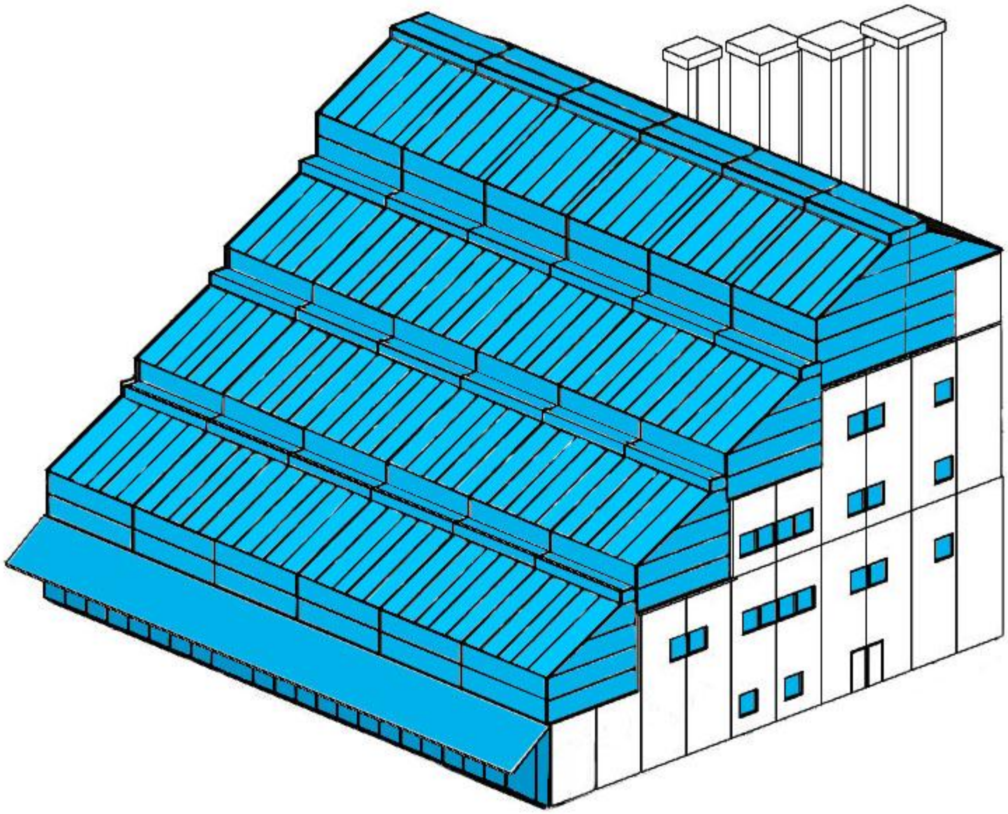
Synthesis
Engineering for Architecture

AEI STUDENT DESIGN COMPETITION

Electrical Report



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ARCHITECTURAL ENGINEERING INSTITUTE

Synthesis
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Executive Summary

Growing Power, Inc. is a nonprofit urban farming organization located in Milwaukee, WI. The Synthesis team has been asked to design a new Vertical Farm to help establish Growing Power as a local and national resource for sustainable agriculture. The farm will be located on the site of Growing Power's headquarters at 5500 Silver Spring Drive, Milwaukee, WI.

The following sections describe the Synthesis lighting/electrical team's goals and overall design. Supplemental material and drawings are included in the appendices of this report.

Lighting/Electrical Goals:

- Promote an educational environment for Growing Power.
- Consider the internal and external impact the electrical system will have on other systems, occupants, and surrounding communities.
- Easily adapt to new building conditions, technological advancements, and geographical regions.

Daylight

The Synthesis lighting and electrical team minimized east west exposure to maximize useful daylight in interior spaces. Architectural programming was coordinated to locate rooms with no outside exposure to now have views into the greenhouses and outside. Low angle sun in winter will preheat interior spaces helping to cut down on mechanical loads. In the afternoon, east facing rooms will not receive daylight and will save energy due to daylight harvesting methods.

Module Greenhouse Design

The Vertical Farm consists of four tiers of greenhouses facing south on the front of the building. The greenhouses have been designed as module components, comprising of six modules per greenhouse. A detailed glazing study was completed in order to understand how different materials transmit different spectrums of light specific to plant growth. Specific design criteria was set fourth pertaining to the exact crops Growing Power will be producing in each greenhouse in a plant matrix. The team designed a supplemental grow lighting configuration to provide a specific intensity and spectrum of light to meet the growing requirements. A shade with light transmission and thermal properties was selected specific to each design set point. Scenarios were run in a daylight model to determine the performance of each greenhouse design. Together, the optimized glazing, supplemental grow lights, and shade system create an ideal plant growing environment for a variety of crop types year round.

Energy and Power

Growing Power will produce energy on site in the form of food waste converted to biogas. This conversion occurs in an outdoor anaerobic digester, located west of the building. This biogas will be used to power a 200 kW microturbine, producing quad-generation.

Quad-Generation – There will be four total outcomes from the microturbine that will be used on site:

- Electricity
- Heating
- Cooling
- Carbon Dioxide

Electricity is a direct result of the microturbine, as well as heat from the flue gas. However, the steam generated by the flue gas will be used to run through an absorption chiller and create a chilled water loop for building cooling. Excess carbon dioxide will be filtered from the flue gas and sent into the closed greenhouse modules. The supplemental carbon dioxide is proven to increase plant growth of more than 40%. The microturbine is responsible for being the prime mover for the entire quad-generation scheme.

Lighting

The building uses extremely efficient lighting. With an overall building Lighting Power Density of 0.39 W/sf, the lighting design power considerations beat the strictest energy codes in the country, including Title 24 by more than 15%. Therefore the building can adapt to any location in the country without changing the lighting. A variety of special fixtures have been selected for specific applications to the Vertical Farm and help improve the overall performance of the building.

SMART Building Design

The collection of Data in the Vertical Farm is essential to its current operation but also to future implementations around the country. A converged IP network has been designed to allow communication between both building systems (lighting, HVAC, occupancy control) and user applications (email notifications, management systems). This allows Growing Power to gain more control over operations and helps the farm learn from its behavior, allowing them to continuously evaluate and optimize its performance.

1.0 Project introduction

Growing Power, Inc. a local Milwaukee, Wisconsin urban farming organization currently feeds more than 10,000 locals each year through school kitchens, restaurants, affordable food baskets, and at farmers markets. Growing Power is looking to increase their sphere of influence and production with the implementation of a new Vertical Farm project located on their existing site, 5500 W. Silver Spring Drive, Milwaukee, WI. Five stories of south-facing greenhouse areas will allow aquaponic production of vegetables, herbs, and fish year round. Expanded educational classrooms, conference spaces, and a demonstration kitchen will further support Growing Power's mission as a local and national resource for learning about sustainable urban food production.

Project Scope – The annual AEI Student Design Competition specifically required the Synthesis Lighting/Electrical team to design and engineer:

- Building power distribution
- Lighting/Daylighting design
- Data/security infrastructure
- Fire alarm system infrastructure

These requests, in conjunction with preliminary information about Growing Power and its needs, led to the development of project wide goals and design criteria for the Vertical Farm.

2.0 Project Goals

The Synthesis Lighting/Electrical team emphasized engineering systems and spaces that are:

Educational

Synthesis is committed to engineering an environment for Growing Power that promotes a meaningful learning experience for everyone who visits the Vertical Farm.

Ecological

The entire electrical system should consider its internal impact on other building systems and occupants while also taking into account the external effect it has on the environment.

Adaptable

Strong emphasis has been placed on designing a prototype building that is easily adjusted to new building conditions, emerging technologies, and geographical environments.

3.0 Integration

The Synthesis Lighting/Electrical team was integral in aiding the entire design of the building and team development. Responsibilities not only included those aforementioned in the project scope, but also included redesigning the building's architecture and creating modular construction solutions. In conjunction with owner goals, Synthesis developed a vision for the entire project.

These goals led the team to unify building systems and architecture as one. The Vertical Farm will adapt to new locations easily through energy efficient design solutions. It will have the ability to learn from its occupants and collect big data through various smart building efforts made possible by the entire team. Integrated building systems will work in sync with its occupants, and complement one another. See the **[Synthesis Integration Report]** to learn more about the buildings complimentary systems.

4.0 Daylighting

4.1 Growing Power as a Landmark

The five-story Vertical Farm will become a striking landmark for its residential Milwaukee neighborhood. The greenhouses, will not only command attention of viewers, but also capture afternoon sunlight that once belonged to the eastern greenhouses. The only way to minimize this is to design the Vertical Farm as far to the west on the site as possible.

