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:

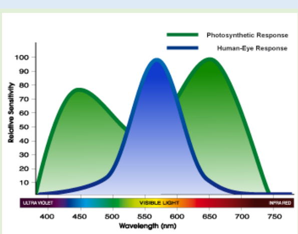
Community Outreach – The vertical farm should be an integral place of the community in which it is placed. The design team paid close attention to how decisions affected the community and how the community can benefit from the design of the systems.

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

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

	Blade Length	Annual Production
Wind	(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).

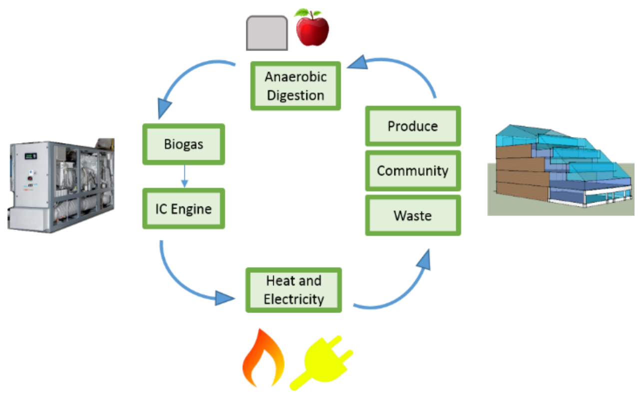

Figure 2. Cogeneration and anaerobic digestion closed loop process

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).

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).

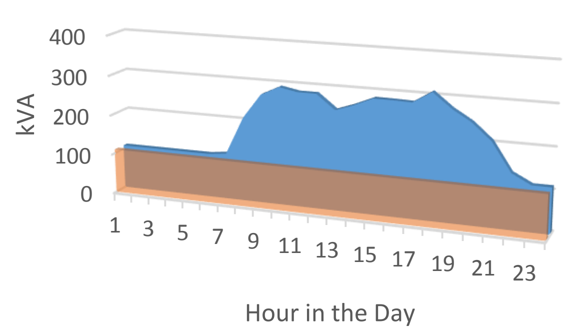

Figure 3. Typical weekday electrical consumption (blue) vs. maximum generator output (orange)

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).

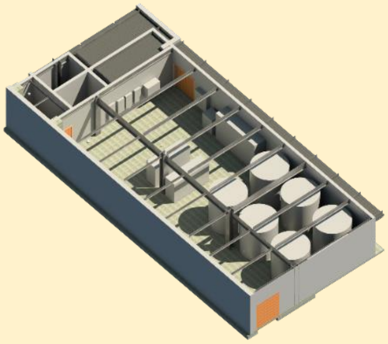

Figure 5. Electrical and mechanical equipment including anaerobic digester tanks.

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.

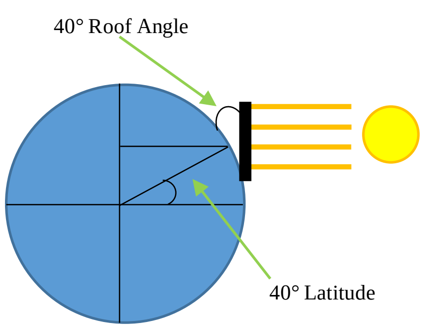

Figure 6. Optimal tilt angle to maximize sunlight exposure

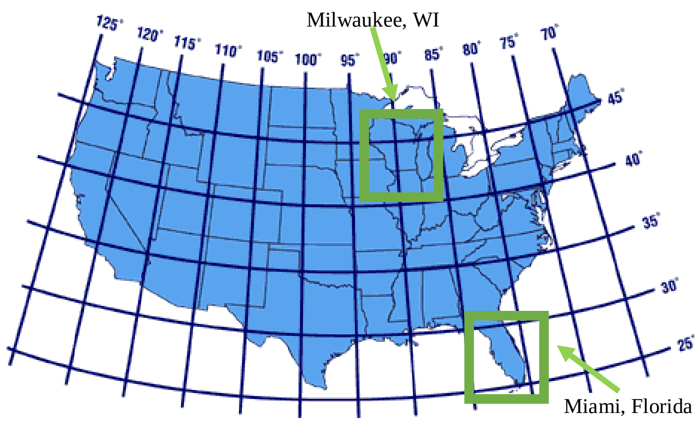

Figure 7. Latitude range of the United States

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).

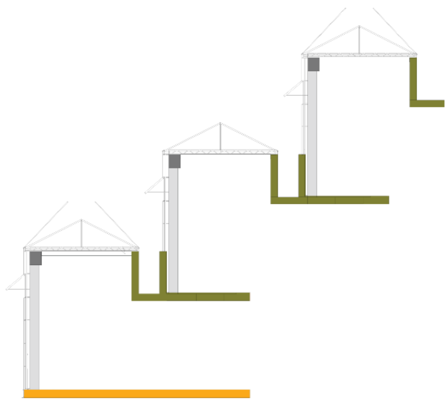

Figure 8. Original roof design for the lower greenhouses

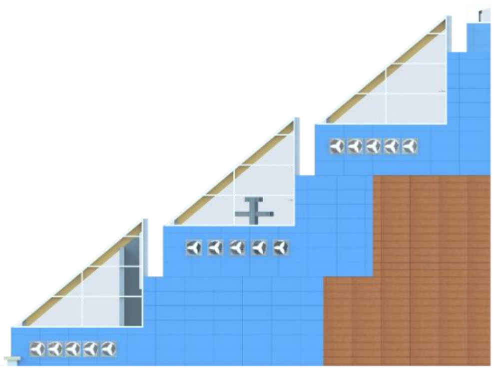

Figure 9. TBD's improved roof design for the lower greenhouses

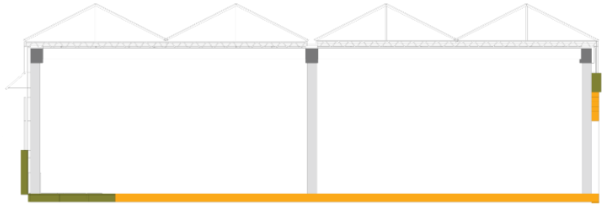

Figure 10: Original roof design for the upper greenhouse

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.

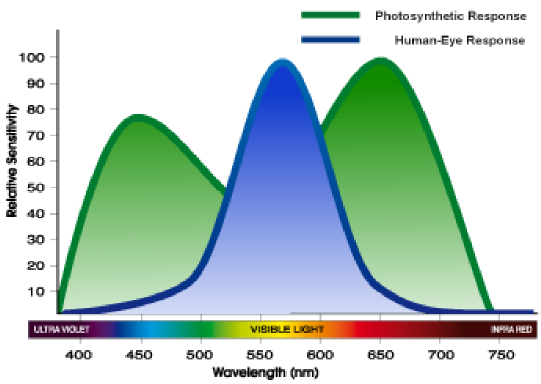

Figure 12. Human response (blue) vs. the plant response (green) to the visible spectrum

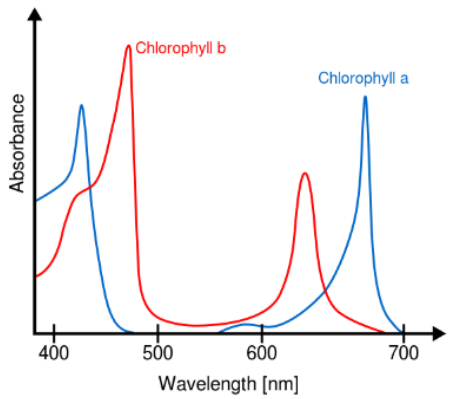

Figure 13. Chlorophyll absorption peaks

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).

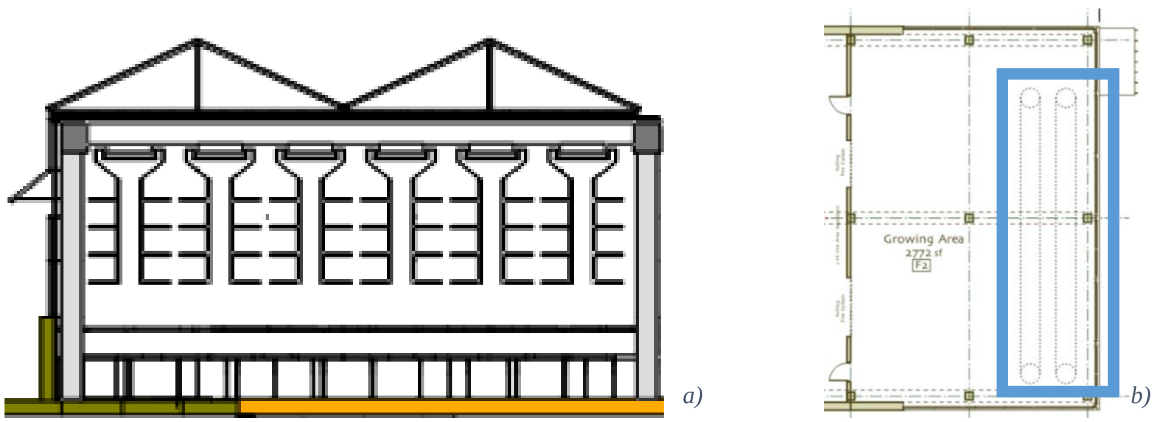

Figure 14. a) Original plant bed system in elevation b) in plan, showing the horizontal rotation

