SPECIAL REPORT

STATE OF THE CANNABIS LIGHTING MARKET

SIX YEARS OF RESEARCH

IN PARTNERSHIP WITH

FLUENCE BY OSRAM

CANNABIS BUSINESS TIMES

THE UNIQUE CHALLENGE OF HORTICULTURAL LIGHTING

When I joined Fluence as CEO in 2018, I was entering the horticulture lighting market after more than 20 years in the broader LED industry. At the time, I considered my knowledge of LED technology robust and certainly sufficient to help grow Fluence into the company it is today. But after spending the majority of my first year visiting cultivators around the globe, I learned one very crucial fact: Horticulture lighting is unlike any other lighting category in the world.

Illuminating an indoor cannabis grow or a commercial tomato greenhouse with a highly optimized lighting strategy requires the same level of intricate knowledge the world's foremost cultivators intrinsically apply across all other areas of their operations. In general, street, stadium and office lighting applications don't require considering the interconnectedness of lighting with other environmental parameters to affect living organisms.

In short, growers are essential to the world's livelihood. Their centuries-long legacies growing, producing and delivering food and medicine to the world's population has informed and paved the way for complex, intricate scientific ventures. And cultivators are hungry for more knowledge. They want to understand how to grow bigger and faster, and how to cultivate better plants with smaller and smaller margins. They want to bring produce and medicine closer to their consumers and do so in an energy efficient way. And as the global population continues to boom—bringing with it a massive increase in food demand—cultivators are evaluating the efficacy of indoor growing environments located in more urban areas. Investors are taking note, too. AgFunder's 2021 AgriFoodTech Investment Report reported a 34.5% year-over-year increase in foodtech and agtech investments. Fluence's market models show investment in LED technology for vertical farming alone will increase by more than 477% by 2025.

In recent years, not only have we observed the meteoric rise in LED adoption, but cannabis cultivators in particular are realizing the benefits of LED lighting strategies at each stage of plant production. As reflected in this year's "State of the Cannabis Lighting Market" report, produced by *Cannabis Business Times* with support from Fluence, LED usage for cannabis cultivation grew by at least 45 percentage points in all stages of growth compared to results from the 2016 report.

2020 was also a landmark year for cannabis legalization, driving an increase in demand for high-quality cannabis products—with recreational and medical cannabis sales expected to grow by 21% through 2025—as well as industry-wide cultivation standards. As this year's "State of the Cannabis Lighting Market" report indicates, cultivators have spoken. LEDs are unequivocally the gold standard for cannabis cultivation.

At Fluence, we are led by science in our exploration of the interaction between light and life to yield a healthier, more sustainable world. In addition to this report, we recently announced results from our multiyear, global research initiative studying the effects of broad-spectrum lighting strategies on cannabis and food crops. In partnership with our network of global cultivators, we will continue to research and discover just how far LED lighting can go in shaping and impacting the world's crops.

> I LEARNED ONE VERY CRUCIAL FACT: HORTICULTURE LIGHTING IS **UNLIKE ANY OTHER LIGHTING CATEGORY IN THE WORLD.**

To helping the world grow smarter, together,

DAVID COHEN,
CEO, Fluence by OSRAM

PHOTO COURTESY OF FLUENCE BY OSRAM

SHINE A LIGHT

OVER THE YEARS, *Cannabis Business Times* has published articles emphasizing the importance of data collection and analysis in building strong, forward-thinking businesses. Both innovation and experimentation are limited without the capability to conduct an objective assessment. That also is why *CBT* has conducted research studies and published reports like this "State of the Cannabis Lighting Market" report, now in its sixth year. While comparing data against past results can lead to new findings, being able to benchmark your operation against industry peers can reveal potential—and missed—opportunities. You can read more about the importance of data tracking in the feature on p. S12.

In this year's "State of the Cannabis Lighting Market" report, made possible with support from Fluence by OSRAM, *CBT* continues to delve into the cannabis industry's lighting use, a key driver of both production and financial efficiency. This year's study, conducted with leading third-party research organization Readex Research, asked cannabis cultivators about lighting types used at various growth stages, their plans for LED adoption in flowering (and what is preventing them from making the switch), growing with vertical racking systems, and more.

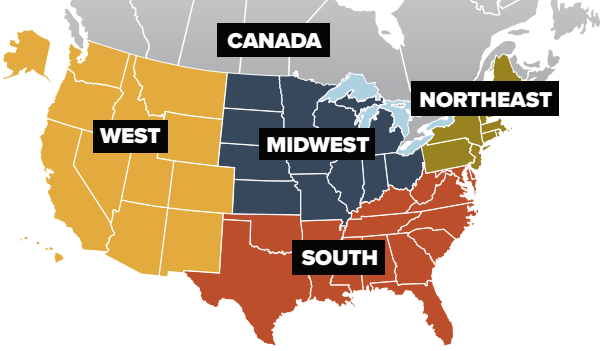
Among other findings and trends, this year's data shows the continued growth of LED adoption across all plant stages. For the first time since this report first launched, more than 60% of growers who answered the questionnaire indicated using LED fixtures across all growth stages. In 2016, LEDs were in use by no more than 21% of growers across all growth stages.

One potential explanation behind what is driving this surge in LED fixture adoption is the ability to customize light output (in certain models). Both university researchers and experimentally minded cultivators have been investigating the impacts of various spectra and intensities on cannabis production. Mitchell Westmoreland, Utah State University researcher, and Jason Sanders, head of cultivation at Texas Original Compassionate Cultivation, explore their findings in the feature on p. S9.

With the industry continuing to turn to LED fixtures, opportunities to leverage cubic square footage through vertical systems has become more appealing. The feature on p. S14 offers tips and best practices from Fog City Farms and Proper Cannabis for those who have added vertical farming to their operations and those considering doing so. Building on the experience of others can be a good way to navigate the potential pitfalls and mistakes that can occur with any change in production methods.

GEOGRAPHIC DISTRIBUTION
OF RESEARCH PARTICIPANTS

(participants could select multiple regions for operations with more than one location)



In what regions does your cannabis cultivation business currently operate?