The large communal area known as the grand outdoor central (GOC) will be located in the very front of the Vertical Farm. This puts it at the forefront for the rest of the community, and exposes it to the most daylight year round. The direct sun will keep the area at its brightest and warmest throughout the year. In Miami, locating the GOC to the east of the building will help shade it, for a more pleasant experience. Simple and informed design decisions like this one will make Growing Power facilities all over the country more pleasant naturally lit experiences.

4.2 Optimizing Useful Daylight Exposure

Architecture that is optimized for natural light allows the majority of daylight in from north and south. Spaces with east or west exposure are much more costly to design for due to extremely low angle sun. Large fins and overhangs are required in order to have a noticeable impact on glare reduction. When reworking the architecture of the Vertical Farm, Synthesis needed to both minimize east and west exposure, and find new ways to bring in southern or northern daylight. Top lighting would take away from useable space in the top level greenhouse. In Milwaukee, northern window exposure will lead to increased heating loads in the winter. For these reasons, the greatest opportunity for useful daylight came from the south.

Instead of giving the southern light to the plants and forcing occupants to receive daylight elsewhere, both the occupants and plants share southern daylight. This is accomplished through diffuse greenhouse glazing and windows between the greenhouse and interior spaces. This provides views into the greenhouse and useful daylight for the occupants. This way, the greenhouses and interior spaces work together in providing useful daylight to both the plants and occupants.

4.3 Integration with Natural HVAC

In order to heat, cool, and ventilate the building without the use of fans, intake and exhaust towers were designed to extend above the building. These towers introduce air into under floor plenums by catching the wind and using natural convection to move it throughout building. The placement of the towers was crucial for the success of the greenhouses. Initially the design team discussed locating them on the east and west, however this led to excessive shading in the growing areas. Therefore the best solution was to locate them along the north façade. This worked well with the increased southern exposure because it minimized the air travel distance to and from the towers.

4.4 Program Organization

Under floor air distribution (UFAD) accompanies the natural HVAC system. It is not ideal in back of house areas. Coordination was needed between all disciplines when separating UFAD and non-UFAD spaces. This separation is illustrated in **Figure E1**. Visit the **[Mechanical Report: Section 9.0]** for further detail on the Natural HVAC system. Several well informed design considerations were taken when organizing the program of the building. As the Vertical Farm sits on the Western side of the site, locating the UFAD spaces to the East preserved views to Growing Power's existing facilities and work yard. In the summer, the building's electrical loads are highest in the afternoon; therefore the need for daylight harvesting is greatest at this time. Eastern shading will not need to be deployed and electric light will be at a minimum, ultimately lowering the peak demand load. In the winter, the building's heating loads are highest in the morning due to the mechanical system preparing the space for occupants. The morning solar heat gain on the eastern façade is also beneficial to lower heating demand loads.

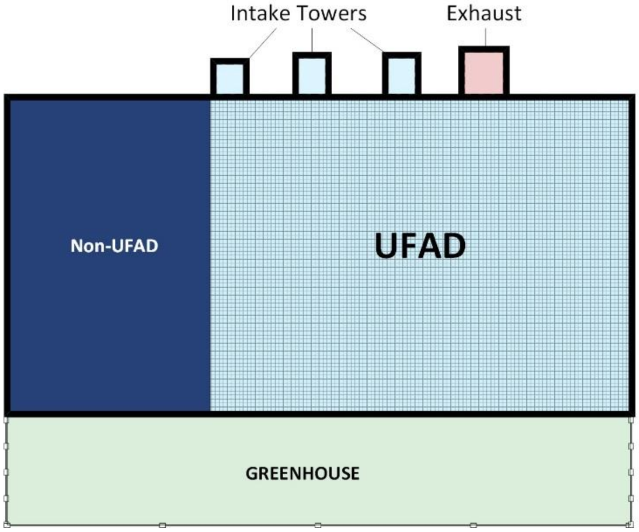

Figure E1: UFAD Separation Diagram

4.5 Façade Design

For the east façade, solar heat gain in the morning is desirable during winter months. Direct sun at the start of the day helps the mechanical system warm the building, however it leads to glare. In the summer, direct solar gain is not desirable and also leads to glare. Strategies to overcome this include external louvers, overhangs, and fins. Preliminary studies using Comfen5 and DaySIM proved that overhangs and fins would need to be in excess of 3' in order to have a significant impact on direct sun. External louvers minimized direct solar glare significantly. However, these would be quite expensive and severely reduce views to Growing Power's outdoor facilities. For these reasons, internal automated shades became the best overall treatment for the eastern façade of the building. Shades integrated with lighting control are a cost effective treatment for east facing windows. Medium gray shades were selected for the eastern façade in Milwaukee due to the needed balance between solar reflectance and contrast ratio. A high contrast ratio (darker color) preserves views and creates a more enjoyable work and learning environment. High solar reflectance (lighter color) will minimize solar heat gain, which is highly beneficial in the summer and warmer climates like Miami. Both east and west facing windows will use a glass type with a 0.25 solar heat gain coefficient and 42% visible transmittance.

4.6 Greenhouse Adjacent Spaces

Diffuse glazing selected for the greenhouse façade creates a buffer before the daylight reaches interior spaces. Synthesis views 100% of this daylight as useful because it is not glaring and benefits the mechanical system greatly in both winter and summer months See DaySIM analysis **[Appendix G]**. Although there are periods of time during which points in the room exceed 2,000 lux, there is little research available to support this as the upper threshold of useful daylight[1].

A 1-hr fire rated, 75% visible light transmitting glass has been selected for spaces adjacent to the greenhouses. In addition, translucent partitions will allow more daylight to reach the middle corridor of levels 3 and 4. In the winter, growing areas will be kept to a minimum of 70°. This effectively eliminates conduction between the interior spaces and greenhouse. The views from various classrooms and offices into the greenhouse will help educate and add enjoyment to each occupant's experience.

5.0 Greenhouse Design

The greenhouses are a key aspect of the Vertical Farm. With the construction of the new building, Growing Power, Milwaukee will become a catalyst for inspiring similar projects nationwide. The success of the farm, and future facilities like it, will ride heavily on the success of the greenhouse design. Not only did Synthesis design the greenhouses for optimum growing conditions, strong emphasis was also placed on creating an environment for urban farmers alike to learn from Growing Power; encouraging a new standard in greenhouse design for the entire urban farming industry.

The Vertical Farm utilizes the entire Southern façade for greenhouse space, with 4 stories of tiered greenhouses climbing up the stepped face of the building. Each tier is considered one greenhouse. Each greenhouse is comprised of six modules. **Figure E2** shows a rendering of one greenhouse module. Although this report focuses on the lighting/electrical design of the greenhouse, it is important to understand the components of the modular greenhouse design. This system is explained in further detail in the **[Synthesis Integration Report: Section 6.0]**.

The next few sections of the report explain how the greenhouse has been designed with respect to the plants. Through the use of effective glazing, operable shade curtains, and tunable grow lights, the greenhouse creates a consistent environment inside that adapts itself to the unpredictable nature of the outside.

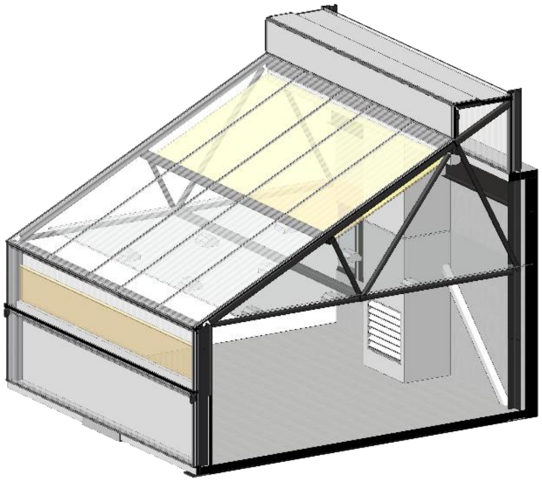

Figure E2: Rendering of a Greenhouse Module

5.1 Daylight Metrics

PAR - Photosynthetically Active Radiation

To gain direction on how to provide light in the greenhouse, the team analyzed how plants actually receive and convert light into usable energy as carbohydrates. It is important to understand that it is not about maximizing the quantity of light delivered to the plants, but more about the quality of light that the plants receive. Just as humans need a balanced diet, plants also need a balanced spectrum of light for good health and optimum growth. Like the human eye, plants are also sensitive to certain portions of the light spectrum. This portion of the light spectrum is referred to as photosynthetically active radiation or PAR, generally occurring between 400-700 nanometers in wavelength[2]. Although the human eye sees in the same range of wavelengths as plants, their action spectra's are very different from one another. The two action spectra can be seen side-to-side for comparison on the following page in **Figure E3 & E4**.

