Depending on the environment, growing cannabis can be a very energy-intensive process. This energy consumption is the leading driver of greenhouse gas emissions for the industry and is one of the biggest opportunities for growers to cut costs, critical in a market where decreasing wholesale prices and increasing competition are putting pressure on grows to be more cost-effective to stay in business.¹

The best time to incorporate energy efficiency and renewable energy measures into a cultivation is before it is built, but there are plenty of retrofit actions that growers can take to improve their energy usage in established facilities, as well.

During the process of designing a cultivation, one of the most immediately impactful actions one can take to reduce energy costs is to grow in a greenhouse or outdoors. However, there are important economic and risk tradeoffs with these options – such as having limited outdoor growing seasons in Colorado and the more complex architecture of a greenhouse – that must be considered when weighing how and where to build your grow.

As shown by the above chart, lighting and HVAC are the largest loads in a typical indoor cannabis facility. For growers looking for low-hanging fruit in existing or new-build indoor facilities, tackling the efficiency of your lighting and HVAC systems is the easiest and most impactful first opportunity.

**Best management practices that will be covered in this report include** (in order of appearance)

- Measurement and verification
- Scheduling
- Lighting
- Greenhouses
- HVAC & Dehumidification
- On-site and off-site power generation

Indoor cannabis cultivation is a resource-intensive process with energy demands as the greatest contributor to the industry’s environmental footprint. While growing cannabis in a controlled indoor space leads to more consistent year-round production, high energy costs and increasing price competition are pushing cultivators to get familiar with the energy impacts. Decisions relating to cultivation facility design should be driven by location-specific metrics and cultivation processes. High energy use and the associated air quality and emissions contribute to negative public perception; therefore, active energy efficiency efforts can help cannabis businesses create positive improvements within communities.
Economic Competitiveness: Energy use represents a significant portion of a cultivation facility’s total operating budget. As the industry continues to mature in Colorado, the market is becoming increasingly price competitive. Organizations that reduce energy consumption, and thereby energy costs, will be better situated to succeed in this increasingly competitive market.

Community Relations: As the cannabis industry continues to grow, the electric demands of cultivation facilities could potentially lead to grid outages that affect the local community. For example, Oregon’s Pacific Power has attributed seven minor community outages to grow operations.²

Environmental Impact: Electricity production is responsible for approximately one third of total greenhouse gas emissions in the United States. Over the past decade, various efforts to mitigate climate change have resulted in national electric demand remaining flat (zero percent growth).

In contrast, Denver’s electricity consumption has continued to increase over the past several years due to a variety of factors, including overall community growth. Electricity use from cannabis cultivation and infused products manufacturing grew from about 1% to about 4% of Denver’s total electricity consumption between 2013 and 2018.

While there is no singular solution for cultivators looking to reduce facilities’ energy profiles, the listed best practices are intended to provide a framework by which organizations can begin to develop a comprehensive energy management plan.
**MEASUREMENT & VERIFICATION**

**Process Description**

You don’t know what you don’t track. It is important for growers to understand and know how their facility uses energy in order to evaluate opportunities for improvement. Developing an appropriate M&V process will depend on both facility-specific factors (size, existing infrastructure, geography, etc.) and an organization’s specific economic and sustainability goals. The following best practices are intended to provide a starting point for facility managers.

**Metrics**

There is currently a paucity of relevant, high-quality energy data in the cannabis industry. Cultivators should measure and share facilities’ energy usage data to make more strategic equipment and process decisions as well as to contribute to an understanding of the current state of the industry. One benchmarking tool is Resource Innovation Institute’s Cannabis PowerScore.

Recommended metrics to track include:

**Table 2: Key Metrics to Track**

<table>
<thead>
<tr>
<th>METRIC</th>
<th>DESCRIPTION</th>
<th>UNITS</th>
<th>NOTES</th>
<th>AVERAGE RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting Yield per Watt</td>
<td>Used to compare lighting technologies and strains.</td>
<td>grams/Watt</td>
<td>Measure grams of flower and trim in dry weight. Use lighting wattages, including ballasts. Measure over one grow cycle and annually.</td>
<td>Overall average 1.0 g/W</td>
</tr>
<tr>
<td>Total Energy Efficiency</td>
<td>Identifies total production efficiency; helps identify trends in building.</td>
<td>grams/kWh</td>
<td>Measure monthly and annually Use total kWhs for building.</td>
<td>Total dried product weight ÷ kWh/cycle = Yield per kWh</td>
</tr>
<tr>
<td>Space Utilization</td>
<td>Demonstrates if the cultivation space is being maximized for production.</td>
<td>grams/sqft</td>
<td>Use square footage of cultivation space only.</td>
<td>39.5g/sq. ft.</td>
</tr>
<tr>
<td>Lighting Intensity</td>
<td>Measures whether the lights are providing the desired photosynthetic photon flux density (PPFD); can help identify correct time to replace lights.</td>
<td>µmol/m²/s</td>
<td>Measure at canopy. Measure for each type of lighting, for each stage of growth.</td>
<td>Refer to Table 3: Lighting Technologies for Cannabis Production</td>
</tr>
<tr>
<td>Daily Light Integral</td>
<td>Measures the daily accumulation of photosynthetically active radiation (PAR) spectrum light reaching the plants.</td>
<td>mol/m²/day</td>
<td>Formula: µmol/m²/s (or PPFD) x 3600s x photoperiod (hr/day) / 1,000,000</td>
<td>Denver Outdoor Avg. Winter 15-30 mol/m²/day Summer 25-45 mol/m²/day</td>
</tr>
<tr>
<td>Load Factor</td>
<td>Used to manage peak power demand; higher Load Factor reduces cost of energy.</td>
<td>kWh / (peak kW * days * 24 hours per day)</td>
<td>Use monthly electricity figures. Days equals days in billing period.</td>
<td>&lt;0.60 = poor 0.60 - 0.75 = fair &gt;0.75 = good</td>
</tr>
</tbody>
</table>
**Guidance on Collecting Data**

Three levels of data, in order from least granular to most, to consider are:

**Level 1** – Properly interpreting and recording monthly utility bills.

**Level 2** – Requesting utility interval data, if available.

**Level 3** – Installing data loggers at the building or sub-meter level.

Utility bills contain great information but are often poorly interpreted and recorded. A facility manager should break out total energy used (kWh), peak demand (kW), consumption-based charges, demand-based charges, and fees and taxes for each bill. Inputting this info (along with water and production data) into a standardized spreadsheet should take only a few minutes each month.

