Synthesis Engineering for Architecture

Table of Contents

Appendix A: References

Codes and Standards:

***Wisconsin Codes* -** Wisconsin Administrative Code (also references ASHRAE 90.1 (2013) and amendments to the NEC (2011))

***Miami Codes* –** Alternate codes to Wisconsin

***California Codes* -** Title-24 (2013) Part 6: Building Energy Efficiency Standards. This code was used to design to the most stringent standards in the country as Growing Power seeks to implement similar Vertical Farms across the nation.

National Codes* -** NEC (2011),*** ASHRAE (2010)

***Lighting Standards* -** IES 10th Edition Handbook

Computer Software:

DaySIM - RADIANCE-based daylighting analysis program, daylight harvesting, and shade operation analysis. This was used in conjunction with Microsoft Excel and LBNL Window 7 for greenhouse daylight analysis and glazing optimization.

***IES VE* -** Building performance modeling software which allowed for integrated building load and energy model analysis with the mechanical team.

***Revit Architecture* -** Building information modeling software used for modeling the site, building architecture, interior design, and lighting design. Basic site sun studies and preliminary daylight analysis were also performed in Revit Architecture.

***Revit MEP* –** Electrical components and wire sizing tool. All electrical loads, branch circuits, conduit, feeders, panel boards, and transformers were modeled in Revit MEP for official drawing documentation, clash detection, and quantity takeoffs.

***Revit ELUM Tools* -** Lighting analysis plugin for Revit. Electrical light level calculations within spaces of the building (confirmed with AGI32)

***AGI32* -** Lighting design, calculation, and visualization (used to confirm Revit ELUM Tools light level calculations)

SKM Power Tools - Electrical engineering optimization tool. Arch flash, ground fault, and overcurrent protection analysis.

References

A. Nabil, J. M. (2005a). Useful Daylight Illuminance: A New Paradigm to Access Daylight in Buildings. *Lighting REsearch & Technology*, 37(1), 41-59. Retrieved from Lighting REsearch & Technnology.

Alera Lighting. (1995). Benefits of Indirect Lighting. Ithica, New York, United States.

Ciolkosz, D. (2014, October). University Greenhouse Operator. (S. E. Architecture, Interviewer)

Company, P. G. (2015). *Gas Outages*. Retrieved from PG&E Corporation: http://www.pge.com/safety/naturaldisaster/stormsoutagessafety/gasoutage/

Energy, A. f. (2015). PVWatts Calculator. Golden, CO, United States.

Growing Power, Inc. (2014). *About*. Retrieved from Growing Power inc. : http://www.growingpower.org/about/

International, V. L. (2013). *PAR and Plant REsponse Curve*. Retrieved from SunMaster Lighting Systems for Greater Yields: http://www.sunmastergrowlamps.com/AboutSunmaster.htm

Mistrick, R., & Chen, L. (2014). The Impact of Snow Cover on Photosensor Control System Performance in a Space with Sidelighting. *Proceedings of the Annual IES Conference*, (pp. 14-16). Pittsburgh, PA.

Shimadzu. (2015). *Visible Transmittance and Visible Reflectance*. Retrieved from Shimadzu: Excellence in Science, Analytical and Meauring Instruments: http://www.shimadzu.com/an/uv/support/uv/ap/solar.html

Torres, A. P., & Lopez, R. G. (n.d.). *Comercial Greenhouse Production: Measuring Daily Light Integral in a Greenhouse*. Retrieved from Department of Horticulture and Landscape Architecture, Purdue University: https://www.extension.purdue.edu/extmedia/HO/HO-238-W.pdf

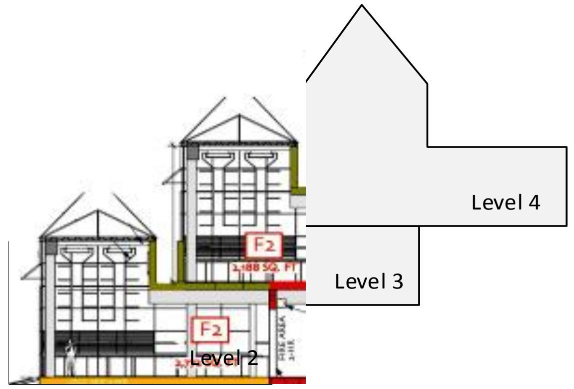
Appendix B: Synthesis Plant Matrix

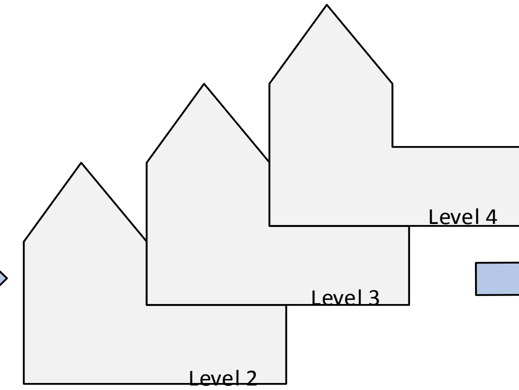
The Plant matrix was created during the initial stages of design. It was used to help the team determine set points for the growing environment in the greenhouse. Research was completed using a variety of resources to compile the matrix, some of these included: on campus greenhouse operators, ASHRAE greenhouse recommendations, agricultural encyclopedias, and online forums for farmers. The plants that are included were listed in the initial program statement for the competition as crops that Growing Power plans to grow in the new Vertical Farm.

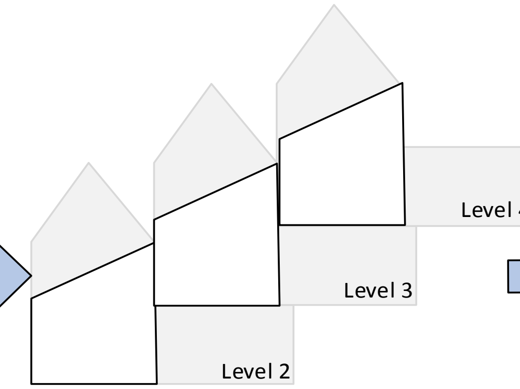
Synthesis Plant Matrix									
Crop Type	**DLI (Mol/Day/m2)**	**PAR (µmol/m2/s)**	**Illuminance (lux)**	**Day Length (Hours)**	**Temperature (°F)**	**Life Cycle (days)**	**Plant Height (feet)**	**Spacing in beds (inches)**	**Spacing in Rows (inches)**
Lettuce	14	150-200	8,100-10,800	24	60-65	30-40	1	12	6
Basil	14	150-200	8,100-10,800	16	70-80	60-90	2	3	12
Beat Greens	14	150-200	8,100-10,801	18	65	35-60	1	3	12
Greens	14	150-200	8,100-10,802	24	65	35-40	2	12	14
Chives	14	150-200	8,100-10,803	18	65		2	6	6
Tomatoes	26	300	16,200	16	64-82	60-100	6	18	30
Cucumbers	20	250	13,500	24	65-70	25	3	12	12
Strawberries	20	250	13,500	18	65-70	60-90	3	6	6

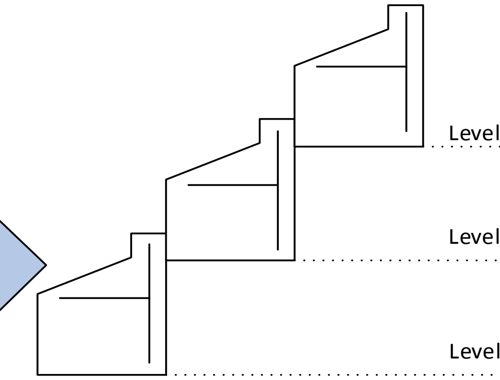
*Life Cycle is an approximate grow cycle for each crop type grown under the conditions recommended in the rest of the plant matrix.
Life Cycle begins after the germination grow period when crops have sprouted.

Appendix C: Greenhouse Transformation



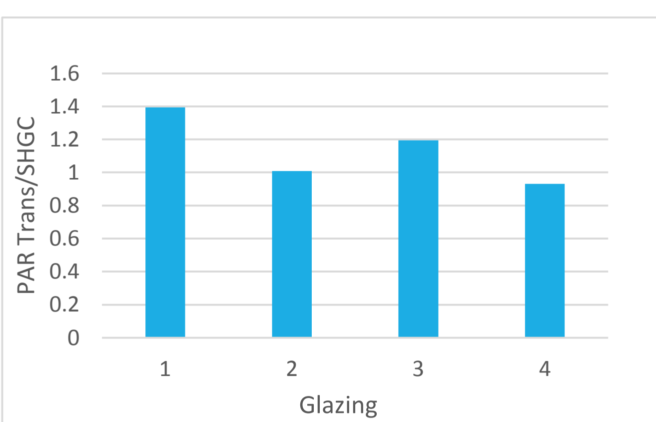






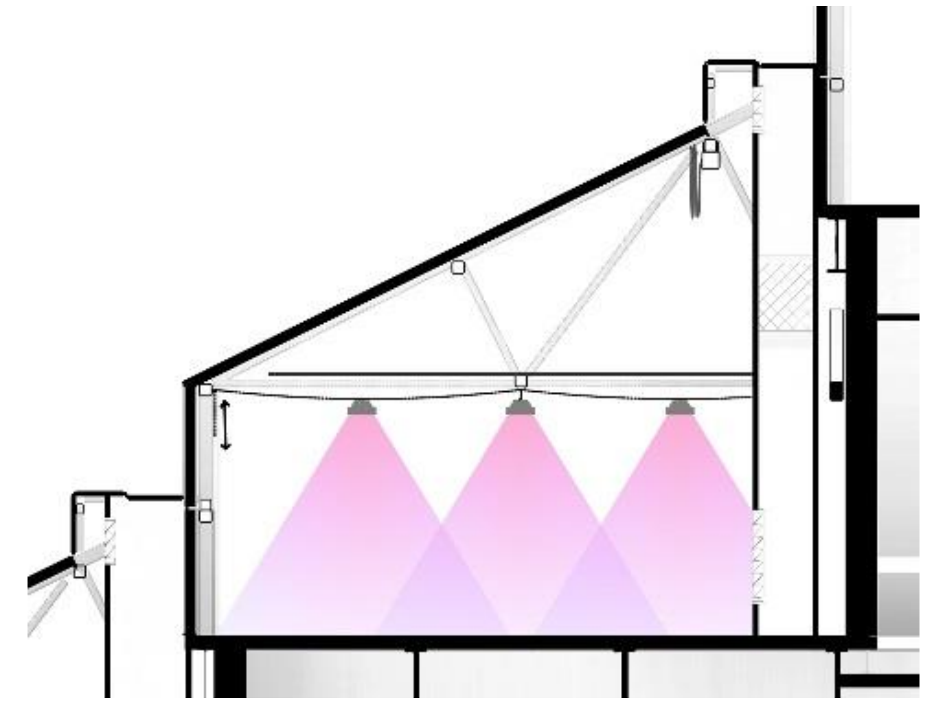
	TKWA Design	Cavity Removal	Eliminate Unused Space	Synthesis Design
Changes that Occured	Original design for the competition provided drawings by TKWA Architects.	Greenhouses were adjusted to remove large gap between each tier.	Transition to a single slope glazing system for smaller, and more adaptable relocation. Overall building width increase to maintain the original area.	Utilize similar single slope design however stagger tiers and coordinate heights by floor in order to decrease shading.
Daylight Delivery	Large glazing area will provide ample daylight to top plants, although the large volume will create shading issues for lower crops.	Similar daylight issues as initial design. The north facing sloped glazing lets in diffuse light. North covered areas in the rear do not receive adequate daylight for sustained plant growth.	Self shading limited between crops. Less depth and more width for higher daylight coverage. Slope optimized incident southern light angle throughout the US.	Module design creates optimum lighting requirements for specific carbon three plants. Minimal structural shading while taking into account mounting of devices and fixtures.
Ventilation	Open loop system, 100% Outside Air	Open loop system, 100% Outside Air	Open loop system, 100% Outside Air	Closed loop heating and cooling system. Lots of benefits including lower loads and increased controllability
Adaptability	Angle of glazing is not optimized	Snow accumulation between greenhouses will become an issue.	Single slope glazing is optimal for multiple locations in the US. Reduced heating and cooling in all climates due to reduced glazing area.	Cooling system, pest control, and carbon dioxide fertilization is sized for Miami. The exact same module can be used anywhere.
Constructability	Tall structure requires concrete and steel system with precast beams. Not ideal. Snow and Rain gutter between greenhouses will cause problems	Similar issues as initial design. Shared walls between greenhouses are difficult to coordinate and construct.	Simple to construct but large top slant poses logistic issues.	Optimal due to consistent and reasonable sized steel and glazing. Allows trusses to be preassembled and trucked to site.
Heating and Cooling	Height of greenhouse will cause stratification resulting in a non-homogenous growing environment	Height of greenhouse will cause stratification resulting in a non-homogenous growing environment. Less glazing than initial design helps.	Less glazing. Reduced stratification resulting in a more homogenous growing enviornment.	Refer to Mechanical Report
Operation Maintenance	Greenhouse is 20' high. This will require a rotational plant system that may have failures and maintenance issues	Similar issues as initial design. Tall growing area will pose problems.	Easier maintenance issues with regards to farming operations. Angled slope is still difficult to maintain	Easier maintenance issues with regards to farming operations. Angled slope is still difficult to maintain
Cost (construction and operation)	Cost of construction will be high due to large floor to ceiling heights	Cost of construction will be high due to large floor to ceiling heights	Reasonable cost due to repeatability	Cost is decreased due to prefabrication offsite and waste is decreased.