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[1] *(A. Nabil, 2005a)*

[2] *(International, 2013)*

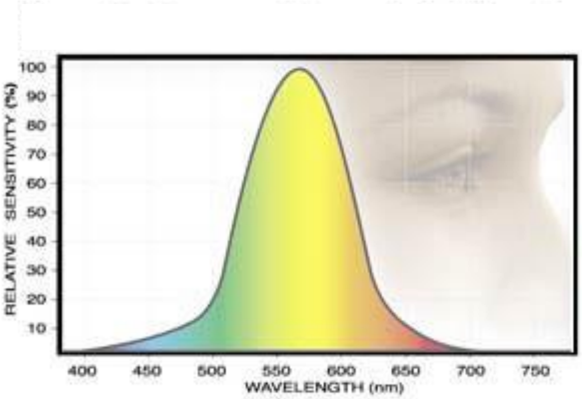

Figure E3: Human Eye Response Curve

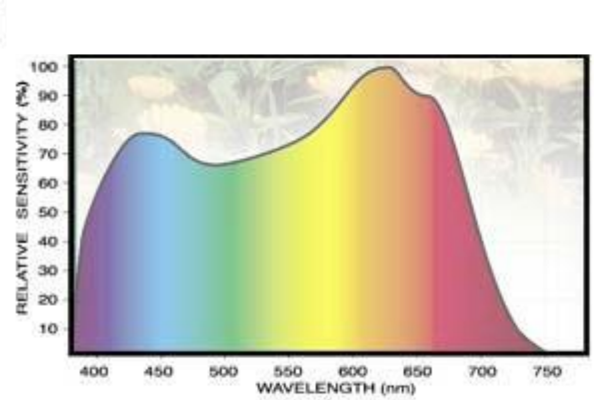

Figure E4: Photosynthetically Active Radiation Curve

In the same way that fat provides the most efficient calories for humans, red and blue light provides the most efficient food for plants. However, a plant that is illuminated with only red or blue light will fail to develop sufficient bulk and mass. Therefore it is necessary to provide plants with natural light that covers the entire spectrum, while also pumping the output of the red and blue regions. Because the spectrum of usable light is so different between plants and humans, the same standards and metrics cannot be used. This PAR spectrum is used to quantify the amount of usable photons that plants are receiving and converting into carbohydrate energy.

The PAR metric is measured in micromoles per meters squared per second *($\mu mol/m^2/s$).* This reports how many moles ($6 \ x \ 10^{23}$) of light energy photons are being emitted within an area of one square meter, every second. Many lighting recommendations for plants are given in PAR, ranging from 100-500 $\mu mol/m^2/s$ depending on the plant species.

DLI – Daily Light Integral

Daily Light Integral (DLI) is the amount of PAR received each day as a function of light intensity ($\mu mol/m^2/s$) and duration (day). It is expressed as moles of light photons (mol) per square meter (m^{-2}) per day (day^{-1}) or: ($\mu mol/m^2/day$). DLI is an important variable to measure because it influences plant growth, development, crop yield, and quality[3]. Routinely monitoring the DLI received by crops is made possible through the use of a *LI-COR* Quantum Sensor. This sensor extrapolates the amount DLI at any point throughout the day and is used to automatically activate the shade system and or supplemental grow lights in the greenhouse.

5.2 Glazing Study

In order to maximize the light efficiency in the greenhouse, the Synthesis team sought to select a glazing material that transmits the most amount of PAR, rather than the visual spectrum of light. Unfortunately, most glazing manufacture's, including greenhouse manufactures, only report the visual transmittance of their products rather than PAR transmittance. As a way around this, the team used Window 7.2, glazing material software to build various configurations of glazing systems. The respective spectral distribution reports were then exported and further analyzed with respect to PAR.

This spectral report lists wavelengths from 300 – 830 nanometers, in increments of 5 nm, along with the corresponding transmittance percentages for each listed wavelength. These individual transmittance values depict the percent of light, specific to each wavelength, the glazing system transmits. Together using all of the transmittances, over all the wavelengths in the spectrum, and using a D65 CIE relative weighting distribution (visual daylight weighting coefficient), the visual transmittance is calculated[4]. See equation ($\tau_{visible}$) below:

$$\tau_{visible} = \frac{\sum_{\lambda} D(\lambda)V(\lambda)\cdot\tau(\lambda)\cdot\Delta\lambda}{\sum_{\lambda} D(\lambda)V(\lambda)\cdot\Delta\lambda}$$

$$D\lambda V\lambda : D65 \ CIE \ Luminosity \ weighting \ coefficient$$

This D65 CIE relative weighting distribution takes the human eye's spectral distribution into account and gives a weighting to the transmittances for the specific wavelengths humans see (**Figure E4**). The Synthesis team developed a similar equation which uses a PAR weighting spectrum (**Figure E5**)

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[3] *(Torres & Lopez, n.d.)*

[4] *(Shimadzu, 2015)*

instead of a D65 CIE weighting spectrum enabling the calculation of the total PAR transmittance for the glazing system. See equation (τ_{PAR}) below:

$$\tau_{PAR} = \frac{\sum_{\lambda} \alpha_{PAR}(\lambda) \cdot \tau(\lambda) \cdot \Delta\lambda}{\sum_{\lambda} \alpha_{PAR}(\lambda) \cdot \Delta\lambda}$$

$$\alpha_{PAR}(\lambda)\text{: } PAR\ weighting\ coefficient$$

The glazing system was evaluated based on the total PAR transmittance that was calculated and compared to the Solar Heat Gain Coefficient ($\tau_{PAR}/SHGC$). Ultimately, a diffuse multiwall polycarbonate glazing system was selected as the best option, not only providing efficient PAR transmittance and low solar heat gain, but also diffusing and scattering the sunlight through the multiple layers of the polycarbonate. Diffuse light is desired in greenhouse applications because plants will receive more uniform light within the space and severe shadows are not cast by structural members, light fixtures, and mechanical systems. Polycarbonate panels are also extremely light weight in comparison to glass, enabling a more adaptable structure that is more resistant to wind loads in other climates.

5.3 Design Criteria

In order to determine greenhouse design conditions, a plant matrix was compiled with crops that are planned to be grown in the vertical farm along with their respective lighting criteria. As seen in the matrix, different plants require different amounts of PAR and DLI that optimize growth and schedule. The plant matrix served as a good way to organize the lighting requirements for the crops Growing Power will be cultivating. **Table E6** shows the lighting portion of the plant matrix, see **[Appendix B]** for the full matrix. The plants were organized into three design conditions according to their respective recommended Daily Light Integrals,

Level 2 Greenhouse = ***14 mol/day***
Level 3 Greenhouse = ***20 mol/day***
Level 4 Greenhouse = ***26 mol/day***
Level 5 Greenhouse = ***14 mol/day***

The three tiered greenhouses are designed for three different DLI values, creating a variety of growing environments for any type of plant. Because the majority of Growing Power's food production will come from leafy greens, the entire roof and first tier (Level 2 and 5 Greenhouses) are designed for the optimal conditions of *14 mol/day*. Grow lighting should be designed for no more than 10 W/sf in greenhouse applications[5].

