Lighting Upgrades for CEF Growth Chambers

ABT 212

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Background

The Controlled Environment Facility, housed inside the Life Sciences building on campus at UC Davis, is currently home to 165 growth chambers used for plant science research, with plans of increasing the number to over 200 chambers in an expansion project set to begin in Summer 2019. These growth chambers are highly controlled indoor plant-growing environments that are designed to recreate the ideal environmental conditions (humidity, temperature, lighting brightness, and spectrum) for plant research. Their lighting system is composed of older lighting technology made up of high-intensity discharge (HID) lights, such as metal halide (MH) and high-pressure sodium (HPS) lamps, fluorescent lights, and incandescent lights that require a lot of electricity to function and which could be replaced with new, more efficient technologies.

Our client defined our project scope to be centered around developing a lighting comparison report that can be used to renovate the current lighting system with modern, more energy efficient, and environmentally friendly solutions to reduce the energy consumption and life cycle impacts of each individual growth chamber.

Figure 1. Reach in growth chamber outside and walk-in growth chamber inside.

Introduction

Plant growth and survival is tied to light duration, intensity, and quality through two mechanisms: photosynthesis, where the plant creates carbohydrates from light energy, and photomorphogenesis, where accessory pigments induce physiological adjustments [1]. These two processes require different properties of light to function. Photosynthesis requires high energy and accepts many wavelengths while photomorphogenesis uses much less energy but requires certain wavelengths, including far-red and blue light, to perform essential tasks like seed germination and vegetative growth [1]. This leads to strict lighting requirements in growth chambers for successful plant growth. Incandescent, fluorescent, and HID lights in growth chambers have been optimized to have these lighting requirements for many different crops. However, these lights can be problematic. They produce large amounts of heat while using up tremendous amounts of electricity, leading to the need for humidifiers, condensers, and other components which keep the environment stable but require even more electricity. These lamps are also produced with mercury, making them hard to dispose of and harmful to the environment.

Light emitting diodes, or LEDs, are a developing lighting technology that could be used to replace HID, fluorescent, and incandescent lights while decreasing electricity usage. LEDs have "low electrical requirements, low heat outputs, dozens of wavelength options, dimmable properties, no hazardous material concerns, and a long life" [1]. Depending on their composition, these lights can produce specific wavelengths which can be combined and controlled digitally to produce a desired spectral output. Older research into LED technology for growth chambers focused on blue, red, and far-red wavelengths, due to their effects on photomorphogenesis, with mixed results [2], [3]. More recent research has switched to using wide-spectrum LED fixtures that match the Sun's spectrum even more closely than HID lights or fluorescent and incandescent combinations. These have had much more promising results than limiting the lights to red and blue wavelengths [4], [5], as well as performed better than fluorescent lights [5]. Plant growth is still best with HID lights, but wide-spectrum LED have the closest results to the plant growth produced by HID [4], [6]. When taking in electricity cost, however, LEDs could still be a better alternative than HID because of the much lower electricity usage, both directly as well as indirectly from lessened heat loads. A 2011 cost benefit analysis for Penn State showed that the change to LEDs would have had a payback period of 6.9 years [1]. With the rapid improvements in technology and dropping prices, the payback period for Davis could be even faster.

Prior Art

As previously stated, the lighting technologies currently installed in the growth chambers include: HID, fluorescent and incandescent bulbs. HID lamps such as metal halide and high pressure sodium use the most electricity and are utilized in research when the plants being observed need to reach maturity. Fluorescent lighting is often used for smaller, younger plants as the light output is less intense than HID, allowing for plants to establish themselves. Fluorescent tube lighting is usually found in between shelving units within the walk-in growth chambers. Lastly, incandescent lighting has one main purpose: provide infrared light that the other two technologies lack. Infrared waves are linked to plants ability to bloom and the speed at which stems and foliage grow. Incandescent lighting is the simplest way to integrate infrared waves into growth chambers and are most often found in accordance in HID lighting chambers [7].

Bulbs	Watts	Lumens	Lifetime
Metal Halide	400	3,000-4,000	2.2 years
High Pressure Sodium	400	4,000	4.5 years
Fluorescent T12- 48" & 72"	60 &160	3,320 &10,600	1.1-1.4 years

Figure 2. Current bulbs used at the Controlled Environment Facility

Though the current technologies being used provide adequate environments for plant growth within the chambers, their electricity costs, materials they are made out of and short lifespans provide ample areas for improvement within the Controlled Environment Facility. As technological advancements in LED lighting strategies prove to be viable options, the switch to LEDs at the current research facility, as well as the planned expansion could help mitigate electricity costs, lifecycle impacts and improve the life span of the lighting options.