Par Transmittance Calculator												
							Multiwall Polycarbonate					
Wavelength	D65 CIE relative spectral power distribution	Relative PAR	Single Clear [H70_3.bsf]		Glass 2507 Layer: NRM.CPF		9011(5.8mm) Air(12.7mm) 9011(5.8)		9024(9.4), Air(5), 9024(9.4)		9026(5.8), Air(5), 9014(9.3)	
			Glazing Transmittance	Rel PAR*Glaz T	Glazing Transmittance	Rel PAR*Glaz T	Glazing Transmittance	Rel PAR*Glaz T	Glazing Transmittance	Rel PAR*Glaz T	Glazing Transmittance	Rel PAR*Glaz T
300	0.0341	0	0.0009	0	0.0037	0	0.0003	0	0.0013	0.00000117	0	0
<--TABLE BREAK 305-360 nm-->												
365	49.3637	0.339	0.0105	0.0035595	0.2445	0.0828855	0.0001	0.0000339	0.0006	0.0000063	0.0005	0.0001695
370	52.0891	0.393	0.0115	0.0045195	0.2491	0.0978963	0	0	0.0003	0.00000345	0.0007	0.0002751
375	51.0323	0.448	0.0138	0.0061824	0.2573	0.1152704	0.0002	0.0000896	0.0004	0.00000552	0.0005	0.000224
380	49.9755	0.493	0.0396	0.0195228	0.2735	0.1348355	0	0	0.0005	0.0000198	0.0004	0.0001972
385	52.3118	0.543	0.1358	0.0737394	0.3061	0.1662123	0.0005	0.0002715	0.0002	0.00002716	0.0007	0.0003801
390	54.6482	0.576	0.2368	0.1363968	0.3605	0.207648	0.0007	0.0004032	0.0004	0.00009472	0.0006	0.0003456
395	68.7015	0.62	0.3191	0.197842	0.4356	0.270072	0.0068	0.004216	0.0006	0.00019146	0.0028	0.001736
400	82.7549	0.649	0.4059	0.2634291	0.515	0.334235	0.0851	0.0552299	0.0171	0.00694089	0.0338	0.0219362
<--TABLE BREAK 405-695 nm-->												
700	71.6091	0.433	0.5734	0.2482822	0.7789	0.3372637	0.8819	0.3818627	0.8859	0.50797506	0.5561	0.2407913
705	72.979	0.382	0.5573	0.2128886	0.7791	0.2976162	0.8903	0.3400946	0.9074	0.50569402	0.5766	0.2202612
710	74.349	0.324	0.5452	0.1766448	0.7793	0.2524932	0.8948	0.2899152	0.9253	0.50447356	0.5917	0.1917108
715	67.9765	0.28	0.5368	0.150304	0.7795	0.21826	0.899	0.25172	0.9325	0.500566	0.6019	0.168532
720	61.604	0.238	0.5321	0.1266398	0.7793	0.1854734	0.9009	0.2144142	0.9263	0.49288423	0.6082	0.1447516
725	65.7448	0.2	0.5247	0.10494	0.7802	0.15604	0.9033	0.18066	0.9175	0.48141225	0.6151	0.12302
730	69.8856	0.159	0.5164	0.0821076	0.7799	0.1240041	0.9031	0.1435929	0.9125	0.471215	0.6233	0.0991047
735	72.4863	0.125	0.5003	0.0625375	0.7805	0.0975625	0.9026	0.112825	0.9182	0.45937546	0.6331	0.0791375
<--TABLE BREAK 740-835 nm -->												
830	60.3125	0	0.401	0	0.7931	0	0.9087	0	0.9354	0.3750954	0.6887	0
		SUM =	53.1821	35.1814582	70.1696	40.2983143	72.8265	42.2223841	72.0823	43.19825221	46.0315	25.0394176
			PAR Trans =	0.626327788	PAR Trans =	0.717422056	PAR Trans =	0.751675849	PAR Trans =	0.769049015	PAR Trans =	0.445771263
			Visible Trans=	0.721	Visible Trans=	0.762	Visible Trans=	0.706	Visible Trans=	0.687	Visible Trans=	0.267
			SHGC =	0.449	SHGC =	0.771	SHGC =	0.718	SHGC =	0.734	SHGC =	0.592
				1.394939395		0.930508503		1.046902296		1.047750701		0.752991998



Appendix E: Grow Lighting

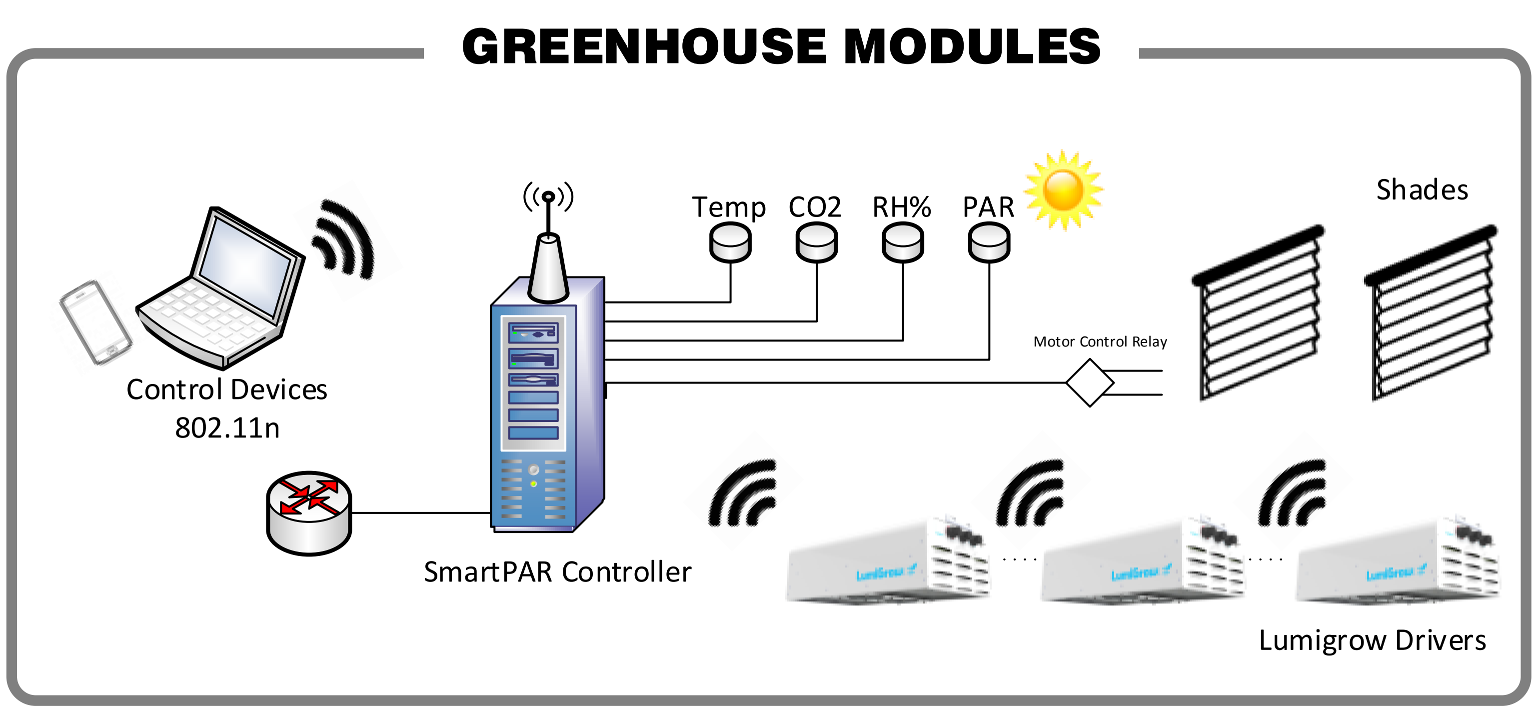
LumiGrow Pro Series Technical Specifications											
Specification	Energy Consumption	Operating Voltage	Operating Frequency	Recommended Electrical Service Allowance		Typical Running Current		Heat Output	Dimensions	Weight	Operating Temperature
Units	Watts	Volts	Hz	Volts	Amps	Volts	Amps	BTU/hr	inches	lbs	Degrees F
Pro 325	325 Watts	100-240 AC	50-60	120	5	120	2.7	940	10 W x 11 L x 5.5 H	9	(-4) to (140)
				240	2.5	240	1.3				
Pro 325 HV	325 Watts	249-528 AC	50-60	277	2	277	0.97	940	10 W x 11 L x 5.5 H	10	(-4) to (140)
				480	1.2	480	0.58				
Pro 650	650 Watts	100-240 AC	50-60	120	8.5	120	5.34	1900	10 W x 17 L x 5.5 H	16	(-4) to (140)
				240	5	240	2.7				
Pro 650 HV	650 Watts	249-528 AC	50-60	277	4	277	1.94	1900	10 W x 17 L x 5.5 H	21.5	(-4) to (140)
				480	2.4	480	1.6				



Average Hours of Grow Lighting Per Day														
Greenhouse	Number of Fixtures	Target DLI	Jan	Februar y	March	April	May	June	July	August	Septem ber	October	Novemb er	Decemb er
Level 2	54	14 mol/day	7.88	7.31	3.18	1.54	0.77	0.33	0.15	0.44	1.29	4.29	7.49	10.86
Level 3	54	20 mol/day	14.28	12.55	6.95	5.03	2.64	2.32	1.03	1.63	3.53	8.62	13.64	17.84
Level 4	54	26 mol/day	19.82	16.28	10.18	9.3	5.65	4.64	2.9	3.58	6.4	12.28	18.75	22
Level 5	90	14 mol/day	7.88	7.31	3.18	1.54	0.77	0.33	0.15	0.44	1.29	4.29	7.49	10.86

Mounting Details

- Fixtures are mounted at 7’ from the floor
- Adjustable metal chain controls height
- The closer the fixtures are to the growing surface, the more intense the PAR values
- Chain attaches to three horizontal structural members spanning between trusses (E-W direction)



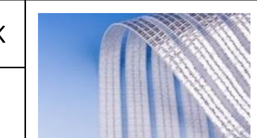
SmartPAR **–** Control protocol for LumiGrow fixtures. Used to program light recipes specific to certain grow cycles and crops as well as general photoperiod control.

Smart PAR is tied into the Li-COR Quantum PAR sensor and will turn on and off based off the data logging device.

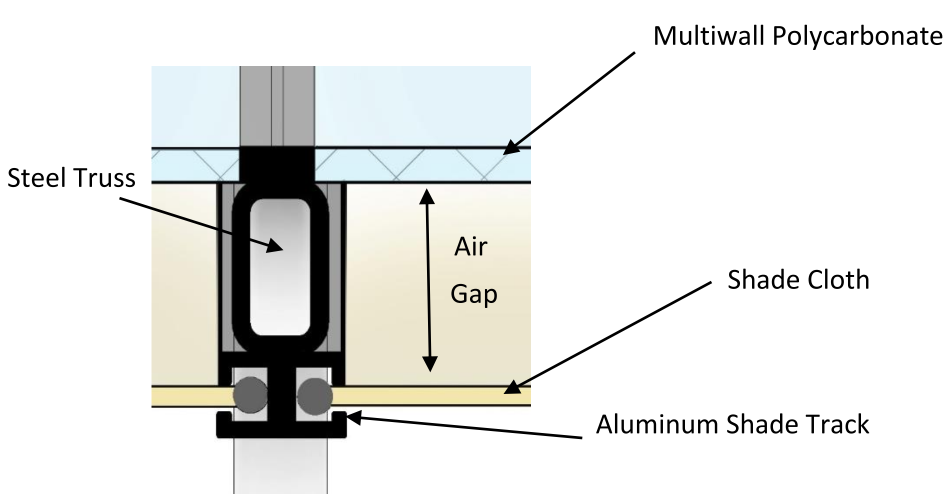
Controlled via wireless signal from the buildings local wireless access point.

