Indoor Horticulture HVAC System Evaluation Project

Sacramento Municipal Utility District

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1. Executive Summary

1.1 Introduction

With the recent legalization of adult cannabis use 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 square feet of planted area (known as the canopy). A facility with 10,000 square feet of canopy might require 400 kW of power for lighting. For comparison purposes, a modern 10,000 square foot commercial office space might require 8 kW for lighting. High-wattage lights produce a significant amount of waste heat. One HPS light is equivalent to a 1 kW heater. This heat needs to be removed by an air conditioning system. Consequently, when HPS lights are on, the combined lighting, cooling, and dehumidification electrical load is typically 80 watts to 100 watts per square foot of planted area. The energy use per 25 square feet of canopy is about the same as the energy use of a house[1] in SMUD's service territory.

Cannabis plants require precise temperature and humidity levels to maintain health and to prevent the growth of mold, fungus, and mildew. Plants are watered frequently, and the soil medium is moist, so the heat from lights causes water to evaporate. Plants also naturally transpire. Consequently, the amount of moisture added to a growing room is significantly different from a normal indoor conditioned space. Compared to an office, a growing room requires a significant amount of heat removal and meticulous humidity control. Many growers use rooftop units (RTUs) or split systems because these systems are familiar to them and are readily available. Typical HVAC systems are designed to condition indoor areas with relatively low heat load per square foot and with no humidity requirements. Air conditioners simply remove some moisture from the air through natural condensation on a cold cooling coil. An HVAC system in a grow room is often sized so that it can remove the heat and maintain indoor temperature, but it is not necessarily capable of removing enough water from the air to achieve the desired humidity levels. Accordingly, growers supplement their HVAC systems by adding dehumidifiers, an additional equipment and energy expenditure.

HVAC manufacturers such as Desert Aire and AAON offer systems specifically designed for horticulture applications. These systems are expected to provide better climate control

[1] This is based on assuming 750 kWh of use per month: https://www.smud.org/en/Rate-Information/2017-rate-change-archive/Rates-for-2018-and-2019

and reduce cooling energy consumption (compared to traditional options). However, there are few case studies of using these systems for cannabis grow operations.

1.2 Project Objectives

The main objectives of this project were to test the viability and potential benefits of using the Desert Aire and AAON systems for commercial cannabis growers. There were several main research questions:

- What are the electrical energy savings (kWh) and electrical demand reductions (kW) savings of Desert Aire and AAON systems compared to traditional systems?
- Does using the system affect the quality of the product?
- Does using the system affect the quantity (yield) and length of time to produce the product?
- What are the financial cost savings for the customer? What is the simple payback?
- Is the technology viable for this application? What is needed for wider adoption?
- Should SMUD provide energy efficiency incentives? Should SMUD develop a custom program for this technology?

SMUD contracted with Cadmus to conduct a study to address these research questions. Cadmus addressed the questions by testing two rooms (one with two AAON systems and one with two Desert Aire systems) in a side-by-side comparison during the flowering growth cycle (approximately 65 days). Table 1 lists the date range of each grow cycle. Two grow cycles were required because some data collected during the first round was lost. Additionally, the weather during the first grow cycle was relatively mild. The second grow provided an opportunity to monitor the room during peak (summer) conditions, which can impact HVAC system performance and cooling requirements.

Grow Cycle	Room A (AAON)	Room B (Desert Aire)
Round 1	3/7/18 – 5/7/18 (61 days)	2/14/18 – 4/18/18 (63 days)
Round 2	6/11/18 – 8/15/18 (64 days)	5/22/18 – 7/23/18 (61 days)

Table 1. Grow Cycle Schedules

1.3 Results

Cadmus monitored two similar flowering rooms at a grow facility[2], one with Desert Aire HVAC systems and one with AAON systems. As shown in Table 2, Room A used two 35-ton AAON SA series water-cooled vertical self-contained units.[3] Room B used one 30-ton Desert Aire VerticalAire series dedicated outdoor air system (DOAS)[4] and one 40-ton Desert Aire TotalAire series DOAS system.[5]

Room	Planted Area (ft^2)	Quantity of HPS Lights	HVAC System Summary	Plant Density (plants per ft^2 of planted area)*	Planted Area per light (ft^2 per light)	Total Energy Use in One Grow Cycle (kWh/ft^2 of planted area)	Total Energy Use per Plant (kWh)
Room A AAON	2,100	108	2 x 35-ton	0.75	19.4	101.6	126.0
Room B Desert Aire	2,255	126	1 x 30-ton 1 x 40-ton	0.90	17.9	87.6	98.6

Table 2. Summary of Rooms with HPS Lights
*1,568 plants in Room A (note 46 plants removed during growing cycle) and 2,024 plants in Room B

The growers used 1,000-watt HPS fixtures and both rooms had the lights on for approximately 12 hours per day. Room A (with AAON units) used 108 HPS lights for a total connected lighting load of approximately 114 kW. Room B (with Desert Aire units) used 126 HPS lights for a total connected lighting load of approximately 129 kW (see Table 3). The plant density[6] and planted area per light listed in Table 2 indicate the number of plants per square foot in Room B was higher than in Room A. Despite the difference, Room B used less energy per square foot of planted area. Observations include:

- Both rooms had lights on primarily during the day (from 4 a.m. to 4 p.m.).
- Both rooms are controlled environments relying entirely on the HVAC systems to reduce humidity with minimal outdoor air infiltration.
- Typical dehumidifiers used in conventional grow rooms reject waste heat back in to the room. The AAON and Desert Aire units reject waste heat to the outside instead.

[2] The facility that participated in this study wished to remain anonymous.
[3] Product data is available here: https://www.aaon.com/Documents/Manuals/SA_IOM_170925.pdf
[4] Product data is available here: https://www.desert-aire.com/dehumidification-systems-verticalaire
[5] Product data is available here: https://www.desert-aire.com/dehumidification-systems-totalaire
[6] Plant density represents the number of plants per square foot of planted area. This value increases as plants are packed more closely together. Before removal of 46 plants from Room A, plant density was 0.77.

- Round 1 data were incomplete. Comparing similar periods during the grow cycles from round 1 and round 2 found no discernable difference, therefore, the results presented in this report are from the 2nd growing cycle.

Table 3 shows average data from the second grow cycle to compare AAON units (Room A) to Desert Aire units (Room B). Overall, the Desert Aire units were more efficient (9.8 EER) than the AAON units (7.5 EER) when lights were on. Units had similar efficiency when lights were off. On average, neither room achieved the targeted relative humidity setpoint[7] of 50%. Comparing the units, the AAON units achieved an average relative humidity that was closer to the setpoint. According to the Desert Aire system designer, these systems were designed to meet 60% RH.

Room and Light Status	OAT (°F)	Room Temp (°F)	Relative Humidity	Light Runtime (hours/day)	Lights (kW)	HVAC (kW)	Plug Load (kW)	EER
Rm A Lights On	73	76	60%	12.2	113.9	77.7	8.6	7.5
Rm A Lights Off	75	68	55%	-	-	67.7	8.4	2.2
Rm B Lights On	70	76	65%	11.8	129.2	70.4	8.3	9.8
Rm B Lights Off	73	69	63%	-	-	56.3	8.1	2.4

Table 3. Comparing Room Conditions and Desert Aire Units (Room B) and AAON Units (Room A)

The average lighting hours of use per day were not equivalent in the rooms, with Room A lights on for about 22 minutes more per day than Room B lights. Despite slightly longer runtime, the lights in Room A still used less energy per day than lights in Room B (as expected because there were 108 lights in Room A and 126 lights in Room B). Although Room A lighting energy and associated waste heat (sensible heat)[8] was lower, the energy consumption of the AAON units in that room was higher. Table 4 shows that the AAON units in Room A used 26% more energy per day than the lights in Room A, while the Desert Aire units in Room B used about the same amount of energy that the lights used in Room B.

[7] As explained in subsequent sections of this report – the reported target was 50% but some trend data indicated the setpoint was 60% or 70% for periods during the growing cycle.

[8] The measured power of HPS lights is equivalent to the heat generated by the lights and may be used to estimate most of the sensible cooling load in a room. For example, the sensible heat produced by three and a half HPS lights (3.5 kW) requires about 1-ton of cooling. A 1-ton HVAC system typically provides about 0.8 tons of sensible cooling and 0.2 tons of latent cooling (sensible heat ratio (SHR) of 0.8). Therefore, a 1.25-ton system would be used to remove the sensible heat for 3.5 kW of lights.

