Greenhouse Cannabis Cultivation with LED Lighting: Bridging the Radiant Heat Gap

Introduction

Greenhouse cannabis growers face a unique set of challenges when balancing lighting, heating, and overall environmental control. Many operations rely on high-pressure sodium (HPS) lamps not only for supplemental light intensity but also for the radiant heat these fixtures emit. This radiant warmth plays a significant role in maintaining proper leaf surface temperatures, facilitating transpiration, and promoting robust photosynthetic activity. However, with rising energy costs, stringent regulatory requirements, and sustainability goals shaping cultivation practices, growers increasingly seek out light-emitting diode (LED) lighting systems for their superior energy efficiency, reliability, and spectral precision.

Despite the clear advantages of LEDs, namely lower energy consumption, longer fixture life, and customizable light spectra, one notable drawback is the reduced infrared radiation they emit compared to HPS lamps. Less infrared means cooler leaf surfaces, which can slow transpiration unless compensated by environmental controls or supplemental forms of heating. This paper explores how greenhouse cannabis cultivators can maintain optimal leaf surface temperature while leveraging LED efficiency, with a special focus on intracanopy or under-canopy lighting.

1. The Role of Radiant Heat in Cannabis Production

1.1 Leaf Surface Temperature and Transpiration

Cannabis sativa flourishes in controlled environments when leaf temperatures are kept within an optimal range, often between 77°F (25°C) and 82°F (28°C), although specific strains may vary slightly.[1] When leaf surfaces are consistently warmer, stomata remain open, thereby promoting gas exchange and the release of water vapor. This transpiration activity supports a healthy nutrient flow from the root zone to the shoots and maintains internal plant temperatures.

HPS lamps naturally emit a spectrum that includes a fair amount of infrared, effectively warming the canopy. By contrast, modern LED fixtures direct most of their energy into photosynthetically active radiation (PAR), with minimal infrared output (Figure 1). As a result, growers who switch from HPS to LED without compensating for the lost radiant heat may observe reduced transpiration rates, especially in cooler climates or during winter growing seasons.

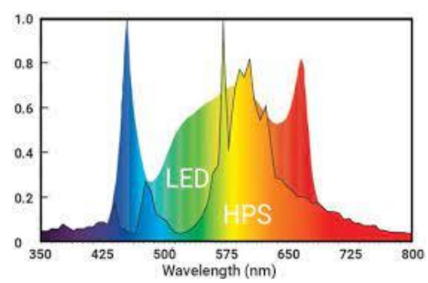

Figure 1. Typical HPS vs LED Spectra

1.2 Consequences of Cool Canopies

If leaf surface temperatures drop below the optimal range for photosynthesis, cannabis plants can experience slower growth, decreased water uptake, and a compromised ability to manage humidity through transpiration. Cool, moisture-laden foliage becomes more susceptible to pathogens such as powdery mildew and botrytis. Hence, the warmth from HPS lamps often provides a "free" environmental buffer, mitigating some of these issues. Moving to LEDs demands a more precise environmental strategy to maintain vigorous growth.

[1] Kisa, M., "Leaf Temperature Management in Controlled-Environment Agriculture," HortScience, Vol. 49, No. 12, 2014, pp. 1380–1385.

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2. The Challenge of Switching to LED Horticulture Lighting

LED lighting fixtures generally feature higher photon efficacy (µmol/J) than HPS lights, enabling them to convert electrical power into usable light more efficiently. As a result, they can provide significant energy savings and a reduced carbon footprint over the fixture's lifespan, which is an increasingly critical factor for commercial cannabis operations subject to strict energy regulations. Furthermore, if a grower chooses to maintain the same power consumption when switching to LED, these fixtures will deliver more PAR light to the plants, thereby enhancing photosynthesis and driving higher yields.

Despite these clear advantages, the lower infrared output from LEDs poses a challenge for cultivators who rely on HPS-induced canopy warming. In cooler seasons, greenhouses switching to LEDs may require additional heating, potentially offsetting some of the energy savings. A precise assessment of the greenhouse's heating capacity, insulation, and local climate is crucial to ensure a seamless transition.

