plants grow. *Dimming to transition between lights on and off can reduce peak loads on HVAC equipment and extend equipment lifetimes. Photoacclimation sequences of control can result in energy savings of 20% in some scenarios. Work with your utility to maximize financial incentives for dimming.*

Control to DLI Targets - When growing indoors, using dimming controls to reach DLI targets rather than PPFD targets can lower *peak electric demand,* since achieving constant DLI does not require having a constant PPFD. *DLI targets allow growers to lower the lighting power during peak hours and increase it during off-peak hours (as defined by local energy providers) to reduce overall energy costs. Utility energy efficiency programs can offer financial incentives for DLI controls.*

[5] Cannabis Cultivation Lighting Research Shows Shifts in Technology, Grower Practices, Cannabis Business Times, 2020

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

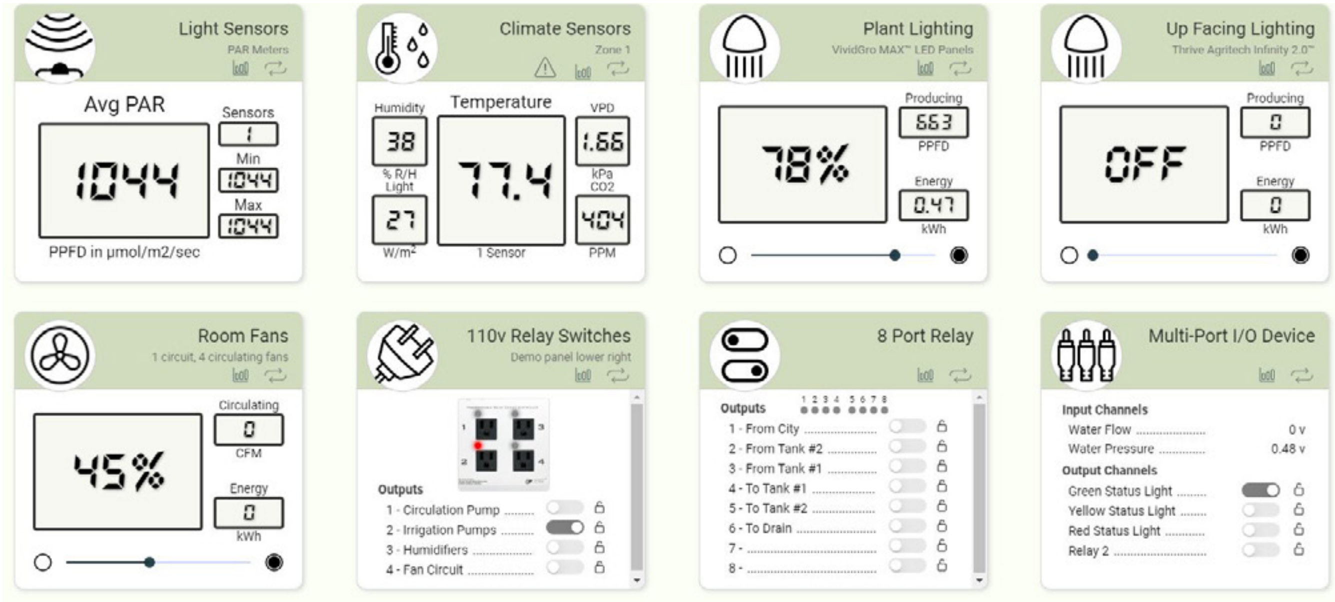
Lighting Controls	Vegetative	Flowering	Ranges of Controls Values
PPFD	Lower	Higher	300 - 1500+ µmols/m²/s
DLI	Less	More	20 - 42 mols/m²/day
Spectral Treatments (R:B ratio)	Higher	Lower	7 - 15%; higher blue for shorter plants
Far Red Treatments	More	Less	Used to manage shade avoidance

Schedule Dimming - With lighting controls, electric lighting solutions can automatically ramp up and down during daily photoperiod transitions and modulate light intensities. The ability to modulate light intensity is more important in greenhouses so they can respond to dynamic solar conditions and maintain PPFD. *Dimming controls for indoor operations can reduce operational expenses when used to match light output throughout stages of the plant growth cycle.*

Tune Spectra - Changing spectra not only affects outcomes for your plants, but also can use more red to use less energy. Some lighting systems offer spectral tuning and growers modulate diode output daily or in different stages of plant development. Spectral tuning can influence plant photoperiod and photomorphogenesis by adjusting red:blue (R:B) and red:far red ratio (R:FR); tuning controls are described more in **Table 4** above. *Utilities incentivizing lighting controls can pay growers for energy savings from spectral tuning.*

PHOTO: COURTESY OF GROWNETICS

[6] This cannabis steering table is provided for greenhouse cannabis cultivators courtesy of Martin Boerema and Colin Brice, Signify plant specialists.



AUTOMATE YOUR CLIMATE & AIRFLOW CONTROL SYSTEMS

Plants thrive in controlled environments with air and moisture managed to maintain target environmental conditions. When HVAC control systems perform, plant growth and development can be amplified.

OPTIMIZE YOUR CLIMATE CONTROLS SYSTEM DESIGN

HVAC control systems can be designed to manage the conditions of the air such as temperature and relative humidity to achieve vapor pressure differential (VPD) target ranges in a controlled cannabis cultivation operation.

Map Your Climate - Map your grow environments to determine horizontal and vertical distribution of sensors based on variability in room conditions. Sensing equipment placement can inform airflow distribution decisions to affect transpiration. Provide more than one sensor per room to sense, log data, and control. *Controls Working Group members recommend placing a sensor to cover an average of 500 canopy square feet (300 - 1,000 sq ft per sensor seen by RII Technical Advisory Council members in the field), but coverage depends on the purpose of the sensor and grow environment setup.*

PHOTO FROM TOP: COURTESY OF MICROCLIMATES; INSPIRE TRANSPIRATION SOLUTIONS

Monitor Which Points - Growers and facilities maintenance personnel are typically not data science experts. Trended historical data can quickly become overwhelming and useless for the people it intends to help. **Table 5** below describes popular climate and airflow data points collected by cannabis growers. *Don't try to go full bore out of the box because not every point will be important to your facility. Decide what climate and airflow data is most important to measure and optimize.*