Room	Lighting Energy Use (kWh per Day)	HVAC Energy Use (kWh per Day)	Ratio of HVAC Energy Use to Lighting Energy Use	Gallons of Water Removed per Day (Liters per Day)	Gallons of Water Removed per Plant per Day
Room A	1,386	1,744	125.8%	386 (1,461)	0.246
Room B	1,523	1,520	99.8%	502 (1,898)	0.248

Table 4. Comparing Daily Lighting and HVAC Energy Use and Water Removal Rates

Table 4 also shows total average gallons of water removed per day and gallons removed per day per plant for each room. The water removal rates per plant in each room are very similar. Table 5 shows the average energy to remove one liter of water. For comparison, a high efficiency unitary dehumidifier can remove 2.5 liters (0.66 gallons) per kWh of energy use but would provide no cooling benefit. Though both systems used more energy per liter of water removed than a high efficiency unitary dehumidifier, the actual conditions significantly impact the efficiency of moisture removal. A dehumidifier in a dry room would use more energy per gallon of water removed than the same dehumidifier in a room with higher humidity. Therefore, the water removal rates in Table 5 should not be directly compared to rated moisture removal efficiency[9].

Room	HVAC Energy Use (kWh per Day)	Gallons of Water Removed per Day (Liters per Day)	Water Removal Rate per kWh of HVAC Energy Consumption	
Room A	1,744	386 (1,461)	0.22 gal/kWh	0.84 L/kWh
Room B	1,520	502 (1,898)	0.33 gal/kWh	1.25 L/kWh

Table 5. Comparing Energy Consumption and Water Removal Rates

The higher ratio of HVAC energy use to lighting energy use and the lower EER of Room A indicate the AAON units operated less efficiently than the Desert Aire units. The AAON units were able to more effectively control humidity, but the amount of water removed per kWh of energy was higher for the Desert Aire units than for the AAON units. Section 3.1 includes additional, detailed information comparing the performance of the units in this study.

[9] For additional information on dehumidification rating, refer to AHRI 910 Standard. http://www.ahrinet.org/App_Content/ahri/files/STANDARDS/AHRI/AHRI_Standard_910_I-P_2014.pdf Moisture removal efficiency (MRE) is typically expressed in pounds of water per kWh. One gallon of water is approximately 8.34 pounds.

1.4 Conclusions

Cadmus reviewed similar periods of the Room A and Room B grow cycles and found that the Desert Aire units operate more efficiently than AAON units. Cadmus compared the energy use of these units to a previous study[10]. The previous study observed energy use of a flowering cycle in a room with similar HPS lights, traditional split HVAC systems, and unitary dehumidifiers. The combined energy use of the HVAC systems and dehumidifiers in the previous study was lower, but a significant amount of air was ventilated to the outside. Exchanging humid indoor air with dry outdoor air substantially reduces the latent load in the room. Due to this difference, Cadmus concluded that a direct comparison of HVAC system performance and energy consumption of the rooms in this study and in the previous study would not provide valid results. Because of the differences in operation, Cadmus was unable to answer the research questions stated in Section 1.2 that involved energy use comparisons.

The AAON and Desert Aire systems reject heat to the outside. Compared to a unitary dehumidifier, this is advantageous when grow lights are on and generating heat because a unitary dehumidifier also rejects heat to the room, which must be removed by the HVAC system. When lights are off, however, the cold coil required to condense water from the air (the dehumidification process) can make a grow room too cold. A unitary dehumidifier, which simply rejects all heat back to the growing room, may be advantageous when lights are off and reheat is otherwise required.

SMUD should consider the following research topics in future studies:

- Investigate humidity tolerance – is 50% relative humidity necessary?
- Study effects of ventilation - outdoor air exchange may reduce humidity very efficiently (at certain outdoor conditions).
- Compare traditional HVAC systems with unitary dehumidifiers to Desert Aire and AAON systems operating in equivalent environments.

[10] Seven Leaves 2017 Indoor Horticulture Study: https://www.smud.org/-/media/Documents/Business-Solutions-and-Rebates/Advanced-Tech-Solutions/LED-Reports/Seven-Leaves-Indoor-Horticulture-LED-Study-Final.ashx?la=en&hash=BAF42446B3952D90CF49B6A564A7C3269252835C

SMUD is currently offering custom incentives for indoor cultivation efficiency technologies. For more information, please call 1-877-622-7683 or visit the websites below:

- Cannabis Information (incentives and case studies)
  https://www.smud.org/en/Corporate/Landing/Cannabis-Operations
- 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 Nathan Hinkle (Cadmus), Mathew McGregor (SMUD) and Dave Bisbee (SMUD).

2. Project Description

2.1 Background

Indoor cannabis cultivation is an energy intensive process. As mentioned above, the lighting demand alone may be nearly 50 times the lighting demand for a typical office space. Not only are demand loads high, but hours of use for lighting typically ranges from 12 to 24 hours per day, depending on the plants' stage of life. These high lighting loads result in corresponding cooling and equipment loads for the cultivators to maintain the desired environmental conditions. Although targets vary, each cultivator has preferred photosynthetic photon flux density (PPFD), space temperature, relative humidity, and carbon dioxide ranges for the plants throughout their grow cycle. Maintaining these conditions is critical to plant production and crop yields. Typical industry ranges for these parameters are summarized in Table 6.

		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 (hours on)		24	18–24	12	n/a	0
PPFD (µmoles/m^2/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	800–1,400	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 6. Typical Environmental Targets for Cannabis Cultivation by Plant Growth Stage[11]

As shown in Table 6, 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 vegetative phase. For these reasons, the flowering phase was the target for this study and analysis.

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

Desert Aire provides the following[12] explanation describing the challenges growers face and the potential advantages of their system for grow room temperature and humidity control:

> *The bottom line for grow room climate control systems is that as plants develop they change the amount of moisture they release. The lighting systems of grow rooms create different levels of heat depending on whether they are in on or off modes. Climate control systems must have the ability to meet the challenges of these changing conditions.*
>
> *When the plants are small, with a low canopy, the evaporative cooling effects of the evapotranspiration that occurs will also be low. With the lights on, the sensible heat ratio (SHR) of the cooling equipment should be moderately high, greater than a 0.75 SHR. This moderately high sensible heat ratio can be achieved with almost any typical air conditioning unit. A problem occurs in the lights-off mode when the standard air conditioner meets the very low sensible demand and turns off before the latent moisture can be removed.*
>
> *However, when the plants have grown, and the room is at high canopy, then the evaporative cooling effects of evapotranspiration will be high and the sensible cooling requirement will be greatly reduced. This is because plants use the ambient heat in the room to convert water into vapor through transpiration.*
>
> *In the lights-on, high canopy scenario the design sensible heat ratio of the air conditioner units is now at a medium-high, 0.50 SHR to 0.60 SHR level. Typical air conditioning units will achieve temperature setpoints rapidly and index off. Without the units operating, the moisture loads (latent) will increase. In the lights-off mode, the same problem occurs as with low canopy plants.*
>
> *One rudimentary method of dealing with this variable sensible heat ratio is to have a set of HVAC equipment that is sized for handling the high sensible load during the low canopy period. Traditional portable dehumidifiers are used to offset high latent loads during the high canopy period. Although it is possible to size such a system, there will be periods where sensible load is added by the dehumidifier and needs to be removed by the air conditioner. This combination is both difficult to balance and significantly inefficient and may result in higher equipment and energy costs.*

2.2 Project Objectives

The main objectives of this project were to test the viability and potential benefits of using the Desert Aire and AAON systems for commercial cannabis growers, in order to address the following research questions:

- What are the electrical energy savings (kWh) and electrical demand reductions (kW) savings of Desert Aire and AAON systems compared to traditional systems?
- Does using the system affect the quality of the product?

[12] "Grow Room Load Determination" https://www.desert-aire.com/sites/default/files/Tech-Note-Grow-Room-Load-Calculation-Application-Note-DA125.pdf

- Does using the system affect the quantity (yield) and length of time to produce the product?
- What are the financial cost savings for the customer? What is the simple payback?
- Is the technology viable for this application? What is needed for wider adoption?
- Should SMUD provide energy efficiency incentives? Should SMUD develop a custom program for this technology?

SMUD contracted with Cadmus to conduct research to address the questions. Cadmus addressed these questions by studying two rooms (one with an AAON system and one with a Desert Aire system) in a side-by-side comparison for a period of approximately 140 days (approximate two cannabis grow cycles).

2.3 Project Scope

Cadmus monitored two similar flowering rooms at a grow facility, both with HPS light fixtures. The monitoring period timelines are summarized in Table 7. The flowering rooms monitored for this study had similar type and configuration of plants.

The key difference, and subject of this study, was the HVAC systems serving each room. Room A uses two 35-ton AAON systems and Room B uses one 30-ton and one 40-ton Desert Aire system. The lighting fixture details and room information are summarized in Table 8. A detailed inventory of installed equipment is provided in Appendix A.

