SevenLeaves 2017

Indoor Horticulture Lighting Study

Sacramento Municipal Utility District

SMUD

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1. Executive Summary

1.1 Introduction

With the recent legalization of adult use cannabis in California, SMUD has received numerous requests for electrical service upgrades from commercial customers planning to operate indoor cultivation facilities. Some of these facilities are large and have significant power requirements. For example, during the flowering stage, commercial cultivators often use one 1,000-watt high pressure sodium (HPS) light fixture for every 16 to 25 sq. ft. of planted area (i.e., canopy). A facility with 10,000 sq. ft. of flowering space can draw up to 550 kW of power for just lighting alone. For comparison purposes, a modern 10,000 sq. ft. commercial office space would require only around 8 kW for lighting. On an annual basis, the energy consumption to support just one cannabis plant is about the same as seven residential refrigerators.

Because the City of Sacramento is the only local government within SMUD's service territory that allows indoor cannabis cultivation operations, these new facilities will be concentrated into a relatively small geographical area. Based on permitting requirements and forecasted growth, certain areas in this region will likely require infrastructure upgrades. This is part of SMUD's normal grid planning process, and SMUD does this type of work for all business customers.

Because cannabis cultivation is now legal in California, SMUD treats cannabis cultivators just like any other commercial customer and works with them to provide the electricity they need to operate their business. SMUD works with them to save energy and money when possible, while ensuring such operational and environmental cost savings do not impact overall cultivation and business productivity (i.e., plant yield and quality).

Recently, LED manufacturers have started to offer products for horticulture applications. While these products are expected to reduce lighting energy consumption by up to 40%, few case studies exist for using these products to cultivate cannabis and validate them as a viable option that will produce the same (or better) results than incumbent technologies, often HPS. Offering incentives to commercial cultivators to use LEDs can help lessen the impacts on the grid and provide SMUD with more flexibility and time to upgrade its infrastructure. Furthermore, establishing a successful local case study will provide useful information for developing energy efficiency incentive programs.

1.2 Project Objectives

The primary objectives for this study were:

- Determine if LED technology is a viable option for cultivating cannabis through the flowering stage (producing the same, if not better, results in place of industry-standard HPS fixtures) and how much energy and demand savings potential may exist.
- Learn more about the energy loads required for indoor horticulture operations, including those for cooling, heating, dehumidification, fan energy, and plug loads, and how they are impacted when growing with HPS versus LED.
- Report any observed energy efficiency opportunities for commercial indoor cannabis cultivation facilities.

1.3 Results

Cadmus monitored two similar flowering rooms at SevenLeaves, one with HPS light fixtures and one with LED fixtures. The monitoring took place throughout two flowering cycles in each room. After analyzing all collected data, we calculated the following savings when comparing the LED results to HPS:

- Overall energy savings of 30% (17,719 kWh)
- Lighting energy savings of 36% (14,166 kWh)
- Overall demand savings of 34% (26.5 kW)
- Lighting demand savings of 41% (22.0 kW)
- Simple payback of 1.7 years for the LED upgrade

We verified the center-of-fixture, canopy-level photosynthetic photon flux density (PPFD) for the LED fixtures aligned with the manufacturer-reported values. We found substantial dependency of cooling energy consumption load on weather, due to intake of outside air and air from the environment surrounding the rooms. Data also suggested the reduced loads in the LED room would allow for HVAC equipment downsizing compared to the HPS room.

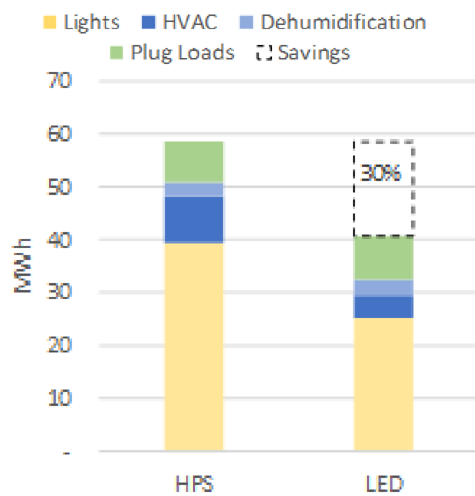

Figure 1: Total energy use during monitored flowering cycles. Cooling & dehumidification values are weather-normalized.

Unfortunately, the crop yields for the LED room were 35-40% lower than SevenLeaves expects from plants grown using HPS fixtures. The HPS yields for this study were both within their expected range. However, the cultivator did comment that the quality of the product grown in LED rooms was excellent, with Terpene, THC (tetrahydrocannabinol), and total cannabinoid levels higher than expected.

During the first LED run, the plants experienced light shock when they first entered the flowering room because the intensity levels were set too high. Since then, the growers have learned about the nuances of growing with LED lights and have avoided such issues. So despite lower than expected crop yields, SevenLeaves staff are optimistic about the potential of growing with LED lights. After this study concluded, a subsequent flowering run in the LED room yielded their best crop yet.

1.4 Recommendations

The findings from this study suggest LEDs can provide the necessary lighting to successfully cultivate cannabis through the flowering phase while reducing energy use and costs. However, with numerous variables impacting the energy use of each system, it is difficult to determine whether interactive effects can be attributed to the lighting system upgrade. Additional research is necessary to determine interactive effects the lighting may have on other energy systems as well as the response of crops. Specific lessons learned and recommendations are detailed in Section 4 - Conclusion.

While additional research is necessary, SMUD is currently offering custom incentives for LED and other technologies for indoor cultivation facilities. For more information, please send an email to indoorcultivation@smud.org or visit the websites below:

- Custom Incentive Program (retrofit projects)
  https://www.smud.org/en/Business-Solutions-and-Rebates/Business-Rebates/Custom-Incentives
- Savings by Design (new construction)
  https://www.smud.org/en/Business-Solutions-and-Rebates/Business-Rebates/Savings-by-Design

1.5 Acknowledgements

While many people contributed to this project, we particularly appreciate the cooperation and efforts of the staff at SevenLeaves as well as Allen Lee, Tom Davies, and Alex Trueblood from Cadmus.

2. Project Description

2.1 Background

Indoor cannabis cultivation is an energy intensive process. As mentioned earlier, the lighting demand alone may be near 70 times the lighting demand for a typical office space. Not only are demand loads high, but hours of use for lighting typically range from 12 to 24 hours per day, depending on the stage of life the plants are in. These high lighting loads result in corresponding cooling and equipment loads to maintain the environmental conditions desired by the cultivators. Although targets vary, each cultivator has preferred photosynthetic photon flux density (PPFD), space temperature, relative humidity, and CO_2 ranges for the plants throughout their growth cycle. Maintaining these conditions is critical to plant production and crop yields. Many lighting types are commonly used throughout the cultivation process such as compact fluorescent (CFL), T5 fluorescent, metal halide (MH), HPS, and LED. Typical industry ranges for these parameters are summarized in Table 1.

		Clone	Vegetative	Flower	Harvest	Drying
Duration		1-2 weeks	2-5 weeks	8-12 weeks	n/a	4-14 days
Lighting Type		CFL, T5, LED	T5, MH, LED	HPS, LED	n/a	n/a
Light Schedule (hrs. on)		24	18-24	12	n/a	0
PPFD (µmoles/m²/s)		75-150	300-600	600+	n/a	n/a
Airflow		Sometimes	Yes	Yes	n/a	Sometimes
Relative Humidity (%)		60-80	55-75	50-60	45-55	45-60
CO_2 (ppm)		400	400-800	800-1400	n/a	n/a
Temperature (F)	Lights on	72-80	74-84	68-84	65-75	n/a
	Lights off	70-78	68-76	68-78	65-75	60-75

Table 1: Typical environmental targets for cannabis cultivation by plant growth stage.[1]

As can be seen in Table 1, the flowering stage requires high PPFD output for 12 hours a day and cooler space temperatures while lights are on, and this stage may last up to 12 weeks. The flowering rooms also make up a higher percentage of the facility's floor area, generally occupying at least three times the area occupied by plants in their

[1] Fluence Bioengineering High PPFD Cultivation Guide v1.2 and general knowledge sources.

vegetative phase. For these reasons, the flowering phase was the target for this study and analysis.

Photosynthetically Active Radiation (PAR)

As reported in Table 1, PPFD is one of the metrics closely tracked by cultivators due to its high impact on plant growth and photosynthesis. Typically, the higher the PPFD, the higher the yields. The following terms are commonly used in horticulture lighting applications and may be referenced throughout this report:

- **Photosynthetically active radiation (PAR)** is light that falls between the spectral wavelengths 400nm – 700nm (basically the visible light range and illustrated in Figure 2), and it is required for photosynthesis.
- **Photosynthetic photon flux (PPF)** is the total amount of PAR produced by a light fixture every second (micromoles/s).
- **Photosynthetic photon flux density (PPFD)** is the amount of PAR that reaches the plant surface (micromoles/m^2/s).

Differentiating between PPF and PPFD is critical to understand lighting performance. For example, a fixture rated at a high PPF value (producing a lot of PAR) may have a recommended mounting distance to the canopy greater than a fixture with a lower PPF rating and, therefore, provide less PPFD than the other fixture. It is important to note that PPFD values are specific to a location and distance from the fixture. A single PPFD value or measurement cannot be extrapolated and applied to the entire canopy area.

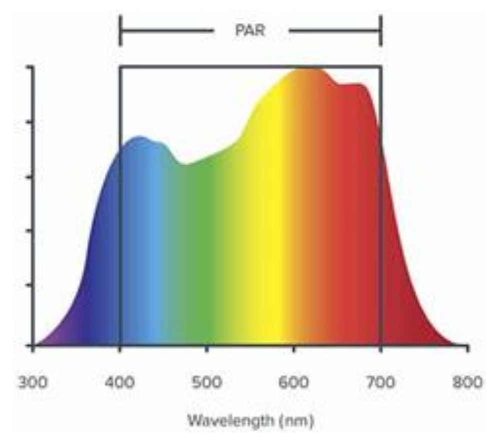

Figure 2: PAR wavelength range.

