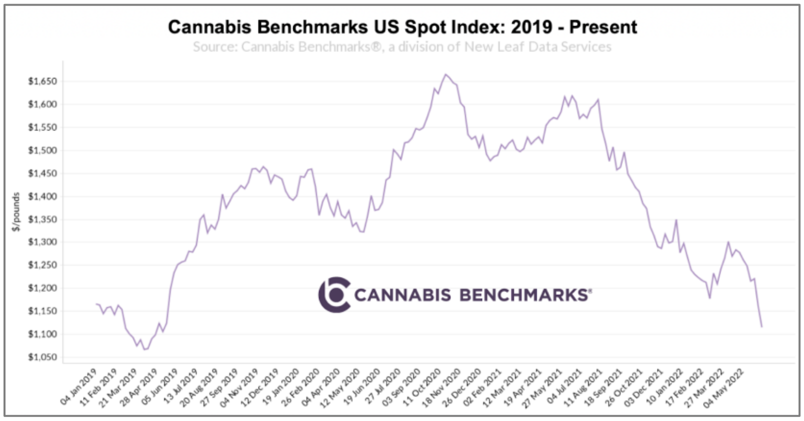
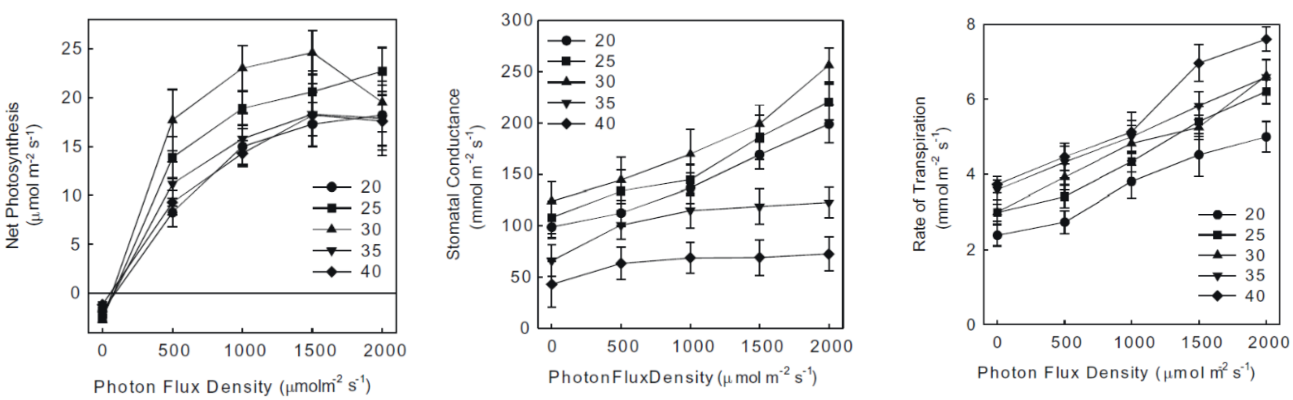
The Goldilocks Approach to LED Lighting for High Intensity Flowering Cannabis

There are a number of trade-offs to be considered when determining the optimal power grow light to be used on an indoor flowering cannabis canopy. This paper explores the relationship between the input power of commercial LED grow lights and the resultant intensity uniformity on the canopy, fitted target efficacy (FTE), reliability, ease of installation & maintenance, and cost.

The North American cannabis industry has seen significant growth in recent years, with the legal cannabis market expanding in both Canada and the United States. However, the industry has also faced numerous economic challenges and uncertainties. Wholesale flower pricing has experienced significant erosion. As seen in the figure (right), the U.S. spot index price for cannabis dropped by roughly 1/3, from $1,600/lb. in 2021 to about $1,100/lb. in 2022[1], and downward pricing pressure continues to impact the economic health of the industry.



