Boulder County Cannabis Cultivation Greenhouses:

A Case Study of Daily Light Integral Controls

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Abstract

Boulder County in partnership with Resource Innovations and with the participation of one Boulder County cannabis cultivator conducted a study to collect data to help improve the understanding and modeling of the potential impacts on electric and fuel use, electric demand and energy costs through the use of daily light integral controls at a Boulder County, Colorado greenhouse.

The study was to provide in-situ data on light loss due to greenhouse shading and glazing. The findings were to be used as the basis for a DLI model that will more accurately account for losses of solar radiation within greenhouses utilized for cannabis cultivation. The results were then going to assist in the assessment of the cost effectiveness of DLI controls and to support the development of rebates for the installation of DLI controls.

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Introduction

To capture PPFD data both inside and outside the facility. Resource Innovations installed three Apogee SQ-500-SS2 full spectrum quantum PAR meters equipped with Bluetooth MicroCache AT-100 data loggers. Starting on July 12th, 2022, Sensor 1 was placed outside of the facility in the southeastern corner, approximately 30' from the building. Sensor 1 served as a baseline dataset for the study, however, a sensor logging failure in the 2nd week of the study required us to utilize PAR data from the National Renewable Energy Laboratory located in Golden, CO. The PPFD measurements utilized from the PAR sensor were used as an input to calculate Daily Light Integral (DLI) to represent cumulative PPFD over the course of each day. Sensor 2 was placed in Room 3 and Sensor 3 was placed in Room 5. All the sensors were set to log data in 5-minute intervals.

Problem Statement

Evaluate DLI lighting controls and their energy impact through electric kWh usage and peak demand.

Analyze DLI sensor data to see if DLI lighting controls are a feasible technology to meet utility rebate requirements.

Proposed Solution

Integrate DLI lighting controls to Building Management Systems and lighting control systems to detect when DLI requirements are met and supplemental lighting can be dimmed or turned off to reduce reduce energy consumption.

Analysis Overview

Our study analyzed datasets from three Apogee SQ-500-SS2 quantum sensors from July 12th, 2022 to July 17, 2023. However, the outdoor DLI sensor malfunctioned two weeks post-installation and in turn, we utilized the National Renewable Energy Laboratory's (NREL), Solar Radiation Research PAR data (*Andreas, 1981*) from their Li-COR LI-190R Quantum Sensor located in Golden, Colorado. The LI-190R PAR data is logged in 5-minute intervals and the data set utilized in our analysis was the same period as Sensor 2 (Room 3) and Sensor 3 (Room 5). The cumulative DLI measurements in both Room 3 and Room 5 were 60% below the NREL benchmark data, which was attributed to the greenhouses structural obstructions as shown in Figure 1-A and Figure 1-B. The NREL data showed 185 days exceeding a DLI of 31.2 representing the median DLI during the study period for outdoor conditions. Room 3 exceeded a DLI of 31.2 for a total of 12 days and Room 5 exceeded a DLI of 31.2 for a total of 32 days which amounted to less than 6% of the study period equaling or exceeding the outdoor median DLI. Without supplemental lighting no day met the median outdoor 31.2 DLI mark, underscoring the essential role of supplemental lighting in the greenhouse.

