## Summary Report of

# Cannabis Cultivator Energy Efficiency Assessments


**Prepared for**
**Boulder County**

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# Contents

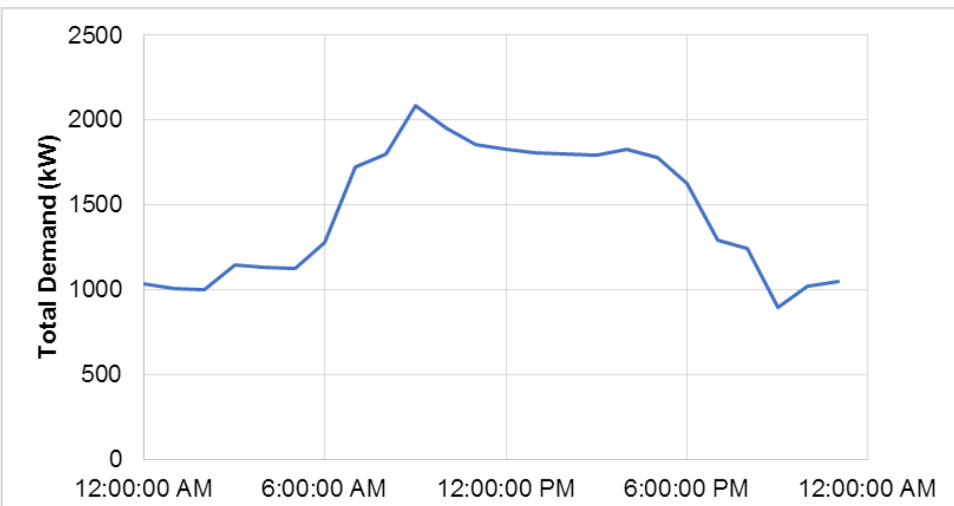
# 1 Executive Summary

## 1.1 Key Findings

ERS has conducted energy assessments of cannabis cultivation facilities in Boulder County to assess the current energy use, productivity, and energy efficiency opportunities at these facilities. ERS analyzed electric interval data for 14 facilities. Of these 14, ERS was able to collect complete electric, heating fuel (natural gas and/or propane), and production data for nine of the facilities. In some instances, facilities were not willing to provide production data, in other cases, multiple sites are served by one natural gas meter, and site level natural gas utility data is not available. Some facilities have no gas service or propane and heat with electricity.

The combined facilities produce an average annual peak electrical demand of just over 2,000 kilowatts (kW) which occurs at 9 a.m. Figure 1-1 illustrates the combined load shape of the 14 facilities analyzed. This load shape is largely reflective of the load shape of most cultivation facilities in Boulder County. There are facilities that operate with different load profiles due to staggered flower room operation, or facilities that operate their rooms at night.

**Figure 1-1.Boulder County Level 24-Hour Average Electric Load Profile – kW**




The Boulder County level site-energy and source-emissions impacts are presented in Table 1-1.

**Table 1-1.Boulder County Level Energy Impacts**

| Annual kWh | Average Peak MW | Annual MMBtu – Natural Gas and Propane | CO2 Equivalent - Tons |
|---|---|---|---|
| 13,208,879 | 2.1 | 11,902 | 10,394 |

ERS compared the performance of the indoor and greenhouse cultivation facilities with the Resource Innovation Institute (RII) PowerScore, a national database of self-reported cannabis facilities. The RII PowerScore database includes self-reported electric energy utility data, production data, and information on facility systems including horticultural lighting and HVAC systems. There are approximately 250 facilities in the database including indoor and mixed light[1] facilities. ERS filtered the data to include either indoor or mixed light facilities where high-intensity discharge (HID, either HPS or MH) fixtures are used for flowering The data was filtered to only include HID fixtures in order to provide a like comparison to peer facilities with the same technology since all facilities in Boulder County currently flower with HID lighting technology. No facility in Boulder County currently makes use of LED fixtures for the flowering phase. The RII database currently includes electric energy use data but does not include fuel use data. The database includes a general description of the type of HVAC system used, but does indicate how the facilities are heated, or what the heating fuel is. Using data from the EIOF assessments, we can compare the facilities in terms of kWh/$sf_{flowering}$, grams/kWh, and grams/$sf_{flowering}$. Comparison to the average Boulder County indoor performance is presented in Table 1-2, with comparisons of mixed light facilities presented in Table 1-3.

**Table 1-2.Boulder County Average Indoor Facility Electric Energy and Productivity National Comparison**

| Metric | Percentile |
|---|---|
| kWh/$sf_{flowering}$ | 40th |
| grams/kWh | 65th |
| grams/$sf_{flowering}$ | 90th |

**Table 1-3.Boulder County Average Mixed Light Facility Electric Energy and Productivity National Comparison**

| Metric | Percentile |
|---|---|
| kWh/$sf_{flowering}$ | 5th |
| grams/kWh | 55th |
| grams/$sf_{flowering}$ | 95th |

It is not possible to make accurate comparisons of facility performance based on electric energy use alone, when comparing to facilities that use fuel for heating. What is clear from the national

[1] Greenhouses are referred to as "mixed light" since they use a mix of natural and artificial light

comparisons, however, is the productivity of Boulder County facilities in terms of grams/$sf_{flowering}$. Indoor and mixed light facilities are in the top 90th and 95th percentiles, respectively, of national facilities that flower with HID technology.

Table 1-4 presents the source energy productivity values as well as the emissions productivity values. Data is presented for indoor and mixed light facilities. Site to source conversations are based on ENERGY STAR conversion values, while equivalent $CO_2$ emissions conversion factors are based on Xcel Energy's emissions factors.

**Table 1-4. Source Energy and CO2e Productivity Metrics**

| | Average | | Min | | Median | | Max | |
|---|---|---|---|---|---|---|---|---|
| | Indoor | Mixed Light | Indoor | Mixed Light | Indoor | Mixed Light | Indoor | Mixed Light |
| Site energy productivity - grams/MMBtu | 201 | 230 | 101 | 229 | 211 | 230 | 289 | 231 |
| Source energy productivity - grams/MMBtu | 75 | 120 | 36.8 | 119 | 89 | 120 | 103 | 120 |
| $CO_2e$ - grams/lb | 0.49 | 0.84 | 0.24 | 0.84 | 0.60 | 0.84 | 0.67 | 0.84 |

Through the assessment process, ERS identified several cost-effective energy efficiency measure opportunities at each site. The results of the portfolio wide assessment are presented in Table 1-5. Simple paybacks after applying incentive estimates ranged from immediate to 13 years and averaged just over 4 years. The measures represented in the table below include:

- LED and ceramic metal halide horticultural lighting
- Retrofitting florescent fixtures with LED tubes
- Packaged HVAC condenser evaporative pre-coolers
- Variable frequency drives on fan motors
- High efficiency packaged HVAC units with hot-gas bypass reheat
- Radiant heating
- Energy curtains
- Lighting controls
- Cold-climate mini split heat pumps to replace electric resistance unit heaters

**Table 1-5. Total Likely Achievable Energy Efficiency Improvements**

| Metric | Value | Units | % Reduction |
|---|---|---|---|
| Annual electric savings | 3,564,171 | kWh | 37.0% |
| Peak demand reduction | 770 | kW | 36.9% |
| Natural gas and propane savings | 1,712 | MMBtu | 11.5% |
| Annual $ savings | $345,197 | | |
| Installed cost | $2,417,720 | | |
| Potential Incentives – Includes Xcel, PACE, and EIOF credits | $963,627 | | |
| Simple payback on energy savings after incentive - years | 4.2 | | |

The key findings of the site level and Boulder County level analysis are below. Further analysis and discussion on each finding are presented in Sections 3 and 4:

- **Energy intensity** - While indoor facilities are more electrically intense due to 100% reliance on artificial lighting, greenhouses are more fuel intense due to poor envelope performance inherent with greenhouses. The greenhouses therefore use approximately 30% less combined electrical and fuel energy per square foot of flowering canopy ($MMBtu/sf_{flowering}$) than the indoor facilities.
- **Productivity** – Mixed light facility productivity in terms of grams of dry usable product per MMBtu of site energy, all fuels included (grams/MMBtu), is approximately 15% better than the indoor facilities. In terms of source energy, the mixed light facilities are almost 60% more productive per unit of energy at the source level. This is due to the lower use of electric energy, which has a much higher site-to
- **Emissions** – When considering grams of product produced per pound of $CO_2$ equivalent emissions ($CO_2e$), the mixed light facilities are nearly 70% more productive.
- **Lighting** - Horticultural lighting across the Boulder County portfolio represents 45% of total annual energy use and 65% of the annual electrical energy use. Horticultural lighting accounts for 69% of the total annual energy use in the indoor facilities, 32% of the total annual energy use of mixed light facilities. This high proportion of energy use necessitates consideration of LED horticultural lighting retrofits.
- **HVAC** - The lower proportional use of HVAC energy in indoor facilities limits the opportunity for cost-effective retrofits to existing systems based on energy savings alone. Since HVAC energy costs are a smaller portion of total energy costs, even large savings reductions produce relatively small cost savings. Those savings weighed against the initial

capital costs needed for large HVAC efficiency improvements yield long payback periods. A more attractive opportunity for HVAC improvements lies in new construction, expansions of existing facilities, or the during replacement of failing or failed HVAC equipment. At these times, cultivators are purchasing HVAC systems and an opportunity exists to promote or incentivize more efficient options. In a retrofit project, the energy savings must support the entire project cost in terms of simple payback. In a new construction scenario, the energy savings between a standard efficiency option and a high efficiency option only need to support the incremental cost between the two systems. This approach produces more attractive simple paybacks and is an ideal time to prevent lost opportunities during facility build-out.

- **Low cost/no cost opportunities** - Several facilities have attractive no cost/low cost opportunities associated with reducing vegetative photoperiod from 24 hours to 18 hours, through staggering the operation of flower rooms to reduce electric demand costs, and through changes in lighting layout to reduce lighting power density (LPD, watts/sf).

## 1.2 Recommendations

- **Education** - Provide education and resources relative to the current performance of LED horticultural fixtures, and best practices on how to grow with LED fixtures. The Resource Innovation Institute (RII) has recently published a best practices guide for LED horticultural, attached here as an appendix. LED performance has improved substantially in the past few years. Retrofitting existing horticultural fixtures with high-performance[2] LED fixtures represents the largest opportunity for energy and demand savings, representing approximately 70% of the identified cost-effective savings opportunities.

  Electric demand charges, and the implications on operating costs, are still not well understood by the cultivator community. ERS recommends that Boulder County present an educational session on Xcel Energy demand rates at an upcoming cultivator workshop.

- **Lighting Power Density –** Facilities with higher lighting power densities (LPD) generally use more energy per gram of product, but these higher LPDs do not achieve higher photosynthetic photon flux densities (PPFD, μmol/sec/m$^2$) values or increased production. This is generally because facilities with higher LPDs had the flower fixtures mounted substantially higher above the canopy. The additional height requires more fixtures in order to achieve the target PPFD values. Proper mounting height and fixture layout will waste less light, instead focusing the light on the canopy.

[2] The energy assessments considered LED fixtures with a photosynthetic photon efficacy (PPE) of >2.4 μmol/joule and a photosynthetic photon flux (PPF) of >1600 μmol/second to be "high-performance".

- **Photoperiods** - Suggest cultivators operating 24-hour vegetative photoperiods consider switching to 18-hour photoperiods, as this reduces lighting energy use for this phase of growth by 25%. This savings approach directly impacts the current cultivation process of those facilities. While 18-hour vegetative photoperiods are common nationally and in Boulder County, the authors cannot provide any conclusive evidence on potential production impacts associated with reducing vegetative photoperiods to 18 hours.
- **Campus Location** - With multiple facilities on one master meter, there is no incentive for individual operations to improve energy performance as they could only realize a portion of that savings, since overall campus electric costs are pro-rated to each site based on their facility square footage. Individual facilities would still directly benefit from reductions in their offset fees that come from the lower energy use as measured on the Boulder County eGauges. Boulder County could encourage the facilities located at a single campus and their property owner to have utility sub-meters installed at the individual locations, or to coordinate their operations relative to flower room scheduling to reduce peak demand and lower the electric rates of the campus population, or to leverage the existing eGauge meters to pro-rate electric costs to each site.
- **Facility Impact on Productivity** – Among these facilities, there is very little correlation between facility systems (lighting, HVAC, etc.), operational parameters (photosynthetic photon flux density, temperature, humidity, etc.), and facility productivity. This is in part due to the similarity of facility types, horticultural lighting technology, and HVAC system types across the portfolio. Plant genetics and cultivator skill play a large role in the productivity and efficiency of these facilities. Consider organizing site visits among cultivators to share experiences and to facilitate "coop-atition" among Boulder County operators. Opportunities for energy and productivity improvements were found at all facilities.
- **Daily Light Integral Controls** - We recommend that Boulder County fund the installation of photosynthetically active radiation (PAR) meters in the greenhouses to trend PPFD and daily light integral (DLI). It is very difficult to estimate the average PPFD at the canopy in a greenhouse due to the complex interactivities between solar irradiance, building geometry, orientation, shading, and other site-specific considerations. The installation of PAR/DLI meters will provide the data necessary to accurately assess the potential impact and cost-benefit of DLI based lighting controls in the greenhouses. DLI controls have the potential to reduce energy and demand, and to provide a more consistent cultivation environment. These systems pair particularly well with LED horticultural fixtures. DLI

based control has shown substantial savings in food crops[3], but their cost-effectiveness in cannabis cultivation, with higher DLI requirement than most other crops grown in greenhouses, is not well documented.