Measuring PAR		
Equipment	Use	Description
LI-190 Quantum Sensor	PAR Sensor	Continuously measures light in the PAR spectrum - 1 per module.
LI-1400 Datalogger	DLI Calculator	Predicts DLI throughout the day. Multiple PAR sensors are linked.

Appendix F: Greenhouse Shade System

Shade Cloth Properties by Greenhouse															
Greenhouse	Target DLI	Shade Manufacturer	Model	System	Material Composition	Pattern	Flame Retardant	Weight	Thickness	Width of strips	Shading Level in Direct PAR	Shading Level in Diffused PAR	UV Light Transmission	K Value	Image
Level 2	14 mol/day	Ludvig Svensson	TEMPA 7965 R FR AG	Track	65% Polyolefin 35% Aluminum	3 Aluminum 1 Diffuse Trans	Yes	190 g/m^2	0.95 mm	4.6 mm	79%	81%	15%	3.3 W/m^2 K	
Level 3	20 mol/day	Ludvig Svensson	TEMPA 7265 D R A W	Track	71% Polyolefin 29% Aluminum	3 Aluminum 1 Diffuse Trans	No	194 g/m^2	0.85 mm	4.6 mm	82%	75%	23%	3.3 W/m^2 K	
Level 4	26 mol/day	Ludvig Svensson	TEMPA 6360 FR	Track	14% Polyolefin 51% Aluminum 10% Polyester 25% Modacryl	2 Aluminum 1 Diffuse Trans 1 Aluminum 1 Diffuse Trans	Yes	121 g/m^2	0.6 mm	4 mm	63%	66%	25%	4.1 W/m^2 K	
Level 5	14 mol/day	Ludvig Svensson	TEMPA 7965 R FR AG	Track	65% Polyolefin 35% Aluminum	3 Aluminum 1 Transparent	Yes	190 g/m^2	0.95 mm	4.6 mm	79%	81%	15%	3.3 W/m^2 K	Same as Level 2

Average Hours of Shading Per Day														
Greenhouse	Shade Cloth	Target DLI	January	February	March	April	May	June	July	August	September	October	November	December
Level 2	TEMPA 7965 R FR AG	14 mol/day	4.36	7.84	13.62	14.52	18.19	19.02	21	20.35	17.4	11.89	5.5	1.8
Level 3	TEMPA 7265 D R A W	20 mol/day	0.16	2.42	7.58	10.58	12.26	17.09	16.91	15.06	9.24	4.68	0.69	0
Level 4	TEMPA 6360 FR	26 mol/day	0	0.15	2.85	8.71	9.5	16.29	14.93	10.93	3.03	0.62	0	0
Level 5	TEMPA 7965 R FR AG	14 mol/day	4.36	7.84	13.62	14.52	18.19	19.02	21	20.35	17.4	11.89	5.5	1.8



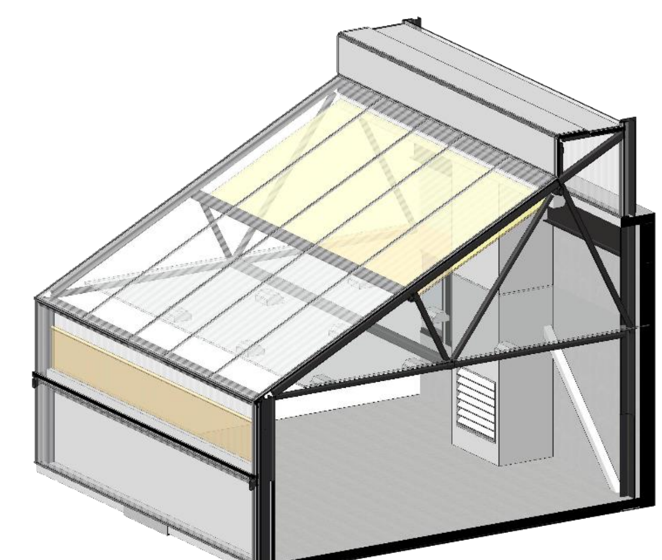
Sloped Shade – The section to the left describes the track mounted shade system. The section is taken through one of the trusses on either side of the module to show how the shades come together creating an air tight seal. The aluminum shade track is mounted on the underside of the steel truss and runs the length of the truss. An air gap is created between the taught shade cloth and the polycarbonate glazing across the entire module. This is beneficial for heat retention and greenhouse cooling, insulating the greenhouse in both scenarios.

The shade system will deploy from the rear of the greenhouse to eliminate shading while rolled up.

Vertical Shade – The front shade will use a similar track system to the sloped shade, however the track will be mounted to the steel column and vertical mullion on either end of the module.

The vertical shade will deploy from the bottom up to eliminate shading while not in use. Both the sloped shade and vertical shade have an aluminum housing with a roller and motor attached.

Shade Motor – (2) Ridder – RW45 motors will be used per greenhouse to move the shade system. Each motor can handle the loads of the 6 module's shades, one for the vertical and one for the slope.



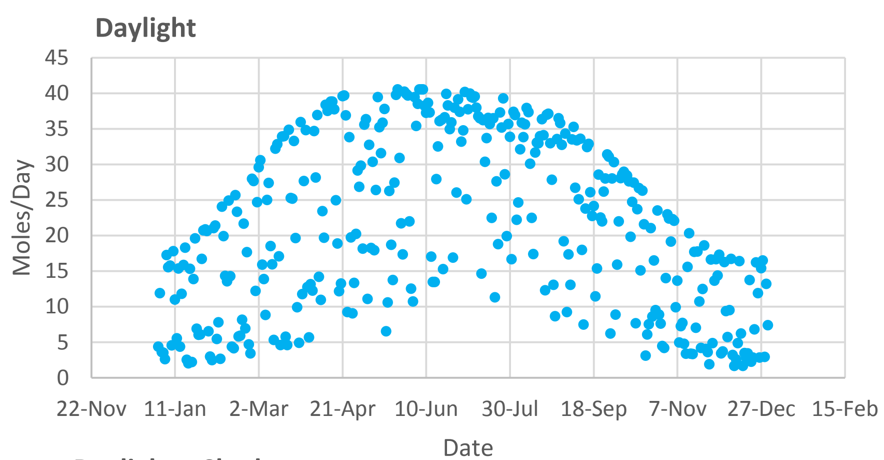
Appendix G: Greenhouse Optimization

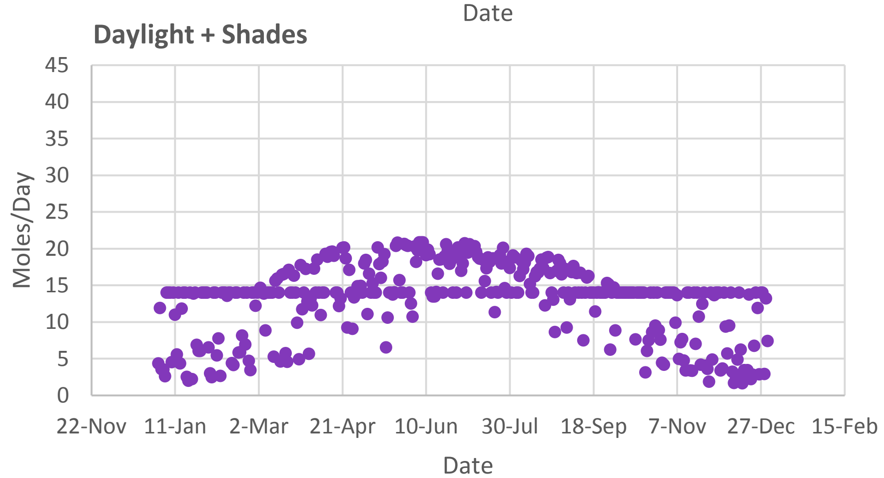
The graphs below plot the DLI measured each day over the course of one year. The effect of shades and grow lights help bring the growing environment to their respective optimal conditions.

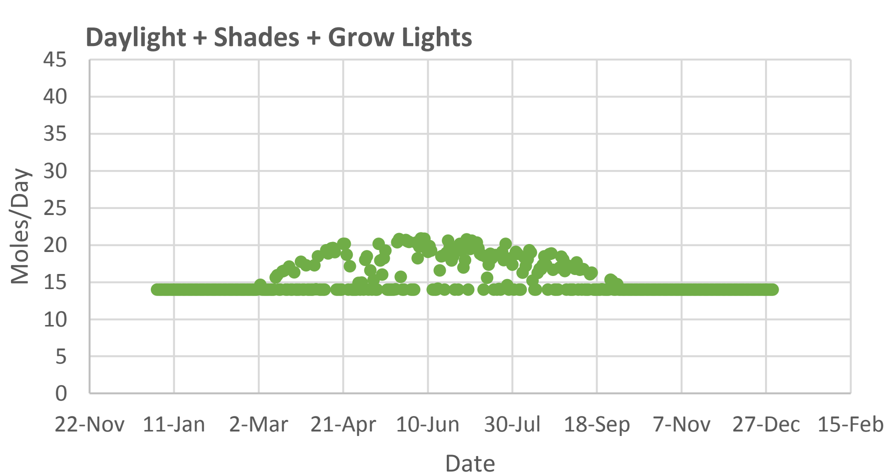
Level 2 & 5 Greenhouse Annual Performance Data	
Target DLI	14 mol/day
Hours grow lights are in operation	1379 Hours/Year
Percentage of the year grow lights on	15.7% of the Year
Number of Days that meet exact target	244 / 365
Percentage of the year that meets target	67%

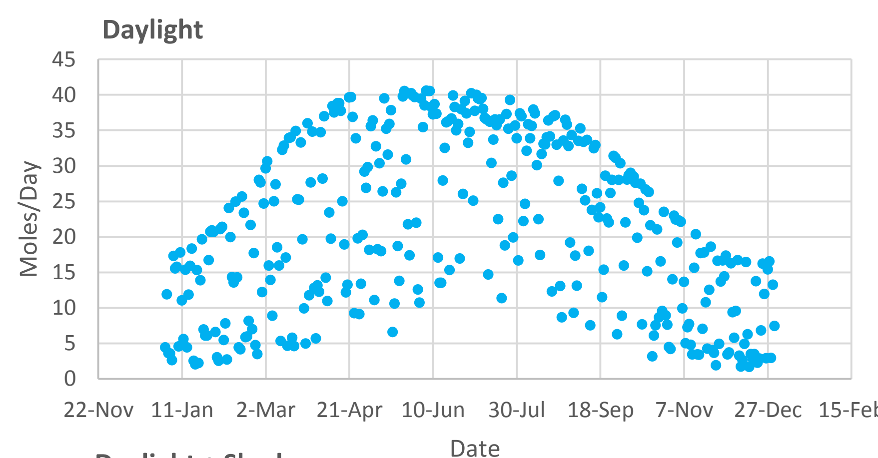
Level 3 Greenhouse Annual Performance Data	
Target DLI	20 mol/day
Hours grow lights are in operation	2725 Hours/Year
Percentage of the year grow lights on	31.1% of the Year
Number of Days that meet exact target	248 / 365
Percentage of the year that meets target	68%