Figure 1-A

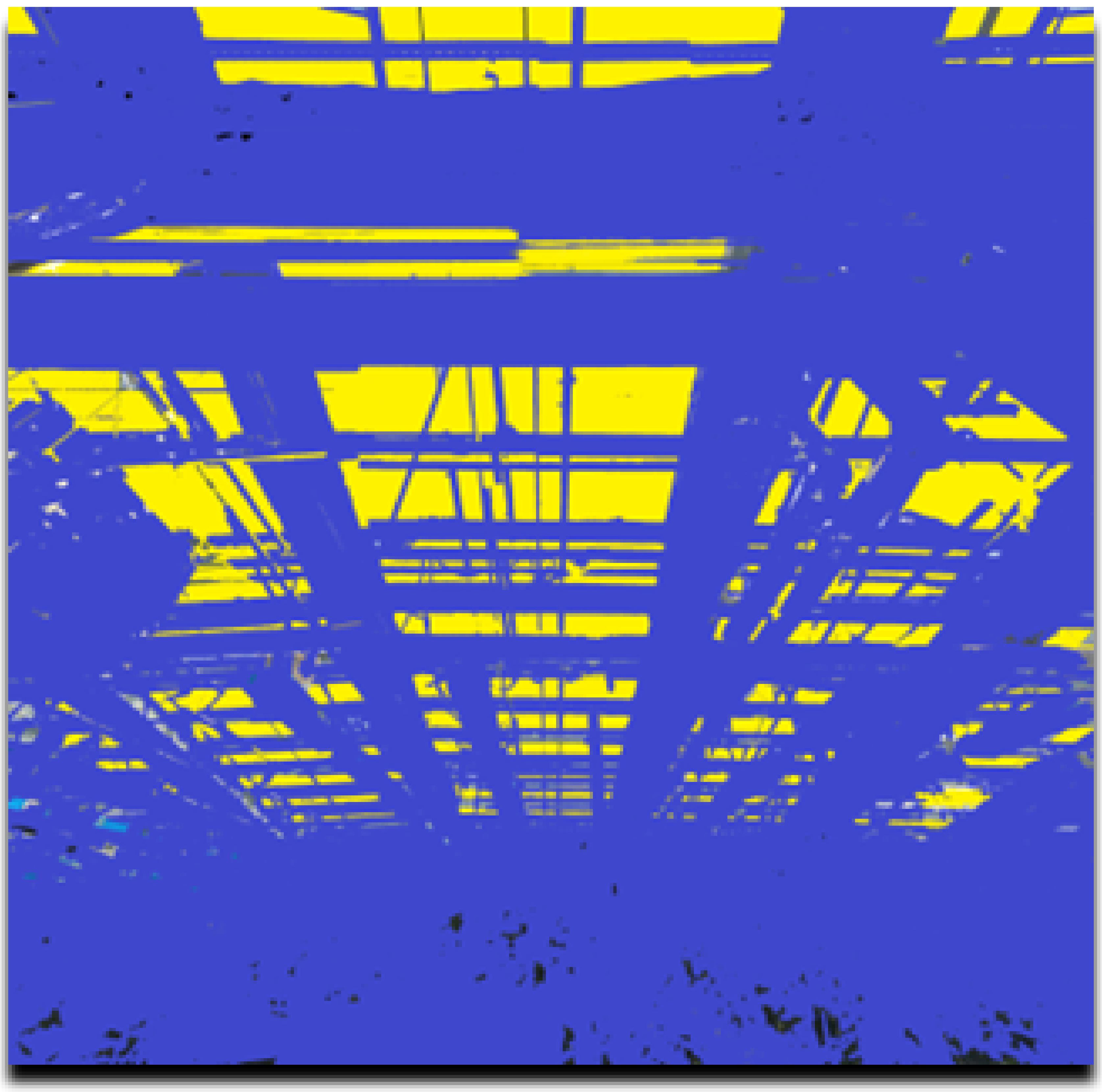