To remain profitable, commercial growers have been seeking creative solutions to increase yields and cut costs. A common strategy implemented by many of the multi-state operators (MSOs) has been to increase light intensity on the canopy – thereby increasing production yields. Although increasing the light intensity increases operating costs due to higher electric bills, the added cost is far outweighed by the increase in revenue from the additional product harvested. The figures below show that photosynthesis, stomatal conductance, and transpiration of Cannabis sativa are all positively correlated with increasing light intensity up to 1,500 ppfd (photosynthetic photon flux density) and beyond.[2] The figures illustrate the



[1] https://www.cannabisbenchmarks.com/reports/

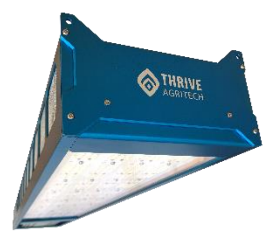
[2] Chandra S, Lata H, Khan IA, Elsohly MA. Photosynthetic response of Cannabis sativa L. to variations in photosynthetic photon flux densities, temperature and CO2 conditions. Physiol Mol Biol Plants. 2008 Oct;14(4):299-306. doi: 10.1007/s12298-008-0027-x. Epub 2009 Feb 26. PMID: 23572895; PMCID: PMC3550641.

impact of ambient temperature on productivity with increasing light levels. In addition to temperature, other critical growing parameters include nutrient supplementation, humidity, and CO_2, which will likely need to be adjusted to maximize production yield. But once optimized, higher light levels tend to produce more biomass.

In response to grower demand for increasing light intensity (ppfd) on the canopy, grow light manufacturers have launched a number of high power solutions. While it may seem obvious that higher power lights produce higher light intensities on the canopy, there are subtleties and complexities that need to be understood to optimize yield, reliability, and cost.

The key to selecting the ideal light is having a deep understanding of the application and the lighting designs generated by the grow light manufacturers. By reviewing the lighting designs of a few leading LED grow lights, we can get to that deeper understanding. The following analysis looks at the implementation of low, medium, and high power LED lighting solutions that are prevalent for flowering cannabis. The low power solution is the ubiquitous 600W LED fixture that was brought to market by several lighting manufacturers as a one-for-one replacement for the 1,000W double-ended high pressure sodium (HPS) light. The medium power LED light is 840W, while the high power light is 1,500W. The modeling puts the fixtures on equal footing by assuming each light has a white light spectrum with an efficacy of 2.8 µmols/joule, and a Lambertian[3] distribution.

600W LED Grow Light



840W LED Grow Light

1,500W LED Grow Light

Evaluation criteria in reviewing the lighting designs include:

- number of lights required to achieve the target ppfd,
- mounting height of the lights,
- relationship between mounting height and variation in light intensity across the canopy,
- overall reliability,
- installation & maintenance cost and complexity,
- fitted target efficacy on the canopy,
- relationship between fitted target efficacy and overall cost

[3] https://en.wikipedia.org/wiki/Lambert%27s_cosine_law

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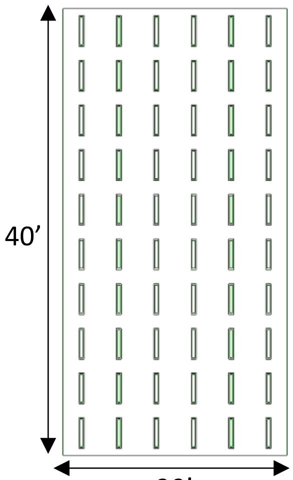
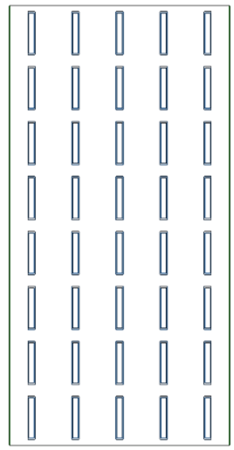
Indoor Warehouse Lighting Designs

A 20’x40’ indoor flower room with maximum allowable mounting distances of 3’ and 4’ was modeled for the analysis of the three different lighting options. The target ppfd was chosen at a relatively high intensity of 1,200 µmols/m^2/sec. Modeling results from the 3’ mounting height scenario are presented below.