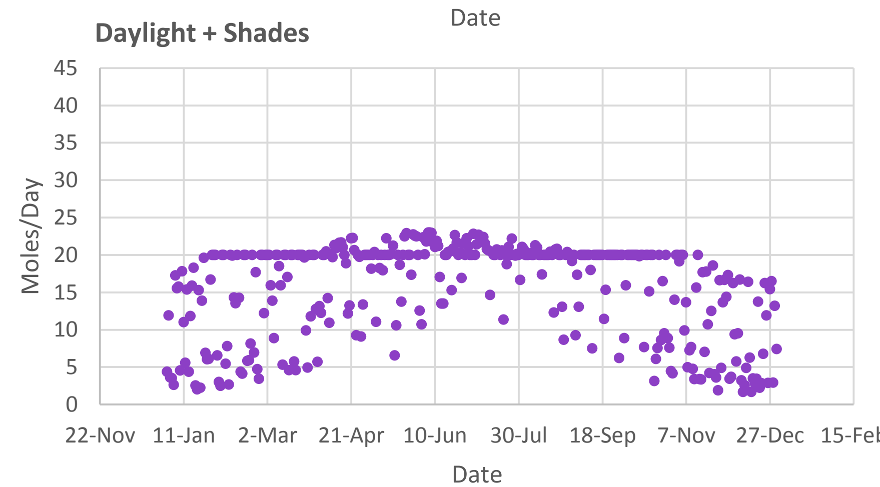
Level 4 Greenhouse Annual Performance Data	
Target DLI	26 mol/day
Hours grow lights are in operation	3998 Hours/Year
Percentage of the year grow lights on	45.6% of the year
Number of Days that meet exact target	194 / 365
Percentage of the year that meets target	53%

