Integration | Construction | Mechanical | Electrical | Structural

GROWING POWER

VERTICAL FARMING FACILITY

TOTAL BUILDING DESIGN

ENGINEERING

Architectural Engineering Institute, Annual Student Competition
Registration Number: 04-2015

GROWING POWER INC.

EXECUTIVE SUMMARY

The client, Growing Power, is a national nonprofit organization which educates the community on sustainable farming, specifically vertical urban farming. The organization's goal is to provide these communities with high quality, healthy, safe, and affordable food.

The integrated design team of Total Building Design (TBD) Engineering was asked to develop and submit plans for the new Growing Power headquarters in Milwaukee, WI. The headquarters will be a five-story vertical farm composed of greenhouse facilities, a market space, offices, and educational spaces for the community. Growing Power has also stressed that they plan to use the developed design as a prototype for future Growing Power facilities in other locations in the United States, namely Miami, FL. The TBD design team investigated what makes a vertical farm successful and aligned that with Growing Power's goals to establish the goals for the project:

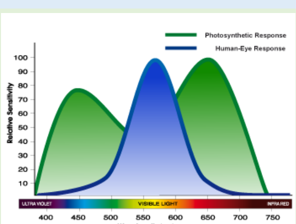
Community Outreach – The vertical farm should be an integral place of the community in which it is placed. The design team paid close attention to how decisions affected the community and how the community can benefit from the design of the systems.

Sustainability – The success of a vertical farm system relies heavily on the concept of self-sustaining technologies in order to justify the energy use associated with indoor farming. The design team therefore implemented many energy saving strategies into the design.

Flexibility – In order for the facility to successfully impact other communities throughout the country, the design implements technologies that are easily relocated and conscious of the surrounding resources. TBD strove to produce a building that will give Growing Power a strong identity.

Economy– As a non-profit organization, careful management of resources is important for success. Throughout the process, TBD designed with a goal to provide energy cost saving techniques in order to reduce energy consumption.

[LIGHTING FOR PLANTS]



Plants receive light differently than the human eye does. As a result, designing lighting systems for plants requires understanding of the PAR spectrum, in which plants have two peak wavelengths for photosynthetic absorption.

[ELECTRICAL HIGHLIGHTS]

On-Site Primary Generator Operation:
A CHP system with 2 paralleling generators offset some of the heating and electrical demand for the vertical farm site.

Greenhouse Optimization:
Plant bed design as well as roof designs were modified to optimize plant growth.

Daylight Availability Analysis:
An analysis of the available PAR levels reaching the plants were calculated to aid the greenhouse design.

Supplementary Grow Lighting Design:
A supplementary grow lighting system was designed based on target PAR levels needed for plant growth.

Façade Optimization:
Vertical fins implemented on the east and west facades provide for shading from harsh direct sunlight.

Digitally Addressable Lighting Control:
Lutron's Energi Savr Node with *Ecosystem* will control LED drivers, sensors, and shades throughout the building.

Total Building Network Design:
A total building network was designed to monitor, control, and integrate many systems implemented throughout the building.

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GROWING POWER VERTICAL FARM

BUILDING DESCRIPTION

The client, Growing Power, is a national nonprofit organization that prides itself in providing communities with healthy, high quality, safe, and affordable food. The mission of Growing Power is to promote sustainable food producing systems throughout their communities, helping to establish food security.

Figure 1: TBD's design for Growing Power Milwaukee, WI

The Growing Power Vertical Farm (fig. 1) is a proposed five-story building located in the surrounding area of Milwaukee, WI. The 52,585 S.F. building will have 11,249 S.F. of south-facing green house space and 41,336 S.F. of mixed use office, educational, and retail space. Because the client operates as a national nonprofit organization, they have a long term vision of using this vertical farm as a prototype for future locations, specifically in Miami, FL. The challenge given to the Total Building Design (TBD) team is to provide Growing Power with a facility that will enable them to achieve their goals, utilizing the best engineering practices.

The electrical design team of TBD Engineering modeled the self-sustaining goals of the client and delivered the community a building that teaches the value of sustainable design. The design of the electrical systems will focus on on-site energy production, energy saving techniques, and optimization of the greenhouse design. The greenhouse design will incorporate optimal structure and glazing, plant bed layouts, and supplementary lighting systems based on daylight availability studies.

PROJECT INITIATIVES

Flexibility

Develop a facility to be used as a prototype for other possible sites across the country, while meeting the changing needs of Growing Power by providing options for continuous improvement.

Community

Strengthen the community outreach by providing ample space for education and enabling the surrounding population to participate in the growing methods used within the vertical farm.

Sustainability

Create a facility with a manageable lifecycle cost aided by the use and optimization of renewable energy, renewable resources, and sustainable practices in design and construction.

Economy

Provide the best product for the budget developed by Growing Power while continuously providing cost savings and exploring funding expansion.

BUILDING ANALYSIS

BUILDING NEEDS AND DEMANDS

Vertical farming is an innovative, forward thinking strategy to year round organic production, however, creating an ideal indoor environment for plants throughout the year requires a massive amount of energy compared to outdoor farming. Therefore, in order to make Growing Power's vertical farming technique sustainable and successful year-round, exploring energy efficient products and energy-saving strategies to offset energy consumption within the building is a major objective.

Because Growing Power's Milwaukee campus will be used as a prototype for future Growing Power buildings in many other locations, designing the building electrical, lighting, façade, and greenhouse systems to be flexible as possible is vital in order to easily relocate this design to other cities with only minor changes.

Additionally, Growing Power should have the ability to track the building energy use and operations in order to see how the prototype is performing and to engage and teach the community about their processes.