38% **17%** **6%** **32%** **10%** Other: 4%

ABOUT THE RESEARCH & PARTICIPANTS

Readex Research conducted the study and compiled the data for the 2021 "State of the Cannabis Lighting Market" report. The questionnaire was sent to *Cannabis Business Times* magazine subscribers with known email addresses and/or e-newsletter subscribers located in the United States, Canada, or other (unknown) North American locations in June and July 2021. Results are based on 156 participants who own or work for an operation that cultivates cannabis indoors and/or in greenhouses with supplemental lighting, unless otherwise indicated. Unless otherwise noted, cultivators who grow outdoors, in greenhouses without supplemental lighting, or grow as a hobby, were excluded from the results. The margin of error for percentages based on the 156 respondents who indicated they own or work for a cultivation operation that grows cannabis in an indoor facility and/or greenhouse with supplemental lighting is approximately ±7.8 percentage points at the 95% confidence level.

LED ADOPTION **CONTINUES TO SURGE**

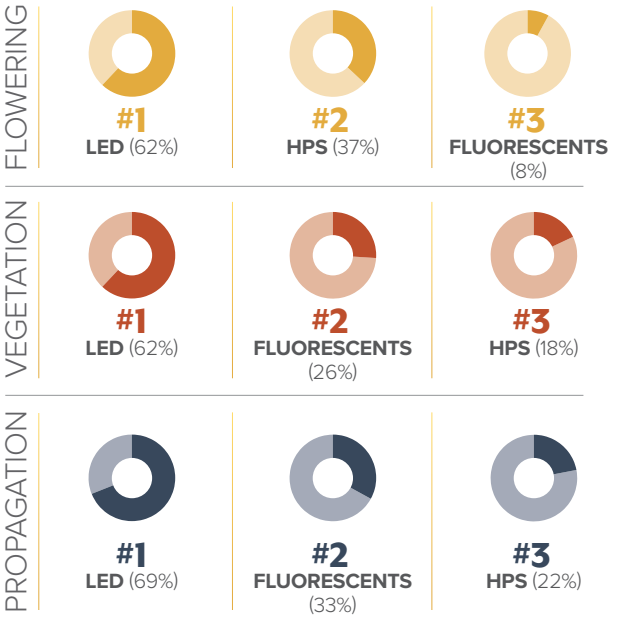
One of the most consistent trends noticed in the historical data of *Cannabis Business Times'* "State of the Cannabis Lighting Market" report is the continued adoption of light-emitting diode (LED) fixtures across all stages of plant growth. In the 2021 report, LED usage grew by at least 45 percentage points in all stages of growth compared to 2016 results.

In this year's research, 69% of participants noted using LEDs during propagation, compared to 33% who use fluorescent lights, 22% who use high-pressure sodium (HPS) fixtures, and 13% who use metal halide (MH) lights. (Nine percent indicated that they use a lighting type not listed in this year's survey.)

In vegetation, 62% of research participants indicated using LEDs, by far the most-used lighting type in this year's study. Fluorescents were the second most-used lighting type (26%), followed by HPS (18%) and MH (17%).

In flowering, 62% of growers who participated in the study indicated employing LEDs, up from 15% in 2016's report and 52% in 2020. HPS fixtures are used by more than a third of participants (37%), while fluorescents and MH lights are used by less than a tenth of cultivators (8% and 6%, respectively).

TOP 3 LIGHTING TYPES



TYPES OF LIGHTING USED – PROPAGATION

	2016	2021	% point change vs. 2016
T5 (high output/HO) lights (or other HO fluorescents)	65%	33%*	↓ 32% pts.
compact fluorescent lights	9%	N/A	N/A
light emitting diodes (LEDs)	21%	69%	↑ 48% pts.
high-pressure sodium (HPS) lights (including double-ended)	16%	22%	↑ 6% pts.
metal halide (MH) lights all	N/A	13%**	N/A
metal halide (MH) lights — ceramic	10%	N/A	N/A
metal halide (MH) lights — quartz	6%	N/A	N/A
other	6%	9%	↑ 3% pts.

*Total exceeds 100% because participants could select all that apply. *Includes compact fluorescents. **Includes all MH lighting types*

TYPES OF LIGHTING USED – VEGETATION

	2016	2021	% point change 2016 vs. 2021
T5 (high output/HO) lights (or other HO fluorescents)	37%	26%*	↓ 11% pts.
high-pressure sodium (HPS) lights (including double-ended)	31%	18%	↓ 13% pts.
metal halide (MH) lights — all	N/A	17%**	N/A
metal halide (MH) lights — quartz	23%	N/A	N/A
metal halide (MH) lights — ceramic	20%	N/A	N/A
light emitting diodes (LEDs)	17%	62%	↑ 45% pts.
other	8%	9%	↑ 1% pt.

*Total exceeds 100% because participants could select all that apply. *Includes compact fluorescents. **Includes all MH lighting types*

TYPES OF LIGHTING USED – FLOWERING

	2016	2021	% point change 2021 vs. 2016
high-pressure sodium (HPS) lights (including double-ended)	62%	37%	↓ 25% pts.
light emitting diodes (LEDs)	15%	62%	↑ 47% pts.
T5 (high output/HO) lights (or other HO fluorescents)	8%	8%*	0% pts.
metal halide (MH) lights — all	N/A	6%**	N/A
metal halide (MH) lights — ceramic	7%	N/A	N/A
metal halide (MH) lights — quartz	5%	N/A	N/A
other	5%	7%	↑ 2% pts

*Total exceeds 100% because participants could select all that apply. *Includes compact fluorescents. **Includes all MH lighting types*

INDUSTRY CONTINUES **ITS UPWARD GROWTH**

According (and potentially driving) this surge in LED adoption is the increasing implementation of vertical racks. These systems allow cultivators to use their facility's cubic footage instead of limiting cultivation activities to the floor space.

Vertical farming in vegetation has remained fairly consistent over the years: In 2017, 31% of research participants indicated growing using vertical racks during vegetation; this increased to 37% in 2021's research, a response in line with more recent years (38% in 2020).

Using tiers in flowering continues to slowly gain adoption, with 21% of this year's research participants indicating growing on at least two tiers, up from 13% in 2017 and 20% in 2020. The plurality of growers who use vertical racks in flowering grow on two tiers (16%), while 22% grow on two tiers during vegetation.