2.2 Project Objectives

The main objective for this project was to test the viability and potential benefits of using LED lighting for cannabis cultivation at local, commercial indoor cultivation facilities. Specifically, we wanted to gain understanding about how using LED lighting in place of the industry standard HPS fixtures during the flowering cycle may impact the following:

- The quality of the product, including yield and potency, as well as any observations on coloring, smell, structure, density, or other industry metrics.
- The energy use (kWh) and electrical demand (kW) of each space including lighting and interactive effects on the plug load and HVAC systems. In addition,

any insights on end-use and load profiles required for indoor horticulture operations such as lighting, plug loads, cooling, dehumidification, and fan energy may help inform potential future studies.

- The PPFD or amount of PAR received by the plants. Since PAR levels are critical to photosynthesis and growth, many cultivators have concerns about the light output or photosynthetic photon flux (PPF) capacity of LEDs compared to HPS fixtures.
- The customer's finances, including simple payback of any upfront incremental costs or continuous maintenance expenses.

In addition to the direct comparison between spaces with the competing lighting technologies, SMUD hoped to gain insight on these issues:

- Whether the LED technology is viable for this application and, if so, what market barriers and potential pathways to wider adoption exist.
- Whether SMUD may want to consider additional research regarding potentially providing energy efficiency incentives or developing a custom program for LED technology specific to indoor agriculture customers.
- Common energy efficiency opportunities observed in commercial indoor cannabis cultivation operations to provide education to the market as customers continue to invest in existing and new cultivation facilities.

2.3 Project Scope

Cadmus monitored two similar flowering rooms at SevenLeaves, one with HPS light fixtures (Room 2) and one with LED fixtures (Room 3). The monitoring took place throughout two flowering cycles in each room. The monitoring period timeline is summarized in Table 2.

Monitoring Period	Room 2 (HPS)	Room 3 (LED)
Round 1	6/21/17 – 8/29/17 (70 days)	8/5/17 – 10/10/17 (67 days)
Round 2	9/13/17 – 11/9/17 (58 days)	10/14/17 – 12/19/17 (67 days)

Table 2: Site monitoring schedule.

The flowering rooms at SevenLeaves monitored for this study had similar equipment installed in the spaces. The HVAC serving the rooms was a mix of existing and new split systems as well as one new packaged unit in each room. The footprints and number of light fixtures differed between rooms, so all results were normalized by canopy area. The lighting fixture details are summarized in Table 3. Figure 3 and Figure 4 show Room 2 and Room 3, respectively. Footprints of the rooms and a detail inventory of installed equipment are provided in in **Error! Reference source not found.**, Figure 8 and Table 6, accordingly.

	Room 2	Room 3
Room Floor Area (ft^2)	2,394	1,731
Canopy Area (ft^2)	1,200	1,231
Fixture Quantity	54	49
Fixture Image		
Model	Nanolux DE HPS	LumiGrow Pro 650e SV LED
Rated Input	1,000 W	595 W (reported typical)
Max Measured Input*	1,072 W	681 W
Reported PPFD	800 min. / 1,200 max.[2] [µmol/m^2/s]	792 µmol/m^2/s (at 30 inches)
Reported PPF	2,100 [µmol/s]	1,100 µmol/s
Efficacy	2.1 µmol/W	1.9 µmol/W
Equipment Useful Lifespan	Fixture & Ballast: 4-5 years Bulb & Reflectors: 8-9 months	50,000 hours (5-12 years)
*Not including anomaly spikes		

Table 3: Room and lighting details.[3]

[2] These values were reported at nanoluxtech.com/super-de-double-ended-fixture; however, they were listed with units of micromoles and no area or duration was provided. Based on the description from the website, we have assumed this is for a 5' on center installation. We also assume they intended these maximum and minimum values to be micromoles/m^2/s, the standard PPFD units.

[3] Images from Nanolux Technology Inc. (nanoluxtech.com) and Lumigrow (lumigrow.com)

Figure 3: Nanolux HPS fixtures installed in Room 2.

Figure 4: LumiGrow LED fixtures installed in Room 3.

2.4 Research Methodology

Cadmus monitored space conditions and lighting levels within two similar flowering rooms at SeavenLeaves. We also monitored the power demand and energy consumption of all equipment in, or serving, each room. We installed a variety of sensors and loggers throughout the spaces. Type, model number, and locations of the sensors are reported in Appendix B, Table 7, Table 8, and Figure 8, accordingly. In summary, we monitored the following:

- Energy consumption of:
  - Lighting systems in each room
  - Plug loads in each room including dehumidifiers
  - HVAC units serving each room.
- PPFD and total PAR at locations in each room
  - 30 inches from fixture (canopy level)
  - 57 inches from fixture (bed level)
- Temperatures and relative humidity levels
  - Throughout each room
  - Supply air in each room
  - Return air in each room
- CO_2 levels in each room

We collected the data at one-minute intervals throughout the monitoring periods. We viewed and/or exported the data to identify and discuss any questions or concerns with the project team on a near weekly basis. This was to ensure the rooms operated as intended and to identify any potential issues as early as possible for the duration of the study.

At the end of each monitoring period, Cadmus exported and compiled all data. We found the operation of inline scrubber exhaust filters creates negative pressure in each room. Cadmus inspected all makeup air entry points and concluded that the outdoor air intake could be determined through analysis of the meter data. We found relatively significant weather dependence due to outside air intake so we weather-normalized results to ensure equivalent room comparisons.

Lastly, we collected yield results, cost information, and feedback from the cultivators at SevenLeaves.

3. Project Results

3.1 Energy Savings

The observed total energy usage for each flower cycle monitored in Room 3 (LED) was significantly less than the usage observed during the monitored Room 2 (HPS) flower cycle (Figure 5). Room 3 (LED) saw a **total energy consumption reduction of 23% and 39%** (13,472 kWh and 22,101 kWh) in round 1 and round 2, respectively, when compared to the average Room 2 (HPS) totals. The figure compares the average energy use of both HPS runs because the first run in the HPS room was 70 days while the second run lasted only 58 days. Both LED room periods were 67 days. There was significant weather dependence of HVAC load due to outdoor air intake so the savings estimates in Figure 5 required adjustment. Figure 6 shows weather-normalized results. The LED room on average used 17,720 kWh less energy than the HPS room; **energy savings of approximately 30%.** Nearly 80% of the savings is attributable to lighting energy reduction and 25% is attributable to HVAC energy reduction. The LED room had slightly higher dehumidification energy use (-1% savings) and plug load

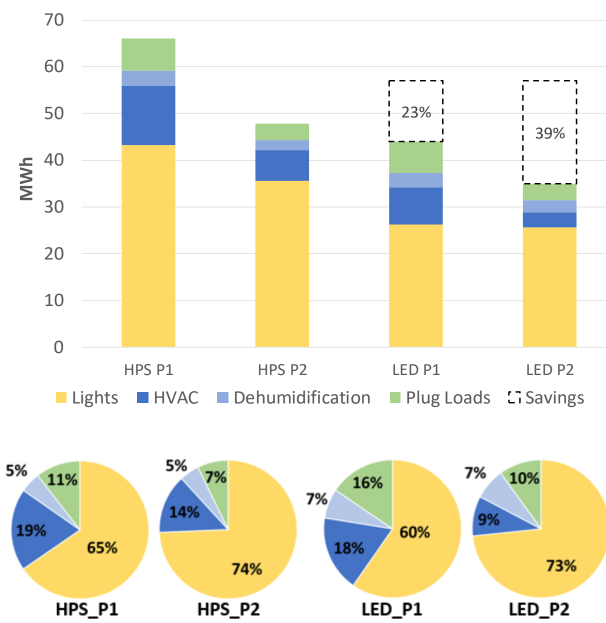

Figure 5: Total energy consumption and end-use breakdown during monitored flowering cycles.

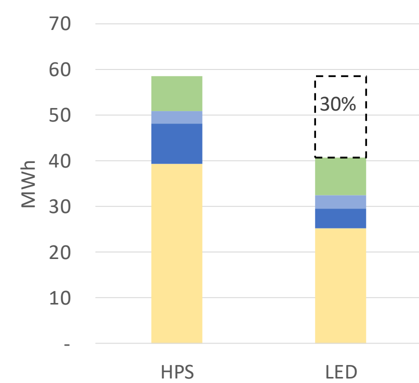

Figure 6: Weather-normalized room comparison and savings estimate.

energy use (-4% savings).

When lights were operating, the average demand of HPS fixtures was approximately 53 kW while the LED light fixtures used about 31 kW. Both lights operated 50% of the time in consecutive hours (12 hours on, 12 hours off). The 12- hour light cycle in the LED room began at 2am and the HPS room lights turned on at 11pm. Figure 7 shows the LED light fixtures use 2.4 kW even though the lights are "off" while the HPS light fixtures do not use any power when the lights are off.

Hourly lighting demand for each cycle can be seen in Appendix C, Figure 14 through Figure 17.

The Room 3 (LED) measured overall coincident **peak demand was 34% less** compared to Room 2 (HPS). Figure 7 shows the measured loads for the day that the peak hour demand was observed. The lighting peak demand for Room 3 (LED) was 41%, or 22 kW less than that of Room 2 (HPS).

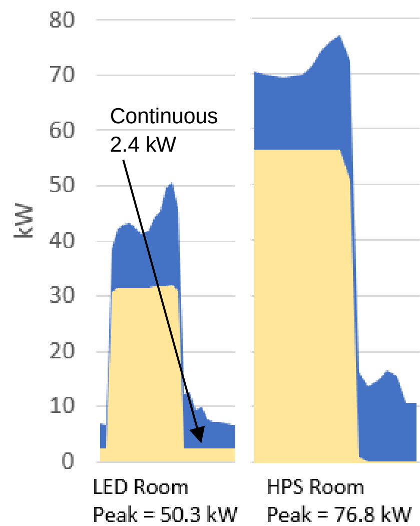

Figure 7: Measured coincident peak demand, one hour shown for each monitored flowering cycle.