**Utility Interval Data**

- Facilities with smart meters can request 15-minute interval data from the energy provider.
- Facilities can also opt to pay for Xcel’s InfoWise service, which uses interval data to create a web-based energy dashboard that provides various insights and metrics. This service costs $150 per month, with a $900 equipment charge if a smart meter is not already in place.
- Cultivators can also install equipment to log energy data. This can be done concurrently with a Building Management System (BMS)/Energy Management System (EMS) installation, or can be done solely for logging energy data. Installation will allow for capturing higher frequency, submetered data that can provide a great deal of insight into how a facility is using energy.

When properly configured and monitored, a robust BMS/EMS can quickly alert a facility manager about broken or malfunctioning equipment, saving facilities from energy waste, equipment failure, power loss and even loss of crop in the event of malfunctioning environmental controls. See below for more information on BMS/EMS systems.

**Building Management Systems/Energy Management Systems**

Facility managers looking for a comprehensive data solution should consider installing a BMS or an EMS. As there are many different types of BMS/EMS systems available on the market, the U.S. Department of Energy has developed a suite of Specification and Procurement Support Materials to help managers identify the right fit for each facility.

**Energy Audit/Engineering Assistance Study**

Performing a comprehensive energy audit or engineering assistance study (EAS) is often the quickest way to acquire the insights needed to develop an effective energy management strategy, but enacting this process typically requires partnering with a qualified third-party provider. Xcel’s Energy Analysis Program is a good starting point for facility managers that are
interested in pursuing these options and also offers several financial incentive programs to reduce an organization’s out-of-pocket costs.

It would benefit the operator to install submeters inside the building to collect power-usage data, such as those manufactured by e-mon or Power TakeOff. Submeters measure the power used in a specific area and/or by certain pieces of equipment, giving a more detailed picture of how and where energy is consumed in the building.

**PORTFOLIO MANAGER**

Because of Denver’s Benchmarking Ordinance, Denver commercial and multifamily buildings that exceed 25,000 square feet are required to analyze and report their energy performance using Energy Star’s free Portfolio Manager tool.

For how to set up an account, cannabis business owners and/or facility managers can refer to the City of Boulder: How-to Guide for Medical and Recreational Marijuana Business License Energy Reporting and Carbon Offset.

**Engage Specialists**

An energy specialist (such as a Certified Energy Manager) can perform any of the above tasks for a cultivator, particularly if a grower should seek out an experienced contractor to install submeters. Interested cultivators should consider a local trade group or association such as Rocky Mountain Association of Energy Engineers.

Additionally, a specialist can perform an on-site energy audit or engineering assistance study (EAS) to reveal and evaluate energy savings opportunities. As mentioned below, Xcel Energy offers related grants/incentives.

As the cultivation industry matures, the availability of energy, water, lighting and space efficiency metrics as related to production data becomes imperative. Individual cultivators – as well as the industry at large – should have intimate knowledge of these measures and of how particular technologies and behaviors affect resource and production efficiency.

**Resources:**
- Xcel Energy - Business Programs & Rebates
- Sample Energy Audit Form
Cultivation facilities in the Denver metro area receive electric service from Xcel Energy and are billed according to total electricity consumption (kWhs) and peak demand (kW). How a facility is operated can have significant impacts on peak demand and the actual cost of energy. Managing the operation of various systems within the facility by setting staggered room schedules can significantly reduce energy costs and negative impacts on the power grid. Reducing peak demand also creates community-level environmental benefits, because energy providers utilize “peaker plants” that are generally older, less efficient and have higher emissions to provide additional electricity during times of high demand.

**PROCESS DESCRIPTION**

**Load-factor Optimization**

Energy-efficient technologies can improve both the total energy use and peak demand of a facility. Operating schedules, on the other hand, play a critical role in minimizing peak demand over the month. Grow rooms, particularly in the flower stage, represent the largest sources of peak energy needs when factoring in lighting, cooling and ventilation. All grow room schedules should be staggered over the 24-hour period so the minimum number of rooms run concurrently. Any overlap of schedules, even for one hour or less, leads to higher spikes in peak electricity demand and higher costs.

Similarly, other energy-intensive processes, such as extraction, cleaning or electric heating, can be staggered and scheduled carefully with lighting cycles to minimize peak power demands.

**SCHEDULING**

**Should I Veg Under a 24hr or 18:6 Photoperiod?**

Growers often ask this question when designing their operation, but what is the right answer? The truth is, both work! By keeping the lights on for 24 hours a day, plants are exposed to 33% more light than an 18:6 schedule. This means more light for photosynthesis. However, regular periods of darkness (lights off) are important for other plant functions. Plants actually use nighttime to take in oxygen (just like people) and burn the glucose that they stored up during the day to grow in a process called cellular respiration. Ultimately, the tradeoff between maximizing light during 24hr versus giving plants a break to use their stored energy in an 18:6 schedule more or less cancels out. The most sustainable strategy from an energy point of view is to employ an 18:6 schedule. This will yield happy and productive plants while keeping your energy bill lower at the same time.
Time of Use

Many utilities are moving toward billing customers with varying rates based on the time of day they use electricity. Xcel Energy does not yet charge time-of-use billing for Secondary General rate customers (the rate category most cultivation facilities fall under). Kilowatt hours cost the same day or night, but energy can be saved by running extra equipment during cooler evening periods. If it is necessary to operate extra grow rooms simultaneously, cultivators should try to schedule those periods overnight when outdoor air temperatures are lower. This can reduce the cooling load during these times of extra production, thereby reducing energy use and saving money.

Lighting

Lighting can be the most energy-intensive component of the cultivation environment. The design of a facility’s lighting system and the types of lamps utilized in the grow process will affect both crop yield and quality. Furthermore, the lighting selection will have a substantial impact on the size of the HVAC system, and is therefore a significant driver of overall energy use in the facility. Employee health and safety should be considered in the design and delivery of indoor lighting, as well.

Process Description

Due to the operational impact of lighting choices, a host of production-related factors must also be considered as cultivators select the appropriate lighting technology.