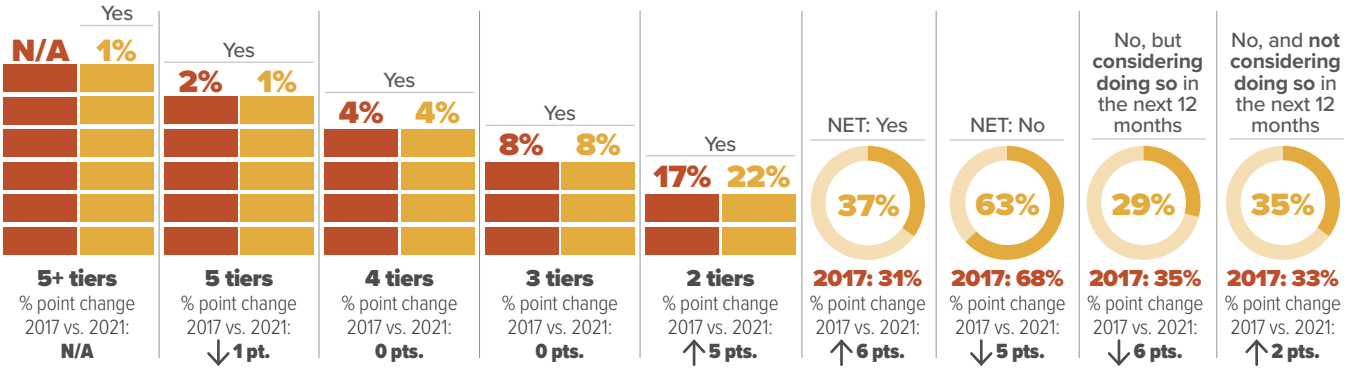
The portion of growers not considering vertical farming in flowering has declined steadily over the years since this question has been included. In 2017, 59% of research participants were not considering a vertical farming system in flowering. This group dropped to 49% in 2021, potentially indicating that more growers have adopted vertical farming systems or are more open to the idea than they once were.

37%
Portion of research participants who indicated using vertical farming in vegetation in 2021.

21%
Portion of research participants who indicated using vertical farming in flowering in 2021.

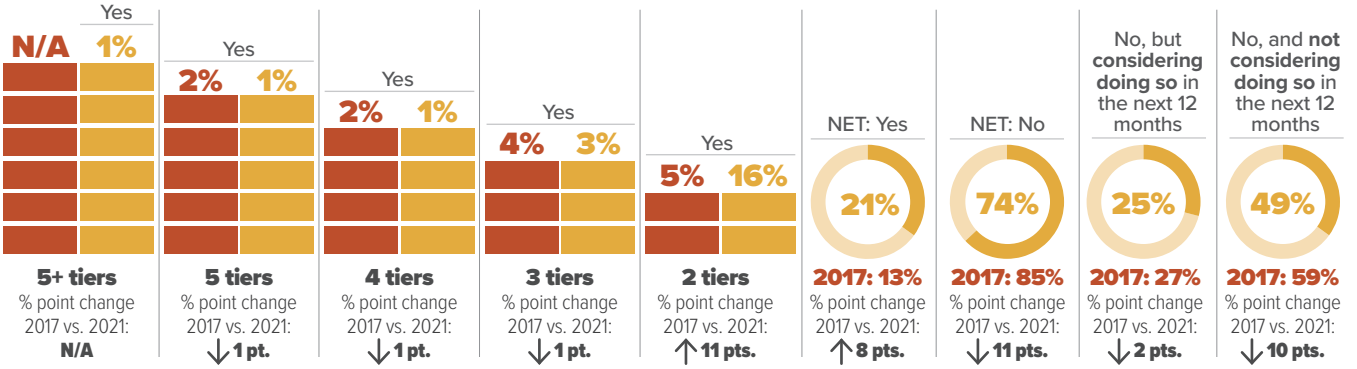
VERTICAL FARMING – VEGETATION

Does your operation use vertical rack systems for cannabis *vegetation*? 2017 2021



VERTICAL FARMING – FLOWERING

Does your operation use vertical rack systems for cannabis *flowering*? 2017 2021



LED HESITANCY DWINDLES, BUT REASONS PREVENTING ADOPTION REMAIN

LED adoption is expected to continue to rise as growers strive for further efficiencies, whether to maximize profitability, comply with state energy use regulations, or both. Of the research participants who currently do not leverage LED fixtures in flowering, 63% indicated they are planning to use or are considering using LEDs in the flower cycle within the next 12 months. About one-third (32%) of participants indicated having no plans to bring LEDs into their flowering spaces.

For those not considering LED adoption, the main reason remains mostly similar to years past—cost. The top three reasons cited about what is preventing LED adoption all involve capital investments into the fixtures: "challenges in securing funding/capital for LED lighting" (cited by 33% of research participants), "payback/ROI is too long" (27%), and "LED lights cost too much to install" (20%). Other common reasons include: "LED lighting doesn't work well for the plants we grow"; "LED lights are too difficult to fit in with my current racking/stacking/shelf"; "LED lights cost too much to operate on an ongoing basis"; "LED lights hurt production/yield"; and "unproven technology." Each of these latter reasons was mentioned by 13% of growers who do not currently use nor plan to use LED lights.

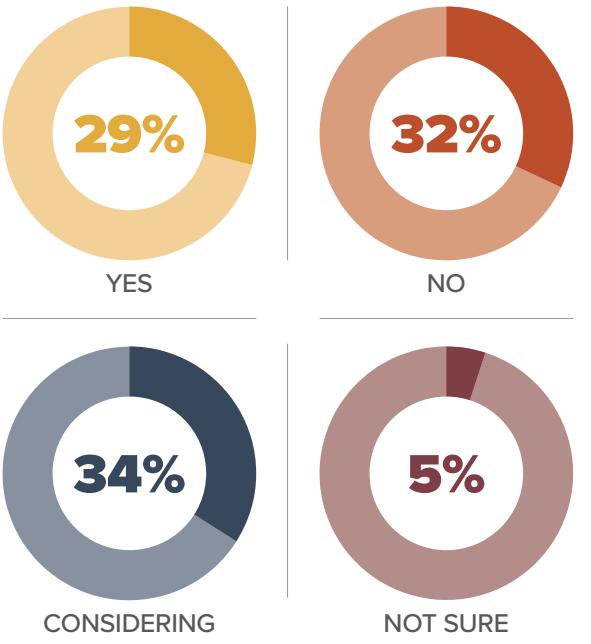
Challenges in securing funding/capital for LED lighting is the #1 reason preventing LED introduction in flowering areas.