Using the energy savings results above and the assumptions listed below, Cadmus determined a simple **payback period of 1.7 years or 9 flowering cycles** for the installation of LED fixtures:

- Pro E 650 LED = $999 each (x49)
- Nanolux Super DE 1000W = $375 each (x54)
- HPS DE bulb replacements = $60 each
- Lifespan of HPS DE bulb = three cycles
- Blended utility rate $0.125 per kWh

Results are shown below in Table 4.

Total Use (kWh)	RM2 (HPS)	RM3 (LED)
Cooling + Dehum.	11,599	7,254
Plug Loads	7,548	8,340
Lighting	39,291	25,124
Total	**58,438**	**40,719**

Peak Demand (kW)	RM2 (HPS)	RM3 (LED)
Cooling + Dehum.	18.3	13.5
Plug Loads	5	5.2
Lighting	53.6	31.6
Total	**76.8**	**50.3**

Table 4: Results summary by end-use. Weather-normalized cooling and dehumidification values.

3.2 PAR Summary

Throughout the monitoring periods, Cadmus collect PPFD readings using LICOR 190R Quantum sensors. We placed two sensors in each room, one at a distance of 57” from the fixture and one at the canopy level – 30 inches from the fixture. Both were located below the center of the fixture. Table 5 shows our recorded canopy-level maximum PPFD values (center-of-fixture). We observed similar PPFD trends at the plant-bed level (57 inches from the fixture) suggesting comparable penetration for both rooms. Figure 18 through Figure 21 in Appendix C show the hourly PPFD readings for all sensors throughout all cycles.

Measurement	RM2 (HPS) Rnd 1	RM2 (HPS) Rnd 2	RM3 (LED) Rnd 1	RM3 (LED) Rnd 2
Maximum canopy PPFD (μmol/m^2/s) under the center of the fixture	783	810	1,060	1,089

Table 5: PPFD measurements.

3.3 Yield Results

SevenLeaves provided measured crop yield results for all strains grown in Room 2 and Room 3 throughout the duration of our study. Since the number of plants for each strain differed between the rooms for each monitoring period, all results were normalized to the canopy area. However, on average, there were 12.2 plants per light and 0.55 plants per sq. ft. in Room 2 (HPS) and 13.0 plants per light and 0.52 plants per sq. ft. in Room 3 (LED), approximately 6% fewer plants per sq. ft. in Room 3 (LED) which may have slightly impacted the results. In terms of yield, Room 2 (HPS) out produced Room 3 (LED) in every instance. Crop yields for the LED room were 35-40% lower than the yield SevenLeaves growers expect from plants grown using HPS fixtures.

In all cases, the strains grown in Room 3 (LED) realized THC levels higher than the THC from crops produced in the HPS room. This suggests the LED fixtures may be outperforming HPS technology for optimizing THC production.

During the first LED run, the plants experienced light shock when they first entered the flowering room because the intensity levels were set too high. Since then, the growers have learned about the nuances of growing with LED lights and have avoided such issues. So despite lower than expected crop yields, SevenLeaves staff are optimistic about the potential of growing with LED lights. After this study concluded, a subsequent flowering run in the LED room yielded their best crop yet.

While the project team attempted to keep the room conditions equal throughout the study, there were some variances, such as changes in the nutrient delivery system and lighting control strategies. For this reason, feedback from the cultivator is a valuable supplement to the objective results. Although yields for Room 3 (LED) from both monitoring periods were 35-40% lower than were historically seen using HPS fixtures, the cultivator did comment that the quality was excellent, noting the overall quality of the product grown in LED rooms was excellent. The Terpene, THC (tetrahydrocannabinol), and total cannabinoid levels were higher than expected.

The Room 2 (HPS) yields for monitoring period 1 were up 34% for one strain and fairly similar to previous harvests for the other strain. This illustrates there is still some variability throughout their crops likely due to adjustments for production optimization.

The cultivators also found the spectral control available with the LED technology to be beneficial. During the second monitoring period in Room 3 (LED), they not only adjusted the lighting intensity during the start and end of the flowering cycle, but were able to adjust the red spectrum just before harvest. The result was increased trichrome growth and terpene levels. The grower was very happy with these results.

Although the Room 3 (LED) yields did not meet their targets, SevenLeaves cultivators were hopeful they will improve future crops as they become more familiar with the LED lighting system.

3.4 Additional Benefits of LED Technology

In addition to energy and cost savings, the cultivator saw several benefits of LED technology including advanced control options and reduced power demand. Since many sites are facing power capacity restraints, installing LEDs rather than HPS in new cultivation spaces may allow facilities to increase the canopy area more quickly than they could with HPS (rather than waiting for power capacity upgrades). During our study, SevenLeaves built-out an additional cultivation room and elected to use the same LumiGrow fixtures.

As mentioned previously, the advanced control gives the cultivators the opportunity to optimize their crops in ways not possible with HPS technology (e.g. adjusting spectral power distribution to increase trichrome growth and terpene levels). They also found their vapor pressure deficit (VPD) targets were much easier to maintain in Room 3 (LED) than Room 2 (HPS) which can lead to HVAC savings by keeping the room at higher temperatures than are typically seen without VPD control.

4. Conclusion

The findings from this study suggest LEDs can provide the lighting necessary to successfully cultivate cannabis through the flowering phase while reducing energy use and costs. However, growing cannabis plants under LED lighting is significantly different then using HPS. Cultivators should expect having to make several changes to their cultivating techniques.

Regarding this study, there are numerous variables impacting the energy use of each system, so it was difficult to determine whether interactive effects could be attributed solely to the lighting system upgrade. There may be steps to take with future studies to obtain more detailed values, which we have outlined in the following subsections.

From the perspective of the cultivators, the LED fixtures offer features not available with HPS that are beneficial, so the LEDs were a positive addition to their process. SevenLeaves cultivators are hopeful future crop yields will continue to improve and are pleased with the savings and the versatility of the fixtures. SevenLeaves has purchased more of the same LED fixtures and installed them in one of their new flowering rooms at the site.

4.1 Lessons Learned

From this and other field studies, we have gained many insights regarding how indoor cannabis cultivation facilities operate, and these insights may impact future research studies. However, it is difficult to conduct a controlled, side-by-side study for the following reasons:

- Flowering cycles rarely occur simultaneously, so it is likely that monitoring periods will be staggered in different rooms.
- Many processes are conducted manually and typically cannot be controlled automatically throughout the cycles. These may include watering, fertigation, lighting control, additional humidification or dehumidification by portable or fixed units, trimming, and others.
- Because plants are living things, cultivators often adjust as needed (in an effort to optimize production) based on their experience, instead of adhering to an unchanging schedule through each cycle.
- To optimize production, cultivators often try different strategies throughout their facility. They may try a different grow media or soil, switch nutrients, or reconfigure a space between cycles (or sometimes mid-cycle) to improve their crop. Unfortunately, these changes can significantly impact a research study.

Another challenge that arose during these studies was the impact of facility start-up. Because of the rapid growth in this sector due to the recent California legalization of commercial cannabis for recreational use, all facilities are essentially new. This means that cultivators are not only determining their process, but often have all new lighting, HVAC, and supporting equipment, much of which they may by unfamiliar with. As with any building, there is typically a commissioning period that occurs before all the bugs are worked out of the system, and this period is not ideal for conducting research. However, the studies need to be conducted in a timely manner so that findings can be published before many facilities are built-out.

Lastly, we discovered that improved comparison metrics may result from asking more specific questions regarding yield and crop production, such as fresh and dry weights for total plants and flowers only.

For future side-by-side field studies we recommend the following:

- Conducting a pre-test of equipment to ensure equivalent operation, especially at new facilities or in new spaces. Check items such as the following:
    - Fan speeds
    - Lighting schedules
    - Set-points (if hoping to keep them equal)
- Request room setup be as similar as possible including:
    - The same quantities and model numbers of equipment be installed where possible
    - Circuit breakers are properly labeled for all items in the spaces
    - Plant spacing and density be equal between the spaces (rather than focusing on overall canopy size)
- Request a grow plan upfront for all comparison rooms including:
    - Outlined strategies for all variables including type, amount, and schedule for: fertigation, watering, media, nutrients, trimming, light dimming, temperature and humidity set points, CO_2 level set points, etc. Also request a plan and schedule for any expected adjustments to these set points (such as reducing the lighting for the final week or trimming plants at 5 weeks).
    - Get the cultivator's commitment to follow the plan as closely as circumstances will allow.
- Collect detailed plant and crop production information:
    - Type of plant (indica or sativa)
    - Which strains

- Number of plants of each strain
- Measured yield values
  - Total THC (%)
  - Total plant fresh weight
  - Flower fresh weight
  - Trim fresh weight
  - Dry flower weight
  - Terpene analysis

4.2 Recommendations and Next Steps

While reviewing the monitoring data, we noticed that the Lumigrow fixtures (49 fixtures) used approximately 2.4 kW when the lights were off. This is due to LumiGrow's onboard fans and standby controls. We recommend using a timer to shut off power 30 minutes after the lights are turned off and 30 minutes before the lights are turned on to eliminate this wasted energy. By implementing this small change, SevenLeaves could save an additional 9,000 kWh or about $1,100 annually.

Although LEDs have been shown to reduce energy consumption for cannabis flowering applications, additional data collection and research is necessary to understand the interactive effects between energy systems. We hope to investigate the following:

- How using LEDs compared to HPS impacts energy and demand with different HVAC systems

- How different control strategies impact energy consumption and demand

- How different LED lighting technologies compare to each other

In subsequent studies, we hope to collect additional data in a laboratory environment or, possibly, a site with LED and HPS technology installed within the same room. Although this would not allow for further investigation into interactive system effects, it would ensure space conditions, schedules, and any other events were consistent between the two testing areas so the crop response could be more accurately determined. SMUD is conducting additional research studies and is also offering custom incentives for LED (and other technologies) for indoor cultivation facilities. For more information, send an email to indoorcultivation@smud.org or visit the websites below:

- Custom Incentive Program (retrofit projects)
  https://www.smud.org/en/Business-Solutions-and-Rebates/Business-Rebates/Custom-Incentives

- Savings by Design (new construction)
  https://www.smud.org/en/Business-Solutions-and-Rebates/Business-Rebates/Savings-by-Design

Appendix A – Room Inventories

The equipment installed in, or serving, each space is summarized below in Table 6. The equipment is operated on similar schedules or to meet similar set points between rooms.