Grow Cycle	Room A (AAON)	Room B (Desert Aire)
Round 1	3/7/18 – 5/7/18 (61 days)	2/14/18 – 4/18/18 (63 days)
Round 2	6/11/18 – 8/15/18 (64 days)	5/22/18 – 7/23/18 (61 days)

Table 7. Site Monitoring Schedule

	Room A (AAON)	**Room B (Desert Aire)**
Planted Area (ft^2)	2,100	2,255
Plant Quantity	1,568	2,024
Fixture Quantity	108	126
HPS Fixture		
Model	Gavita Pro Plus 1000W EL DE HPS	
Rated Input	1,000 Watts	

Table 8. Room and Lighting Details

Figure 1 and Figure 2 show the rooms being tested. These rooms are totally enclosed systems and do not ventilate air to the outside.

Figure 1. Room A, Served by AAON Units

Figure 2. Room B, Served by Desert Aire Units

The AAON units (Model# SA-035-3-A-ER09-000) serving Room A incorporate a modulating hot gas reheat loop to control humidity. Reheat coils, downstream of the evaporator coils, are piped to the lead cooling circuit, a constant speed compressor. This provides the unit with a dehumidification mode of operation whenever the cooling load is satisfied.

The two 35-ton AAON units serving Room A are connected to a cooling tower dedicated to Room A and to two additional 35-ton AAON units serving another room. The cooling tower fan is on a VFD and a 15-horsepower pump, also on a VFD, circulates chilled water.

Desert Aire units are designed to dehumidify spaces with high humidity levels (such as those with an indoor swimming pool). The 30-ton and 40-ton Desert Aire units serving Room B each have a dedicated air-cooled condenser with four 1.5 horsepower fans.

Appendix A includes pictures and additional information for the HVAC systems and other systems serving Room A and Room B.

2.4 Research Methodology

The building has permanent monitoring sensors installed. Assisted by Envision Technologies staff, Cadmus downloaded one-minute data on a weekly basis that included:

- HVAC system power
- Indoor temperature
- Indoor humidity
- Condensate flow rate (gallons per hour)
- Lighting system power
- Carbon dioxide level
- Supply temperature and relative humidity
- 120 V plug load (for multiple rooms)

Some energy-using components of the AAON systems were not recorded. For these components (cooling tower fans, chilled water pump), Cadmus used spot measurements to estimate average power. Cadmus also used spot measurements of the carbon dioxide scrubbers and wall fans (see Appendix A) to estimate total plug load power for each room.

3. Project Results

3.1 Detailed Findings

Table 9 lists the planted area, number of 1,000-watt HPS lights, HVAC system size, planted area density, and total energy use for one grow cycle for the two grow rooms at this facility. The planted area density listed in the table is simply the planted canopy area per HPS light.

Room	Planted Area (ft^2)	Quantity of HPS Lights	HVAC System Summary	Plant Density (plants per ft^2 of planted area)*	Planted Area per light (ft^2 per light)	Total Energy Use in One Grow Cycle (kWh/ft^2 of planted area)
Room A AAON	2,100	108	2 x 35-ton AAON units	0.75	19.4	101.6
Room B Desert Aire	2,255	126	1 x 30-ton 1 x 40-ton Desert Aire unit	0.90	17.9	87.6

Table 9. Summary of Rooms with HPS Lights
*1,568 plants in Room A (note 46 plants removed during growing cycle) and 2,024 plants in Room B

Room A (AAON units) used 108 HPS lights and Room B (Desert Aire units) used 126 HPS lights. The table shows that the number of plants per light and planted area per light was different in the rooms. Room B was more densely packed and used less energy per square foot of planted area (87.6 kWh for Room B and 101.6 kWh for Room A).

Because planting configurations were slightly different, Cadmus also compared the HVAC energy use per light. The heat generated by one 1,000-watt HPS light is constant in each room studied. The heat must be removed by the HVAC system; therefore, the energy use per light removes the variance in energy use due to the lighting power density differences in the rooms. Figure 3 shows a comparison of the average power of the HVAC and plug loads in each room for one HPS light. The figure shows the average power per light when lights are on and when lights are off for each room.

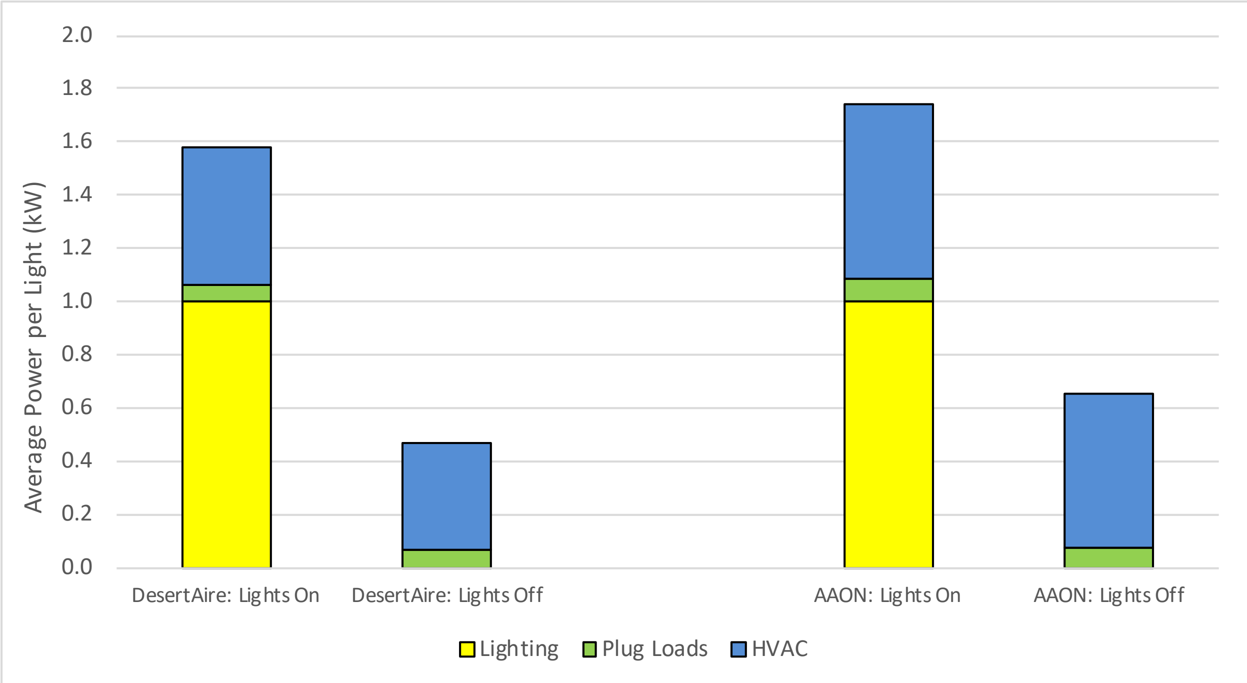

Figure 3. Comparison of Rooms in On/Off Mode: Average HVAC and Plug Power per 1,000-Watt HPS Light During Flowering Stage

The figure shows that the Desert Aire units had lower energy use per HPS light compared to the AAON units.

Cadmus calculated the sensible heat (in kBtu) provided to the space from the energy use of the lights, plug loads, and supply air fans. They also calculated the latent heat for each hour from the rate of condensate, assuming that the latent heat of vaporization of water (970 Btu/lb) is a reasonable estimate of sensible heat absorbed by the condensate. The assumed a constant value of 8,090 Btu/gallon to determine the latent heat removed by the HVAC systems during each hour of the study.

Overall, the Desert Aire units were more efficient (9.8 EER) than the AAON units (7.5 EER) when lights were on. Figure 4 summarizes the key data during the study for Room A, served by AAON units. For detailed charts of the summary data presented here, see Figure 10 in Appendix B.