To maintain the target value for the non-profit organization, energy cost saving techniques should be utilized.

[BUILDING SUMMARY]

Milwaukee, WI

Miami, FL

MILWAUKEE SITE:

Typical Daily Peak Building Electrical Demand:

310 kW

Yearly Electrical Energy Consumption:

1,776,185 kWh

Latitude: 43°N

Longitude: 87.95°W

Surface Azimuth: 0°

POWER

POWER GENERATION

In order to offset the typical peak daily building electrical demand of **310 KW** and the yearly power consumption of **1,776,185 kWh**, simulations and calculations were performed to decide the optimum alternative energy solution the Milwaukee site (SD|II)

SOLAR & WIND

To promote the awareness and education of sustainability throughout the community, TBD wanted to provide Growing Power with every opportunity to showcase their contribution to the effort. In addition to the sustainable statement that the greenhouses demonstrate, solar and wind power were also explored.

A summary of the power that could be produced using photovoltaic (PV) arrays and wind turbines can be seen in Table 1. Ultimately, site constraints did not allow TBD to optimally utilize PV arrays or wind turbines in Milwaukee, but in recognizing their large educational benefit, TBD has outlined a set of criteria for future use by other prototypes, including issues that arose that contributed to the decision to not use these strategies in Milwaukee, (SD|III,IV).

Table 1. Solar and wind energy potential, respectively

Solar	SF	Annual Production
	(m^2)	(kWh)
	173	20,023

Wind	Blade Length	Annual Production
	(m)	(kWh)
	3	11,731

COGENERATION

Since renewable sources were not sufficient, sustainable measures in offsetting the building electrical demand, onsite power generation was utilized. In conjunction with the mechanical partners, TBD designed a Cogeneration system, also known as a Combined Heat and Power (CHP) system, which involves generating power with the intention of recapturing the waste heat to use for building heating (fig. 2). Additionally, this system can be coupled with an anaerobic digester for methane production or a soybean biodiesel producer depending on the site location to create fuel for the generators. For Milwaukee, an anaerobic digester was utilized (Mech|8).

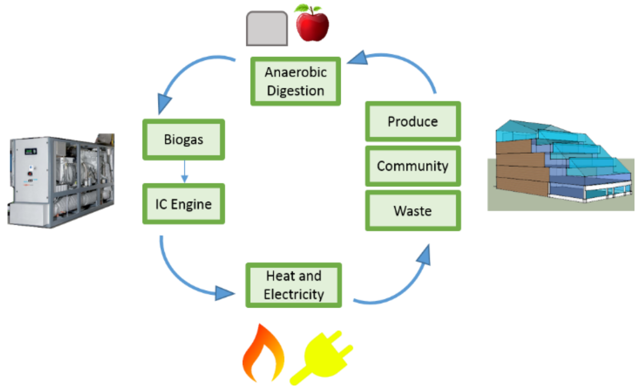

Figure 2. Cogeneration and anaerobic digestion closed loop process

To perform at the highest efficiency, the thermal to electrical demand of the site and the CHP facility should be equal. In order to achieve this ratio at Growing Power's Milwaukee site, the generator was sized based on a bottoming cycle.

[INTEGRATED SOLUTION]: COMBINED HEAT AND POWER DESIGN

Bottoming Cycle is a way to size a CHP system in which the heat from the generator is the primary product utilized, and the power generated is the secondary product. The mechanical and electrical team worked closely together to analyze the building's heating and electrical loads to optimally size the generator to offset as much of the demands as possible, while maintaining the efficiency of the CHP system. The results proved the system to be 87% efficient (Mech|10).

Power is generated by two **55 kW** internal combustion engines, which will use biogas produced from the anaerobic digestion process as well as natural gas from the utility to offset building demands. One generator can run at full output, and a second generator can run on part-load operation as needed to meet the heating demand. Utilizing two paralelling generators allows for a longer life span, since each can be rotated and used at the lower output operation. Implementing two small generators is also beneficial for redundancy, as well as for easier removal and repair. Additionally, energy costs and reliance on the grid are reduced by using natural gas instead of electricity during on-peak hours (Mech|12).

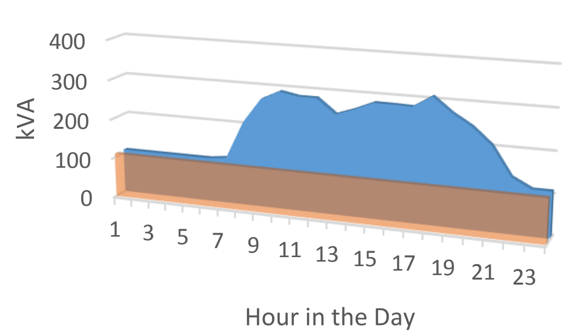

Figure 3. Typical weekday electrical consumption (blue) vs. maximum generator output (orange)

With a typical daily electrical peak demand of **310 KW** (fig. 3), the generators, both performing at their maximum output, offset the building's nighttime load by an average of **98%** and offset the daytime load by an average of **41%** (SD|II).

ELECTRICAL DISTRIBUTION

The main electrical room (fig. 5) is in the basement of the building, which includes an areaway that was added on the east end for easy removal or replacement of equipment. Incoming power from an exterior utility transformer feeds an 800A 480/277V paralleling switchboard comprised of four sections. The first section is for the incoming utility power, and the second section includes the relay and synchronizing controls, which ensures that all of the incoming power generated on-site has the same frequency, phase, and voltage as the grid.