Table 6: Equipment details and quantities by room.

	Equipment Description	Flowering Room 2 (HPS) Quantity	Flowering Room 3 (LED) Quantity
	Nanolux DE 1000W HPS Light Fixture	54	0
	LumiGrow Pro E 650 585W LED Light Fixture	0	49
	LumiGrow SmartPAR Network – Router + AP, Part 810-00015-A	0	1
	Hurricane 16” Classic Wall mount Fan Product #736503	30	18
	Titan Controls ARES 8 LP CO_2 Generator	4	3
	Quest Dual 205 Dehumidifier – Part 4033060	2	2

	Can-Fan Filter, 14” Inline Scrubber Exhaust Ventilation Blower (1700 CFM)	1	1
	Bryant 548-F-P-X-060-000-AB 5-ton Commercial Packaged Heat Pump	1	1
	Trane 5-ton Split-System Heat Pump Outdoor: 4TWA3060B3000AA Indoor: TEM4A0C60S51SAA	2	0
	Trane 7.5-ton split System Heat Pump Outdoor: TWA-090-D30RAB Indoor: TWE-090-D300AB	1	0
 	Rheem 5-ton Split-System Single-Stage Air Conditioner Outdoor: RA1460AC1NB Indoor: RH1T6024STANJA	0	2

Appendix B – Monitoring Equipment

Cadmus monitored the space conditions within the rooms using a mix of temperature, temperature & relative humidity, PAR, and CO2 sensors. A summary of space condition sensors is below in Table 7 and Figure 8 shows the locations.

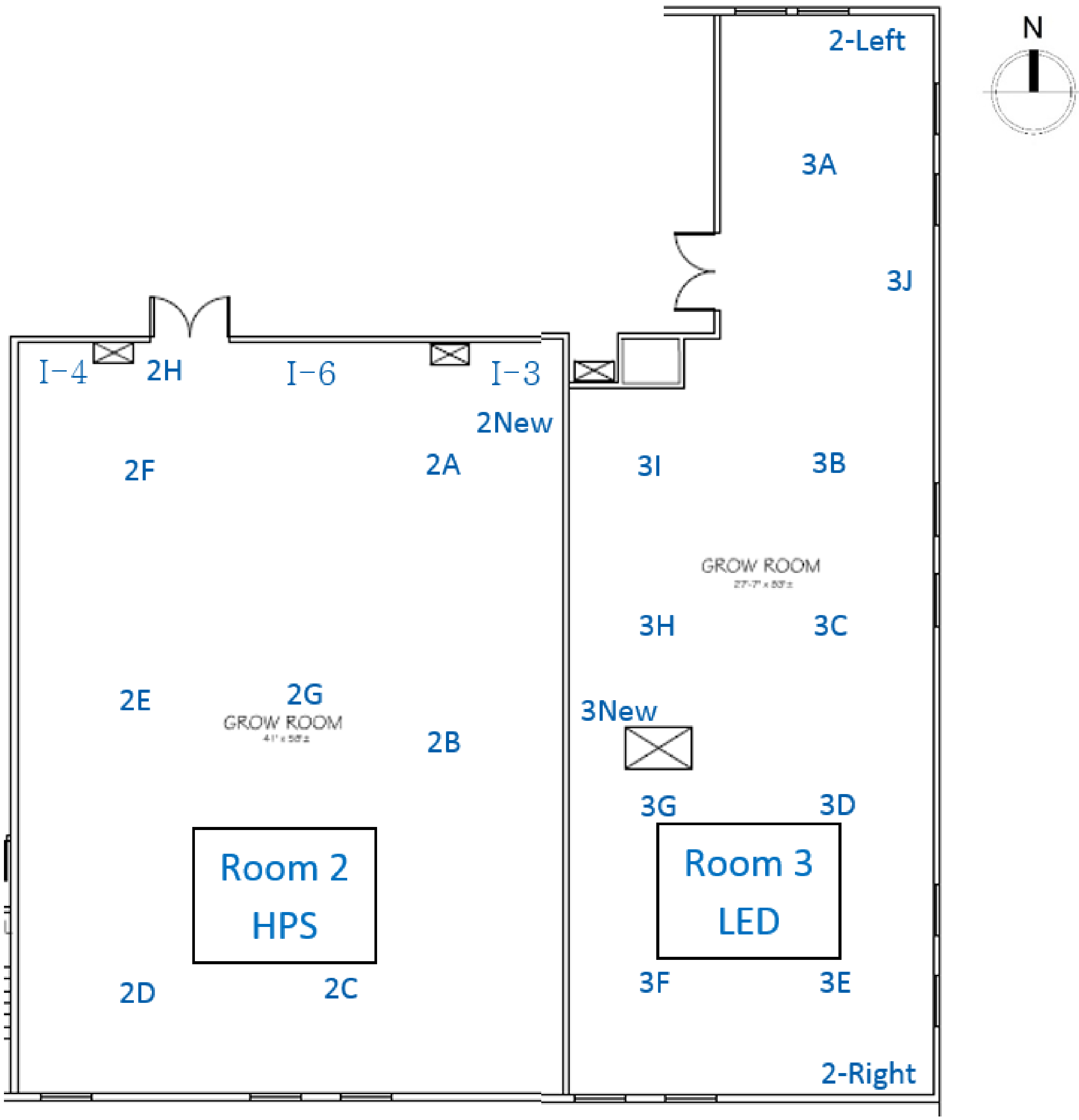

Figure 8: Sensor Locations

Table 7. Space Condition Monitoring Devices

	Device Description	Flowering Room 2 (HPS) Qnty/Location	Flowering Room 3 (LED) Qnty/Location
	Onset S-THB 12-bit Temperature/Relative Humidity Smart Sensor	Quantity: 10 2C, 2D, 2New-SA, 2New-RA, I3-SA, I3-RA, I4-SA, I4-RA, I6-SA, I6-RA	Quantity: 10 3C, 3H, Left-SA, Left-RA, Left-MA, Right-SA, Right-RA, Right-MA 3New-SA, 3New-RA
	Onset S-TMB 12-Bit Temperature Smart Sensor	Quantity: 5 2A, 2B, 2E, 2F, 2G	Quantity: 6 3A, 3B, 3D, 3F, 3G, 3I
	Telaire TEL-7001 CO_2 Sensor	Quantity: 1 2H	Quantity: 1 3J
  	LICOR LI-190R Quantum PAR Sensor + EME Systems 2.5V Output Universal Transconductance Amplifier (UTA) + Onset S-VIA-CM14 12-bit Voltage Input Adapter Sensor	Quantity: 2 2D	Quantity: 2 3B

We monitored power demand of the lighting, HVAC, and plug loads at their respective panels using current transducers, Onset Wattnodes, pulse adapters, TRMSA modules, and Hobo RX3000 loggers. The RX3000 provided a cellular connection so all data points were visible from the online portal at Hobolink.com. A summary of installed power metering devices is below in Table 8. Note that the summary below is the final installation list, some meters were added throughout the project as additional end-use disaggregation was desired, so not all the devices listed below were installed for the entire duration of the cycle.

Table 8. Power Monitoring Devices

	Device Description	Location (Panel), Service	Quantity
	Current Transformers	Panel C, RM2 Plug Loads Panel E, Main Supply RM3 Panel D, RM2 Lighting Panel E, RM2 HVAC Panel E, RM3 HVAC Panel E, RM3 Lighting Panel E, Mother Room Lighting Panels B & C, RM2 HVAC	4 3 3 1 4 2 1 5
	Continental Control Systems WattNode AC Energy Meters Onset S-UCC-M006 Electronic Switch Pulse Input Adapters	Panel E, Main Supply RM3 Panel D, RM2 Lighting	1 1
	Onset S-FS-TRMSA 2-Channel FlexSmart TRMS Modules	RM2 & RM3 Power	9
	Hobo RX3000 Remote Monitoring Station Data Logger	RM2 & RM3 Power RM2 Space Conditions RM3 Space Conditions	2 2 2

Appendix C – Supplementary Data

Figure 9 shows average demand by hour of the day for LED lights. Note the lighting demand of about 45 Watts per fixture (approximately 2.4 kW in total for the room) even when lights are off.

