SPECIAL REPORT

STATE OF THE CANNABIS LIGHTING MARKET

FLUENCE BIOENGINEERING

CANNABIS BUSINESS TIMES

FLUENCE BIOENGINEERING IS PROUD TO BE A THOUGHT LEADER IN HORTICULTURE LIGHTING, AND IT IS OUR GOAL TO CONTINUE TO REFINE OUR UNDERSTANDING OF PLANT PHOTOBIOLOGY TO ADDRESS THE EVER-INCREASING DEMANDS OF AND INNOVATION IN CULTIVATION OPERATIONS.

In 2016, Fluence Bioengineering sponsored *Cannabis Business Times'* first "State of the Cannabis Lighting Market" report. Our message to readers in that first report delivered a bold prediction: "In the same manner as the semiconductor industry reshaped business, compound semiconductors (specifically LEDs) will transform the cultivation world."

Now, 24 months later, we can validate that prediction. Compound semiconductors have transformed the cultivation world, especially commercial cannabis. As you will discover from this report, LED adoption has exponentially grown. More growers are using LEDs in their indoor or greenhouse operations throughout all growing stages than ever before.

Fluence Bioengineering is proud to be a thought leader in horticulture lighting, and it is our goal to continue to refine our understanding of plant photobiology to address the ever-increasing demands of and innovation in cultivation operations.

Our focus at Fluence is you, the cultivator. Our mission: to enable you to succeed with solutions based on science and research. We thrive by helping clients make informed decisions and achieve their cultivation and business growth objectives.

To help ensure our clients' success, we collaborate with strategic partners and research institutions to discover innovative ways lighting systems can be used to produce quantifiable and repeatable results. We conduct numerous controlled environment experiments to better understand how photosynthetic photon flux density (PPFD), spectral composition and photoperiodic light treatments can increase yield and quantitatively alter cannabinoid profiles and terpene expression.

Our recent acquisition by OSRAM brought together purpose-built horticulture technology with a global lighting leader that shares our mission to be a global innovation leader. OSRAM has armed us with substantial resources to continue advancing LEDs and to invest in new technologies to help advance cannabis cultivation practices. We are dedicated to helping growers deliver higher quality products and establish themselves as leaders in the developing controlled environment agriculture industry.

But we aren't in this lighting game alone. For the industry to continue to innovate and support cultivators in their efforts to produce the best possible crops, we need more information on cultivators' strategies, challenges, concerns and goals. Essentially no cumulative data had existed about the cannabis lighting market, until now.

Fluence is proud to be the exclusive sponsor of *Cannabis Business Times'* third-annual "State of the Cannabis Lighting Market" report. With three years of data, lighting trends can now be identified, making this year's report the most comprehensive yet. We support *CBT's* efforts to share scientific knowledge and industry trends, as we believe the data in this report will give cultivators meaningful insights into the future of profitable cannabis cultivation.

DAVE COHEN
CEO
Fluence Bioengineering

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THE IMPORTANCE OF RESEARCH

AGRICULTURAL AND INDUSTRY ADVANCEMENTS have helped us discover why light is so beneficial to plant production and that its manipulation can improve plant growth and increase yields. To craft lighting plans, cannabis cultivators often ask: What should my photosynthetically active radiation (PAR) levels be? What is the ideal spectrum? Is my Daily Light Integral (DLI) timed right?

Indeed, cultivation business owners and operators have become savvier about light quality's importance to their crops' health, yields, and cannabinoid and terpene contents. They commonly seek evidence of a lighting product's effectiveness before they buy—that's according to the third-annual *Cannabis Business Times'* "State of the Cannabis Lighting Market" report, where 72% of research respondents rated "scientific research supporting product development" as "important" or "very important" to lighting purchase decisions.

This year's report offers *Cannabis Business Times'* most in-depth lighting market research to date. With three years of data, trends have begun to emerge, from lighting types used (for example, more cultivators said they are using LEDs across all cannabis growth stages, compared to previous studies) to vertical farming practices (which showed an 18 percentage-point jump from 2016), and more.

In addition to the raw data, you'll find practical information on how to conduct lighting tests (*S. 10*), how growers can work with utility companies to obtain maximum rebates (*S. 13*), and The Design Light Consortium's first-ever baseline standard for horticulture lighting manufacturers and how it can help utility companies and growers (*S. 14*).

Thanks to Fluence Bioengineering's generous support (for the third consecutive year), *Cannabis Business Times* was again able to partner with nationally recognized research company Readex Research to study cultivators throughout North America about their lighting usage and related practices. And thank you, *Cannabis Business Times'* readers, for participating in this important research project.

72%

PORTION OF RESEARCH RESPONDENTS

WHO RATED "SCIENTIFIC RESEARCH SUPPORTING PRODUCT DEVELOPMENT" AS "IMPORTANT" OR "VERY IMPORTANT" TO THEIR LIGHTING FIXTURE PURCHASE DECISIONS.

FACILITY

IT'S NO SECRET that different plant growth stages require different lighting strategies. While nearly all research participants agree on the PAR levels needed during various growth stages, little consensus exists as to which lighting strategy is best for each stage.

While cultivators' lighting preferences still vary, however, this year's research showed an increase in the number of cultivators using light emitting diodes, a newer lighting technology more commonly referred to as LEDs: It is the only lighting technology to see double-digit increases during all growth stages between 2016 and 2018.

Growth Stage: Propagation

Nearly half (47%) of this year's research participants said they use LEDs during the propagation period, compared to 21% in 2016. This represents a 26 percentage-point increase over two years. However, T5 (high output/HO) lights (or other HO fluorescents) are still used by a slim majority of growers (51%), compared with 65% in 2016 and 63% in 2017.

Growth Stage: Vegetation

In vegetation, LED use was the most common among lighting types among research participants: 46% of growers reported using LEDs during this growth stage, climbing from 17% in 2016.

Nearly a third (32%) said they use quartz and/or ceramic metal halide (MH) lights during this growth stage—a drop of 11 percentage points from 2017. (*CBT* did not calculate net MH responses in 2016.)