Lighting technologies should be measured in terms of photosynthetically active radiation (PAR), or the measure of the specific light spectrum characteristics. PAR accounts for the spectrum of light between 400 nanometers (nm) and 700nm, most of the light spectrum used for photosynthesis. Infrared (IR) and ultraviolet (UV) light spectrums fall outside of PAR readings and thus do not register with standard light spectrum measuring equipment. IR and UV light are actually classified in a range of light referred to as biologically active radiation (BAR). The concept of BAR is still new, and so for the purposes of this guide, the focus will be on PAR. The intensity of the lighting system or photosynthetic photon flux density (PPFD) is measured in micromoles per second per meter square (µmol/s-m2) and should be carefully monitored for optimal plant growth. This can be measured using a light meter with a quantum sensor.
Lumens are for Humans

If you’re familiar with lighting measurements, you have probably noticed that this document does not discuss some of the attributes usually important for interior lighting. The factors that determine light quality for plant growth are different from those to consider for working and living spaces. Measurements that are largely irrelevant for cannabis lighting include lumens, footcandles and lux.

Equipment Overview

Historically, the top three lighting technologies used have been T5 fluorescent, metal halide (MH) and HPS. There are now several different options to choose from, including (but not limited to): LED, light emitting plasma (LEP), CMH, and various combinations of these. LED adoption by cultivators appears to be growing. If you are considering an LED-lit grow environment, a peer-reviewed resource that may be helpful is Cultivating Cannabis with LED Lighting - A Primer: What You Need to Know.

Many of these lighting types have specific spectrums of PAR and are generally used for one stage of growth or another. Prescribing specific heights above canopy for lighting systems is not recommended, as PPFD, age of fixture, bench height and plant height will all dictate the location of the fixture. Fixture design and optics will also dictate where the light lands, and at what photon density at various heights, so height and location of fixture should be decided on with the help of the manufacturer to optimize photon density and limit waste. There should be a perpetual review of micromole levels for cannabis and the need to adjust fixtures with the aid of a good light meter to obtain the necessary PPFD.

Lighting fixtures emit energy in the form of light, as measured in PAR or photosynthetic photon flux (PPF), and reflectors direct the light toward the canopy with varying levels of sophistication and success. LEDs tend to be directional in nature and thus generally do not require reflectors. Knowing the lighting output of a fixture alone without understanding, properly configuring and measuring the lighting intensity at the canopy will result in suboptimal lighting conditions. Below are general uses and specifications for each of these technologies.

Table 3: Lighting Technologies for Cannabis Production

<table>
<thead>
<tr>
<th>LIGHT TECHNOLOGY</th>
<th>GENERAL USE/GROWTH STAGE</th>
<th>SPECTRUM</th>
<th>RATED LIFE IN HOURS</th>
<th>INTENSITY* IN PPFD</th>
<th>EFFICACY IN µMOLES/J</th>
</tr>
</thead>
<tbody>
<tr>
<td>T5/T8 Fluorescent</td>
<td>Plant propagation — mothers, clones and early veg</td>
<td>Broad spectrum with ability to select different color “temperatures”</td>
<td>20,000</td>
<td>150 - 500</td>
<td>0.84 (T8)</td>
</tr>
<tr>
<td>Metal Halide</td>
<td>All stages of growth (most commonly vegetative)</td>
<td>Broad spectrum with blue and green peaks</td>
<td>6,000 - 15,000</td>
<td>500 - 800</td>
<td>TBD</td>
</tr>
<tr>
<td>Ceramic Metal Halide</td>
<td>All stages of growth</td>
<td>Broad spectrum</td>
<td>20,000</td>
<td>800</td>
<td>1.46</td>
</tr>
<tr>
<td>High Pressure Sodium (single-ended)</td>
<td>All stages of growth (most commonly flower)</td>
<td>Broad spectrum with yellow and red peaks</td>
<td>5,000 - 20,000</td>
<td>700 - 900</td>
<td>0.94-1.34</td>
</tr>
<tr>
<td>High Pressure Sodium (double-ended)</td>
<td>All stages of growth (most commonly flower)</td>
<td>Broad spectrum with yellow and red peaks</td>
<td>5,000 - 20,000</td>
<td>700 - 2,000</td>
<td>1.70-2.2</td>
</tr>
<tr>
<td>Light Emitting Diode</td>
<td>All stages of growth</td>
<td>Broad spectrum or Single wavelengths with ability to fine tune colors, UV/Far-red options</td>
<td>50,000</td>
<td>up to 1,500</td>
<td>1.70 - 2.7</td>
</tr>
<tr>
<td>Light Emitting Plasma</td>
<td>All stages of growth</td>
<td>Broad spectrum plus UV</td>
<td>30,000</td>
<td>700 - 900</td>
<td>1.00</td>
</tr>
</tbody>
</table>

*Intensity is measured at manufacturer’s recommended mounting height.

**Times listed are the time it takes to reach 70-90% of original output, depending on the number listed by the manufacturer. Lights will sometimes need to be replaced before this time to maintain optimal performance.
**Best Practices**

**System Design**

When designing for indoor cultivation, it is important to identify and understand target light levels for optimal growth. The correct measurement for obtaining best results is PPFD measured at the top of the canopy. Once an operator has determined the target PPFD, the cultivator should work with an engineer or vendor to design the system around the target. If a manufacturer cannot assist in the design and technical review, the cultivator should consider seeking a more capable vendor, or be sure to have an appropriate consultant on the team.

An important consideration when designing a lighting system is PPFD uniformity. Ensuring crops receive uniform light intensity will help ensure that the crop grows uniformly. Deficiencies in light intensity often occur at the edges of cultivation spaces, such as aisles and walls. These areas often produce decreased yields due to a lack of light. Lighting vendors should provide light plans that at the very least show minimum, maximum and average PPFD of the designed area. PPFD uniformity can be improved by choosing the proper reflector type when using HID lighting, or in general by increasing the density of light fixtures. Further efficiency can be gained by using reflective coatings and paints on walls, floors and equipment to direct photons back toward the crop. In greenhouses, sensors can be used to monitor light during the day and turn lights on and off based on the amount of sunlight and the target PPFD. This is a great way to get the most out of a crop while trying to minimize electricity use.