- **Outdoor Air Economizing** – Boulder County has an excellent climate for offsetting a portion of cannabis facility HVAC loads through the introduction of outdoor air. This measure is extremely rare in cannabis cultivation facilities as most facilities operate with a $CO_2$ enriched atmosphere. Cultivators are also concerned about introducing biological contamination into their facilities through outdoor air. Mold spores, insects, and pollen from outdoor hemp or cannabis cultivation could adversely impact production. HVAC systems with filters having a MERV 14 rating can mitigate the introduction of mold, mildew, pests, and pollen from through outdoor air.

  One Boulder County cultivator has experimented with economizing with good results. They introduce a small amount of outdoor air through the rooftop units. The ventilation of the space associated with the introduction of outdoor air has lowered their operational $CO_2$ from 1,000 PPM to 600 PPM. This cultivator reports better growth at the lower $CO_2$ level, and states that the environmental conditions are more stable. This facility also has proportionally lower HVAC use then other very similar facilities. A more precise way to control the introduction of outdoor air would be through dual-enthalpy sensors. Enthalpy is a measurement of the amount of energy is a pound of air (Btu/lb). By measuring the indoor enthalpy and the outdoor enthalpy, control systems can modulate outdoor air to maximize the available cooling benefit. Dual enthalpy sensors require regular maintenance and calibration to remain effective.

# 2 Summary of Approach

This section summarizes the data leveraged and the analysis methods employed in the assessment of the individual facilities and at the portfolio level.

## 2.1 Data Collection

ERS collected data on individual facilities through site-visits, communication with the site operators, site supplied production data, eGauge electric interval data, electric utility data, natural gas utility data, on-site measurements, and traditional and wireless logging meters.

A summary of the data points and sources are provided in Table 2-1.

[3] Harbick, K et al. *Electrical savings comparison of supplemental lighting control systems is greenhouse environments.* 2016 ASABE Annual International Meeting http://elibrary.asabe.org/abstract.asp?aid=47203&t=5

**Table 2-1. Data Points and Sources**

| Data Point | Data Source |
|---|---|
| Facility equipment, layout, and operational details | Site visits, mechanical plans and schedules |
| Electric interval data | County eGauges |
| Solar intensity proxy | County eGauges |
| Electric utility bills | Provided by the site as applicable/available |
| Fuel utility bills | Provided by the site as applicable/available |
| PPFD | Measured on site with an Apogee quantum flux meter at the canopy |
| Temperature | Handheld Amprobe meter, traditional HOBO T/RH loggers, Infisense wireless T/RH loggers |
| Relative Humidity | Handheld Amprobe meter, traditional HOBO T/RH loggers, Infisense wireless T/RH loggers |
| $CO_2$ concentration | Handheld Amprobe meter, Infisense wireless T/RH loggers |
| Leaf surface temperature | Testo infrared thermometer |
| Watering rates | Provided by the site as available |
| Production data | Provided by the site as available |
| Historical weather data | NOAA |
| Typical meteorological year data (TMY3) | NREL |

## 2.2 Analysis Methods

This section presents an overview of the analysis performed to model and disaggregate existing energy use, and to assess the potential for cost-effective energy efficiency measures at individual locations.

### 2.2.1 Energy Analysis

ERS conducted site visits to collect site specific information on equipment, facility use, operational schedules, and key environmental metrics. Additional data was collected as noted in Table 2-1 above.

eGauge data was used to analyze the annual electric energy and demand. Electric energy data were regressed against numerous independent variables to identify strong and weak correlations, and to develop daily load profiles. Available monthly fuel data were regressed against monthly heating degree days (HDD) at different balance temperatures to identify balance temperature with the strongest $R^2$. These HDD values were then used to normalize fuel use to weather. The profiles and correlations were then used in conjunction with the site-specific equipment, operational details, and watering rates to build an energy model. The energy model was then calibrated with the eGauge and fuel data (where applicable), resulting in models that accurately reflect site specific load profiles, energy end-use disaggregation, and annual energy use (within 5% of actual).

### 2.2.2 Energy Efficiency Measure Assessment

ERS was tasked with identifying low cost/no cost measures as well as measures requiring larger investments. The assessment of measures considered several elements unique to each facility including:

- **Preference of the site** – If the site already had an energy efficiency project in mind, it was included in the assessment
- **Site requirements for payback on investment** – Though no site specified a specific timeline for return on investment, all indicated that short paybacks on energy savings were a necessity.
- **Cost effectiveness of the proposed measure** – Measure with a simple payback of 10 years or more, after potential Xcel, PACE, and EIOF credits, were generally not included. The exception to this is if the facility had a specific project in mind, in which case the assessment was included.
- **Level of facility disruption associated with a measure** – Consideration was given to the level of disruption a measure may cause to facility operation. While lighting retrofits are unobtrusive, substantial envelope work is likely to cause large disruptions to the operation of the facility.
- **Capital requirements of a measure** – The payback on investment were used as the litmus test for inclusion in a site report. Large capital costs none the less present a substantial hurdle (even with short paybacks), due to the Industry's lack of access to traditional sources of capital.
- **Ability of site-staff to operate and maintain the proposed system** – The cultivators wear many hats in the operation of their facility. Complex systems that require careful oversight to operate and maximize performance (such as water-cooled chiller plants, or combined heat and power systems), present substantial additional tasks for the operators to manage, in addition to an increase in maintenance costs.

# 3 Existing Facility Performance and Productivity

Substantial data was collected on each of the assessed facilities, which allowed for a "deep dive" into the performance of the individual facilities, and across the Boulder County portfolio. This section will present the aggregated Boulder County data. Individual sites are not identified, and data is presented in such a way as to ensure cultivator anonymity and confidentiality.

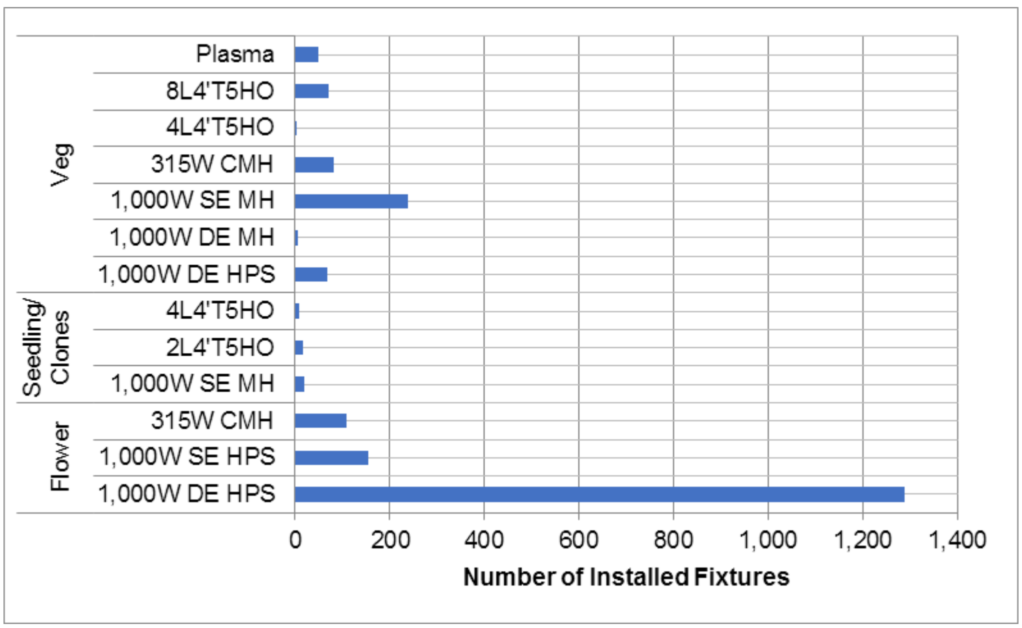
## 3.1 Review of Systems and Practices

This section reviews the lighting, HVAC, envelope, and cultivation parameters of the assessed facilities.

### 3.1.1 Lighting Technology and PPFD

All the sites make use of some form of HID lighting for flowering, and most use HID for vegetative growth as well. There is a clear standard practice for flower lighting technology based on the data presented in Figure 3-1. The standard for veg is less clear as a broader array of fixture technologies are employed for that phase of growth.

**Figure 3-1. Quantity of Horticultural Fixtures by Technology Type**




| Fixture | Name | Lighting Technology |
|---|---|---|
| Plasma | Plasma | Plasma |
| 8L4'T5HO | 8 lamp 4-foot T5 high output | Fluorescent |
| 4L4'T5HO | 4 lamp 4-foot T5 high output | Fluorescent |
| 2L4'T5HO | 2 lamp 4-foot T5 high output | Fluorescent |
| 315W CMH | 315-watt ceramic metal halide | High Intensity Discharge |
| 1,000W SE MH | 1,000-watt single ended metal halide | High Intensity Discharge |

| | | |
|---|---|---|
| 1,000W DE MH | 1,000-watt double ended metal halide | High Intensity Discharge |
| 1,000W DE HPS | 1,000-watt double ended metal halide | High Intensity Discharge |

PPFD measurements, measurements of the photosynthetically active radiation hitting the plant canopy, were taken at all site visits except one, where the fixtures were not on during the visit. Measurements were taken with an Apogee quantum flux meter and were recorded in µmol/m²/s. PPFD values were relatively consistent in veg rooms, ranging between 400-600, but varied more dramatically in flower rooms. The impact of fixture height and layout, and their influence on the light pattern from the fixture, were apparent. Moving the meter just a few inches horizontally or vertically, produces changes to the reading of +/- 100%. It was common to find PPFD values ranging from 500-1100 across the canopy of a given flower room. Table 3-1 presents the ranges of flower room PPFD measured on site.

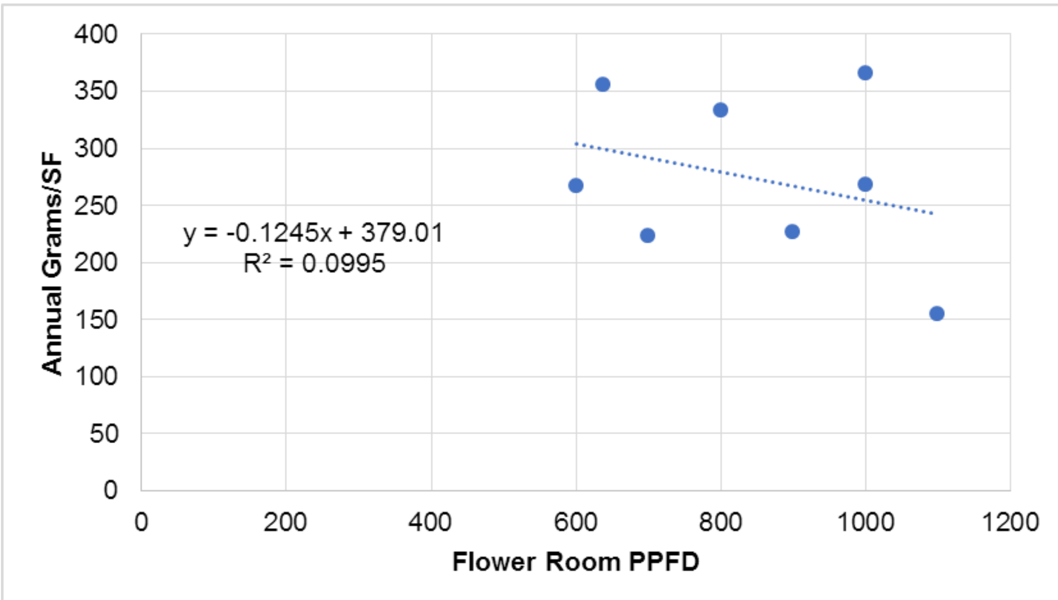
**Table 3-1. Flower Room PPFD Measurements**

| Flower Room | Measured PPFD Range |
|---|---|
| 1 | 600-1200 |
| 2 | 400-1100 |
| 3 | 400-800 |
| 4 | 400-800 |
| 5 | 400-800 |
| 6 | 900-1100 |
| 7 | 400-700 |
| 8 | 600-1400 |
| 9 | 600-1400 |
| 10 | 600-1400 |
| 11 | 600-1400 |
| 12 | 600-1400 |
| 13 | 600-1400 |
| 14 | 600-1400 |
| 15 | 400-500 |
| 16 | 400-700 |
| 17 | 900-1300 |
| 18 | 900-1300 |
| 19 | 700-1300 |
| 20 | 700-1300 |
| 21 | 900-1100 |
| 22 | 900-1100 |
| 23 | 900-1100 |
| 24 | 900-1100 |
| 25 | 900-1100 |

These values themselves do not provide much insight. But when facility PPFD is compared to facility production output, there is an interesting result.

There is wide-spread belief, and the academic research to back it[4], that light intensity is a key driver for plant growth. When other environmental factors are optimized, the rule of thumb states that for every 1% increase in light intensity, there will be 1% more growth. The correlation for this is weak however among Boulder County cultivators. Figure 3-2 presents a plot of flower room PPFD against annual facility production.

**Figure 3-2. PPFD vs. Grams/sf$_{flowering}$**




The relationship between facility productivity and PPFD is not apparent in the above plot. If anything, it suggests that grams/sf$_{flowering}$ decreases with increased PPFD. This result does not dispute that light intensity drives photosynthesis, but instead suggests that PPFD is but one factor that impacts facility productivity. Plant genetics, cultivator skill and cultivator experience substantially impact production. High lighting levels do not guarantee high yields.