T5s were the third-most popular lighting type—28% of respondents reported using them in this year's study (down from 37% in 2016).

High-pressure sodium (HPS) lights also experienced a drop among growers during vegetation: a quarter (25%) of research participants said they use HPS lights in 2018 versus 31% in 2016.

Growth Stage: Flower

In flower, the research found that HPS remains the most-used lighting type in cannabis cultivation: 51% of growers said they use them, a 6 percentage-point lead over the next closest fixture, LED; 45% of growers in 2018 said they use LEDs versus 15% in 2016, a 30 percentage point increase during that period.

MH lights are less popular during flower than during vegetation: 11% of growers said they use either MH

LIGHTING USED IN **PROPAGATION**

	2016	2017	2018	2016-2018 Difference
T5 (high output/HO) lights (or other HO fluorescents)	65%	63%	51%	↓ 14 pts.
light emitting diodes (LEDs)	21%	36%	47%	↑ 26 pts.
high-pressure sodium (HPS) lights	16%	N/A	N/A	N/A
metal halide (MH) lights -ceramic	10%	N/A	N/A	N/A
compact fluorescent lights	9%	19%	9%	0 pts.
metal halide (MH) lights - quartz	6%	N/A	N/A	N/A
sulphur plasma lights	2%	N/A	N/A	N/A
magnetic induction lights	1%	11%	7%	↑ 6 pts.
other	6%	21%	23%	↑ 17 pts.

22%

PORTION OF GROWERS IN **2017** WHO SAID THEY WERE PLANNING ON IMPLEMENTING LED LIGHTING DURING THE FLOWERING PERIOD WITHIN THE NEXT 12 MONTHS

**Total may exceed 100% because respondents could select all that apply. **2017 results are based on the 294 research participants who grow only indoor and/or in greenhouses using supplemental lighting. 2016 results are based on 117 research participants who grow in indoor and/or greenhouses (with or without supplemental lighting) and/or outdoors.*

LIGHTING

33%

PORTION OF GROWERS IN **2018** WHO SAID THEY WERE PLANNING ON IMPLEMENTING LED LIGHTING DURING THE FLOWERING PERIOD WITHIN THE NEXT 12 MONTHS

quartz or MH ceramic lights during this period (down 6 percentage points from 17% in 2017). (*CBT* did not calculate net MH responses in 2016.)

The LED Factor

Despite the data showing LED rise across the board, LEDs are still too expensive for some: 46% of 2018 respondents who do not use LEDs for the cannabis flowering stage (the only stage for which study participants were asked this question) and do not plan to within the next 12 months (or are unsure) cited initial cost as the main factor preventing them from converting (compared to 59% in 2017, no data for 2016).

More than a third (37%) still perceive the technology as unproven (down from 43% in 2017, no data for 2016), while more than a quarter (29%) of those not planning on adding LEDs felt the return on investment (ROI) was too long (28% in 2017, no data for 2016).

Despite some doubters, a third (33%) of growers who currently do not use LED technology during the flower period said they are planning on doing so within the next 12 months. In 2017, only 22% of growers who did not use LEDs during flower were planning on doing so within that same time period.

LIGHTING USED IN VEGETATION

	2016	2017	2018	2016-2018 Difference
T5 (high output/HO) lights (or other HO fluorescents)	37%	38%	28%	↓ 9 pts.
high-pressure sodium (HPS) lights	31%	30%	25%	↓ 6 pts.
metal halide (MH) lights - quartz	23%	15%	12%	↓ 11 pts.
metal halide (MH) lights - ceramic	20%	31%	24%	↑ 4 pts.
light emitting diodes (LEDs)	17%	36%	46%	↑ 29 pts.
compact fluorescent lights	3%	N/A	N/A	N/A
sulphur plasma lights	2%	5%	2%	0 pts.
magnetic induction lights	2%	4%	3%	↑ 1 pt.
other	8%	8%	7%	↓ 1 pt.

LIGHTING USED IN FLOWERING

	2016	2017	2018	2016-2018 Difference
high-pressure sodium (HPS) lights	62%	68%	51%	↓ 11 pts.
light emitting diodes (LEDs)	15%	36%	45%	↑ 30 pts.
T5 (high output/HO) lights (or other HO fluorescents)	8%	7%	7%	↓ 1 pt.
metal halide (MH) lights - ceramic	7%	13%	8%	↑ 1 pt.
metal halide (MH) lights - quartz	5%	6%	3%	↓ 2 pts.
compact fluorescent lights	3%	N/A	N/A	N/A
sulphur plasma lights	1%	5%	1%	0 pts.
magnetic induction lights	1%	3%	4%	↑ 3 pts.
other	5%	9%	9%	↑ 4 pts.

**Total may exceed 100% because respondents could select all that apply. **2017 results are based on the 294 research participants who grow only indoor and/or in greenhouses using supplemental lighting. 2016 results are based on 117 research participants who grow in indoor and/or greenhouses (with or without supplemental lighting) and/or outdoors.*

LIGHTING CHALLENGES

Participating cultivators cited various challenges as their top concerns when it comes to lighting, including: managing heat loads (18% of respondents cited this as their greatest lighting challenge), managing energy costs (15%), choosing the right lighting type for each growth stage (13%), adjusting lights to the environment (7%), and ensuring consistent lighting across crops (6%).

The most common challenge cultivators face in lighting, however, has nothing to do with how fixtures interact with the environment: Over a fifth of cultivators (21%) said their greatest lighting challenge was figuring out lighting's exact impact on plant growth and terpene/cannabinoid content.

So Where Do Cultivators Find Lighting Information?

As markets mature, cannabis cultivators are turning to trusted information sources to help them address those challenges. Industry publications are the only consensus pick in trusted sources of lighting information, with more than half of study participants (57%) ranking trade magazines in their Top 3 information sources. Just under half (48%) rank colleagues/industry peers in their Top 3 sources of lighting information, while industry researchers and studies are among the Top 3 for 42% of growers.