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Maximizing Production & Efficiency

Racks

Many cultivators are moving to tiered production on vertical racks or shelving. This strategy is most common in vegetation rooms where plants are smaller and require lower light intensity. Fluorescent lights or LEDs are typically used in these stacking situations because they radiate less heat and can be placed closer to plants. A common question is, “How far away from the canopy should lights hang?”

While each light is different, the most important factors to consider when hanging lights are the temperature of the canopy and how many micromoles are hitting it. Ensuring the plants are consistently receiving the appropriate micromole level of lighting and the appropriate temperature level is essential for efficient growth.

Pruning

Pruning is important to maximize production. Some plants may need to be topped in the vegetative stage to keep them short and bushy. Light can only penetrate a portion of a dense canopy. Taller plants take more time to grow and ultimately produce less yield per kWh.

For these reasons, it is important to prune plants multiple times throughout the growth cycle. Typical pruning activities consist of pruning off all underdeveloped branches on the bottom third of the plant and removing large leaves that are either blocking light or not receiving light. While sometimes counterintuitive, by removing plant material, pruning allows the plant to redirect resources from underdeveloped areas to parts of the plant that will ultimately increase the overall yield.

GREENHOUSES

Greenhouses will continue to take over a large portion of the cannabis industry as regulations become more favorable. Any expansion plans should at least take into consideration greenhouse production, as it can be a much more sustainable approach although results will vary significantly based on location and design choices. With greenhouse production, lights will be needed only occasionally for supplemental light. Weather stations wired to a quantum meter should be used to ensure lights are only activating when the meter dips below the minimum micromole target. These weather stations allow for the most efficient use of electricity.

When designing greenhouse cultivation facilities, many of the system designs with regard to lighting will be different when compared to indoor cultivation. Greenhouse lighting is still based on desired PPFD, but must take into consideration how much natural light/sunlight will be obtained. Light fixture count will undoubtedly decrease in most geographies compared with indoor operations, as the lights will be used only to supplement during periods of low sunlight levels.

Another aspect of greenhouse lighting system design is controllability. Many light fixtures and associated ballasts or drivers have the ability to be dimmed. There are times in both stages of growth that the plants may desire a light level lower than the full output. Therefore, cultivators can reduce energy consumption with a dimming control system. A control system can also stagger the power up and power down of any room and can help prevent unnecessary power spikes and potential damage to electrical equipment.

SEE ALSO: Appendix B: Greenhouses
Trellising
Trellis nets should be used in most grow systems to support plants as they flower, as well as when they spread branches to increase light penetration. Cultivators should install trellis netting in the first week of the flower stage before plants stretch. Installing low trellising early will help keep the plants stable and support heavier bud development. Branches should be spread and placed evenly through the holes in the trellis netting to maximize benefit. Often multiple trellises will need to be applied to the same crop over the course of flowering, depending on the size of the plants.

Adjustable Light Fixtures
It can be beneficial to have adjustable ratchets on the light depending on the technology, layout and manufacturer’s recommendations. Having the ability to move the light closer to shorter plants can greatly increase the level of micromoles the plant receives. It can also be helpful to pull the lights up and away from taller plants to prevent burn. Cultivators should be sure to use non-combustible cables or chains when using adjustable lighting fixtures.

Lighting Maintenance & Replacement
Proper maintenance of lighting and lighting components is important for performance and efficiency. A dirty optic lens or reflector could reduce performance by more than 10%. Different lighting technologies have different maintenance considerations.

High-Intensity Discharge Lighting
Aluminum Reflectors: Calcium, dust and sulfur will damage reflectors and decrease efficiency. Cultivators should follow the manufacturer’s recommendations for cleaning reflectors, as any wiping of the reflector can damage the finish. This should be done once every six months, or more often if heavy accumulation of dust is noticed. Tracking micromole levels at the canopy level will insure the proper amount of photons is hitting plants. Replacing bulbs and reflectors when they are underperforming is a sustainable approach.

Bulbs: Cultivators should make sure lights are unplugged and have had at least 20 minutes to cool before cleaning or replacing. Using glass wipes to wipe down the bulb and lens is advised, if applicable. Cultivators should wipe down lights once every two months or between harvests, but should not wipe the base of the lamp or the socket. Most manufacturers recommend replacing bulbs every 12 months, along with the reflector. However, bulbs used on a 12 hours on/12 hours off (“12/12”) schedule will typically have more rated life hours remaining after one year. Tracking micromole levels at the canopy level will ensure the proper amount of photons is hitting the plants. Tracking light levels and only replacing bulbs or lenses when they are underperforming is a more sustainable approach.

Ballasts: While magnetic ballasts should be replaced every two to three years because of decreased efficiency, electronic ballasts can often perform eight to 10 years. Buying a light once consisted of purchasing a bulb, ballast and reflector separately. However, most new technology includes an electronic ballast with the reflector, so no choice needs to be made.

- **Magnetic**: Magnetic ballasts preceded electronic ballasts, and are heavier, less efficient, and noisier than electronic ballasts. However, they may come with a longer warranty than electronic ballasts, and are less expensive and easier to repair.
- **Electronic**: Electronic ballasts have sensitive circuitry that is more difficult to repair than magnetic ballasts. Many electronic ballasts have dimmable options that can help put less light on the plants during sensitive stages of growth. The dimmable option can also be helpful in controlling the room temperature in extreme weather conditions. As mentioned above, the electronic ballast is more efficient, creates less heat and noise, and typically lasts longer than a magnetic ballast. RFI (radio frequency interference) has been a problem with older electronic ballasts, but manufacturers have been working hard to correct that deficiency.

Cords/Connection: Cultivators should thoroughly check electrical cords for any damage, cuts or abrasions that could affect performance. Also, cords should be inspected for secure connection at the outlet as well as the fixture.

LED
Optics: Some LED manufacturers will utilize a glass or plastic optic over the diodes. These optics should be cleaned every two months with a nonsolvent cleaner and nonabrasive microfiber cloth.

Diodes: Top-of-the-line diodes are rated to maintain up to 90% of their output for 50,000 hours. That’s over a decade on a 12:12 schedule.
(a grower will need to consider if 10% loss of light is acceptable). However, they are still relatively new, and the technology is still improving. Even if the diode is capable of lasting 50,000 hours, drivers would also need to last that long, and consideration would need to be taken for how often the optic lens would need replaced.