Further to this point are Figures 3-3 and 3-4. Figure 3-3 plots flower room PPFD against flower room LPD. We again see a weak correlation, with higher LPDs generally representing lower PPFD. In Figure 3-4, we take the comparison one step further, comparing flower room LPD to overall facility energy use.

[4] Bugbee, Bruce. *Effects of Radiation Quality, Intensity, and Duration on Photosynthesis and Growth.* International Lighting in Controlled Environments Workshop, 1994

**Figure 3-3. Flower Room PPFD vs. Flower Room LPD**

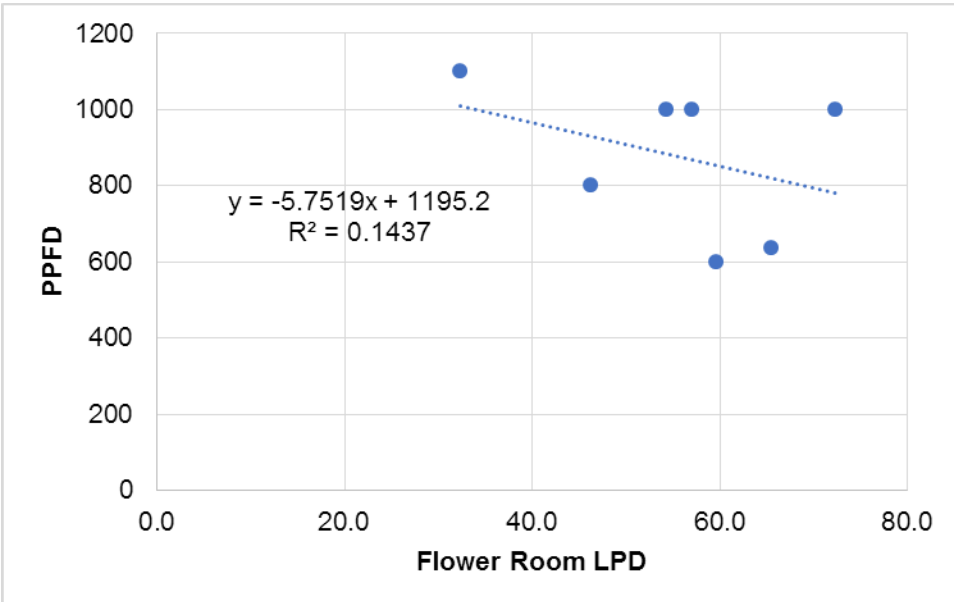
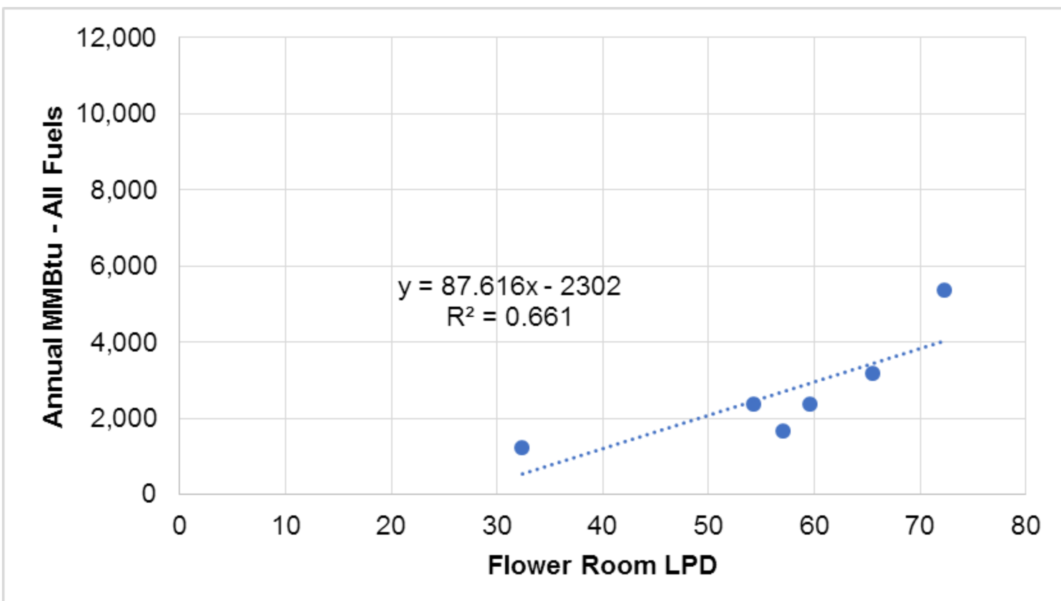



**Figure 3-4. Flower Room LPD vs. Annual Energy Use**



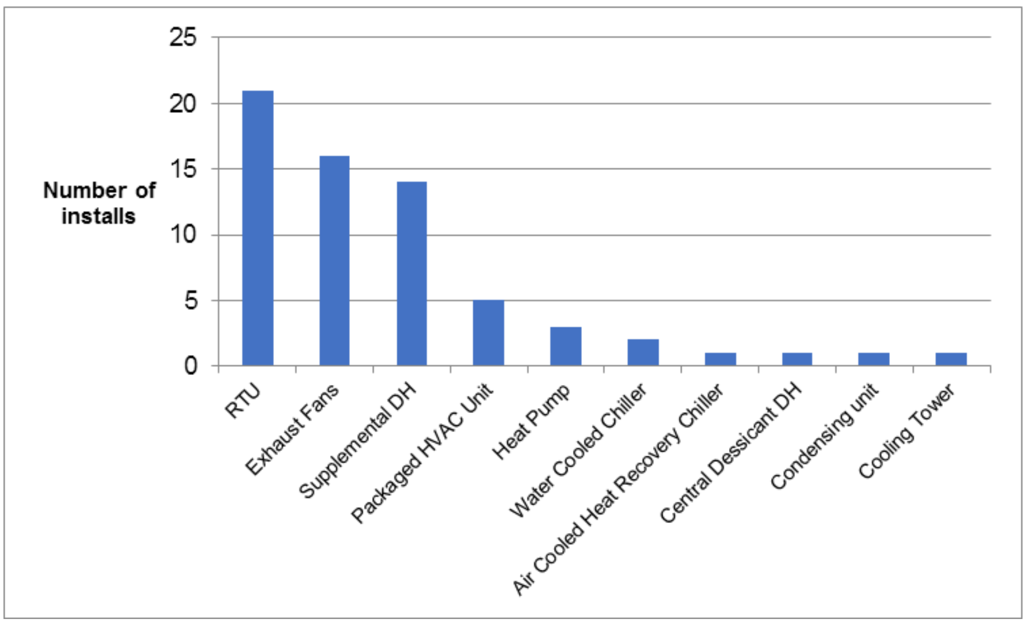

Here a correlation can be seen; as flower room LPD increases, total facility energy use increases.

To summarize; for these facilities higher PPFD does not correlate to higher production, and higher LPD does not correlate to higher PPFD. But higher LPD *does* correlate with higher energy use. Those with fixtures mounted closer to the canopy had the highest PPFD with the lowest LPD, while those that mounted their fixtures furthest from the canopy had higher LPDs and lower PPFDs. The sites with the lowest LPD and highest PPFD are making use of 315W ceramic metal halide fixtures. Ceramic metal halide fixtures and LED fixtures have the potential to provide target PPFD values at lower LPDs than high pressure sodium or metal halide fixtures.

### 3.1.2 HVAC Systems

Most of the facilities are served by packaged rooftop or ground mounted HVAC units. Of those facilities, the majority do not make use of supplemental dehumidification. While some of the units struggled to maintain room temperature during hot weather, and many experience issues of freeze up during operation in the winter, many facilities operated successfully with standard duty packaged HVAC systems. Typical packaged HVAC units are designed to provide cooling down to approximately 34° F. Operating these units at ambient conditions lower than that can cause the units to freeze. All major brands offer a low-ambient kit as a factory or field installed option. This is an important addition to any packaged HVAC units operating in cold climates. The traditional greenhouses are served by ventilation fans and evaporative pad walls for evaporative cooling. Figure 3-5 provides the quantities of each system type installed.

**Figure 3-5. HVAC System Quantities**




### 3.1.3 Building Type

All the indoor facilities are renovations of existing buildings. The buildings are older commercial and industrial spaces. Some of the facilities are just starting up, while others have been operating at the same location for up to 7 years. Facilities that addressed ceiling and roof insulation and have high albedo roofing should see the benefits of reduced solar heat gain in summer months. Table 3-2 provides a summary of building types and insulation systems.

**Table 3-2. Building Type and Insulation**

| Building Type | Insulation | Quantity |
|---|---|---|
| CMU and Metal | Spray Foam | 1 |
| Concrete and Metal | Spray Foam | 2 |
| | Unknown | 1 |
| | Uninsulated | 1 |
| Greenhouse | N/A | 2 |
| Hybrid | Insulated-unknown | 1 |
| Metal | Unknown | 1 |
| | Insulated-unknown | 1 |
| Metal Building | Spray Foam | 2 |
| | Unknown | 1 |
| CMU and Wood Frame | R18 | 1 |

## 3.2 Summary of Cultivator Interest

During the energy assessments, ERS had the opportunity to discuss the motivations, barriers, and needs of the cultivators relative to energy use and facility productivity. Highlights of those conversations are presented below.

- The cultivators were welcoming and were open to the process. They were curious and openly expressed interest in learning more about energy use and efficiency opportunities.
- The group was open to conversations about LED horticultural fixtures. Previous experience has shown that commercial cultivators are often reluctant to entertain the idea of converting to LED. Several are now actively pursuing incentives for partial or full retrofits to LED fixtures for veg and flower phases. The cultivators will need more information on the latest developments in horticultural lighting, and ideally the opportunity to consult with commercial cultivators that have successfully switched to LED.
- The cultivators' primary interest is in production. Many conversations revolved around how they could get more light and more canopy, while reducing HVAC loads. Many facilities operate at the limits of their cooling capacity during the hottest weather. They understand they do not have the cooling capacity to add lights or canopy with their current configuration.
- There is an understanding that certain strains are notably more productive than others, but consumer preference compels the cultivators to offer a wide variety of ever-changing strains. The common practice of mixing strains within a given flower room precludes the identification of energy savings associated with certain strains at a facility, but work is underway elsewhere by ERS and others to attempt to quantify strain-based efficiency.

- There is a general lack of understanding regarding how peak demand charges are calculated and how they impact a sites electric utility rate. Cube Resources has provided a link to an explanation of demand rates on each site's energy dashboard (analysis of eGauge data for trends). It is recommended that Boulder County provide a brief educational session on demand rate charges at an upcoming cultivator workshop. ERS can provide a sample load shape and energy data to use for demonstrative purposes[5].
- The primary barriers to adopting more efficient technologies and practices are as follows:
  - Access to capital
  - Too busy to investigate alternative options
  - Potential disruption of operations
  - The need for short paybacks on investment
  - Lack of data or analysis to support the decision. Opportunities associated with horticultural lighting and HVAC impact the primary systems responsible the conditions of the cultivation environment. Many cultivators have had negative experiences with HVAC or lighting systems that were not properly designed. Cultivators are reluctant to adopt new horticultural lighting or HVAC system types without rigorous, defensible data and analysis validating the proposed performance. Due to the emergent nature of the industry, there are few designers and contractors with the experience needed to accurately assess the impact of alternate systems on cultivation space conditions and control.
  - Disbelief that LEDs can perform on par with double-ended (DE) high pressure sodium (HPS) fixtures

## 3.3 Facility Performance

This section presents data and analysis on the performance of the facilities including energy and productivity metrics and relationships, energy end-use disaggregation, Boulder County level load shapes, and examples of weather and solar radiation dependence. As noted earlier in this report, data is presented in a manner that maintains the anonymity and confidentiality of the participants.

[5] This data would reflect real world performance but would not consist of actual facility data due to confidentiality concerns

### 3.3.1 Energy and Productivity Metrics

This section will present several graphs and plots summarizing performance and investigating the relationships between variables. Each figure will be introduced and will be followed by a brief explanation of the interpretation of the data.

Figure 3-6 plots the range of productivity values for all sites that submitted production data and heating utility data and includes all facility types. The average value is also plotted. This plot includes all energy use (electric and fossil fuels) converted to millions of Btus (MMBtu).

**Figure 3-6. Grams per MMBtu of all site energy**

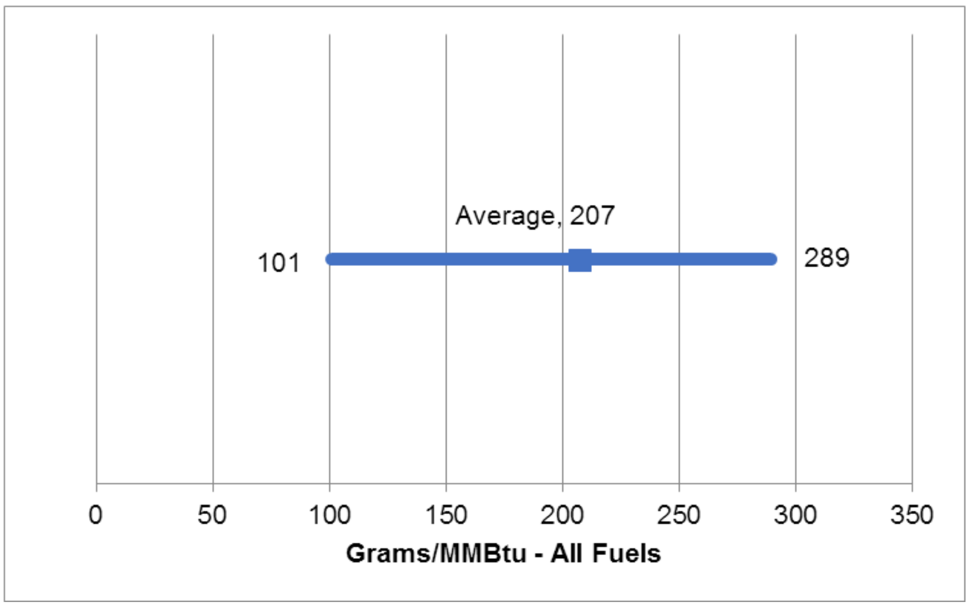



Figure 3-6 shows a range of values and includes facilities that struggled with production issues during the data period of review. If those outliers are removed, and only facilities with typical operation are included, the range tightens. Figure 3-7 plots these values and again includes all facility types.