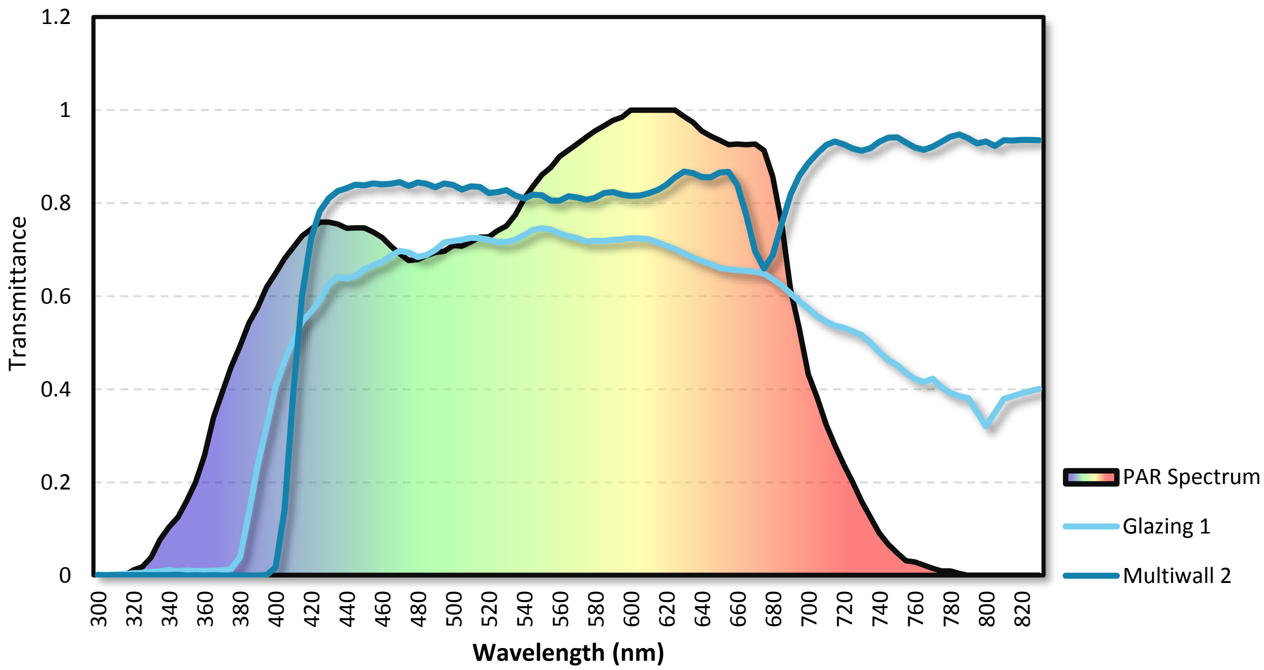

Figure E5: The spectral distributions for Glazing 1 (single pane clear glass) ($\tau_{PAR} = .62$) and Multiwall 2 (Polycarbonate double pane panels) ($\tau_{PAR} = .76$).

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[5] *(Ciolkosz, 2014)*

Table E6: Lighting recommendations portion of plant matrix

Crop Type	DLI (Mol/Day/m2)	PAR (µmol/m2/s)
Lettuce	14	150-200
Basil	14	150-200
Beat Greens	14	150-200
Greens	14	150-200
Chives	14	150-200
Tomatoes	26	300
Cucumbers	20	250
Strawberries	20	250

5.4 Supplemental Grow Lighting

There are 54 *LumiGrow Pro 325* fixtures are spaced over the potential growing area in each greenhouse to provide an average of 14 moles per day to the plants if running for the entire 24 hour period. The LED grow lights emit photons at wavelengths specific to the PAR spectrum, which supplement the daylight (transmitted through the PAR optimized polycarbonate glazing) absorbed by the plants. The fixtures are also tunable in their spectral outputs, meaning that Growing Power staff can easily manipulate the PAR outputs of each fixture - specific to certain plants or grow periods. This is beneficial because not all plants use the exact same PAR curve. The PAR curve previously discussed is an average absorption curve for carbon-three plants (leafy green vegetables).

The fixtures are mounted at 7' from the floor of the greenhouse, 4' from the calculated growing surface, and 1' below the thermal divider. There will be 9 grow lights per greenhouse module, hung from an adjustable metal chain, and mounted to the supporting steel structure. See **[Appendix E]** for more information on the grow lights and a mounting detail in **Figure E7**. A Li-COR Quantum Sensor will be used in conjunction with a data logging device (*SmartPAR* system) to measure PAR throughout the day along with instantaneously predicting the Daily Light Integral. The DLI and PAR values read by the Quantum Sensor will dictate when and how often the grow lighting will supplement the daylight to the plants.

The fixtures emit a specific PAR ($\mu mol/m^2/s$), therefore the amount of light supplemented by the fixtures is a function of how long they are on each day. For example, if the daylight absorbed by the plants (measured by the quantum sensor) is 10 moles that day, the grow lights only need to supplement 4 additional moles to reach the target conditions for 14 moles/day; therefore they need to run for 6.8 hours that day. This is explained in the following calculation:

$$Hours\ of\ Operation = \frac{\#\ Moles\ Needed}{Growlight\ DLI}(photoperiod)$$

Although the fixtures are each 325 watts, which creates a connected lighting load of about 17,550 VA per greenhouse (7.24W/sf average), the fixtures will only operate for 15% of the year in the Level 2 and 5 Greenhouses, 32% of the year in Level 3 Greenhouse, and 41% of the year in the Level 4 Greenhouse in order to meet the design criteria of 14, 20, and 26 mol/day respectively. **[Appendix G]**

***Control System* –** Information from the Li-COR sensor is collected in a central control processor as part of the *LumiGrow SmartPAR* system. The controller is responsible for calculating and predicting DLI from PAR sensor readings. Control signals are sent wirelessly to individual *LumiGrow* fixtures, and low voltage signals are sent to shade motors. This control scheme is easily adjusted and managed by greenhouse operators from laptops or tablets. Data from the system will be continuously reported back to the building management server via Ethernet.

Visual display screens linked to the building network server will be mounted in each greenhouse reporting data read and received by the Quantum Sensor. This will help visitors compare growing environments while touring the facility as each greenhouse has different target DLI values.

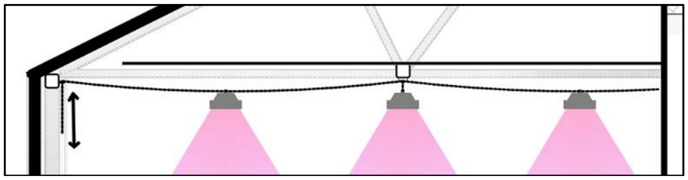
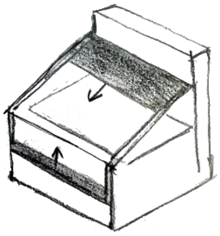


Figure E7: Partial greenhouse section mounting detail

5.5 Operable Shade Curtain System

Just as grow lighting is used to help supplement PAR to reach the target DLI values for each greenhouse, a suspended shade curtain will help block PAR on days that are over the target Daily Light Integral. The shade curtains also have important heat retention properties that are utilized at night when heating demands are highest. The *LudvigSvensson: Tempa* shade family uses alternating aluminum strips with polyester fabric in a woven structure that creates excellent energy savings, light shading, and diffusing properties. The aluminum strips reflect infrared light out during the day and back into the greenhouse at night, helping to both heat and cool the environment. This type of material is desirable because it uses a single-screen solution for shading, cooling and maximum energy saving. Because each tiered greenhouse has different design criteria, each will have a different shade cloth material to shade or transmit the recommended PAR. The exact shade cloth materials and specific mounting details are located in **[Appendix F]**.

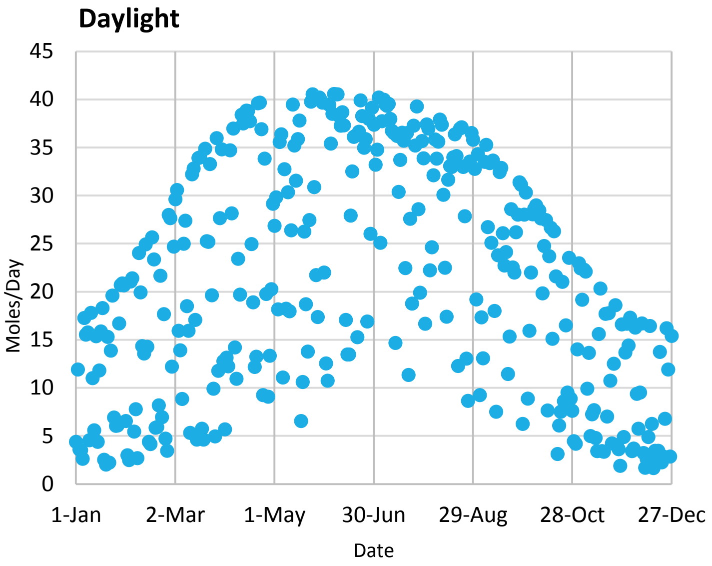


For each module, the shade system is comprised of two shade components: one sloped shade mounted just below the sloped glazing at the top, and one vertical shade mounted on the southern wall of the greenhouse. The two end modules will also have side shades on the east and west walls. The top, sloped shade will be mounted to a horizontal steel member spanning between the two trusses on either side of the module. The shade will deploy down the slope of the glazing between the trusses on either side of the module. An aluminum track is mounted underneath either truss and secures each side of the shade cloth. The track helps to keep the shade cloth taught at all times and creates an air tight seal between the glazing and the shade curtain. The vertical shade on the front wall deploys from the bottom up; shading the entire exposed glazing area. See **[Appendix F]** for mounting details.