3. Intracanopy and Under-Canopy Lighting Strategies

3.1 Intracanopy Lighting

Intracanopy lighting refers to the practice of installing additional, lower-wattage LED bars or strips within the foliage to illuminate and gently warm areas that would otherwise remain shaded. This technique has been successfully employed in vertical farming and with greenhouse-grown vine crops such as tomatoes. In cannabis cultivation, it serves to enhance lower-canopy photosynthesis by strategically placing supplemental fixtures so that leaves beneath the uppermost layer receive adequate photosynthetically active radiation, thereby reducing shading and promoting a more uniform rate of photosynthesis throughout the plant. Additionally, although LEDs emit less infrared energy than HPS lamps, positioning these fixtures closer to the foliage provides a localized heating effect that helps maintain stable leaf temperatures and regulates transpiration in the lower regions of the canopy.

However, mounting intracanopy fixtures in a densely populated canopy is often difficult, and maintaining these lights, through tasks such as cleaning and repositioning, can be labor-intensive. These challenges can reduce the overall effectiveness of intracanopy lighting, potentially offsetting its benefits in enhancing photosynthesis and thermal regulation.

3.2 Under-Canopy Lighting

Under-canopy lighting extends this concept to the lower extremities of the plant, shining light upward from beneath the foliage.[2] Cannabis cultivators often notice that the bottom-most leaves and bud sites receive minimal light intensity, which hinders their development. By adding LED light bars near the base of the plant, growers can optimize bud formation, especially in dense canopies.

Though under-canopy fixtures do not replicate the level of infrared radiation found in HPS, the moderate amount of heat they do produce can help balance environmental conditions in these darker, cooler zones. As a result, the risk of botrytis or mildew declines, and growers may see higher transpiration rates and more uniform bud development across all canopy layers.

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[2] Sloper, J. and Smith, G., "Utilizing Intracanopy Lighting for Dense Cannabis Canopies," Frontiers in Plant Science, Vol. 10, 2019, 1152.

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4. Energy Efficiency and Operational Considerations

4.1 Balancing Investments and Long-Term Savings

Switching to LED systems involves initial capital costs for fixtures and possibly additional HVAC adjustments. While this outlay can be daunting, long-term gains often include 30-40% reductions in energy consumption and significantly lower bulb replacement costs.[3] In today's cannabis market, where wholesale prices have dropped and margins have tightened, even small improvements in efficiency can make a significant difference in overall profitability.

4.2 Impact on Heating and Cooling

The heat load in a greenhouse environment must be carefully balanced. During warm months, fewer heat-emitting fixtures can reduce reliance on cooling systems, lowering operational costs. However, supplemental heating is sometimes necessary when outside temperatures drop. This trade-off is simpler to manage if cultivators have already invested in robust greenhouse insulation and well-calibrated HVAC systems.

Notably, advanced LED fixtures generate less heat at the canopy level, enabling better temperature stratification, rather than pockets of overly hot zones beneath HPS lights. This can pave the way for more uniform climate control and reduced plant stress. Over time, consistent environmental parameters can lead to higher cannabinoid content and improved terpene profiles.[4]

5. Environmental Management and VPD

5.1 The Importance of VPD (Vapor Pressure Deficit)

VPD, the difference between the vapor pressure inside leaf stomata and that of the surrounding air, is a central factor in plant physiology. Cannabis crops perform best when the VPD level is maintained within a specific range, often around 0.8 to 1.2 kPa for vegetative stages, shifting slightly higher during flowering.[5]

When transitioning from HPS to LED, growers must recognize that reduced leaf surface temperatures can lower transpiration rates, thereby decreasing VPD. This drop can cause an accumulation of moisture around the leaf, leading to higher humidity levels and potential pathogen pressure. Greenhouse operators should continuously monitor both temperature and relative humidity and adapt ventilation and heating to keep VPD at an optimal set point.

5.2 Coordinating Lighting with HVAC

In modern greenhouse environments, HVAC systems and lighting controls often operate hand-in-hand. Some LED systems can be integrated with climate control software that modulates output based on changing temperature and humidity conditions.[6] By aligning lighting schedules with greenhouse climate management, cultivators can steadily maintain canopy-level temperatures and stable VPD, regardless of fluctuating external weather patterns.

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[3] Kostic, L. and Zezelj, D., "Comparing Energy Efficiency of LED vs. HPS in Greenhouse Hemp Cultivation," Journal of Sustainable Agriculture, Vol. 22, No. 4, 2020, pp. 341–349.