Another section contains two backfeed circuit breakers for the two paralleling 55KW generators, which are also housed in the main electrical room. If the building electrical demand is lower than the generator output at times, power will be exported back to the utility. Net meters are provided in order to measure and control the amount of electricity that is flowing to and from the grid.

The last section of switchboard provides distribution to the building loads, which include a lighting panelboard, mechanical equipment panelboards, greenhouse equipment panelboards, and receptacle panels via a 112.5 kVA transformer and distribution panel. Additionally, an emergency lighting panel will be fed through a central inverter, which provides ninety-minutes of backup battery in an outage for life safety systems.

[AQUAPONICS]

Aquaponics is a technique for growing plants that creates a symbiotic cycle between fish and plants. As fish are raised, nitrates build-up in the tanks, which must be removed to provide for a healthier fish environment. However, in aquaponics, this nitrate-rich water is utilized for cultivating plants in water, as the plants use the nitrates as nutrients. The nitrate-free water is then recirculated back to the fish.

Figure 4. Aquaponics system

However, the generators can also supply power during an outage for optional, yet critical, loads on the panelboards serving the equipment in the greenhouses. Even a couple minutes without power to the aquaponic pumps and fans could ruin Growing Power's growing processes (fig. 4). To ensure that the greenhouse processes do not shut down, the generator will prioritize these panelboards through contactors. Contactors are placed upstream of each panelboard and receive signals from the building automation system (BAS). Based on the generator loading, the BAS can open a contactor to shut off that panel and shed the load.

For future locations where Growing Power wants to implement solar and wind power, additional circuit breakers can be added to the distribution section of the switchboard, where the incoming power harvested can backfeed the switchboard via a DC voltage to AC voltage inverter (D2,D3,D10).

[INTEGRATED SOLUTION] DESIGN COORDINATION

In order to house all the mechanical and electrical equipment, which includes specialty systems for the greenhouses, additional space was allotted in the basement. The mechanical, electrical, and structural teams had to work closely to ensure all equipment fit in the structure with the proper clearances (Int|2).

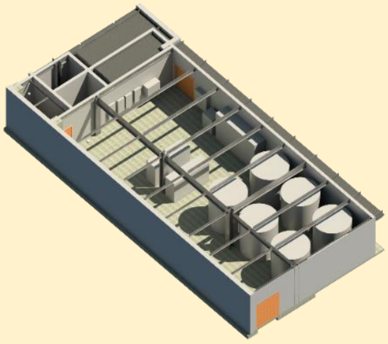

Figure 5. Electrical and mechanical equipment including anaerobic digester tanks.

LIGHTING & DAYLIGHTING

GROWING SPACES

ROOF & GLAZING DESIGN

Integral to the success of Growing Power's vertical farm is ensuring that adequate daylight is available to produce a wide variety of crops through aquaponic techniques. Instead of using pre-manufactured greenhouses, TBD optimized the design of the greenhouses to maximize the amount of daylight reaching the space, minimize the amount of supplementary electric lighting required, and eliminate unnecessary glazing to lower heating demands.

For maximum sun exposure, a glazing with a visible transmittance of 91% was utilized. Analysis on the original gabled roofs of the 2nd, 3rd, and 4th floor cascading greenhouses show that eliminating the eastern and western glazing reduced the glazing area by **22%** and only reduced the spatial daylight autonomy by **2.6%**. Consequently, these areas were replaced with circulation fans for greenhouse processes.

Through further elimination of the northern glazing, the glazing area was reduced by **41%** and the spatial daylight autonomy was only reduced by **8%**, which is still imperceptible. Therefore, TBD designed a new roof structure that maximizes sunlight exposure while minimizing glazing area to alleviate heating and cooling costs (SD|V).

The optimum angle to maximize sunlight incident on a surface is the degree of latitude that the site is located (fig. 6), which for Milwaukee is 43°N [(1)]. The TBD electrical team worked with the structural team to design a minimal roof structure with a single slope of **40°** for prototypical purposes (Struc|11). This latitude angle is about halfway between the main portion of the United States, whose latitude ranges from around 25°N to 50°N (fig. 7). At any new Growing Power location in the United States, the roof angle will always be within 10 to 15° of the optimal angle. Improvements to the original roof design can be seen in figures 8 and 9 on the next page.

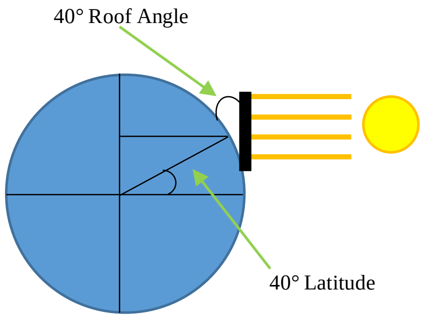

Figure 6. Optimal tilt angle to maximize sunlight exposure

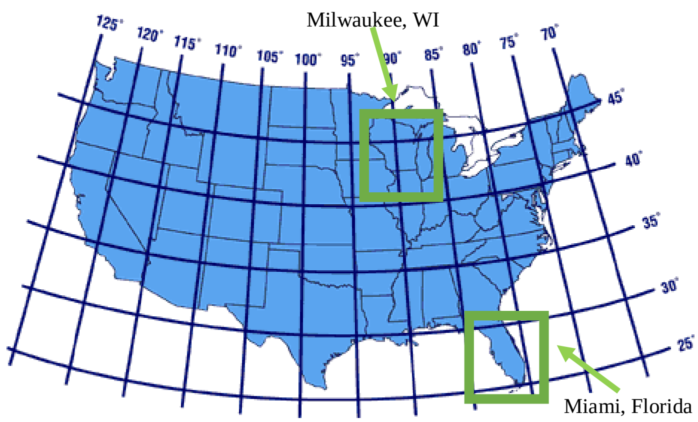

Figure 7. Latitude range of the United States

For the 5th floor greenhouse, the original multi-gabled roof required redundant structural components (fig. 10). TBD's electrical team worked with the structural team to minimize the amount of structure and maximize the amount of daylight exposure. The 40° single-slope roof designed for the lower floors was not continued on the 5th floor due to structural height concerns (Struc|12). An analysis between the electrical and structural teams resulted in a single gabled roof with a tilt of **15°**, which decreased the height but still provided an angle for increased southern exposure (fig. 11).