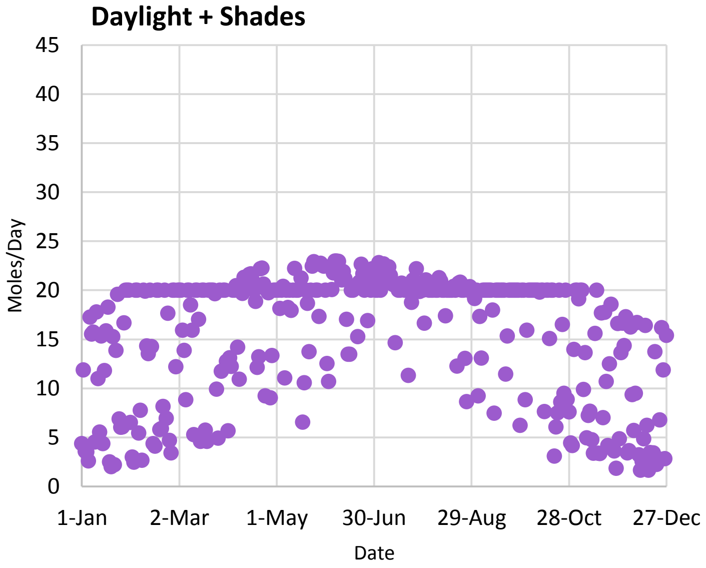
The *SmartPAR* system will allow automated and scheduled operation of all greenhouse shades. The motorized shades will deploy and contract throughout the day, providing the correct DLI to the plants. The Li-COR sensor will therefore be linked to both the shade control and supplemental grow light control.

5.6 Greenhouse Performance

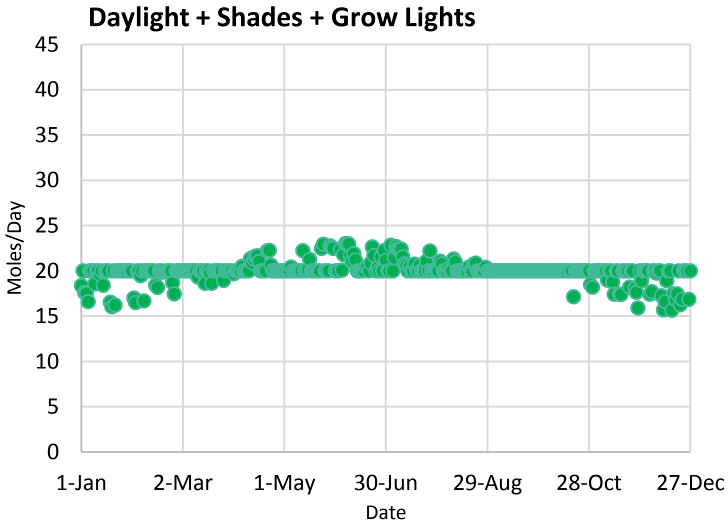
A Daysim (daylight analysis software tool) model was used to accurately analyze greenhouse performance over the course of a typical year. The three graphs on the right show the optimization of Greenhouse 2 *(20 mol/day target)*. The graphs plot the DLI inside the greenhouse each day over the course of one year. The first graph shows the ambient weather conditions the plants receive in the greenhouse without the use of the shade curtain or supplemental grow lighting. The next graph shows the effect that the shade curtain system has on the Daily Light Integral, while the third graph shows the final effect that both shades and grow lights have on the DLI absorbed by the plants. Together, the components of the greenhouse system create a consistent environment *(20 mol/day)* inside the greenhouse despite the changing sky conditions each day throughout the year.



Daylight



Daylight + Shades



Daylight + Shades + Grow Lights

6.0 Energy

6.1 Growing Power as an Ecosystem

When designing a building that produces food for the community, it is important to understand naturally occurring agricultural ecosystems. Traditionally, plants live and grow in soil, bearing fruits and vegetables each season. Once these plants die, their remains break down and fertilize the very soil in which they once thrived. The fertile soil serves as excellent ground for new seedlings to sprout and begin the cycle over again, thus creating a self-sustaining ecosystem.

Growing Power is an ecosystem within the community. They currently import local food waste for composting soil and fertilizer. In the Patterns developed by TKWA (architects who provided the competition approved drawings) it was expressed that Growing Power wanted to mimic the natural cycle of food production, using food waste as a fuel source for onsite energy production. This energy is directly used to power the Vertical Farm, ultimately providing the community with food. This establishes Growing Power an integral part of the local ecosystem.

Figure E8: Growing Power as an Ecosystem

6.2 Anaerobic Digester

An onsite anaerobic digester is responsible for creating biogas from food waste collected from Growing Power's existing operations and other resources around the community, such as universities, farms, and local businesses. Tipping fees charged by Growing Power will be less than the local landfill, thus offering a financial incentive for local businesses to participate. The anaerobic digester is divided into two stages. The first stage takes in food waste and produces three outputs – biogas, solid fertilizer, and liquid fertilizer. The liquid fertilizer is sent to the second stage digester where additional biogas is produced and stored. The biogas is ultimately combusted in a 200 kW microturbine in the building. The excess fertilizer (solid and liquid) is harvested for composting nutrient rich soil at existing greenhouse sites. Food waste will be delivered daily to Growing Power. This will produce 2.2 million BTU per hour of biogas to be used to by the microturbine.

6.3 Microturbine

The 200 kW Capstone Microturbine is responsible for generating electricity on site for the Vertical Farm. It not only produces electricity for the building's mechanical and electrical systems, but it is also the prime mover in the quad-generation scheme. The microturbine initially delivers 250 kVA at 480Y/277V to the building's main switchgear, which parallels with the WE Energies (Wisconsin Electric, local utility) power grid to allow for excess electricity to be sold back to the grid, or needed supplemental electricity to be drawn from it. A microturbine was selected over an internal combustion engine because of the small load associated with the peak annual energy usage of 144 kW. The smaller physical size, ultra-low emissions, and limited noise levels associated with the microturbine were also beneficial. The microturbine has the capability to run all of the time, regardless of food waste supply and biogas fuel. In case of a food waste shortage, Growing Power relies on a natural gas tie in, in order to keep the microturbine running.

Biogas is a desirable fuel source because of its renewable nature. It is not a resource that needs to be extracted from the earth. Instead, it is already being produced every day by the local residents and businesses in Milwaukee. See **[Mechanical Report: Section 5.0]** for more information on biogas as a fuel source for the microturbine.

As a result of the peak electrical demand being only 144 kW, Growing Power will be producing far more energy than it will be using. As Growing Power will be tied into the electrical grid, they will be selling this excess power back to the utility. For a detailed explanation on the overall power consumption and production visit **[Appendix H].**

6.4 Quad-Generation

A typical combined heat and power system is commonly referred to as "co-generation", however the Synthesis "quad-generation" process describes a system that gives four outputs: heat, power, cooling, and carbon dioxide. The microturbine produces 200 kW of electricity and exhaust gas that is directly used in a heat exchanger, to provide heating.