**Figure 3-7. Grams per MMBtu of all site energy – outliers removed**

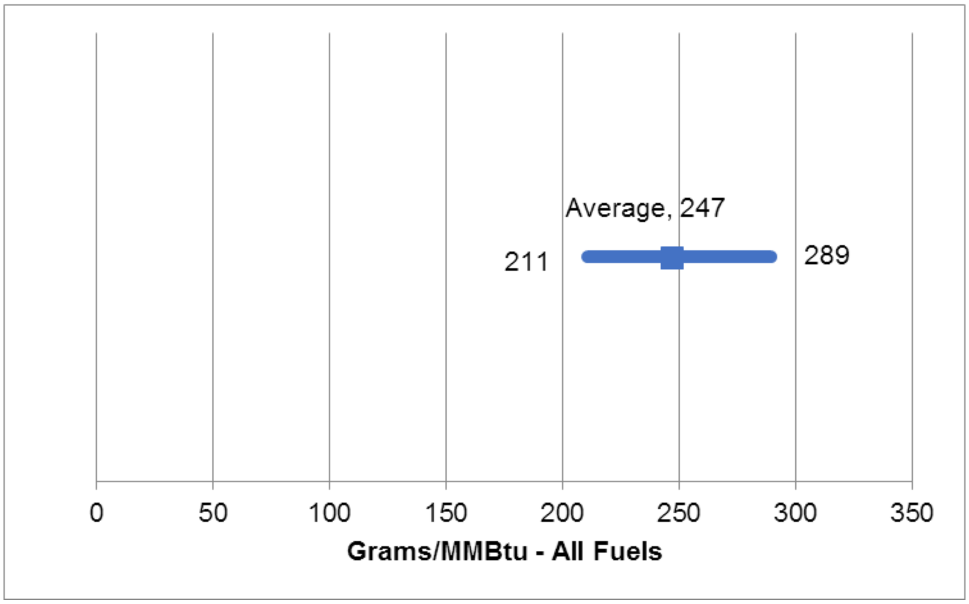
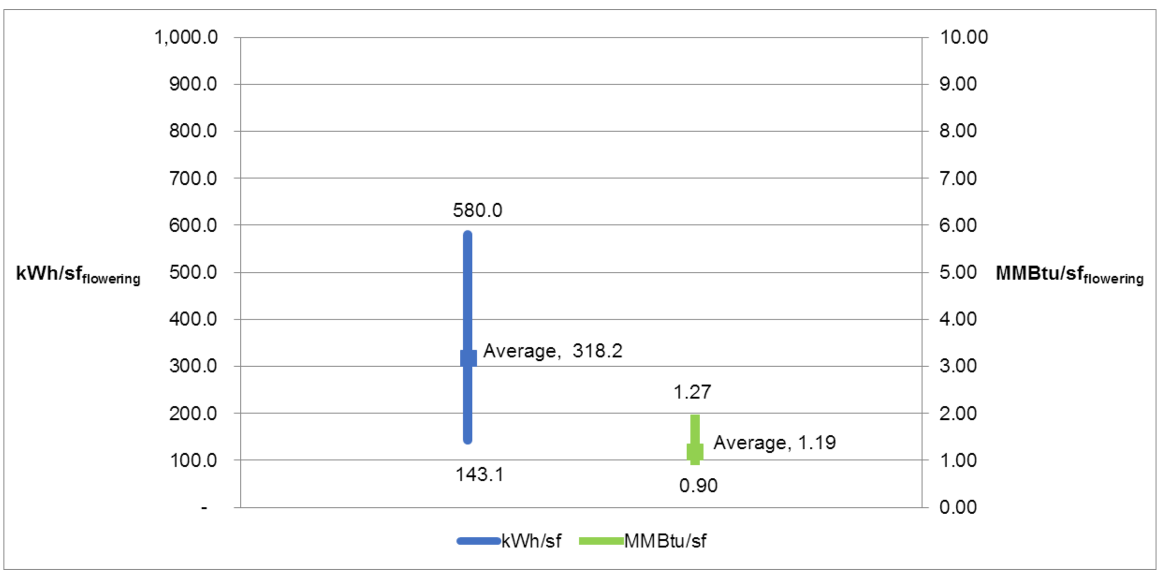



Figure 3-8 graphs the electrical and all fuels (electric and fossil fuels) energy per $sf_{flowering}$. The $kWh/sf_{flowering}$ data can be misleading as it includes facilities that heat with electricity as well as those that heat with fuel. The $MMBtu/sf_{flowering}$ plot provides a more complete view of the energy consumption.

**Figure 3-8. Energy per square foot of flowering canopy**




### 3.3.2 Energy End-Use

This section presents the break-out of energy end-uses for indoor and mixed light facilities. Disaggregations are provided for electric energy and for all fuels.

As with the previous section, each figure will be introduced and briefly discussed.

### *All Facilities*

Figure 3-9 presents the electrical energy end-uses for all facilities with complete electrical data. Figure 3-10 presents the end-uses for all fuels converted to their site equivalent MMBtu values for sites with complete utility records.

**Figure 3-9. All Facility Electric End-Use**

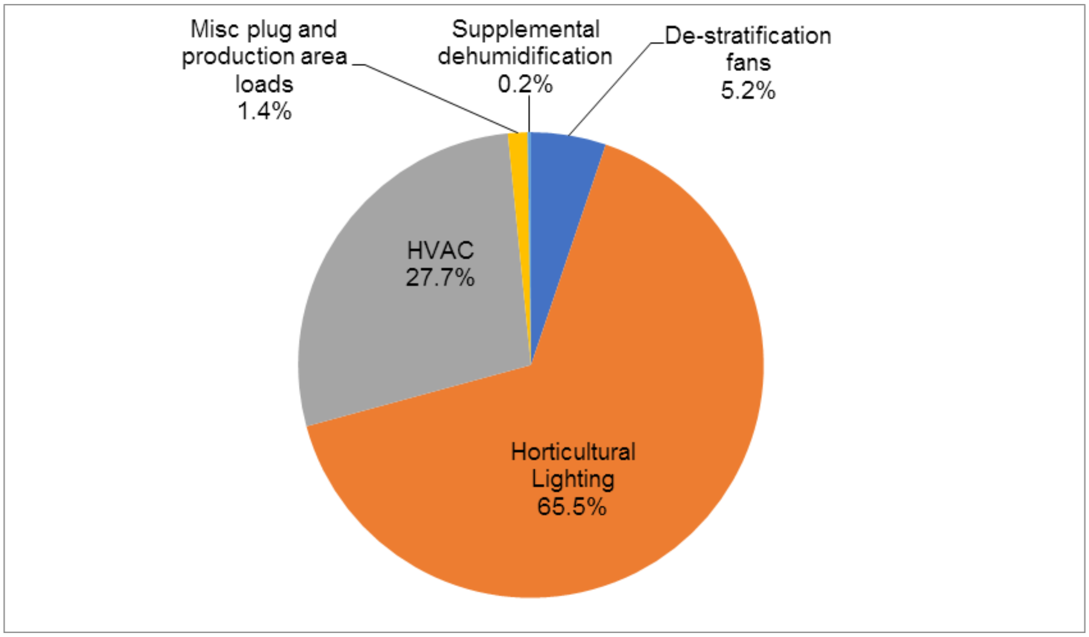



**Figure 3-10. All Facility All Fuel End-Use**

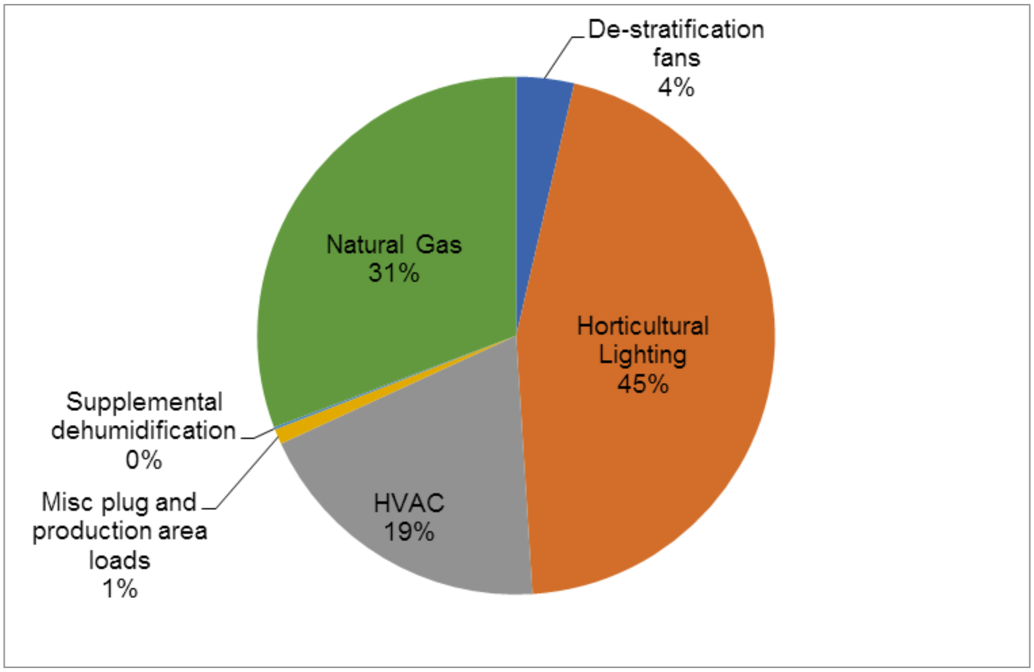


Figure 3-9 show that lighting dominates the electric energy use of all facilities. Figure 3-10 however shows that across all facilities with complete data, natural gas accounts for 31% of the total energy consumption. This is driven almost exclusively by mixed light facilities as seen in the following sections.

### *Indoor Facilities*

Figure 3-11 presents the electrical energy end-uses for all indoor with complete electrical data. Figure 3-12 presents the end-uses for all fuels converted to their site equivalent MMBtu values for indoor sites with complete utility records.

**Figure 3-11. Indoor Facility Electric End-Use**

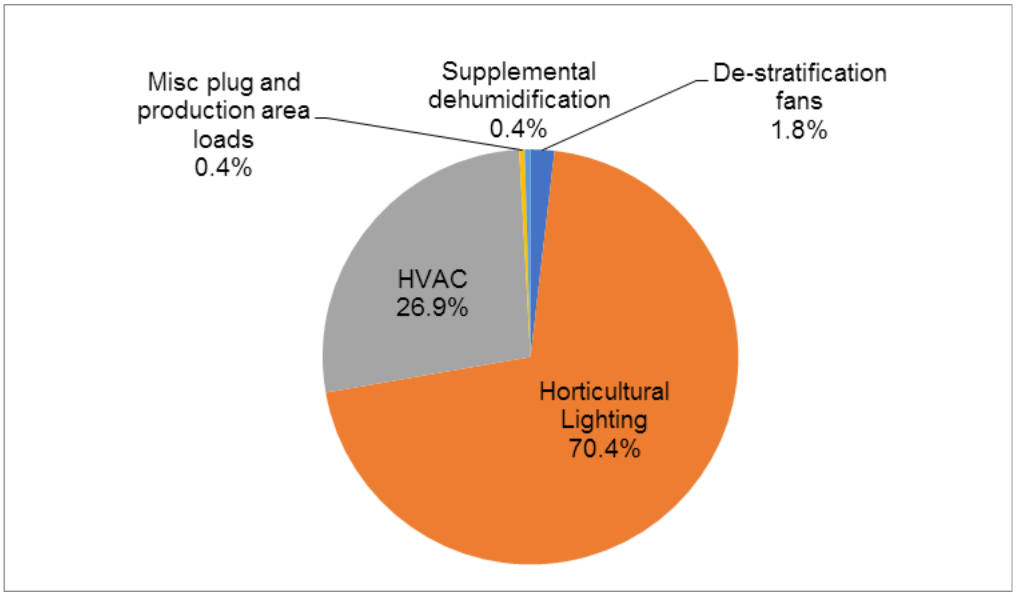
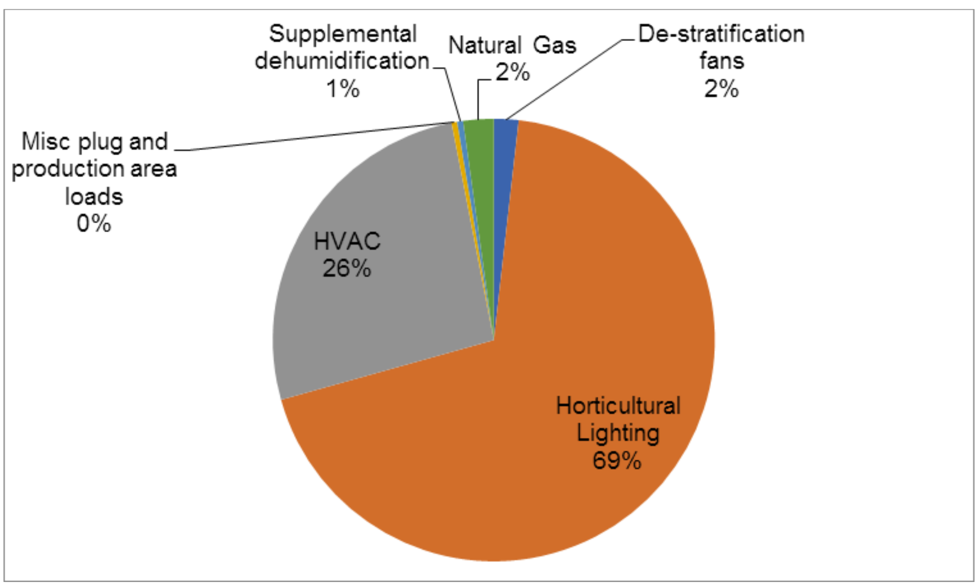



**Figure 3-12. Indoor Facility All Fuel End-Use**



From the above we can see that horticultural lighting dominates both the electric and all fuel energy use of the indoor facilities. The proportion of total energy associated with lighting is greater than some literature on the subject would suggest. We offer the following potential reasons why.