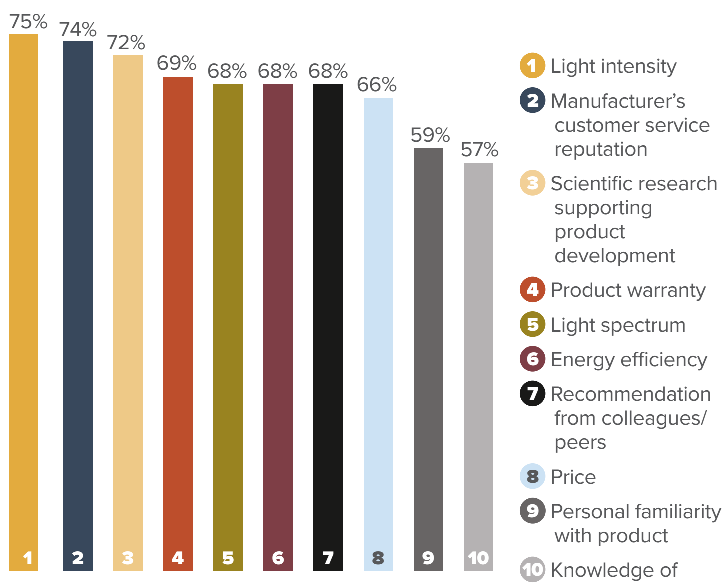
The availability of resources outside of industry peers and dedicated cannabis blogs (which 21% of growers said was among their Top 3 information sources) is a fairly new reality. Until recently, scientific research and academic studies on cannabis horticulture were few and far between. Today, international cannabis markets such as Canada and Israel are forging the path for university-sponsored research, and state-sanctioned partnerships between U.S. cannabis companies and universities, like those seen in Pennsylvania, are starting to flourish—all of which will offer more information and insight into the complexities of cannabis cultivation.

Why Buy?

Scientific information that is currently available on lighting is highly regarded by cultivators. As was mentioned in the introduction of this report, 72% of survey respondents say the availability of

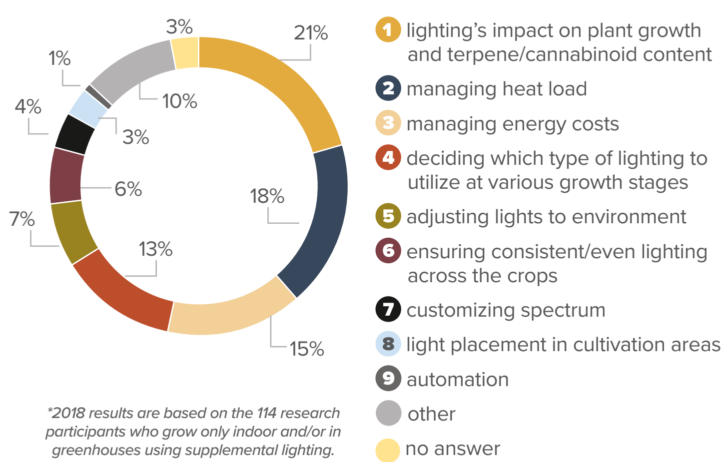
TOP 10 MOST IMPORTANT FACTORS WHEN MAKING LIGHTING PURCHASES

These 10 items were ranked as "important" or "very important" by the majority of 2018 survey respondents:



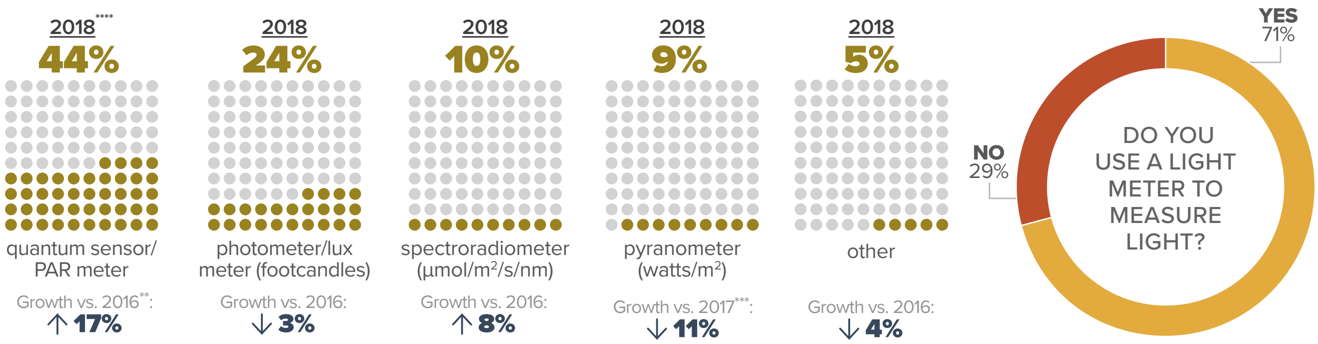
*Total may exceed 100% because respondents could select all that apply.

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



*2018 results are based on the 114 research participants who grow only indoor and/or in greenhouses using supplemental lighting.

LIGHT METERS USED



**Total may exceed 100% because respondents could select all that apply. **2016 results are based on the 117 research participants who grow in indoor and/or greenhouses (with or without supplemental lighting) and/or outdoors. 2016 data is not available for pyranometer. ***2017 results are based on the 169 research participants whose operation collected light intensity (PPFD) and/or light quality (spectrum) data. ****2018 results are based on the 114 research participants whose operation grows cannabis in an indoor facility and/or greenhouse with supplemental lighting.*

scientific research supporting product development is an "important" or "very important" factor in their decision to buy lighting fixtures, but it is not the most important factor. Both light intensity and the vendor's customer service reputation were cited by more cultivators as "important" or "very important" (75% and 74%, respectively).

Rounding out the Top 10 most important factors in lighting purchases are: product warranty (69%), light spectrum (68%), energy efficiency (68%), recommendation from colleague/peers (68%), price (66%), personal familiarity with product (59%), and knowledge of salesperson (57%).

Making Data-Informed Decisions

Cultivators aren't waiting for university researchers to tell them what the optimal conditions for cannabis cultivation are; many are performing their own data tracking. Nearly all (95%) of study participants in both 2017 and 2018 tracked at least one data point about their operations. General humidity and ambient room temperature are the most commonly tracked data points—both are tracked by more than 80% of 2018 survey participants.