[INTEGRATED SOLUTION]: ROOF GREENHOUSE STRUCTURE

Although the 40° single-slope design would have been ideal from a daylighting standpoint, it created issues for the structural and mechanical team. This slope produced a greenhouse height that not only was a large amount to condition for the mechanical team, but it also created large localized wind pressures and snow drifts for the structural team. As the angle did not affect the daylight in this case, a table was formed to analyze the increase in the amount of structure for the increase in angle, as members can obstruct daylight. This resulted in an optimal 15° roof angle (Int|12).

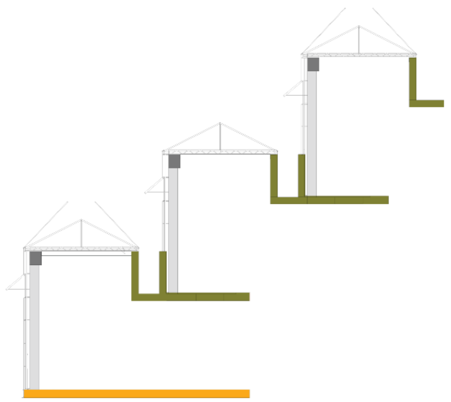

Figure 8. Original roof design for the lower greenhouses

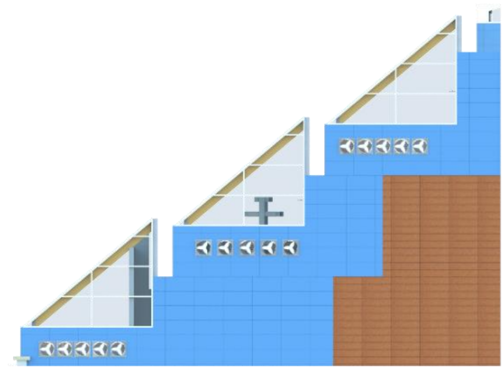

Figure 9. TBD's improved roof design for the lower greenhouses

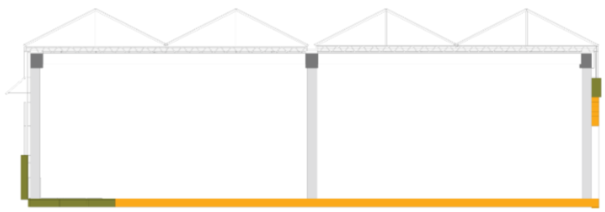

Figure 10: Original roof design for the upper greenhouse

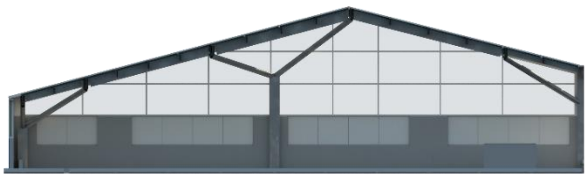

Figure 11: TBD's improved roof design for the upper greenhouse

LIGHTING FOR PLANTS

Analyzing light for plants requires a different process than for humans, as plants do not absorb light the same way humans do. Typically, light is quantified by a flux density metric called illuminance [lumens/m^2 or lux], which is weighted based on the human eye's response to electromagnetic radiation in the visible spectrum (400-700nm) of the global radiation spectrum.

The photosynthetic process of plants, however, is triggered by the absorption of electromagnetic radiation within a spectrum known as photosynthetically active radiation (PAR). The amount light in the PAR region reaching a plant is quantified using a flux density metric known as photosynthetic photon flux density (PPFD) [μmol $m^{-2}s^{-1}$] (fig. 12) [(10)].

The essential green pigment found in plants, Chlorophyll, has two specific forms, "a" and "b", that are responsible for capturing this energy. Chlorophyll "a" and chlorophyll "b" have specific absorption peaks within the PAR spectrum (fig. 13). Optimal plant growth requires radiation at these peak wavelengths.

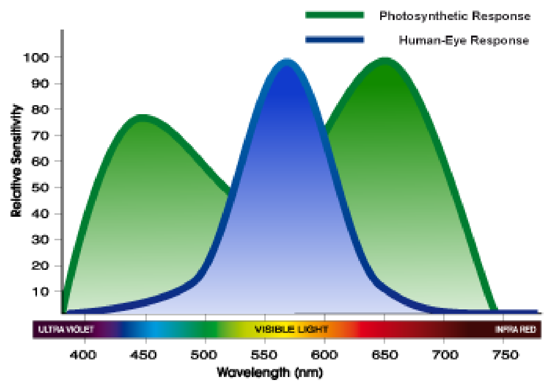

Figure 12. Human response (blue) vs. the plant response (green) to the visible spectrum