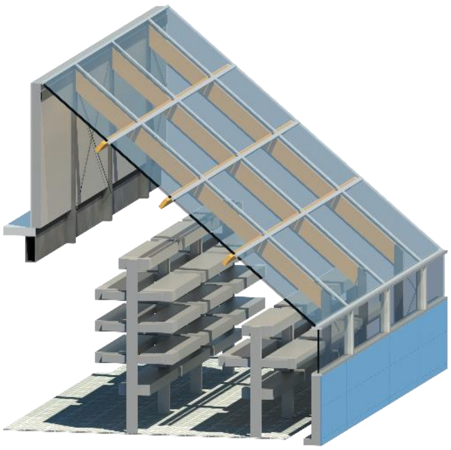

Figure 15. TBD's vertical bed design

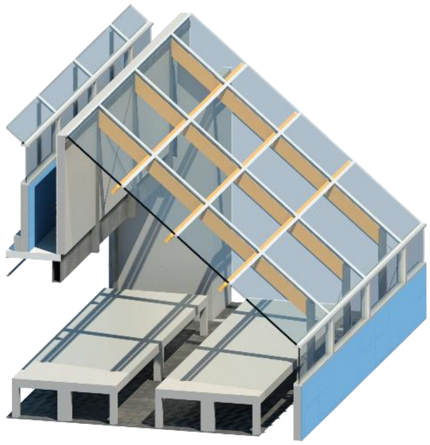

Figure 16. TBD's horizontal bed design

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).

[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).

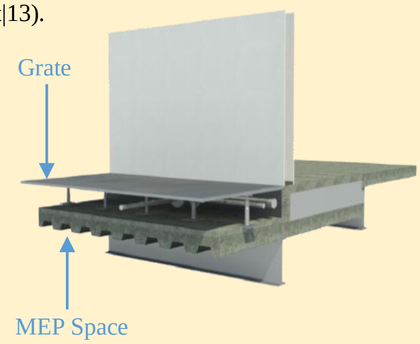

Figure 18. Floor grate system in greenhouses

Figure 17. Illumitex ES2 supplementary grow light fixture

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.

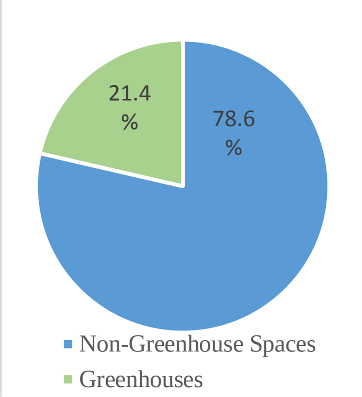

Figure 20. Building area program

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).

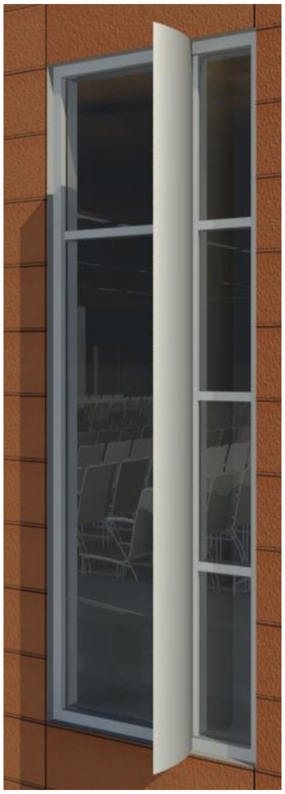

Figure 21. Vertical fins design to block direct sunlight

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).

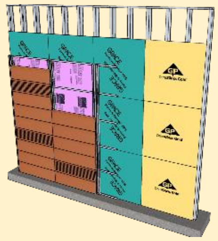

Figure 22. Rain screen façade

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).

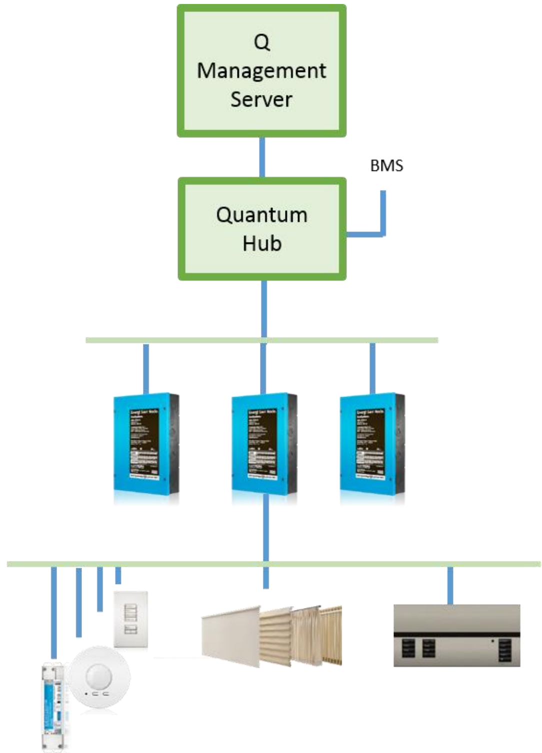

Figure 23: Lutron lighting control system

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).

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).

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

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.

SUPPORTING DOCUMENTS

REFERENCES

CODES AND HANDBOOKS

Wisconsin Commercial Building Code

International Building Code 2009

IECC 2009

2010 Florida Building Code

National Electrical Code 2011

NFPA 72

Illuminating Engineering Society Handbook 10th Edition

COMPUTER PROGRAMS

Autodesk Revit 2014

ElumTools 2014

DAYSIM

Ecotect Analysis 2011

Microsoft Excel 2013

REPORT IMAGES

Figure 2: Generator image in cycle figure courtesy of Viessmann

Figure 4: Aquaponics image courtesy of Nelson Pade

Figure 7: United Stated Latitude map courtest of Tutapoint

Figure 12: Visible spectrum response image courtesy of Sunmaster Grow Lamps

Figure 13: Chlorophyll absorption peak graph courtesy of Wikipedia

Figure 17: Grow Light image courtesy of Illumitex

Figure 19: Greenhouse shading image courtesy of Svensson

Figure 23: Lighting control system images courtesy of Lutron

Figure 25: Systems power image courtesy of SmartDesks

Figure 26: Machine-Room-Less Elevator image courtesy of Otis

Figure 27: Device images courtesy of Advantech, Silicon Labs, Schneider Electric, Mantra, Home Auto, Excel Networking, Microm, & EC&M

SD1: PV solar radiation map courtesy of NREL

SD2: Wind resource map courtesy of NREL

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1. Brooks, William P.E.; Dunlop, James P.E. Photovoltaic (PV) Installer Resource Guide. NABCEP. Dec. 2014.Web. March 2012.
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14. Cisco and Johnson Controls. Building Automation System over IP (BAS/IP) - Design and Implementation Guide. Aug. 2008. Web. Nov. 2014
15. Haworth. Power Base™ Brochure. Feb. 2015. Web. 2015.
16. OTIS Elevator Company. GEN2®. Jan. 2015. Web. 2014.
17. A Practical Guide to Fire Alarm Systems (2011): n. pag. CSAAIntl. 2011. Web. 10 Feb. 2015.

ADDITIONAL RESOURCES

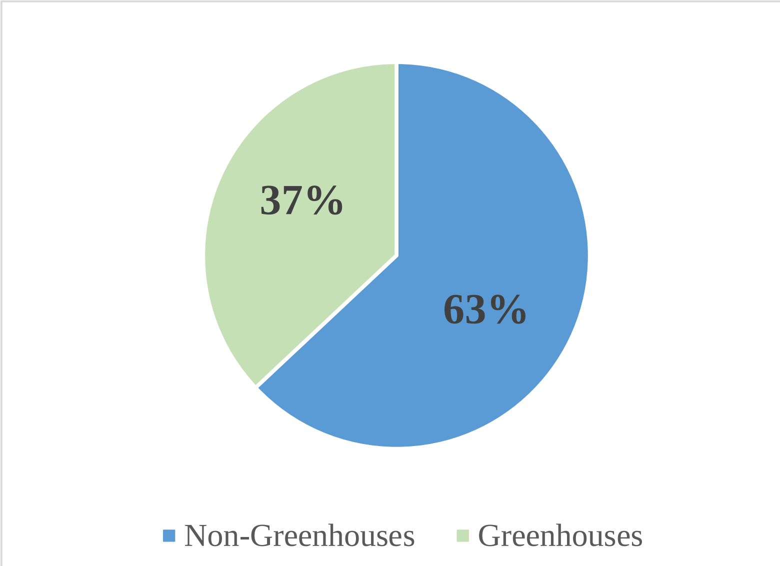
Dr. Richard Mistrick, PE. Lighting and daylighting advising.

Gary Golaszewski, PE, LEED AP. Interviews on power distribution.

