# ABT 212-001: A PATH TO ZERO NET ENERGY

## Spring 2018

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# FINAL PROJECT REPORT

# ENERGY AND EFFICIENCY IN UC DAVIS GREENHOUSES

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## Abstract

After receiving a grant valuing about $2M from Design and Construction Management, greenhouse managers Gary Pearson and Ronald Lane have decided to use this money for energy efficiency upgrades to their facilities. This is because there are over 200 greenhouses, most of which constantly control lighting and temperature. At such large scale, small improvements can lead to significant savings. The greenhouses, however, vary by model and levels of technological advancements and there is little in the way of energy measurements available for these different types. By performing an analysis on greenhouse energy use, this project will provide insights and estimates about greenhouse energy usage as well as propose feasible energy efficiency interventions. Successful interventions will benefit our clients, UC Davis researchers, the UC Davis Energy Conservation Office, and the UC as a whole. Furthermore, reduction in energy usage will benefit the world as a whole by reducing carbon emissions.

## Introduction

The UC Davis greenhouses consume energy 24 hours a day, 7 days a week. The vast majority of this energy is used for lighting, cooling, and heating. With over 200 greenhouses on campus, the scale is vast. Unfortunately, very little of the greenhouse energy use is monitored and total use is unknown. Having recently received a large grant for upgrades, the greenhouse managers would like to investigate how the greenhouses use energy and whether there is any low-hanging fruit for energy savings. The ultimate goal of this project is to propose informed interventions that will improve overall energy efficiency. We also provide insights and estimates regarding the energy usage of the different types of greenhouses.

## Methodology

First, it was necessary to identify which greenhouses to measure and define what technology levels they fall into. These technology levels are defined specifically for this project because research has not provided a consistent evaluation of types of greenhouses by technology. These descriptions are provided in Table 1, which also includes the specific greenhouses investigated as part of this project. This facilitated literature the review process by allowing comparison across categories instead of focusing on specific greenhouse configurations.

Data was then collected for each of the greenhouses identified as candidates. This method is described below.

1. Perform a walkthrough to gather measurements and nameplate information of greenhouse features like cooling pads, furnaces, and lighting.
2. Information on greenhouse dimensions was pulled from FacilitiesLink at .http://facilitieslink.ucdavis.edu/
3. Worked with electricians to gather measurements of current draw.
4. Power measurements are gathered from wattmeters on plug loads.
5. From nameplates, we gathered technology specification information.
6. Interviews with greenhouse managers proved useful for determining technology behaviors and usage scenarios.

Using the gathered data, energy usage calculations were performed and totals obtained. Equipped with this information, low investment energy efficiency options were investigated using a combination of literature review, observation, and conversation with knowledgeable parties.

The greenhouses we looked at were Orchard Park (except for #607), Large Core, and Small Core. This is representative of a total of 88 greenhouses, meaning we are not looking at 100+

greenhouses on campus. This is due to jurisdiction and ownership issues as well as accessibility and data availability.

Even though we performed calculations only on Orchard Park greenhouse #608, it is representative of the other 68. Orchard Park # 607 is a unique case and was omitted from the study.

Walkthrough data for each of the greenhouses is available in the Appendices.

| Designation | Technology Level | Description | Units Investigated | Representative Quantity |
|---|---|---|---|---|
| 1 | Low | Completely passive, may use thermal storage technologies such as colored walls, solar concentration, and convective temperature control. | None | 0 |
| 2 | Medium | Timer- or sensor-driven lighting control and basic thermostat for heating/cooling. | Orchard Park | 69 |
| 3 | High | Includes level 2 technologies plus a control system. May include humidity control, position control, photovoltaic glazing, and other non-conventional technologies. | Core, Large | 5 |
| | | | Core,Small | 14 |

**Table 1. Designation of greenhouse levels for the purposes of this study**

## Energy Calculations

Since most of the greenhouses do not directly monitor energy consumption, indirect methods were used. Annual usage for the largest contributors – lighting and heating- were estimated. Cooling is achieved by evaporative cooler, which uses a small pump to wet the pads and two fans to move and the air across the pads. Because of this, the energy usage for cooling is negligible in comparison to heating and lighting and was omitted.