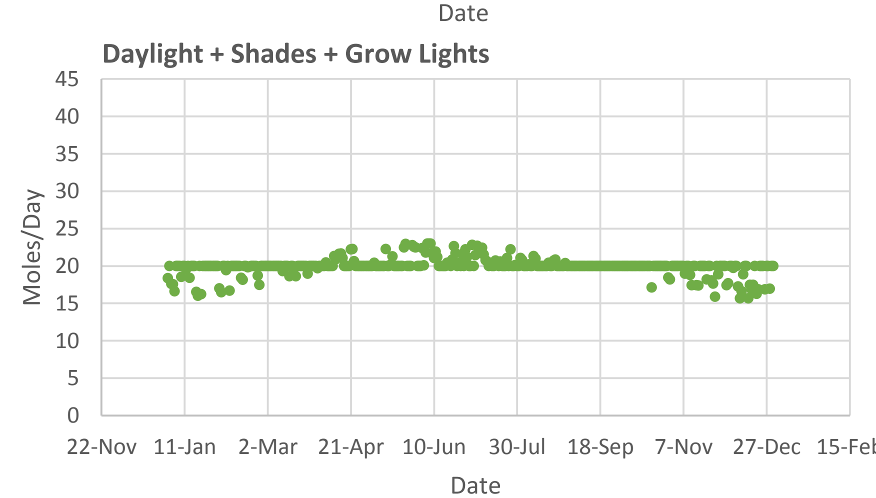


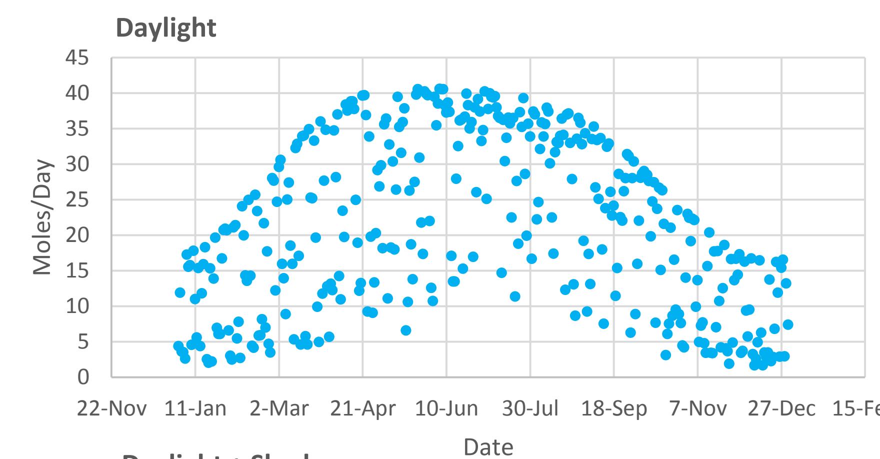


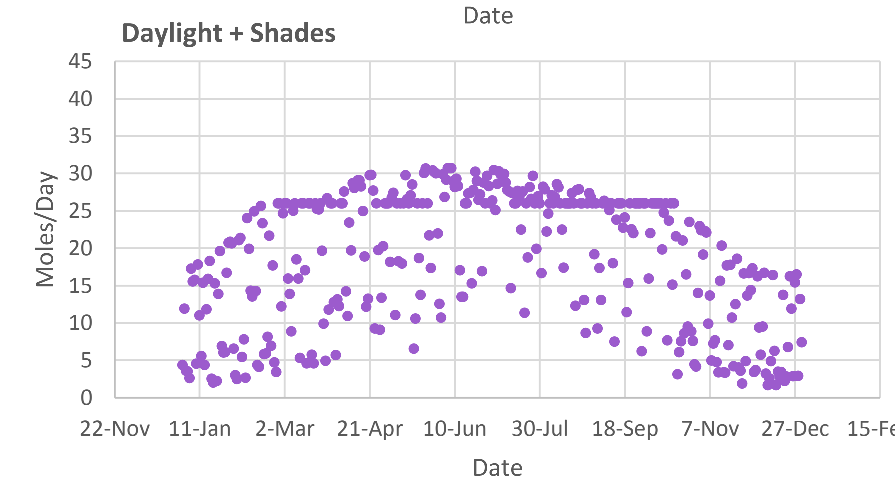


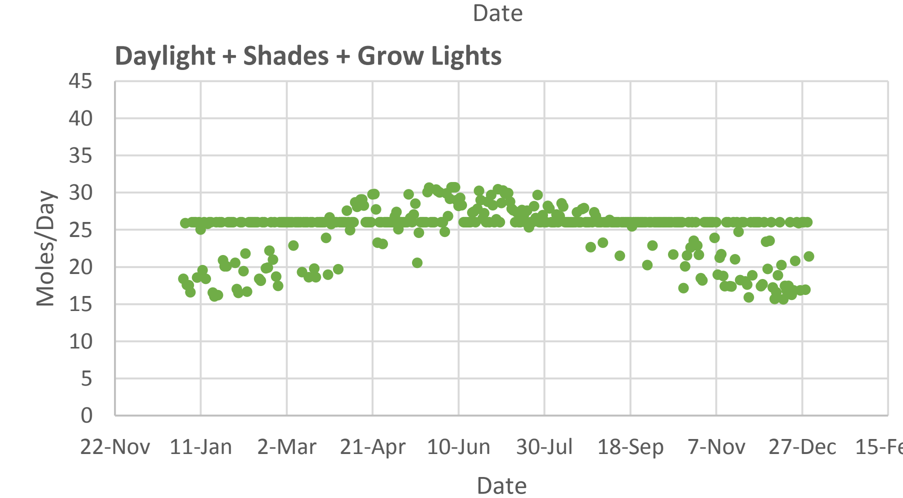










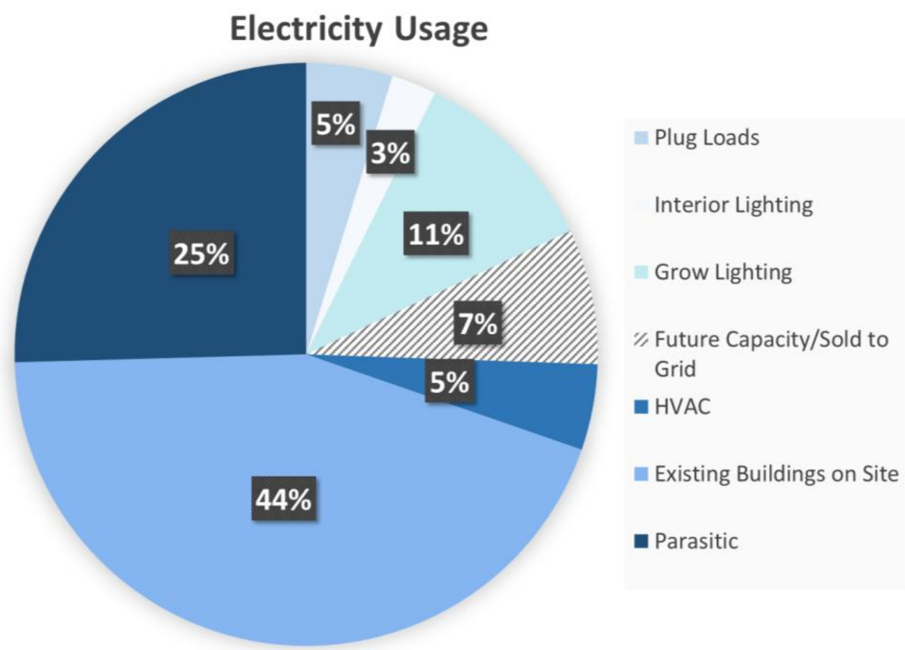


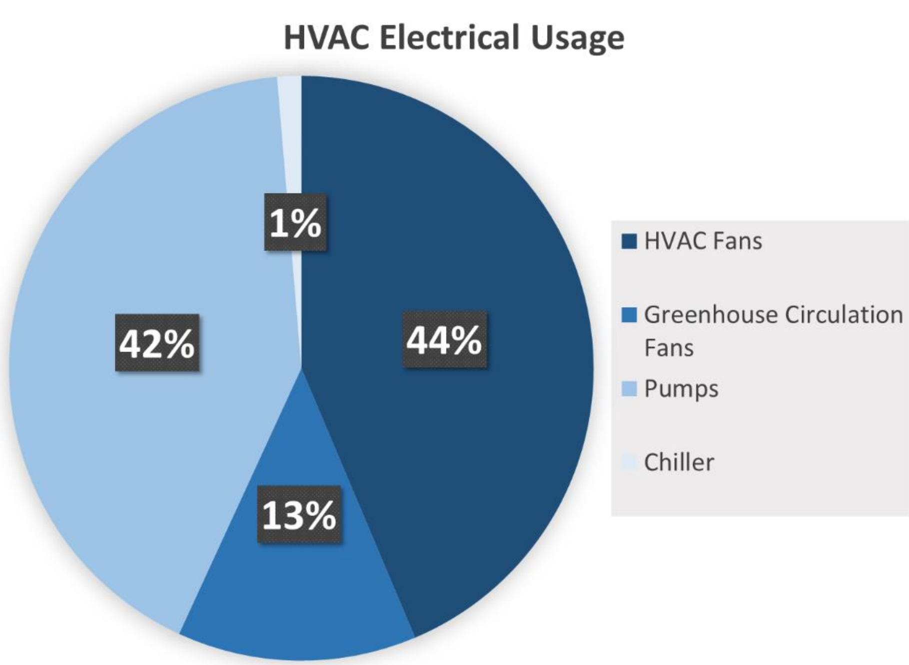
Appendix H: Energy Usage

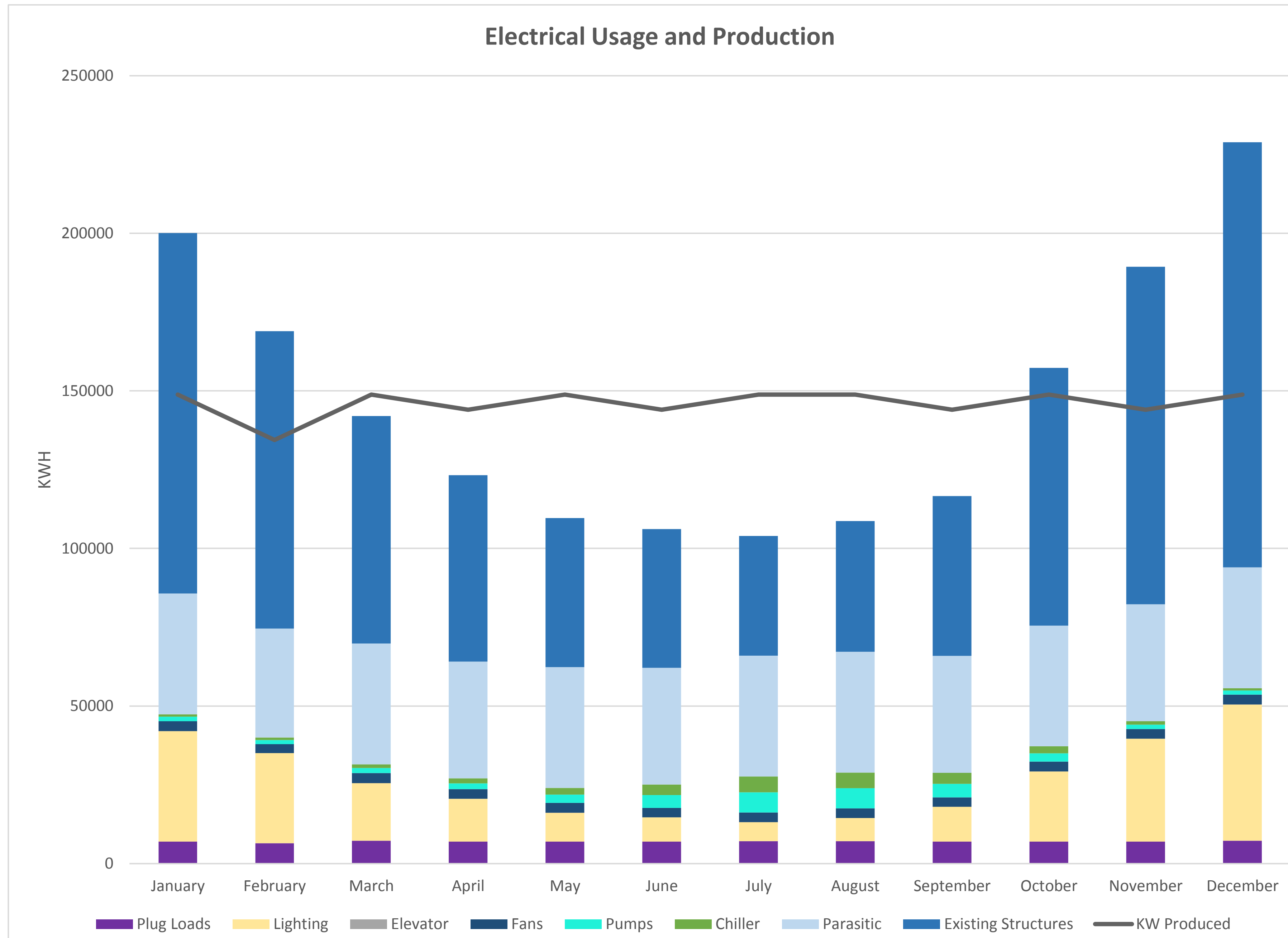
The electrical usage on the Growing Power site is **1,774,000 KWH** from the microturbine each year. Growing Power will use **1,640,940 KWH** each year on the entire Milwaukee site. This usage includes an estimate that was made by the Synthesis team for the usage of Growing Power's existing facilities which include their four large greenhouses and head house. This means that as a whole Growing Power will be producing more power than it uses, making the building **108% Net Zero**.

The Graphs below detail the energy usage for the Growing Power site. The Electricity Usage and HVAC Usage pie charts on the left side of the page detail the usage over an entire typical year. The bar graph directly below illustrates the electrical usage per month by category. There is also a gray line that fluctuates just below 150,000 KWH each month. This line indicated the amount of power produced on site.

When the bar graphs are below that line, Growing Power will be producing more power than it uses. When the bar graph exceeds the production line, it indicated that Growing Power will be buying energy from the grid in these months. Due to the nature of the Vertical Farm and the heavy reliance on grow lighting in the winter time, the graph looks much different than traditional buildings.

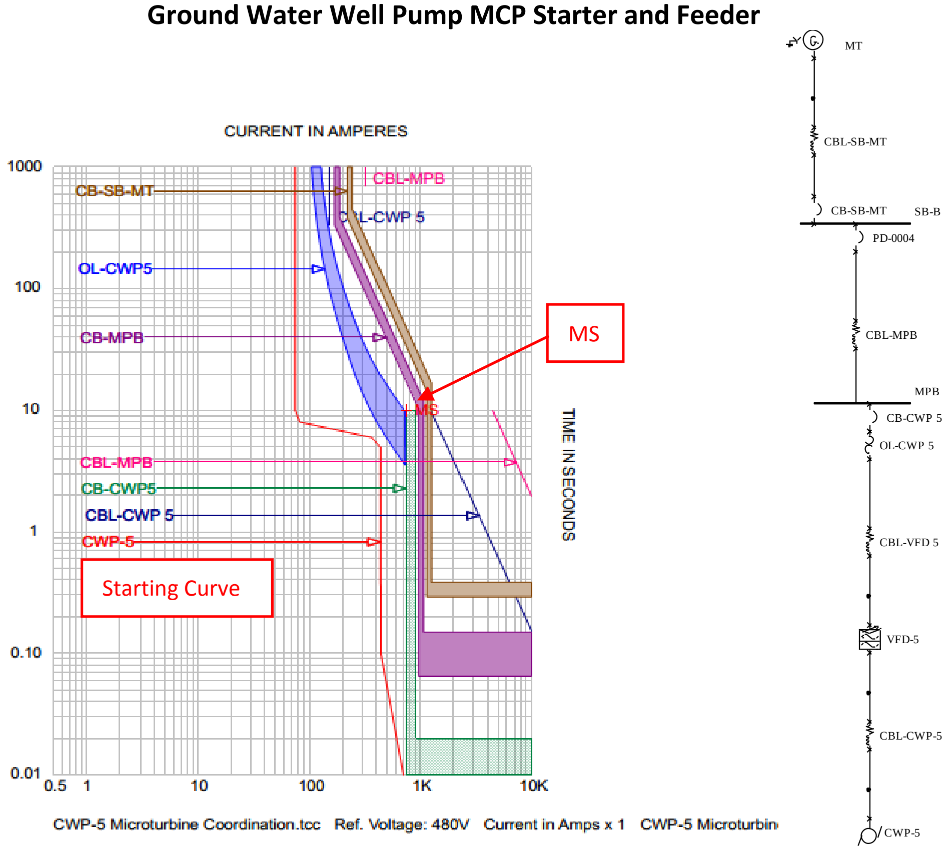




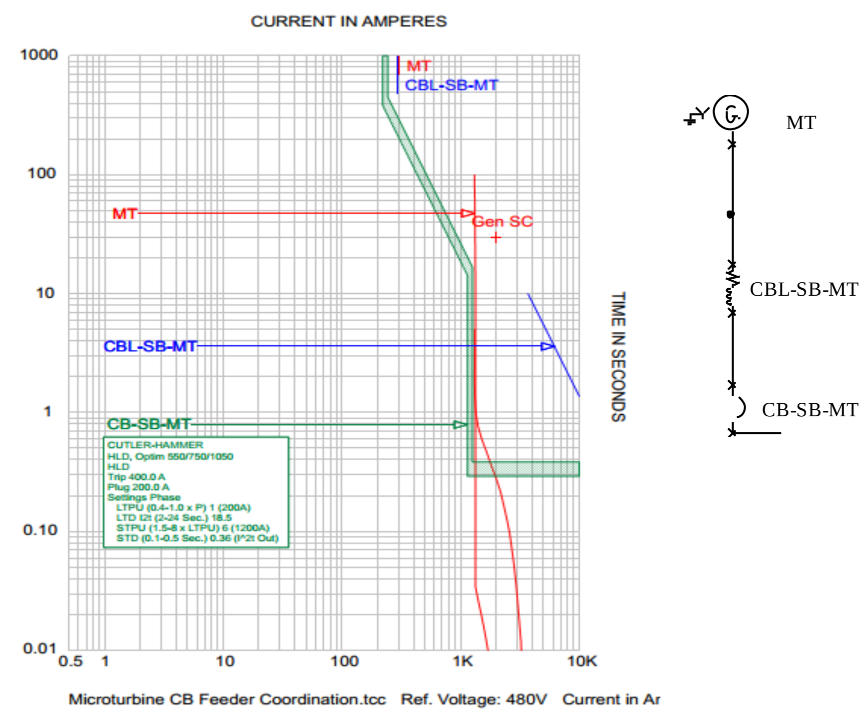


Over current protection of key components and loads of the electrical system...

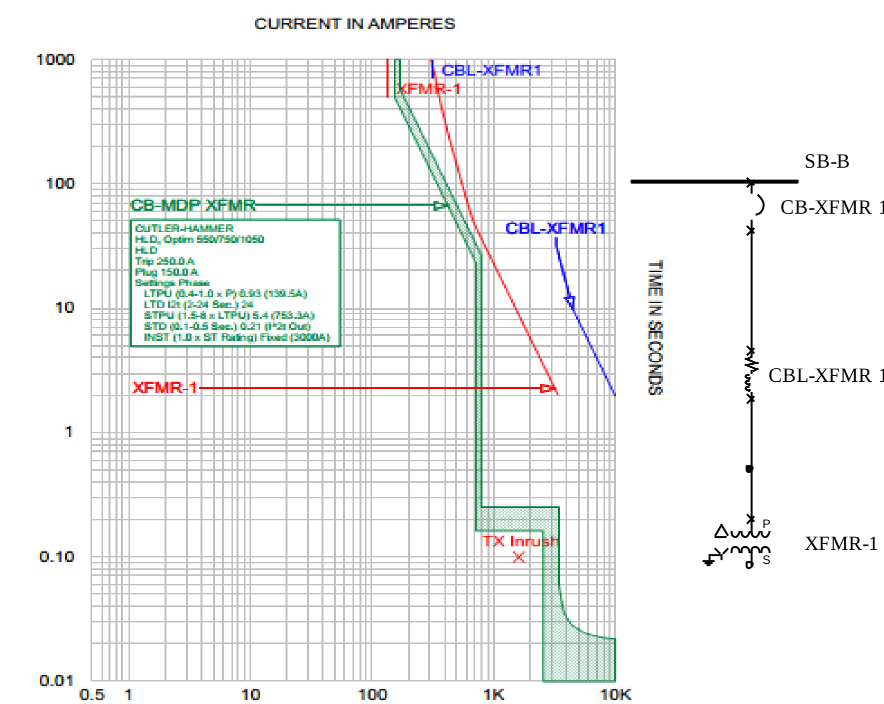
Ground Water Well Pump MCP Starter and Feeder



Microturbine (MT) Molded Case Circuit Breaker and Feeder



Transformer Circuit Breaker and Feeder



Motor Overload Protection:		
Function	Design Criteria	
Pickup	125% of FLA if SF≥1.15 115% of FLA if SF=1.00	Set below feeder ampacity
Time Dial	Fixed (Class 20)	Below MS (motor safe stall point)
CWP-5 Circuit Breaker:		
Size to:	125-160% of FLA	Below feeder damage curve
Pickup	200% LRA Coordinated w/ inrush	Feeder damage curve must be above max fault current and inst. clear curve

Microturbine Main Switchboard Circuit Breaker:		
Function	**Design Criteria**	
Long Time Pickup	125% of FLA	Set below feeder ampacity
LTD, STPU & STD	Minimum	Set to intersect with MT decrement curve
I^2T	Out	The breaker may never trip if set to I^2T in
INST	Above MT decrement curve	Below cable damage curve

Transformer Circuit Breaker:		
Function	**Design Criteria**	
Long Time Pickup	100-125% FLA	Below transformer damage curve Below cable ampacity
LTD, STPU & STD	Set to coordinate downstream	Set below transformer damage curve
INST	200% of inrush	Below cable damage curve Cable damage curve must be above the maximum fault current at the CB total clear curve

Synthesis
Engineering for Architecture

Arc Flash Analysis

Bus Name	Bus kV	Bus Bolted Fault	Bus Arcing Fault (kA)	Prot. Dev. Bolted Fault (kA)	Prot. Dev. Arcing Fault (kA)	Trip/Delay Time (sec.)	Breaker Opening Time/Tol (sec.)	Ground	Equip. Type	Gap (mm)	Arc Flash Boundary (in)	Working (in)	PPE Level	Label #
DP-1	0.208	2.78	1.77	2.78	1.77	0.14	0	N	PNL	25	4	18	CAT 0	#0005
DP-2	0.208	2.78	1.77	2.78	1.77	0.14	0	N	PNL	25	4	18	CAT 0	#0005
DP-3	0.208	2.78	1.77	2.78	1.77	0.14	0	N	PNL	25	4	18	CAT 0	#0005
DP-4	0.208	2.78	1.77	2.78	1.77	0.14	0	N	PNL	25	4	18	CAT 0	#0005
DP-B	0.208	172.91	172.91	171.69	171.69	0.15	0	N	PNL	25	19	18	CAT 1	#0005
GHP-2	0.48	5.64	3.42	1.99	1.21	2	0	Y	PNL	25	74	18	CAT 3	#0006
GHP-3	0.48	5.64	3.42	1.99	1.21	2	0	Y	PNL	25	74	18	CAT 3	#0006
GHP-4	0.48	5.64	3.42	1.99	1.21	2	0	Y	PNL	25	74	18	CAT 3	#0006
GHP-5	0.48	5.64	3.42	1.99	1.21	2	0	Y	PNL	25	74	18	CAT 3	#0006
MDP	0.208	10.36	4.46	8.8	3.79	0.01	0	N	PNL	25	6	18	CAT 0	#0010
MP-B	0.48	5.57	3.98	3.47	2.48	0.15	0	Y	PNL	25	18	18	CAT 1	#0011
SB-B	0.48	5.71	3.46	2	1.21	2	0	Y	PNL	25	74	18	CAT 3	#0012