Heat will also be used in an absorption chiller, creating chilled water used for cooling. The fourth output, carbon dioxide, is the major component in the exhaust gas. The exhaust gas is cooled and directly pumped into the greenhouses to elevate CO2 levels. It is desirable because supplemental CO2 facilitates increased plant production in the closed greenhouse system. **Figure E8** below summarizes the quad-generation process. For a more detailed explanation on the quad-generation process visit the **[Mechanical Report: Section 6.0].**

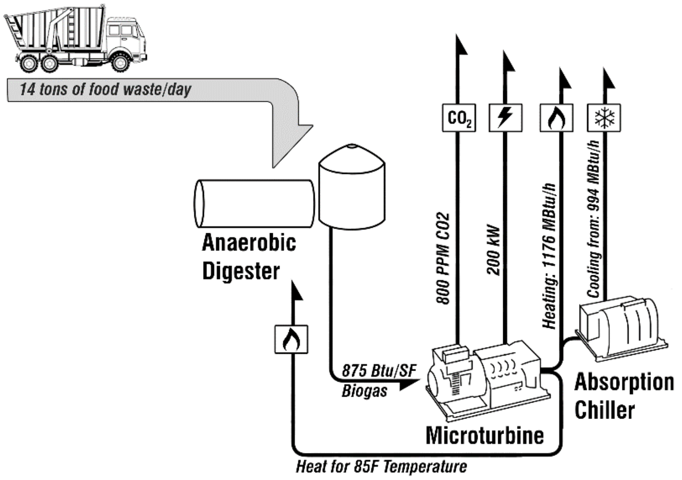


Figure E9: Quad-Generation Process

6.5 Photovoltaic Panels

Arrays of stationary south facing photovoltaic (PV) panels are mounted on the overhang extending from the Market. The array faces Silver Spring Drive, along with the existing array to the east of the building. Total connected power for the new array is 17.5 kW DC[6]. The PV's will be mounted on a 37° slope, which is optimized for Growing Power, Milwaukee. This yields some of the highest energy year round. Although the optimized annual yield happens closer to 35°, the 37° slope provides more energy during winter months. This is beneficial because the Vertical Farm will require much more power due to grow lighting in the winter than other times of the year. The slope of the photovoltaic array and overhang will decrease as the building is designed to be located closer to the equator. For example, the optimal angle for Growing Power, Miami will be 18°.

The market will be completely shaded from direct sun between March 21st and September 21st, due to the PV array. The limited solar heat gain in the summer and increased solar radiation in the winter is desirable for heating and cooling loads in the market space. A section of the building, and more information about the photovoltaic panels is explained in **[Appendix L].**

The payback period for this system will be slightly over 16 years, which is typical of static photovoltaic arrays, regardless of the amount. Tracking panels were looked into as an even more efficient means of harnessing sun energy, however the function of the array as an overhang would be sacrificed and the payback period would double. Although the payback is longer than desired, the photovoltaic arrays on display in front of the building advertise Growing Power as a green site to the community.

7.0 Power Distribution

Growing Power's Vertical Farm will have three main sources of energy, the 200 kW microturbine, a photovoltaic array, and a tie in to the the utility company, WE Energies. These three sources of energy each funnel into the building's main switchgear at 480Y/277 volts. From there the power is sent to the basement mechanical loads (89 kVA) on the basement distribution panel and the buildings 4 greenhouse panels (18 kVA each). The rest of the power is sent through a 112.5 kVA 208Y/120V transformer located in the basement electrical room. From there, power is distributed to the buildings general lighting, receptical, and simple motor loads via local distribution panels on each floor. For a general overview of the power system in the building and amore detailed explanation of the main switchgear and distribution panels see **[Drawing E109]**.

7.1 Limited Mechanical Loads

The entire building's mechanical system loads amount to just 118 kVA (480Y/277V). Generally for a building of this size and function, the loading would be considerably higher. However, the mechanical system functions primarily through wind pressure and thermal buoyancy principles, thus reducing fan energy. The second floor and above are heated and cooled using a natural HVAC system utilizing the custom designed air intake towers and exhaust chimney in the rear of the building.

The use of an absorption chiller eliminates the need for a large refrigerant compressor. The largest mechanical load on the electrical system is the conservatively sized 50 Horsepower (60 kVA) groundwater pump from the geothermal well back to the building. It accounts for more than half the entire electrical load of the mechanical system, and is so large because of how deep the well is and how far

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[6] *(Energy, 2015)*

the water needs to be pumped back to the building. **[Appendix H]**

7.2 Load Classifications

Basement Equipment Loads – The large mechanical loads in the basement of the building run on 480Y/277V power. The mechanical system components are detailed in the mechanical equipment schedule in the **[Synthesis Mechanical Drawing: M110]**.

General Loads – Smaller loads in the building that run on 208Y/120V: receptacles, lighting fixtures (except for greenhouses), audiovisual, small motor loads, and kitchen equipment.

Priority Loads – All greenhouse receptacles and lighting fixtures are considered priority loads, as well as any connected load related to the operation of the aquaponic systems and shade control motors. It is important to keep the greenhouse loads separate from the general building loads in cases of reduced energy availability.

Emergency Loads – This includes anything related to life safety and means of egress. This is comprised primarily of emergency lighting (which by code requires 0.2 w/sf lighting and 2 fc egress paths), and fire protection loads. Emergency lighting and exit signs contain small integral 1.5 hour battery packs.

7.3 Emergency Power

It is important to the Quad-Generation scheme that the microturbine stays up and running at all times. Therefore, the emergency power for the building will be in the form of natural gas. If biogas ever becomes unavailable the fuel source for the microturbine will switch from biogas to utility natural gas. This is a deemed a reliable emergency fuel source by the local jurisdiction because pipeline interruption is highly unlikely. The microturbine is designed specifically for this application and has two fuel source inputs.

Although the electrical system is sized to 365 kVA, and the microturbine will be producing 250 kVA (0.8 power factor), the system will rarely be running at full load. This is beneficial because the microturbine will be able to provide all of the power to the building the majority of the time. The 17.5 kW photovoltaic array provides power to the system when solar radiation is available. There will be few peak electrical load instances when Growing Power will need to draw power from the electrical grid.

***Worst Case Scenario* –** Although the natural gas grid is deemed reliable, there is still a possibility that outages occur due to gas line repairs, natural disasters, digging damages, and gas leaks[7]. In the case of a biogas, natural gas, and electrical outage the Vertical Farm has the necessary life safety requirements by the NEC 2011 and Wisconsin Administrative Code for occupants to safely exit the building. Battery packs have been added to the necessary fixtures in order to achieve a uniform 2 fc illuminance in the necessary means of egress.

7.4 Electrical Room Coordination

As Synthesis redesigned the building the team was able to place the electrical rooms, main mechanical shaft, and IT rooms adjacent to core spaces (stair and elevator shafts). This allows backbone cabling and piping to be erected early in construction before interior partitions. The electrical rooms are located in the Southwest corner of the Vertical Farm. Although the electrical rooms are not perfectly stacked, they remain in close vicinity to one another, minimizing feeder runs and saving time and money during construction.

7.5 Smart Distribution Panels

All panels in the building will be intelligent for controllability and data collection. Each incorporates a processor within each branch panel that is linked to a local IT room's IP switch. The data link allows each individual circuit on the panel to be controlled and metered by the building automation system via BacNET/IP. Through this method Growing Power will have a full understanding of how the Vertical Farm is using energy.

***Occupancy Control* –** Occupancy control over lighting is accomplished using a digitally addressable lighting interface (DALI) control protocol. Up to 64 devices, regardless of location and circuit, can be individually controlled through DALI. This is beneficial because light fixtures do not need to be circuited with regards to controllability and installation is simple. Micro controllers receive data from local occupancy sensors, vacancy sensors, photosensors, and DALI wallstations. Each device has a digital address, and each address is programmable. This however, is not the case for receptacles.

In order to control branch circuit receptacles by occupancy sensor, the receptacles need to be circuited according to the room the occupancy sensor is serving. Therefore each room has a single branch circuit for its receptacles. The occupancy sensor speaks to the DALI microcontroller via radio frequency

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[7] *(Company, 2015)*

signals. This information is sent to a relay device on the DALI bus which will switch power to room receptacles (Figure 5). As a result, all receptacles will be switched on or off based on the occupancy sensor. This system is useful for limiting “phantom” plug loads that are not necessary after hours. The occupancy sensor override to the main time clock helps prevent this by cutting power to receptacles. **[Appendix N]**

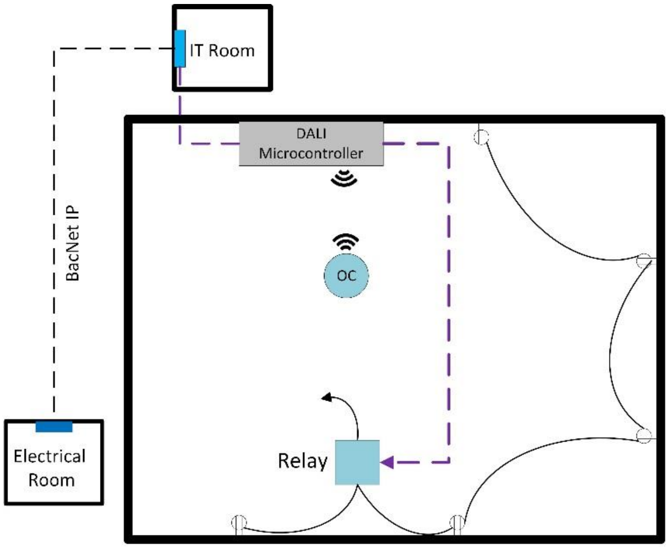

Figure E10: Branch Receptacle Control

Metering – The smart panel system monitors and reports power consumption of each branch circuit. At all times, the panel meters the flow of current and instantaneously reports this data back to the building management server. This will aid Growing Power in understanding the exact energy break down of the building.