**Fans:** Some LED fixtures also include cooling fans. Most advanced LED manufacturers build lights without fans. These fans have moving parts that can fail and may need to be replaced. Cultivators should look for wet location-rated fixtures, indicated with an IP65 or higher label.

**Cost of Light**

It is important to consider all applicable costs when designing or updating a facility’s lighting setup. Purchase price is a small portion of the total cost over the equipment lifetime. Cost to operate, useful life, maintenance costs and disposal costs – as well as failure scenarios and associated costs – should be calculated and included in lighting decisions.

**Resources:**
- Gavita Lighting - Lumens are for Humans
- Greenhouse Product News - Greenhouse Lighting Options
- ACF Greenhouses - Indoor Plant Grow Light Guide
- Economic Analysis of Greenhouse Lighting - Light Emitting Diodes vs. Intensity Discharge Fixtures

**CASE STUDY:**

**HPS to LED conversion in Veg**

The Clinic replaced 72 1000w single-ended HPS lights in their vegetative room with a mix of 6 bar and 10 bar BML (now Fluence) LED lights. There was an immediate electrical savings of 36,360W in that room. The Clinic also saw a decreased demand on their aging HVAC equipment due to the lower load in the room and ability to increase the temperature set point without detriment to the crop. In addition to the energy reduction in the room, the LED lights have actually sped up the process to get the plants to the right size and decreased the growing period by 1-2 weeks.

**By the numbers:**

<table>
<thead>
<tr>
<th></th>
<th>Original Configuration</th>
<th>New Configuration</th>
<th>Monthly Electric Savings</th>
<th>AC Tonnage Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>72 HPS single ended</td>
<td>72 BML LED fixtures (36 660w, 36 333w)</td>
<td>36 kW 19,000 kWhs</td>
<td>10 Tons</td>
</tr>
<tr>
<td>Monthly Electric Savings</td>
<td></td>
<td></td>
<td>$1,400</td>
<td></td>
</tr>
</tbody>
</table>
Climate control systems can account for 50 percent or more of the total energy consumption in an indoor cultivation facility. Climate control consists of multiple components such as heating, ventilation, air conditioning (HVAC) and dehumidification. As such, proper climate system design, installation, commissioning, and maintenance are crucial aspects of a sustainable cultivation process. Proper climate design is critical to operational efficiency and biosecurity. In many cases, climate control will be the single largest capital investment a cultivator makes after real estate. While purpose-built cannabis cultivation facilities allow for optimal climate design, the majority of indoor cultivation sites are repurposed facilities – which adds a layer of complexity to the HVAC optimization equation.

**PROCESS DESCRIPTION**

In addition to requiring different approaches for purpose-built versus retrofitted facilities, optimizing climate system operations will depend on myriad facility-specific factors such as size, layout, growing method, lighting system design, watering schedule and local ambient conditions. Due to the complexity of HVAC and dehumidification systems, it is strongly recommended that facility managers consult with a HVAC/mechanical designer familiar with the cultivation space. Engineering firms stamping mechanical designs must be licensed by the Colorado Secretary of State. Installing contractors operating in Denver must be licensed by the city in addition to holding a license from the State of Colorado. Facility managers may also find it beneficial to select engineering firms with specific sustainability credentials such as a Certified Energy Manager® or LEED® accreditations.

It is important to note that typical HVAC systems are designed for comfort cooling and occupancy ventilation. These systems can present challenges in cultivation environments that will need to be understood and addressed at the design phase. Systems specifically designed for process cooling will often address these challenges and should be considered when budget allows.

Cooling is not the addition of cold air, it is the removal of heat. The act of cooling is simply the absorption and relocation of British thermal units.
(BTUs) – the amount of thermal energy required to change the temperature of one pound of water one degree in one hour. The more energy efficient the heat exchange, the more energy efficient the cooling system.

It is important to understand the efficiency of the system as a whole for the intended purpose when evaluating any climate system.

Commonly used equipment ratings SEER (Seasonal Energy Efficiency Rating), EER (Energy Efficiency Rating) and IPLV (Integrated Part Load Value) are limited to specific uses and often specific equipment. On the surface, a high rating might make one system look more energy efficient than another. For instance, when comparing the EER rating on a 100-ton chiller and the EER rating on a three-ton mini-split air conditioner, it might appear that using 33 mini splits is more energy efficient. This is not the case, as the other components of the chiller system (fan coils, pumps, transport energy, etc.) are not accounted for in this rating. Further, adding up the running load amps (RLA) of 33 three-ton mini splits and comparing those to the RLA of one 100-ton chiller will show that the 100-ton chiller consumes significantly less energy in operation.

COOLING METHODOLOGY

Evaporative Cooling

Evaporative cooling is a low-energy cooling method in which heat is absorbed from the space through the evaporation of water. Although this is an energy-efficient method of cooling for comfort applications and is especially attractive in dry climates, evaporative cooling is not recommended for cultivation spaces due to the introduction of humidity to the space.

Mini Splits

Small, ductless HVAC units allow for quick owner installation at a relatively low cost. These units have high-efficiency and low-ambient temperature options available. They are a viable option for small-scale facilities (less than 1,000 square feet in size), but should not be considered in large operations due to the limitation on available tonnage and, therefore, the additional space and electrical connection points required. These systems lack direct dehumidification control and are designed for comfort cooling applications, though they will provide some indirect dehumidification capability (if the space’s relative humidity is high enough) as a byproduct of the cooling process. The important thing to note is that the dehumidification capability cannot be directly controlled, which means that it does not allow the cultivator precise control of the indoor relative humidity (RH).

Standard HVAC Systems

Generally described as rooftop units (RTUs), these units are common and relatively inexpensive. The complete HVAC system comprises a supply fan, filtration (limited), compressor, condenser and evaporator contained in a single housing. Air from the cultivation space is moved through ducts to the unit’s evaporator, where heat is removed, and cold air is returned to the cultivation space. This is generally an inexpensive option with mid-range energy efficiency, but can present challenges associated with excessive ductwork, redundancy, low temperature operation and requirements for building ventilation.

Many existing facilities are using RTUs in ways that are far beyond the original design intent of the systems. This leads to poor performance and high energy bills. Frequently, microbial problems arise due to the inability of these systems to successfully manage the cultivation environment.