CO_2 (carbon dioxide) is becoming a bigger point of interest for cultivators. In 2017, 62% of cultivators said they tracked CO_2 concentration in their grow environments. That number increased by 10 percentage points in 2018 to 72% of growers.

The portion of cultivators who track light intensity (photosynthetic photon flux density—PPFD) and/or light quality (spectrum) also increased, albeit slightly, between 2017 and 2018, from 57% to 59%, as did the portion of those who track growing media electrical conductivity (EC) (39% to 46%) and growing media pH (58% to 61%). Fewer growers tracked nutrient solution pH in 2018 than 2017 (dropping from 76% in 2017 to 70% in 2018) and nutrient solution EC (55% to 51%).

TOP 3 SOURCES OF HOW CULTIVATORS GATHER LIGHTING INFORMATION

1. INDUSTRY PUBLICATIONS
2. INDUSTRY PEERS
3. INDUSTRY RESEARCH AND STUDIES

DATA COLLECTED

	2017	2018	% point difference
relative humidity	81%	71%	↓ 10 pts.
humidity	N/A	82%	N/A
ambient room temperature	79%	83%	↑ 4 pts.
nutrient solution pH	76%	70%	↓ 6 pts.
CO_2 concentration	62%	72%	↑ 10 pts.
yields	N/A	67%	N/A
media pH	58%	61%	↑ 3 pts.
nutrient solution electrical conductivity (EC)	55%	51%	↓ 4 pts.
light intensity (PPFD)	50%	51%	↑ 1 pt.
light quality (spectrum)	41%	30%	↓ 11 pts.
media EC	39%	46%	↑ 7 pts.
leaf surface temperature	30%	30%	0 pts.
root zone temperature	29%	32%	↑ 3 pts.
air speed	18%	19%	↑ 1 pt.
other	16%	10%	↓ 6 pts.
NET: light intensity (PPFD) and/or light quality (spectrum)	57%	59%	↑ 2 pts.
indicated at least one	95%	95%	0 pts.
none	5%	5%	0 pts.
no answer	0%	0%	0 pts.

***2017 results are based on the 294 research participants whose operation grew cannabis in an indoor facility and/or greenhouse with supplemental lighting. ***2018 results are based on the 114 research participants whose operation grows cannabis in an indoor facility and/or greenhouse with supplemental lighting.*

VERTICAL FARMING

...IN 2018

VEGETATION

YES 39% **NO** 61%

No, but considering doing so in the next 12 months: 22%
No answer: 0%

FLOWERING

YES 18% **NO** 82%

No, but considering doing so in the next 12 months: 18%
No answer: 2%

**2018 results are based on the 114 research participants who grow only indoor and/or in greenhouses using supplemental lighting.*

...IN 2017

VEGETATION

YES 31% **NO** 68%

No, but considering doing so in the next 12 months: 35%
No answer: 1%

FLOWERING

YES 13% **NO** 87%

No, but considering doing so in the next 12 months: 27%
No answer: 2%

**2017 results are based on 294 research participants who grow in indoor and/or greenhouses with supplemental lighting.*

...IN 2016

YES 21% **NO** 77%

No, but considering doing so in the next 24 months: 21%
No answer: 3%

**2016 research participants were not asked in which growth stage they utilized vertical farming. **2016 results are based on the 117 research participants who own or work for an operation that grows cannabis.*

UTILITY REBATES: GROWING AWARENESS

Price of lighting equipment is cited as an important purchasing factor for two-thirds of cultivators (66%). And more growers report exploring, and applying for, utility rebates with their local energy providers. A majority of cultivators (51%) explored utility rebate incentives to subsidize the cost of LED lighting solutions in 2018, 11 percentage points more than in 2017 (40%). (LEDs were the only type of lighting for which rebate incentive questions were posed to research participants.)

However, fewer research participants said they received rebates in 2018 than did in 2017. Only 1 in 10 growers (11%) reported receiving rebates on LED purchases this year, compared to 17% in 2017. Nearly a quarter (23%) of cultivators said they have yet to submit for rebates despite having explored the opportunity (18% in 2017).

The number of growers, however, who are aware of utility rebates increased from 2017: 28% of research participants who use LEDs for propagation, vegetation or flowering did not know about utility incentives in 2018, versus 31% in 2017.

Vertical Farming

Vertical farming is another way growers can maximize crop space and yields, despite state regulations limiting square-footage, and more growers are leveraging vertical racking systems today than in previous years. In 2016, 21% of cultivators said they used vertical racks (they were not asked to specify which growth stages). In 2017 and 2018, research participants were asked to indicate during which growth stages they used vertical racking (vegetation or flowering). This year, 38% of respondents said they use vertical racks during vegetation and 18% use them in flowering (compared to 31% during vegetation and 13% in flowering in 2017).

Looking to the future, 22% of research participants who are not using vertical racking in the vegetative stage plan to do so within the next year, as do 19% of those not currently racking in the flowering stage.

CULTIVATION FACILITY SIZE

What is **the area** of your operation's total plant canopy?

80,000 sq. ft. or more	13%
50,000 - 79,999 sq. ft.	6%
25,000 - 49,999 sq. ft.	13%
10,000 - 24,999 sq. ft.	20%
5,000 - 9,999 sq. ft.	15%
2,500 - 4,999 sq. ft.	10%
1,000 - 2,499 sq. ft.	9%
less than 1,000 sq. ft.	14%

**2018 results are based on the 114 research participants who grow only indoor and/or in greenhouses using supplemental lighting.*

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

73% indoor facility

33% outdoors

30% greenhouse with supplemental lighting

13% greenhouse without supplemental lighting

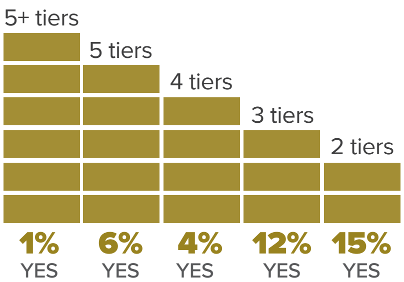
84% **NET: indoor facility and/or greenhouse with supplemental lighting

**Total may exceed 100% because respondents could select all that apply. **To examine lighting trends among cultivators, CBT's research looked at the responses of the 84% of participants (114) who grow only indoor and/or in greenhouses using supplemental lighting. Responses from participants who grow outdoors or in greenhouses without supplemental lighting were excluded from the final report.*

VERTICAL RACK SYSTEMS AND CANNABIS CULTIVATION

Does your operation **use vertical rack systems** for cannabis *vegetation* (not including propagation)?