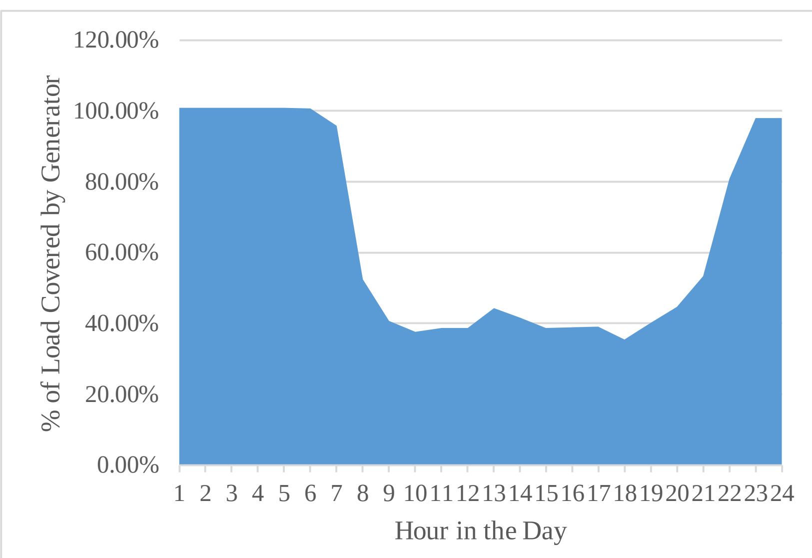
Sara Lappano, PE, LC, LEED AP BD+C. Interviews on net-zero strategies and power distribution.

Dr. Robert Berghage. Campus greenhouse & aquaponics tour

BUILDING ELECTRICAL LOAD ANALYSIS

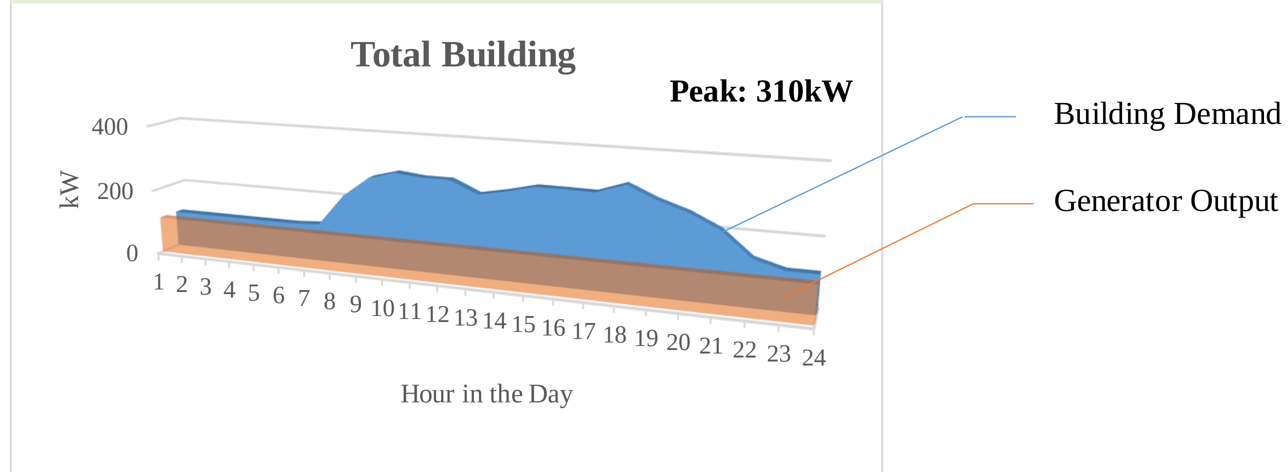


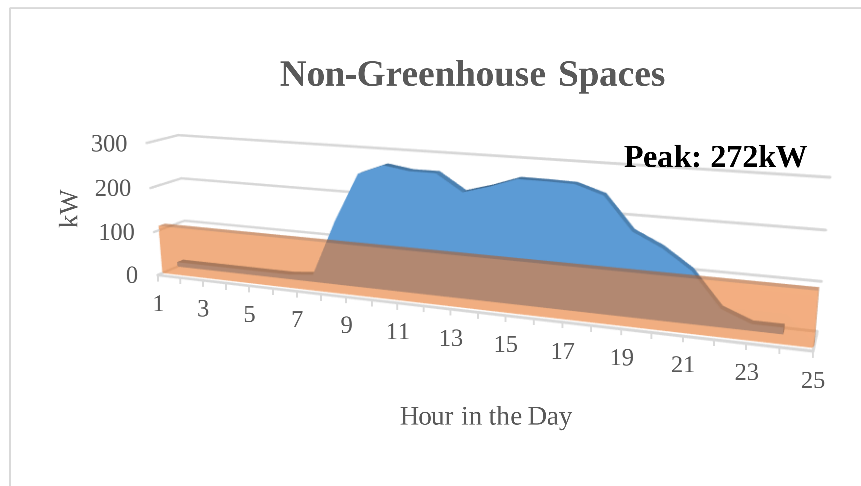
The total building load is **536kW,** and the power density is **10 W/SF.** Shown above is the load breakdown per section of the building.

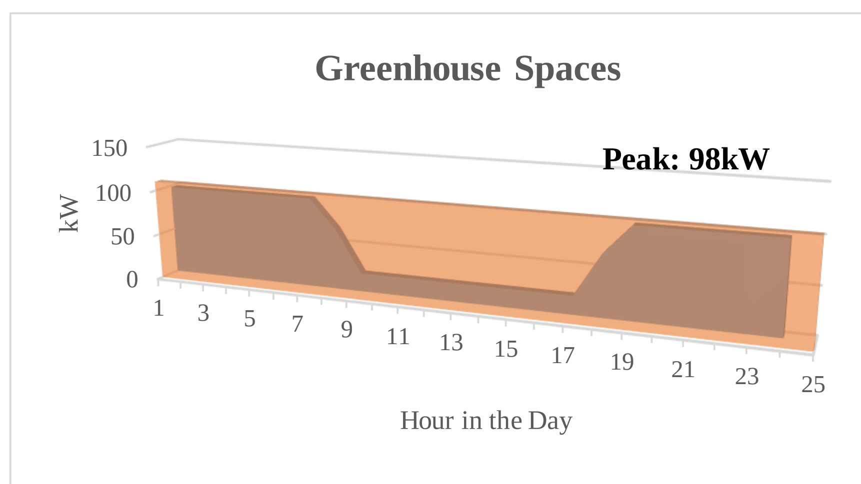


At maximum output, the two generators can completely offset the building load at night, and during the day the system can offset about **40%** of the building load due to scheduling.

TYPICAL DAILY ELECTRICAL LOAD PROFILES





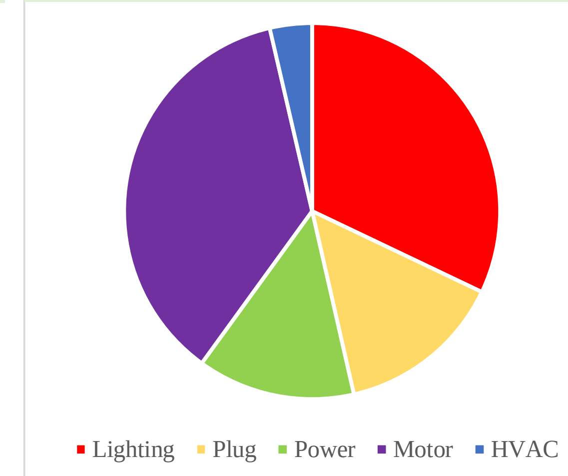


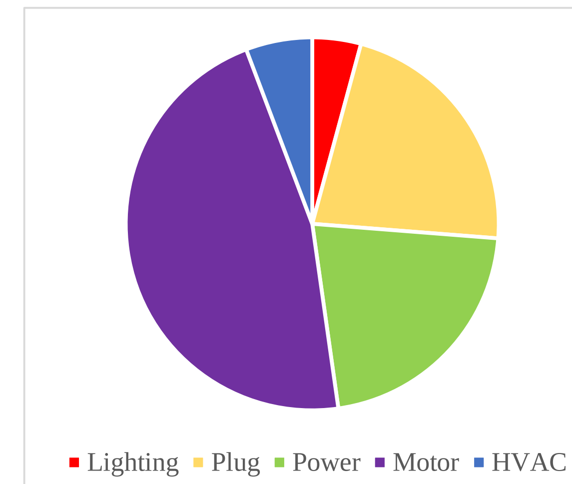
ANALYSIS

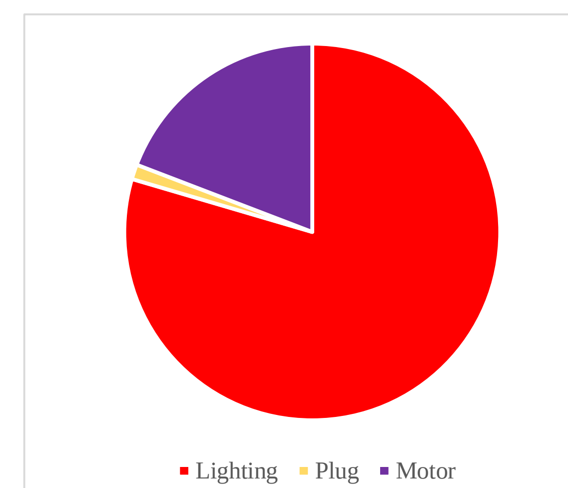
In the **non-greenhouse spaces**, the load profile follows a typical shape for educational/office shape, having a peak in the middle of the day and leveling off at night. Motors dominate the load types, as the building contains many water source heat pumps, anaerobic digester motors, and rain water pumps.