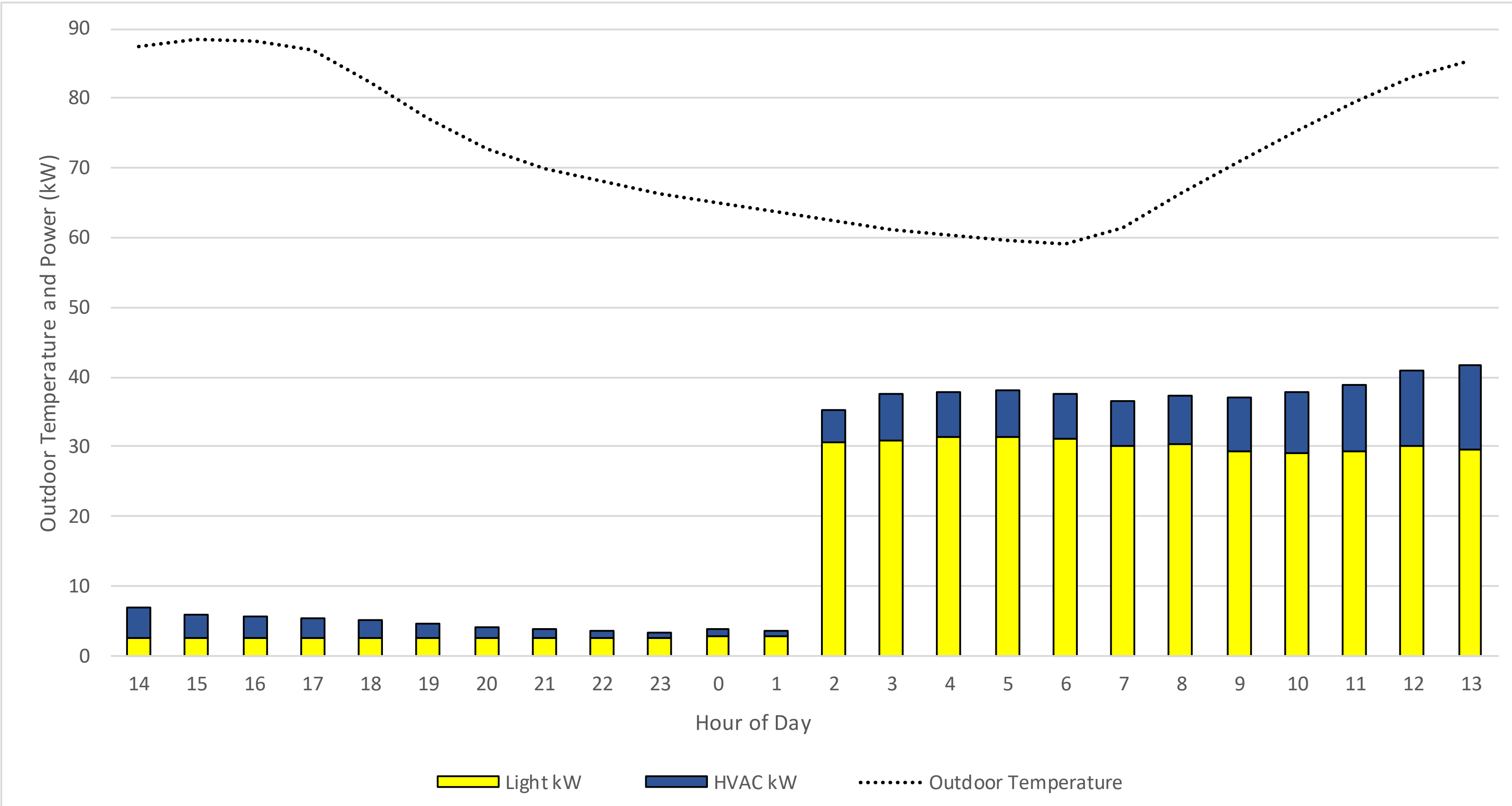

Figure 9: Room 3 (LED) Lights and HVAC average demand by hour of day.

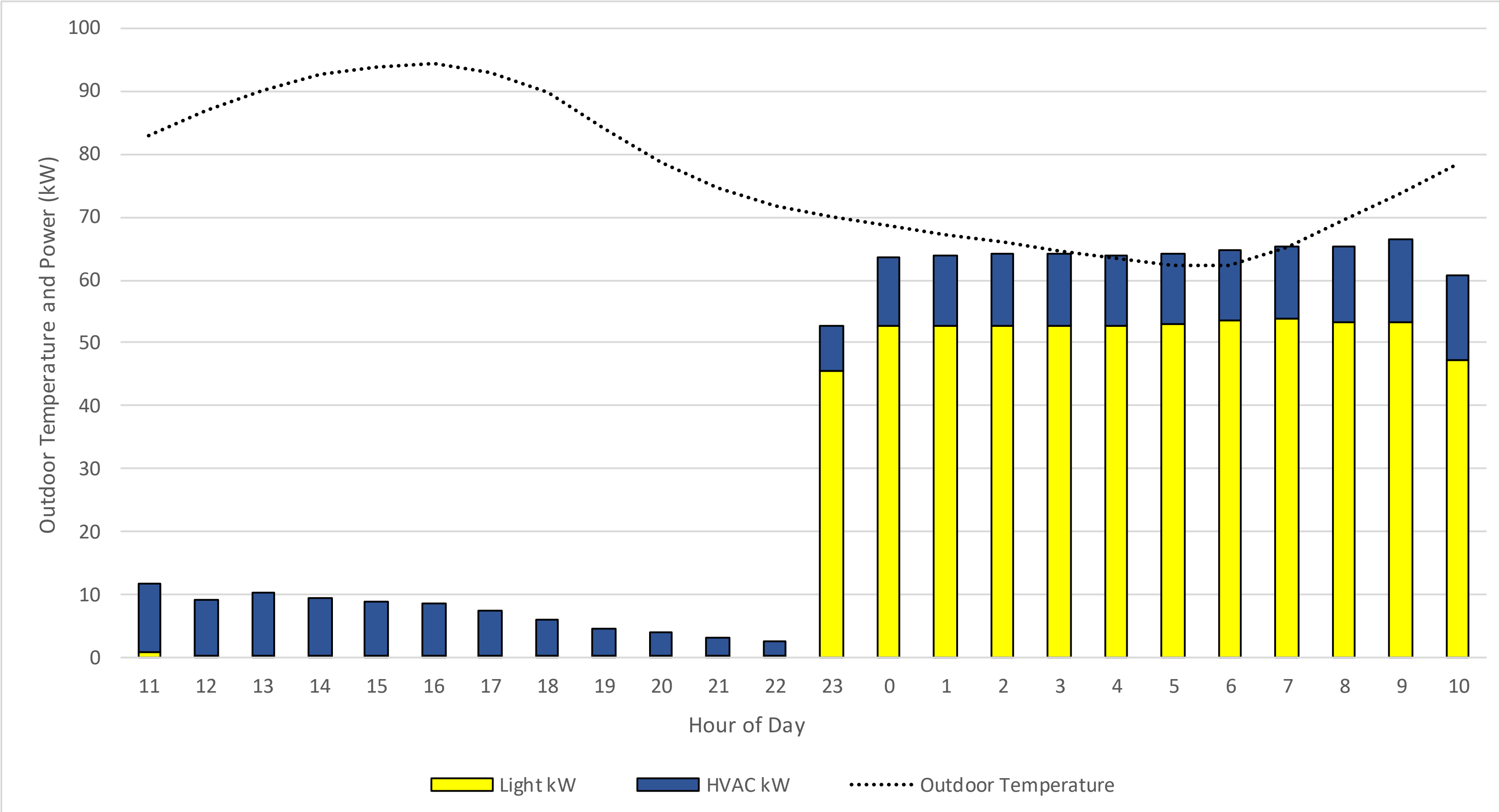

Figure 10: Room 2 (HPS) Lights and HVAC average demand by hour of day.

Comparing Figure 11 with Figure 12, the HVAC loads are very different when the lights are off. This may be due in part to differences in air infiltration and building shell characteristics of each room.

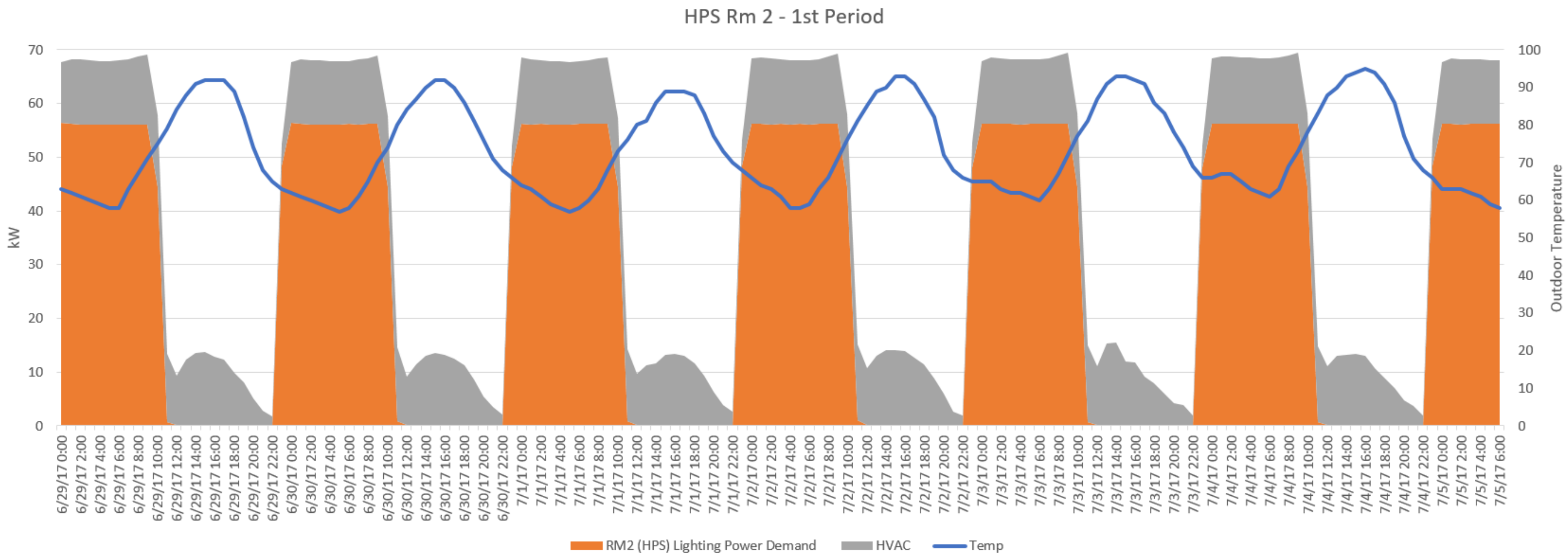

Figure 11: Room 2 (HPS) Lights and HVAC time series – note HVAC use after lights turn off.