2018

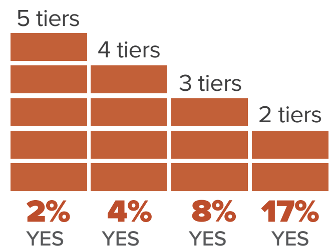


22% no, but **considering doing so** in the next 12 months

39% no, and **not considering doing so** in the next 12 months

0% no answer

2017



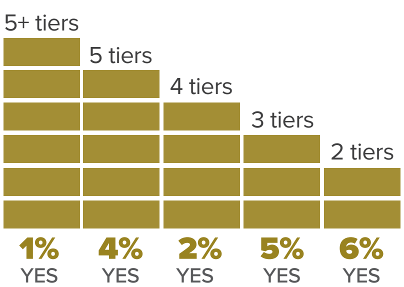
35% no, but **considering doing so** in the next 12 months

33% no, and **not considering doing so** in the next 12 months

1% no answer

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

2018

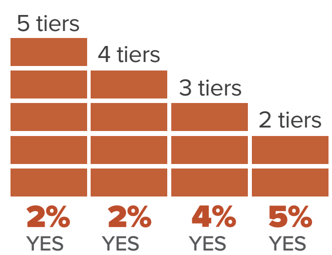


19% no, but **considering doing so** in the next 12 months

61% no, and **not considering doing so** in the next 12 months

2% no answer

2017



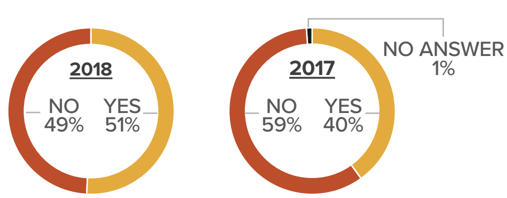
27% no, but **considering doing so** in the next 12 months

59% no, and **not considering doing so** in the next 12 months

2% no answer

2018 results are based on the 114 research participants who grow only indoor and/or in greenhouses using supplemental lighting. 2017 results are based on 294 research participants who grow in indoor and/or greenhouses with supplemental lighting. **2016 research participants were not asked how many levels they utilized in vertical farming. * Figures rounded to nearest percent.*

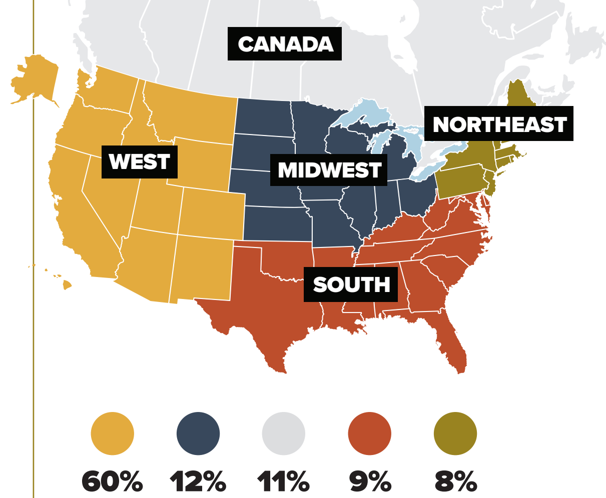
Has your operation **explored utility rebate incentives** to subsidize the cost of LED solutions?



***2017 results are based on the 140 research participants whose operation uses LEDs for propagation, vegetation and/or flowering. **2018 results are based on the 65 research participants whose operation uses LEDs for propagation, vegetation and/or flowering.*

GEOGRAPHIC DISTRIBUTION

OF RESEARCH PARTICIPANTS



ABOUT THE RESEARCH & PARTICIPANTS

Research for the "2018 State of the Lighting Industry" report was conducted online by third-party researcher Readex Research in August and September, among subscribers to *Cannabis Business Times* magazine and/or its e-newsletter located in the United States, Canada, or other (unknown) North American locations.

Results are based on 114 respondents who own or work for an operation that cultivates cannabis indoors and/or in greenhouses with supplemental lighting. Cultivators who grow outdoors or in greenhouses without supplemental lighting were excluded from the results. The margin of error for percentages based on the 114 respondents who indicated they work for a cultivation operation that grows cannabis is ±9.0 percentage points at the 95% confidence level.

PHOTOS BY PETER REEVES, GREENSEAL

HOW TO DESIGN AND RUN A CONTROLLED EXPERIMENT

A guide to help you conduct side-by-side testing to determine impacts on yields and other plant characteristics.

BY **JAMES EAVES, PH.D.**

Given the shortage of proven cultivation knowledge and data, the big opportunity lies in learning faster than the competition. One critical skill for accomplishing that is knowing how to design an experiment. This article explains that process using a lighting research project as a case study. The project was based on a research partnership between Greenseal Cannabis Company, Voltserver Inc. and Université Laval. Several lighting companies also contributed, including BIOS Lighting, Fluence Bioengineering, Illumitex and P.L. Light Systems.

Experimental Design

A controlled experiment is the process of manipulating conditions and collecting data to answer a question. For example, will increasing CO_2 from 1,000 ppm to 1,100 ppm increase yields? The "design of experiments" (DOE) is the process of planning the experiment to ensure that you are generating the right data (and enough of it) to answer your question.

Developing a Hypothesis

The DOE process starts with a question to which the answer is important to your business. Each experiment we perform is the output of a structured process for identifying and ranking potential research opportunities. We identified lighting as a top opportunity because it is:

- one of the grower's largest capital expenses,
- likely the single most important factor for yields and quality, and
- there's been almost no rigorous academic cannabis lighting research.