### Lighting

Each of the Orchard Park greenhouses control lighting schedules with manually set timers that allow for two active periods. For all units, these periods are set as 5:00 am – 9:00 am and 5:00 pm – 9:00 pm, resulting in 8 hours per day that the lights are turned on for a total of 2920 hours annually. Combining this with manual power measurements of 963 W per light and fixture counts, usage was calculated according to the following equation:

$$E = N \times P \times t \times \frac{1\ kWh}{1000\ Wh}$$

Where

$E$ = Energy use of lighting system, in kilowatt-hours

$N$ = Number of lighting fixtures per greenhouse

$P$ = Power draw of an individual lighting fixture, in watts

$t$ = Time in one year during which lighting is active, in hours

The same equation was used for the Core greenhouses, taking into account differences in lighting schedule and measured power draw. In contrast to the scheduling of the Orchard Park lights, the Core greenhouses utilize light level meters to turn on the lights anytime levels drop below 450 $\frac{W}{m^2}$. This significantly reduced the active lighting time to 1388.25 hours annually. This number was obtained by assuming active periods of 5:00 am – dawn and dusk – 9:00 pm. Sunrise and sunset times were obtained for the KEDU weather station in Davis, CA for use in this calculation. Interestingly, the measured power draw was different for the Core greenhouses despite the lights being rated similarly at 1000 W. Core greenhouse lighting was measured to draw only 714.7 W of power. The Core lighting system power draw was obtained through field measurements of current draw on each leg of three-phase power supplying the lights. Power draw for each leg was calculated according to

$$P = I_1 \times V_1 + I_2 \times V_2 + I_3 \times V_3$$

Where

$P$ = Power draw of all connected lighting fixtures, in watts

$I_j$ = Measured current draw for single leg of 3-phase supply voltage, in amperes

$V_j$ = Voltage of corresponding leg of 3-phase supply voltage, in volts

As shown, results were totalized across all three legs. Dividing this total power draw by the number of lights on at the time of measurement resulted in average power draw per light.

### Heating

The Orchard Park greenhouses obtain their heating from the centralized campus steam system. Heat from the steam travels through a heat exchanger into a hot water loop that supplies each of the houses. Greenhouse #608 had previously been equipped with sensors to read the inlet and outlet temperatures of the hot water being supplied to it, and an appropriate flow meter logged the volumetric flow rate of the hot water for this specific greenhouse. From this information, a heat calculation could be performed according to the following equation:

$$Q = F \times c_p \times \rho \times (T_R - T_S) \times t \times$$

$Q$ = Heat lost by water, in kilojoules. Equivalent to energy used to heat greenhouse.

$F$ = Flow of heating hot wáter, in $\frac{m^3}{s}$
$c_p$ = Specific heat of water at constant pressure, taken to be $4.18\frac{kJ}{kg\cdot K}$
ρ = Density of water, taken to be $997.1\frac{kg}{m^3}$
$T_S$ = Inlet water temperature, in Kelvin
$T_R$ = Outlet water temperature, in Kelvin
$t$ = Time over which data was taken, in seconds

This value was then combined with boiler efficiency to obtain the final amount of natural gas used annually:

$$Q_{BTU} = \left(\frac{Q}{Eff_{Boiler}}\right)\left(\frac{0.95BTU}{kJ}\right)$$

Where
$Q_{BTU}$ = Natural Gas used to heat greenhouse, in BTU
$Q$ = Heat lost by water, in kilojoules. Equivalent to energy used to heat greenhouse.
$Eff_{Boiler}$ = Boiler efficiency, taken to be 0.92