- The graphs above are based on one year of actual electric and fuel consumption. The lighting energy can be calculated with high confidence due to 15-minute interval data and a thorough cataloging of on-site equipment. There is a high level of confidence in the accuracy of the break-out of lighting energy use shown above.
- Most indoor facilities are served by simple RTUs with a supply fan. There is no pumping energy, or air handler or fan coil fan energy that would exist with chiller-based systems.
- Many of the facilities achieve dehumidification through the RTU alone, with no supplemental dehumidification. Supplemental DH is often thought of as necessary for RTU based systems, and energy projections often include notable energy use associated with supplemental dehumidification.

### *Mixed Light Facilities*

Figure 3-13 presents the electrical energy end-uses for mixed light facilities with complete electrical data. Figure 3-14 presents the end-uses for all fuels converted to their site equivalent MMBtu values for mixed light sites with complete utility records.

**Figure 3-13. Mixed Light Facility Electric End-Use**

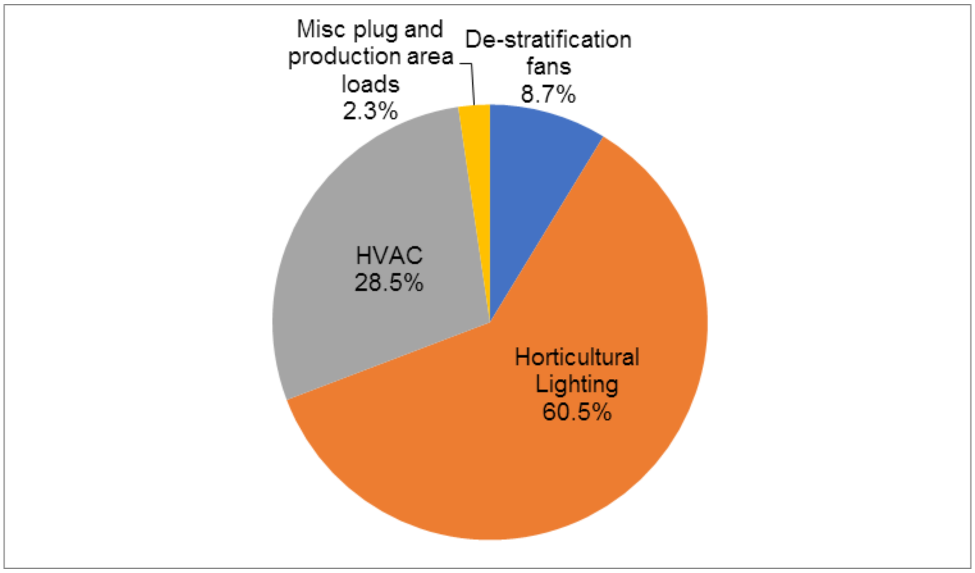
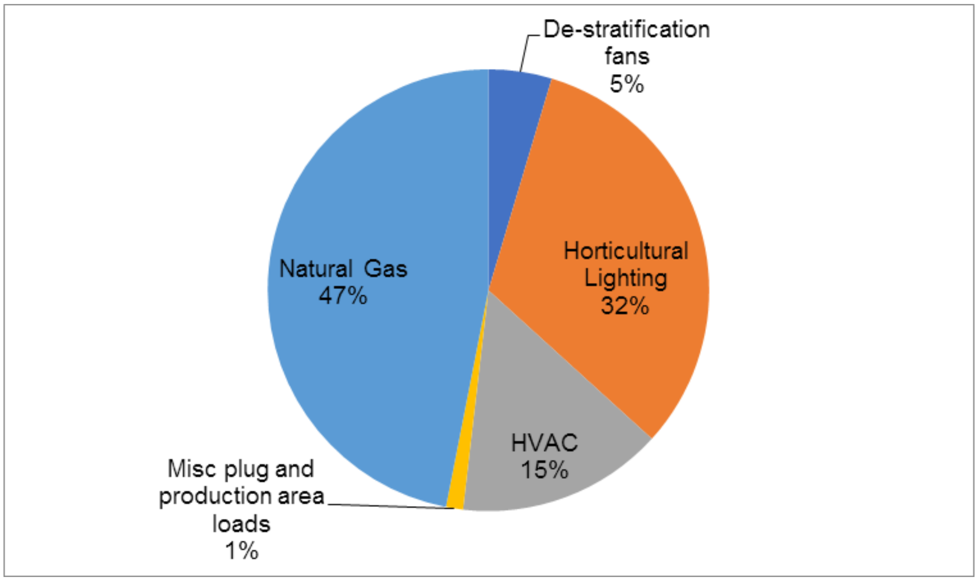


**Figure 3-14. Mixed Light Facility All Fuel End-Use**

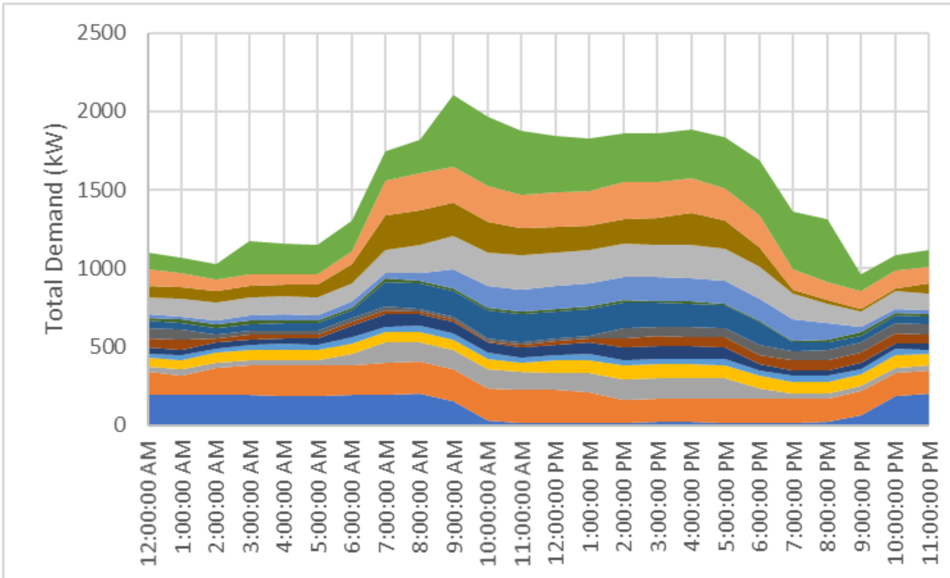



There is a clear difference in total energy disaggregation between indoor and mixed light facilities. In the mixed light facilities, HVAC energy accounts for approximately 65% of the total energy use. This is primarily due to the use on natural light for satisfying a portion of the plants lighting needs.

### 3.3.3 Aggregated Load Shapes

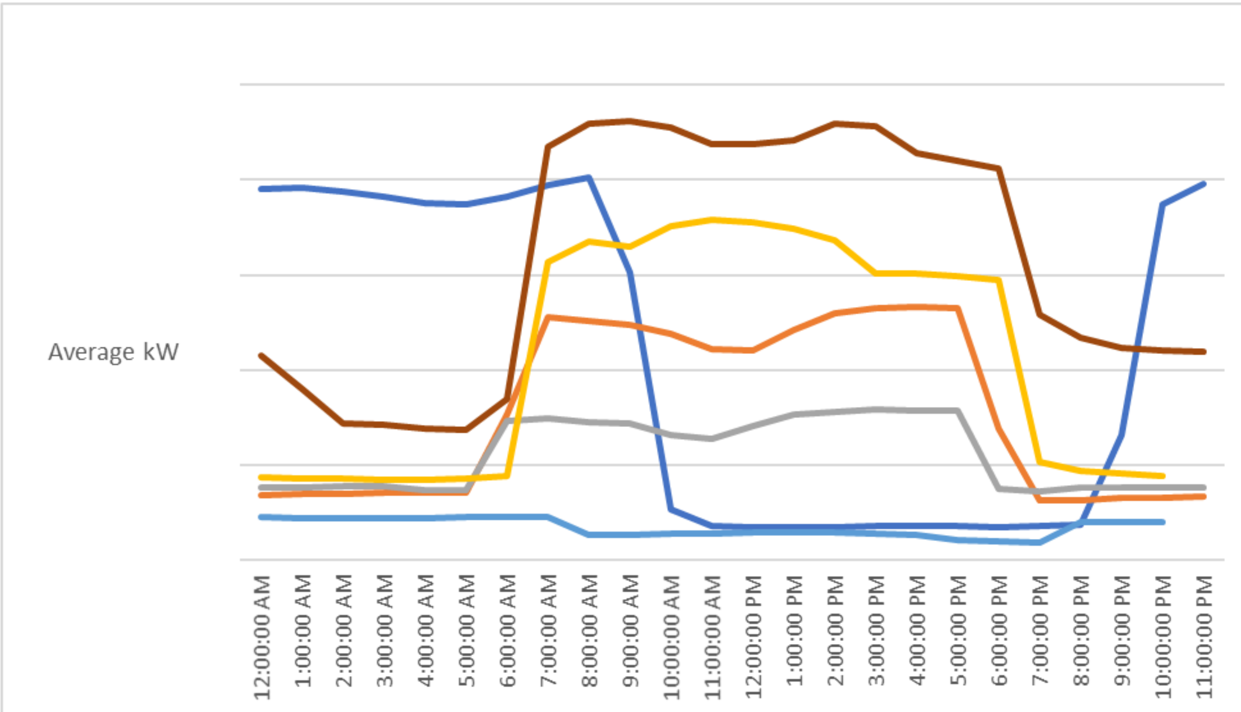
In this section, the aggregated load shapes will be presented. These load shapes represent the average annual 24-hour load profile of each facility. Figure 3-15 plots the cumulative load of all facilities.

**Figure 3-15. Cumulative Boulder County Level Load Profile – Stacked Area Graph**




On average, Boulder County peak demand occurs at 9 AM and is driven in large part (50+ %) by the campus meter and one additional large facility. They all begin their flower photoperiods at 8 AM – 9 AM producing high demand values.

**Figure 3-16. Campus Location Overlaid Load Profiles**




### 3.3.4 Weather and Solar Radiation Dependence

Electric interval data from eGauge meters, as made available by Cube Resources, was used with NOAA historical weather data to assess the weather dependence of electric energy use at the facilities. The output of a local photovoltaic (PV) array (solar panels), also monitored by an eGauge is provided on the eGauge dashboard for mixed light facilities. This data was used in assessing the relationship between solar radiation and mixed light facility electric energy use. Where available, monthly fuel data was regressed against heating degree days to assess the weather dependence of fuel use. The following graphs illustrate typical weather dependencies for indoor and mixed light facilities, and solar radiation dependency for mixed light facilities.

Figure 3-17 presents the weather-based regressions typical of an indoor facility operating all flower rooms at once.