WARNING
Arc Flash and Shock Hazard
Appropriate PPE Required

74 in	Flash Hazard Boundary
12 cal/cm^2	Flash Hazard at 18 in
Category 3	Arc-rated shirt & pants + arc-rated coverall + arc-rated arc flash suit
480 VAC	Shock Hazard when cover is removed
00	Glove Class
42 in	Limited Approach
12 in	Restricted Approach
1 in	Prohibited Approach

3

Location: SB-B
Synthesis Engineering
AEI Student Design Competition
Team#: 04-2015 Submitted: 02/11/15 By: Engineer
Warning: Changes in equipment settings or system configuration will invalidate the calculated values and PPE requirements

WARNING
Arc Flash and Shock Hazard
Appropriate PPE Required

4 in	Flash Hazard Boundary
0.09 cal/cm^2	Flash Hazard at 18 in
Category 0	Nonmelting or Untreated Fiber with Weight >= 4.5 oz/sq yd
208 VAC	Shock Hazard when cover is removed
00	Glove Class
42 in	Limited Approach
Avoid Contact	Restricted Approach
Avoid Contact	Prohibited Approach

0

Location: DP-1
Synthesis Engineering
AEI Student Design Competition
Team#: 04-2015 Submitted: 02/11/15 By: Engineer
Warning: Changes in equipment settings or system configuration will invalidate the calculated values and PPE requirements

WARNING
Arc Flash and Shock Hazard
Appropriate PPE Required

19 in	Flash Hazard Boundary
1.3 cal/cm^2	Flash Hazard at 18 in
Category 1	Arc-rated shirt & pants or arc-rated coverall
208 VAC	Shock Hazard when cover is removed
00	Glove Class
42 in	Limited Approach
Avoid Contact	Restricted Approach
Avoid Contact	Prohibited Approach

1

Location: DP-B
Synthesis Engineering
AEI Student Design Competition
Team#: 04-2015 Submitted: 02/11/15 By: Engineer
Warning: Changes in equipment settings or system configuration will invalidate the calculated values and PPE requirements

WARNING
Arc Flash and Shock Hazard
Appropriate PPE Required

74 in	Flash Hazard Boundary
12 cal/cm^2	Flash Hazard at 18 in
Category 3	Arc-rated shirt & pants + arc-rated coverall + arc-rated arc flash suit
480 VAC	Shock Hazard when cover is removed
00	Glove Class
42 in	Limited Approach
12 in	Restricted Approach
1 in	Prohibited Approach

3

Location: GHP-5
Synthesis Engineering
AEI Student Design Competition
Team#: 04-2015 Submitted: 02/11/15 By: Engineer
Warning: Changes in equipment settings or system configuration will invalidate the calculated values and PPE requirements

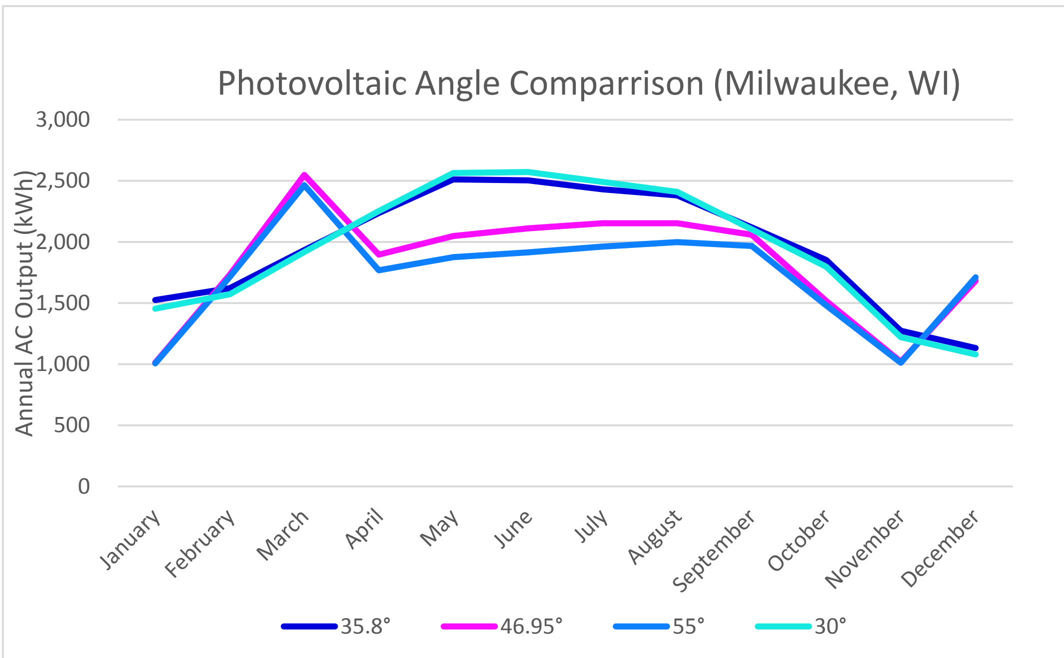
Appendix J: Lighting Power Density

SYNTHESIS LIGHTING CRITERIA										
Space Type	#		Area (ft²)	Ave. Illuminance (lx)		LPD (W/ft²)		Total Power (W)		%Better Than
		Space Type		Goal	Designed	Goal	Designed	Goal	Designed	T-24/ASHRAE
Whole Building (No Greenhouses)			46,628				**0.39**		18048.2	
Whole Building (Greenhouses)			57,857				**1.71**		98973.2	
Growing Area 1	1	**GREENHOUSES**	2375	*See PAR*	-	*10.00*	*7.39*	*23750.00*	*17550*	*26%*
Growing Area 2	1		2401	*See PAR*	-	*10.00*	*7.31*	*24010.00*	*17550*	*27%*
Growing Area 3	1		2409	*See PAR*	-	*10.00*	*7.29*	*24090.00*	*17550*	*27%*
Growing Area 4	1		4044	*See PAR*	-	*10.00*	*6.99*	*40440.00*	*28275*	*30%*
Storage 1 - Basement	1	**INDUSTRIAL**	3450	*100*	130	*0.60*	*0.10*	*2070.00*	*352*	*83%*
Storage 2 - Basement	1		2381	*100*	130	*0.60*	*0.12*	*1428.60*	*288*	*80%*
Processing Area (Low Bay)	1		1372	*300*	356	*0.90*	*0.16*	*1234.80*	*224*	*82%*
Shipping/Receiving (Low Bay)	1		1154	*300*	324	*0.90*	*0.25*	*1038.60*	*288*	*72%*
Workshop	1	**VOLUNTEER**	864	*100*	110	*0.90*	*0.35*	*777.60*	*298.96*	*62%*
Mud room	1		174	*200*	274	*0.60*	*0.28*	*104.40*	*49*	*53%*
Showers/Lockers	2		414	*200*	215	*0.75*	*0.47*	*621.00*	*390*	*37%*
Break Area	1		481	*100*	127	*0.73*	*0.24*	*351.13*	*113.5*	*68%*
Market - Cashier		**RETAIL**		*200*	230					
Market - Retail	1		3421	*500*	560	*1.20*	*0.31*	*4105.20*	*1053.38*	*74%*
Market - Circulation				*200*	180					
Vestibule	1		100	*20*	50	*0.60*	*0.25*	*60.00*	*24.5*	*59%*
Restrooms (2)	2		222	*200*	232	*0.60*	*0.44*	*266.40*	*194*	*27%*
Office (2)	2		100	*300*	350	*1.00*	*0.48*	*200.00*	*96*	*52%*
Gathering Area	1	**CONFERENCE/ EDUCATION**	3722	*300*	356	*1.23*	*0.41*	*4578.06*	*1519.44*	*67%*
Break-Out	1		1239	*100*	254	*0.73*	*0.39*	*904.47*	*480*	*47%*
Restrooms	2		195	*200*	195	*0.60*	*0.50*	*234.00*	*194*	*17%*
Classrooms (2) w/ comp.'s	2		1120	*300*	400	*1.20*	*0.46*	*2688.00*	*1039.44*	*61%*
Classroom	1		441	*300*	400	*1.20*	*0.70*	*529.20*	*309.72*	*41%*
Storage Areas	1		345	*100*	132	*0.60*	*0.32*	*207.00*	*112.11*	*46%*
Incubator Reception	1		344	*300*	392	*1.10*	*0.38*	*378.40*	*132*	*65%*
Incubator Office (2)	2		117	*300*	405	*1.00*	*0.41*	*234.00*	*96*	*59%*
Demo Kitchen	1		650	*400*	455	*0.99*	*0.84*	*643.50*	*548*	*15%*
Open Office	1	**STAFF/OFFICE**	753	*300*	368	*0.75*	*0.46*	*564.75*	*348*	*38%*
Director	1		308	*300*	312	*0.75*	*0.45*	*231.00*	*139.21*	*40%*
Meeting room	1		375	*300*	365	*1.23*	*0.55*	*461.25*	*207*	*55%*
Reception - Desk	1		345	*300*	358	*0.73*	*0.32*	*251.85*	*109*	*57%*
Reception - Waiting				*300*	332					
Copy	1		139	*300*	378	*0.60*	*0.35*	*83.40*	*48*	*42%*
Restroom (2)	2		182	*200*	225	*0.60*	*0.53*	*218.40*	*194*	*11%*
Lounge	1		298	*100*	126	*0.73*	*0.37*	*217.54*	*109*	*50%*
Stairs	15	**SUPPORT**	234	*100*	95	*0.60*	*0.08*	*2106.00*	*295.2*	*86%*
Electrical	6		77	*100*	130	*0.60*	*0.32*	*277.20*	*147*	*47%*
Corridor B	1		2751	*100*	120	*0.60*	*0.10*	*1650.60*	*280.5*	*83%*
Corridor 1	1		1217	*100*	107	*0.60*	*0.24*	*730.20*	*291*	*60%*
Corridor 2	1		2733	*100*	108	*0.60*	*0.15*	*1639.80*	*414.5*	*75%*
Corridor 3	1		2533	*100*	111	*0.60*	*0.19*	*1519.80*	*488*	*68%*
Corridor 4	1		1232	*100*	108	*0.60*	*0.30*	*739.20*	*365.5*	*51%*
Elevator Lobby	1		1172	*150*	200	*0.60*	*0.32*	*703.20*	*376*	*47%*