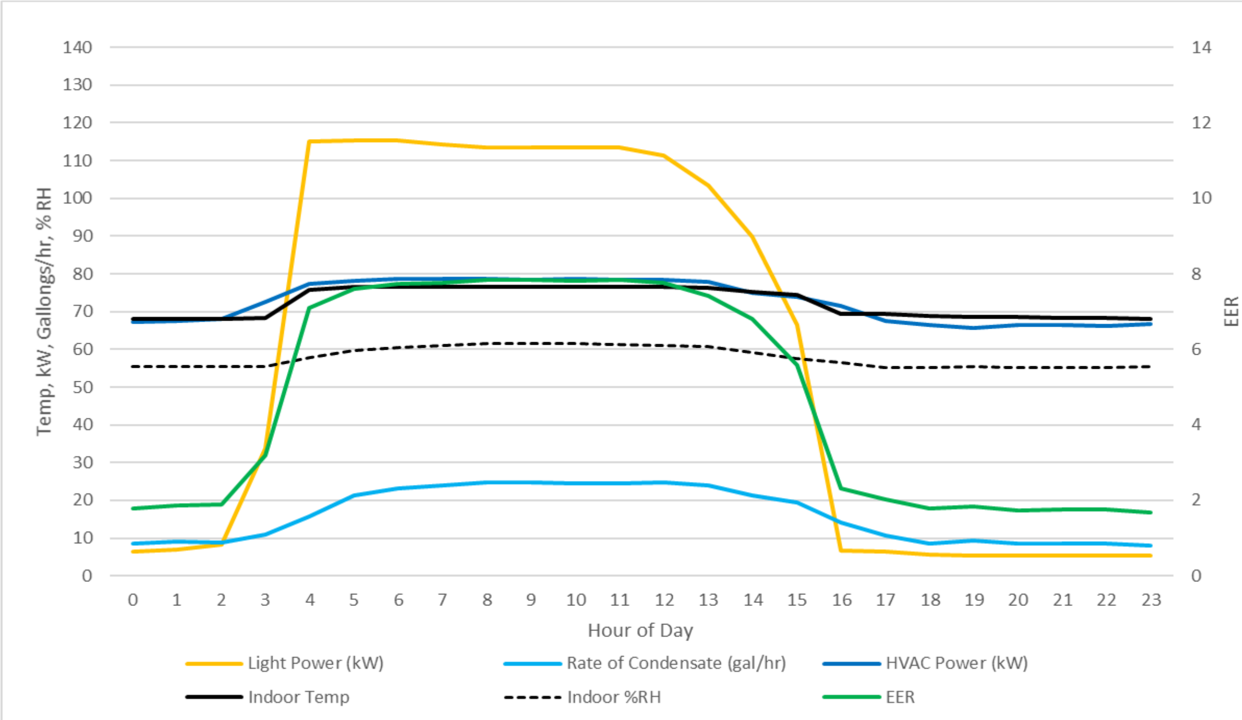

Figure 4. Summary of Hourly Data for Room A, AAON Units

Figure 5 summarizes the key data during the study for Room B, served by Desert Aire units. For detailed charts of the summary data presented here, see Figure 10 in Appendix B.

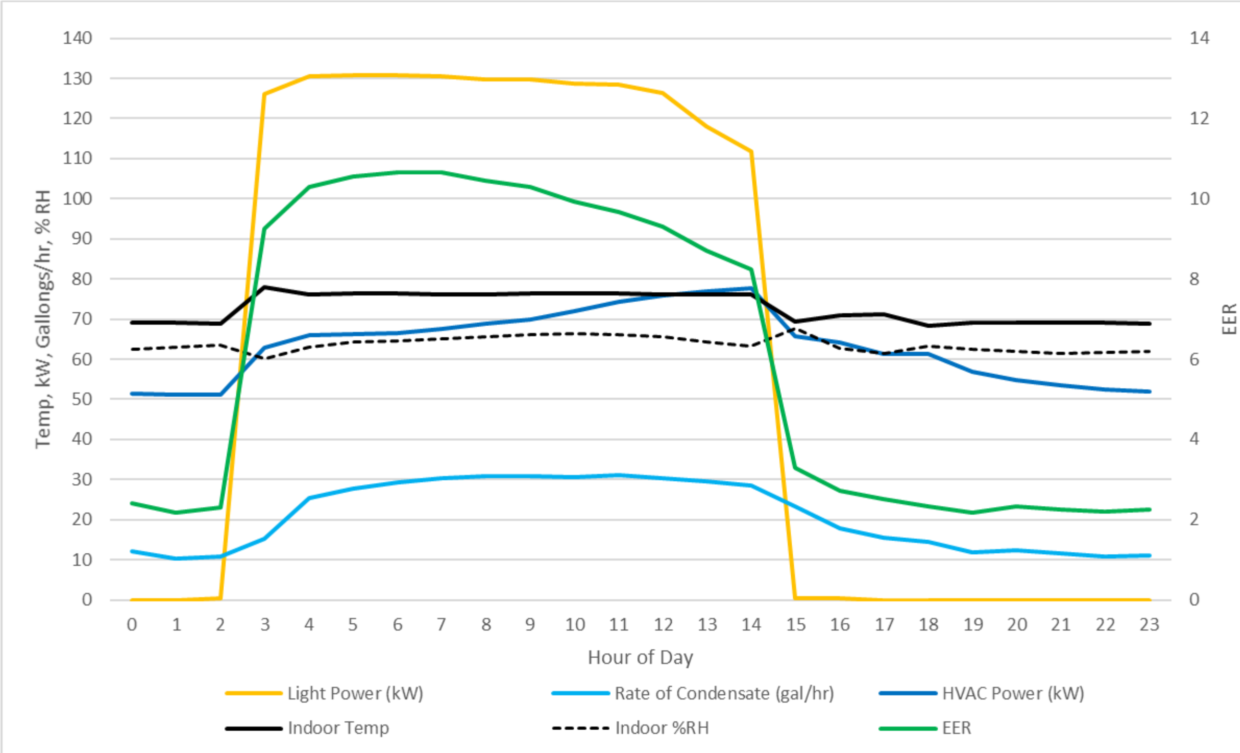

Figure 5. Summary of Hourly Data for Room B, Desert Aire Units

Table 10 shows a comparison of average data for the AAON units (Room A) and Desert Aire units (Room B) when lights are on and when lights are off.

Room and Light Status	OAT	Room Temp (°F)	Relative Humidity (%)	Lights (kW)	HVAC (kW)	Plug Load (kW)	Sensible Heat (kBtu)	Latent Heat (kBtu)	SHR	EER
Rm A Lights On	73	76	60%	113.9	77.7	8.6	395	183	0.68	7.5
Rm A Lights Off	75	68	55%	0.0	67.7	8.4	57	77	0.43	2.2
Rm B Lights On	70	76	65%	129.2	70.4	8.3	461	229	0.67	9.8
Rm B Lights Off	73	69	63%	0.0	56.3	8.1	28	109	0.20	2.4

Table 10. Comparison of Average Energy Use (kW per hour) of Desert Aire Units (Room B) and the AAON Units (Room A)

Table 11 shows another metric for each room - the average power density in Watts per square foot of planted area.

Room and Light Status	Lights (W/ft^2 planted area)	HVAC (W/ft^2 planted area)	Plug Load (W/ft^2 planted area)	Total (W/ft^2 planted area)
Rm A Lights On	54.2	37.0	4.1	95.3
Rm A Lights Off	-	32.2	4.0	36.2
Rm B Lights On	57.3	31.2	3.7	92.2
Rm B Lights Off	-	25.0	3.6	28.5

Table 11. Comparison of Average Power Density Between Rooms

It is important to note that the SHR values represent the actual HVAC unit production; not the actual design SHR values, or SHR when the relative humidity and temperature setpoints are precisely achieved.

Figure 6 summarizes the daily average setpoints and actual conditions for both “lights on” and “lights off” modes for both rooms. The hashed lines in the chart represent data during “lights off” mode. According to facilities personnel, the relative humidity target was 50%. The trend data indicate the humidity setpoint (light purple line) was 60% during the first few weeks and then set to 50%.

The AAON units (green solid line and green hashed line) appear to follow the 60% RH setpoint relatively well. The “lights off” mode 50% RH setpoint is achieved for the next few weeks, but the “lights on” mode is generally above 50% RH. The Desert Aire trend data did not include the relative humidity setpoint for the first three weeks. After about three weeks, both rooms were set to 50% relative humidity. From the fourth week through the end of the growing cycle, the AAON and Desert Aire units did not meet the 50% relative humidity target during “lights on” mode, with the Room B exhibiting higher relative humidity.