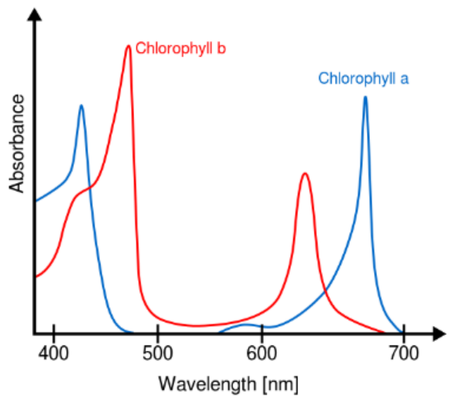

Figure 13. Chlorophyll absorption peaks

To analyze the amount of daylight reaching a plant in a day, a metric called the daily light integral (DLI) [mol $m^{-2}d^{-1}$] is used. Studies on lettuce grown in hydroponic applications have shown a DLI between 14 and 17 yields optimal growth. With a DLI below 14 mol $m^{-2}d^{-1}$, plant chlorophyll is not absorbing enough radiant energy, and above 17 mol $m^{-2}d^{-1}$, CO_2 entry through the leaves may be hindered, having adverse effects. For simplification, a DLI of 14 mol $m^{-2}d^{-1}$ is also known as 14 PAR, a term which will be used for the remainder of this analysis [(8)].

PLANT BED DESIGN

Analysis of the original plant bed design showed that although the combination of vertical beds rotating in a horizontal plane plus stationary horizontal beds underneath allows for more growing space per floor area, obstruction from overhead beds creates a light loss problem (SD|VI). As a result, the original plant bed design (fig. 14) was divided into two parts to analyze further: vertical beds rotating in a vertical plane versus one layer of stationary horizontal beds (fig. 15, fig. 16).

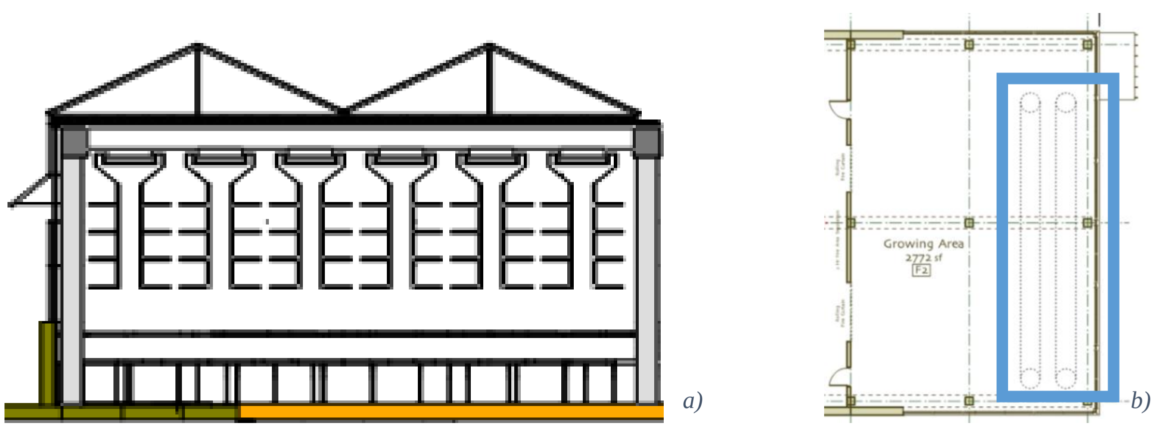

Figure 14. a) Original plant bed system in elevation b) in plan, showing the horizontal rotation

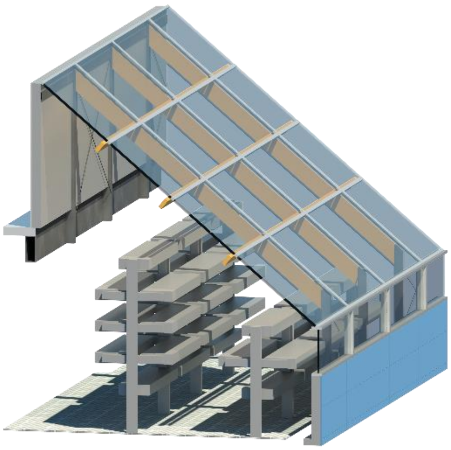

Figure 15. TBD's vertical bed design

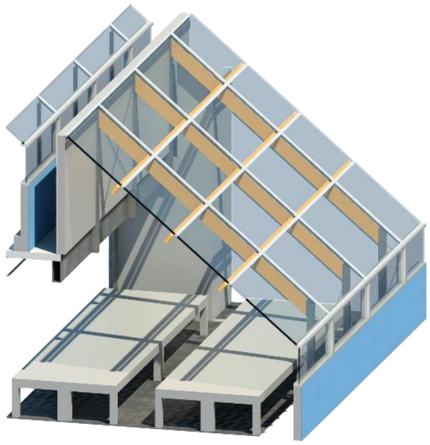

Figure 16. TBD's horizontal bed design

DAYLIGHT AVAILABILITY ANALYSIS

To determine which bed layout receives the most PAR, a daily light integral (DLI) analysis was performed, which calculated the amount of PAR [mol $m^{-2}d^{-1}$] reaching each of the bed configurations. This measurement was then used to quantify the amount of supplementary lighting needed to compensate for days when there is insufficient daylight. Studies show that the most suitable design criteria for determining the amount of supplementary light needed was not through an average PAR method for the beds, but through a percentile exceedance method. This method provides a way to quantify the percentage of days in a year that supplementary lighting is needed and thus shows if a location is a suitable area for optimal plant growth. A location with a higher percentile would require less supplementary lighting and, as a result, less energy use because sunlight alone is sufficient in reaching the plant's daily light integral (3,4). The equation below provides a formula to the supplementary lighting design process:

$$available\ daylight\ integral + supplementary\ light\ integral = daily\ light\ intregral\ (DLI)$$

In the Milwaukee design, the target daily light integral for each plant bed was 14 PAR, and the percentile exceedance value chosen was 95%. This metric, **14 PAR $_{95\%}$**, ensures that at least 14 PAR reaches a bed for 95% of the days of a year. The first step in this process is to determine the **available daylight integral** for both the horizontal and vertical beds through accurate modeling and annual simulations with weather files. The results of these simulations can be seen in Table 2 for both bed configurations for the lower greenhouses as well as the top greenhouse (SD|VII,VIII).