0.39 W/ft²

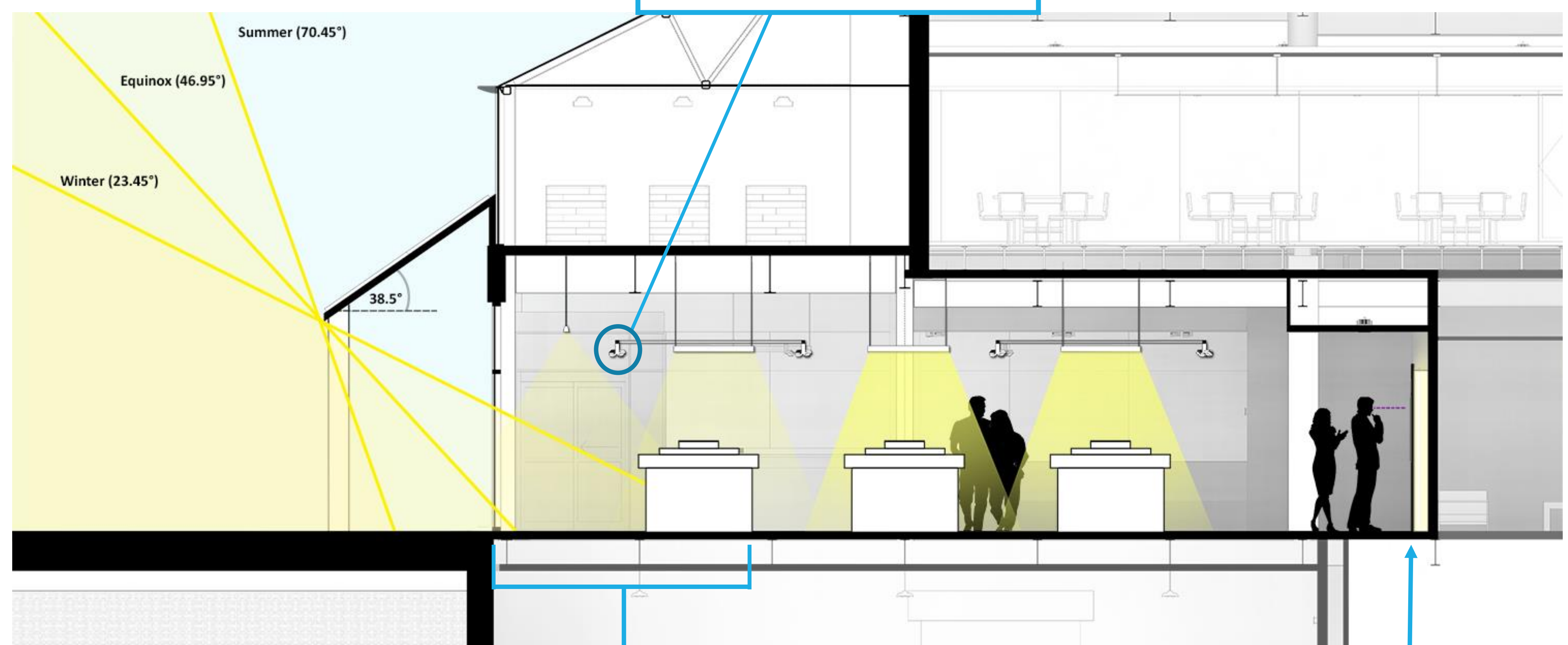
Whole Building Lighting Power Density

This design beats Titles 24 and ASHRAE by 15%, making it adaptable to almost any location nationwide. It should also be noted that many local jurisdictions require the space by space method, therefore this design would need to be evaluated by the space by space lighting power densities.



The PV array awning depth was optimized for minimal summer solar heat gain and useful winter solar heat gain. The tilt of the PV array was optimized for annual yield

Track mounted fixtures are remotely controlled through ELV dimming



8'-6" deep PV overhang only admits direct sun into the market through 60% VT glazing during winter months to minimize heating load

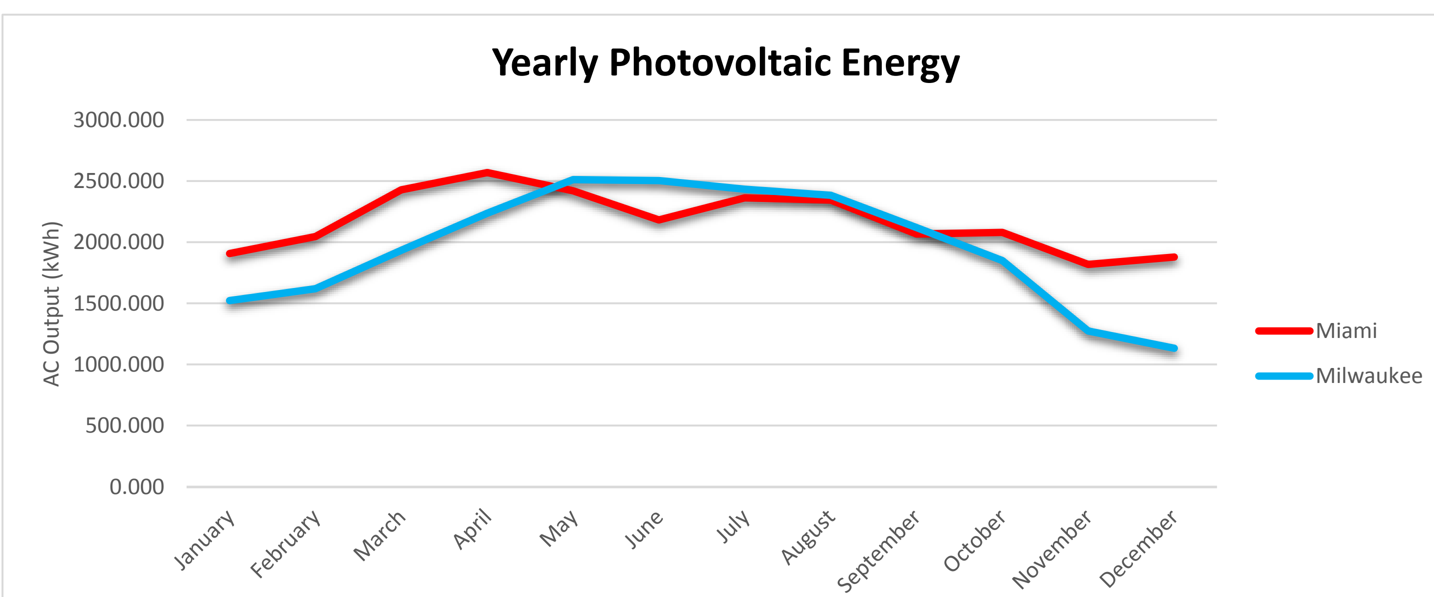
Daylight Controlled Zone: All lighting (except track fixtures) within 20' from southern glazing

Building Education Dashboard: Displays real time building data & statistics

Ex: "1,524 kWh solar energy used in January. Equivalent to 436 loads of laundry"*

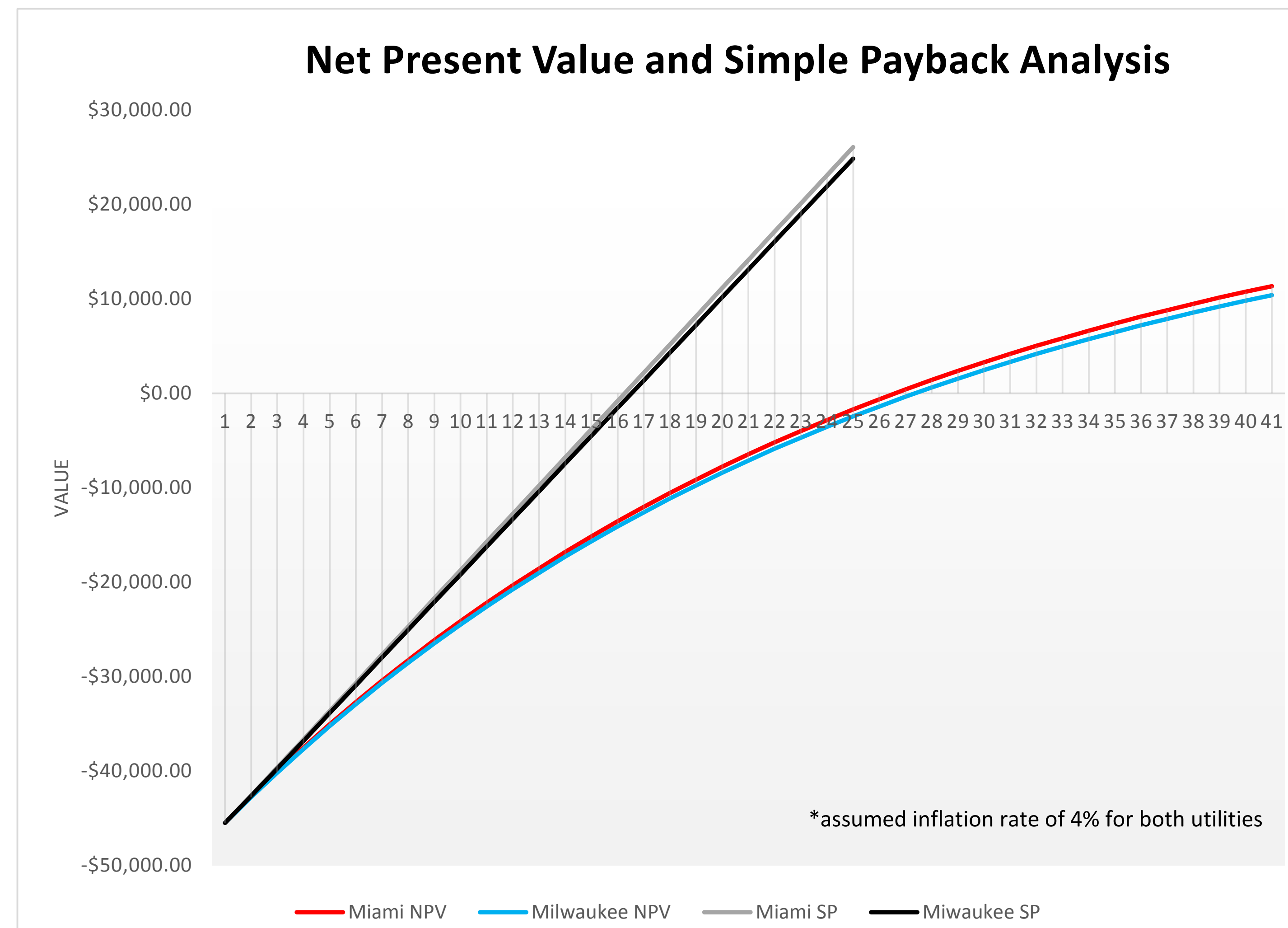
Milwaukee Annual Solar Energy Usage					
Month	Solar Radiation (kWh/m²/day)	Irradiance (W/m²)	DC array Output (kWh)	AC System Output (kWh)	Value ($)
January	3.089	95.771	1,596.729	1,524.093	182.89
February	3.768	105.493	1,697.065	1,621.080	194.53
March	4.180	129.589	2,024.434	1,933.717	232.05
April	5.213	156.388	2,342.400	2,237.424	268.49
May	5.794	179.617	2,628.759	2,512.382	301.49
June	6.169	185.057	2,621.715	2,504.875	300.58
July	5.910	183.220	2,547.167	2,432.299	291.88
August	5.744	178.072	2,492.371	2,382.633	285.92
September	5.191	155.728	2,218.421	2,120.678	254.48
October	4.233	131.221	1,937.196	1,851.203	222.14
November	2.850	85.486	1,338.252	1,273.260	152.79
December	2.334	72.344	1,192.151	1,132.268	135.87
Total	54.475	1,657.99	24,636.66	23,525.91	**$ 2,823.11**

Miami Annual Solar Energy Usage					
Month	Solar Radiation (kWh/m²/day)	Irradiance (W/m²)	DC array Output (kWh)	AC System Output(kWh)	Value ($)
January	4.416	136.906	1992.302	1906.897	209.76
February	5.266	147.461	2137.648	2047.621	225.24
March	5.652	175.202	2536.851	2428.354	267.12
April	6.278	188.330	2681.470	2569.056	282.60
May	5.797	179.720	2530.619	2420.783	266.29
June	5.438	163.131	2283.908	2183.186	240.15
July	5.693	176.492	2470.451	2363.254	259.96
August	5.640	174.841	2447.745	2343.354	257.77
September	5.172	155.148	2162.054	2067.514	227.43
October	4.963	153.859	2173.380	2079.978	228.80
November	4.384	131.511	1902.388	1818.532	200.04
December	4.330	134.235	1964.406	1880.019	206.80
Total	63.029	1,+16.836	27,283.220	26,108.546	**$ 2,871.94**