What is preventing your operation from introducing LED lights in the flower cycle within the next 12 months?*

challenges in securing funding/capital for LED lighting	33%
payback/ROI is too long	27%
LED lights cost too much to install	20%
LED lighting doesn't work well for the plants we grow	13%
LED lights are too difficult to fit in with my current racking/stacking/shelf	13%
LED lights cost too much to operate on an ongoing basis	13%
LED lights hurt production/yield	13%
unproven technology	13%
adding LED lights along with other lights makes production too complicated	7%

*Total exceeds 100% because participants could select all that apply. Base: those who only own or work for a commercial operation that grows cannabis indoors and/or in a greenhouse with lighting and does not use LED lights and are not considering LED lights in the next 12 months or are not sure (15)

Is your operation planning to use LED lights in the cannabis flower cycle within the next 12 months?



Base: those who only own or work for a commercial operation that grows cannabis indoors and/or greenhouse with lighting and does not use LED lights (41)

63% **of growers** who do not currently use LEDs in flowering are planning to or considering doing so in the next 12 months.

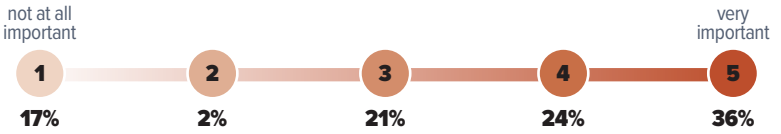
TOP FACTORS WHEN PURCHASING LIGHTING FIXTURES

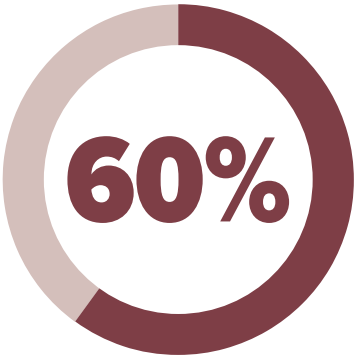
As in past "State of the Cannabis Lighting Market" reports, cost is a significant factor for cultivators purchasing a lighting fixture. However, in 2020, other considerations, such as light intensity and spectrum, product warranty, and scientific research and development, ranked higher. This year, the investment piece ranked first, with 51% of research participants placing "price" in their top five most important factors guiding lighting purchasing decisions. Light spectrum (45%), energy efficiency (44%) and light intensity (40%) were other important factors noted by growers in this year's study.

A possible sign of LEDs becoming the industry-standard fixture, more than a third (35%) of growers surveyed this year indicated that any fixtures they would considering purchasing must be LED. Comparatively, only 3% reported requiring that the fixtures be HPS.

While just missing the top-five cut, dimmable light intensity capability was another top factor highlighted by growers when making fixture purchasing decisions. More than a quarter (29%) of growers ranked dimming capabilities in their top five most important purchasing factors, and 60% noted it as "important" or "very important" to their facility's cultivation operations.

How important to your operation is dimming with regard to controlling light intensity and allowing for greater lighting flexibility in your garden?





Portion of research participants who rated lighting fixture dimming capabilities as "important" or "very important" to their cultivation operation.

IMPORTANCE OF LIGHTING

How important are each of these factors when purchasing a lighting fixture?*

price	51%
light spectrum	45%
energy efficiency	44%
light intensity	40%
must be LED	35%
dimmable light intensity	29%
scientific research supporting product development	26%
product warranty	24%
manufacturer's customer service reputation	24%
customizable light spectrum	19%
recommendation from colleague/peers	15%
personal familiarity with product	11%
utility rebates offered	10%
no-cost trial period	7%
passive cooling mechanism	7%
knowledge of salesperson	5%
must be HPS	3%
must be plasma	2%
must be T5 (high output/HO) lights (or other HO fluorescents)	2%
must be MH-Ceramic	1%
must be MH-Quartz	1%
other	3%

*Answers reflect portion of research participants who noted these factors as "very important" or "important"

TOP LIGHTING CHALLENGES REMAIN CONSISTENT

Compared to last year's report, the greatest lighting challenges cited by this year's study participants remained unchanged, but the order was shuffled. In this year's report, "managing energy costs" was the top lighting-related challenge (15% vs. 13% in 2020), followed by "ensuring consistent/even lighting across the crops" (14% vs. 17% in 2020), "lighting's impact on terpene/cannabinoid content" (13% vs. 14% in 2020), "managing heat load" (10% vs. 12% in 2020), "automation" (10%, new to the list this year) and "lighting's impact on plant growth (yield, internodal spacing, etc.)" (10% vs. 16% in 2020).

TOP LIGHTING CHALLENGE

2021
MANAGING ENERGY COSTS

2020
ENSURING CONSISTENT/EVEN LIGHTING ACROSS THE CROPS

What is your cannabis cultivation operation's **greatest challenge** when it comes to lighting?

RANK	TOP CHALLENGES IN 2021		TOP CHALLENGES IN 2020	
1	managing energy costs	15%	ensuring consistent/even lighting across the crops	17%
2	ensuring consistent/even lighting across the crops	14%	lighting's impact on plant growth (yield, internodal spacing, etc.)	16%
3	lighting's impact on terpene/cannabinoid content	13%	lighting's impact on terpene/cannabinoid content	14%
4	managing heat load	10%*	managing energy costs	13%
5	automation	10%*	managing heat load	12%
T-5	lighting's impact on plant growth (yield, internodal spacing, etc.)	10%*		

Note: Percentages are rounded to nearest integer.