Literature Review

We started by reviewing the research (academic and industry) on the topic. For instance, spectrum research for other plants indicates that a grower could harm the plant's development by excluding certain wavelengths, but otherwise suggests that if a light provides a broad spectrum (like a multivitamin), then the plant will take what it needs. But we wanted to know: *How do spectrum quality differences across full-spectrum lights impact yields?*

Regarding the impact of intensity, researchers documented in a 2008 study published in the journal *Physiology and Molecular Biology of Plants* that cannabis net photosynthesis increased with light intensity up to a PPFD (photosynthetic photon flux density, a measure of light intensity) of as much as 2,000. This is about five times more intense than a double-ended HPS mounted 36 inches above the canopy. This suggested the possibility of substantially increasing yields by substantially increasing light intensity.

Yet the researchers did not answer our question because research has also shown that measuring changes in net photosynthesis is not a reliable way to estimate changes in final yields. One industry study by Fluence Bioengineering, however, did find substantial yield increases resulting from higher PPFD. So, our second question we wanted to address was: *What is the relationship between high light intensity and yields?*

Research Methods

A well-defined research question makes it easy to define the data you need to answer the question confidently (in a statistical sense). For instance, imagine you increase CO_2, and your yields increase by 5 grams per square foot. How confident are you that increasing CO_2 increased yields? If yields typically vary by roughly 4 grams from one harvest to the next, then maybe you wouldn't feel confident. If the typical variation was 1 gram, then you should be more confident. Then if you increased CO_2, but also happened to change the process for taking clones, you might wonder how much of the yield increase was caused by the CO_2 and how much by the new cloning method. My point is that if your question is well defined, then there is a standard protocol you can follow to help you feel confident about the final answer implied by your experimental results.

We wanted to measure *the impact of light intensity and spectrum on yields*. We decided to manipulate these factors by using several different types of commercially available lights that vary in intensity and spectrum. These included double-ended HPS, broad-spectrum LEDs and purple LEDs. Eight different models in all provided varying spectrums and intensities at the canopy that ranged from around 450 PPFD to an average PPFD of nearly 2,000. Light intensities were measured using a quantum sensor.

Control and Treatment Groups

Next, we needed to grow individual tables of plants under the different lights. Our reference group, or control group, would be plants grown 36 inches under double-ended HPS lights. The other table-light combinations are called treatments. The environmental conditions for each treatment and the

control are kept *as similar as possible*, except for the lights.

Randomization

To account for the fact that clone health and potential will vary, we randomly assigned clones to each table. This is called *randomization*.

Number of Replicates

This brings us to one of the most critical steps in the DOE process: *How many times should we grow groups of plants under each light?* In other words, should we have one table growing under Light A or more? This is the number of *replicates or repetitions of the experiment,* and to be sufficiently confident about your final results, you need a sufficiently high number. Otherwise it's impossible to rule out that some other *confounding factor* (e.g., Treatment 1 was randomly stocked with healthier clones) drove your results. (Note: This is one way to calculate the number of repetitions to conduct. An experienced consultant may be able to help configure the number of times most suitable to a cultivator's particular environment.)

To select the number of replications, researchers commonly use the following formula:

$$\#Reps = 2(t_{\alpha/2} + t_{2\beta})(\frac{\sigma}{\delta})^2$$

Where: $t_{\alpha/2}$ and $t_{2\beta}$ are "t values" associated with the probability of a Type I error (α in the formula) and a Type II error (β in the formula). A Type I error (a "false positive") occurs when we detect differences that don't actually exist, whereas a Type II error occurs when we fail to detect a difference that does exist. δ is the minimum difference you'd like to be able to detect confidently, and σ is the standard error in differences (e.g., typical variation in yields) observed across similar past experiments.

Example

The probability of a Type I error (α) is typically set at 5%, while 10% or 20% is typically used for a Type 2 error (β). No theory is behind this—it's just convention. Suppose we used 5% and 20%, respectively. From growing the same cannabis strain under similar conditions in the past, we estimated the standard error in yields to be 30 grams. If you do not have past

data to use, you have two other options: You can use data from other researchers for comparable experiments, or you can do a pilot study to create your own estimate. Finally, assume we want to be able to detect a yield difference as small as 60 grams per table.

Step 1: The first step is to find $t_{\alpha/2}$. An easy way is to use the TINV() function in Excel. The function takes two inputs: α and the "degrees of freedom." The calculation for the degrees of freedom changes with your experimental design, but if you're completely randomizing your plants, then you can use the number of plants per treatment as an estimate. So suppose you have 64 plants per treatment, then you would input "=TINV(0.05,64)," which gives you 1.997.

Step 2: Find $t_{2\beta}$ by inputting =TINV(2*(1-β), 64) = TINV(2*(1-0.2), 64), which gives you 0.847.

$$\#Reps = 4.40 = 2(1.997 + 0.847)(\frac{30}{60})^2$$

So for this example, we would need five replications per treatment. In other words, for each light-table combination, we needed to repeat the experiment a minimum of five times.

Control

There are many ways to conduct experiments—by changing multiple factors at once and conducting a statistical analysis, or changing a single factor and observing its impact on the plant environment. In our experiment, we chose to manipulate a single factor: light intensity. So to help maintain similar growing environments across the tables, we kept them all in the same room and minimized light from spilling over from one table to another using panda film. We added fans and kept one side of the tables open to increase airflow. We monitored temperature, humidity, CO_2 levels and fertigation. Since plants that grow faster will consume more water and nutrients, we've recently added tensiometers (which measure soil moisture) and data loggers, so we can be sure that watering occurs when a treatment's soil moisture reaches a certain threshold. You will also want to employ a CO_2 meter to ensure it is being distributed to the crop adequately during the trial.