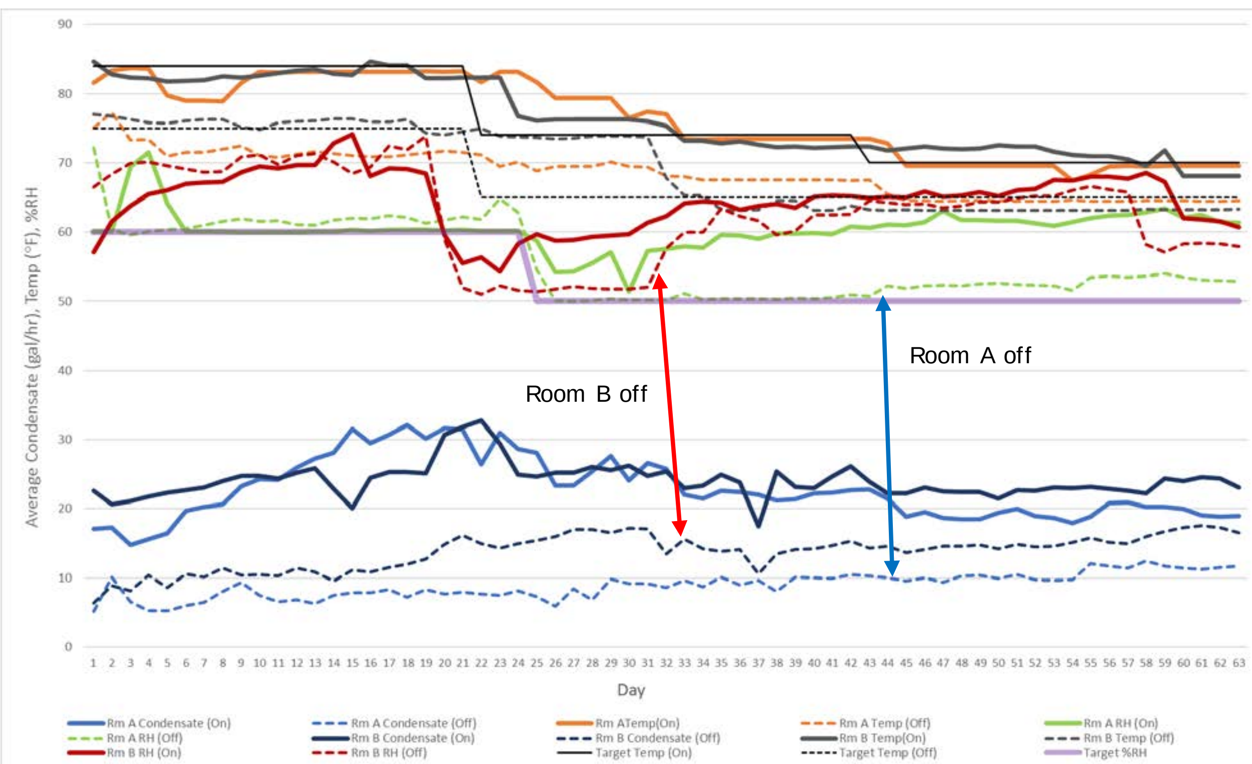

Figure 6. Trending Daily Average Setpoints and Actual Conditions for Both Grow Rooms
Note Condensate rate in Room B was reduced by the ratio of plants in Room A to Room B to make a more direct comparison

After approximately four weeks into the growing cycle, the relative humidity achieved during "lights off" mode generally increased, and the rate of condensate removal was about the same or increased. The blue and red arrows point to these trend lines in Figure 6. With an increase of water removal, one would expect a decrease in relative humidity. Presumably, relative humidity is increasing during "lights off" mode because of increased plant transpiration as plants grow. The temperature and humidity setpoints in Room A appear to exceed the capability of the AAON units around day 45, and the Desert Aire units around day 33 (for additional detail, see Figure 15 in Appendix B). Figure 7 shows the hourly trend data for Room A, with a blue arrow pointing to the same point in Figure 6 and Figure 7.

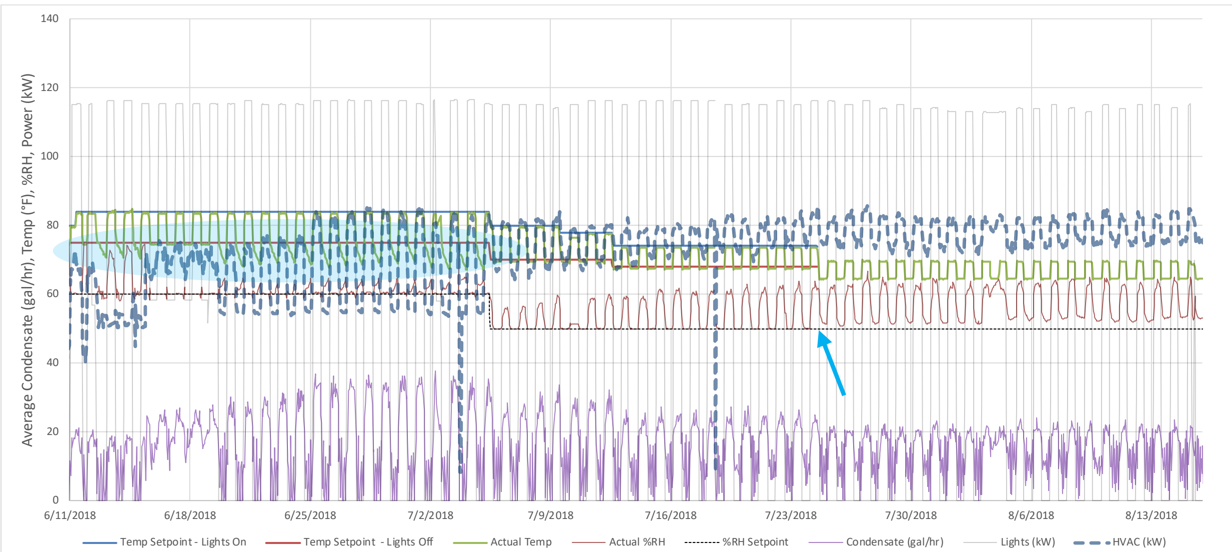

Figure 7. Room A (AAON Units) Trend Data

Figure 7 also shows the power of the AAON systems and the lights. For most of the growing cycle, the AAON systems used between 60 and 80 kW continuously. Even when lights were off, the HVAC system power did not drop significantly, an indication that a substantial amount of energy was used for moisture removal. See Figure 10 - Figure 12 in Appendix B for additional details.

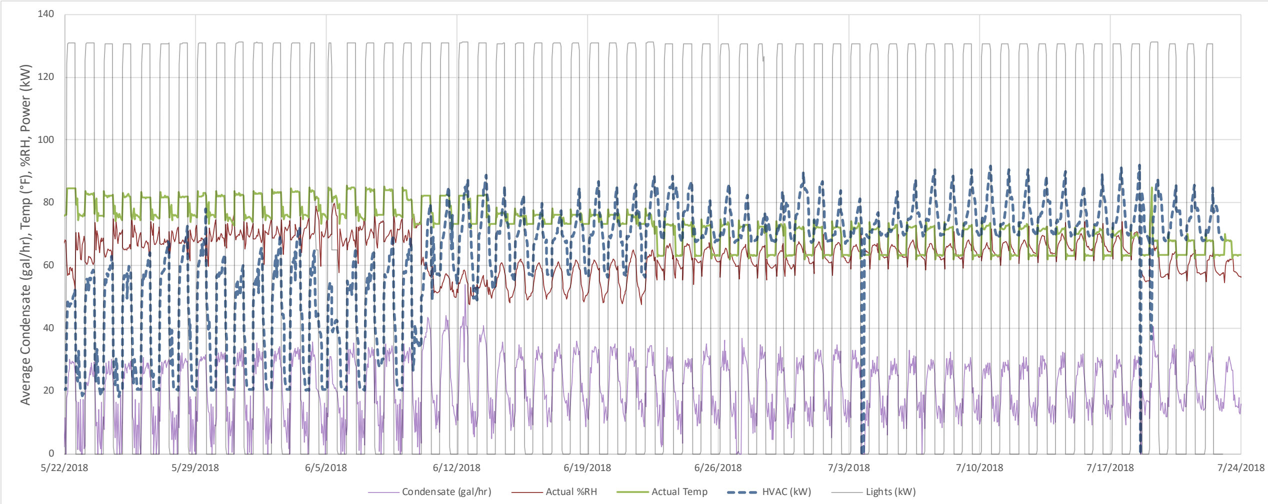

Figure 8. Room B (Desert Aire Units) Trend Data

Figure 8 shows the Desert Aire units also used a significant amount of energy for moisture removal, but substantially less during the first few weeks of the growing cycle (with combined power of Desert Aire units ranging between 20 and 60 kW. After the first few weeks of the growing cycle[13], the relative humidity setpoint was set to 50%. The Desert Aire units were able to achieve this setpoint during the fourth and fifth weeks of the growing cycle. After approximately six weeks, the Desert Aire units maintain an average daily relative humidity of about 60%, which increases to about 65% during the final weeks of the growing cycle. According to the system designer, the Desert Aire units were sized to maintain 60% relative humidity for Room B. The temperature setpoints (84 °F when lights on, 75 °F when lights off) were satisfied during this time. The AAON systems in Room A overcooled the room at night during the first 3 weeks of the growing cycle (see green line in the light blue shaded region in Figure 7 above and Figure 13 - Figure 15 in Appendix B for additional detail).

Differences in outdoor temperature can impact the efficiency of HVAC systems: Figure 9 shows the relationship of system efficiency with outdoor temperature. The figure shows that the average EER of the AAON units does not appear to vary with changing outdoor temperature, while the average EER of the Desert Aire units does appear to have temperature dependence. Since the AAON units (Room A) use water-cooled condensers, a relatively constant EER is expected. The Desert Aire units use air-cooled condensers and the curve generally matches the expected EER versus temperature curve for an air-cooled HVAC system.

[13] The relative humidity setpoint for the first few weeks of the cycle was not recorded.