The Core greenhouses utilize natural gas fired furnaces and a blower fan to heat air and circulate it throughout the building. This means they use a combination of electricity and gas for the purpose. Field measurements of combined current draw due to the blower fan and gas pump were taken by electricians using a clamp ammeter. Knowing these utilize 120V supply voltage, power was obtained according to

$$P = I \times V$$

Where
$P$ = Power draw of all connected lighting fixtures, in watts
$I$ = Measured current draw for single leg of 3-phase supply voltage, in amperes
$V$ = Voltage of corresponding leg of 3-phase supply voltage, in volts

This rate of consumption was multiplied by estimated usage hours for heating purposes. Since temperature setpoints are standardized across greenhouses where possible, temporal usage information was obtained from the flowmeter data available for Orchard Park #608. Since this data only covered a ~15 day period, the percentage of time that heating was active over this period was multiplied by the total hours in a year to extrapolate annual heating hours. Because the period for this measured usage occurred during the Spring, it is expected that this estimate is representative of the whole year. Heating requirements in Spring are greater than in Summer and less than Winter's requirements, so a good balance is struck between the two.

Annual heating requirements of the furnaces were calculated using efficiency and natural gas consumption values specified for the model of furnace in use according to the following equation:

$$Q = U \times A \times HDD \times \frac{1}{EER} \times \frac{24\ hour}{1\ day}$$

Where

$Q$ = Energy obtained through natural gas, in BTU

$U$ = Thermal transmittance of construction material, taken to be $1.13 \frac{W}{m^2 K}$

$A$ = Exposed surface area, taken to be $294.86\ m^2$ for Small and $481.02\ m^2$ for Large.

$HDD$ = Heating degree days for 2017, in $^{\circ}\mathrm{C} \cdot hour$

$EER$ = Energy efficiency ratio, taken to be 0.79

The thermal transmittance value (also known as U-value colloquially) was obtained from the assumption that the Core greenhouses are completely made of glass. No supporting structure was taken into account. The surface area obtained for each greenhouse was similarly assumed to count all exposed surfaces of the greenhouse – no accounting was taken for fan inlets or venting outlets.

Heating degree days for 2017 were obtained from www.degreedays.net using a base temperature of 18.5 °C. Since only differences are being used to calculate heating degree days, the conflict between Kelvin and Celsius in the unit analysis is moot, as one degree Kelvin is equivalent to one degree Celsius.

# Results

The final energy usage for the greenhouses under study are presented by Table 2. Annually, the Core and Orchard Park greenhouses together use 2.6 gigawatt-hours of energy. This is equivalent to 8300 MMBTU. At $0.06 per kWh and $0.84 per therm of natural gas, this comes to an annual expenditure of $128,000.00.

| | # of units | Single Greenhouse | | All Greenhouses | |
|---|---|---|---|---|---|
| | | Annual Energy Use (kWh) | Annual Energy Cost ($) | Annual Energy Use (kWh) | Annual Energy Cost ($) |
| Core, Small | 5 | 25,281 | $983.75 | 126,406 | $4,918.75 |
| Core, Large | 14 | 48,258 | $2,025.78 | 675,617 | $28,360.94 |
| Orchard Park | 69 | 26,651 | $1,378.70 | 1,838,948 | $95,130.33 |
| **Total for all units** | | | | **2,640,971 kWh** | **$128,410** |

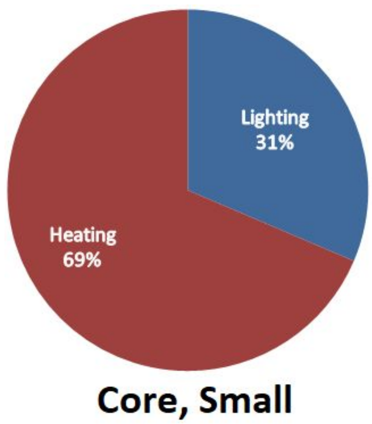
Table 2. Total energy use for individual greenhouses as well as totals across all greenhouses of that type. Figures shown are in kWh-equivalents. Totals across all greenhouses investigated are presented in the bottom row.