In the **greenhouse spaces**, grow lighting dictates the load profile, as some plants require supplementary lighting throughout the night. During the day, small fans and pumps will run to operate the greenhouses, but grow lighting does not have to be at full output.

LOAD BREAKDOWNS

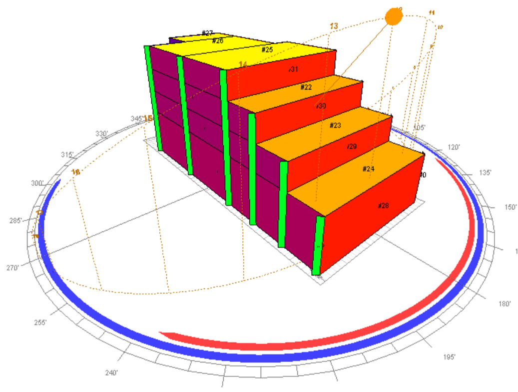




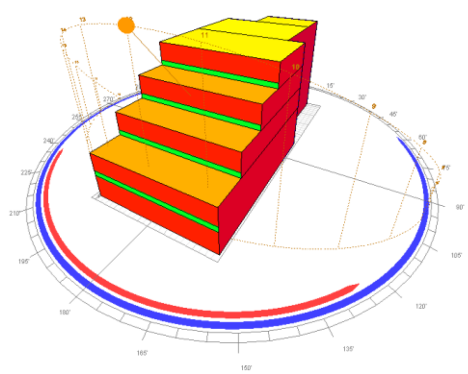


SOLAR POWER STUDY

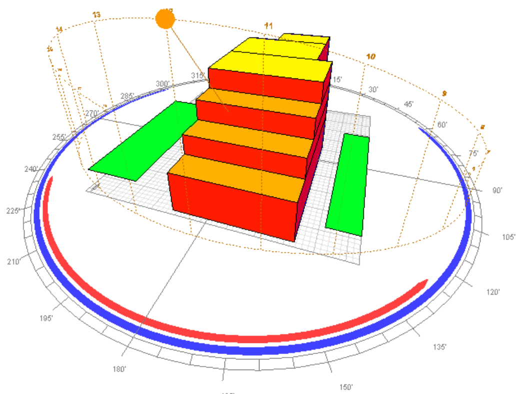
PV ARRAY DESIGN ITERATIONS



EAST & WEST FINS

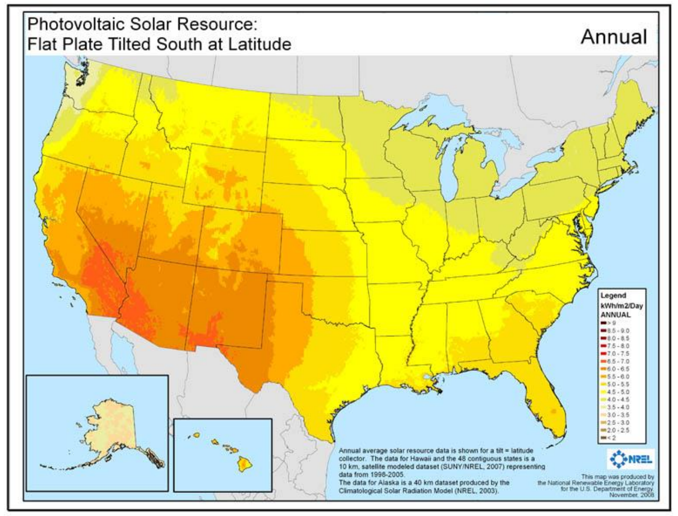


SOUTHERN-FACING



PARKING LOT

Yearly Analysis			
	SF (m^2)	Annual Production (kWh)	% Building Energy Offset
Milwaukee Fins	83	9,576	0.54%
Milwaukee South	41	5,283	0.30%
Milwaukee Parking	173	20,023	1.13%
Miami Parking	173	38,442	2.16%



SD1: Photovoltaic Solar Resource map

PROCESS

Prototyping was the main challenge in analyzing the feasibility of solar power for Growing Power's building. Keeping the building footprint tight was a major design goal so that the photovoltaic arrays could be implemented for any future Growing Power location. As a result, all array designs analyzed were implemented into the building fabric. Arrays are shown in green on the left.

One array included fin-type panels on the east and west side of the building.; another included panels implemented into the south façade, from the floor to the workplane (3 feet high) so as to not disturb the plant bed daylight availability; and the last option was to place panels overtop parking stalls.

Using the computer software Ecotect with a Typical Meteorological Year (TMY) weather file for Milwaukee, the amount of solar radiation reaching the array surface over a year was calculated, which was then converted to an actual energy production (kWh), taking into account typical conversion and efficiency losses of 15%.

ANALYSIS

The table on the left shows that the arrays in both Milwaukee and Miami were unsuccessful in generating a sizeable amount of energy to offset the building load due to the limited area of panels. The fins and parking stall arrays would be shaded for half the day, and the south facing arrays eventually would have been blocked by the new roof design. As a result, solar power was not implemented into the design.

However, there are many areas within the United States that would be much more successful in harvesting solar power. The map to the left portrays the average potential energy per year that could be harvested from solar power across the United States. These maps should be consulted to see if solar power is viable in future Growing Power Locations, as solar power can easily be incorporated into the electrical distribution. Refer to the Construction Management report for an example payback analysis (CM|4).

WIND POWER STUDY

PROCESS

Keeping the building footprint tight for matters of prototyping, building-mounted wind turbines were investigated first. However, case studies show that building-mounted wind turbines cause vibration, noise, and load issues. Furthermore, although there are no height restrictions by Milwaukee code, tower heights of wind turbines should be at least 30 feet above surrounding areas in order to avoid turbulent wind flow(2). However, since the Milwaukee site is in a residential area, the electrical team decided this would not be ideal aesthetically.

Small, commercial horizontal wind turbines, which are more efficient than vertical wind turbines, were analyzed next. Using yearly Milwaukee weather data, the numbers of hours at different speeds were analyzed. Then, the power that could be potentially generated at each speed by a 3 meter long blade was calculated using the equation shown. Multiplying that number by the number of hours at that speed in a year, the yearly energy generation was calculated, taking into account a 30% efficiency factor.

Wind Generation Equation

$$P = 0.5 \times \pi \times r^2 \times 1.23 \times v^3$$

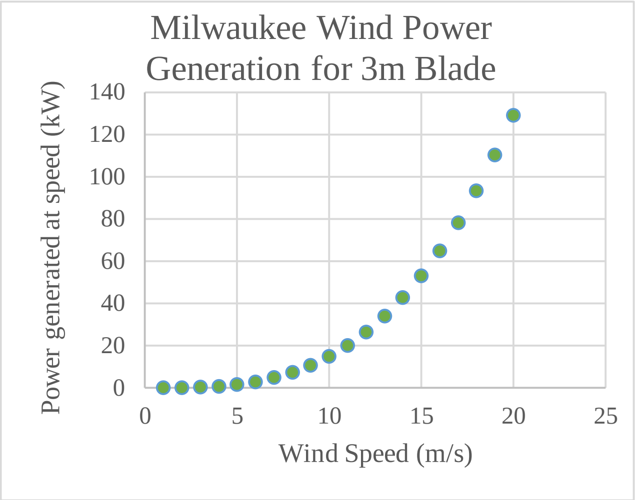
P = Power in Watts

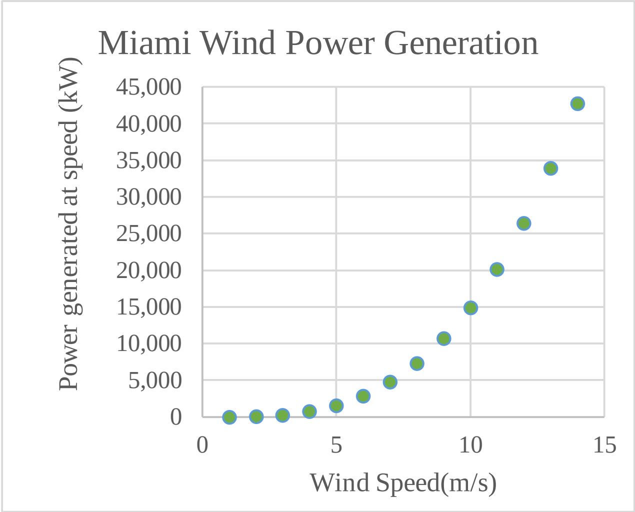
r= radius of wind turbine blade

v = wind velocity

RESULTS

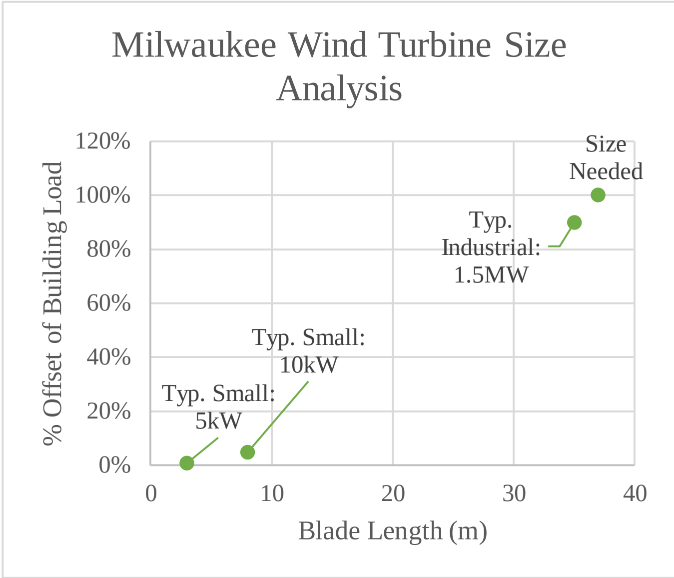
Yearly Analysis		
	Milwaukee	Miami
Annual Production (kWh)	11,731	6,833
% Building Energy Offset	0.66%	0.38%