Table 2. Available daylight integral percentile exceedances

	Horizontal Bed Configuration		Vertical Bed Configuration	
	14 PAR Percentile	Average PAR Deficiency	14 PAR Percentile	Average PAR Deficiency
Lower Greenhouses	89.9%	4.0	52.9%	5.0
Top Greenhouse	96.7%	2.7	79.6%	2.3

The best and most efficient location for plant growth in Growing Power's vertical farming facility is in the top greenhouse on a horizontal bed. This was only bed location to reach the target 14 PAR $_{95\%}$, so it will require the least amount of supplementary lighting. The horizontal beds performed much better than the vertical beds in general, and the least efficient location for growing would be in a vertical bed in the lower greenhouse. However, for educational purposes, both vertical and horizontal bed configurations will be utilized in Growing Power's design.

SUPPLEMENTARY LIGHTING DESIGN

Using the percentile exceedance results, the **supplementary light integral** was calculated to meet the **target daily light integral** of 14 PAR. Knowing the average deficiency from 14 PAR for each bed, the amount of supplementary PPFD needed was calculated. This number was then compared to the PPFD output of horticulture lighting fixtures in order to decide the amount of fixtures needed.

A lightweight, wet-location rated (IP66) LED strip fixture will be utilized (fig. 17) which has light output in the PAR spectrum that peaks at the same wavelengths as chlorophyll absorption. For the horizontal beds, these fixtures will be mounted to a thin, adjustable bar overtop the beds in order to minimize obstructions from daylight and provide for flexibility. For the vertical beds, fixtures will be mounted underneath each bed to provide light to the beds below.

These fixtures connect to a waterproof power bar, which provides for a plug-and-play operation. A maximum of four fixtures can be plugged into the power bar, and power bars can be connected together to complete a circuit. Additionally, these fixtures can be dimmed [7]. This setup is ideal for an educational facility, as lighting can easily be modified (SD|IX).

Figure 17. Illumitex ES2 supplementary grow light fixture

[INTEGRATED SOLUTION] GREENHOUSE GRATE

A floor grate system was designed by TBD's structural team to provide for a convenient space for electrical conduit and plumbing piping, as well as for a safe walkway (fig, 18) (Int|13).

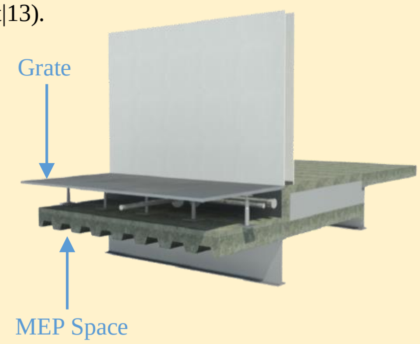

Figure 18. Floor grate system in greenhouses

GREENHOUSE SHADING

Greenhouses typically require a glazing with a high visible transmittance of 91%. However, as seen in the available daylight integral results above, some beds receive above the maximum preferred 17 PAR, which can harm the plants. For extreme cases, a retractable interior shading system will be used to limit the daylight and optimize the daily light integral via photosensor algorithms. *Living Shade's Svensson Climate Screens* (fig. 19) provide specific shading options depending on a location's climate, so each new Growing Power building

Figure 19. Svensson Screens

should re-assess shading options [6]. For Milwaukee, the *XLS* option is recommended due to the site having wet plants and high heating costs. The *Firebreak* line of XLS screen reflects sunlight away and traps heat at night, thus saving energy and heating costs (Table 3).

Table 3. Screen performance properties

Type	Direct Light Transmission	Diffuse Light Transmission	Energy-Savings
XLS 16 Firebreak	36%	34%	62%

GREENHOUSE GENERAL LIGHTING

For general occupant lighting in the greenhouses, a wet-rated surface mount fixture was implemented. In the lower greenhouses, the fixture will be mounted to the open ceiling structure in the back half of the greenhouse that does not have glazing. For the penthouse, since the entire space has glazing, the fixture will be mounted to the truss structure above (SD|X).

COMMUNITY SPACES

FAÇADE

Replication of the symbiotic process of the fish and plants was the main concept for the lighting design in the communal spaces of the building. The goal was to have the lighting respond seamlessly to natural daylight in the space. As occupants utilize daylight, less energy is used for electrical lighting, which gives back to the environment, creating a symbiotic relationship.

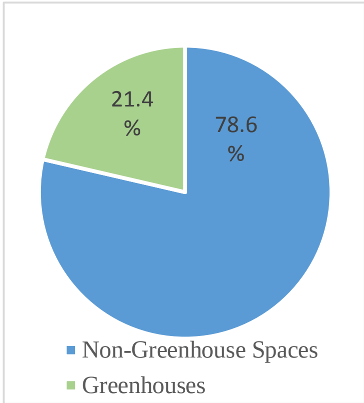

Figure 20. Building area program

As the building will be primarily occupied during the day, when plant growth and the opportunity for education is most abundant, the building should take full advantage of the naturally occurring daylight in non-growing spaces, which comprises about 78% of the building area, in order to alleviate additional energy usage (fig. 20).