In the Core greenhouses, energy use for heating far outweighs that of lighting. However, for the Orchard Park greenhouses, lighting is the greatest offender. This is due to the improved efficiency from using radiant heating supplied by the centralized campus steam system. The boilers used to produce the steam are extremely efficient. Though it is not mentioned as an intervention due the large investment required, energy efficiency and carbon output would be vastly improved by retirement of the gas-fired furnaces in exchange for radiant heating. It is also expected that plant production would improve due to gentler heating, reduced airflow, and better mixing of thermal gradients.

Breakdowns of energy usage by lighting and heating are presented in tabular form by Table 3 and in visual form by the pie charts of Figures 1, 2, and 3.

| | | Annual Use (kWh) | Annual Use (BTU) | Annual Use (Therms) | Annual Cost ($) |
|---|---|---|---|---|---|
| Core, Small | Lighting (Electricity) | 7,937 | 27,082,203 | 271 | $555.59 |
| | Heating (Gas) | 17,016 | 58,060,271 | 581 | $487.82 |
| | Heating (Electricity) | 328 | 1,120,706 | 11 | $22.99 |
| Core, Large | Lighting (Electricity) | 19,843 | 67,705,507 | 677 | $1,388.98 |
| | Heating (Gas) | 27,759 | 94,717,351 | 947 | $795.82 |
| | Heating (Electricity) | 657 | 2,241,411 | 22 | $45.98 |
| Orchard Park | Electricity | 19,617 | 66,937,271 | 670 | $1,373.22 |
| | Gas | 7,034 | 24,001,083 | 240 | $201.66 |

**Table 3. Breakdown of Energy used for lighting and heating. Orchard Park values could not be disaggregated.**



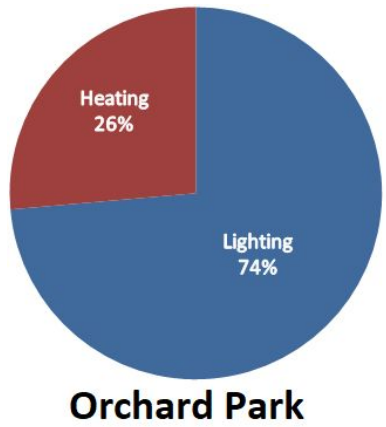




**Figure 1. Energy use by application for Orchard Park greenhouses**

**Figure 3. Energy use by application for Small Core greenhouses**

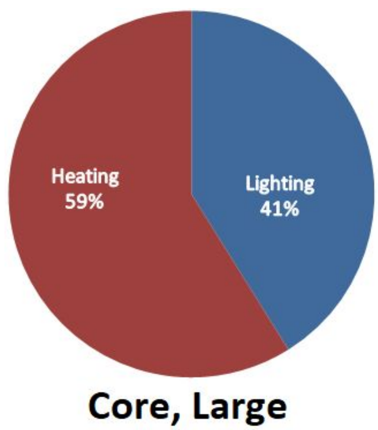



**Figure 2. Energy use by application for Large Core greenhouses**

Because different heating setpoints are required by different crops, a sensitivity analysis was performed for the furnace heating requirements in Core. Heating degree days were obtained using base temperatures of 10, 13, 15.5, 18.5, 21, and 24 °Celsius. A graph of the results from this sensitivity analysis are shown in Figure 3 below. This information is also presented in tabular form by Table 4.