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%

Choose VPD Targets - *Vapor pressure differential* (VPD) sensors do not exist; VPD values are calculated using *relative humidity* of the air in the space and leaf temperature. The VPD is then calculated assuming the plant is at 100% RH. **Figure 2** below illustrates a VPD calculation for plants in a room set to 78 F and 60% RH when leaf temperature is measured to be 78 F. Actual leaf temperature is greatly impacted by leaf water loss and how much light leaves reflect and absorb. This varies greatly by variety and a lot of other factors that are rarely measured. Two plant varieties growing in the same room right next to each other or two leaves of the same plant in different levels of canopy will have different VPDs. *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 and then dial in HVAC system automation to tailor VPD to your specific cultivars for your system.*

Adjusting Setpoints - You may need to change your environmental controls philosophy when changing the ways you perform other processes in your facility, for

Figure 2: VPD - The Differential Between Grow Room and Leaf Conditions

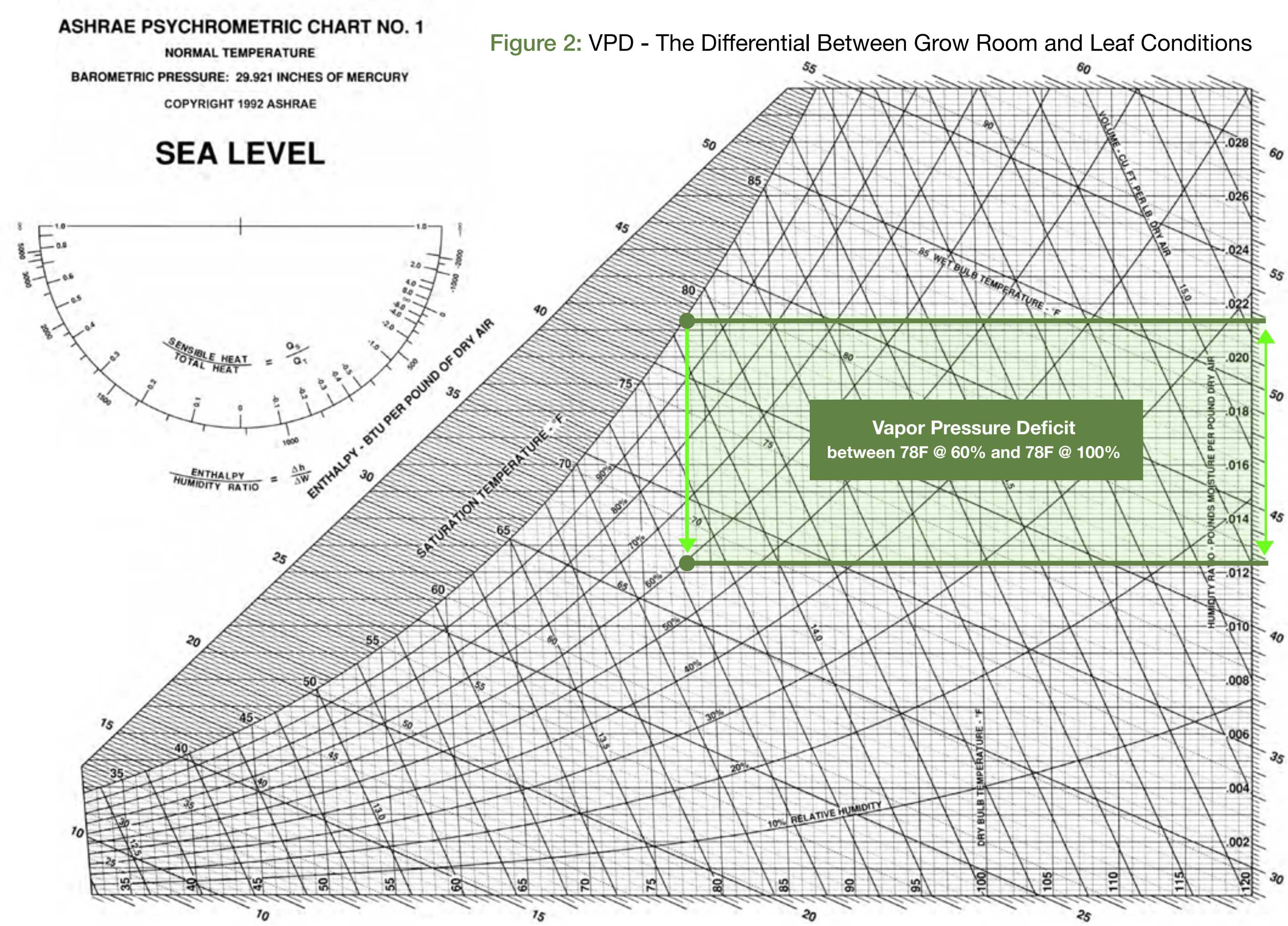


CHART: COURTESY OF DESERT AIRE AND ASHRAE

[7] Cannabis H2O: Water Use & Sustainability in Cultivation, RII, University of California Berkeley Cannabis Research Center & New Frontier Data, 2021

instance switching lighting system type. When moving to LED from a high-intensity discharge light fixture like HPS, lower heat output from LED fixtures means you can increase temperature setpoints while maintaining the same VPD targets (see **Table 6** below). *Consider increasing temperature setpoints during 'lights on' periods to use less cooling. You can save energy and money while keeping your plants happy with the same VPD target.*

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

Plan for Energy Recovery - Recovering energy that would otherwise get wasted can be a sustainable way to reduce energy consumption. Growers in some regions may also be required to avoid using new energy by using HVAC *energy recovery* equipment. All cultivators can reduce operating costs by using equipment like heat recovery chillers, hot gas *reheat,* or energy recovery wheels which recover energy via air or water (hydronic). How your HVAC system can implement your controls strategy depends on your climate. *Ensure your HVAC equipment has sufficient capacity during dynamic outdoor conditions. During design, describe how your HVAC equipment will recover energy so controls sequences of operation can accomplish energy recovery goals. Beware of comfort cooling controls that do not account for both temperature and humidity.*

PHOTO: COURTESY OF INSPIRE TRANSPIRATION SOLUTIONS

PURCHASE CLIMATE & AIRFLOW CONTROLS EQUIPMENT

Select HVAC controls that will accurately provide insights on plant health and energy performance.