7.6 Raised Access Floor

There will be a raised access floor on levels 2-4 where under floor air distribution (UFAD) will occur. The Natural HVAC system utilizes air intake towers in the rear of the building to introduce outside air into the plenum. The electrical benefits to this system are as follows:

Building adaptability – If floor plans change over time, the receptacle layout is much easier to modify compared to hard wiring everything through permanent partitions.

Shorter runs – Instead of wiring wall mounted receptacles through the ceiling plenum and down inside the partition, the contractor can run conduit more directly to the load, creating shorter overall run lengths.

Easier to install – Because the conduit takes a more direct route, it saves the construction team time and money when installing.

Localized Load Placement – With a raised access floor, it becomes much easier to place receptacles and other hard wired loads directly where they need to be.

8.0 Lighting Design

8.1 Concept & Overview

The lighting system has been designed with three key factors in mind, efficiency, controllability, and aesthetics. It has been designed in accordance with ASHRAE 90.1 (2011), Title-24 (2013), NEC (2011), and in conjunction with standards from the IES Handbook (10th Edition). Design criteria were developed through a combination of the most stringent energy codes in the country. This ensures that no matter where Growing Power decides to build their next vertical farm, the lighting will meet the local jurisdiction’s code with minimal changes.

8.2 Color Rendering

Criteria for color rendering were developed through ASHRAE design guides and related research. Color Rendering Index (CRI) has been recently used to determine the ability of a light source to render color similar to that of daylight. The linear nature of this metric, makes it a simple single metric for determining color rendering capabilities of artificial lighting. A CRI of 90+ was determined to be an achievable goal with long lasting benefits as lighting becomes more advanced.

The energy efficient Vertical Farm pushes the envelope in emerging technology by lighting with the most modern sources. However due to the process by which LED’s produce light, they typically fall behind other light sources when rendering red colors. For this reason additional criteria was developed for the market, where customers will be selecting colorful foods based on the way they look and feel. R9 and MacAdam binning are important metrics when designing the market lighting. R9 performance represents the ability for a light source to render reds, and similar MacAdam binning values between fixtures reduce noticeable color variation. This means that fixtures selected for lighting food in the market will have truly similar color rendering properties (similar chromaticity values).

Track and aisle lighting in the market within 3 MacAdam steps of one another was selected with an R9 value of 50+. White light sources outside of a 3 step MacAdam from one another lead to noticeable color variation, therefore the strict binning criterion was developed.

8.3 Efficiency

The entire lighting system for the building beats the best of Title-24 and ASHRAE standards by at least 15% for both space-by-space and whole building LPD. This meets the most stringent ordinance in the US (San Francisco), which requires a 15% better LPD than Title-24. The Milwaukee lighting system will remain as a constant part of the design when relocating the Vertical Farm to anywhere in the country. All of the lighting fixtures are long lasting, efficient LED sources, using minimal connected load. Overall, interior lighting amounts to 2% of the building's annual energy usage, and 0.25 W/sf. **[Appendix J]**

8.4 Controllability

Lighting Control – The lighting design is broken up into three components of controllability. 0-10V, digital addressable lighting interface (DALI), and electronic low voltage (ELV). Back of house fixtures have simple auto-on/auto-off control via passive infrared (PIR) occupancy sensors. Market general lighting utilizes 2 zone daylight harvesting with 0-10V dimming for maximum energy savings. All track lighting is easily controlled by market employees via ELV, or reverse phase dimming on two circuits.

All other lighting in regularly occupied spaces is controlled through DALI interface. This is an open protocol, which allows flexibility in fixture selection and control architecture. Groups of individually addressable light fixtures have been put into control loops for local control at wallstations. These are located in offices, classrooms, meeting rooms, and gathering areas to allow for easy occupant control of scenes and dimming. Photosensors and occupancy sensors are tied to DALI microcontrollers to enable energy savings through daylight harvesting and PIR sensing. Spaces along the east façade utilize photosensors to minimize over dimming that may occur due to snow cover[8]. Third party shade motors are given commands via Ethernet to maintain useful daylight levels in spaces adjacent to the greenhouses and along the eastern façade. **[Appendix M]**

Growing Power employees will have local lighting control from smartphones, tablets, and laptops. Individual DALI microcontrollers will speak back to a full floor processor and are linked to a patch panel. The patch panel speaks back to the main IT room on the 2nd floor through fiber where data can be transferred to other servers. Through this method each DALI control processor exchanges information with the building network server.

8.5 Offices, Classrooms, & Gathering Areas

Energy efficiency and visual comfort are key in spaces that may be used for long periods of time. Many of the interior spaces above the first floor utilize direct/indirect lighting for task and general illumination. The indirect component creates a comfortable environment for gathering space attendees, students, and administrative workers. Light diffused by white ceilings is spread evenly throughout task planes to provide soft illumination and minimize laptop or cell phone screens. The down light component works in harmony with the indirect lighting by providing an extra punch of light onto the work surface. This provides higher delivered lumens (to the work plane) per watt than strictly indirect lighting[9].

8.6 The Market

The market is the culmination of the hard work at Growing Power. Here, Growing Power will not only display and sell organic food, but also promote and educate the community about sustainable agriculture and modern urban farming. The lighting, in conjunction with the architectural configuration of the space, creates a stimulating market environment that embodies all that Growing Power stands for.

Eye on the prize – Emphasis on the food is the main goal. High color quality with minimal perceived variation is achieved through fixtures which adhere to the design criteria mentioned in section 8.2. Contrast (3:1) is maintained between the task and aisle illuminance to create a more dramatic presentation of the final products being sold.

The open floor plan allows visitors to move freely throughout the space. 4' moveable tables are accessible from four sides and display the variety of food options Growing Power offers. They are organized in a grid and are enhanced by the two lighting sources above.

General illumination is provided by the linear downlights mounted between tables and above the aisle ways at 10'. Unlike typical linear downlights, the *Ammerlux Producer* fixtures emit a desirable "bat-wing" beam spread that extends light further away from the fixture on either side (**Figure E11**). This distinctive beam spread is effective in retail applications because it provides illumination to both

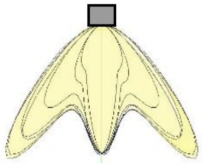

Figure E11

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[8] *(Mistrick & Chen, 2014)*

[9] *(Alera Lighting, 1995)*

the floor and the display to either side.

Track lighting is an adaptable lighting solution that provides the necessary emphasis on the food tables no matter their configuration. This scheme is used to accent the food and focus the customer's attention. In the display area there is a continuous grid of *Ammerlux* single circuit 120V track, hung at 10'. Mounted to the track are 2200 lumen adjustable fixtures with a 30° beam spread. Together, the linear downlights and track fixtures combine to provide 50 fc of illuminance on the display tables and 17 fc in the aisles. Although the IES recommends a 10 fc average illuminance in the aisle, a contrast of 50 fc to 10 fc (5:1) would cause the floor to appear dark, thus the contrast ratio has been designed to 3:1.

Seafood Counter – The Seafood Counter on the western wall of the market serves fresh perch and tilapia that are raised in house through aquaponic production. It is pronounced by an architectural ceiling header that drops below the rest of the exposed ceiling in the display areas. A concealed portion of track is mounted behind the header concealed from view and back lights the signage on the rear wall. Circular downlights illuminate the work area. The concealed lighting and the architectural change in ceiling heights help to distinguish the Seafood Counter as a significant component to the market.

Checkout Counter – The Checkout Counter sits opposite the Seafood Counter on the eastern wall of the market. An architectural header is used to signify the counter's presence in the space along with hanging pendants mounted at 7.5'. A row of pendants line the counter top and bring the light down to a local level creating a warmer interaction between the consumer and the Growing Power cashier.

The incoming daylight from behind the counter will create a high contrast between the background and the cashier's face, leading to less distinguishable features. Introduction of the pendants reduces this contrast and preserves the interaction between the two by providing vertical illuminance on the cashier's face and balancing out the daylight. **Figure E12** describes this scenario.