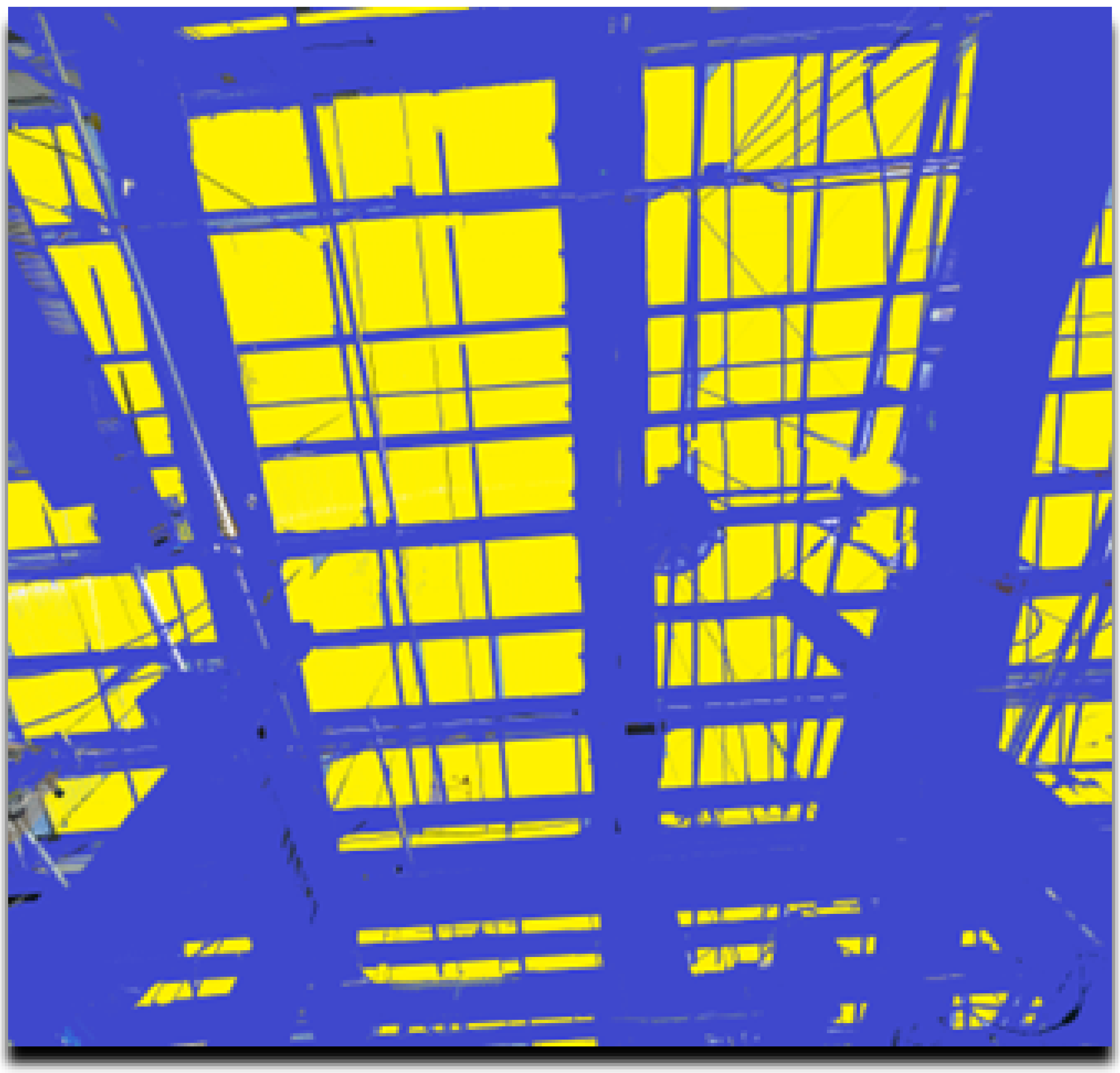