Recover Energy - Some growers can use hot gas reheat, depending on HVAC system type. Some regions and ASHRAE guidelines require 75% of reheat energy *capacity* to come from recovered energy. *Hydronic systems with heat recovery chillers or combined heat and power (CHP) systems can provide site-recovered energy. You can also use water side economizers, which truly reduce run-time of compressors, producing chilled water without supplemental compressors. Controls for these systems are crucial to accomplish energy recovery goals.*

Sense Right - If you plan to use sensors for both monitoring and control, you need a minimum of three individual sensors to assess which piece of equipment is malfunctioning. By the time you see problems on your plants it is often too late. HVAC controls need sensors to provide signals we cannot see. *Work with your controls partners to purchase the right quantities and types of sensors because automation systems make choices for your critical HVAC systems that maintain plant health.*

Note Manufacturer Hardware -Sensors should be in aspirated boxes shielded from light. *Aspirated* boxes include a downstream fan to provide continuous air movement around the sensor and remove humidity accumulated from the grow environment. *Aspiration and shielding keeps radiation from affecting temperature and humidity readings.*

CONFIGURE CLIMATE & AIRFLOW CONTROLS EQUIPMENT

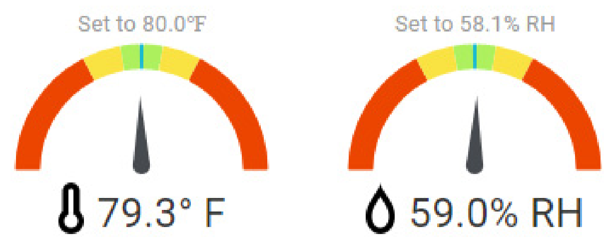
Set up your HVAC hardware to respond appropriately to sensed conditions.

Sense Conditions of Your Plants - When the crop grows, conditions change, and the way growers manipulate cultivars can alter canopy density and the ways sensors receive data. Ensure sensors are placed at the top of the plant canopy, not on the wall by the door. Consider intracanopy sensors to map microclimates at several levels. Group sensors together to gain insights on how to choose setpoints. For greenhouses, avoid placing climate and airflow sensors where they may be in direct sunlight or exposed to wind to avoid false readings. *Place environmental sensors at the top of the canopy or intra-canopy at spots of interest. Consider monitoring a few indicator plants to gather more points like leaf temperature and plant water and nutrient content.*

Weigh Carefully - Weigh values from sensors to influence your HVAC system setpoints. When measuring plant conditions, sense leaf temperature directly and get several measurements across three tiers of the canopy. *Decide how to weigh input from sensors to calculate average conditions that inform HVAC system responses; some growers control for their pickiest cultivars. VPD controls use an offset between space temperature to assume an average leaf temperature, or can use direct input from grower field measurements.*

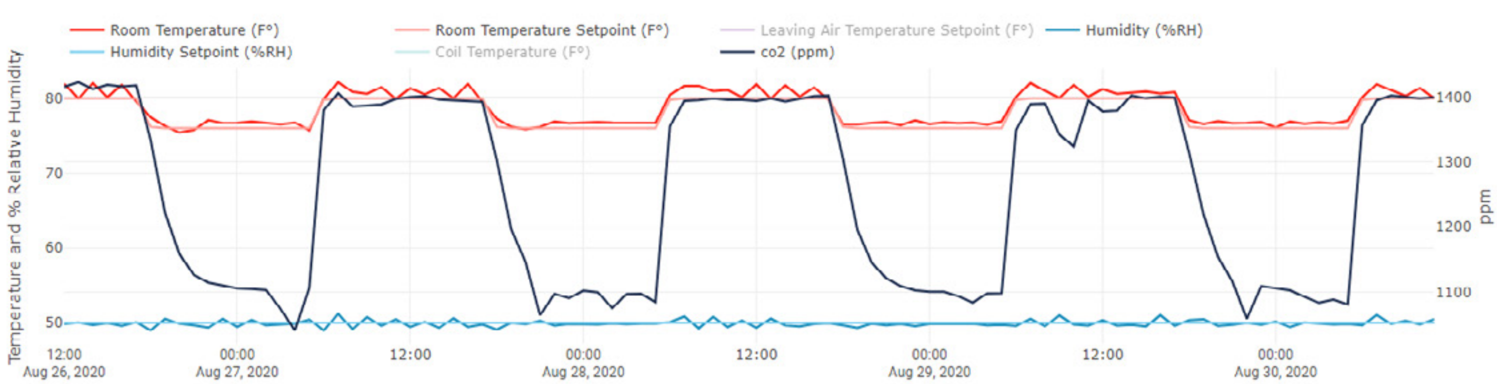
Resolution & Accuracy - Ensure that sensor resolution and accuracy of the equipment you are choosing fits your use case. Check the working range of the sensors. RH sensors for human comfort cooling controls usually have issues with the high-humidity growing environments. Read the fine print of specification sheets to understand your targets and the conditions the equipment will be in can set you up for success. *Sensors that are designed to detect small changes in a typical range of conditions often do not have the same levels of resolution at more extreme ends of their range.*

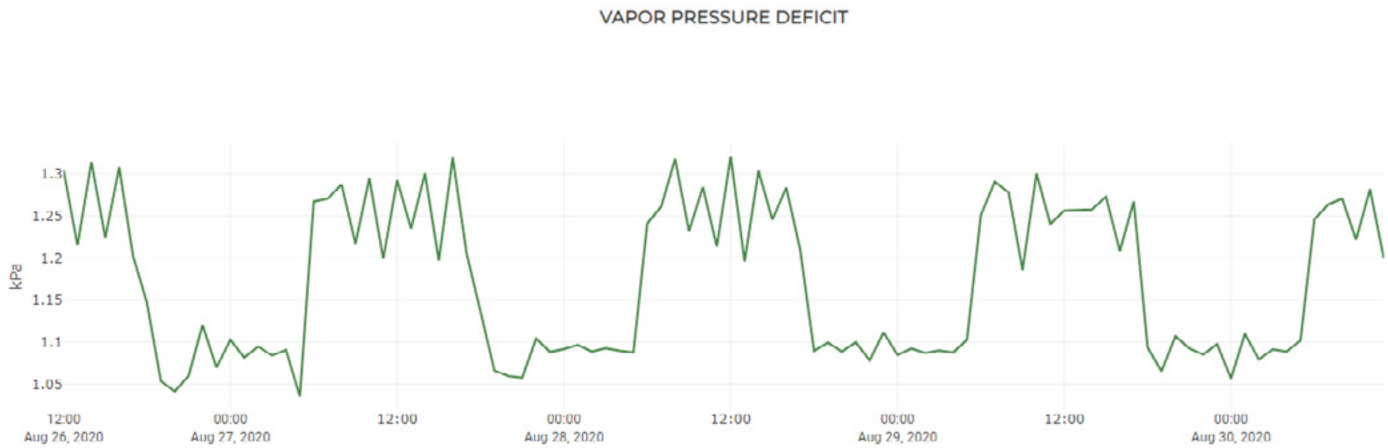
Calibrate - Sensors need to be maintained to achieve optimal environmental conditions. During *commissioning,* verify readings and calibrate sensors by comparing outputs with output from calibrated sensors that are otherwise stored and only used for the purpose of calibration. ASHRAE standard 90.1 requires new temperature sensors be calibrated for accuracy to ±2°F over the range of 40°F to 80°F. New humidity sensors should be accurate to ±5% over the range of 20% to 80% RH. *Calibrate sensors annually, as readings drift and lose accuracy over time. How deeply control and optimization can be accomplished depends on the controls manufacturer.*