Methodology

While researching various modern lighting technology, especially LED technology, we gathered sensor data to observe the energy usage of the various components of the growth chambers. We obtained two types of datasets: one from the controller in each growth chamber and one from HOBO data loggers installed for our project. The full dataset from the controller contained the following data: analog input temperature, setpoint temperature, analog output for the 3-way glycol valve, analog input humidity, humidity setpoint, demand to add more humidity, openness of the damper for dehumidification, lighting levels for each set of lights, and the duty cycle for heaters. The dataset for the HOBO data loggers contained: amperage for each of the three AC electrical phases going into the growth chamber, chilled water supply temperature, and chilled water return temperature. Using the given data, one could theoretically make estimates as to how much energy each is allocated to heating, cooling, electricity.

After prior art research and confirming with our client at the Controlled Environment Facility, we finalized our list of constraints and considerations to be the following:

- No impact to ongoing research efforts at facility
- Energy Usage
- Spectrum
- Lumen Output
- Cost/bulb
- Maintenance Costs
- Lifecycle Impacts
- Sizing

All LED technologies chosen for our recommendations would have to fit within these constraints.

Results and Discussion

By diving into the data and the literature, we were able to better identify the needs of an individual growth chamber. Using the data from the loggers and controller, we found a couple things. It would have been best to have current transformers (CT's) on each subsystem so we could properly delineate each part of the growth chamber that uses energy. Unfortunately, we ran into a few dead ends when calculating the total energy consumption of a single growth chamber. The chamber that we were logging the high-intensity discharge lighting data from did not have data for the duty cycle of the heater, meaning we could not delineate how much energy was being consumed by the heater. CT's were also not placed on the lights individually, so in order to delineate the lighting in our data calculations, we used information from the specification sheet [8] to calculate how much energy each type of bulb would theoretically use. We could then subtract this value (referred to as “lighting” in Fig. 3 and 4) from the total electricity usage and call the remainder “electricity”. This value for electricity would then be the sum total for the heater, the electricity usage of the controller, the fan, and any other miscellaneous electricity demands inside the chamber.

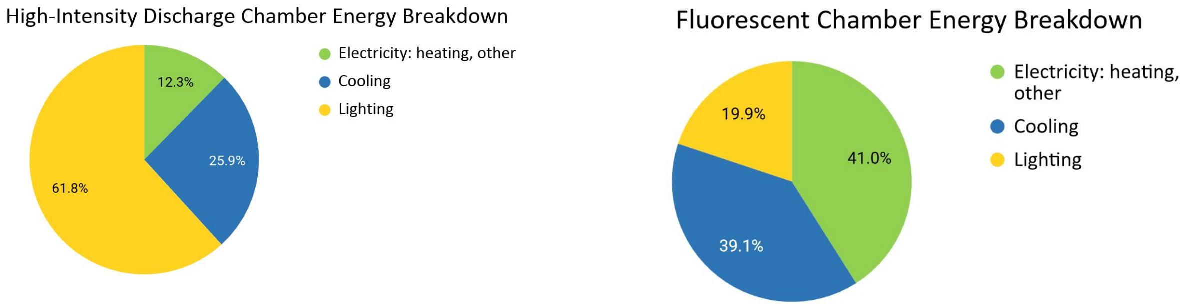


Figure 3. Energy usage in a fluorescent chamber and an HID chamber with the energy broken down into ‘Lighting,’ ‘Cooling,’ and ‘Electricity: other.’

As seen in Fig. 3, in the HID chamber the lighting accounts for approximately 62% of electricity use while in the fluorescent chamber the percentage drops to around 20%. Both these numbers are significant, and they show that renovating the lighting will have a significant impact on the energy used by the Controlled Environment Facility.