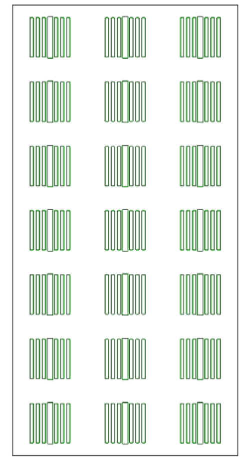
600W: 60 Lights



840W: 40 Lights

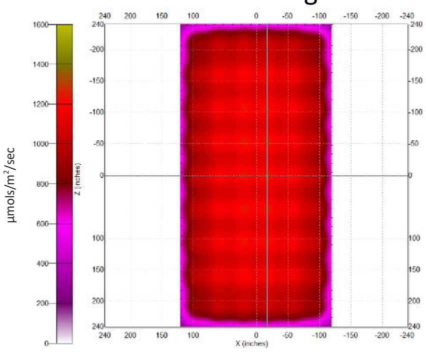


1,500W: 21 Lights

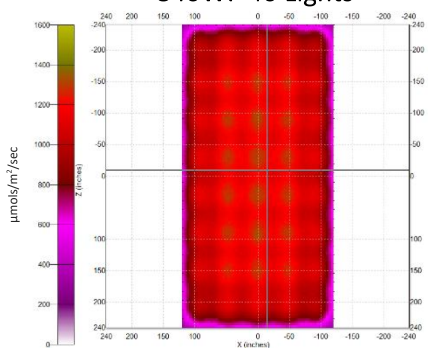


Intensity on Canopy with 3’ Mounting Height

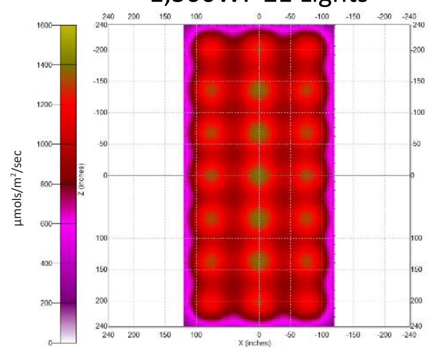
600W: 60 Lights



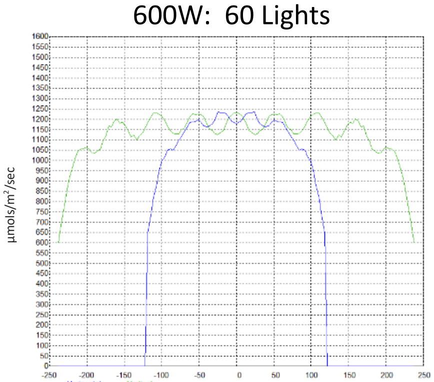
840W: 40 Lights



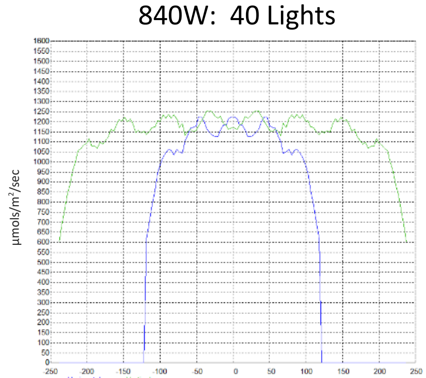
1,500W: 21 Lights



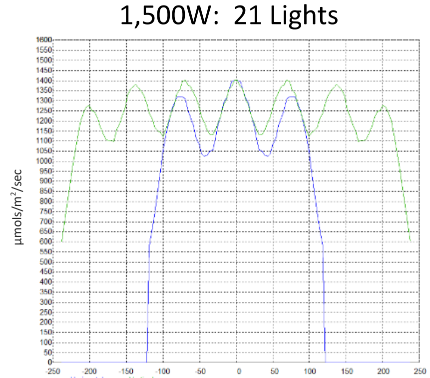
600W: 60 Lights



840W: 40 Lights



1,500W: 21 Lights



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Discussion of results at 3' mounting height

Although all three lights (600W, 840W, and 1500W) can achieve the target light intensity of 1,200 µmols/m²/sec, there are significant differences in the uniformity of the lights across the canopy. For the 600W and 840W lights, the peak-to-valley variation in light intensity on the canopy is less than ±3%, while the variation for the 1,500W light is approximately ±15%. The "hot spots" created by the 1,500W light are evident in the heat maps from the modeling results shown above. These hot spots can have a significant impact on a cannabis canopy, potentially leading to uneven plant growth, reduced yields, and increased susceptibility to disease and other environmental stressors.