**Figure 3-17. Average kW vs. Outdoor Air Temperature - °F**

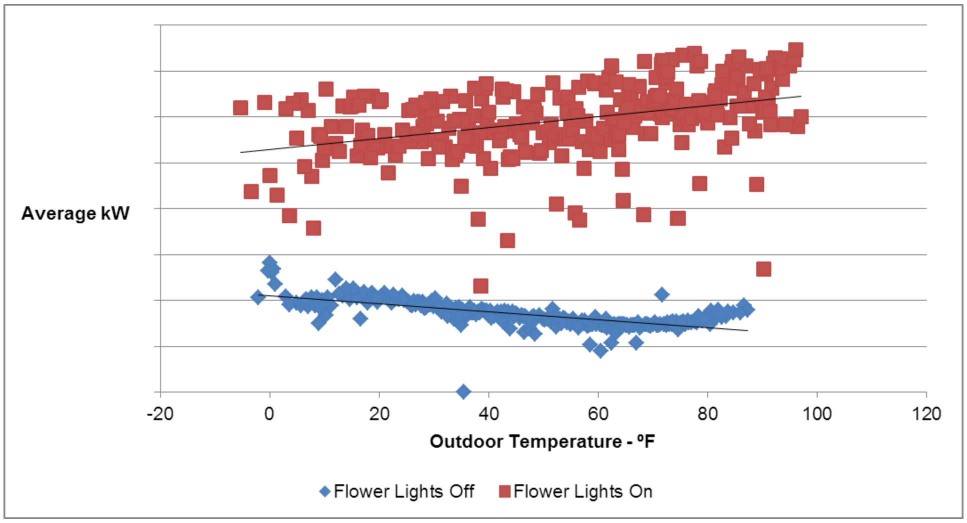
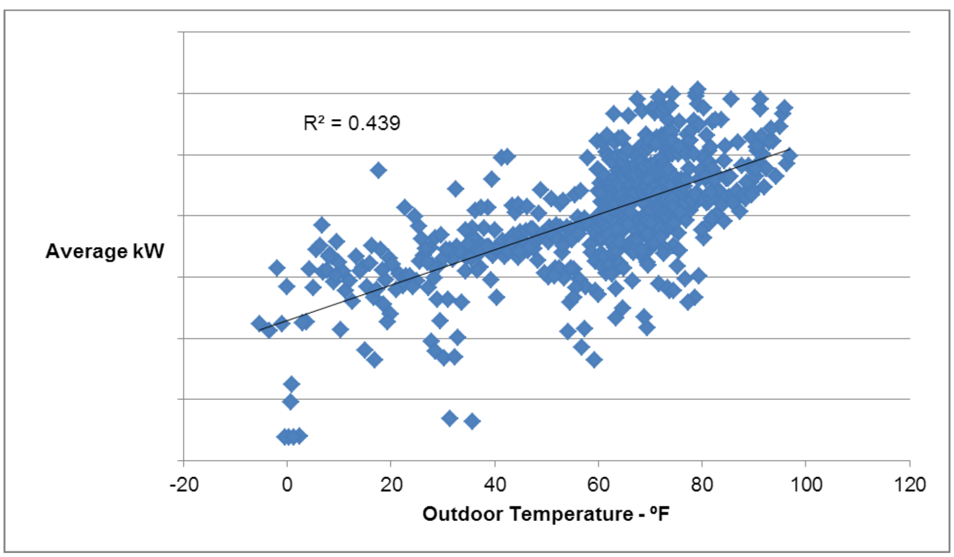



Figure 3-17 illustrates several important observations.

- The facility energy behavior relative to ambient conditions is dependent on whether the lights are on or off. The correlation between energy use and ambient conditions is stronger when the lights are off and provides a basis to assess envelope performance.
- Energy use when the lights are on is dominated by the internal lighting and HVAC loads. While there is a correlation with ambient conditions, that correlation is weak.

Figure 3-18 plots the average kW against outdoor air temperature for a typical facility that operates staggered, or opposing, flower room schedules.

**Figure 3-18. Average kW vs. Outdoor Air Temperature, Staggered Flower - °F**

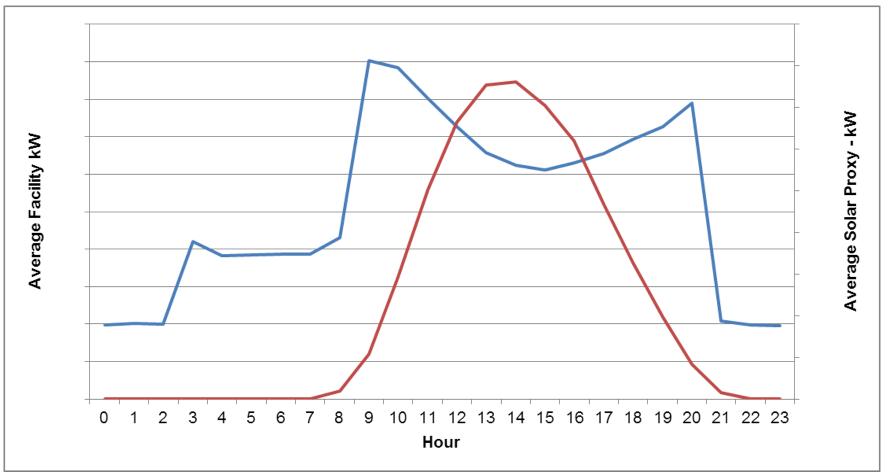


This figure shows a clear relationship between average kW and outdoor air temperature, but again that correlation is weak, further illustrating the dominant role the internal loads play in energy use.

Mixed light facilities rely on sunlight for a portion of their horticultural lighting needs. All the facilities reviewed had some method of dimming the lights in response to ambient levels of solar radiation. Two facilities use threshold control based on outdoor PAR readings, and one facility manually turns the lights on and off based on the judgement of the cultivator.

Solar proxy data, in the form of kW output of a local photovoltaic array, was used to examine the relationship between solar radiation and average facility kW. The typical annual load shape of facility kW and solar proxy is presented in Figure 3-19.

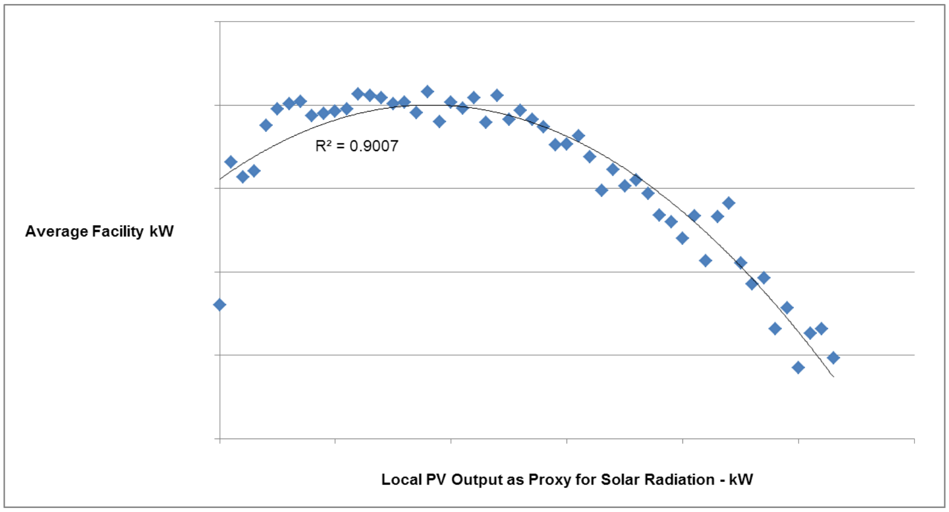
**Figure 3-19. Average Daily Load Shape and Solar Proxy**




The above clearly demonstrates the impact of increasing solar radiation on facility kW. As the flower bays come online at approximately 9AM, demand spikes. As the sun rises higher in the sky, less artificial light is needed, and the facility kW begins to drop in response. As the sun begins to lower in the sky, facility kW ramps due to additional supplemental lighting for the remaining duration of the photoperiod (until 9PM).

Figure 3-20 plots the relationship between facility kW and the solar radiation proxy values.

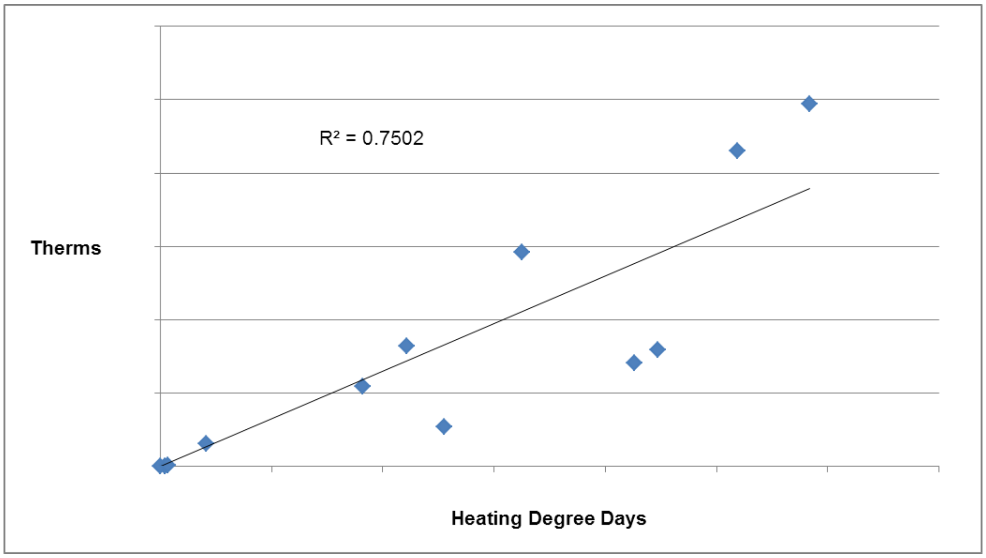
**Figure 3-20. Solar Radiation Proxy vs. Average kW**




The above shows the very strong (R2=0.9) correlation between solar radiation and facility kW. This relationship emphasizes the benefit of threshold lighting controls in mixed light facilities.

Heating fuel utility data was limited as several of the facilities are all electric, and several more are behind a single natural gas master-meter, with no way of disaggregating the use among the facilities served by this meter. The fuel data analyzed did consistently yield clear correlations between heating degree days and fossil fuel use. A typical plot is provided in Figure 3-21. $R^2$ values among the sites analyzed ranged between 0.7 and 0.9.

**Figure 3-21. Natural Gas Use vs. Heating Degree Days**




### 3.3.5 Relationships Between Key Metrics

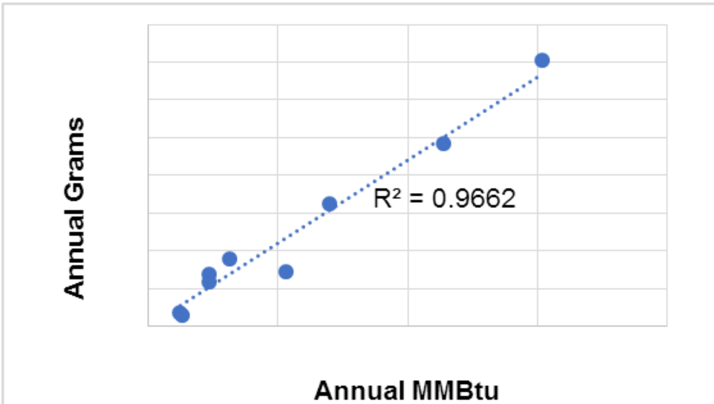
Here a selection of plots is provided which compare key metrics against one another to identify the variables that drive energy use or productivity.

Productivity is shown in:

- Grams – Grams of dry usable product. Includes flower and trim that is used for extraction.
- Grams/$sf_{flowering}$ – The annual total production in grams divided by the total square feet of flowering canopy.

Figure 3-22 plots annual all fuel energy use against annual production.

**Figure 3-22. Annual Total Energy Use vs. Total Annual Production**

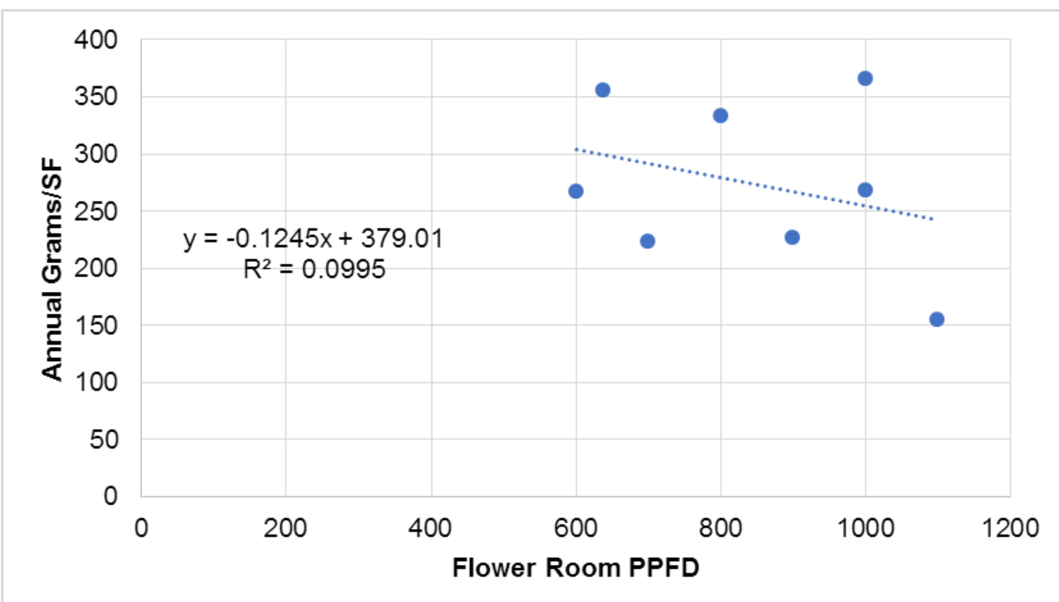



The above plot includes indoor and mixed light facilities. This plot demonstrates a clear relationship between production and total energy use across diverse facility types.

The following plots and narrative are also reported in Section 3.1.1 but are repeated here as they relate to overall facility performance.

Figure 3-23 presents a plot of flower room PPFD against annual facility production.

**Figure 3-23. PPFD vs. Grams/$sf_{flowering}$**



The relationship between facility productivity and PPFD is not apparent in the above plot. If anything, it suggests that $grams/sf_{flowering}$ decreases with increased PPFD. This result does not dispute that light intensity drives photosynthesis, but instead suggests that PPFD is but one factor that impacts facility productivity. Plant genetics, cultivator skill and cultivator experience substantially impact production. High lighting levels do not guarantee high yields.

Further to this point are Figures 3-24 and 3-25. Figure 3-24 plots flower room PPFD against flower room LPD. We again see a weak correlation, with higher LPDs generally representing lower PPFD. In Figure 3-25, we take the comparison one step further, comparing flower room LPD to overall facility energy use.