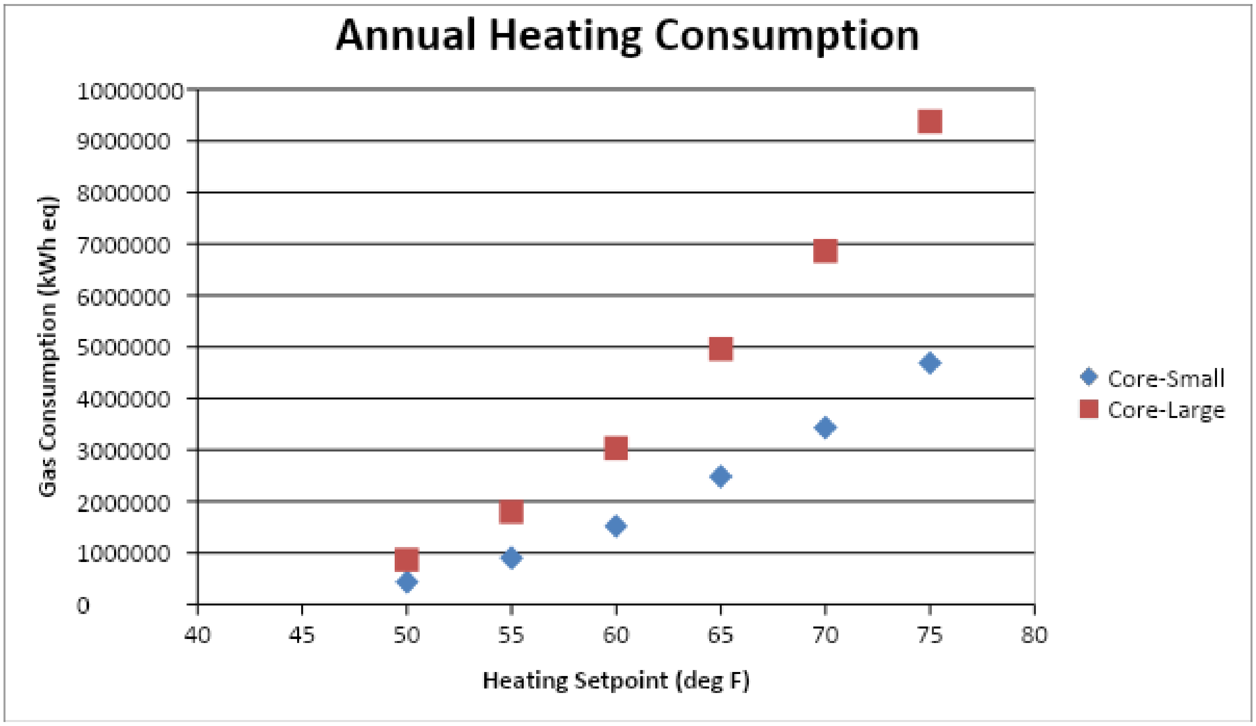



**Figure 4. Results from sensitivity analysis of heating requirements for different heating setpoints.**

Finally, the ratios of total use for each set of greenhouses are shown in Figures 3 and 4.