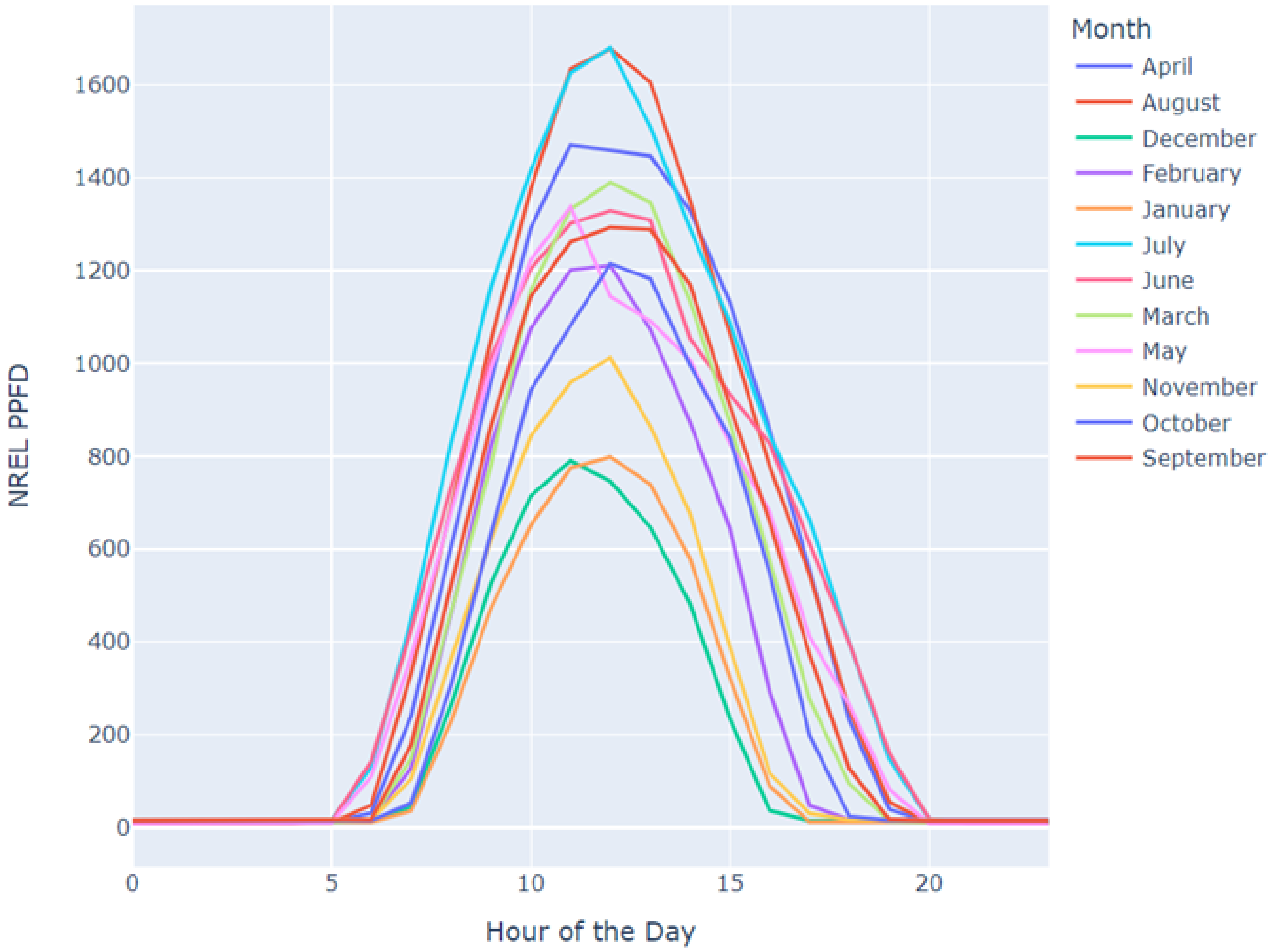