Control for Supply Air - Once you know your *sensible and latent loads*, work with your project team to determine supply air volume needed to meet the capacities of the room load, driven by the latent and sensible load requirements of the rooms. *Refrigeration coil characteristics will influence required supply air volume setpoints, which can be described in air changes per hour (ACH). Controls Working Group members report sizing 10 to 20 ACH for cultivation, with some cases as high as 30 - 40 ACH. Consider reducing supply air volume setpoint during dark periods.*

PHOTO AND CHART: COURTESY OF INSPIRE TRANSPIRATION SOLUTIONS





OPERATE CLIMATE & AIRFLOW CONTROLS EQUIPMENT

Functionally performance test your equipment so critical systems maintain optimal environmental conditions and minimize operating costs.

Respond to Light and Water - Orchestrate your HVAC controls to call and respond to your lighting controls. When lights go off, humidity spikes, and controls can give your 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. *Cooling, heating, ventilation, and dehumidification equipment should monitor both lighting and irrigation controls activities for faster response times and happier plants.*

Maintain VPD - Improve yield by optimizing transpiration rates at the plant canopy. Keep VPD in target ranges by measuring leaf temperature at different levels of the canopy to inform targets like those in **Table 7** below. Implement Standard Operating Procedures (SOPs) to affect VPD by modulating temperature and RH in your grow rooms. *Greenhouse controls can be more complicated because they have to contend with more extreme variations in climatic conditions and solar radiation that are harder to predict.*

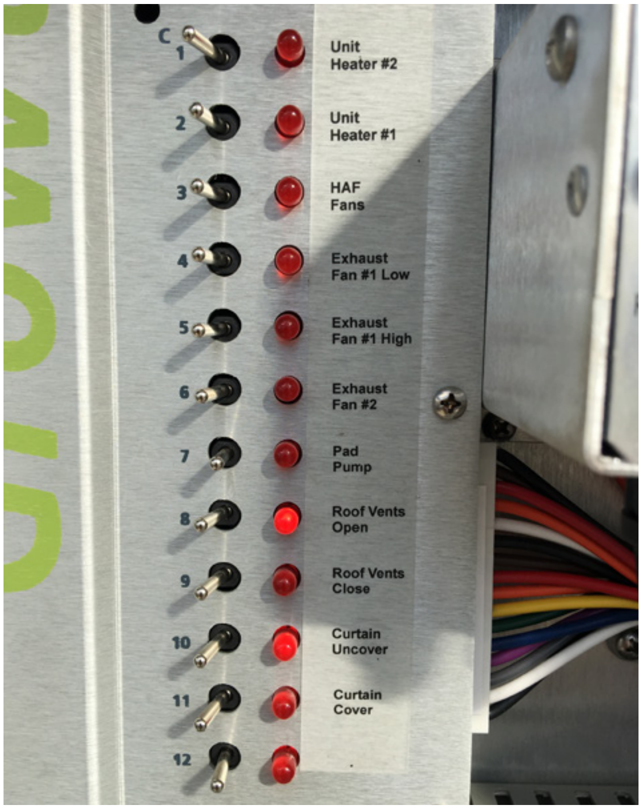
Table 7: Climate & Airflow Controls for Cannabis Steering by Stage of Plant Growth[8]

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

CHART: COURTESY OF INSPIRE TRANSPIRATION SOLUTIONS

[8] This cannabis steering table is provided for greenhouse cannabis cultivators courtesy of Martin Boerema and Colin Brice, Signify plant specialists.

Figure 3: Greenhouse Controller Climate & Airflow Controls



Greenhouse Effect - Daily and seasonal variation of the sun can quickly influence facility heat gain, plant photosynthetic rate, and transpiration rate at varying rates across the canopy in a greenhouse. Use smart controls that are purpose-built for greenhouses that can adapt to this variability and avoid microclimates **(see Figure 3 at left)**. Many flows of energy and water are interrelated and influence each other. The presence of plants dramatically affects greenhouse microclimates and controls necessary to maintain optimal conditions. *Environmental control systems that can forecast solar conditions and analyze factors like solar heat gain are essential for minimizing upfront cost and energy usage of greenhouse HVAC systems.*

Empower Plants to Save Energy - For greenhouses, plant empowerment principles suggest keeping a uniform ratio of average temperature to DLI to keep plants in good balance and can reduce energy consumption. On days with high sunlight, allow the temperature to climb to reduce cooling requirements. Optimize growth by supplementing CO_2 in balance with light levels and environmental conditions. *To reduce operational expenses, prioritize CO_2 enrichment while keeping temperature and DLI in balance.*