**Figure 3-24. Flower Room PPFD vs. Flower Room LPD**

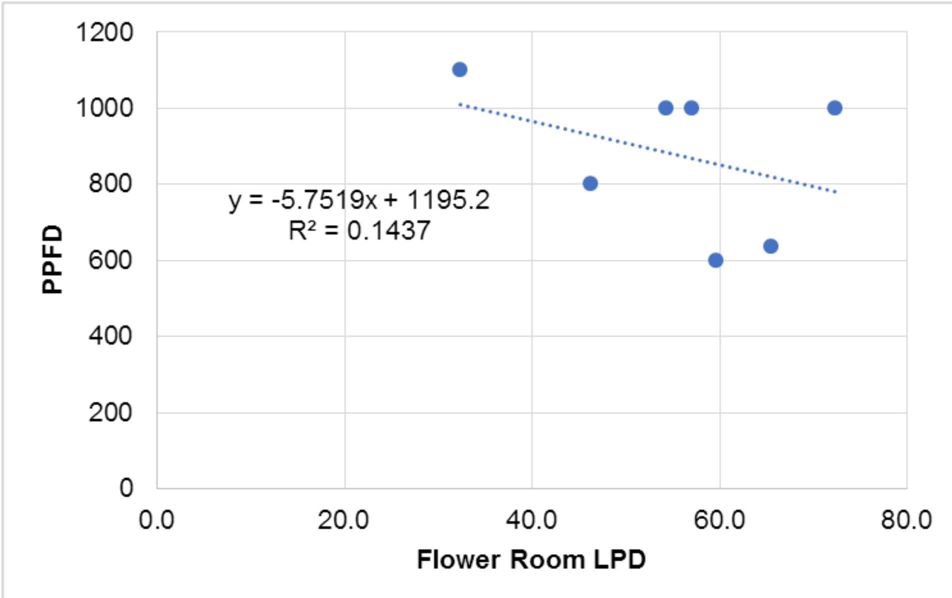
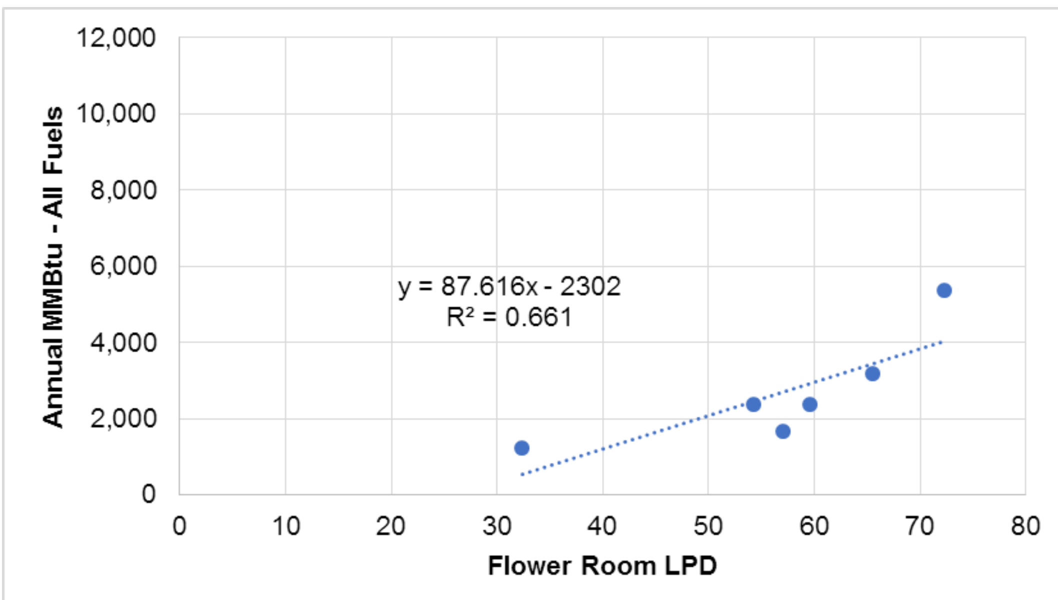



**Figure 3-25. Flower Room LPD vs. Annual Energy Use**




Here a correlation can be seen; as flower room LPD increases, total facility energy use increases.

To summarize; for these facilities higher PPFD does not correlate to higher production, and higher LPD does not correlate to higher PPFD. But higher LPD *does* correlate with higher energy use. Those with fixtures mounted closer to the canopy had the highest PPFD with the lowest LPD, while those that mounted their fixtures furthest from the canopy had higher LPDs and lower PPFDs. The sites with the lowest LPD and highest PPFD are making use of 315W ceramic metal halide fixtures.

# 4 Summary of Proposed Measures

This section summarizes the common proposed energy efficiency measures and other measures that were not cost-effective.

## 4.1 Recommended Energy Efficiency Measures

The recommended measures are based off the site-specific analysis generated for each facility. Measures were prioritized based on the criteria described in Section 2.2.2, above. A summary of the recommended measures and their impacts is presented in Table 4-1.

**Table 4-1. Recommended Energy Efficiency Measures**

| Measure Type | Quantity | kWh Savings | Peak Demand Impact - kW | Natural Gas Impact - MMBtu | Cost Savings | Estimated Installation Cost |
|---|---|---|---|---|---|---|
| Envelope | 1 | - | - | 1,904.0 | $18,850 | $109,300 |
| HVAC | 17 | 904,916 | 138.0 | 3,655.0 | $120,051 | $897,340 |
| Lighting | 21 | 3,332,459 | 649.5 | (1,344.6) | $307,212 | $2,236,370 |
| Lighting Controls | 3 | 240,658 | 68.9 | - | $32,173 | $30,000 |
| Operational | 7 | 269,048 | 152.4 | - | $35,889 | $0 |
| **Total** | **49** | **4,747,081** | **1,008.8** | **4,214.4** | **$514,175** | **$3,273,010** |

Table 4-2 presents the recommended measures based on their installation cost. This table illustrates the low cost, mid-cost, and higher cost opportunities and their relative savings magnitude.

**Table 4-2. Measures by Installation Cost**

| Measure Cost | Number of Measures | Electric Savings - kWh | Demand Impact - kW | Fossil Fuel Impact - MMBtu | % kWh Savings | % Demand Impact | % Fossil Fuel Savings | Potential Xcel Incentive | Potential PACE Rebate | Potential EIOF Credit | Average of Simple Payback (Years) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No Cost | 10 | 604,367 | 278 | - | 13% | 28% | 0% | $0.00 | $0.00 | $0.00 | - |
| Low Cost (<$5,000) | 5 | 72,906 | 8 | - | 2% | 1% | 0% | $2,500.00 | $395.00 | $1,895.00 | 4 |
| Mid Cost (<$50,000) | 15 | 612,419 | 92 | (296) | 13% | 9% | -7% | $45,940.00 | $33,747.00 | $42,216.00 | 3 |
| High Cost (>$50,000) | 19 | 3,457,389 | 631 | 4,511 | 73% | 63% | 107% | $279,071.00 | $316,448.00 | $335,783.00 | 8 |
| **Total** | **49** | **4,747,081** | **1,009** | **4,214** | **100%** | **100%** | **100%** | **$327,511.00** | **$350,590.00** | **$379,894.00** | **4.2** |

### 4.1.1 Horticultural Lighting

Horticulture lighting is the largest energy end use for the facilities and therefore also represents the largest potential energy savings opportunity. LED horticulture lighting has rapidly improved in recent years. The best "600 watt" LED horticulture fixtures now achieve the same PAR light output as 1,000 W double ended (DE) HPS fixtures yet do so with less power. Top performing LED fixtures have a photosynthetic photon flux (PPF) of 1600-1700 μmol/s and achieve photosynthetic photon efficacy (PPE) performance of close to 2.6 μmol/J. PPE is the best representation of a given horticulture fixture's energy efficiency.

LED designs for greenhouses have evolved from "spot" type fixtures that mimic traditional HID fixtures to linear designs that distribute light more evenly than traditional designs and minimize shadowing.

Ceramic metal halide (CMH) fixtures are another lighting technology that can be used in lieu of older style fixtures. CMH fixtures are typically rated for 315 watts, and a general rule of thumb is that one 1,000-watt DE-HPS fixture can be replaced with two 315-watt CMH fixtures. CMH fixtures are substantially cooler than HPS fixtures, which allows them to be placed closer to the plant canopy. CMH fixtures also have a broader spectrum, which some cultivators prefer. Table 4-3 provides a list of PPE values for different fixture technologies.

**Table 4-3. Lighting Technology PPE**

| Technology Type | Photosynthetic Photon flux Efficacy (PPE) |
|---|---|
| Fluorescent | 0.9 |
| Single ended HPS | 1.0 |
| Ceramic metal halide | 1.6 |
| Double ended HPS | 1.7 |
| LED – 2017 test data | 2.5 |

Incentives are available for qualifying horticultural fixtures from Xcel, PACE, and the EIOF credit.

### 4.1.2 Evaporative Condenser Pre-Coolers

Given that many of the facilities operate with packaged HVAC units, and that many are near the maximum cooling capacity of their system during hot weather, evaporative condenser pre-coolers present an attractive retrofit opportunity.

These systems spray a mist of de-mineralized water into the incoming air stream that removes heat from the outdoor condensing unit. During warm dry months, this mist provides evaporative pre-cools the incoming air stream, which reduces the work needed to reject heat from the system. These systems not only reduce demand, but also provide 10%-15%more cooling capacity to existing units, providing an additional buffer against overheating during hot weather. The units only operate during the summer months and a portion of the shoulder seasons. They need to be shut down over the winter, but less cooling capacity is needed then.

Xcel and PACE both provide incentives for these systems, and EIOF credits can be applied as well.

### 4.1.3 Veg Photoperiods

Facilities operate with a vegetative photoperiod of either 18 or 24 hours. Several Boulder County facilities still operate with 24 hour veg photoperiods. Reducing the veg photoperiod from 24 hours to 18 hours produces veg lighting savings on the order of 25% of the electricity consumption in that portion of operation. This has both utility energy charge savings and potential for demand charge savings. This is a no cost measure. There is disagreement in the industry on which photoperiod is "best" and the limited study information available presents contradictory findings. As this measure directly impacts the cultivation methods at the target facilities, cultivators should carefully observe the impact of reduced photoperiods to ensure satisfactory vegetative cycle growth.

### 4.1.4 Stagger Flower Room Lighting Schedules

Indoor cannabis cultivation facilities typically operate their flower rooms in one of two ways; they either operate all flower rooms at once, with all flower rooms coming on for 12 hours, and then shutting off for 12 hours. Or half of the flower rooms are operated for one 12-hour photoperiod, and the other half of the flower rooms operate on an opposing 12-hour schedule. Staggered flower room operation is one of the most impactful strategies to reducing peak demand and peak demand charges. Staggered flower rooms can also reduce peak cooling demand and reduce use of heating fuel via waste heat recovery.

66% of the facilities within Boulder County operate all flower rooms at once, incurring high peak demands relative to the average demand of the facility. This load factor plays a key role in the overall utility rate of a given site. Facilities that operate with staggered flower room schedules have peak demand and average demand values that are much closer, producing a higher load factor, and yielding a lower utility rate. Figure 4-1 provides the daily load profile of a typical facility operating all flower rooms concurrently and the load profile if the facility were to operate staggered flower room schedules.

**Figure 4-1. Concurrent vs. Staggered Flower Room Operation**

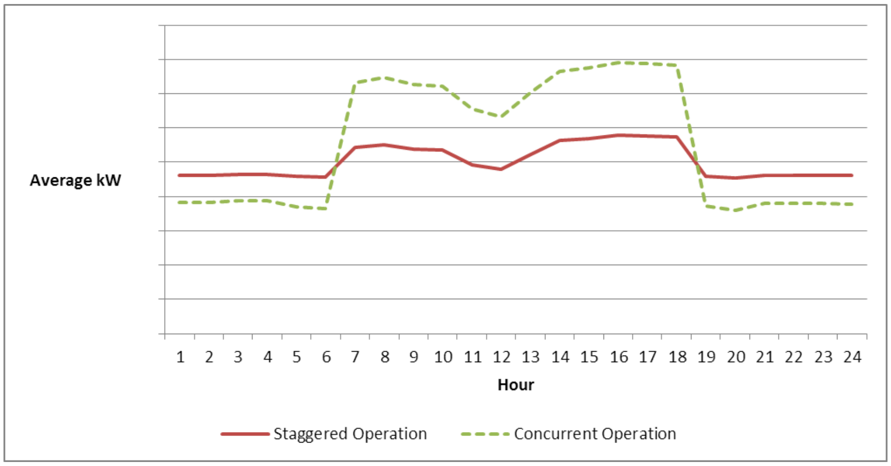



Table 4-4 provides an example of Xcel's rate table for Secondary General service as of June 2018. All independently metered facilities in Boulder County are on a Secondary General service rate and multiple facilities served by a single meter are on a Primary General service rate.