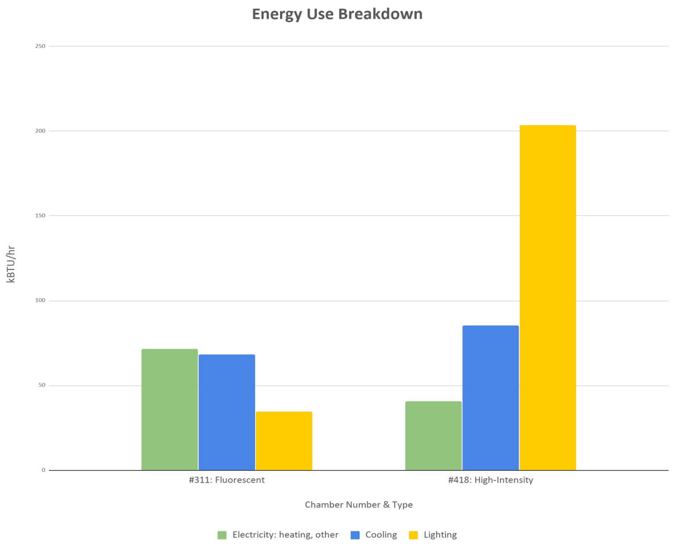


Figure 4. Comparison of energy usage in a fluorescent chamber versus an HID chamber with the energy broken down into ‘Lighting,’ ‘Cooling,’ and ‘Electricity: other.

Products

After analysing the data we received from the CTs, we then understood the importance of finding better lighting alternatives to the current systems. The search for LED technologies that would meet or exceed all constraints began. From the start, the relatively small size of the chambers proved to be the biggest obstacle in finding appropriate lighting solutions. Measuring only 72” x 32” x 66”, the size limitations dramatically reduced the amount of LED products we could consider as viable replacements. Dimensions along with the need to provide adequate photosynthetic photon flux (PPF) for comparable spectral output became the two constraints that allowed us to narrow down the vast field of LED technologies. After much research, we decided on five LED replacement fixtures for both HID and fluorescent lighting.

Once we settled on five products for each type of lighting, we reached out to the client to assist us in choosing the LED fixtures that would best meet the specified constraints, as well as cause no interruption to the ongoing research at the Controlled Environment Facility. Through careful selection and placing higher values on certain constraints such as PPF, spectrum, cost, lifetime and dimmability, we came to an agreement on one technology each for both HID and fluorescent replacements.

Product (HID)	PPF	Cost	Lifetime	Dimable
Fluence VYPR 2p 630W	1700 umol/s	$1,300	50,000 hours	Yes

Figure 5. Chart for the VYPR LED chosen to replace the HID fixtures in the growth chambers https://fluence.science

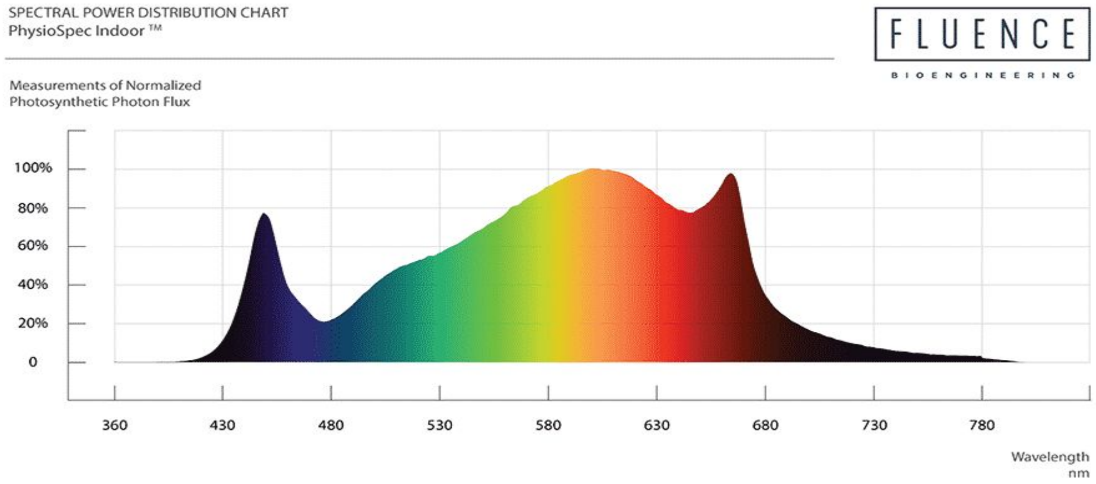


Figure 6. Spectral chart for the VYPR LED chosen to replace the HID fixtures in the growth chambers https://fluence.science