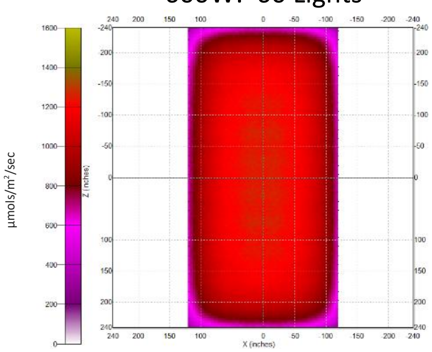
There is minimal uniformity difference between the 600W light and the 840W light – both are in an acceptable range for an optimized lighting solution. However, the solution using the 600W light requires 50% more lights than the 840W solution (60 lights vs. 40 lights). With all else being equal, growers prefer fewer lights because this represents a reduction in installation and maintenance cost and complexity. Additionally, fewer lights means fewer potential points of failure, so overall reliability is higher with the 840W lighting design. Although the 1,500W solution requires half the number of lights as the 840W solution, there is a significant penalty to pay for the non-uniformity of light across the canopy.

Designs with 4' Mounting Height

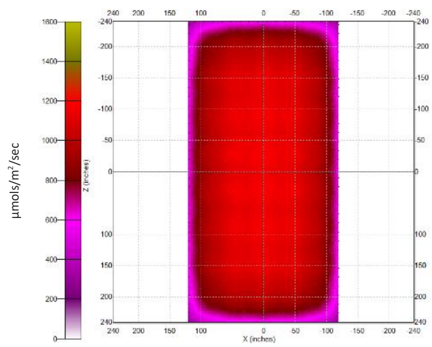
Modeling results with the lights raised to a mounting height of 4' above the canopy are shown below. The lighting designs remain unchanged, only the mounting height has been increased to improve the uniformity results with the 1,500W light.