Figure 1-B



Results

Figure 2. NREL Sensor Average Hourly PPFD Values Per Month

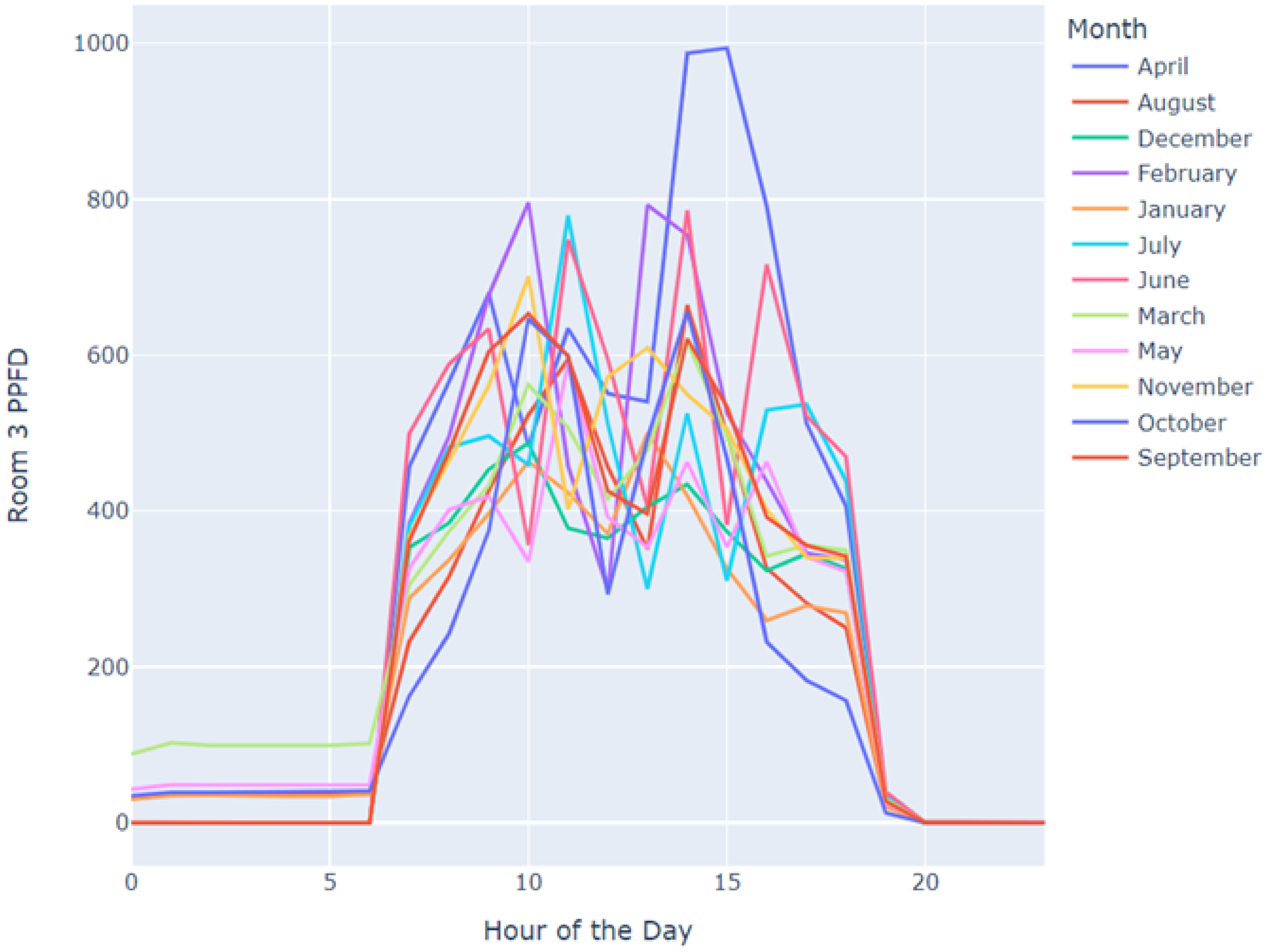


Analysis

Shown in Figure 2 is a plot of the average PPFD values for each month from the NREL SSRL sensors against the hour of the day. The NREL SRRL data reflected standard outdoor PPFD values, peaking near noon in the summer months (June, July, August). Intensity increased to over 1600 umol/m^2/s in July and August but dipped to below half of that in December and January. The average daily DLI was 45 in July and August, while December and January saw an average DLI of 17. The winter in Boulder was cooler than historical averages by an average of 3.6F during the study period, while the summer was warmer than historical averages by an average of 0.4F during the study period.