[4] Chandra, S., Lata, H., and ElSohly, M.A., "Cannabis sativa L.: Botany and Biotechnology," Springer International Publishing, 2017.

[5] Faust, J.E. and Logan, J., "Expanding on Vapor Pressure Deficit in Horticultural Environments," Horticultural Reviews, Vol. 42, 2019, pp. 335–368.

[6] Park, Y. and Runkle, E.S., "Dynamic Light and Temperature Control in Controlled-Environment Agriculture," HortTechnology, Vol. 30, No. 4, 2020, pp. 534–549.

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6. Practical Steps for Implementation

6.1 Assessing Greenhouse Layout and Canopy Structure

Before making the switch to LED or introducing under-canopy lighting, a thorough assessment of the greenhouse layout is essential. Elements such as plant spacing, row width, and trellis design will dictate where and how additional fixtures can be placed. Areas of the canopy that were previously warmed by HPS lamps should be noted, as these zones may need targeted intervention (e.g., extra heating or supplemental LED lights).

6.2 Choosing the Right LED Fixtures

Not all LEDs are created equal. When exploring intracanopy or under-canopy fixtures, consider factors such as spectrum, efficacy (µmol/J), thermal management, and durability under humid greenhouse conditions. Some products are designed specifically to withstand frequent splashing or high moisture levels, which is essential for in-canopy installations. These grow lights should be certified with an ingress protection rating of IP66 or IP67, which indicates the lights are designed to operate in these harsh conditions. It is equally important to ensure the lighting fixtures are certified for safety (UL8800) and are listed on the qualified products listing from Design Lights Consortium (DLC).

6.3 Adjusting Irrigation and Nutrient Regimens

Because leaf temperatures and transpiration rates can shift when changing lighting technologies, cultivators should monitor water consumption and nutrient uptake closely. If intracanopy or under-canopy fixtures increase metabolic activity in lower leaves, plants may demand more frequent irrigation or altered nutrient ratios. Maintaining close oversight of EC (electrical conductivity) and pH in the root zone ensures that plants receive balanced nutrition throughout the transition.

7. Incorporating LED Lighting Without Sacrificing Plant Transpiration

A practical and increasingly popular approach to upgrading from HPS to LED involves replacing HPS lamps with Thrive Agritech's Pinnacle HP LED lights – see Figure 2. Certified for safety under UL880 and registered on DLC's qualified products list, Pinnacle HP LED fixtures are specifically designed for high-intensity horticultural applications, providing robust photon output for top-of-canopy coverage while significantly reducing energy use and excess heat. By mounting these fixtures at a suitable height as specified in a customized lighting design, growers can deliver a uniform blanket of illumination on the canopy that is necessary for vigorous growth.

To preserve adequate leaf surface temperature, Thrive Agritech's Boost LED lights can be installed below the canopy (Figure 3). These slim, water-resistant fixtures offer a balanced spectrum conducive to both vegetative and flowering phases, ensuring that buds and leaves in shaded areas still receive sufficient photons. Although LEDs do not emit as much infrared energy as HPS, placing Boost fixtures in proximity to lower leaves can provide a localized warming effect. This helps maintain optimal transpiration rates, preventing the lower canopy from becoming a cold, humid zone susceptible to fungal or pathogenic outbreaks.

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Figure 3. Pinnacle HP LED Lights in greenhouse cultivation facility

Figure 2. Boost LED Lights below canopy

7.1 A Real-World Example

Looking at a specific example of switching from HPS to LED is instructive.

HPS Lighting

Most 1,000W double-ended high pressure sodium lights actually draw about 1,080W, as there are conversion losses from the power supply. For a typical HPS light, roughly 20-30% of the electrical input is converted into visible light that drives photosynthesis. Top of the line 1,000W double-ended HPS lights typically achieve about 1.9 µmol/j, which results in about 1,900 µmols/second of PAR light. The remaining 70-80% of the input energy is released as heat. Approximately 50-60% is emitted as radiant (infrared) heat due to the high temperatures within the arc tube, while the remaining 10-20% is lost via convective processes.[7,8] Due to the location of the HPS lights several feet above the plants, any convective heat is unlikely to reach the canopy. Of the roughly 50% of the input power that is converted to radiant heat, only about 10-20% (mostly in the near-infrared range) is absorbed by the leaves to increase leaf surface temperature. The remainder of the radiative heat is mostly reflected or transmitted, which helps the plant avoid excessive heating.[9,10]