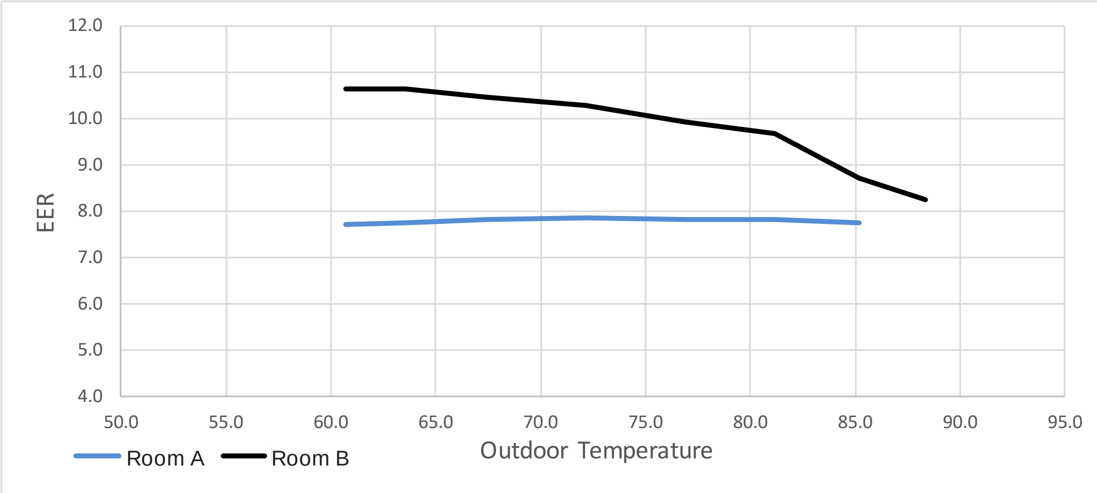

Figure 9. EER versus Outdoor Temperature for Room A and Room B Systems

Although the AAON units maintained relative humidity that was closer to the setpoint (See Table 10) a comparison of energy consumption and the operating efficiency in Figure 9 indicate the Desert Aire units operated more efficiently than AAON units.

3.2 Yield Results

The grower stated that the quantity, quality and time requirements for all four grow cycles during this project were comparable to the products produced in other rooms within this facility.

4. Conclusions and Recommendations

According to staff, the efficiency of the AAON units may be affected by physical constraints in the duct work that do not allow them to perform optimally. In particular, the hot gas reheat loop may have insufficient airflow. This is an installation constraint that could be avoided. We were not able to confirm this or estimate how it might impact AAON performance. Facilities personnel believe the AAON units reheat coil does not have the capacity to meet the target temperatures when the lights are off. This is a system design constraint and was evident during the first few weeks of the growing cycle (See blue shaded region in Figure 7) but not evident thereafter.

The AAON and Desert Aire systems reject heat to the outside. Compared to a unitary dehumidifier, this is advantageous when grow lights are on and generating heat because a unitary dehumidifier also rejects heat to the room, which must be removed by the HVAC system. When lights are off however, the cold air required to condense water from the air (the dehumidification process) can make a grow room too cold. A unitary dehumidifier, which simply rejects all heat back to the growing room, is advantageous when lights are off and reheat is otherwise required.

Cadmus reviewed similar periods of the Room A and Room B grow cycles and found that the Desert Aire units operated more efficiently than AAON units. Cadmus compared the energy use of these units to a previous study. The previous study observed energy use of a flowering cycle in a room with similar HPS lights, traditional split HVAC systems, and unitary dehumidifiers. The combined energy use of the HVAC systems and dehumidifiers in the previous study was lower, but a significant amount of air was ventilated to the outside. Exchanging humid indoor air with dry outdoor air substantially reduces the latent load in the room. Due to this difference, Cadmus concluded that a direct comparison of HVAC system performance and energy consumption of the rooms in this study and in the previous study would not provide valid results. Because of the differences in operation, Cadmus was unable to answer the research questions that involved energy use comparisons.

SMUD should consider the following research topics in future studies:

- Investigate humidity tolerance – is 50% relative humidity necessary?

- Study effects of ventilation - outdoor air exchange may reduce humidity very efficiently (at certain outdoor conditions).
    - Determine whether relative-humidity demand-controlled ventilation is acceptable for growers
    - Conduct analysis of the sensible heat ratio through the growing cycle and compare to typical weather to assess feasibility and determine optimal “lights on/off” times each month of the year.

- Compare traditional HVAC systems with unitary dehumidifiers to Desert Aire and AAON systems operating in equivalent environments. High-efficiency unitary dehumidifiers can remove over 2.5 liters (0.66 gallons) of water per kWh.

Appendices

Appendix A – Room Inventories

The equipment installed in or serving each space is summarized in Table 12. The equipment is operated on similar schedules and to meet similar setpoints in both rooms.

	Equipment Description	Number in Room A (AAON)	Number in Room B (Desert Aire)
	Gavita Pro Plus 1000W EL DE HPS	108	126
	Hurricane 16” Classic Wall-Mount Fan Product	28	23
	Max-Fan Filter, 14” Inline Scrubber Exhaust Ventilation Blower	10	10
	Desert Aire QV30P4E73544C 30-Ton HVAC Unit	N/A	1

	Equipment Description	Number in Room A (AAON)	Number in Room B (Desert Aire)
	Desert Aire QS40A4E73992 40-Ton HVAC Unit	N/A	1
	Luvata LCS822-022-4C Condensers for Desert Aire Units	N/A	2
	SA-035-3-A-ER09-000 35-Ton AAON Units	2	N/A
 	Reymsa RTU-606175-A with Fan on VFD 50% Dedicated to Both AAON Units in Room A	1	N/A
 	15 Horsepower Chilled Water Pump on VFD 50% Dedicated to Both AAON Units in Room A	1	N/A

Table 12. Equipment Details and Quantities by Room

Appendix B – Supplementary Data

Figure 10 shows hourly temperatures, HVAC system demand, condensate removal rate, and indoor humidity in Room A (AAON units). Figure 11 and Figure 12 show trend data for selected weeks during the growing cycle.