Results

Figure 3. Room 3 Sensor Average Hourly PPFD Values Per Month

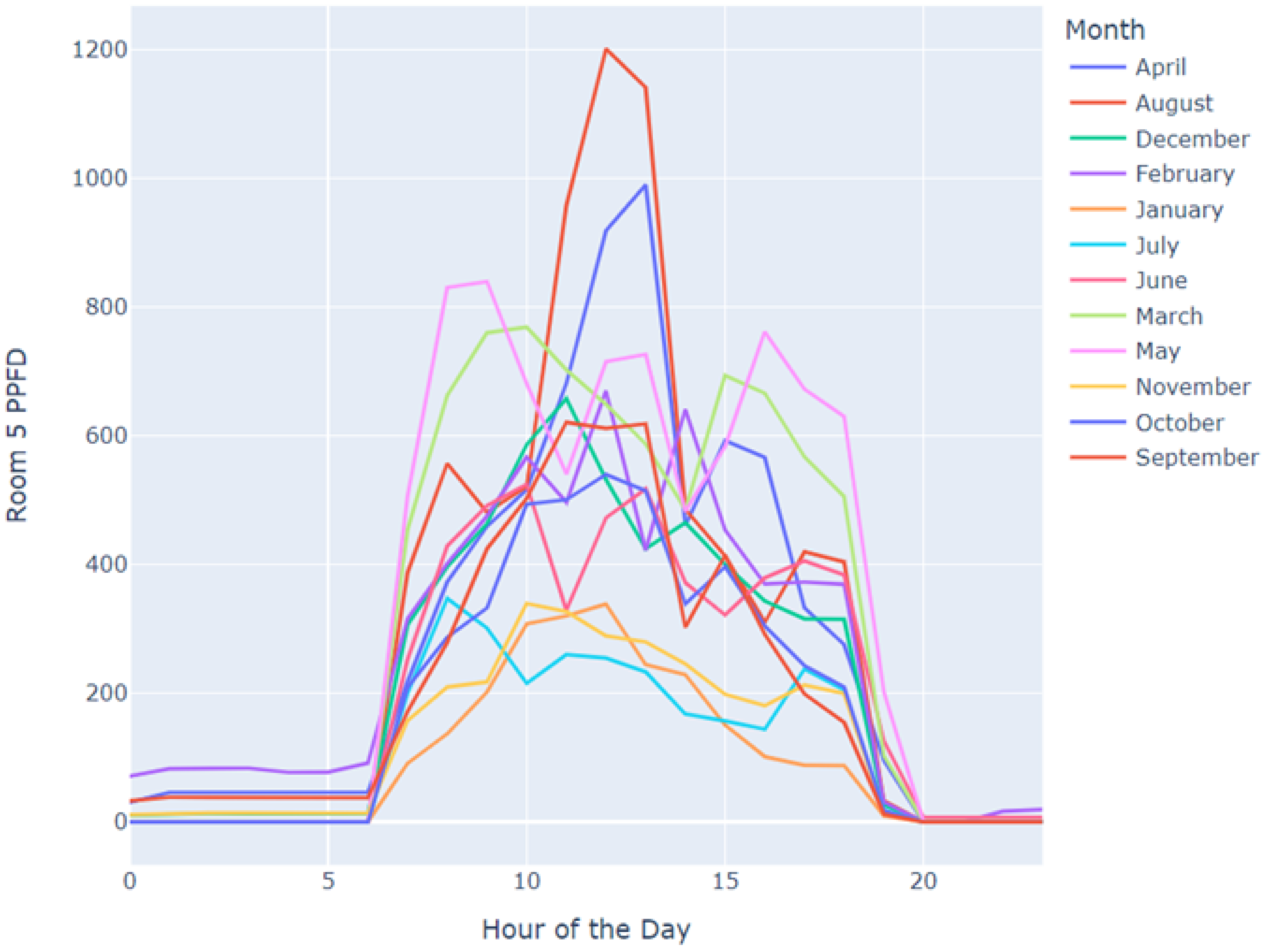


Analysis

Shown in Figure 3 is a plot of the average PPFD values for each month from the Room 3 sensor against the hour of the day. Inside Room 3, PPFD levels were subdued compared to outdoor readings, primarily due to the greenhouses structural shading. With supplemental lighting and open thermal curtains, illumination reached 500 umol/m^2/s by 8:00 AM. However, between 11:00 AM and 2:00 PM, levels dropped due to shading, increasing in the afternoon until the lights were switched off and curtains drawn at 7:00 PM. Room 3's lighting remained stable year-round and suggesting adjustments were made to compensate for reduced winter ambient light.

Results

Figure 4. Room 5 Sensor Average Hourly PPFD Values Per Month



Analysis

Shown in Figure 4 is a plot of the average PPFD levels for each month from the Room 3 sensor against the hour of the day. A similar pattern was observed in Room 3 with distinct reductions in PPFD throughout the day. Much of the daily variation is due to the usage of supplemental lighting. In November and January, the lowest lighting levels were recorded. While in March, April, May and August, the highest levels were observed.

Conclusion

Greenhouse design significantly influence indoor PPFD levels, necessitating the need for supplemental lighting. As a result, substantial artificial lighting was essential to reach the desired DLI values of this cultivator.