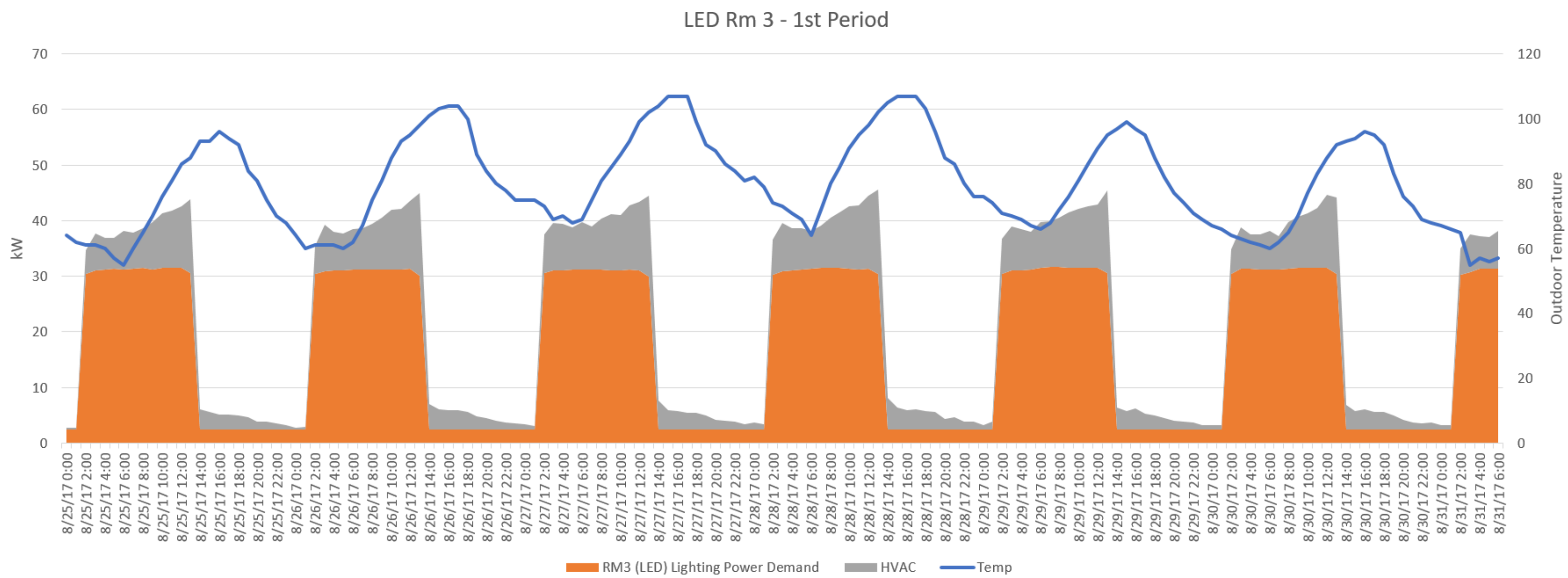

Figure 12: Room 3 (LED) Lights and HVAC time series – note HVAC use after lights turn off – much lower than HPS Room.

Figure 13 and Figure 14 show the average indoor humidity and temperature of the LED and HPS rooms relative to outdoor temperature when lights are on and off. Figure 15 provides a direct comparison of the LED and HPS rooms. In general, conditions were similar. One notable difference was the LED room humidity levels when lights were on. While indoor temperatures were approximately the same, the LED room humidity averaged 60%, the HPS humidity averaged 50%.