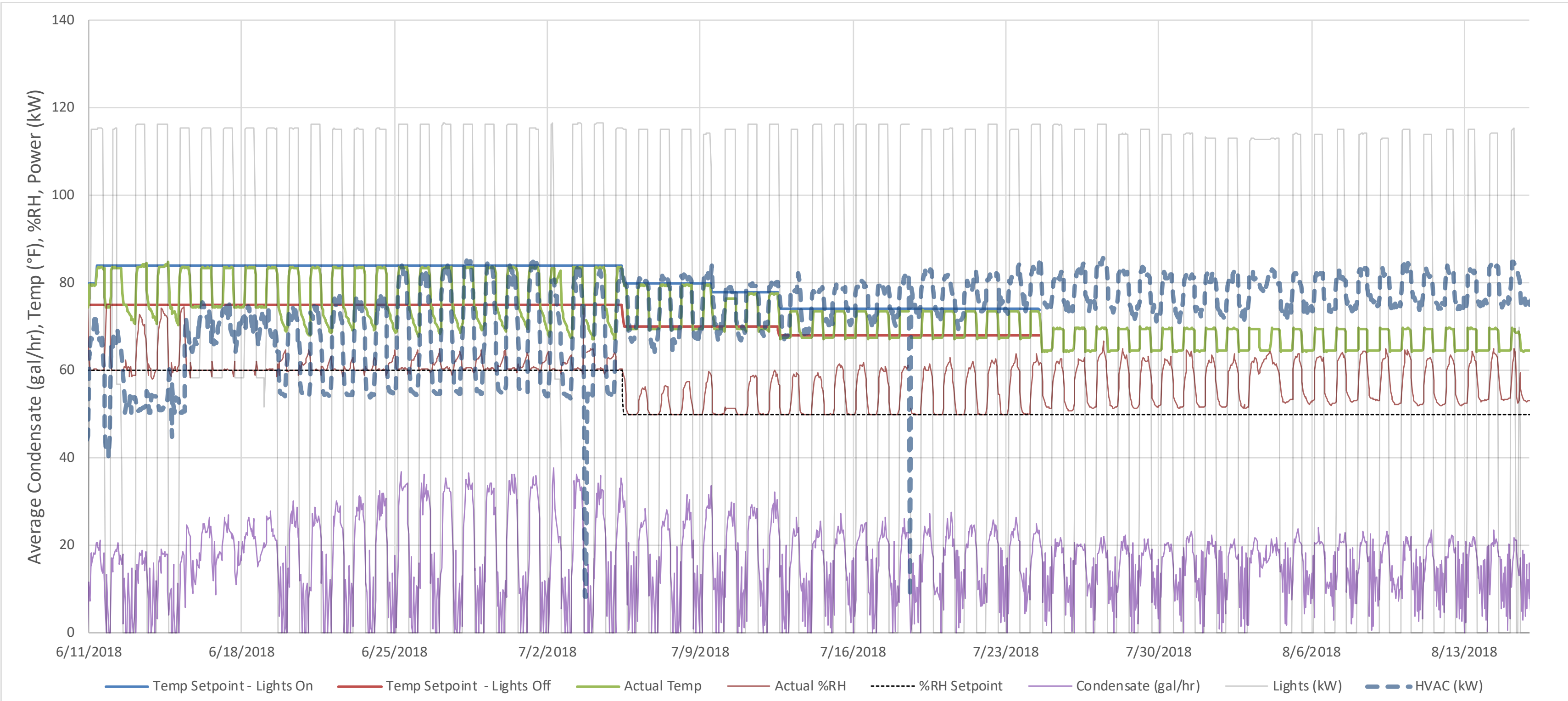

Figure 10. Trend Data for Room A

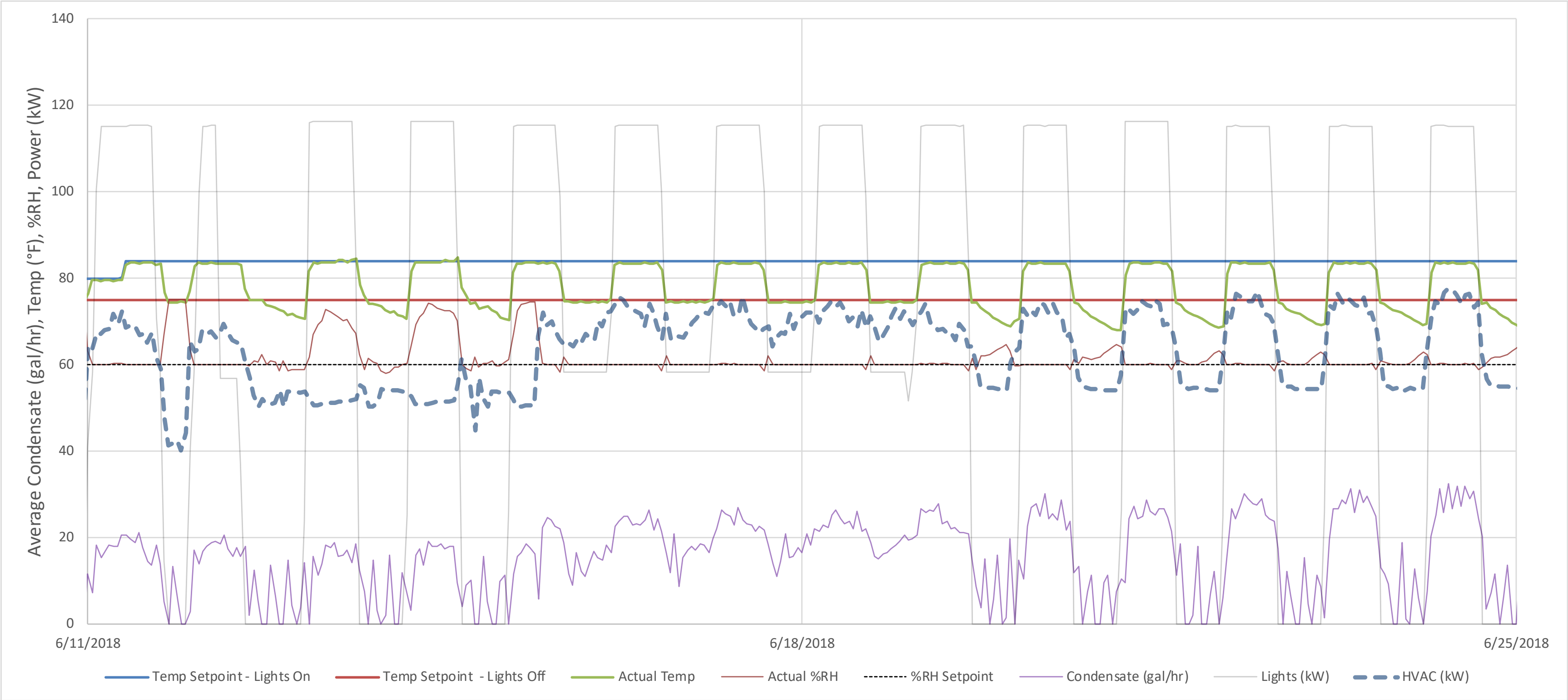

Figure 11. First two weeks of Room A grow cycle

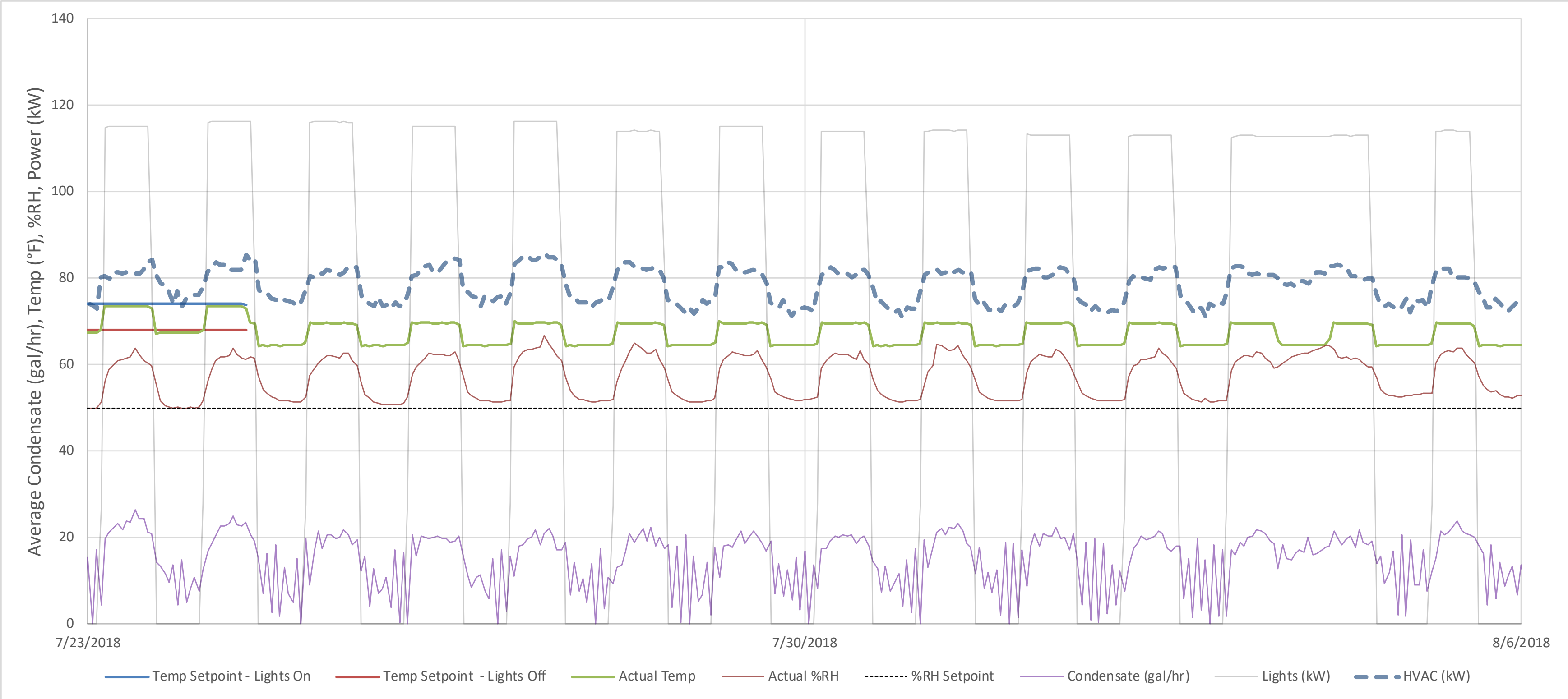

Figure 12. Room A grow cycle – Showing relative humidity % is no longer maintained when lights are off

Figure 13 shows hourly temperatures, HVAC system demand, condensate removal rate, and indoor humidity in Room B (Desert Aire units). Figure 14 and Figure 15 show trend data for selected weeks during the growing cycle.

