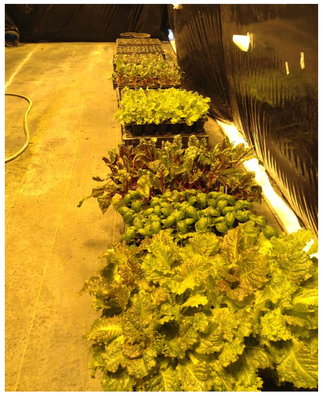
Improving Energy Efficiency in Controlled Environment Crop Production

Minnesota Department of Commerce, Division of Energy Resources

Investigators: Outsourced Innovation, LLC

in collaboration with the University of Minnesota



Lettuce under High Pressure Sodium Lights

High Pressure Sodium (HPS) Lighting and Research Setup

Lighting & Crop Production

Rapid advancements in solid state lighting will transform lighting markets.

***Hypothesis*: Light emitting diodes (LEDs) save energy and maintenance costs compared to conventional high pressure sodium (HPS) when sole source lighting is used to propagate crops *without* compromising production outcomes.**

LEDs promise other non-energy benefits:

- Light technology to extend the growing season
- Grow crops in vacant warehouses (urban agriculture or vertical farming)
- Tune light wavelengths by plant to optimize growth (create a light recipe)
- More intense PAR light to shorten plant cycle time
- Lighting equipment that is a more cost-effective
- Economic benefits in Minnesota from locally sourced crops

	Morphological (Growth Response)	**Photosynthesis** (Light Response)	**CO2 Response**
CYCLE 1			
Swiss Chard	None	Yes @ High light levels (LED)	Yes @ 400 ppm (LED)
Lettuce	None	Yes @ high light levels (LED)	None
Basil	Taller (HPS)	None	None
Cucumbers	Larger Size Taller Height (HPS)	None	None
CYCLE 2			
Swiss Chard	None	Yes @ high light levels	Yes @ 400 ppm
Lettuce	None	Yes @ high light levels	Yes @ 200 & 600 ppm)
Basil	Larger leaf width Taller Plant (HPS)	None	None
Cucumbers	Taller Height More Leaves (HPS)	None	None
CYCLE 3			
Swiss Chard			
Lettuce			
Basil			
Cucumber			

Energy Summary Analysis

Notes:
1. Installation occurred on 3/23, lights on 3/24 6:00 am
2. 1 HPS bulb did not work, so 1 LED light fixture was also turned off (same location)
3. Data is only 75% of actual due to 1 lamp being out
4. Data will only be used from July 1st through Oct 1st. This removes all the broken HPS issues

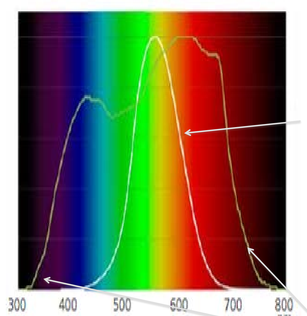
Real Start	3/24/2014	6:00:00 AM
Usable Start	7/1/2014	6:00:00 AM
Stop	9/30/2014	12:00:00 AM
Days	91	
Interval	15 mins	

Channel	Description	Total Hours ON	Total Hours OFF	Total Hrs	% ON	Max-kW	Min-kW	Avg-kW	Fixtures / Room	Watt/fix	Total kWh	AVERAGE Daily kWh usage	$/kWh	Total -$	PF
1	HPS Lighting	1662.25	521.75	2,184	76%	4.2	-	3.929	4	982.5	6,530.44	71.76	$ 0.108	$ 705.29	99.27%
2	LED Lighting	1662.25	521.75	2,184	76%	2.312	-	2.228	4	557.0	3,702.96	40.69	$ 0.108	$ 399.92	95.11%
3	LED Fans	2184.00	0.00	2,184	100%	0.209	(0.09)	0.160	2	104.5	352.61	3.87	$ 0.108	$ 38.08	79%
4	HPS Fans	2184.00	0.00	2,184	100%	0.212	-	0.154	2	106.0	340.28	3.74	$ 0.108	$ 36.75	80%

Research Method

Characterize the energy load and plant growth when the *only* variable is the light source (LumiGrow Pro LED vs. Earth Works HPS).

1. **Established 2-windowless 144 square foot cultivation chambers (Cell 1 & Cell 2)**
2. **Utilized DENT ProElite and data loggers on single-phase, 4-channel circuit to monitor energy load.**
3. **Ambient temperature set at 70 degrees, Cell 1 & 2 utilized independently controlled air circulation and HVAC.**
4. **Characterized light performance**
5. **Evaluating plant morphology and CO2**
6. **Total of 612 seedlings, 3-10 week growth cycles to study:**
   - ✧ **90 Basil Plants**
   - ✧ **90 Leaf Lettuce**
   - ✧ **90 Swiss Chard**
   - ✧ **36 Cucumbers**

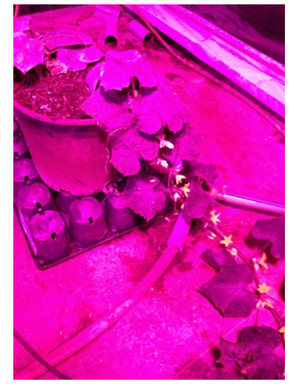


Human Visible Light

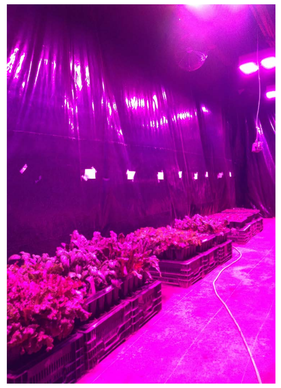
Plant Light for Photosynthesis

Research Outcomes as of 1/1/2015

- Measured Energy savings is 40%; 18 hr daily use
- Lumigrow LED performed better than product specifications
- Power quality and total harmonic distortion within DLC standards
- PAR light of HPS *degraded* more than 10% at 4,000 hours
- PAR light of LED *improved* by 8% at 4,000 hours



Leaf Lettuce and under LED Lighting



Light Emitting Diodes (LED) and Research Setup

Further information

- **Annual LED source energy savings in 2013 *more than doubled* from previous year.**
- **Only a small fraction of LED total savings realized in 2014**
- **Market penetration of LEDs in crop production is low**
- **Long-term color stability poorly understood and adds cost and complexity to LEDs**
- **Predicting color stability will increase crop grower confidence in LEDs**

Citations

Manufacturing Roadmap, SSL Research & Development, US Department of Energy, August 2014

Dorais, M., *Use of Supplemental Lighting for Vegetable Crop Production, Light intensity, crop response, nutrition, crop management, cultural practices*, Oct. 2003

Canadian Green House Conference 2003, PAR Light Recommendations

Sabzalian, M., et al, *High performance of vegetables and flowers and medicinal plants in red/blue LED incubators for indoor plant production*, Agronomy for Sustainable Development; Oct 2014, Vol 34, Issue 4 p. 879.886