Variable Refrigerant Flow

Variable Refrigerant Flow (VRF) systems are refrigerant-based heat pump systems that allow the use of one outdoor condensing unit with multiple fan coil unit (FCU) zones within a facility. Each FCU has variable cooling capacity to meet load, promoting a higher level of indoor unit zoning and distributed cooling without the ductwork that would be typical of a packaged HVAC system. Further, VRF systems, which include variable speed compressors that offer varying cooling loads, allow for variation in power consumption. With these systems, heat can be redirected to cooling zones (and vice versa) to offer energy savings. This is typically more useful in an office environment where loads vary based on external environmental conditions than in cultivation facilities where loads stay consistent. Further, VRF systems lack the latent capacities requisite for the amount of dehumidification required in cultivation facilities, and do not allow for direct humidity control. Overall, VRF is a more energy-efficient
option than traditional HVAC methods, but is comparatively expensive to purchase and install; will require extensive infrastructure with multiple small compressors in larger facilities; and will require the use of a separate, stand-alone dehumidification system. VRF also carries the potential risk of leakage from exposed refrigerant piping.

**Chilled Water Systems**

Chilled water systems offer a standard solution for large-scale process cooling, data centers, large-scale buildings such as hospitals and airports, and energy-intensive manufacturing operations. In this system, the packaged water cooling machine (i.e., chiller) maintains a constant discharge water temperature (typically around 45 degrees F) from the warmer water returning from the space, thereby removing BTUs and heat load. This chilled water is then pumped indoors to distributed fan coils or air handlers throughout the space.

Chillers come in two types: air-cooled, which can be located outdoors and expel heat to the ambient air; or water-cooled, which can be located inside and expel heat to a cooling tower.

Chilled water systems are typically more expensive than traditional HVAC on small and mid-sized facilities, but on large facilities they are an extremely competitive option. Along with high energy efficiency, chilled water systems offer:

- The ability to isolate cultivation spaces without dedicating compressors to specific zones of the facility. This promotes the highest levels of system redundancy and allows for a reduction in the number of compressors needed when cultivators are “flipping” flowering rooms, which reduces system cost, electrical infrastructure and peak load operation.
- A high level of installation flexibility, allowing for changing capacity within any given space without changing the central system design.
- Dedicated dehumidification control when coupled with a reheat system; dehumidification can occur without sub-cooling the space.
- The ability to design for redundancy, as backups can take over if one piece of equipment fails.
DEHUMIDIFICATION METHODOLOGY

Cultivation facilities are notoriously high-humidity environments due to the massive amounts of water being added to the space. Ultimately, the water that is applied to plants is transpired by the plants and then needs to be removed from the space. The needs of dehumidification equipment will change as the parameters in the room change. The warmer the rooms can be kept during lights-off periods, the more efficiently dehumidification equipment will operate.

Standalone Dehumidifiers

Standalone dehumidifiers typically consist of small, free-hanging (plug and play) dehumidification units used to supplement the dehumidification offered by the cooling system during lights-on periods and as the primary source of dehumidification during lights-off.

Standalone dehumidifiers are more energy-intensive than larger-scale dehumidification methods due to the use of small compressors, and output is limited by temperature parameters in the space (the lower the temperature, the less output the units produce). Generally, standalone dehumidifiers are the most affordable and easiest systems to integrate, but due to their plug-and-play nature, they can be difficult to integrate with other climate control equipment.

Reheat

Without a standalone dehumidifier to achieve dehumidification, AC systems often cool the air below the desired temperature, and then reheat the cooled air as needed. There are several methods to accomplish this reheat. For smaller grows, generally it is more energy-efficient to use standalone dehumidifiers than to rely on a standard AC system with electric or fossil-fuel reheat for dehumidification. However, chilled-water systems with heat recovery and AC systems with integrated hot gas reheat can provide cooling and dehumidification very efficiently for medium-size or larger grows.

- **Electric reheat:** Electric heat strips are utilized to produce heat. Electric reheat is not energy-efficient, and standalone dehumidifiers will save energy compared to this option.
- **Natural gas or propane reheat:** Natural gas or propane is used to produce heat in order to reduce the ambient-air relative humidity. More advanced air handlers (in chilled water or standard HVAC systems) will often have this as an integrated option, or this function can be achieved with stand-alone gas heaters.

- **Hot-water reheat:** Common in chilled-water systems, hot water is supplied to fan coil units through a gas-fired boiler system. Advanced systems can vary the flow rates of hot and chilled water to achieve environmental set points in the most efficient way, saving energy.

- **Chilled-water system heat recovery:** A chilled-water system can be designed to perform the needed reheat by using recovered heat from the system’s condenser coil (basically, the heat removed through the dehumidification process is reinjected into the airstream prior to distribution to the room.) The cooled and dehumidified air is reheated through a heat exchanger with the water heated from the condenser.

- **Hot gas reheat:** Some more sophisticated rooftop AC systems come equipped with an additional outdoor condensing coil for reheat. This additional coil and the associated controls allow the system to reject heat to the outdoors when cooling is required in the space (lights-on periods), or to use the other condenser coil for reheat when there are minimal sensible cooling needs (during lights-off periods).

Desiccant

Desiccant dehumidifiers use desiccant media to absorb moisture from the space by rejecting the added moisture to an exhaust air scavenger airstream. For this system to work optimally, the desiccant media is heated on the exhaust side so that the moisture can be released outside to the environment, and the desiccant is reused. Desiccant humidifiers require the lowest amount of energy and can operate in a wide range of temperatures, but can be cost-prohibitive and are generally only used on large-scale facilities.

Economizers

“Economizer” is another term for free cooling, utilizing the outdoor ambient environment to assist with temperature management of the cultivation space. Air-side economizers
are units that utilize ventilation as a cooling method when ambient temperatures are below the set point in the cultivation space. While air-side economizers are an energy-efficient solution, they create more problems in cultivation environments than they solve with regard to CO₂ enrichment, biosecurity and odor control, and are generally not recommended (See “Ventilation and CO₂” section for additional details).

Water-side economizers (or fluid coolers) can be utilized in both chilled water systems and in water-cooled condensing units and allow for free cooling without ventilation. When utilized in chiller systems, water-side economizers can reduce wintertime energy consumption dramatically by bypassing the compressors entirely when temperatures drop below 40 degrees F, utilizing cold outdoor temperatures to chill the water. On water-cooled condensers (in certain geographies) fluid coolers can be utilized in place of cooling towers for the condensing water loop.