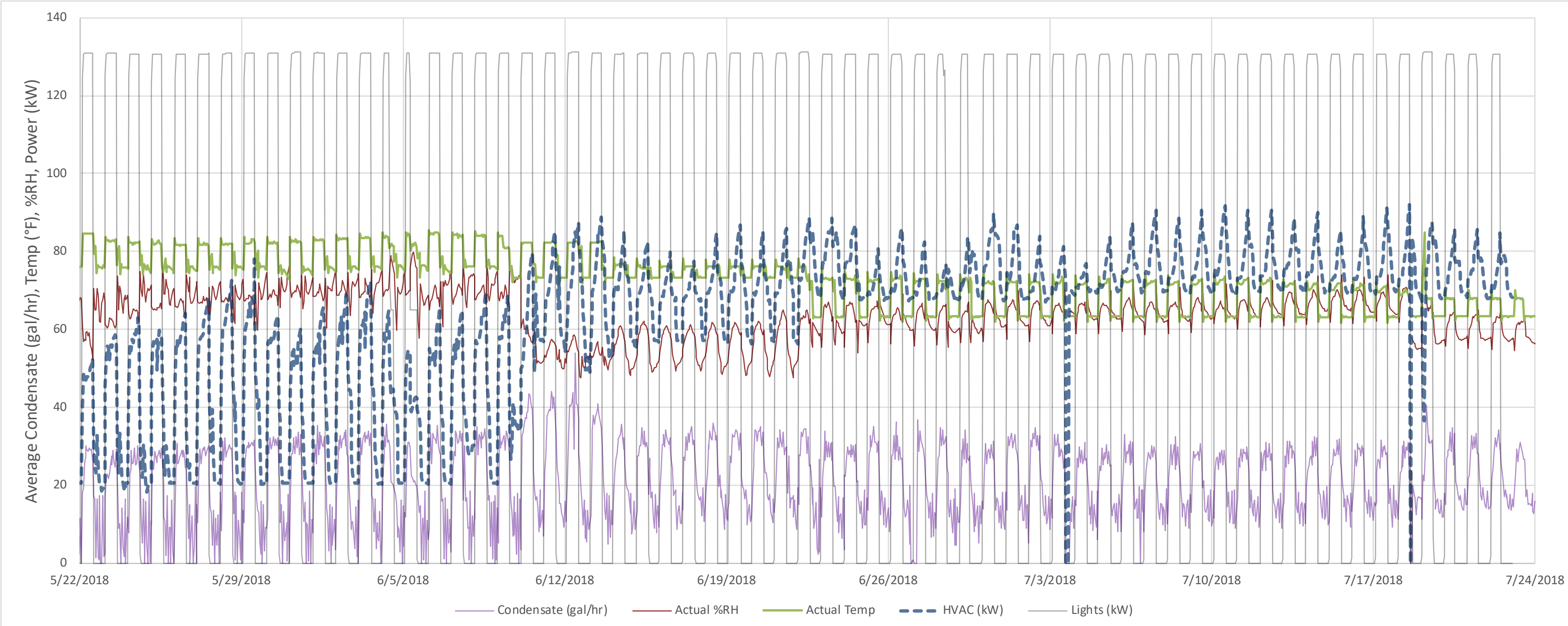

Figure 13. Trend Data for Room B

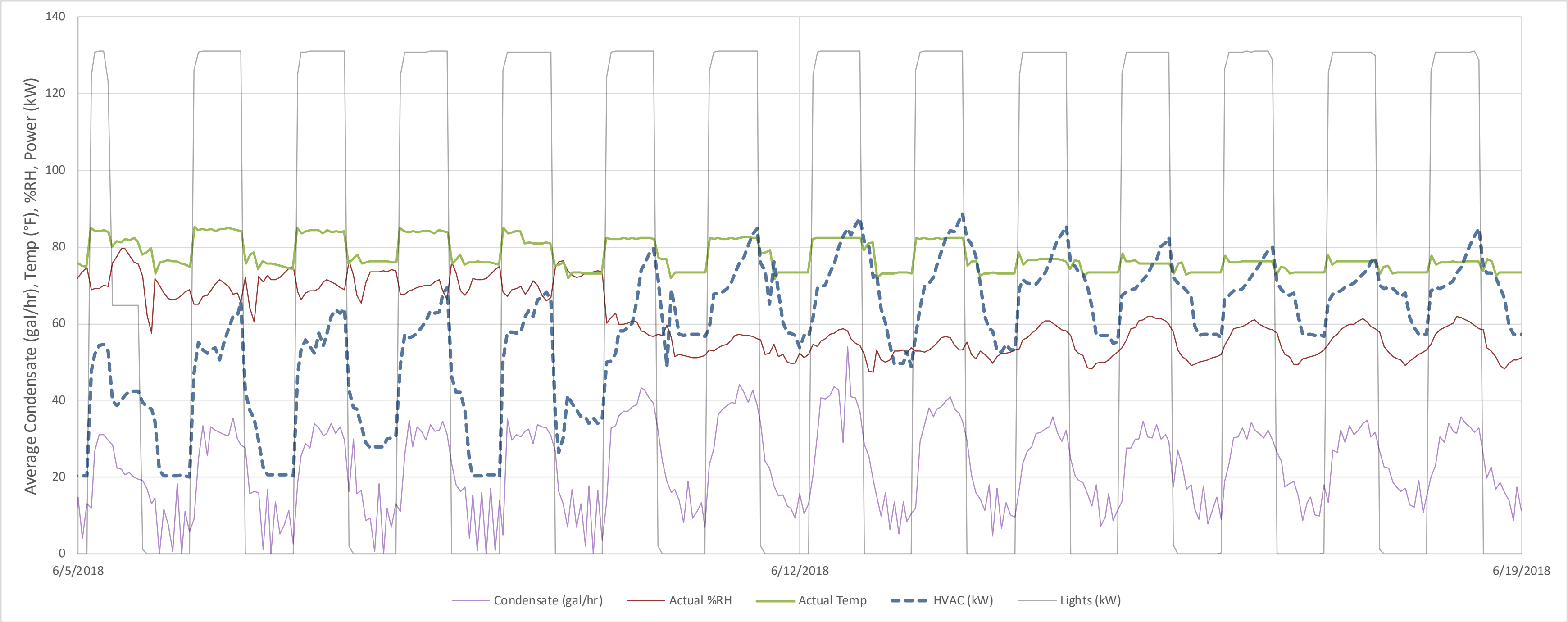

Figure 14. Additional Trend Data for Room B – Weeks 3 and 4 (temperature setpoint change from 84 to 74 when lights are on and 75 to 65 when lights are off)

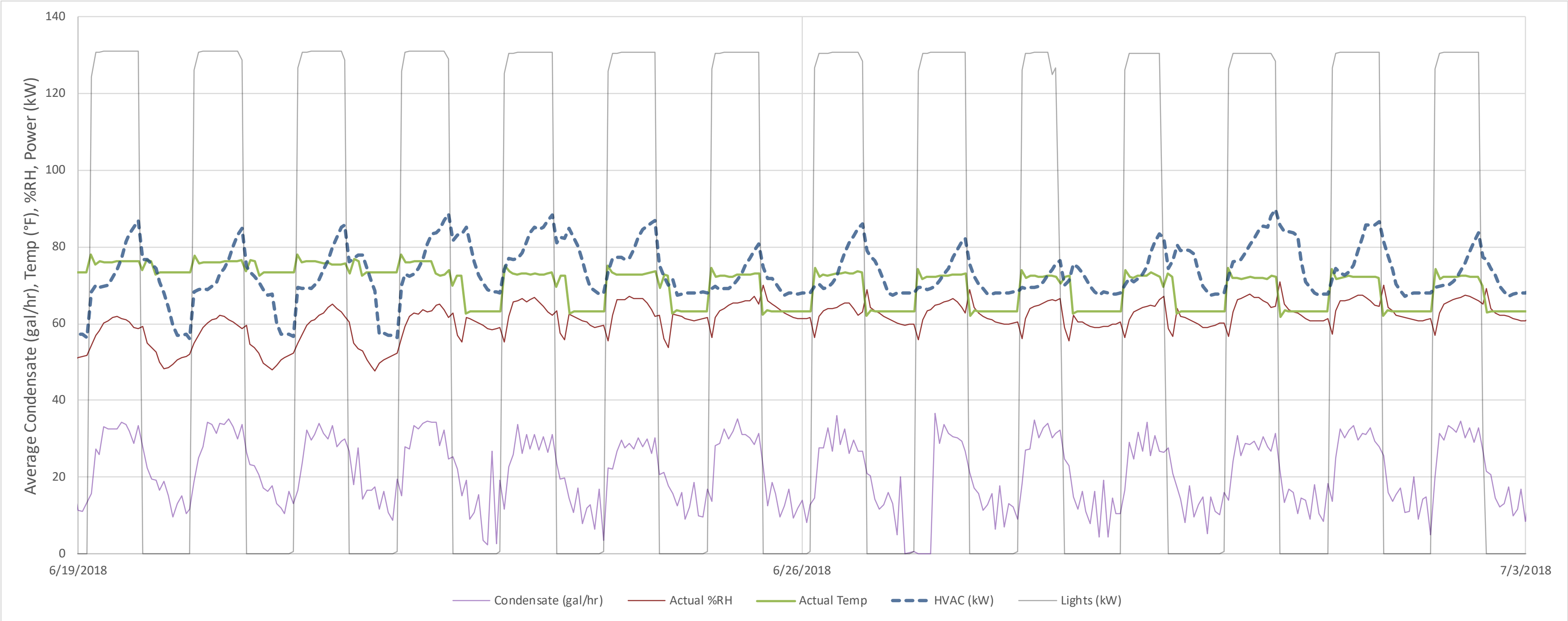

Figure 15. Additional Trend Data for Room B – increasing relative humidity possibly due to increasing plant transpiration