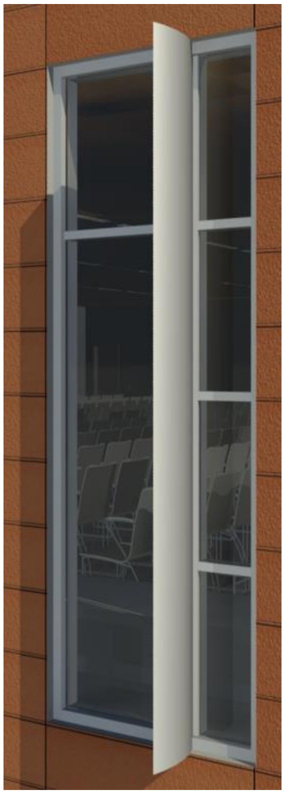

Figure 21. Vertical fins design to block direct sunlight

The original window configuration was optimized to increase daylight availability. Two visible transmittance (VT) values were analyzed. A VT of 71% required shades to be deployed for **40%** of the year to maintain a target illuminance value. As a result, the VT was lowered to 54%. Miami-Dade Certified vertical fins were also added to the east and west façade's windows in order to block uncomfortable direct sunlight and minimize the amount of time the shades need to be deployed in order to maintain views to the exterior (fig. 21). This design was an improvement, as shades only needed to be deployed for **12%** of the year. Additionally, the new design can save **81%** energy through utilizing automated

[INTEGRATED SOLUTION]
FAÇADE DESIGN

A rain screen (fig.22) was designed with the intent of providing a flexible façade system to implement in many locations (Int|10).

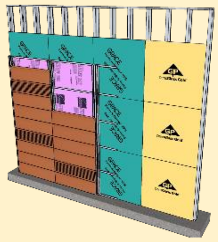

Figure 22. Rain screen façade

photosensor controls in the control zones, whereas the first iteration could only save **17%** energy (SD|XI).

INTERIOR SPACES

Throughout the building, LEDs were utilized as the light source. By implementing low wattage sources, the lighting power density (LPD) was designed **63%** under the lighting power density allowed by code IECC 2009. Additionally, the color temperature is standard throughout the building at 4000K, as it more seamlessly transitions with daylight than a warmer source.

The lighting control system implemented into the building is the *Lutron Energy Savr Node* (11) with Ecosystem (fig. 23). A node can digitally address zones of LED drivers via two control loops, each of which can control 64 LED drivers. Photosensors, occupancy/vacancy sensors, and wall stations can also be connected to the loops. Nodes are linked to other main control devices, such as motorized shade controllers and lighting scene controllers and can then refer back to the Quantum lighting management system, which allows users to monitor, control, and optimize these systems through a server. Utilizing this flexible control system allows facility personnel to easily reconfigure lighting zones, receive maintenance alerts, and monitor energy savings (SD|XII).

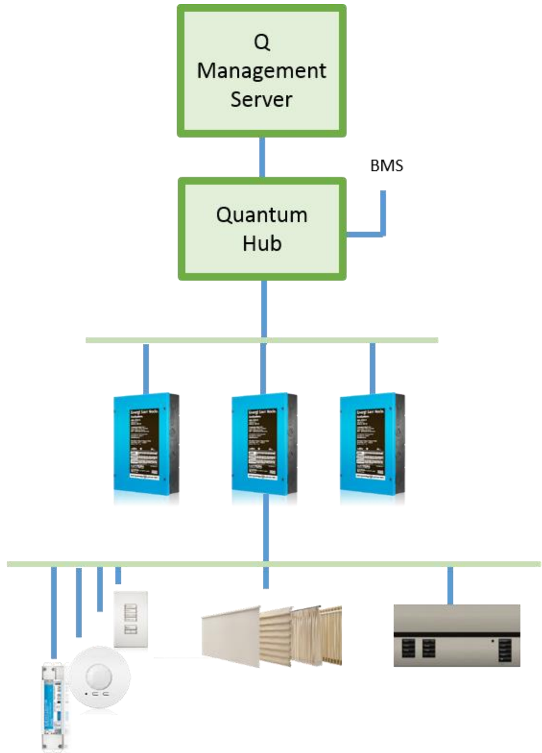

Figure 23: Lutron lighting control system

The main spaces to highlight in the building include the Market, Gathering Space, Classroom, Conference Room, and Open Office (D4,D5).

MARKET

In the Market space, the electrical team aimed to establish the environment of a traditional indoor farmer's market. As the market is the main entrance, a thematic, low-bay fixture for ambient light was implemented into the exposed structural ceiling. Additionally, LED track lighting highlights the main counters to provide lighting for critical tasks and displays (SD|XIII).

GATHERING SPACE

In the Gathering Space, used for everything from lectures to open houses, flexibility in the lighting and control system was key, as there is no fixed furniture in the space. A linear scheme was developed that implemented a recessed linear fixture in line with a recessed two-lamp adjustable downlight, providing opportunities to light the space in many ways. Through a wall station scene controller, preset scenes can be configured for typical tasks in the space, such as audio/visual presentations, lectures, displays, or charrettes. These wall stations can not only control the lights, but they can also control the motorized shades within the room (fig. 24) (SD|XIV).

[INTEGRATION SOLUTION]:
Design Coordination

The removal of columns within the middle of the gathering space reduced plenum space, which required careful systems integration and coordination between the electrical, structural, and mechanical team. Between beams, a linear scheme of slot diffusers and lighting fixtures solved this issue (Int|15).