AIR MOVEMENT
Air movement over the plant canopy is critical for transpiration of moisture and the prevention of pests and fungus. Cultivators should examine cubic feet per minute (CFM) per watt when evaluating canopy fans for efficiency.

Destratification fans are important to energy-efficient climate management, particularly when ceiling heights exceed 10 feet. Destratification fans create vertical airflow and ensure that heat and humidity trapped at the plant canopy reach the ceiling, where the cooling and dehumidification equipment is typically located and can exhaust heat and moisture.

Airflow and airspeed both need to be studied more closely in controlled cannabis environments so that the industry can create baseline standards; however, the baseline generally accepted for most crops for airspeed is 1 m/s.

VENTILATION AND CO₂
In many CO₂-enriched environments, ventilation or air-side economization may waste significant amounts of CO₂ (which can conflict with the energy code and efficiency efforts overall).

Cultivators should carefully weigh efficiency gains associated with ventilation against CO₂ waste to determine accurate costs and greenhouse gas emissions associated with both. Limiting ventilation can also be helpful to biosecurity efforts and in minimizing exposure to contaminants, possibly reducing reliance on pesticides or fungicides.

Although common, gas-fired CO₂ generators should not be used in modern indoor grow facilities. Generators contribute high levels of waste heat while operating and many are not vented properly, leading to dangerous indoor environments. Bottled CO₂ is a better substitute practice.

DESIGN STANDARDS
The American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) publishes commonly accepted HVAC standards for architects and engineers. As a starting point, facility owners may benefit from familiarizing themselves with ASHRAE 90.1, Energy Standard for Buildings. ASHRAE has also published an Advanced Energy Design Guide Series focused on reducing energy building use, which is available as a free PDF download.

BEST PRACTICES
One of the most common mistakes made by business owners is failure to invest in regular HVAC system maintenance. While initial system design and equipment procurement are critical, all HVAC systems require regular maintenance to ensure peak operating efficiency. Periodic inspections should be completed, during which time filters should be inspected and replaced, condenser/evaporator coils should be cleaned and electrical connections should be checked. The U.S. Environmental Protection Agency (EPA) recommends semi-annual maintenance checkups for all commercial HVAC systems.

As described above, selecting the most energy-efficient HVAC and dehumidification systems is highly dependent on operational factors, including the size of the facility and the budget. Below are some general energy-efficiency recommendations:
For very small facilities, mini-split systems can be an efficient HVAC option.

For larger facilities, variable refrigerant flow and chilled water systems offer higher efficiency and redundancy compared to standard packaged systems.

If using stand-alone dehumidifiers, cultivators should consider pints per kWh when evaluating for efficiency. Cultivators should also pay attention to performance curves – dehumidifiers are rated at Association of Home Appliance Manufacturers (AHAM) standards of 80 degrees and 60 percent humidity, but some manufacturers publish output at 86 degrees and 80 percent humidity, which can be misleading if it not being compared using a common reference.

Chilled-water systems with heat recovery and AC systems with integrated hot gas reheat are the two most energy-efficient options for achieving integrated cooling and dehumidification.

Desiccant dehumidification can be highly efficient, but costly.

Cultivators should seal spaces to reduce CO exhaust, improve biosecurity and reduce odors emanating from the facility.

Cultivators should keep rooms warmer at night to manage latent load.

When possible, cultivators should provide shade for outdoor condensing units to reduce operating temperature and extend life. However, it’s important that provision of shade does not interfere with airflow around air cooled condensers, as interference with airflow can result in diminished capacity.

Resources:

- ASHRAE, Air Conditioning, Refrigeration and Heating Institute, See sample Preventative Maintenance schedule in appendix.
OVERVIEW

While the previous section discussed best practices pertaining to energy demand reduction, a comprehensive energy management strategy should also consider opportunities for supply-side improvements. Nearly all cultivation facilities in Denver receive electricity directly from the grid. For Xcel Energy customers, this means that the electricity being consumed in Denver facilities is generated using a mix of technologies as outlined below.

Table 4: Xcel Energy - Power Supply Mix for Colorado Customers

<table>
<thead>
<tr>
<th>Energy Supply</th>
<th>Total Generation Mix (%)</th>
<th>Median Lifecycle CO₂ Emissions (grams/kwh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>39.1%</td>
<td>1001</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>32.7%</td>
<td>469</td>
</tr>
<tr>
<td>Wind</td>
<td>23.5%</td>
<td>12</td>
</tr>
<tr>
<td>Solar</td>
<td>3.3%</td>
<td>46</td>
</tr>
<tr>
<td>Hydroelectric</td>
<td>1.4%</td>
<td>4</td>
</tr>
<tr>
<td>Other*</td>
<td>0%</td>
<td>-</td>
</tr>
</tbody>
</table>

*Includes biomass, oil and nuclear generation

There are two primary approaches to supply-side energy optimization that cultivators should consider as part of a broader energy-management strategy:

- **On-Site Power Generation:** One approach for facility managers looking to make supply-side improvements is on-site power generation. While a host of on-site generation technologies exist in the marketplace, two of the more common on-site options for cultivators to consider are solar photovoltaic (PV) and combined heat and power (CHP). While the economic, environmental and resiliency benefits of these technologies will vary depending on facility-specific factors, one advantage all on-site generation options share is the elimination of transmission losses. Roughly 5 percent of grid-generated electricity is lost in the transmission and distribution process. Onsite renewables such as PV may offset only 10% to 15% of a facility’s energy consumption, unless an area other than the roof footprint of the cultivation building is available to host PV panels.

- **Off-Site Optimization:** The second approach is entering into an alternative energy supply contract with a utility company. As discussed more specifically in the topic breakout, Denver businesses have multiple clean-energy procurement options. While utilizing this approach does not typically have the same economic or operational benefits associated with on-site generation, off-site optimization likely represents the simplest alternative for cultivators looking to reduce the environmental impact of their facilities.

As with the demand-reduction strategies presented in the previous section, there is not a one-size-fits-all solution to supply-side energy management. While the following best practices are intended to provide a starting point for discussion, facility managers are strongly encouraged to consult with a licensed professional prior to acting.