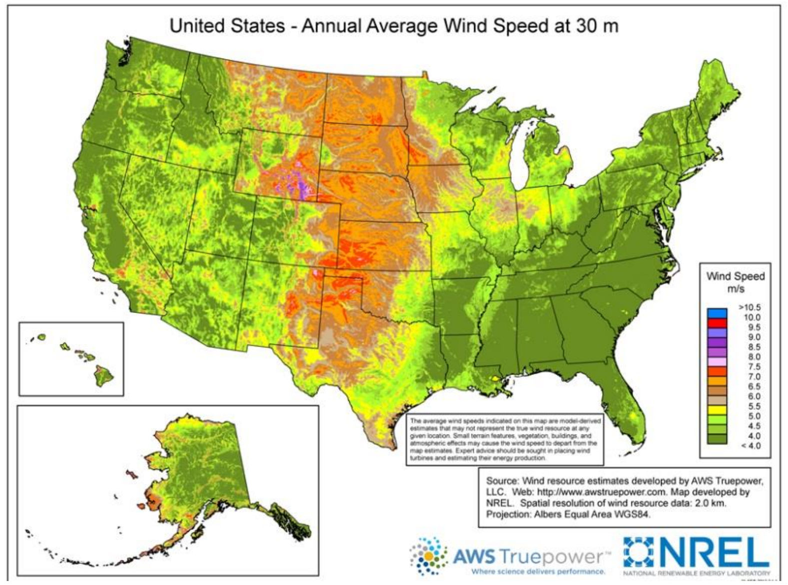


ANALYSIS

The 3 meter long wind turbine blade that was analyzed for Milwaukee is a typical size for a small commercial wind turbine. Other size blades were also analyzed for comparison, including another small commercial wind turbine with an 8 meter blade and an industrial size wind turbine with a 35 meter blade. The results can be seen above. For a wind turbine to completely offset the building load in Milwaukee, a 37 meter blade is needed. Space for this large of a turbine was not available on site.



Due to this extremely low offset and poor space allocation for the turbine, it was decided that wind power system would not be viable for the Milwaukee site. However, the electrical distribution system can still incorporate wind power if a future site decides it would be viable. The map below portrays the average potential energy per year that could be harvested from solar across the United States. These maps should be consulted to see if these strategies are viable in future Growing Power locations.



SD2: Annual average wind speed map

GREENHOUSE DESIGN

GREENHOUSE GLAZING AREA COMPARISONS

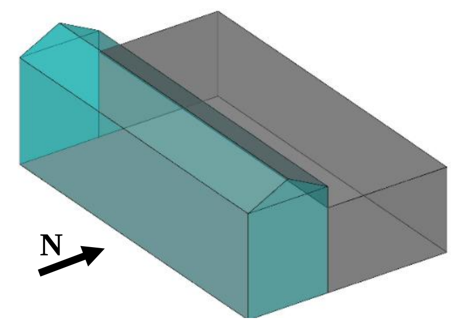
DESIGN ITERATIONS

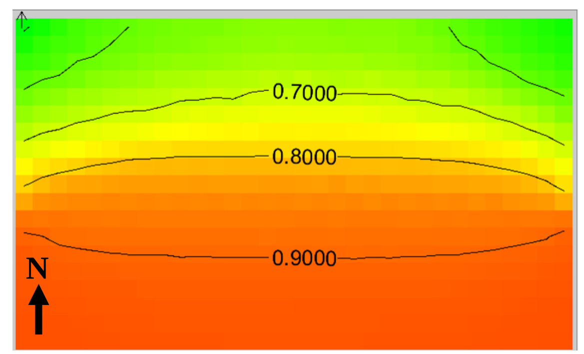
1. By eliminating the eastern and western greenhouse glazing, the glazing area was decreased by 22% and the sDA was barely affected.
2. Further analysis showed that eliminating the eastern, western, and northern glazing reduced the original glazing area by 41%. However, the sDA decreased by only 8%.
3. Therefore, the new design balances daylighting and glazing area. The new glazing area is equitable to the original design without the eastern, western, and northern glazing, and the sDA was restored to close the original amount.

SPATIAL DAYLIGHT AUTONOMY $sDA_{4000,\ 50\%}$ = %

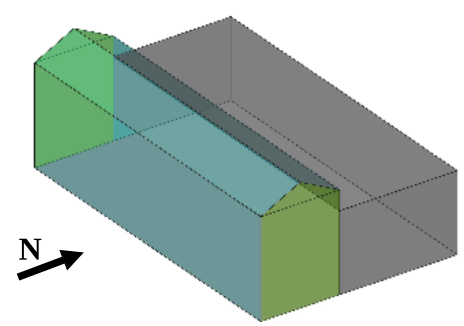
Percentage of time in the year that 50% of the points in the space reach 4000 lux (typical daylight illuminance) utilizing strictly daylight.