The selection of the Fluence VYPR 2p over the other four products came down to the amount of PPF emitted and its wide ranging spectrum chart. The biggest obstacle in replacing traditional HID lighting is their ability to produce high amounts of lumens and the high rate of PPF output. Up until a few years ago, LEDs could not compete in those two categories, but with recent technological advancements, LEDs can now bridge the gap between them and HIDs. The VYPR 630 watt system from Fluence had the highest PPF output at 1,700 umol/s. The spectrum chart ranked second in comparison to the other lighting technologies, but the small difference in spectrum did not outweigh the gain in PPF. Other specifications include a lifetime of 50,000 hours, which breaks down to 11 years of use at 12 hours per day. The fixture is also dimmable and will allow researchers to fully control the amount of light emitted in their chambers, as well as saving electricity when the fixture does not need to be at full power. Overall, the Fluence VYPR 2p will be a great replacement product for the Controlled Growth Facility.

Product (Fluorescent)	PPF	Cost	Lifetime	Dimable
FGI Lightbar 185W	487 umol/s	$525	50,000 hours	Yes

Figure 7. Chart for the FGI LED chosen to replace the fluorescent fixtures in the growth chambers https://forevergreenindoors.com/collections/featuredproducts

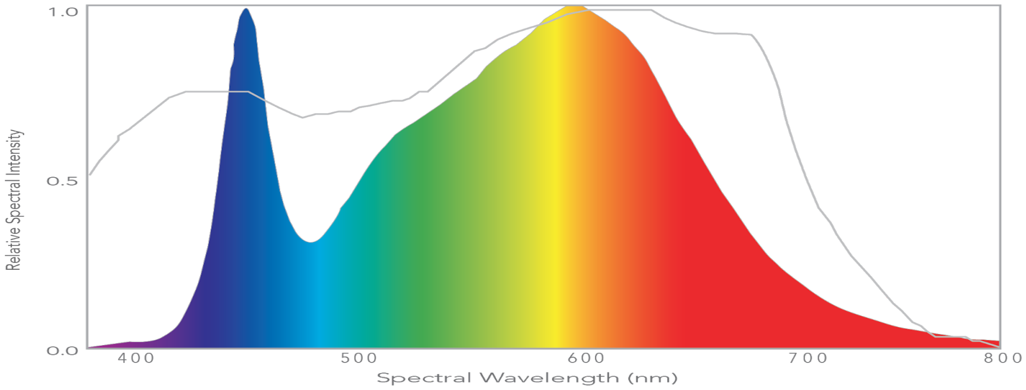


Figure 8. Spectral chart for the FGI Lightbar LED chosen to replace the fluorescent fixtures in the growth chambers. https://forevergreenindoors.com/collections/featuredproducts

Unlike the LEDs chosen to replace HID technology, the five fluorescent replacement products had one standout in the group. Upon comparison the FGI Lightbar 185 watt was in a league of its own. Not only did the product have the highest PPF output at 487 umol/s, but it also had the most comprehensive spectrum of the final five products. The lifetime of the fixture is set at 50,000 hours, which amounts to 11 years of service at 12 hours per day. In comparison to the traditional fluorescent T12 lights, the lifetime of this product is 9 to 10 times longer. The Lightbar is also dimmable allowing for control over the amount of light output. It is common for researchers who utilize fluorescent tube lights to not have a full chamber or a full shelf of plants. The dimmability of this product can dramatically decrease wasteful energy consumption within the 105 chambers that use fluorescent lighting.