Intensity on Canopy with 4' Mounting Height

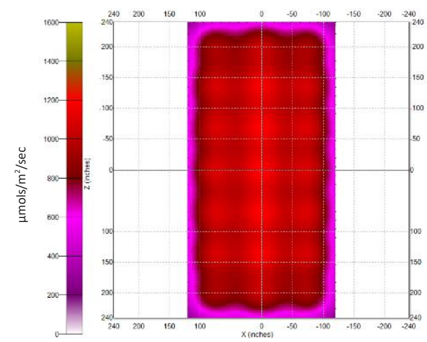
600W: 60 Lights



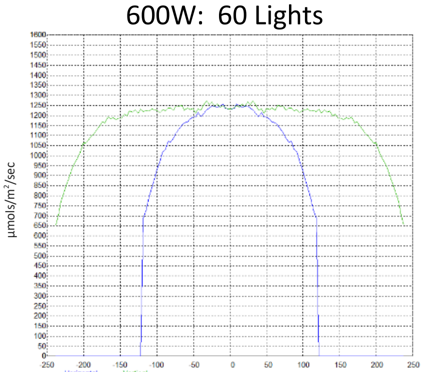
840W: 40 Lights



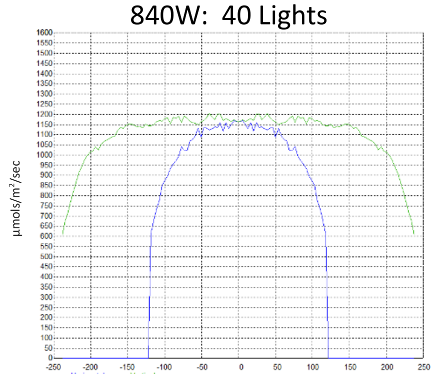
1,500W: 21 Lights



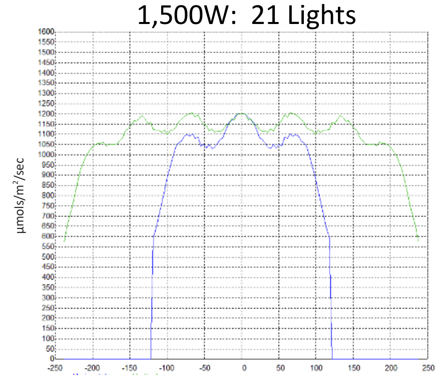
600W: 60 Lights



840W: 40 Lights



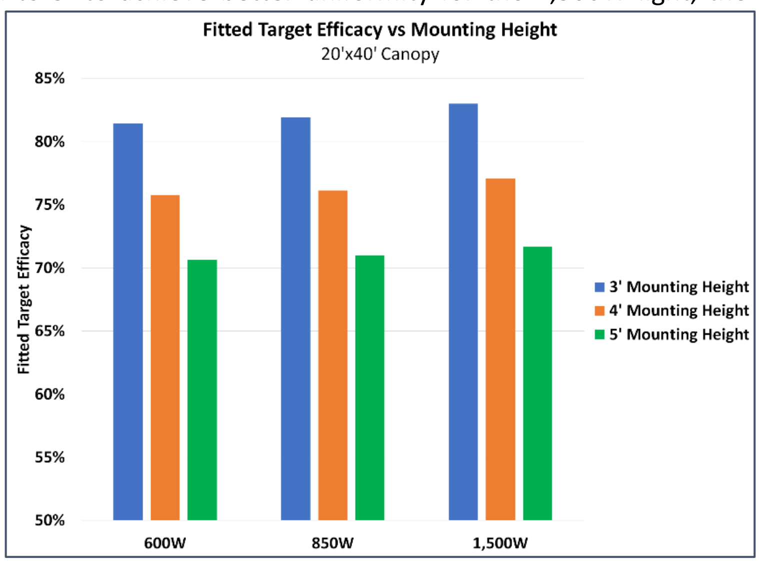
1,500W: 21 Lights



Discussion of results at 4' mounting height

From the figures above, the lighting deigns at 4' mounting height are more uniform for each solution when compared against the 3' mounting height designs. The uniformity for the 600W and 840W designs are nearly perfect. Light uniformity on the canopy for the 1,500W design has improved, but is still exhibiting roughly ±10% variation.

Although increasing the distance from the lights to the canopy will improve the uniformity on the canopy, there is a downside to increasing the mounting height. As the distance from the lights to the plants increases, the fitted target efficacy (FTE) is reduced, thereby reducing the overall intensity on the canopy. The FTE represents the percentage of light emitted from the light source that reaches its target – in this case the plant canopy. For a point source, engineers sometimes refer to the inverse square law to describe the FTE. However, horticulture lights are extended sources that do not conform to the inverse square law when located in proximity to the canopy. For the 20'x40' canopy used in the analysis presented in this paper, the relative intensity on the canopy is reduced by 7% by increasing the mounting distance from 3' to 4'. If the mounting height were raised to 5' to achieve better uniformity for the 1,500W light, the intensity on the canopy would drop by a total of 13% relative to the 3' mounting height. The relationship between mounting height and FTE for the case of the 20'x40' canopy is shown in the chart (right). Although additional lights can be added to make up for the loss of intensity on the canopy, doing so will increase the cost of the lighting solution. It can be reasonably estimated that if the canopy intensity is reduced by 10% due to the need to increase the mounting height, the capital expenditure on the grow lights will need to be increased by a corresponding 10% to achieve the target ppfd.



Conclusions

With the recent move from commercial cannabis growers toward higher ppfd on the canopy to increase production yields and profitability, choosing the right lighting solution is far more complicated than simply choosing the highest power grow light. In this paper, we evaluated the trade-offs in the implementation of three grow lights with distinct input powers (600W, 840W, and 1,500W). Lighting designs were generated at various mounting heights and resultant intensity distributions on the canopy were evaluated from the perspectives of uniformity and fitted target efficacy. In addition, the implications to reliability, installation, maintenance, and cost were studied.

Lighting manufacturers make grow lights for the cannabis industry that range from below 100W to more than 1,500W for a range of applications that span from tissue culture to flower. The 600W light that we

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evaluated produced excellent uniformity on the canopy but was underpowered for the target ppfd. This resulted in a 600W lighting design that required more lights than alternate approaches. The higher number of lights represented more points of failure (lower reliability) and higher installation & maintenance cost and complexity. If the ppfd target was lower, the 600W light may have been the ideal solution because the higher power alternatives would have struggled to achieve the uniformity requirements.

At the other end of the spectrum, the lighting design for the 1,500W light required the fewest number of lights to achieve the target ppfd. However, to meet the uniformity specification, the lights needed to be mounted substantially higher. And this caused a significant reduction in FTE with a corresponding increase in capital cost as more lights were required to boost the intensity back to the target.

The 840W light was able to achieve very high uniformity even at the close mounting height of 3'. Although the uniformity was slightly worse than that of the 600W light, it was still more than acceptable. With far fewer fixtures than the 600W light and a much closer mounting height than the 1,500W light, the 840W light found the right balance of performance and cost. As Goldilocks discovered, the porridge tastes best when it's served at just the right temperature.

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