WHERE CULTIVATORS ARE GROWING & THEIR FOOTPRINTS

Each year, *Cannabis Business Times* asks participants to provide details about their facilities to gain some context for the data and to learn more specifically about cultivators who are using lighting to power their grows. Similar to 2020's report, the vast majority of research participants indicated growing exclusively with artificial lighting as 79% of participants reported growing in an indoor facility. Meanwhile, 29% of participants rely on a mix of natural and supplemental lighting, growing in a greenhouse with supplemental lighting. (Cultivators who have multiple facility types could select more than one.)

Total growing areas varied greatly, with 21% cultivating in facilities that are 50,000 sq. ft. or more, and 14% with canopies covering less than 1,000 sq. ft.

What is the area of your operation's cannabis crop production (total plant canopy)?

250,000 sq. ft. or more	3%
150,000 - 249,999 sq. ft.	4%
100,000 - 149,999 sq. ft.	4%
80,000 - 99,999 sq. ft.	2%
50,000 - 79,999 sq. ft.	8%
25,000 - 49,999 sq. ft.	7%
10,000 - 24,999 sq. ft.	16%
5,000 - 9,999 sq. ft.	21%
2,500 - 4,999 sq. ft.	8%
1,000 - 2,499 sq. ft.	13%
500 - 999 sq. ft.	8%
less than 500 sq. ft.	6%

34,500 sq. ft. AVERAGE CANOPY SIZE

CULTIVATION FACILITY TYPES

In what **type of facility** does your operation grow cannabis?

79% indoor facility

35% outdoors**

29% greenhouse with supplemental lighting

10% greenhouse without supplemental lighting**

Note: Total may exceed 100% because participants could select all that apply.
***To examine lighting trends among cultivators specifically, CBT's research looked at only the responses of the 156 participants (94%) who grow indoors and/or in greenhouses using supplemental lighting.*

GROWING UNDER HIGH LIGHT INTENSITIES

Researchers and growers continue to explore how high light intensities can optimize cannabis operations.

BY **JOLENE HANSEN**

For cannabis growers operating in greenhouse or indoor cultivation facilities, finding the perfect lighting strategy is an ongoing quest. Advances in lighting technology continue to illuminate the complex relationship between cannabis and light. For many growers and researchers, the emphasis has shifted from light color or spectral quality to light intensity—specifically, high light intensities that go beyond sunlight intensity.

DEFINING HIGH LIGHT INTENSITY

To understand what constitutes high light intensity, Mitch Westmoreland, Ph.D. candidate and Research Associate at Utah State University's Crop Physiology Lab, starts with simple reference points—like the sun.

Photosynthetic photon flux density (PPFD), measured in micromoles of photons per square meter per second, remains the standard of measurement for light intensity in growing environments. Westmoreland describes PPFD as an instantaneous value reflecting how much photosynthetically active radiation (PAR) hits the leaf each second.

In Westmoreland's experience, he's found many cannabis growers happy to hit 700 to 1,000 PPFD. For perspective, he puts peak outdoor light intensity on a midsummer day at 2,000 PPFD.

Jason Sanders, head of cultivation at Texas Original Compassionate Cultivation (TOCC), estimates the average cannabis facility grows at 900 to 1,000 PPFD during flower. TOCC grew in that range before beginning research on spectral quality and light intensity in early 2020 in partnership with Fluence by OSRAM.

"If you can get above 2,000, you're really pushing it," Westmoreland says. "That's a very high light intensity." But he cautions that photosynthetic rates level off dramatically when PPFD exceeds 2,000 micromoles.

EXPLORING HIGH INTENSITY LIMITS

TOCC's light intensity trials with sole source lighting have involved PPFDs from 1,000 up to 2,500—an upper limit determined mainly by the facility's power capabilities.

"We maxed out our load," Sanders says. "We learned that the best value was around that 1,800 micromole level for cannabis. As we start increasing from 1,000 micromoles up to 1,800, we saw about a 1% increase in yield for every 1% increase in light intensity. That started to diminish from 1,800 to 2,500." While yield increased up to 2,500 PPFD, it was more bell curve than linear beyond 1,800 PPFD.

The biggest surprise? "It was amazing to see the

According to TOCC's studies, yield increases start to plateau once light intensity exceeds 1,800 PPFD.

PHOTO COURTESY OF FLUENCE BY OSRAM

plants take the light," Sanders says. "I would have thought that we would have seen some type of phototoxicity—some kind of leaf curl, burning, something—but the plants were able to handle it."

Although cannabis is a high-light crop capable of achieving high photosynthetic rates at high light intensities, Westmoreland says there's a ceiling to how much light any plant can take.

"Physiologically, plants can only handle so much in terms of using that energy for photosynthesis, and so they have to come up with ways to dissipate that energy," Westmoreland says.

When light overwhelms a plant's photosynthetic machinery, damage can result. Researchers are still discovering how cannabis handles stressors that come with high light.

A Texas Original Compassionate Cultivation team member scouting crops.

INTERACTING WITH SPECTRAL QUALITY

TOCC's next study is focused on effects of different light spectra at various PPFDs. The best yields to date have been with Fluence's broad-spectrum R4 lighting. Type 1 (high-THC, low-CBD) cannabis grown at 1,500 PPFD under R4 showed 17% higher yields in dry bud weight as compared to R6. Higher fractions of red light (corresponding with higher R numbers) tracked lower yields for the company.

Westmoreland and Sanders report photobleaching—bleached, white flower tips—at higher light intensities with test treatments where more red is added to the spectra. For TOCC, no photobleaching was observed under R4 spectrum at PPFDs of up to 2,500 micromoles/m^2/s.

"Photobleaching seems to be an interaction between light intensity and light quality," Westmoreland says. "It seems that a higher fraction of red makes plants more prone to photobleaching. It also tends to happen just at the high light intensity, regardless of the fraction of red." He suggests photobleached tips are most likely above 60% to 70% red.

But Westmoreland also notes USU testing shows photobleaching does not lower cannabinoid concentration or affect yield. "It's just a cosmetic thing," he says.

MOVING BEYOND BIOMASS

Westmoreland says USU hasn't yet seen good evidence that cannabinoid concentration increases in proportion to yields under high light intensities. "But it does take energy to make cannabinoids. It takes energy to make terpenes. The source of that energy is light. So, it's not completely ridiculous to think that more light also means more cannabinoids," he says. "The gray area there is we don't necessarily know what the ceiling is yet."