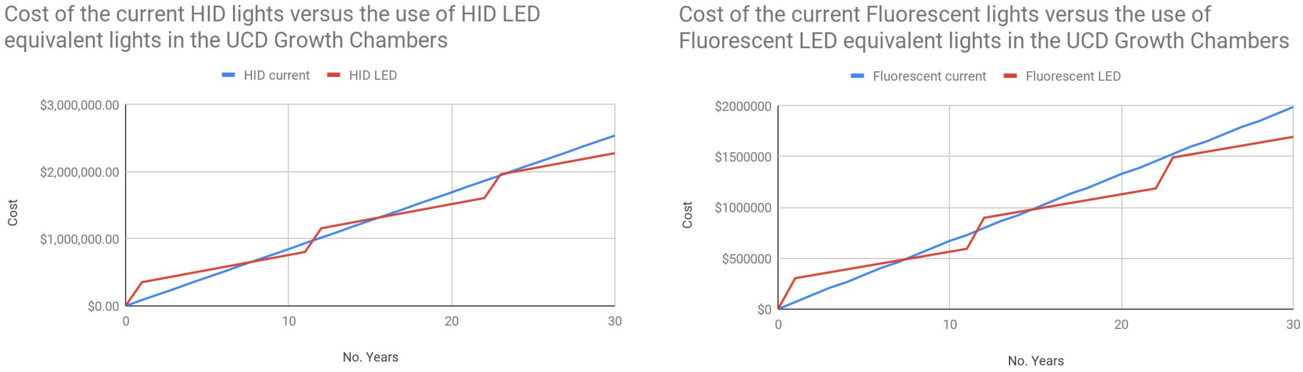
Cost benefit analysis

A cost benefit analysis was done based on the first-choice for both HID and Fluorescent LED replacements. The analysis took into account the cost of each bulb C_{bulb}, the lifetime of the bulb t_{life}, the number of bulbs needed in all the chambers of that bulb type n_{bulb}, and the cost of electricity for UC Davis C_{elec} through the equation:

$$C_{total} = ceil(t_{total}/t_{life}) * n_{bulb} * C_{bulb} + C_{elec} * 365 * t_{total}$$

This led to the total cost C_{total} at year t_{total}.

As shown in Fig. 9, the simple payback period of LEDs replacing HID and Fluorescent light bulbs in all the chambers is around 7 years. This is due to their longer lifespan and low energy usage. Because of the LED's high initial costs, however, it takes around 15 years for the technology to remain lower cost than the current technology.


Cost of the current HID lights versus the use of HID LED equivalent lights in the UCD Growth Chambers

Cost of the current Fluorescent lights versus the use of Fluorescent LED equivalent lights in the UCD Growth Chambers

Figure 9. Simple cost comparison of LED technology to current lighting technology in the UC Davis growth chambers over thirty years of operation. Results show a potential payback period of 7 years, though the high cost of the LED bulbs mean that a true payback period might be closer to 15 years.

However, these graphs do not take into account many properties and developments that make LEDs even more desirable. These include the dramatic decrease in the price of the technology, in 2011 Philips iW Reach Powercore retailed at $4000 and provided 7,400 lumens of lighting at 130 W with a 42,000 hour lifetime [9], requiring 2 lights to replace 10 fluorescent bulbs and 10 incandescent bulbs. This means that in eight years, the initial cost has dropped three-fold to light a chamber. With their long lifespan, this could mean another three-fold drop or more by the time the LED lights need to be replaced. Other considerations to make the switch to LEDs include the increasing cost of HID and fluorescent bulbs due to legislation like the Clean Energy Bill of 2007 which stopped all US production of magnetic ballasts required for HID and fluorescent lights by 2012.

However, there are other sources of uncertainty in our price calculations. One of the most important questions that remains is, how heating and cooling changes due to the removal of HID and fluorescent bulbs, will affect energy usage. Research has shown mixed results, depending on the location and required temperatures. The Penn State results showed a lower usage of energy due to lower heat loads [1] while other research has shown a need to increase energy use to provide more heat to the plants [4]. A more comprehensive data retrieval experiment should be performed to get data on the energy use of all the independent processes in the chamber during normal operations. This will provide more accurate energy usage data to calculate how heating will be impacted by changes in the lighting system. An LED to current technology comparison experiment could also be performed on actual chambers to provide cost data that this study could not. These include maintenance and retrofitting costs, final operational costs, among others.

Conclusions

The objective of this study was to evaluate if the CEF would benefit from switching to LED lighting technologies to decrease their energy usage while not impacting current research. The current results show that LEDs could start saving the facility money in the long term by year 15, without taking into account decreasing costs of the technology and increasing costs of electricity, which could make this payback period happen sooner. The results also show that the LEDs would not impact research. The improved spectrum, dimmability control, and PPF output would be a net benefit to research instead. This study also provides some recommended LED lights that can replace HID lights, the Fluence VYPR 2p, and fluorescent lights, FGI Lightbar 185W. Both lights fit the constraints determined throughout the course, and were chosen with the advice of CEF personnel.

For all these advantages, this study is incomplete and we recommend at least two further experiments to get more data. The most important one would be to get the real energy usage of each individual process in both a HID and a fluorescent chamber, rather than rely on energy usage data sheets. This would provide the final proof needed to show that the CSF can use LED lighting technology to save both on cost and energy usage.

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