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6 Xcel Energy - Energy that Works for Colorado
7 IPCC Renewable Energy Sources and Climate Change Mitigation
8 U.S. Energy Information Administration
ON-SITE POWER GENERATION & STORAGE

Power generated on-site, commonly referred to as distributed generation (DG), can deliver economic, environmental and operational benefits to cultivation facilities in certain situations. Two DG technologies cultivators should evaluate are solar photovoltaic arrays (Solar PV) and natural gas cogeneration systems (Combined Heat & Power, or CHP). While these on-site generation options can result in excellent returns for facilities, implementation is a complex process and requires technical expertise, detailed coordination with the local utility, and careful financial planning. Cultivators should consult with an experienced technical specialist as part of the assessment process.

PROCESS DESCRIPTION

Performing a desktop feasibility study (also known as a qualification study) is typically the first step in the on-site power-generation procurement process. Facility managers should retain a technical specialist to perform this study, which is provided free of charge by many on-site power generation specialists. While there are many approaches to desktop feasibility studies, the process typically requires facility managers to fill out a brief survey and provide six to 12 months of utility bills. Using this information, specialists can build a high-level model that provides a “ballpark” economic, environmental and operational impact assessment.

If the desktop feasibility study indicates an attractive value proposition, the next step is performing a Level 1 Feasibility analysis. The EPA provides a sample Level 1 Feasibility Analysis for facility managers to review; in the event a project proceeds, a Level 2 Feasibility Analysis is subsequently performed.

During this process, project-specific design engineering is accomplished, equipment options are formally evaluated and detailed financial analysis is completed. Following the conclusion of the Level 2 Feasibility Analysis, the project team is typically ready to submit necessary permits, with construction beginning shortly thereafter.

Financial planning for cannabis businesses can be different from traditional businesses. Many financial stimuli from local, county, state and federal entities exist to accelerate the adoption of energy-efficiency measures and renewable technologies, and they should be thoroughly leveraged. However, for a cannabis business,
it would be wise to consult with financial specialists before making assumptions about tax treatments with regard to renewable investment tax credits, utility rebates, and operating expense deductions versus capital expenses (depreciation).

Table 5: No-Carbon and Low-Carbon Energy Sources for Cultivation Facilities

<table>
<thead>
<tr>
<th>ENERGY TYPE</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar PV</td>
<td>Solar Photovoltaic Systems (Solar PV), convert sunlight into usable electricity. Solar panels use sunlight to generate electricity, and inverters convert that electricity from variable direct current (DC) to alternating current (AC) at the correct voltage, frequency, and phase needed to tie into the facility’s electrical infrastructure and the larger electrical grid. For cannabis cultivation facilities, these systems will most frequently be installed on the building’s roof, though some properties might be able to benefit from solar system installed on the ground (ground-mounted) or in the facility’s parking lot. Because the economic returns from on-site solar systems are typically dependent on utility-specific regulations, facility owners should consult with utilities prior to project design.</td>
</tr>
<tr>
<td>Cogeneration (CHP)</td>
<td>CHP systems use a natural gas generator (engine, turbine, or fuel cell) to produce electricity and repurpose the waste products to offset the facility’s HVAC and CO₂ needs. When done properly, this process can reduce a cultivation facility’s emissions footprint by 25 percent to 45 percent, generate attractive economic returns and serve as reliable source of power during grid outages. While CHP systems offer an exciting value proposition, these systems also feature comparably complex technology and require significant technical expertise throughout the design, build and maintenance phases. Cultivators looking to benefit from CHP technology should enlist a qualified third party to guide the process.</td>
</tr>
<tr>
<td>Wind</td>
<td>Small wind turbine systems can be installed alone or in conjunction with solar photovoltaic systems. The small size and variability of energy produced by these systems makes them most applicable for supplementing another power source. The amount of energy small wind turbines can provide depends on the site, size and height of the turbine, but small wind systems for commercial buildings typically generate 20 kilowatts to 100 kilowatts. To determine the amount of wind energy available at a site, installing an anemometer for at least 12 months prior to system purchase is recommended. Wind power is not commonly used in metropolitan areas as permitting and conformance with local zoning and building codes may prove challenging.</td>
</tr>
</tbody>
</table>

Figure 2: Comparison of energy inputs and associated outputs of standard or grid energy use versus a Combined Heat and Power (CHP) system.

Resources:
- National Renewable Energy Laboratory - Solar Energy Basics
- Environmental Protection Agency - CHP Benefits
- National Renewable Energy Laboratory - Commercial & Industrial Solar Best Practices
- U.S. Environmental Protection Agency - CHP Project Development Steps
- Xcel Energy - Distributed Generation Guidelines
- Boulder County Marijuana Energy Impact Offset Fund
Off-Site Energy Supply

An alternative for cultivators looking to reduce the environmental footprint associated with electricity production is to explore off-site energy supply opportunities. Denver facilities served by Xcel Energy should investigate the Solar Rewards Community program, commonly referred to as solar gardens.

Program Description

Colorado was the first state to offer community solar opportunities for customers of investor-owned utility companies, and Denver grow facilities can benefit from renewable energy production situated and managed off-site. Customers “subscribe” to a portion of the solar array and benefit from the array’s output over medium- and long-term contracts. Any entity with an Xcel electric account can benefit from this arrangement, including building owners, renters or managing parties. Recently, community solar developers have been hesitant to contract with the cannabis industry. It is important to continue reaching out to developers to assist in the evolution of this portion of the clean energy industry.

Best Practices

In Denver, electricity consumers can also choose to independently contract with the owner/operator of a qualified solar array. Under this arrangement, a third party builds a community solar system and sells the electrical output to Xcel. Xcel then credits the customer for that electricity on the customer’s monthly electric bill, commonly referred to as net-metering. It is important to note that cultivators may or may not save money by participating in this arrangement, as agreements are made directly with the owner of the community solar array. The utility simply acts as a facilitator in this arrangement. Contracts are generally longer-term, where monthly electric savings outweigh financing costs leading to positive cash flow for the customer.

Resources:

- Xcel Energy - Community Solar Program
- Colorado Energy Office Community Solar Information

Sustainability Aspects and Impacts

- GHG emissions
- Land use
- Climate
- Regional stakeholder alignment
- Operational and compliance budgets