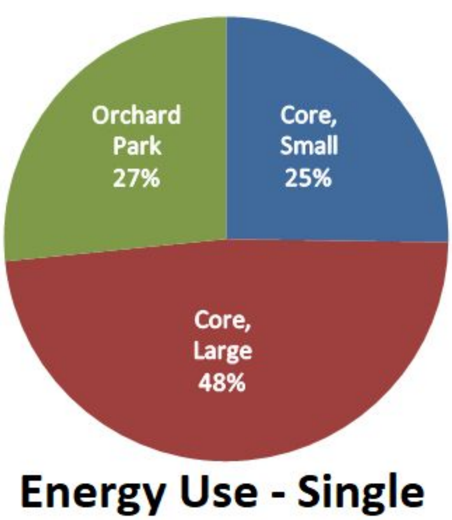



**Figure 5. Energy use breakdown by individual greenhouse of each type investigated**

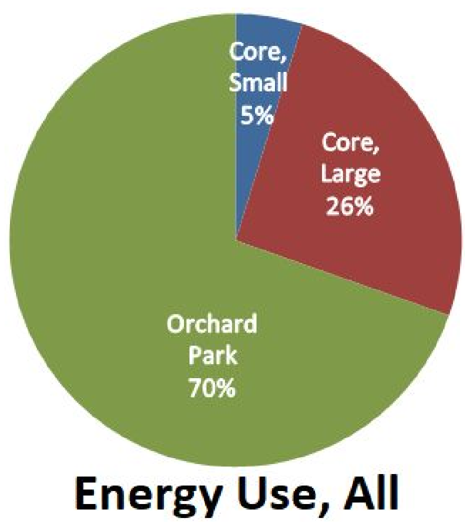



**Figure 6. Energy use breakdown by total across all greenhouses of each type**

## Change Orchard Park Greenhouse Lighting Schedules

The lights in Orchard Park are controlled with a timer that turns on and off the lights. The lights are on from 5-9 am and from 5-9 pm all year, even if the sun is shining within these times. Changing the schedule of the lights twice a year to better match dusk and dawn times will result in significant energy savings. In addition, this intervention would not have any cost for the greenhouse managers outside of labor and planning.

The chart in Appendix 1 shows the average sunrise and sunset times for each month in 2017 at using the location of Sacramento, California. The UC Davis campus is approximately 15 miles from this location, so times are representative.

The proposed schedule according to the sunrise and sunset times would be:

- October 1st - April 30th 5-9 am / 5-9 pm
- May 1st - September 30th 6-8 am / 7-9 pm

With this schedule, the lights would be on 8 hours per day from October until April and 4 hours per day from the beginning of May until the end of September. Compared to the current calendar where the lights are on 8 hours a day this would result in saving 4 hours a day of lightning over 6 months. This intervention applies to 70 greenhouses in Orchard Park (#607 is included) and each greenhouse has 4 light fixtures that demand 963 W of power.

The annual energy use is

$$0.963\ \frac{kW}{light} \cdot 4\ \frac{light}{greenhouse} \cdot 70\ greenhouse \cdot 8\ \frac{h}{day} \cdot 365\ \frac{day}{year} = 787,348.8\ \frac{kWh}{year}$$

The cost for this usage considering that UC Davis pays \$0.07/kWh is:

$$787,348.8\ \frac{kWh}{year} \cdot 0.07\ \frac{\$}{kWh} = 55,114.42\ \frac{\$}{year}$$

With the intervention, the annual energy use would be:

October – April:

$$0.963\ \frac{kW}{light} \cdot 4\ \frac{light}{greenhouse} \cdot 70\ greenhouse \cdot 8\ \frac{h}{day} \cdot 182\ \frac{day}{year} = 392,595.84\ \frac{kWh}{year}$$

May-September:

$$0.963\ \frac{kW}{light} \cdot 4\ \frac{light}{greenhouse} \cdot 70\ greenhouse \cdot 8\ \frac{h}{day} \cdot 183\ \frac{day}{year} = 197,376.48\ \frac{kWh}{year}$$

Combined Annual Use:

$$Annual\ energy\ use = 392,595.84\ \frac{kWh}{year} + 197,376.48\ \frac{kWh}{year} = 589,972.3\ \frac{kWh}{year}$$

The cost for this amount of usage considering that UC Davis pays $0.07/kWh would be:

$$589,972.3\ \frac{kWh}{year} \cdot 0.07\ \frac{\$}{kWh} = 41,816.36\ \frac{\$}{year}$$

As shown in Table 4, implementing the intervention would result in saving 197,376.5 kWh of energy and $13,816.36 each year. Since the savings from this application are dependent on how long the intervention is in place, our recommendation is to employ it as soon as possible to maximize benefit.

| | Energy Use (kWh/year) | Cost ($/year) |
|---|---|---|
| **Without Intervention** | 787,348.80 | 55,114.42 |
| **With Intervention** | 589,972.30 | 41,298.06 |
| **Annual Savings** | **197,376.50** | **13,816.36** |

Table 4. Energy and cost savings gained by reducing lighting duration to 4 hours for 6 months out of the year