Results

Our experiment's results run counter to the current industry paradigm. In our facility, using HPS lights at 36 inches provides around 450 PPFD. The exact PPFD depends on the spillover from other tables. But the highest yields in our experiment resulted from using a full-spectrum LED that provided an average PPFD of nearly 2,000. Specifically, we have been able to increase yields from between 40% and 70% above our *control* by increasing light intensity up to nearly 2,000 PPFD. This lighting configuration uses more electricity compared to HPS, but for every dollar we spend on more electricity to increase light intensity, we increase the value of our yields by as much as $8 CAD.

Finally, the results of our tests showed that spectrum doesn't appear to matter much for yields when comparing full-spectrum lights. Thus, at Greenseal, rather than focusing on metrics such as dollars per watt, or searching for a magic spectrum, we simply select full-spectrum lights that minimize the cost of delivering our target PPFD to our plants.

JAMES EAVES, PH.D., is an agricultural economist and professor at Université Laval. He is also the Head of Innovation at Greenseal Cannabis Company, which uses advanced vertical farming methods to grow cannabis in Stratford, Ontario.

4 TIPS FOR WORKING WITH YOUR UTILITY COMPANY

Utilities are critical business partners, if you know how to work with them.

BY **DEREK SMITH**

Despite historical tensions between cannabis cultivators and utilities, cultivation operators can benefit significantly by developing close working relationships with their power providers. As margins become squeezed by competitive pressures, wringing profit from your property often starts with cutting energy expenses.

Retrofitting cultivation facilities for energy efficiency can drive more than 50 percent savings on energy, and utilities often subsidize technology upgrades. These incentives can be worth hundreds of thousands of dollars. Yet, *Cannabis Business Times* recently found that 49 percent of growers using LED lights didn't seek to understand incentive opportunities from their utilities, leaving money on the table.

On the flip side, a 2017 survey of 90 Washington and Oregon cannabis growers conducted by the Northwest Power and Conservation Council found that 32 percent of respondents want to work with their local utilities to make their operations more efficient. However, only 9 percent of respondents had been contacted by their utilities, indicating that it may be necessary for growers to initiate first contact.

Regardless of how you come together—once you do, consider these four tips to maximize the value of your utility relationship.

1. Understand your power needs and your utility's capabilities before signing on a property. As you plan your operation, think carefully about the technology you'll use (e.g., lighting type(s)) and size your HVAC systems accordingly to ensure you don't overbuild. It's possible your site doesn't have the power capability you'll need. If this is the case, you could be facing a mountain of unbudgeted expenses to cover upgraded utility infrastructure. It's also possible that the utility's hookup timeline won't meet your start-up schedule. In areas of the country with busy construction markets, you may need to wait six months or more than a year to receive the electricity you need. (Note: In these cases, there are alternatives, such as co-gen, solar and batteries, that can make you operational and generating revenue sooner.)

COGENERATION AND COMBINED HEAT AND POWER (CHP)

Cogeneration (co-gen) through combined heat and power (CHP) is the simultaneous production of electricity, heat and carbon dioxide.

2. In most cases, utilities want to sell you power and treat you equally. Energy Trust of Oregon works closely with its grower customers to model savings from a variety of technologies and also help them learn from the other growers' experiences. That said, be aware that some utility companies or executives may have a bias against the cannabis industry or concerns about serving it because of federal issues. For example, Efficiency Maine is currently denying incentives to cannabis producers.

3. However, if you do pay into the utility system, you should receive the benefits that come with doing so. Meaning, if incentives are available to other rate-paying customers who are making energy-efficient choices, those incentives should also be available to you. Demand that you are treated like any other customer.

4. Invite your utility representatives to your facility and help them understand your business. Your utility partner may be willing to invest their own resources in exploring ways for you to use less energy and save money. For example, Amplified Farms partnered with its utility, Sacramento Municipal Utility District (SMUD), to test LEDs and found electricity savings.

The reality is that utilities are critical suppliers with which you need clear communications to protect your investments—if your power goes down, or if your environmental conditions aren't ideal, your plants and profits will be impacted.

Non-profit services, such as Resource Innovation Institute, can help if you need assistance in maximizing your relationship with your utility.

HEADSHOT COURTESY OF DEREK SMITH

DEREK SMITH is executive director of the Resource Innovation Institute (ResourceInnovation.org), a non-profit whose mission is to promote and quantify energy and water conservation in the cannabis industry.

BY **CASSIE NEIDEN**

INCENTIVIZED EFFICIENCY

The Design Light Consortium's (DLC) new Quality Product Listing (QPL) technical requirements set a first-ever baseline standard for horticulture lighting manufacturers, providing a resource for utility companies to offer energy incentives to controlled environment agriculture producers. Here, DLC Technical Manager Damon Bosetti shares how the requirements were gathered, and how utilities, growers and manufacturers can use them to their advantage.

Cassie Neiden: Will you first tell us a bit about the Design Light Consortium's mission?

Damon Bosetti: Utilities are accountable to their rate payers and to their government regulators, oftentimes at the state level. These utilities need to show prudence for how they're spending those efficiency program dollars. So, they could maintain in-house staff who can evaluate performance claims in efficacy, but to come up with a custom calculation for every single product that comes across their desks for efficiency incentives would be really time consuming and duplicative.

So what we do at the Design Light Consortium is create these standards, called a Qualified Product List (QPL), which is a list of products that meet our minimum requirements. We've been doing that for many years with general illumination. Utilities can show that efficient products are being incentivized to the regulators and prove they're spending their rate payers' money wisely, all toward the policy goals of achieving more energy efficiency every single year.

People will always start to gravitate more toward new technology, but if we can accelerate that adoption curve by a few years, we'll end up wasting less energy over that intervening transformation.

Neiden: Why did you decide to focus on horticultural lighting QPLs?

Bosetti: Controlled environment agriculture is one of the more rapidly growing load categories for many of our utility members. We started studying it in earnest about a year and a half ago. That process included multiple rounds of draft commentary and comments upon the drafts. We finished and published the specification on Oct. 1.

Neiden: Who did you seek out to gather those comments? And how did the comment process work?