> **"... it's not completely ridiculous to think that more light also means more cannabinoids."**
>
> – MITCH WESTMORELAND, PH.D. CANDIDATE AND RESEARCH ASSOCIATE AT UTAH STATE UNIVERSITY'S CROP PHYSIOLOGY LAB

Exploring that relationship is now a focus for USU researchers. "We have sufficient evidence that spectral quality might have a small impact on cannabinoid concentration and morphology, but the bigger question is what does light intensity do?" Westmoreland says.

A new state-of-the-art, 10-chamber, canopy gas exchange system may help with answers. "We can look at photosynthetic responses in real time to the different light intensities, and we can also relate that to yield and cannabinoid concentration at the end of the life cycle," Westmoreland says. "We're also looking at the interactions with high light and nutrition and high light and temperature, because all of these things interact and affect yield."

ADAPTING LIGHTING TYPES

When TOCC first began lighting studies, the 2,000-square-foot facility grew under high pressure sodium (HPS) bulbs. An interest in LEDs and the opportunity to conduct lighting trials and see LED benefits led to change, and TOCC now runs all LEDs with dimmable switches.

"I think the greatest challenge for growers now is being able to hit those high PPFD numbers and still have the environmental parameters still dialed into the grower's setpoints," Sanders says.

PHOTOS COURTESY OF TEXAS ORIGINAL COMPASSIONATE CULTIVATION

In HPS grow setups, growers will need to increase their number of lights and ramp up HVAC systems to handle the added heat load. "With the new technology of LED, then you can get to those light levels without having the heat problems," Sanders adds.

Westmoreland agrees that extra thermal load is an obstacle for HPS growers at high light intensities: "That's where LEDs become really nice. They don't have quite as much thermal radiation, and the thermal radiation they do produce goes up, away from the plants. So, you can run these lights much closer to the canopy and potentially get a higher light intensity."

ESTABLISHING BEST PRACTICES FOR HIGH LIGHT

When TOCC started growing under high light, plants grew in peat-based media in No. 5 pots. It is now trialing 6x6 rockwool cubes. Sanders feels the larger root zone offered a buffering effect at high light intensities; smaller root zones are much less forgiving. "You've got to really be on your A-game," he says.

By growing under higher light intensities, the plant responds differently to its surrounding environment. With peat, TOCC increased the EC in its normal feed program to accommodate high light in flower. With rockwool, the team runs increased phosphorus at the beginning of flower, then drops back to normal for the rest of the flower cycle.

Sanders also increased TOCC's veg cycle from two weeks to three, to allow more maturation before rockwool-grown plants hit high light. Propagation runs at 150 to 200 PPFD. In veg, that jumps to 350 to 550. From veg to flower, Sanders slowly increases intensity from 550 to 1,800 PPFD during a week-long photoacclimation that kicks off eight weeks of flower. He's also increased CO_2 enrichment levels to between 1,000 and 1,200 ppm.

Westmoreland reminds growers to have a light meter and use it. "The human eye is a terrible light meter, especially at high light intensity," he says. He suggests monitoring throughout the day over the course of a few weeks, especially if you grow in greenhouses that experience light fluctuations. From there, expect water demand to increase under high intensity, and adjust nutrient solutions to accommodate the change.

LOOKING BEYOND PPFD

Westmoreland encourages growers to look at daily light integral (DLI, the amount of PAR light hitting a designated area over 24 hours), not just instantaneous PPFD.

"If it's raining outside, you're not really interested in how many raindrops are falling at any given moment. What we're interested in would be accumulated total. That's the exact same thing for plants," he says. "We can think of photons as raindrops. We're not necessarily interested in the instantaneous number of photons hitting a crop or a leaf at a given time, but we're interested in the long-term accumulation of those photons. That's ultimately what's contributing to the yield."

Westmoreland explains that outdoors in Logan, Utah, where he's located, the maximum DLI in midsummer is about 60 moles per meter squared per day. (For context, 1 mole equals 1 million micromoles.)

While outdoor light intensity varies throughout the day, controlled environments can run constant light intensity all day long. "You can get daily light integrals that are approaching 100, depending on how hard you push your plants. That's what I would consider to be high light intensity in terms of integrated over the whole day," he explains.

As growers advance in understanding optimal light intensities for cannabis, Westmoreland says the total amount of light accumulated over the entire crop is key.

For Sanders, it's an exciting time. "I think that it is really awesome that we're in a time period now where we can look at kind of a light recipe here. We can dial in intensity, so we can start at low PPFDs and then ramp them up as these plants get into flower and really optimize it," he says. "As a grower, it's awesome to have this extra tool in the toolbox now."

Growing under high-intensity fixtures in a smaller root zone creates little margin for error, according to Jason Sanders, head of cultivation at Texas Original Compassionate Cultivation (TOCC).

HANSEN HEADSHOT COURTESY OF JOLENE HANSEN

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A POWERFUL COMBINATION

Growers can complement their lighting strategy with expert data measurement tactics. BY **DOUGLAS J. GUTH**

Growers acclimating to new lighting systems need to monitor and tweak environmental controls during each production phase.

The importance of tracking key cannabis grow parameters cannot be overstated. Without key environmental and production data, system optimization becomes difficult and subjective as any modification becomes impossible to compare with prior iterations, whether those be fertigation recipes, irrigation rates, or environmental variables.

Data tracking becomes even more critical for growers transitioning from traditional high-pressure sodium (HPS) lighting to LEDs, a decision that impacts nearly every aspect of cannabis production.

"What you don't monitor, you can't measure," says Gretchen Schimelpfenig, technical director of the Resource Innovation Institute (RII), a nonprofit providing crop-optimizing guidance and data for cultivators.

For example, she suggests that "all growers should measure temperature and relative humidity to calculate the vapor pressure deficit (VPD) plants are experiencing in their grow rooms. This ensures growers understand how HVAC and dehumidification systems are performing when lights are on or off and can also help them determine the actual temperature adjustment needed when switching from HPS to LED."

HPS fixtures have long been the industry standard, but more cultivators are turning to LEDs, or light-emitting diodes, for benefits that include increased cost savings and higher light intensity, Schimelpfenig says.