## Install photo-switches in Orchard Park

Another method of shortening the time that lights are used in Orchard Park greenhouses would be to install a photosensitive switch in the line supplying power to the ballasts that fire the HPS light fixtures. This device is also known as a dusk-to-dawn switch and is commonly used to control walkway lighting and Christmas lights. This would force them to behave similarly to the Core greenhouses, reducing the annual time they are active to 1388.25 hours from 2920 hours. Employing the same calculations as were used for the two-time manual schedule change mentioned in the above paragraph, the results shown in Table 5 were obtained. Considering a device cost of $15.00, actual savings would be $53,420.00.

| | Energy Use (kWh/year) | Cost ($/year) |
|---|---|---|
| **Without Intervention** | 787,348.80 | $55,114.42 |
| **With Intervention** | 5,347.54 | $374.33 |
| **Annual Savings** | **197,376.50** | **$54,740.09** |

Table 5. Energy cost and savings gained by installing photosensitive switch at Orchard Park light fixtures

## Replace HPS lightning with LEDs

LEDs are a new sustainable source of lighting for greenhouses. Because LEDs are more efficient than previous installations of sodium light bulbs they should be considered for replacing them in the UC Davis Greenhouses to increase efficiency. LEDs are more ideal for the use in greenhouses because of pros such as their ease in transitioning between on and off conditions which stress sodium bulbs. They also efficiently spread more light without any extra materials needed to reflect the light in a desired direction. LEDs do not have as many failing parts as is the case with sodium bulbs allowing them to last for longer periods of times before needing replacements. LED can also produce a very narrow spectrum of light without losses to IR or UV radiation. LPS (low pressure sodium) lights are the only available type of sodium light that can be used to such effect.

The only downside to replacing sodium lights with LEDs would be the upfront cost and in installation. LED lights on such a scale would be a costly investment initially, but would save about 0.58 cents per hour in the long run.

### Install Water-Filled Polyethylene Bags

Within the passive methods of heating, thermal storage, by means of polyethylene sleeves filled with water installed between the cultivation lines, has shown a positive effect by increasing night temperatures and production in a culture sensitive to low temperatures such as pepper. Currently this system is ready to be visited in a greenhouse parral with pepper cultivation in soil. Passive heating avoids using major sources of energy like generators to keep greenhouses at an ideal temperature.

## Conclusion

We narrowed down five interventions for efficiency which either had potential for great energy savings in the future or were easily implementable. They deal with light: changing lighting schedule, installing pyranometer-driven switches, dusk-to dawn switches and heat usage: using water-filled polyethylene bags. Changing lighting schedules by season, installing dusk-to-dawn, and polyethylene bags are easy changes to make currently. Pyranometer-driven switches and LED lights are more costly options but they also yield great energy savings from research and estimated calculations.

## Future work

- Fiscal and energy savings calculations for polyethylene bags and LED lights.
- Design and investigate pyranometer system for detecting light levels in Orchard Park greenhouses. This would be a more robust version of the photosensitive switch method.
- Install appropriate sensors in representative greenhouses to directly measure energy usage.

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# Appendix

## A1. Average sunset and sunrise times chart

*Average sunrise and sunset times in Sacramento, 2017. Source: www.timeanddate.com*

| **Month** | **Sunrise** | **Sunset** |
|---|---|---|
| January | 7:20 am | 5:10 pm |
| February | 6:56 am | 5:43 pm |
| March (clock change) | 7:14 am | 7:14 pm |
| April | 6:28 am | 7:43 pm |
| May | 5:54 am | 8:11 pm |
| June | 5:42 am | 8:31 pm |
| July | 5:55 am | 8:27 pm |
| August | 6:21 am | 7:57 pm |
| September | 6:43 am | 7:12 pm |
| October | 7:16 am | 6:26 pm |
| November (clock change) | 6:48 am | 4:53 pm |
| December | 7:16 am | 4:47 pm |