Monitoring and adjusting lighting levels in greenhouses is crucial for product quality and efficient lighting use. Given the variability in lighting levels due to greenhouse design and orientation, it's vital to equip cultivators with real time data relating to their PPFD levels and DLI to fine-tune their lighting strategies.

Given the complexity and layout of the participants facility, the installation of DLI sensors would not be eligible for for incentives from Xcel Energy due to not meeting the demand savings needed to meet Xcel's simple payback requirements. However, we recommend that cultivators pursue Xcel Energy's Custom Efficiency program if they are thinking about installing DLI controlled lighting systems. With each facility's construction and layout being unique, there is a strong possibility of a DLI sensor project meeting the necessary requirements for the Custom Efficiency program.

Recommendations

Promote PAR and DLI Sensors: Encourage facility operators to invest in PAR and DLI sensors. Despite their cost and setup, these tools can enhance facility energy efficiency. There are a variety of PAR and DLI sensors available to facility operators, however, sensors manufactured by Apogee Instruments and Li-COR Biosciences are recognized as the most accurate and reliable. Individual sensors with data logging can range in price from $300 to $700 for a single sensor and it is recommended to have a minimum of four sensors in a 20'x20' canopy area. PAR and DLI sensors integrated into facility building management systems can increase costs, however, allow for up to the minute data analysis and lighting dimming which can lead to increased utility bill savings and overall facility controllability. Offering equipment, expertise, and support can motivate cultivators to harness this data, ensuring consistent lighting levels and predictable harvests.

Recommendations Cont.

Enhance Light Absorption: Most greenhouse structures, made of galvanized steel, absorb over 60% of incoming light. Applying white paint or specialized reflective coatings can boost ambient light levels. A study by the American Coating Association (*Backer, 2019*) showed significant lighting increases in dark vs. white rooms. In a greenhouse, even a modest 10% light increase being redirected to the plants could reduce supplemental lighting use by around 175,000 kWh annually.

Examine Greenhouse Design vs. Energy Use: Investigate the balance between greenhouse construction, energy costs, and supplemental lighting. While insulated structures are energy-efficient for many applications, they might compromise light levels due to the increase in building obstructions in cannabis applications. In contrast, simpler designs like hoop houses offer 80-90% light transmission yet have higher heating and cooling demands. Due to these tradeoffs, a detailed analysis can guide Colorado cultivators in making informed choices on their buildings design.

Adjust Operating Hours: Consider starting operating earlier in the day. Utilizing energy during cooler morning hours in the summer months can offset nighttime heating and reduce afternoon cooling needs. In winter, with limited PPFD post-3:00 PM, it's beneficial to close curtains early to retain heat. If feasible we recommend the facility operators adjust their operating schedule outside of Xcel Energy's peak summer periods of 3:00 PM to 6:00 PM weekdays and non-holidays, to reduce their energy usage, peak demand and electric costs.

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Terms and Definitions

- **Photosynthetic Active Radiation (PAR):** The portion of the light spectrum used by plants to promote photosynthesis which is between 400 - 700 nanometers. This is different from the visible spectrum that humans can see.

- **Photosynthetic Photon Flux Density (PPFD):** The amount of light or PAR that reaches the plant or the number of photosynthetically active photons that fall on a given surface each second. It is reported as umol/m2/s-1, which is the total measurement of photons that fall on a square meter of surface every second.

- **Daily Light Integral (DLI):** The number of photosynthetically active photons that are delivered to a specific area over a 24-hour period. There are several formulas that exist for calculating DLI and our preferred formula for calculating is PPFD x (3600 x photoperiod)/1,000,000. Cannabis is a high light plant and has shown to absorb up to 65 mols/m2/day or a DLI of 65 (*Llewellyn 2022*). Each cannabis phenotype will require a different target DLI and is based off their lineage and the cultivator preference. Below is an example of how DLI is calculated and displayed.

Ex: Flowering Stage Cannabis - **750** PPFD x (**3600** Seconds in an Hour x **12** Hour Photoperiod)/1,000,000 Moles in a Micromole = **32.4 DLI**

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