**Table 4-4. Xcel Secondary General Service Rates**

| Item | Cost |
|---|---|
| Service Charge | $ 34.40 |
| Production Meter Charge | $ 9.30 |
| Load Meter Charge | $ 9.30 |
| Per kW distribution demand | $ 5.51 |
| Summer kW | $ 17.08 |
| Winter kW | $ 9.82 |
| kWh rate | $ 0.03 |
| Days in summer season (June 1-Sept 30) | 122 |
| Days in winter season (Oct 1-May 31) | 243 |

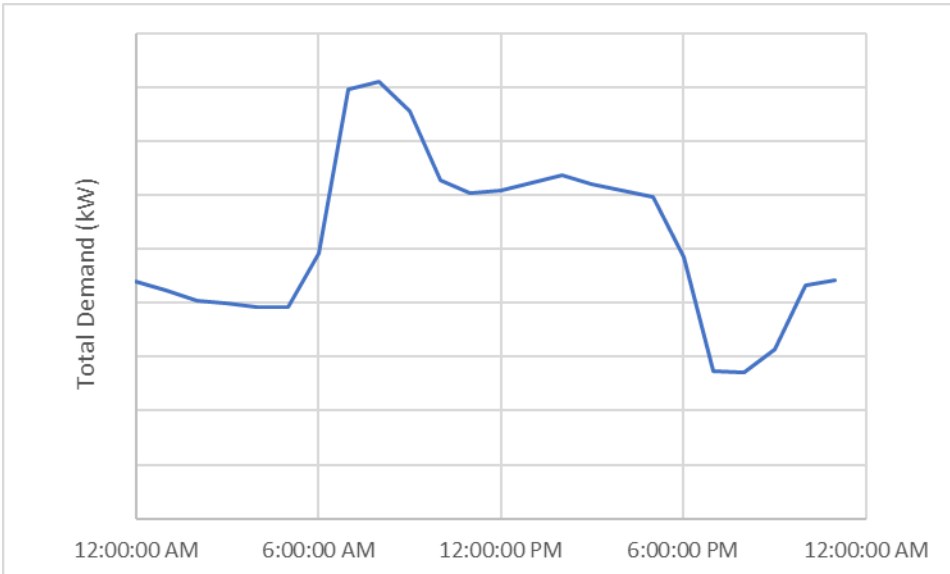
Based on the above rates and the example illustrated in Figure 4-1, staggering the operation of the flower rooms would produce electric energy cost savings of 9%.

While ERS categorizes this measure as "no cost", facilities will have to weigh the operational impacts of switching from concurrent to staggered operation. Depending on the existing operation of the facility, the cultivator may feel they need staff on site 24/7, or the installation of remote facility monitoring equipment to provide visibility into facility status during unoccupied hours.

### *Campus Location*

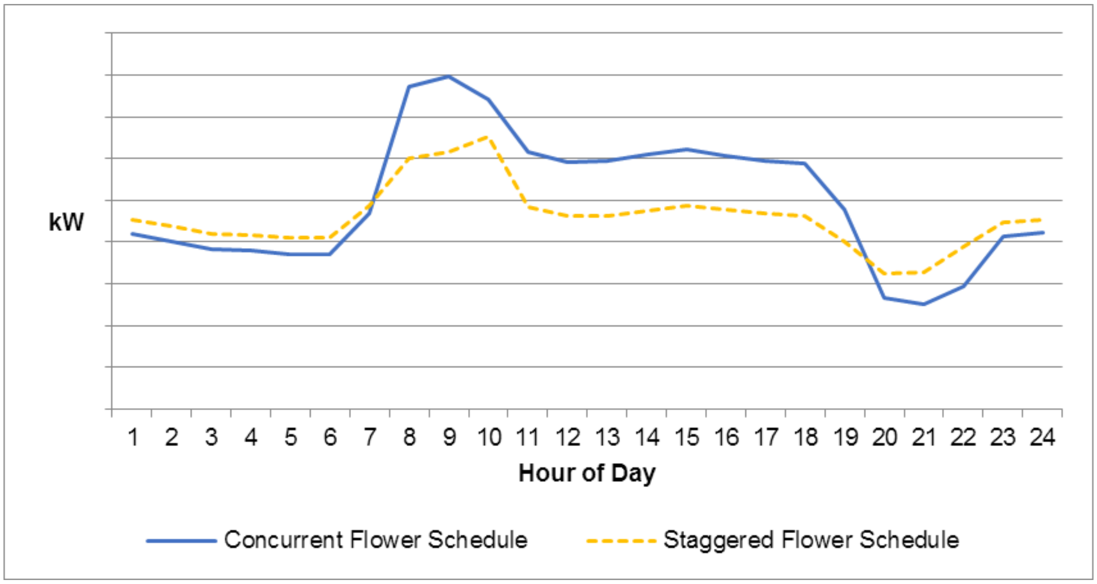
The campus location presents a special case where several facilities are served by one master-meter. This presents a major challenge to the implementation of energy efficiency measures, including the staggering of flower room operations. This also presents complications with application for Xcel rebates, Renewable*Connect, and consideration of a behind the meter solar project, as the landlord is the Xcel account holder and the party that must submit such applications. Figure 4-2 presents the cumulative load profiles of the campus located facilities.

**Figure 4-2. Campus Location Load Profile**




These facilities all operate concurrent flower room schedules. One of the locations operates flower rooms overnight, while the others operate during the day. The campus location collectively accounts for approximately 35% of Boulder County's peak demand. The cultivators located here have little incentive to adjust operating schedules as the utility cost savings are not directly returned to the individual site responsible for the change or improvement. To take advantage of the potential cost savings associated with staggered flower room schedules, the campus facilities will either need their own electric utility meters, or they will need to coordinate efforts to flatten the load profile of the entire campus so that the cost and benefits are spread among the facilities. The existing eGauges could also be used by the property owner and cultivators to pro-rate energy costs based on energy use instead of facility area. Figure 4-3 plots the current campus load profile and the load profile if all facilities were to operate staggered flower rooms.

**Figure 4-2. Campus Location Potential Staggered Load Profile**




The utility rate structure for Primary General Service is more complicated than Secondary General service as different demand rates (transmission, generation, distribution) make use of different demand values (summer demand and winter demand). The staggered load profile shown in Figure 4-2 above would generate approximately $40,000 in demand (kW) savings and $10,000 in energy (kWh) savings. The staggered load profile above is illustrative, and further refinement and optimization of individual site scheduling could yield even greater savings.

### 4.1.5 Packaged HVAC

Most facilities are served by packaged light commercial HVAC units. These units are in near constant use since cooling is required year-round to offset the large internal loads associated with rejected heat from horticultural lighting, and dehumidification loads from plant transpiration. These units are generally not intended for such heavy use and are not designed to provide cooling when ambient temperatures fall below 30-34°F.

As these units are mission critical, regular preventative maintenance should be performed by qualified technicians. While there are energy savings associated with regular maintenance, those savings pale in comparison to the potential crop losses associated with HVAC unit failure.

As packaged HVAC units approach the end of their life, or fail, they should be replaced with high efficiency, variable speed packaged units with hot-gas-bypass dehumidification. Hot- gas-bypass is a form of heat recovery which can be used to improve the dehumidification performance of a packaged HVAC unit.

Low-ambient operation kits are also available as factory and field installed options. These optional systems allow for reliable cooling at much lower ambient temperatures, mitigating unit freeze up and ensuring cooling capacity in the winter months.

#### 4.1.6 HVAC Controls

The relatively simple HVAC units in use do not lend themselves to sophisticated control systems. Advanced rooftop controls have been well studied in commercial applications and generate substantial and reliable savings. The applicability of these systems to indoor cultivation is not entirely clear, as many of their energy saving features would not be utilized. The enhanced economizing function of ARCs is not beneficial as the facilities operate with a $CO_2$ enriched atmosphere and economizing with outdoor air through the RTU would dilute the $CO_2$ concentration. Facilities would have to operate with lower $CO_2$ levels to take advantage of the potential energy savings. While there are opportunities for improved facility monitoring through ARCs, the simplicity and operation of the existing HVAC systems do not present a meaningful opportunity for efficiency improvements through more advanced control systems. While the fan motor speed control associated with ARC systems could yield savings in indoor cannabis cultivation, it is difficult quantify the savings with confidence. The authors are unaware of any case-studies of ARCs used in indoor $CO_2$ enriched cultivation facilities. The opportunity for reduced fan speed would be highly dependent on the specific unit's capacity and the sensible and latent loads of the facility.

#### 4.1.7 Envelope Measures

For most of the year, the indoor cultivation facilities are exothermic; they create more heat than they need for maintain space conditions. This presents an interesting decision relative to envelope performance. If the envelopes of the existing facilities were improved, more of the internal heat gain would be trapped within the envelope, requiring more HVAC energy to remove that heat. An envelope with less resistance to heat flow will allow some of the internal heat gain to migrate through the envelope when exterior temperatures are lower than then internal temperatures. This thermodynamic thought-exercise, combined with the weather-independent nature of facility energy use, and low proportion of heating energy and cost reduces the prospect of cost-effective energy savings through envelope improvements.

This does not mean that envelope improvements are detrimental to these sites, only that they are not cost-effective on energy savings alone. Several sites received spray foam on the roof and a high albedo roof surface in the summer of 2019. Anecdotally, sites report that they can feel the difference. There is no question envelope improvements will reduce heat gain in the summer and heat loss in the winter.

Further, the warm, moist air within the cultivation spaces has a greater vapor pressure than the air outside the facility for most of the year. This results in vapor drive and the migration of air from the interior to the exterior through the envelope elements. If the envelope has poor performance, the warm moist air moving through the envelope can create conditions that support mold and mildew.

## 4.2 County-Wide Opportunities

Boulder County's engagement with this industry is already producing results. Numerous facilities are pursuing energy efficiency measures and incentives as a result of these studies, and multiple facilities have commented on the benefits of having the opportunity to discuss their energy use and energy efficiency opportunities in detail. We applaud the efforts of Boulder County and encourage continued leadership in this sector. With that in mind, we offer the following.

- How Boulder County can further assist their cultivators:
  - Cultivator training and education
    - LED horticultural lighting – LED technology continues to advance rapidly and offers energy and performance benefits over traditional HID fixtures. Not all LED fixtures are created equally. To successfully retrofit 1,000W DE HPS fixtures 1-for-1 with LED fixtures requires high PPF and PPE LED fixtures.

      Cultivation methods may have to change as well. Reductions in infrared light from LED fixtures may reduce leaf surface temperature, which plays a critical role in transpiration.
  - Contractor training/education for those serving these facilities locally
    - Numerous facilities have struggled with their HVAC systems, and primarily rely on HVAC contractors. Boulder County could provide training to local HVAC contractors on the dynamics of indoor cultivation facilities and key considerations for selecting equipment and trouble shooting performance problems.
  - Recommendation for "special" LED incentives to lower simple payback and drive early adoption of the latest technology
    - ERS has found a high level of interest in LED fixtures, with almost all sites expressing interest. While top-tier LEDs are very expensive compared to the standard fixture technology (up time 4 times the cost of a 1,000W DE HPS) the Xcel, PACE, and EIOF credits bring the simple paybacks on LED retrofits tantalizingly close. The calculated paybacks are still a bit longer then cultivators would prefer. If PACE and the EIOF were able to offer a bonus on

LED incentives, targeting a 3-year simple payback, Boulder County could be positioned for wide-scale adoption of LED technology.

- How Boulder County can use these findings to assess future performance:
  - The individual site reports, and this Boulder County level report, have established baseline performance metrics for 2018-2019. As Boulder County proceeds with the next phase of industry engagement, these benchmarks can be used to assess changes in performance going forward. ERS has provided a simple spreadsheet to the cultivators that can be used to track their energy and productivity metrics going forward.
- Measures or strategies that require cooperation between cultivators and Boulder County:
  - Several sites have expressed interest in solar, but most feel they lack the space for a meaningful installation.
  - Xcel Energy's Renewable*Connect program could yield cost savings in the form of reduced EIOF offset payments. It seems that most cultivators are not aware of the program and the potential benefits to their operational costs. Boulder County may consider presenting briefly on this topic at a cultivator workshop, covering the requirements and terms of the program as well as the potential operational costs benefits from reduced EIOF payments.

## 4.3 Recommendations for future work

This study as envisioned and implemented by Boulder County is the most in-depth assessment of a population of cannabis facilities that the authors are aware of. This report includes data and analysis that is of great interest to the controlled environment horticultural industry as there continues to be a lack of detailed data on the energy performance and efficiency opportunities in this industry. Future work Boulder County may consider to further advance the performance of Boulder County cultivators and contribute the national body of data include the following:

- **Best practices for cultivation** - As discussed previously the data strongly implies that strain-specific genetics and cultivator skill play a large role in the productivity of a facility. Many of the facilities are physically similar, with similar PPFD values, and similar environmental parameters, yet some facilities produced 60% less grams/$sf_{flowering}$ than the leading facilities. As noted by Jacob Policzer of the Cannabis Conservancy during the December 2019 cultivators' workshop, "coop-atition" among Boulder County cultivators can raise the performance of those participating facilities by sharing lessons learned and best practices.
- **LED case studies with local cultivators** – At least one local cultivator who is planning to retrofit with LEDs expressed interest in being the basis for a case study on pre and post

LED facility energy use and productivity. The industry is lacking a rigorous and transparent and pre and post evaluation of LED productivity and energy impacts.

- **DLI study** – Daily light integral controls have the potential to further reduce lighting energy use in mixed light facilities. Accurately quantifying the impact of DLI controls as compared to manual or threshold controls through engineering equations alone is very difficult due to the complexities of estimating PPFD at the canopy within a mixed light facility. By installing logging/trending PAR/DLI meters, Boulder County will be able to quantify the savings potential of DLI controls and investigate the relationship between DLI and the solar proxy data provided by Cube Resources. This data can facilitate more accurate estimates for any future mixed light facilities considering DLI controls.
- **ARC study** – Advanced rooftop controls have been well studied in commercial applications and generate substantial and reliable savings. The applicability of these systems to indoor cultivation is not entirely clear, as many of their energy saving features would not be utilized. ARC systems are relatively inexpensive, and the monitoring capabilities they provide of RTU performance could prove to be highly educational, in addition to the potential for energy savings. Boulder County should consider a pilot installation of an ARC system with metering to quantify the savings potential of these systems. Given the quantity of RTUs in Boulder County, and successful pilot could present a new avenue for HVAC savings in these facilities.