Figure 6: Market Checkout Section

Building Education Dashboard – Along the north wall of the market there is a wall devoted to educating community members and other visitors about Growing Power's energy consumption. The wall incorporates an architecturally pronounced extrusion that houses the building dashboard display screens and is serviceable from behind. This extrusion is lit from behind using linear LED cove lights creating a glowing effect that emits on all three sides (bottom meets the floor). See **[Appendix L]** for feature wall lighting and dashboard details.

Using the QA Graphics interface, Growing Power will display their data using a template created specifically for them. The Building Education Dashboard will present real time data about energy consumption of the building and specific components (i.e. lighting). Growing Power will be able to display metrics to show the overall efficiency of the Vertical Farm ecosystem. For example, with collected data from market cash registers and package scanning, the dashboard could display lbs of food sold per lbs of food waste received.

When presented in a well-organized and intentional manner, this information will effectively educate visitors and other aspiring urban farmers who visit Growing Power. As they monitor and report more and more data, drawing trends across disciplines will become a constant theme. Growing Power will begin to make these connections and learn from their habits as the farm evolves into the future.

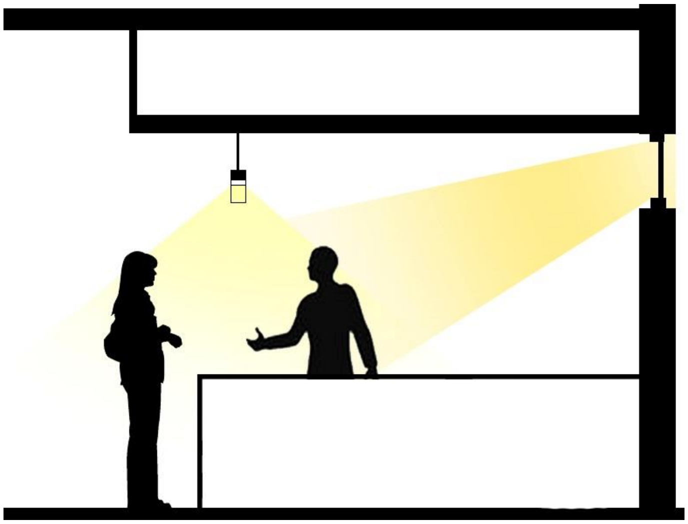

Figure 5: Market Section

9.0 SMART Building Design

Growing Power must embrace data as a resource for self-improvement. Typical building systems (security, AV, HVAC, lighting…) are organized as stand-alone operations. Meaning the systems are uninfluenced by one another and function entirely on their own. This building model does not work as an organized unit.

Systems within the Vertical Farm will not function in this way and instead they are converged over a single IP network. The various systems will have influence over one another. This allows for:

- Improved productivity
- Improved user experience
- User education
- Reduction of energy usage

The Vertical Farm is one of the first of its kind. Growing Power seeks to implement a network of vertical farms around the country. As a prototype building, Growing Power must learn from each implementation throughout the process. In order to begin, the Milwaukee Vertical Farm needs to be analyzed and evaluated. What is learned will not only improve future vertical farms, but also continuously optimize Growing Power, Milwaukee.

9.1 BIG Data

In order to improve Growing Power must collect information about energy use, system operation, and business management. The converged IP network brings all information back to a central hub of data collection servers.

***Network Architecture* –** Multiple systems within the building are ultimately tied together through fiber connections. This is the backbone cabling for the entire system. The fiber is run from the main server room (2nd floor) to local IT rooms on every other floor. A CAT 6A patch panel in each IT room works as the link for various building operations. Each floor's network IP switch and BacNET/IP switch are cross-patched to transfer data between devices, controllers, and servers. In the main server room, multiple servers are cross-patched together (local area network). Included with these will be data collection servers so that information about building operation and user interface is stored. Growing Power will use this information to continuously improve productivity.

9.2 Full Building Automation

Implementing SMART building system integration will require additional programming and applications for controllers and databases. The Synthesis Lighting/Electrical design team recognizes this and has put in place the infrastructure for a truly intelligent smart building. This means that no matter what level of smart building Growing Power chooses to implement, higher sophistication can easily be adopted.

***The Integrated Building (Level One)* –** Information will be shared between building systems though the building automation server. Example:

- Occupancy sensor will effect both lighting and HVAC control

***The SMART Building (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

***The Informed SMART Building (Level Three)* –** Information will be shared between building systems through 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

***The Intelligent SMART Building (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

[Appendix O]

10.0 Design Adaptability

The Growing Power Vertical Farm has been designed first for its current location at 5500 W. Silver Spring Dr. Milwaukee, WI. Growing Power views the new Vertical Farm as the first of its kind and aims to establish it as a local and national resource for sustainable urban farming education. With the average age of farmers at over 65 years of age[10], Growing Power believes they are responsible for educating the youth across the country. As founder Will Allen states: "our goal is a simple one: to grow food, to grow minds, and to grow community[11]."

The farm has been designed as a prototype model to inspire other Vertical Farms around the country. Although Synthesis has designed the building for any climate, Growing Power requires a specific plan for the next possible farm to be located in Miami, Florida. This section describes how the prototype will adapt to the new Miami location.

10.1 Daylighting

The architectural layout and programming of the prototype has been designed with daylight in mind for any geographical location. Results of moving to Miami are as follows:

- The Grand Outdoor Central will be moved to the eastern side of the building to warm it in the morning and keep it cool in the evening.

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[10] (Growing Power, Inc., 2014)
[11] (Growing Power, Inc., 2014)

- South facing rooms with greenhouse views will receive less daylight in Miami than Milwaukee due to the amount of time the greenhouse shades will be deployed.
- As in Milwaukee, the shade operation schedule will depend on the PAR transmittance of the polycarbonate glazing.
- Aluminum louvers will be needed for east facing windows. Shade operation with daylight harvesting will work with this to minimize solar glare and preserve views.
- North facing windows should now be introduced between the Natural HVAC intake towers. The new windows will deliver useful indirect daylight into the building without the effect of heat loss.

10.2 Greenhouse Design

The closed, modular greenhouse design creates an adaptable system that functions well in any climate around the country. The greenhouse module will adapt to its new environment in Miami in the following ways:

- The same angle of glazing will let in more useable PAR light due to a lower angle of incidence.
- As more PAR light will be admitted, a lower PAR transmittance glazing is desired if designing for current target DLI set points.
- Solar Heat Gain admitted by the glazing will be higher with the current polycarbonate material, however the cooling system is designed to handle this increased load as designed for Milwaukee.
- The current 25mm polycarbonate thickness preforms well against wind loads in Miami.
- Grow lights will still be configured in the same manner, however they will be used less due to the ample amount of useful daylight available year round.
- Shade system will use the same mounting and deployment methods, however the shade cloth material will change with respect to the new polycarbonate PAR transmittance.

10.3 Energy

The Miami Vertical Farm will function using the same quad-generation scheme as Milwaukee. The size of the anaerobic digester and microturbine will remain the same.

- Before selecting a site, Growing Power must secure initial contracts and agreements with local food waste providers. This will ensure a continuous supply of food waste for the digester.
- The natural gas grid will continue to be a secondary fuel source for the microturbine.
- The electrical grid will still be paralleled with the microturbine so that Growing Power can buy or sell energy as needed.

Because Growing Power will be providing around 42% of its annual electrical generation to their existing facilities, Growing Power will have a large excess amount of power in Miami. The location of the Vertical Farm should be coordinated with the implementation of a new community, developing a micro grid and creating an ecosystem encompassing both. The new community will receive excess power from the Vertical Farm as well as a healthy food supply, in turn they will provide Growing Power with a constant source of food waste.

This model should be the basis for new urban development and will help spawn numerous similar operations like it, creating healthy self-supporting urban ecosystems. **[Appendix H]**

10.4 Electrical, Lighting, and Controls

The power distribution scheme will remain the same when relocating the Vertical Farm to Miami. The lighting power densities meet and any code that would potentially be required in the United States, including Title 24 2013 standards for plug and lighting control. The only changes that would need to occur would be changing wire sizes to meet voltage drop requirements of the local jurisdiction.

11.0 Conclusion

The lighting and electrical system educates the buildings occupants and Growing Power itself through the use of data collection and SMART building controls. The efficient lighting and quad-generation establishes Growing Power as an ecological presentence in the Milwaukee community. And the adaptable nature of the building’s daylight, greenhouse, and lighting components all contribute to the prototype nature of the Vertical Farm. The combination of these outcomes creates a model urban farm for Growing Power and the entire industry.