The best lighting and data measurement strategies are intimately linked, she adds. Alongside industry go-tos such as humidity and temperature, growers are wise to gauge CO_2 concentration, media pH, root zone temperature and other metrics.

Columbia Care, a multistate operator (MSO) that cultivates, manufactures and sells cannabis products, assesses those key parameters and more, such as wind speed and air circulation, across 1.76 million square feet of growing space at 27 U.S. locations.

Eric Culberson, the company's vice president of horticulture, says some modifications to Columbia Care's fertigation strategy were necessary when the company upgraded to LEDs with different spectra and intensity from its previous HPS and plasma technology—changes recognized following rigorous data collection and analysis.

"The difference we see under LEDs is potential for greater swings in pH, EC [electrical conductivity] and moisture when the plants are not getting what they need, when they need it," Culberson says. Transpiration typically increases in concert with light intensity, or photosynthetic photon flux density (PPFD), pulling more water from fertigation solutions. "This was part of the reason why we began using so many tools and sensors—so we can be in the driver's seat no matter the light source."

Because LEDs typically are more powerful than HPS lamps, it's imperative for growers to calculate both the pH and EC of growing media under newly installed lights, Culberson says. Measuring EC is ideal in determining if plant nutrients are sufficient, with an elevated EC reading implying higher concentra-

PHOTO COURTESY OF COLUMBIA CARE

> **Gain confidence with your data first**—become comfortable with using it and confident in its accuracy."
>
> – GRETCHEN SCHIMELPFENIG, TECHNICAL DIRECTOR, RESOURCE INNOVATION INSTITUTE (RII)

tions of fertilizer. (Cultivators encountering high EC in nutrient solution should dilute the solution with extra water.)

The grow environment adjustments have been worth it, Culberson notes, who described the transition "like hitting a greased slide."

"Our yield and potency improved, and the structure of our flowers was fuller," he says. "We saw the improved morphology and structure in our plants indicative of a better nutritional profile."

Without baseline data to compare against and robust data collection capabilities, Culberson would be hard-pressed to make these determinations. Columbia Care uses an anemometer to track wind speed, as good air circulation promotes water evaporation on leaf surfaces, reducing the potential for damaging fungal infections.

"All of these measurements are governing factors on plant performance, driving and indicating whether a plant can or can't metabolize," Culberson says. "Watching these metrics keeps plants in a sweet spot of production at all times. We don't have to guess, or assume like growers used to when sampling a small portion of a grow."

WORKING WITHIN THE SYSTEM

Growers acclimating to new lighting systems need to monitor and tweak environmental controls during each production phase, Schimelpfenig says. In the flowering stage, for instance, growers retrofitting from HPS to LED can maintain the same VPD targets but should increase HVAC temperature setpoints by seven or eight degrees to preserve desired VPD.

"That's because LED fixtures give off less heat," Schimelpfenig says. "It's important to take several distinct measurements of leaf temperature across the canopy to accurately reprogram your controls. The temperature adjustment for rooms growing younger cannabis may be different. Because lower-wattage light fixtures do not put off as much heat into the room as fixtures for flowering, when the switch is made to LED, the increase in temperature might be smaller."

No matter the growth stage, Schimelpfenig suggests placing sensing equipment in an aspirated box shielded from light. Additionally, growers should measure environmental readings in several places to account for microclimates.

"Think about the zones of control that you have, and how you want to get feedback from those zones," Schimelpfenig says.

Columbia Care has implemented a rolling daily system in checking plant particulars. Culberson says rotating crop measurements give producers insights on cultivating cannabis in various growth conditions, including when fine-tuning parameters during a lighting change.

Most Columbia Care facilities are nine-week turns (corresponding to the duration of each flowering period). Daily data checks provide a pulse of a facility, allowing growers to know if their crop is trending in the right direction.

"We can look at data points and use them as a jumping-off point," says Culberson. "We'll dive into the data and get actual photos to make sure we know the issue. For example, show me your oldest mother stock so I can see if the color and structure is right. Or put a pH probe in a pot and take a picture of the reading."

With temperature and humidity readings being a constantly moving target, it can be challenging for growers to establish consistent growing trends, Schimelpfenig says. Considering the variability of room conditions, RII recommends that growers place sensors covering an average of 500 canopy square feet. However, coverage depends on the purpose of the sensor as well as your crop's environmental set-up.

Of course, not every cultivator is well-versed on the complex minutiae of every growing metric. Those just starting out can harness integrated systems and analytics software, gleaning a few crucial data points before incorporating this information into standard operating procedures.

"Gain confidence with your data first—become comfortable with using it and confident in its accuracy," Schimelpfenig says. "Verifying your data is a good idea before you start controlling and automating. Research your existing equipment and its sequence of operations to make sure it orchestrates in harmony."

Schimelpfenig suggests checking what communication procedures your power and data management systems are using, as more "handshakes" between systems can equate to incompatibly and, eventually, the need for expensive translation protocols.

Back up data regularly both on- and off-site, keeping records for two weeks before replicating them in the cloud or external hard drive. Cloud storage, in particular, protects owners from outage-related data loss or systems going offline.

Ultimately, any step growers take to track data is a good one, remarks Culberson. Even a cheap light meter can assess how your lighting is best used in conjunction with other plant growth metrics.

"A good grower looks at a variable and understands how that impacts all the other variables," Culberson says. "There's all sorts of data one needs to look at before they execute on remediation, and that all goes back to the system."

DOUGLAS J. GUTH is a Cleveland Heights, Ohio-based freelance writer and journalist.

HEADSHOT COURTESY OF DOUGLAS J. GUTH

Since 2017, Fog City Farms has used a two-tier, LED-equipped vertical racking system in its flowering room.

5 BEST PRACTICES FOR VERTICAL FARMS

Considerations for layouts, irrigation systems and more when growing in tiers BY **JODI HELMER**

James Cunningham started growing cannabis indoors, on a single tiered surface under high pressure sodium (HPS) lights. The setup worked for more than a decade, but the advent of more efficient light-emitting diode (LED) lighting inspired him to rethink the setup at Fog City Farms.