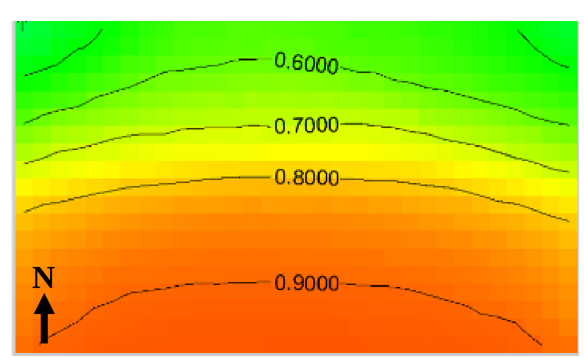
ORIGINAL GABLE



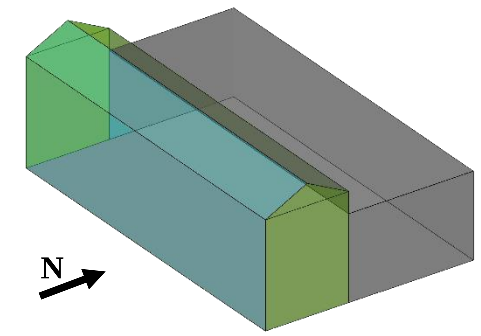


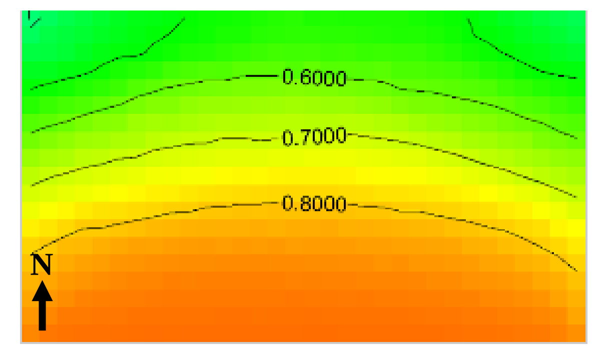
1. ORIGINAL GABLE WITHOUT EAST AND WEST GLAZING



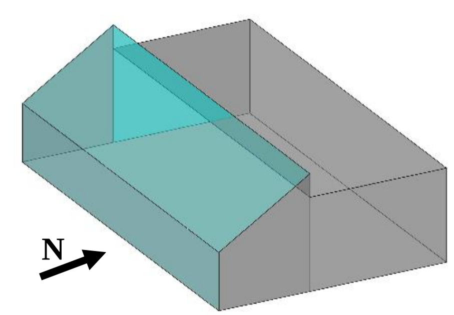


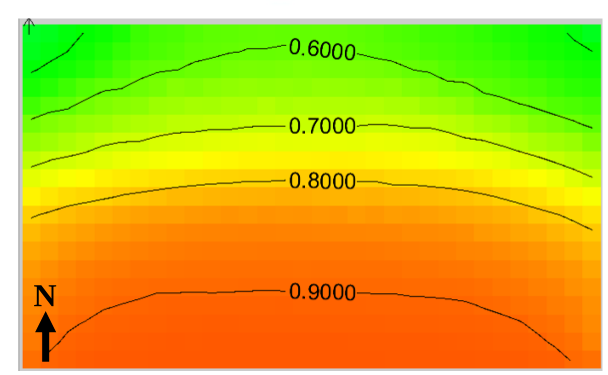
2. ORIGINAL GABLE WITHOUT EAST, WEST, AND NORTH GLAZING

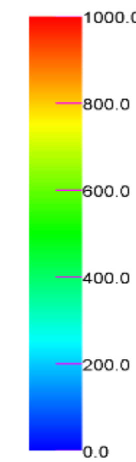




3. TBD DESIGN

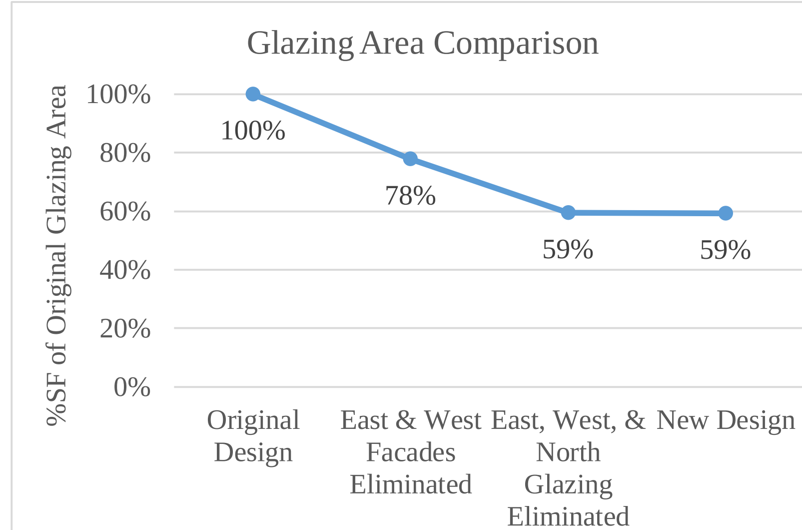


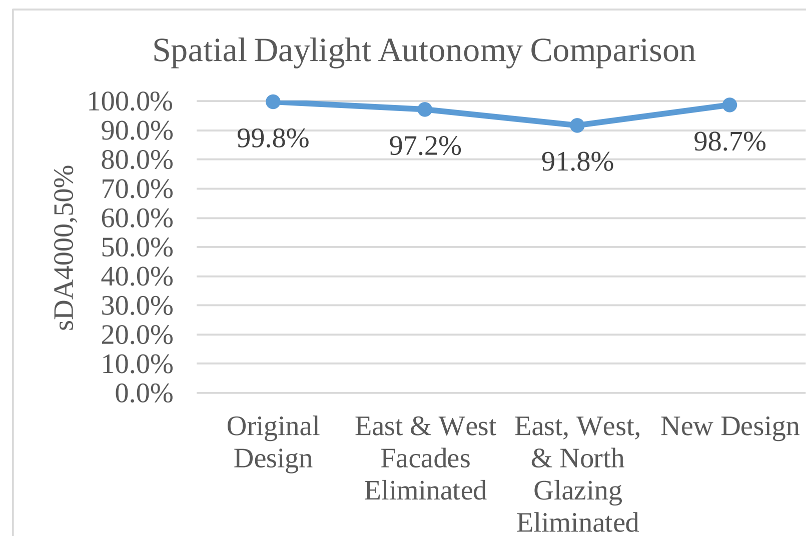




This scale shows the illuminance values in lux that the pseudo-colors represent.

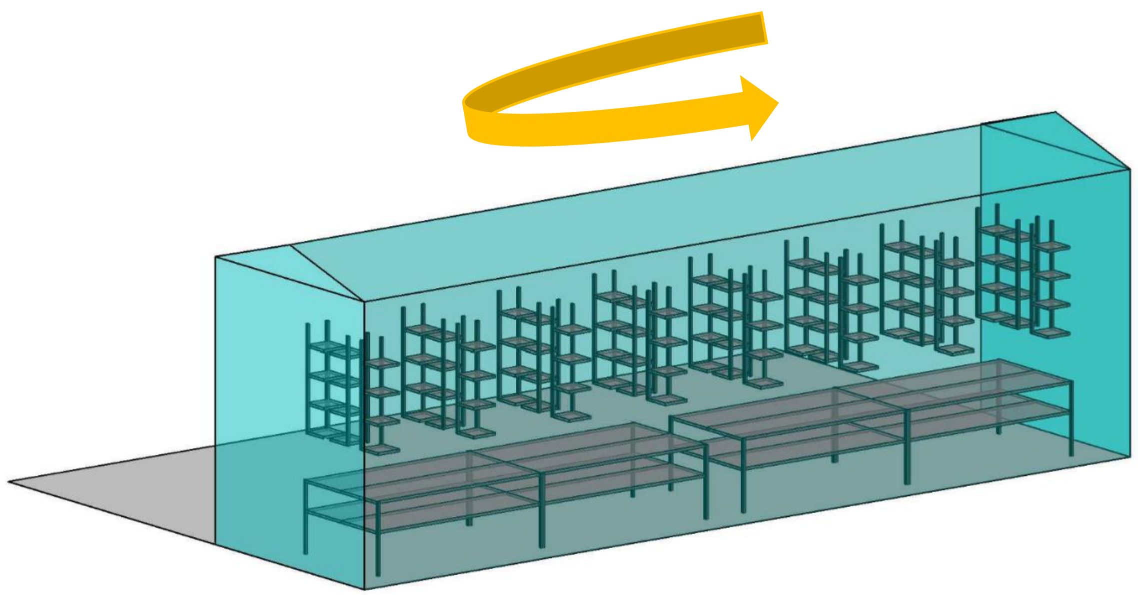
The points within each contour reach $DA_{4000,50\%}$ for the associated percentage of the year.