PHOTOS: COURTESY OF ROB EDDY

PHOTO: COURTESY OF SILVER BULLET WATER TREATMENT

AUTOMATE YOUR WATER CONTROLS SYSTEM OPTIONS

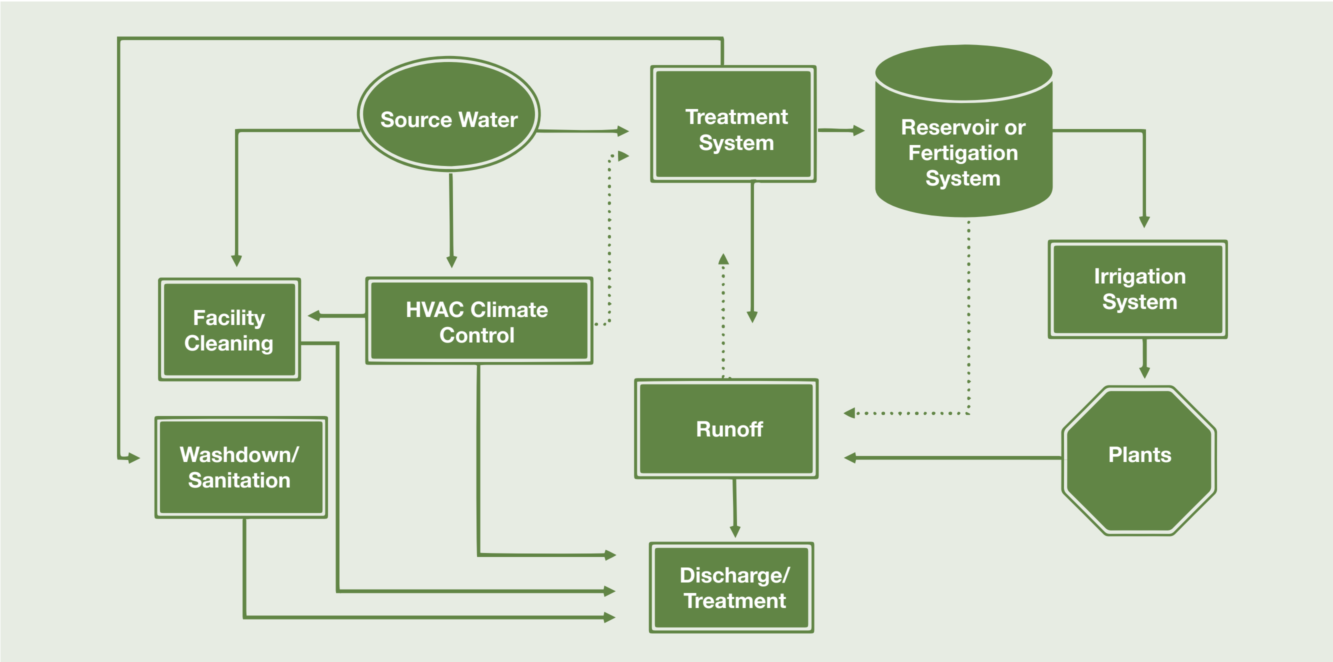
Make a closed loop with an effective water management system that maximizes plant production with a perfect fertigation mix while recapturing and reusing water to maximize efficiency.

OPTIMIZE YOUR WATER CONTROLS SYSTEM DESIGN

Several processes in your facility can be designed to manage water treatment and minimize use of source water.

Understand Leach - Different *substrates* have higher water-holding capacity and also vary by *leachate percentage.* Depending on watering techniques used, 25% of irrigation water may drain through substrate and become runoff water. Substrates such as peat or coir contain carbon and tend to produce an organic-laden leachate. Because rock wool is a naturally mined product, it may contain naturally occurring metalloids and introduce chemicals into leachate. *Choose substrates with lower leach percentage to manage less runoff. Lower leach may be achieved with water culture approaches that recirculate irrigated water.*

Figure 4: Processes Managed by Water Controls Systems



Test and Treat - Before any water is used for plant cultivation, analyze your source water. **Figure 4** above illustrates the inputs and outputs of water treatment systems for cannabis cultivation and where treated water is used in your facility. *Track parameters like those shown in **Table 8** at right as well as heavy metals, inorganics, and nutrients coming into your treatment system. Also check on bicarbonate content, otherwise pH control can be a serious challenge. Especially look out for high Na levels, which in higher concentrations can prohibit growth. Growers may treat source water using reverse osmosis (RO) or carbon filtration processes. Reverse osmosis is not often required.*

Irrigate Thoughtfully - Different irrigation system types offer centralization and automation. Determine your desired *watering rates* by stage of cultivation so you can map your targets to data gathered by your sensing equipment. *Fully automated inline injection systems, and semi-automated systems with timed doses improve on batch mixing and hand watering which offer no automation or centralized control. Watering events can range from 1 - 20 per day depending on your choice of substrate[9].*

Consider Recapture and Reuse - The dotted lines in Figure 4 represent opportunities for water *recapture and reuse* from irrigation and HVAC systems. Every facility is a bit different with varying microbial loads and water quality. Cannabis is a *bio-accumulator* and growers must ensure heavy metals in HVAC condensate are removed before reuse. Runoff water must also be treated to manage leachate and disinfect before reuse. Growers can use blend tanks for source water, recaptured condensate, and runoff water. *Save considerable operational expenses by reducing use of source water.*

Table 8: Water Controls Parameters Measured by Cannabis Cultivators

Water Data Collected	Percentage of Growers Collecting, 2020
Nutrient solution pH	76%
Substrate pH	54%
Nutrient solution electrical conductivity (EC)	51%
Media EC	38%
Root zone temperature	21%

PURCHASE YOUR WATER CONTROLS SYSTEM

Install the infrastructure necessary to manage facility water and for reclamation processes.

Store and Test Reclaimed Condensate - Reclaimed condensate from HVAC systems can often provide more than 50% of daily irrigation water capacity, but

CHART: COURTESY OF SILVER BULLET WATER TREATMENT

[9] Cannabis H2O: Water Use & Sustainability in Cultivation, RII, University of California Berkeley Cannabis Research Center & New Frontier Data, 2021
[10] Cannabis Cultivation Lighting Research Shows Shifts in Technology, Grower Practices, Cannabis Business Times, 2020

you need to reserve space for water storage tanks. For space constrained operations, installing the tanks can be an issue, especially when being added to an already existing facility. Newly built facilities or existing facilities with room to expand can add water storage capacity relatively cheaply and easily. *Regularly test and process stored condensate water for microbiological and heavy metal contamination to ensure that condensate does not introduce adulterants to the growing environment.*

Select Sensors - Determine what data is audited by external organizations and map to your required sensor array to support data collection. All sensors interacting with water should be rated for use in wet locations and vapor-tight. *Sensors for measuring pH and EC come with calibration liquids; keep these and use them to maintain reliable readings.*

CONFIGURE YOUR WATER CONTROLS SYSTEM

Determine how irrigation water will be mixed with nutrients to fertigate plants and how other controls systems interact with your water management system.