"For a long time, LED had a bad reputation for underdeveloped flower growth," recalls Cunningham, CEO of Fog City Farms, based in Santa Cruz, Calif. But then things changed. "We started to hear from a few different LED growers [who] were producing comparable yields and comparable quality flower to HPS."

In 2017, citing the high cost of square footage for indoor space in Santa Cruz and advances in lighting technology, Cunningham transitioned to a two-tiered vertical system with LED lights for cannabis plants in the flower stage. In the vegetative growth stage, plants remain in a greenhouse where square footage is less expensive and lighting requirements are lower.

Cunningham credits the move with providing the space he needed to develop the Fog City Farms brand and sustain its wholesale operation.

"When you go vertical, you're producing half the heat with [LED lights] with the same amount of cooling," he explains. "What we used to have to build a two-story building for, now we can throw up some racks and make use of our cubic footage rather than [our] square footage." In other words, since Fog City is already cooling the air above the canopy, it leveraged LEDs' lower heat loads to "grow up."

Matt LaBrier also adopted a vertical strategy to maximize the cubic footage when designing the Proper Cannabis facility in St. Louis, implementing double- and triple-stacked systems utilizing LEDs.

"[Under LEDs] we were seeing buds that were tighter and terpene tests that were higher than what we'd see with traditional HPS lights," says LaBrier, chief operations officer at Proper Cannabis. "We knew that if we were going to build a facility and consider it state-of-the-art, HPS and a single-tiered system was out of the question."

Adopting a multi-tiered operation is not without its challenges, however. These best practices can help growers transition to LED lighting in vertical systems.

1. PLAN LAYOUTS FOR NECESSARY EQUIPMENT

When planning Proper Cannabis' 90,000-square-foot cultivation and manufacturing facility, LaBrier knew that a vertical system would require workers to move scaffolding in

PHOTO COURTESY OF FOG CITY FARMS

and out of the flower room and climb ladders to access plants on the top racks. The layout had to include wider aisles to accommodate the additional infrastructure.

"One challenge to vertical farming is efficiently working on the upper tiers," says Jeff Gumaer, Proper's cultivation director. "The primary reason for a wider aisle would be to access these spaces with your equipment. The rows don't need to be wider than 4 feet to execute this, but you have to have the right tools."

Proper Cannabis uses a specially designed platform system that can fit within that space and expands to 7 feet lengthwise, allowing two team members to work on the equipment at one time.

"It also folds up so that it easily rolls in and out of our aisles when we need to move the workstation," Gumaer says.

2. CONSIDER SPACING

Growers must use different strategies for plant spacing in a multi-level LED system than a conventional single-tier operation using HPS lights. The reason? Depending on the fixture, light intensity drops dramatically the farther plants get from the LED lights. However, because LEDs produce far less by-product heat, plants can be placed closer to the fixtures to create an equivalent relative light intensity at canopy. The correct spacing between the light source and the plant can create dramatically different results for cannabis plants in flower.

"Under LED lights, cannabis plants growing 6 inches from the lights can thrive, showing no signs of light or heat stress," LaBrier says. "Plants growing too close to HPS lights would be hating life."

Proper uses a PAR meter to measure light intensity at the top of the canopy and adjusts the lighting accordingly to target a 700 to 900 photosynthetic photon flux density (PPFD) range, Gumaer says.

"The distance between your plants and lighting in any stage of growth has to do with what percentage you are running your lights on. A general answer would be 12 inches to 18 inches from the lights at 100% output," he says.

In a vertical system, Cunningham suggests shrinking the space between the light and canopy and controlling the environment so your genetics can produce to their full potential.

3. MANAGE MICROCLIMATES

Managing environmental factors like airflow, humidity, light intensity, and vapor pressure deficit is essential in all indoor farms, especially in vertical grows.

"The more plants there are in a room, the more chances there are for microenvironments to develop throughout the space," LaBrier explains.

In fact, LaBrier says that there can be hundreds of microclimates within a 10,000-square-foot room. To maintain the right environment, he suggests growers install additional sensors to track data at various ceiling heights, different plant heights and even within trays.

"There is less air movement, and it's a few degrees warmer on the top rack," he explains. "When you think about a production plan … you have to be really cognizant of where we're putting certain strains because there are small microclimates throughout the room. It's true of traditional growing, but it's exacerbated by vertical growing."

4. ADJUST IRRIGATION

Irrigating multiple levels of cannabis plants in a vertical system can lead to disproportionate runoff to lower tiers. To avoid overwatering, Cunningham suggests choosing the correctly sized pipe diameter for each tier to balance the irrigation supply and properly sized pressure regulation emitters to ensure an even distribution of water, isolating supply channels to service different levels.

Proper Cannabis uses a specially designed platform to help team members reach upper canopy tiers.

The irrigation piping also determines the height of the bottom tier, as gravity requires a certain amount of fall per foot for the water to drain. To maximize the number of levels and start the bottom tier as low as possible, it's best to place the drain in the middle—or install multiple drains—to minimize the drop needed to drain the water, Cunningham adds.

5. ADAPT CULTIVATION SCHEDULES

The intensity of LED lights combined with growing environment modifications can lead to faster plant growth. One study published in *Agronomy Journal* found that plants grown under LED lights produced up to 800 grams of cannabis compared to 300 grams for HPS-grown plants.

Faster growth might seem good for growers transitioning to LED lights in a vertical system, but it requires managing to ensure plants don't get too close to the light in the flower stage. Growers also have to consider how it will affect their workflow, LaBrier adds.

"LEDs help push plants along a little quicker in a positive way, and things that used to take nine weeks were finished in eight or eight-and-a-half-weeks," he explains. "You have to think logistically about how that will work in a commercial operation where you harvest every week and how it interacts with hang times and cure times."

While the approach to vertical farming in flowering is different than a traditional single-level, transitioning to a multi-level farm is worth the effort and investment, Cunningham says. He believes it's the future of cannabis.

"There are huge advances being made with LEDs," he says. "As power becomes more of a regulator in the indoor farming space and farmers educate themselves, everyone is going to go to LED in vertical farming."

JODI HELMER is a North Carolina-based freelancer who covers the intersection between agriculture and business.

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