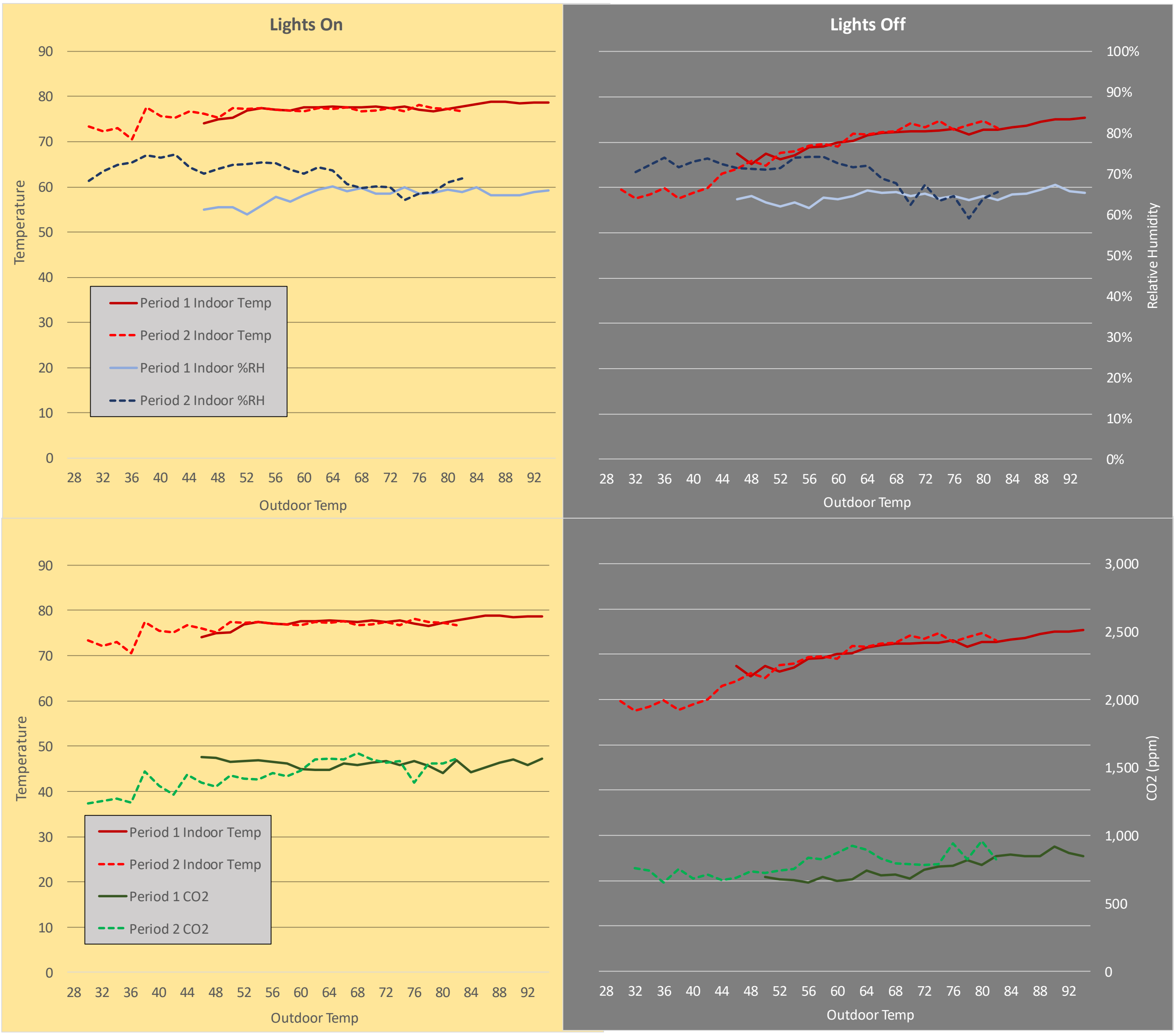

Figure 13: LED Room – Comparing Indoor Conditions

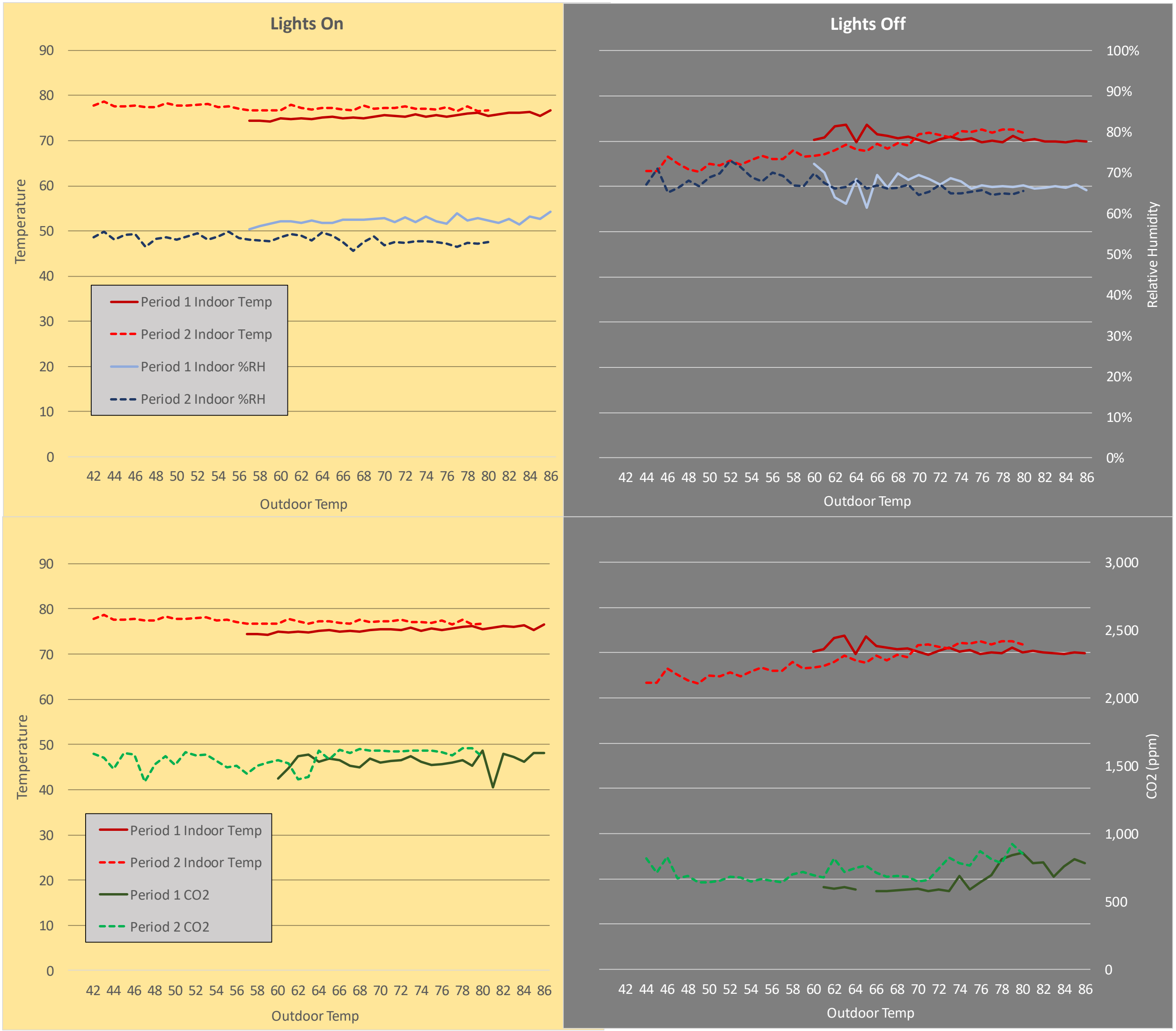

Figure 14: HPS Room – Comparing Indoor Conditions

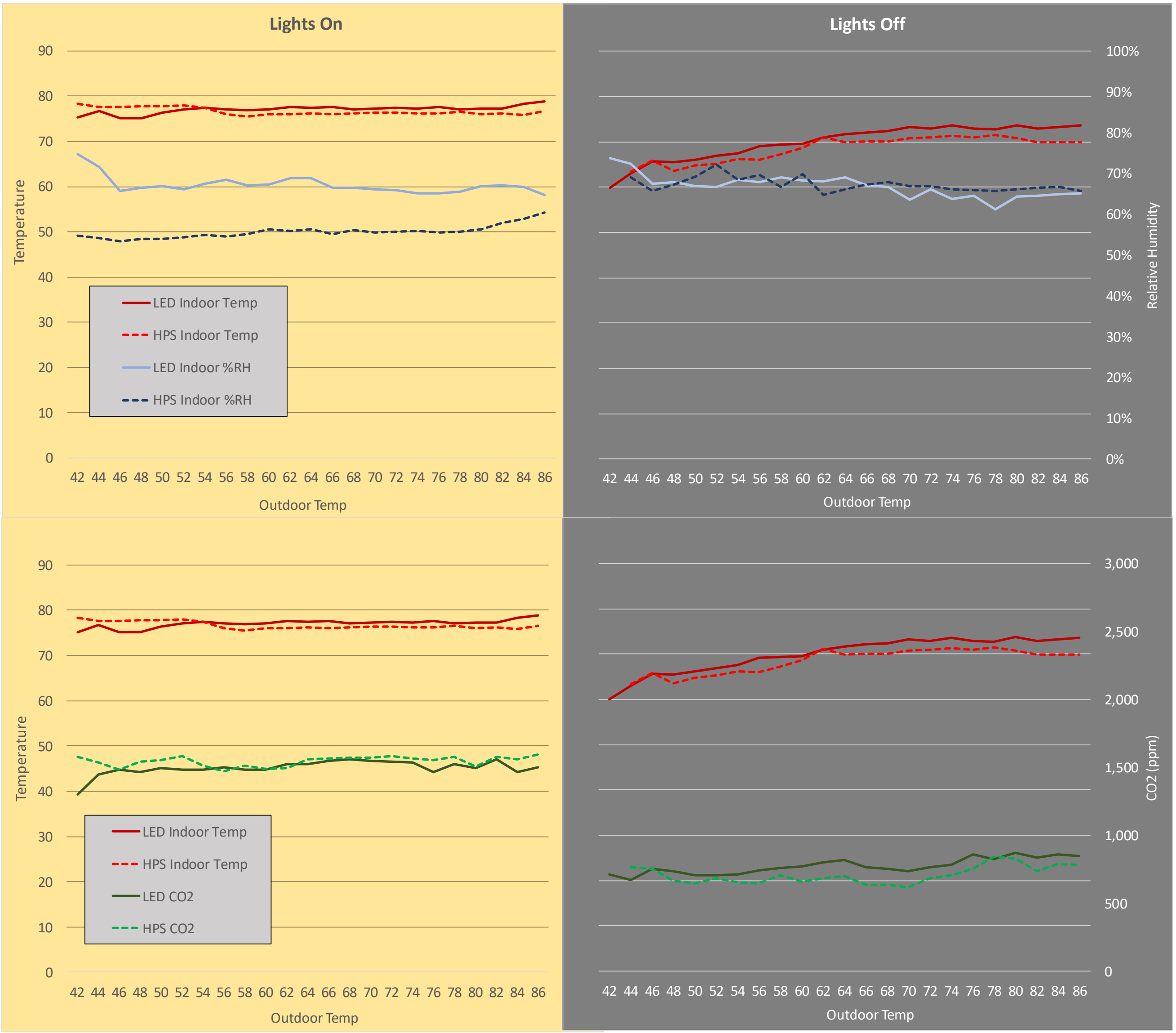

Figure 15: Comparing HPS to LED Room – Indoor conditions

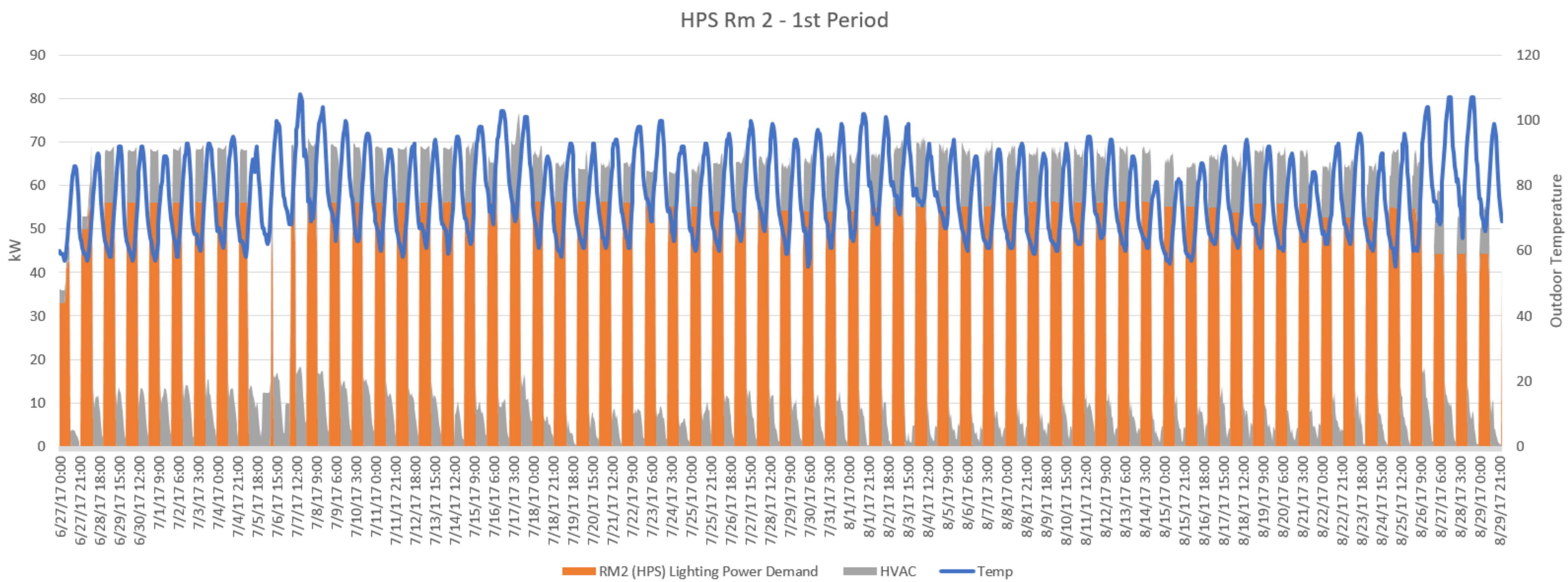

Figure 16: Room 2 (HPS) lighting and HVAC power demand for monitoring period 1.

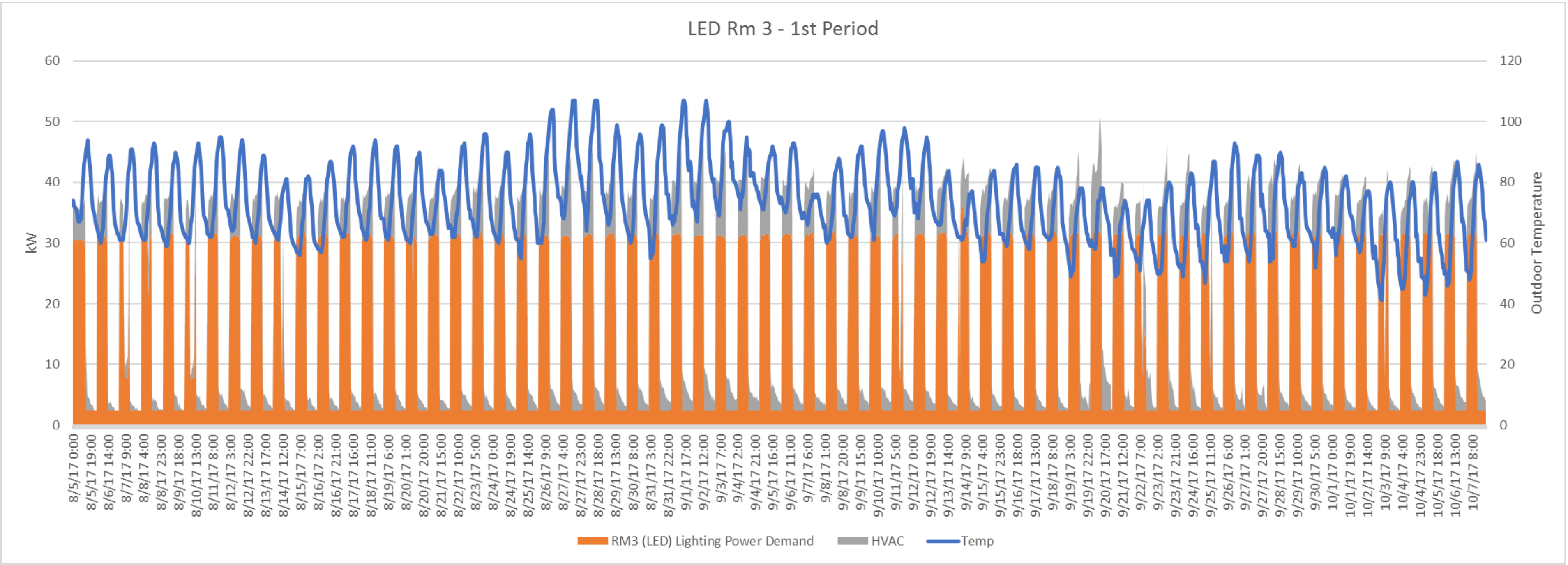

Figure 17: Room 3 (LED) lighting and HVAC power demand for monitoring period 1**.**