Blend or Dilute - Decide how water will be mixed to achieve your desired fertigation solution. Some cannabis growers reduce the high cost of using RO water as the sole source of irrigation water by diluting RO water with municipal or ground water at 2:1 or 3:1 mixed with recovered HVAC condensate to use RO systems less and avoid rejecting RO wastewater. *Consider how source water might be mixed with treated reclaimed condensate and/or runoff water to rebalance pH and nutrients.*

Set Up Irrigation - Water management systems help you track soil moisture, conductivity of media, root zone temperature, and other key inputs to inform your watering processes. Consult recommended irrigation controls in **Table 9** below and implement your schedule per your target watering rates and configure your root zone sensors to verify your controls are executing properly. *Consider having your HVAC and lighting equipment monitored by your water management system so it can control based on water losses and gains from these interactive systems.*

OPERATE YOUR WATER CONTROLS SYSTEM

Irrigate plants efficiently to minimize water use while monitoring conditions to maximize plant health.

Evaluate Effectiveness - Take microbial and heavy metals samples weekly and have third party lab certify results if possible. Conduct testing at regular intervals on both input and outputs of your treatment system. *Conduct pre-post analysis to show that microbiological levels have been reduced to inform and continuously improve treatment processes.*

Drip Irrigation - Researchers have shown that the efficiency of drip irrigation systems can be further enhanced through the use of substrate and ambient environment sensors which monitor each the moisture content, temperature, humidity, and electrical conductivity of the cultivation environment in real time, and can automatically start and stop irrigation whenever conditions reach pre-programmed parameters. *Precise targeting of drip irrigation can reduce water consumption by 30% to 70%, and improve water productivity by 20% to 90%.*

Table 9: Water Controls for Cannabis Steering by Stage of Plant Growth

Watering Controls	Vegetative	Flowering	Ranges of Controls Values
EC Growing Medium	Decrease	Increase	1.8 - 4.5 EC
EC Irrigation Water	Decrease	Increase	2 - 2.8 EC
Substrate Water Content	Increase	Decrease	45 - 65%
Day-Night Water Content Decrease	Decrease	Increase	2 - 10% (5 - 15% with rock wool)
Irrigation Cycle Length and Frequency	Short & Higher	Long & Lower	50 - 150 ml per dripper
Start Time First Irrigation	Earlier	Later	1-3 hours after sunrise/lights on
Stop Time Last Irrigation	Later	Earlier	3-5 hours before sunset/lights off

[11] This cannabis steering table is provided for greenhouse cannabis cultivators courtesy of Martin Boerema and Colin Brice, Signify plant specialists.

Micro-Pulse Irrigation - Emerging technologies using sensor-based systems can deliver steady micropulses of water to each plant. *Researchers have found that the use of microbursts of water or nutrient solution are far more water-efficient than even drip irrigation methods which tend to saturate the grow medium, resulting in higher levels of runoff.*

Keep DWC Clean - When using *deep water culture* (DWC) approaches, well managed hydroponic systems can be purpose-built to reclaim and reuse water, but also run the risk of microbial or pathogen outbreaks and oxygen depletion. *Many DWC and aeroponic installations have large groupings of plants with root zones directly connected via piping and the nutrient stream. Test and actively manage fertigation water to avoid extensive disease outbreaks and substantial crop loss.*

Using Stored Water - Monitor conditions of stored water and track its use. If tanks are free-standing they are more susceptible to temperature changes and stored water may need to be *tempered* with treated source water to achieve desired water temperature. *Ensure stored water is treated properly and flushed as required to maintain water quality. Measure cultivation water use separately to determine water efficiency performance.*

RESOURCE INNOVATION INSTITUTE

To learn more about water management systems, check out Cannabis H2O: Water Use & Sustainability in Cultivation, this report explores ways that water is used by cannabis growers, establishes key benchmarks for water use across different types of facilities, identifies innovations that are driving greater water-use efficiency, and offers strategic recommendations for producers and regulators to advance water-use efficiency throughout the industry.

[Cannabis H2O: Water Use & Sustainability in Cultivation]

PHOTO: COURTESY OF GRO IQ / INFISENSE

INTEGRATING CONTROLS SYSTEMS

Plants and their surrounding environment need to work in harmony for optimized growth. Integrated systems in your facility coordinate and automate their performance to optimize plant production, reduce labor costs, and increase yields.

AUTOMATE YOUR POWER CONTROLS SYSTEM

Power management systems coordinate energy sources to drive processes optimizing your facility for plant production and efficient operation.

Increase Resilience and Reliability - Power management systems reduce facility vulnerability for small and large operations alike and can be financed in a service model. *Use power management systems to optimize building system operation and decide where your power comes from at different times of day to avoid peak demand rates. Partner with your utility to manage demand and receive financial incentives.*

Submeter Usage - Monitor power usage to understand vital information about facility efficiency. Keep an eye on mission-critical systems and those that use a lot of energy like lighting and HVAC systems. Decide what level to meter; consider sub-metering each room. *Submeter rooms by function and mode of control to understand where your power is going. If you have many similar rooms (like flowering rooms), submeter a sample of them to get a good snapshot.*

Consider Energy Mix - As you monitor and automate processes at a granular level you can plan your energy usage to flexibly use different sources of energy to save money and reduce your environmental footprint. The right mix of energy depends on your utility rates, your level of desired flexibility and resilience, and processes happening in your facility. *Microgrids* offer independence from the grid using a variety of energy sources such as natural gas combined heat and power (CHP) and renewable energy sources like solar. Choose when your energy comes from your microgrid or the utility grid. *Use power controls to select energy sources that adapt to regulations or utility landscape issues in your region. You can rely upon these systems to deploy backup power as needed and at minimal impact to your plants and energy bills.*

Benefit from Backup Power - Test battery storage and power supply system failure modes to understand how they fail and what they stop providing to your mission-critical lighting, HVAC, and water systems and how backup power responds to save your crops. If using battery storage, you can generate revenue selling power back to the grid. *Intelligently respond to changes in energy supply and demand using power management systems.*

AUTOMATE YOUR INTEGRATED FACILITY SYSTEMS

Conduct your systems from a centralized platform to conduct your lighting, HVAC, and water systems and processes in concert.