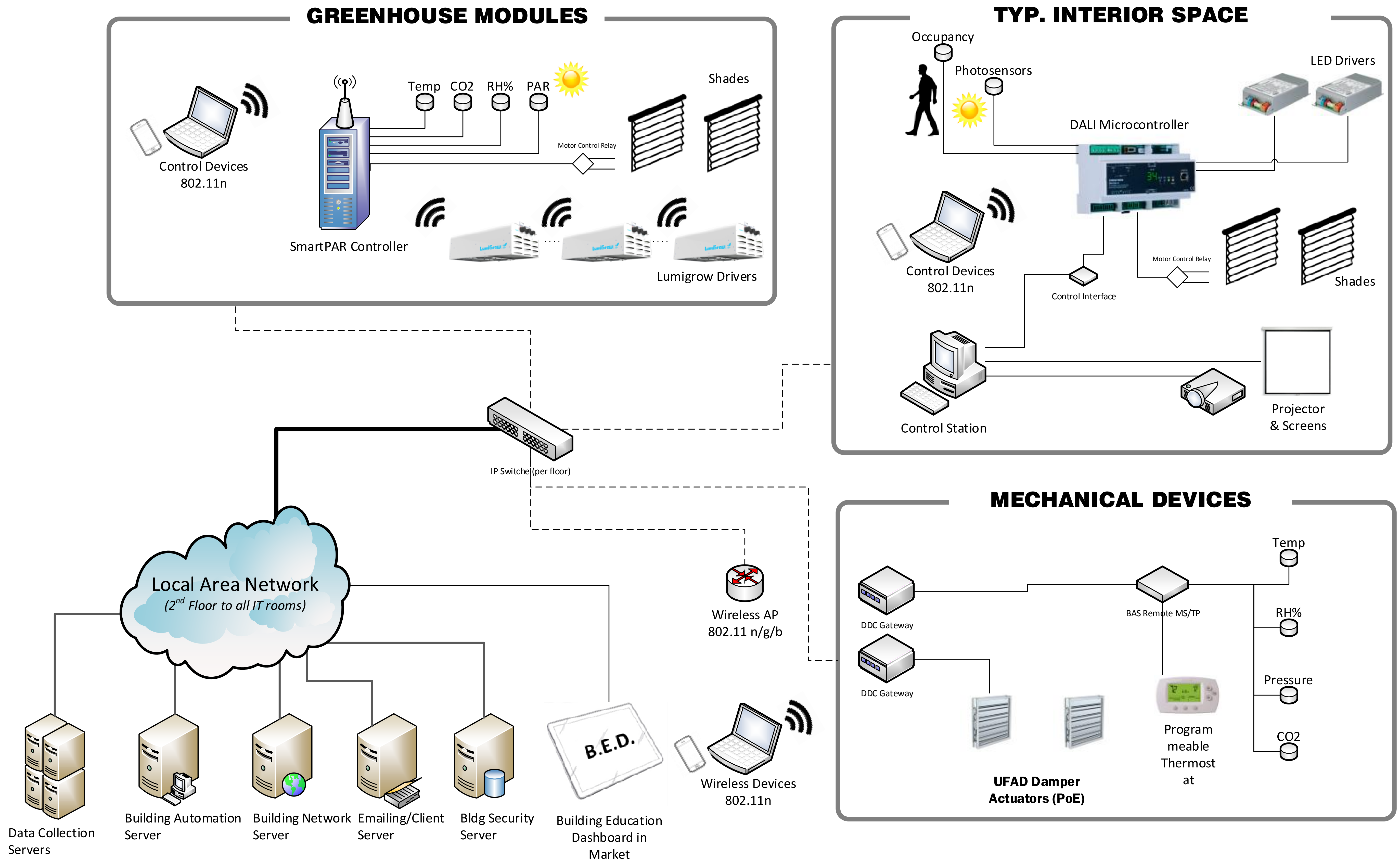


Initial photovoltaic studies and research showed that, no matter the size, a 15-17 year payback was an adequate assumption for payback in Milwaukee. For this reason, Synthesis designed the PV awning as both a shading feature for the market and a way to advertise the sustainability of Growing Power to the community. Solar radiation was evaluated using PV Watts (typical PV parameters), local weather data, and IES Virtual Environment for analysis. After tilt angle was optimized for both Milwaukee and Miami locations, a simple payback and present value analysis were done in order to calculate the return on investment. Utility rates used were from WE Energies (Milwaukee) and Florida Power & Light (Miami). The initial cost was kept the same at $2.6 /W DC. The NPV and simple payback studies are shown below. Simple payback stayed within the assumptions, while the net present value does not break even until 26 years.

Growing Power should be aware of the potential payback period for the PV array. Renewable energy and education are both important focuses of the Vertical Farm. Their biggest benefit will be during winter months when grow lighting is being used in the greenhouses. An increase in angle will provide more direct solar irradiance during winter months and therefore more power, however a much lower annual yield and much longer payback. Therefore, Growing Power must optimize its PV array for the maximum annual yield in order to minimize payback and benefit from any rates at which they could sell power back to the utility grid.



Control Narrative by Space Type																			
Space Type	Floor	Manual On/Off	Override Dimming	Occupancy	Vacancy	DALI Scene Control	Photosensor Dimming (2 zone)	Photosensor Dimming (3 zone)	Photosensor Shade	DALI Shade	Time Clock Sweep	Elevator RFID Access	Receptacle Relay	Branch Circuit	Spectrum Tuning	GH Shades	PAR Diming	Description
Greenhouses	2-5	✓										✓	✓		✓	✓	✓	SmartPAR control unit will extrapolate DLI for the day based on weather data and quantum PAR sensors. Shades and grow lighting will activate or be tuned accordingly.
Basement General	B	✓		✓								✓	✓	✓				Lights and Receptacles will always be controlled from a 20 min delay occupancy sensor
Basement Storage	B	✓		✓								✓	✓	✓				Lights and Receptacles will always be controlled from a 20 min delay occupancy sensor
Processing/Shipping/Receiving	1	✓	✓	✓			✓				✓		✓	✓				Lighting controlled via 20 minute delay occupancy sensor. Time clock will allow receptacles to be active during business hours (8am-5pm). Receptacles will be switched via 20 minute occupancy control relay (5pm-8am).
Volunteer Areas	1	✓		✓									✓	✓				Lights and Receptacles will always be controlled from a 20 min high sensitivity occupancy sensor
Market	1	✓	✓			✓	✓				✓		✓	✓				Lights and receptacles will be controlled via time clock. 8:00 am the lights and receptacles will turn on and be controlled via photosensors and override dimming. 5:00 pm the lights and receptacles will turn off unless overridden by a manual on/off switch.
Gathering/Break-Out	2	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓				Lights will function on DALI occupancy (auto on/off) sensors at all times via DALI bus. Time clock will allow receptacles to be active during business hours (8am-5pm). Receptacles will be switched via 20 minute occupancy control relay (5pm-8am). Photosensor algorithm will control lighting within corresponding dimmed zone for daylight harvesting.
Classrooms	3	✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓				Lighting will be controlled via high sensitivity 20 min vacancy (manual on/ auto off) sensors at all times via DALI bus. Time clock will allow receptacles to be active during business hours (8am-5pm). Receptacles will be switched via 20 minute occupancy control relay (5pm-8am). Photosensor algorithm will control lighting within corresponding dimmed zone for daylight harvesting.
Small Offices	3-4	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓				Lighting will be controlled via high sensitivity 20 min occupancy sensors at all times. Time clock will allow receptacles to be active during business hours (8am-5pm). Receptacles will be switched via 20 minute occupancy control relay (5pm-8am). Photosensor algorithm will control lighting within corresponding dimmed zone for daylight harvesting.
Demo Kitchen	3	✓	✓	✓							✓	✓	✓	✓				Lighting will be controlled via high sensitivity 20 min occupancy sensor at all times. Receptacles will be active during business hours and will be switched via time clock to occupancy control after hours.
Open Offices	4	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓				Lighting will be controlled via high sensitivity 20 min occupancy sensors at all times. Time clock will allow receptacles to be active during business hours (8am-5pm). Receptacles will be switched via 20 minute occupancy control relay (5pm-8am). Photosensor algorithm will control lighting within corresponding dimmed zone for daylight harvesting.
Stairs	All	✓	✓	✓														Lighting controlled via 5 min high sensitivity occupancy sensor at all times.
Restrooms	All	✓		✓			✓				✓		✓	✓				Lighting controlled via 5 min high sensitivity occupancy sensor at all times.
Corridors	All	✓		✓				✓	✓		✓	✓	✓	✓				Lighting controlled via 5 min high sensitivity occupancy sensor at all times.
Workshop/Storage	1	✓			✓						✓		✓	✓				Lighting controlled via 5 min high sensitivity vacancy sensor at all times.


GREENHOUSE MODULES
Control Devices
802.11n
Temp
CO2
RH%
PAR
Shades
Motor Control Relay
SmartPAR Controller
Lumigrow Drivers
TYP. INTERIOR SPACE
Occupancy
Photosensors
LED Drivers
DALI Microcontroller
Control Devices
802.11n
Control Interface
Motor Control Relay
Shades
Control Station
Projector
& Screens
IP Switches (per floor)
Local Area Network
(2nd Floor to all IT rooms)
Wireless AP
802.11 n/g/b
MECHANICAL DEVICES
Temp
DDC Gateway
BAS Remote MS/TP
RH%
DDC Gateway
Pressure
CO2
Program
meable
Thermost
at
UFAD Damper
Actuators (PoE)
Data Collection
Servers
Building Automation
Server
Building Network
Server
Emailing/Client
Server
Bldg Security
Server
B.E.D.
Building Education
Dashboard in
Market
Wireless Devices
802.11n

Levels of SMART Building Integration

	System	Plain Vanilla	Level One	Level Two	Level Three	Level Four
		No Integration	Shared Building Network - and - Building Systems Exchange Data	Converged Network and Building Systems Exchange Data with User Applications	Single, Normalized Database collecting from every system	Meta-level Applications leveraging Normalized Database information for trend analysis, automation, etc…
	System	Stand Alone Systems	Data Exchange Info	Data Exchange Info	Data Exchange Info	Data Exchange Info
Building Systems	Greenhouse Shade Control	Building systems are stand-alone and do not exchange data	Tie with SmartPAR to BAS	Tie with SmartPAR to BAS	All system data captured and normalized for Growing Power goals	Primary data exchange through normalized database, override automation commands to building systems and user applications possible
	Greenhouse Lighting Control					
	Greenhouse HVAC Control					
	HVAC Controls			Tie to calendar/email		
	Lighting Control		Tie with DALI to BAS	Tie with DALI to BAS		
	Shade Control			Tie with DALI to BAS & calendar		
	Receptacle Control					
	Fire/Life Safety		Sent to BAS	Sent to BAS		
	Metering		Sent to BAS	Sent to BAS		
	Physical Security		Tie to AD	Tie to AD		
	Elevator		Tie to BAS	Tie to BAS		
	Voice System					
	Videoconference System			Tie to cal		
	Energy Management		Tie to BAS	Tie to BAS		
	Room Scheduling		Tie to occ	Tie to cal		
	AV Control System		Tie to occ	Tie to calendar & email		
User Applications	Greenhouse Management	Plain Vanilla building systems do not exchange data with the user applications	Data exchange from building systems to user applications does not happen at this level	Converge with BAS for greenhouse data exchange	Converge with BAS for greenhouse data Vs food waste in/out	Trend analysis tied in to building automation must be discussed with Growing Power for more specific goals. This will be beneficial especially for experimental greenhouse operation.
	Market Management					
	Facilities/Shipping Receiving					
	IT Network Management			TBD in CD		
	Calendar Application			Converge with BAS for HVAC optimization	Data collecting for HVAC optimization	
	Email Application			Converge with BAS for building alerts	TBD in CD	
	Directory Application			Converge for personal device lighting control	Specific energy usage	
	Mass Notification			Converge with BAS for building alerts	TBD in CD	

Each level of SMART building integration will require additional programming and applications for controllers and databases by a 3rd party control team. The Synthesis Lighting/Electrical design team recognizes this and has put in place the infrastructure for up to "Level 4" integration. This means that no matter what level Growing Power chooses to implement, higher levels can easily be adopted.

Level One – Information will be shared between building systems though the building automation server

Example: Occupancy sensor will effect both lighting and HVAC control

Level Two – Information is exchanged between user applications and the building automation system

Example: The building calendar application will adjust the HVAC system in the gathering space to pre-cool before large events. This will counter the effect of latent load and minimize work done by the system

Growing Power officials get system alerts via email or smartphone application

Level Three – Information will be shared between building systems though the building automation server

Example: Growing Power has a better understanding of how energy is being used. lbs of food sold vs lbs of food waste used for energy

Level Four – Normalized data collection is used a means to improve each Growing Power site. Trends are identified by applications and adapted to automatically

Example: The system learns typical occupant behavior

Notes:

BAS = Building Automation System
AD = Automation Device
cal = Calendar Application
Occ = Occupancy sensor Control
TBD in CD = To be discussed with Growing Power in CD phase for optimal data harvesting, user control, and/or building automation

Simple Definition		
Scenario	Analogy	Result
Level 1	Two people working INDEPENDENTLY in separate rooms	Information in each room is shared only within that room
Level 2	The two people now work TOGETHER in the same room	Each party has influence over one another
Level 3	A transcriber is included to collect INFORMATION.	Data is collected
Level 4	An additional party identifies trends and the two people ADAPT	Work improves with time