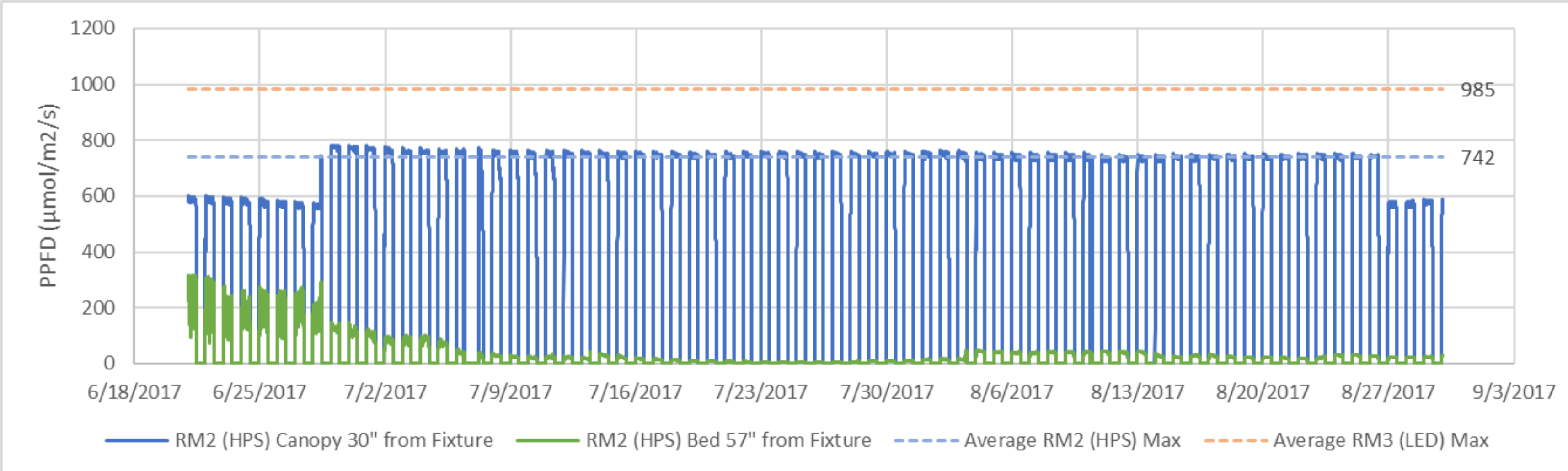

Figure 18: Room 2 (HPS) PPFD for monitoring period 1.

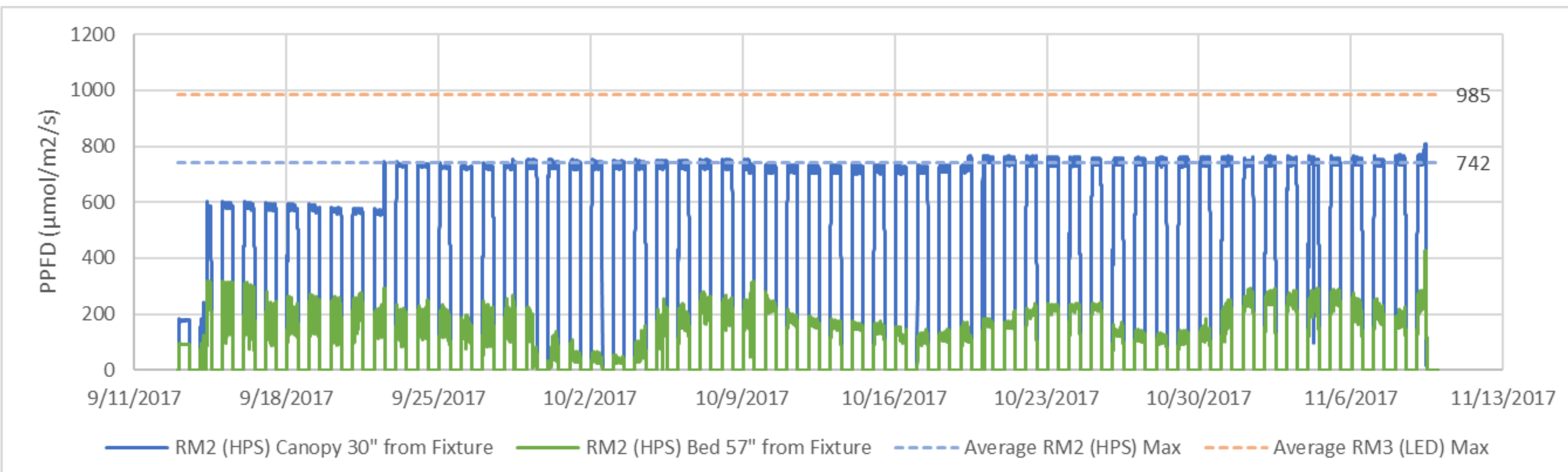

Figure 19: Room 2 (HPS) PPFD for monitoring period 2.

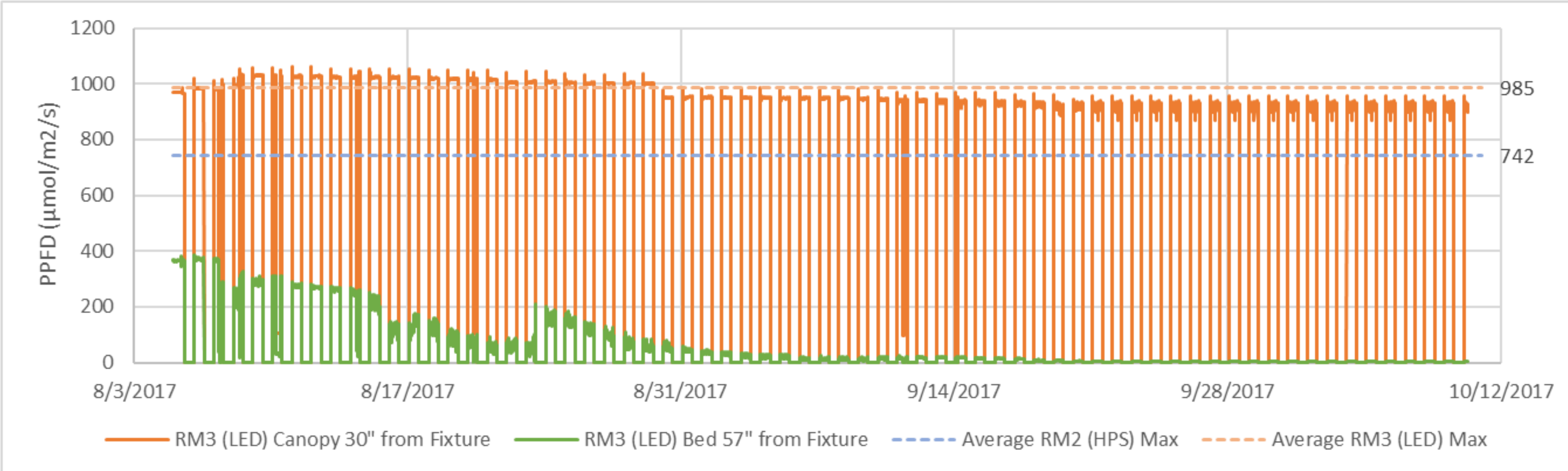

Figure 20: Room 3 (LED) PPFD for monitoring period 1.

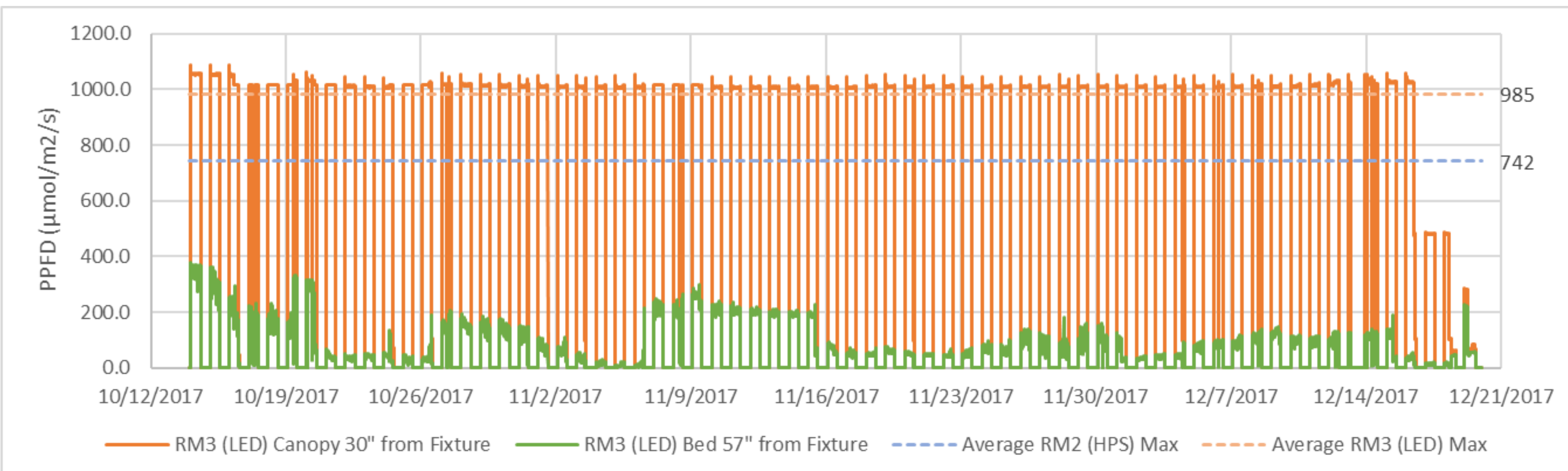

Figure 21: Room 3 (LED) PPFD for monitoring period 2.