Know Who's the Boss - Some environmental controls will be in your hands, and some will be managed by *packaged controls.* Most lighting and HVAC systems can follow communication protocols to transfer data between your *environmental control system* and system equipment. *Use your environmental control system to send setpoints to packaged controls. Your environmental controls can monitor and respond to the outputs of packaged controls so you can trust your purpose-built systems and allow internal control logic and safeties to be controlled by the manufacturer.*

Retrofit Controls - Understand what controls products, devices, and model numbers you have and how they currently control your systems. Integration may be very expensive if you try to keep every original system. Some

PHOTO ON PREVIOUS PAGE: COURTESY OF TSRGROW older controllers can be retrofitted, but some things are better to purchase new technology that offers improved accuracy and new features. *Prioritize what is most important to integrate and evaluate what software is needed to talk to your various hardware.*

Connect Your Systems - Innovative growers integrate controls together, orchestrating their environmental control systems in concert with each other. Eliminate employees walking, turning dials, flipping switches, and managing schedules to give growers more time with plants and data. Automation also enhances and ensures plant health and vitality. *Greenhouse facilities have different priorities and key systems to integrate, including glazing systems and unique types of HVAC systems that present special integration challenges. Control system upgrades can pay for themselves by saving energy, maintaining consistent environmental conditions. Automation frees up growers to scout for pests and diseases that may have gone unnoticed, which can improve crop quality, minimize crop degradation, prevent crop loss and increase your facility's productivity.*

Unify Control - Empower your facility with a single software interface and reduce the number of controllers to manage all processes in your facility. You can implement standard operating procedures using control panels where growers can monitor and fine-tune systems in real-time. Create closed-loop islands of control that share information with a central environmental control system to use open protocols like *Application Programming Interfaces (API)* to exchange information and unite data at a headend controller to monitor all of your islands and route alarms through one secure system. *Unified controllers present your data in a normalized fashion and store trended historical information in a centralized database. Benefit from labor reduction costs, mitigate risks associated with the use of multi-control systems, harmonize data across systems, and make data-driven decisions.*

Consider Interoperable Systems - Partner with vendors who make it easy to integrate hardware and software and build their equipment to enable data integration through open API so you can add your own automated sequences. Understand how reputable the controls system manufacturer is, the longevity of their company, and their customer support. *Ask your vendors questions about their open or closed philosophy and work with those who will make things easier. Partner with vendors that share detailed technical data and are accessible and knowledgeable experts about integration.*

Partner with Integrators - System integrators unify systems together that don't usually talk to each other and work together. Their independent software connects systems, gets them to communicate, and controls and automates lighting, climate and airflow, and water management processes. Work with a strong integrator to take accountability for any issues during post-installation. *Consider directly hiring a Master Systems Integrator early in your controls project to work with your engineering and architecture team. Efficiency programs may offer rebates for systems integrators to centralize data and save energy.*

Avoid Translation - Check what communication protocols your systems use and compatibility to avoid expensive translation protocols. It is ideal to minimize handshakes between systems. More handshakes means more openings for incompatibility and conversion errors. *Use common platforms to integrate power and data management systems.*

Close Loops - Create feedback loops between your sensors. Install closed loop sensors in similar places to record lighting, climate, moisture, and airflow data in the same spots. *Inputs that drive outputs should connect to systems directly by commanding setpoints to control systems. Integrated systems talk and share output data to inform other systems to create closed loops.*

Trend Data - Unified controllers collect actual facility data that can benefit your business. Choose which data to gather and save, and which analysis to routinely perform to evaluate your performance. *Trended information can be used by internal teams to improve production. Facility energy performance data can be shared with external partners like utilities and energy efficiency programs to demonstrate energy savings and receive financial incentives.*

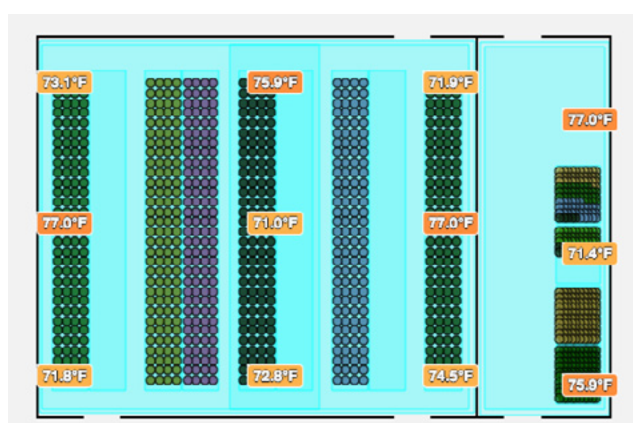


PHOTO: COURTESY OF COURTESY OF GROWNETICS

GROWER STORY

Cannabis growers are succeeding through integrated controls systems. According to ***Daniel Vlad, CTO of Artizen Cannabis*** *located in Washington state, "The environment control system we have deployed in one of our dry rooms manages the entire environment from a single 'brain,' hence eliminating environment bouncing and providing the ability to set control dependencies between the various monitored parameters. This centralized approach is further enhanced by a well-thought-out user experience design, flexible program configuration, monitoring alert system, mobile access, and the ability to implement controller redundancy. This implementation has helped improve the environment's stability, saved countless hours of management time, and helped save energy. We are looking forward to expanding this system to other areas of our flagship indoor grow facility".*

AUTOMATE YOUR DATA ANALYSIS

Use data to generate reports to review alerts, insights, and recommendations for improved facility performance using diagnostic software.

Start Small - Integrated controls systems and analytics software can help a cultivator, no matter the size of the grow facility. Often the most successful projects start simply with just a few data points. Over time the analytics software is built up through interaction between cultivators and service providers. *Through curiosity and insight provided by automation and fault detection, you can grow your controls strategy, benefit from analytics, and reap a more productive harvest.*

Know Your Grow - Monitor before you control or automate. Gain confidence with your data first; become comfortable with using it and confident in its accuracy. Verify your data is good before you start controlling and automating. Research your existing equipment and its sequence of operations to orchestrate in harmony. *Prioritize the systems you automate first. How will your control philosophy evolve? Which systems will you monitor, and what will you control?*