Figure 24. Gathering space

CLASSROOMS

To provide for a more pleasant working environment, daylighting strategies were important for these spaces. As a result, the original western classroom was relocated to increase exterior wall area and offer more window area. Direct/indirect pendants dimmed through photosensors provide ambient lighting, while wall washers highlight the white board, and downlights highlight the speaker’s workplane at the podium. For modes such as audio/visual presentations, lectures, and general notetaking, a wall station scene controller is provided. Additionally, automated motorized shades, controlled through photosensors, are utilized and will lower or raise to maintain an illuminance that maximizes daylight and minimizes electric lighting (SD|XV).

CONFERENCE ROOM

The conference room was also repositioned from a central location, in order to increase the amount of daylight through additional window glazing. Scene control was an important factor in this space, as modes such as audio/visual presentations and meetings require very different illuminance levels. To achieve a flexible environment, three layers of light were implemented. Recessed linear fixtures highlight the conference table; wall washers highlight the whiteboard; and downlights provide ambient light toward the outer perimeter. A wall station will also be used in this space for preset scene control as well as shade control (SD|XVI).

OPEN OFFICE

The open office, reconfigured to a more central location of the building to improve circulation, contains direct/indirect fixtures for ambient light, and task lighting is implemented at the desks for more local control. Plenty of daylight penetrates the space, so electric light dimming as well as automated shading is controlled via photosensors (SD|XVII).

SUB-SYSTEMS

TELECOM

The main telecom room is on the third floor of the building, which houses the data racks, security equipment, and building automation systems (SD|XIX). Each voice/data outlet placed throughout the building will feed into the patch panels located on the racks in the telecom room. Furthermore, power systems furniture with a four-circuit configuration will be implemented in the open office area and will provide each workstation with two CAT 5 drops per desk for data equipment, three duplex receptacles, and one duplex receptacle dedicated for a computer [15] (fig. 25). Utilizing a power systems furniture design allows for easier management of cables within the work area (D2,D3).

Figure 25. Typical power systems furniture setup

SECURITY

Growing Power's building is open to the community. However, there are areas that need to be secured from the public. Card readers are implemented in the elevator lobbies in order to access the 4th floor office space, and they are also placed at the doors to the mechanical, electrical, and other equipment rooms for safety reasons. Security cameras will also be placed throughout the building in areas with expensive equipment for surveillance. (D2,D3).

FIRE ALARM

Based on IBC 2009 and NFPA 72, fire alarm devices were placed throughout the building. The main fire alarm equipment is located in the basement. For visual fire alarm notification, strobes were placed throughout the building based on their candela values, which is a rating to indicate how far away the strobe light can be seen. For audible notification, combination horn/strobes were also placed in main areas of the building based on appropriate decibel levels for the occupants to be alerted. Smoke detectors were located in elevator lobbies for elevator recall, as well as HVAC ducts in order to prevent smoke from spreading throughout the building [17] (D6, D7, SD|XVIII).

Figure 26. Machine-room-less elevator highlighting its (B) compact gearless machine, (C) compact controller, and (E) small hoistway

ELEVATORS

The original elevator at the north end of the building will be utilized as a freight elevator in order to deliver equipment to greenhouses. An additional elevator was added in a more central location of the building to be used as a passenger elevator. However, space for another elevator machine room was limited in the basement due to all the specialty mechanical and electrical equipment. To solve this issue, a machine-room-less elevator was implemented. This type of elevator does not require a full elevator machine room, as all of the controls are in the shaft [16] (fig. 26).

TOTAL BUILDING NETWORK

To create a holistic building that seamlessly integrates the vastly different systems throughout the spaces, a building network was implemented that can monitor and control devices from one server (fig. 27). The most significant reason for embracing this system is to help Growing Power in its mission to prototype their building. By tracking the operations of the systems, building operations can be analyzed and easily adapted to the climates of future Growing Power sites. Additionally, statistics from the systems can be displayed to the community to increase awareness of sustainable design and processes.

Figure 27. Building network system

The main piece of equipment in this network is the building automation system server, which can be accessed by any computer that is on a shared network, or through an internet browser remotely. The server is connected to a BACnet/ Internet Protocol (IP) backbone, which is comprised of Ethernet wiring. Stemming from the backbone are BACnet/IP devices, controlling and monitoring many different types of building systems, such as energy meters, panelboard controls, HVAC controls, lighting controls, security devices, telecom, fire alarm devices, and greenhouse controls. All of these devices report back to the server for one, convenient location to control and view operations of building systems [14] (SD|XIX).

CONCLUSION

The world is limited in its resources, while an ever increasing population threatens to deplete the land by both consuming the food produced in agricultural fields and by replacing farm land with new buildings. The solution to producing enough food to meet the increasing demand while conserving land is the vertical farm. The electrical design team of TBD Engineering has designed a five-story vertical farm facility in Milwaukee to enable the client, Growing Power, to carry out its vision of providing the surrounding community with healthy, affordable food.

The lighting and electrical design incorporates a growing facility which focuses on optimized plant production through a thorough investigation of PAR values. The PAR study deduced the quantity of supplemental radiation required for successful growth.

Through the use of lighting controls and daylight analysis, the design eliminated excess energy consumed by the building. In addition, onsite power generation through a combined heat and power system helped offset 41% of day-time loads and 98% of nightly loads.

The building network serves as an educator to both the community and Growing Power by tracking data that will help analyze building performance to aid in the design of future Growing Power vertical farm sites in other locations.

The Growing Power Vertical Farming Facility is a modern solution to meet an increasing demand in food. The electrical team of Total Building Design has designed the facility with an emphasis in optimized growing space and energy saving methods throughout the building to give Growing Power a facility that properly represents Growing Power as a leader in healthy and environmentally conscious food production.