LED Lighting

For a high-efficiency LED grow light, typically around 40-50% of the electrical input is converted into visible light that is utilized for photosynthesis.[11] If we were to replace the 1,000W HPS light with a high-efficiency 840W LED top light with efficiency of 3.5 µmol/j, the resultant PAR output would be roughly 2,950 µmols/second. Since there is little to no radiative heat generated by LEDs, the balance of the input power (50%-60%) is converted to convective heat. Just like with the HPS top light, convective heat from the LED top light is unlikely to reach the canopy. However, by adding two 120W lights below the canopy, the convective heat would be captured by the plants as the heat rises through the canopy. Recent research

[7] U.S. Department of Energy, "Solid-State Lighting Program," available at: https://www.energy.gov/eere/ssl
[8] Signify (formerly Philips Lighting), "Lighting Solutions," available at: https://www.signify.com/en-us/lighting-solutions
[9] Monteith, J. L. and Unsworth, M. H. (2013). Principles of Environmental Physics: Plants, Animals, and the Atmosphere. 4th ed. Academic Press.
[10] Sims, D. A. and Gamon, J. A. (2002). Relationships between leaf pigment content and spectral reflectance across a wide range of species, leaf structures and developmental stages. Remote Sensing of Environment, 81(2-3), 337–354.
[11] U.S. Department of Energy, LED Basics, available at: https://www.energy.gov/eere/ssl/led-basics

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indicates that roughly 20-30% of the convective heat flux incident on a leaf may be absorbed, leading to an increase in leaf surface temperature.[12, 13]

Table 1 below calculates the input power, PAR, and heat generated from both the 1,000W HPS light and an 840W LED top light with two LED under-canopy lights. The table compares the estimated amount of heat absorbed by the plant leaves in each case.

Table 1. Example of replacing an HPS light with an LED top light and two under-canopy LED lights

	HPS	**LED**
Input Power to top light (W)	1,080	840
Input Power to under canopy light (W)	0	240
Total Input Power (W)	1,080	1,080
PAR light output (µmols/sec)	1,900	3,600
Radiant heat from top light (W)	500	0
Radiant heat absorbed by plant leaves (W)	50	0
Convective heat from under canopy light (W)	0	144
Convective heat aborbed by plant leaves (W)	0	43
Heat aborbed by plant leaves (W)	50	43

Implementing a dual LED strategy, using both under-canopy and top-canopy fixtures, can effectively compensate for the loss of radiant heat typically observed with HPS lighting. This approach elevates leaf surface temperature, which in turn promotes both transpiration and photosynthesis. Although the overall electrical input remains similar between the HPS and LED configurations in this example, the LED system delivers a substantially higher amount of PAR light that is more uniformly distributed across the entire canopy. Moreover, greenhouse operators can opt for lower-wattage LED top lights to maintain equivalent PAR levels at the canopy top while reducing total energy consumption.

8. Future Outlook for Greenhouse LED Use

As the global cannabis market expands, the demand for efficient and sustainable production will only grow. LEDs continue to advance in efficiency, and ongoing research focuses on refining the ratios of light spectrum to heat output. Many greenhouse cultivators are also exploring hybrid setups, a combination of LED and HPS, where a subset of HPS fixtures is retained for infrared benefits while LEDs supply the bulk of the photosynthetic light.

In the coming years, data-driven systems that integrate lighting, HVAC, and nutrient delivery will become commonplace. Sensors placed throughout the greenhouse will feed real-time information into adaptive algorithms, automatically adjusting LED intensity, temperature, and humidity to maintain a consistent microclimate across all layers of the canopy. Through careful design and the adoption of solutions like Thrive Agritech's Pinnacle HP and Boost systems, growers can reduce energy consumption, ensure robust yields, and maintain the subtle but critical benefits of radiant heat for thriving cannabis crops.

[12] Monteith, J. L. and Unsworth, M. H. (2013). Principles of Environmental Physics: Plants, Animals, and the Atmosphere. 4th ed. Academic Press.
[13] Jones, H.G. (2014). Plants and Microclimate: A Quantitative Approach to Environmental Plant Physiology. 2nd ed. Cambridge University Press.

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