Figure 5: Dashboard of Trended Facility Data

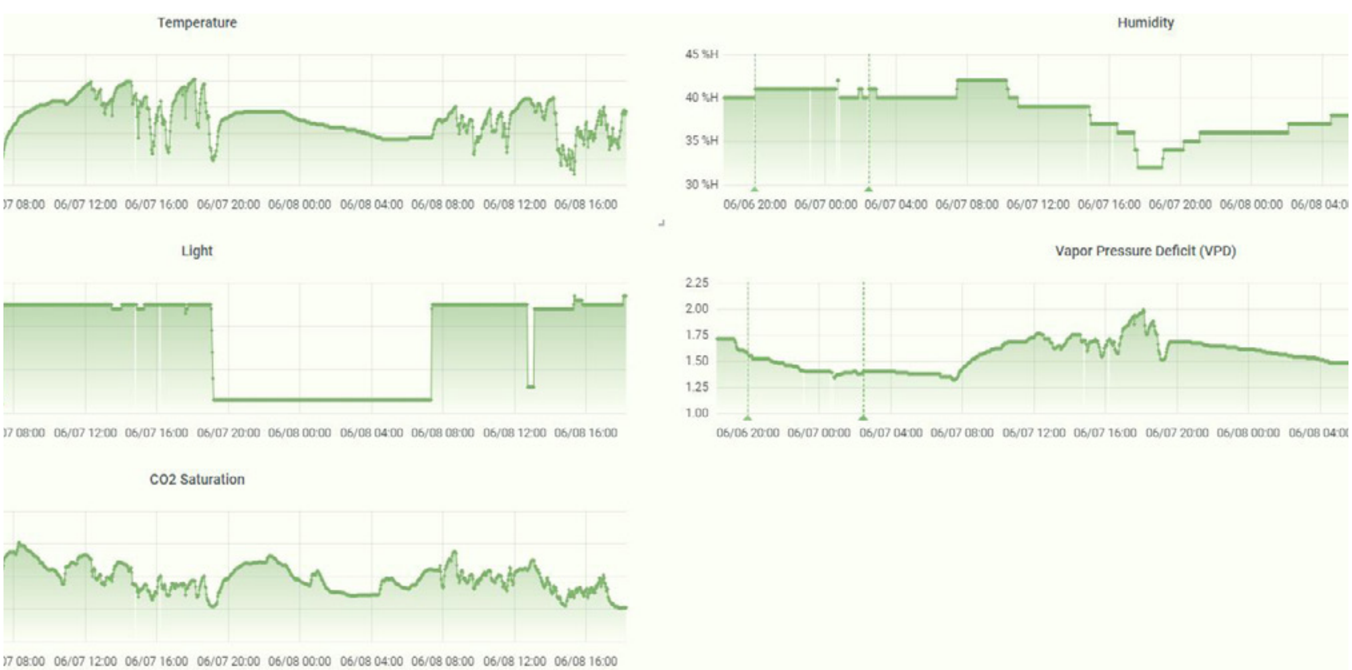


CHART: COURTESY OF MICROCLIMATES

Automate Analytics - Control systems typically contain hundreds of sensors measuring various conditions and collecting data at regular intervals to track historical trends. **Figure 5** on the previous page shows how a typical control system can generate tens of thousands of data points from a cultivation facility every single day. Data can quickly become overwhelming and useless for the people it intends to help. *Software tools on the market today can relieve the burden of data analysis from the grower and can prioritize alarms by importance. Analytics software changes data into actionable information. Fault Detection and Diagnostics (FDD) software analyzes data from control systems and presents clear and actionable insights to growers in a user-friendly way.*

Flag Problems - Most control systems generate alarms when certain conditions are out of range. However, cultivation facilities rely on precise control, and too often, alarms occur when it is too late, and issues have become an emergency. Augment human vision with data from sensors and proactive trend analysis. Analytics software detects problems in the system well before reaching an emergency alarm state by searching for patterns in control system data and alerting the user when conditions begin slipping away from the norm. *Take action using your FDD software's recommended resolutions to fix issues.*

Reduce Labor - A well-built integrated controls system with analytics software reduces the amount of time a cultivator spends managing environmental conditions and identifying issues in a facility. Have a dedicated facility manager on staff to perform preventative maintenance. *Focus your facilities personnel and contractors on detecting slips in performance before issues become too large to truly optimize performance.*

Quantify Yield Increases - When production and chemistry data are integrated into analytics software and paired with environmental, lighting, and irrigation data, a grower becomes empowered to explore ways of tweaking facility performance to optimize yields. *Measuring changes in environmental conditions and correlating that data to yield is a powerful way to leverage control system data for increased crop production.*

Share Data with Your Team - Make data analysis a step in your operation's production cycle. Have a data review cycle for each grow room at the end of each harvest to understand performance information. Set your baseline and catch when your yields don't meet expectations faster. *Meet on a monthly basis to proactively build a culture around data that integrates your controls and information systems with the day to day interactions of staff with the facility.*

Build Trust - Data enhances your understanding of your facility and improves your skills and augments your team's observations and expertise. Avoid confusion years down the line by documenting the source of data. Help teams trust reported insights by clearly presenting where data comes from and how calculations are performed. *Understanding the controls and monitoring systems is fundamental to trusting automated controls and analysis platforms.*

Transfer Data - Make it easy to transfer facility performance information to external partners like efficiency program staff so they can understand energy savings of controls strategies. Raw data from your environmental control system may be too granular for third parties to provide value to your operation. *Understand what format is compatible with your partners so you can maximize the benefits of working with them and minimize time required to gather data. Utilities often verify savings using spreadsheets and will let you know what trended data they need to give you financial incentives.*

Store Data - Be resilient and avoid lost or overwritten data by backing up your trended information regularly. Determine how long you want to store your historical logs of lighting, HVAC, and water trends; multiple years of data allow you to make year-over-year comparisons. Some growers store data redundantly both on- and off-site, keeping records for two weeks before replicating them in the cloud or to an external hard drive. Be prepared for reporting data to regulators or partners like utilities and energy efficiency programs. *Cloud storage can protect you from data loss from power outages or systems going offline by copying it off-site.*

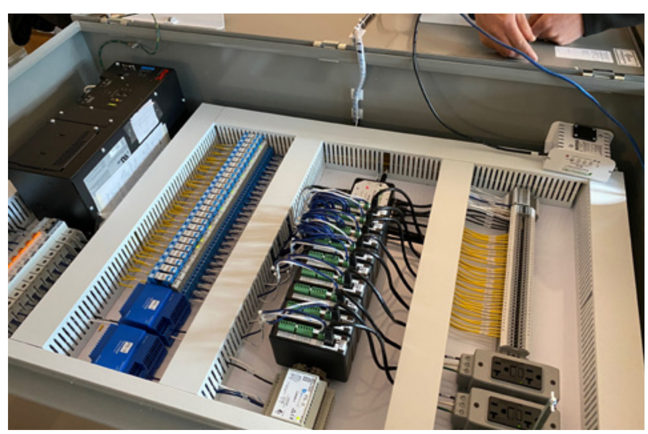


PHOTO: COURTESY OF ZARTARIAN ENGINEERING

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