Bosetti: Our spec-specific research list had over 400 email contacts on it. We have a very thorough stakeholder engagement process: We have a technical advisory committee; we have an industry advisory committee made up of large, medium and small manufacturers around the world; and we also have a horticultural working group of our utility members who are especially interested in horticultural topics. In addition, we did a lot of outreach and market research, trying to find manufacturers, academic researchers, etc.

One of the largest producers that we spoke with was AeroFarms, who we met at a Department of Energy horticultural lighting roundtable in Nashville earlier this year. They gave us some great information on how this extremely large, extremely high-volume lettuce production facility uses their LED light fixtures. We received very valuable commentary from two groups at Rensselaer Polytechnic Institute, the Lighting Resource Center (LRC) and Lighting Enabled Systems & Applications (LESA). There's a multi-university consortium called GLASE (Greenhouse Lighting and Systems Engineering) that was extremely helpful and includes researchers from other universities, including Cornell and Rutgers.

Neiden: How does the incentive program work?

Bosetti: The DLC doesn't set policies or incentives. The way utilities run their programs, how they decide to incentivize products or not, is completely up to them and their own regulatory and environmental landscape.

A utility chooses to refer to our list as part of their due diligence. They will have some kind of rebate form for incentives that the grower uses to report to the utility what their intention is. The utility would check the product code against our QPL website list. If the lighting fixtures meet the requirements, the utility would issue their approval and tell the grower to go ahead.

Neiden: As the DLC was developing this horticulture lighting QPL list, what was one of your big takeaways?

Bosetti: The first thing I would like to emphasize to people is that this is a minimum performance specification for a relatively new technology and application. And when you go back and look at other kinds of energy efficiency efforts, usually the first step you take with a new technology is not the most aggressive one. It is a baseline.

So, in that philosophy, we set our efficacy threshold that any qualified product must meet a 1.9 micromoles-per-joule efficacy requirement, which is about 12-percent more efficacious than a 1,000W high-pressure sodium fixture. That's a big number. And it's meant to be. And we're not saying that 1.9 micromoles per joule is the best that an LED fixture can do; the sky's the limit, and we're eager to see how that changes in the years to come. But we think that is a reasonable thing to ask of an LED horticultural lighting fixture, and that will be a performance floor for any product to be in our QPL.

One of the common pieces of feedback we received was that efficacy is not the only thing of importance. Photon spectrum matters as well. For a given environment and crop, blue, red or green light may be more important. So in addition to the total photosynthetic photon flux output (all µmol/s, in the 400 to 700 nanometer (nm) range, abbreviated as PPF), we will be reporting the subcomponents too, in 100-nanometer-wide "bins." Users will see the total PPF, along with specific "blue" (400 to 500nm), "green" (500 to 600nm), "red" (600 to 700nm), and "far red" (700 to 800nm) flux totals.

Also, these are not simply self-reported numbers by the manufacturers; these are going to all be reported through third-party-certified test labs.

DLC HORTICULTURAL LIGHTING TECHNICAL REQUIREMENTS

Parameter/Attribute/Metric	Requirement	Requirement Type	Method of Measurement/Evaluation
Photosynthetic Photon Flux (PPF) (µmol/s)	N/A	Reported	(LM-79-08) 400-700nm range, with 400-500nm, 500-600nm, and 600-700nm bins reported alongside the total
Far-Red Photon Flux (PF_{FR}) (µmol/s)	N/A	Reported	(LM-79-08) 700-800nm range
Spectral Quantum Distribution (SQD)	N/A	Reported	(LM-79-08) 400-800nm range
Photosynthetic Photon Intensity Distribution (PPID) (µmol/s/sr)	N/A	Reported	(LM-79-08) 400-700nm range
Photosynthetic Photon Efficacy (PPE) (µmol/J)	≥ 1.9 (µmol/J), with -5% tolerance	Required/ Threshold	(LM-79-08) 400-700nm range
Photon Flux Maintenance, Photosynthetic (PFM_P)	Q_{90} ≥ 36,000 hours	Required/ Threshold	(LM-80-15 / TM-21 or LM-84 / TM-28) 400-700nm range
Photon Flux Maintenance, Far Red (PFM_{FR})	Report time to Q_{90}	Reported	(LM-80-15 / TM-21 or LM-84 / TM-28) 700-800nm range
Driver Lifetime	≥ 50,000 hours	Required/ Threshold	Driver Technical Specification Sheet, Fixture Technical Specification Sheet, and *In-Situ Temperature Measurement* Test (ISTMT)
Fan Lifetime	≥ 50,000 hours	Required/ Threshold	Fan Technical Specification Sheet, Fixture Technical Specification Sheet
Warranty	5 years	Required/ Threshold	Legal Warranty Terms & Conditions
Power Factor	≥ 0.9	Required/ Threshold	Electrical testing per LM-79-08
Total Harmonic Distortion, Current (THDi)	≤ 20%	Required/ Threshold	Electrical testing per LM-79-08
Safety Certification	Appropriate Horticultural Lighting designation by OSHA NRTL or SCC-recognized body	Required/ Threshold	Per safety certification body

Neiden: How will these standards be updated and adjusted, and when can we expect the manufacturer listing?

Bosetti: We are committing ourselves to a two-year major cycle, and then there'll be a 12-month short minor cycle within it. The major cycle is going to be the next time the efficacy requirements change. The efficacy requirements will not change for 24 months, starting from Oct. 1. At month 18 of this major cycle, we're going to go into our database of product performance and calculate the 15th percentile for efficacy. This will be that number in micromoles per joule for the fixture, that 15 percent of listed products are below, and 85 percent of listed products are above. We will notify the industry that this will be the new threshold value that goes into effect for new applications on Oct. 1, 2020. And, we will give an extra six-month grace period, to April 1, 2021, to any listed products that are below the threshold. This will give them 12 months to update or sell through their existing products before introducing new models, which is something we wanted to accommodate. Logistics constraints are real, and we want to give everyone ample notice and time to adjust.

The goal is to have the QPL populated with this first fixture listing sometime in mid-November and then work through the backlog of currently available products that will need to be qualified and listed. ●

Editor's note: Find more information on DLC's Horticultural Lighting requirements at designlights.org/horticultural-lighting. This interview was edited for length, style and clarity.