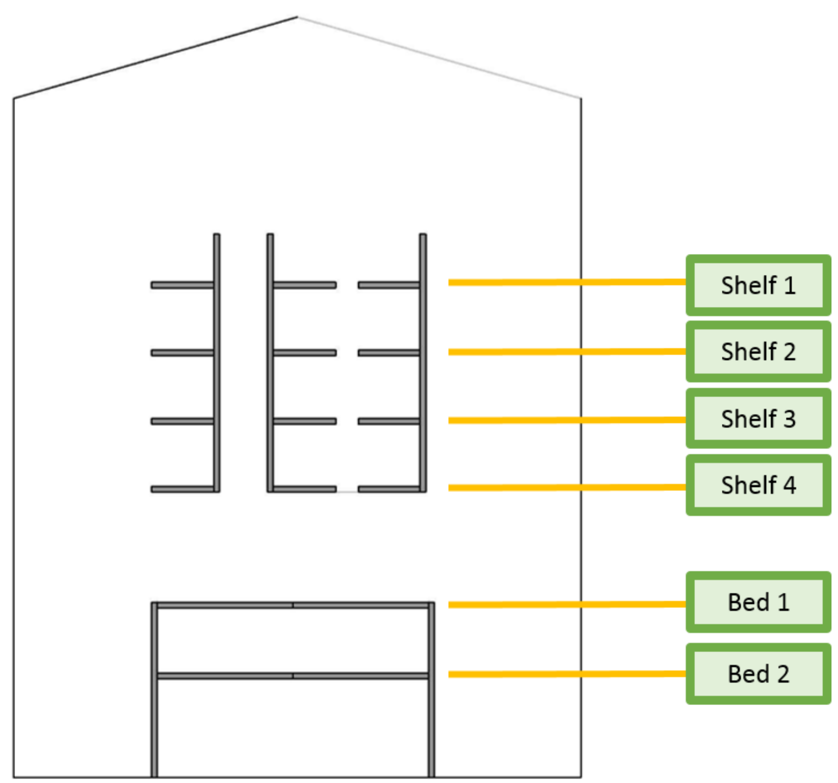




ORIGINAL PLANT BED DAYLIGHT AVAILABILITY ANALYSIS

ORIGINAL DESIGN

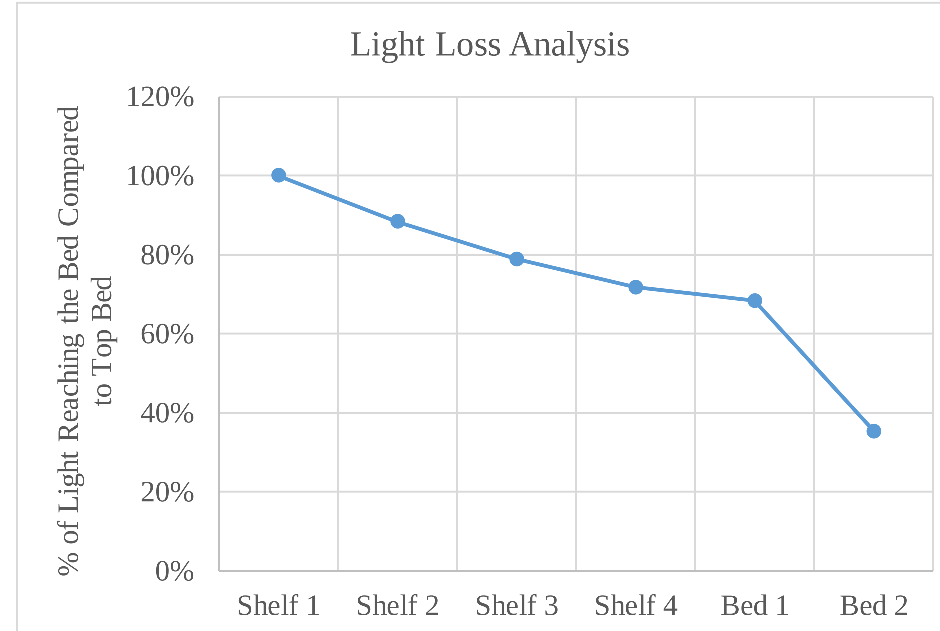




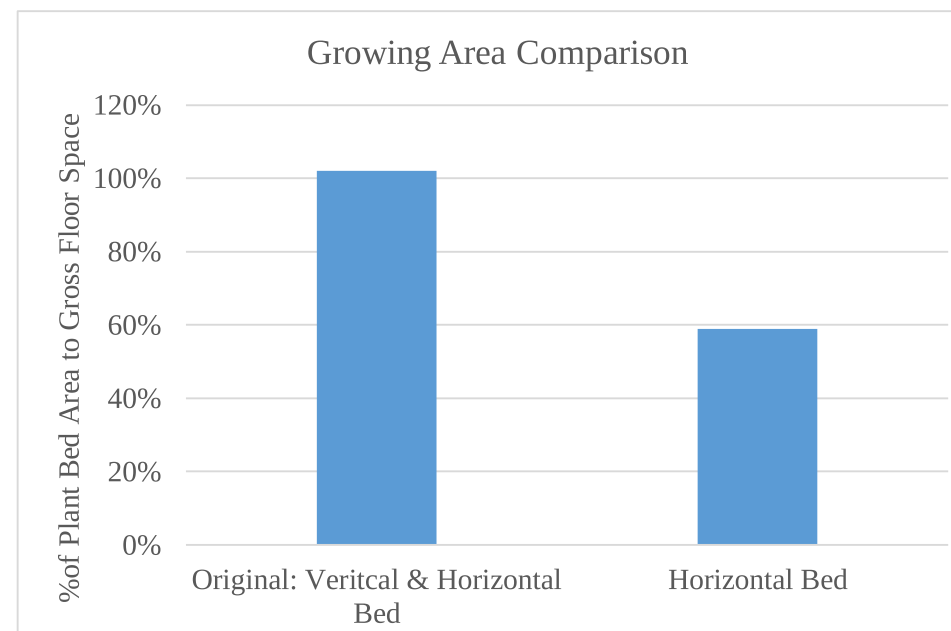
The original plant bed design combined vertical plant beds rotating in a horizontal plane over stationary horizontal plant beds.

ANALYSIS

To analyze the original bed design, a custom calculation grid was created for the model that included only points on the beds, and a yearly daylighting study was performed.



Results showed a **downside** to the original design. Each successive bed below the top bed loses a significant amount of light. By the time the light reached the lower bed, there is a 65% loss of light, as in the bottom beds receive 35% of the light that the top beds receive. Even though the beds will rotate in a horizontal plane, lower beds will still never get the chance to receive the same amount of light as the top beds.



One **benefit** of implementing the original plant bed design, though, is that it provides a large amount of growing space per gross floor area of greenhouse when compared to a traditional plant bed layout, which implements one layer of horizontal bed.

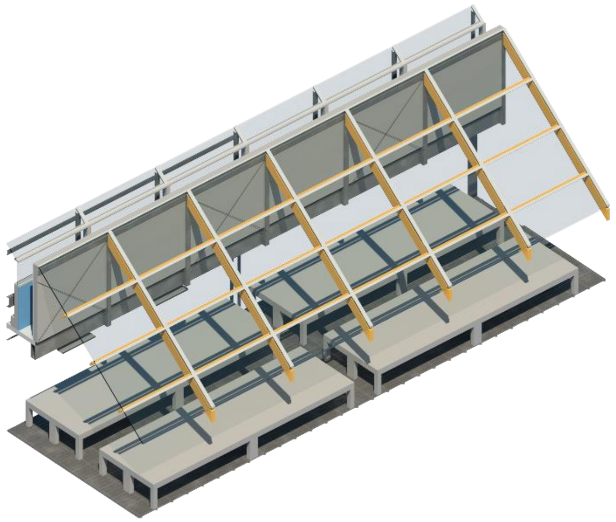
However, overall these results were not acceptable. Consequently, the original plant bed design was analyzed separately. The new designs include long layers of vertical beds rotating in a vertical plane from one layer to another to even out the performance across all the planters, as well as one layer of a stationary horizontal bed.

Daylight Availability for TBD's Horizontal Beds

$$\textit{available daylight integral} + \textit{supplementary light integral} = \textit{daily light integral}$$

Yearly Daysim Illuminance Output

To acquire the most accurate results, a complicated custom sensor points file was created that contained points only on each of the beds. A simulation was then performed that produced daylight illuminance values for each point, for every hour year, producing over 24 million data points to analyze for all the configurations described.



PAR Conversion & Data Processing

Daylight illuminance values for each point, for every hour of the year, were then converted to PAR values using the equations below[5]:

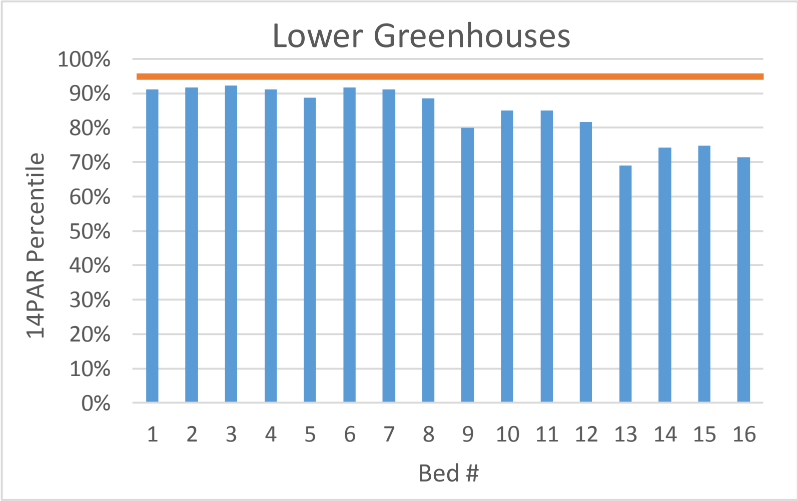
$$Illuminace\ (lux) \times \frac{1\ PPF\ Sunlight}{54\ Lux} = \frac{\mu mol}{m^2 \cdot sec} PPFD$$

$$\frac{\mu mol}{m^2 \cdot sec} \times \frac{84600 sec}{1 day} \times \frac{1 mol}{10^6 \mu mol} = \frac{mol}{m^2 \cdot day} PAR\ (or\ DLI)$$

An average PAR value per day was calculated for each point, and then points were grouped into their associated beds to create a daily PAR average for that bed.

14 PAR Percentile

Using the daily PAR average values per bed, 14 PAR Percentile values were calculated for each bed, which portrays the percentage of days in the year that a bed receives 14 PAR or more. The results below show that the single layer of horizontal bed configurations perform very well in terms of available daylight for plants, as the target percentile is 95%. However, for days when beds do not receive an average of 14 PAR, supplementary grow lighting will need to supply an average of 2.7 to 4 PAR.

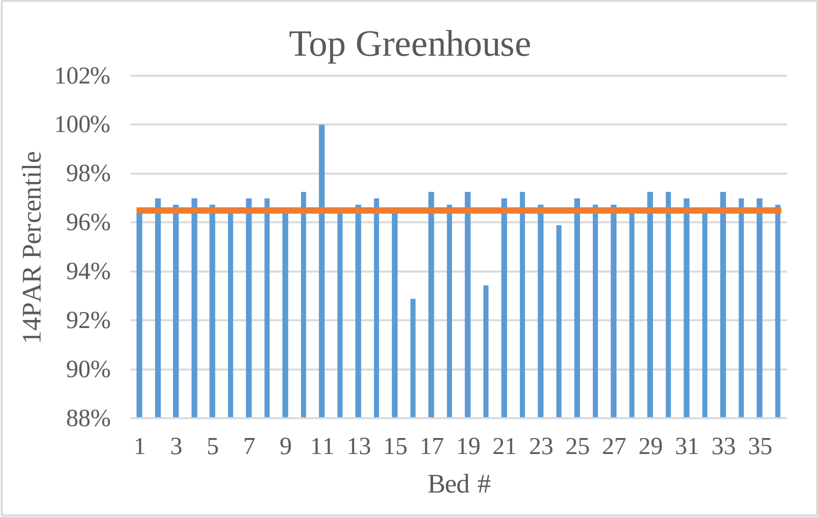


14 Par Percentile in the Space:

89.9%

Average PAR Deficiency in the Space:

4.0



14 Par Percentile in the Space:

97%

Average PAR Deficiency in the Space:

2.7

DAYLIGHT AVAILABILITY FOR TBD'S VERTICAL BEDS

ANALYSIS

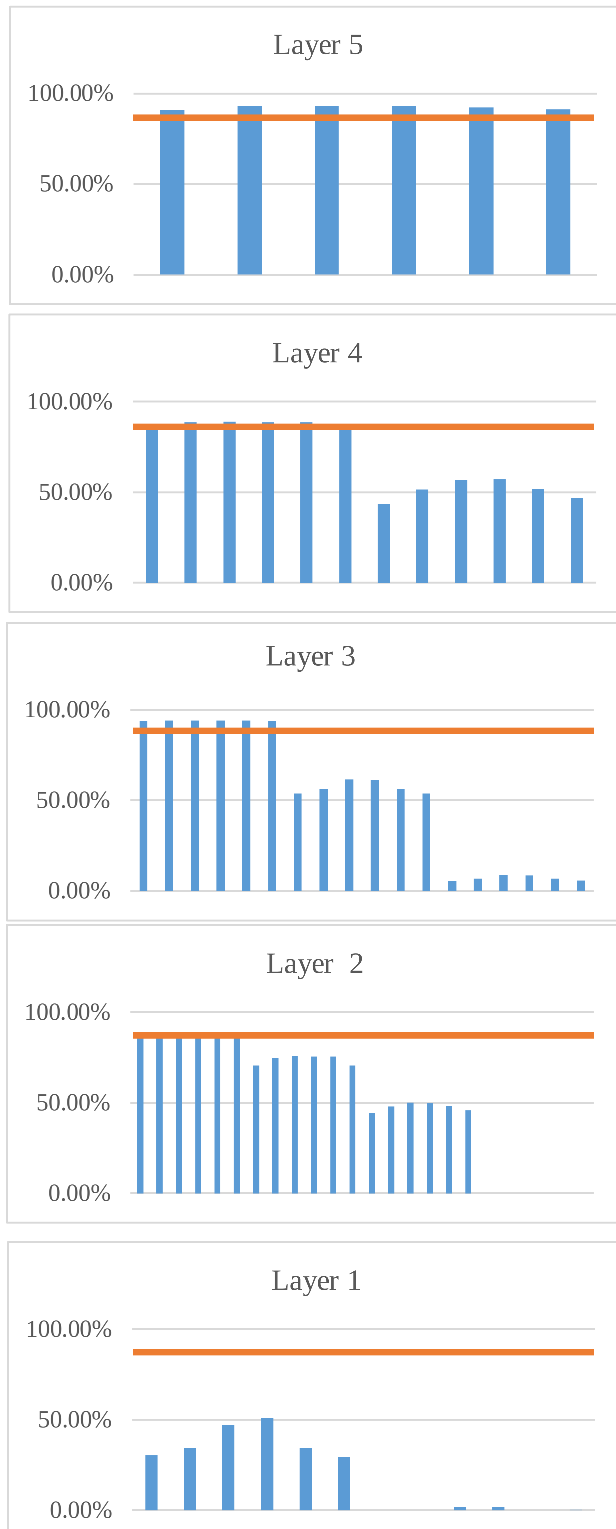
The same process described for the horizontal beds was then performed for the vertical beds.

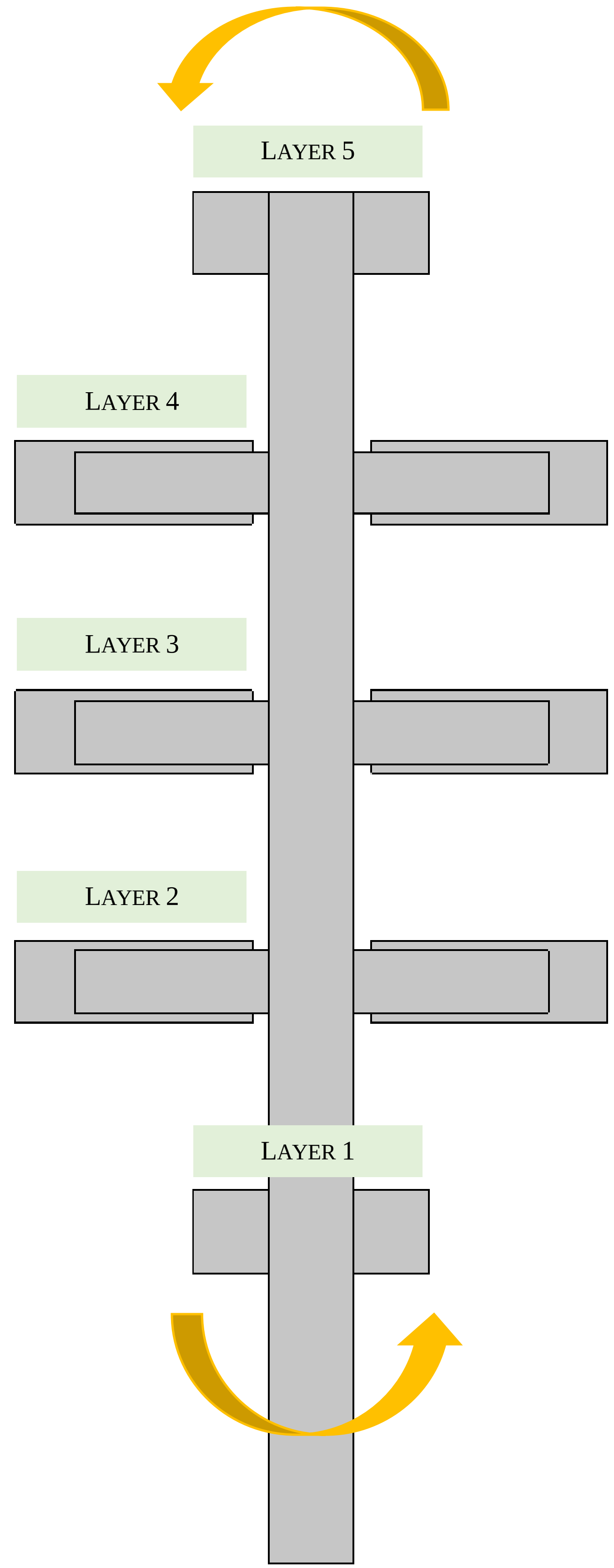
Each graph shows the 14 PAR Percentile values for each bed at a specific level in the vertical bed configuration.

Results show that lower beds receive sufficiently less PAR than upper beds. Beds towards the back of the room also are much more PAR deficient, as beds towards the front of the room block sunlight. In the lower greenhouses, the vertical beds only receive 14 PAR 52% of the year, and the top greenhouse vertical beds only receive 14 PAR 79% of the year.

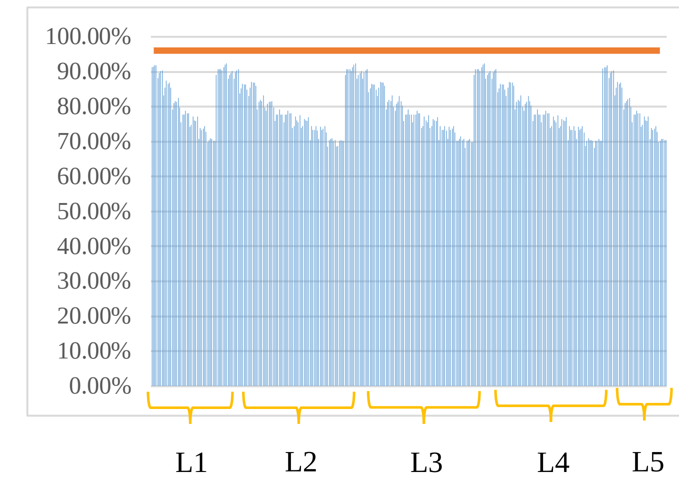
As a result, the vertical bed configuration would need to utilize more supplementary lighting that horizontal beds to make up for an average of 2.3 PAR to 5 PAR. However, if these beds were rotated throughout the day, these results could be improved.

LOWER GREENHOUSES





TOP GREENHOUSE



SUMMARY

LOWER GREENHOUSES

14 PAR PERCENTILE IN THE SPACE:

52.9%

AVERAGE PAR DEFICIENCY IN THE SPACE:

5.0

TOP GREENHOUSE

14 PAR PERCENTILE IN THE SPACE:

79.63%

AVERAGE PAR DEFICIENCY IN THE SPACE:

2.32

SUPPLEMENTARY LIGHTING DESIGN

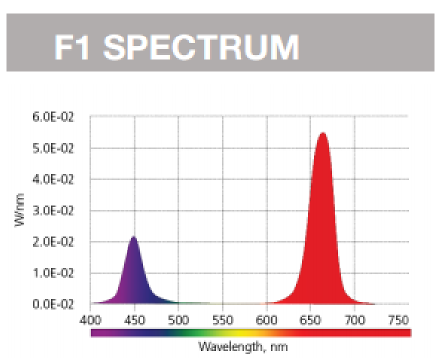
$$available\ daylight\ integral + supplementary\ light\ integral = daily\ light\ integral$$

PROCESS

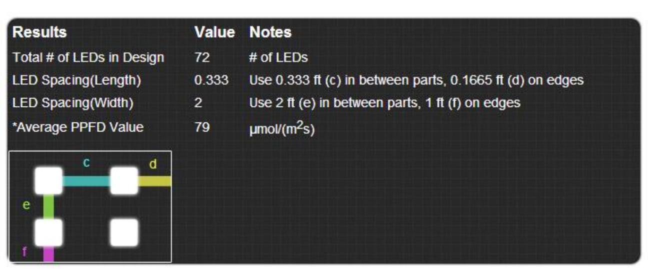
In order to specify the amount of supplementary grow light fixtures needed to make up for the PAR deficiency, a target of 4 PAR emitted from the grow lights was used for design.

4 PAR = 46 PPFD

An output of around 46 PPFD is needed by a fixture per bed. The manufacturer *Illumitex* offers a calculator[9] estimation of the amount of LED chips needed to achieve that amount of PPFD. After defining the ideal spectrum, the area to be illuminated, and the arrangement of LEDs in the fixture chosen (type ES2), results show that the beds require 2 rows of LEDs in order to create a uniform illuminance. Unfortunately, this amount emits for almost double the PPFD needed (79 PPFD) for the horizontal beds and almost four times the amount needed for the vertical beds (176 PPFD). However, these fixtures can be dimmed to reach the optimal amount of PPFD needed.



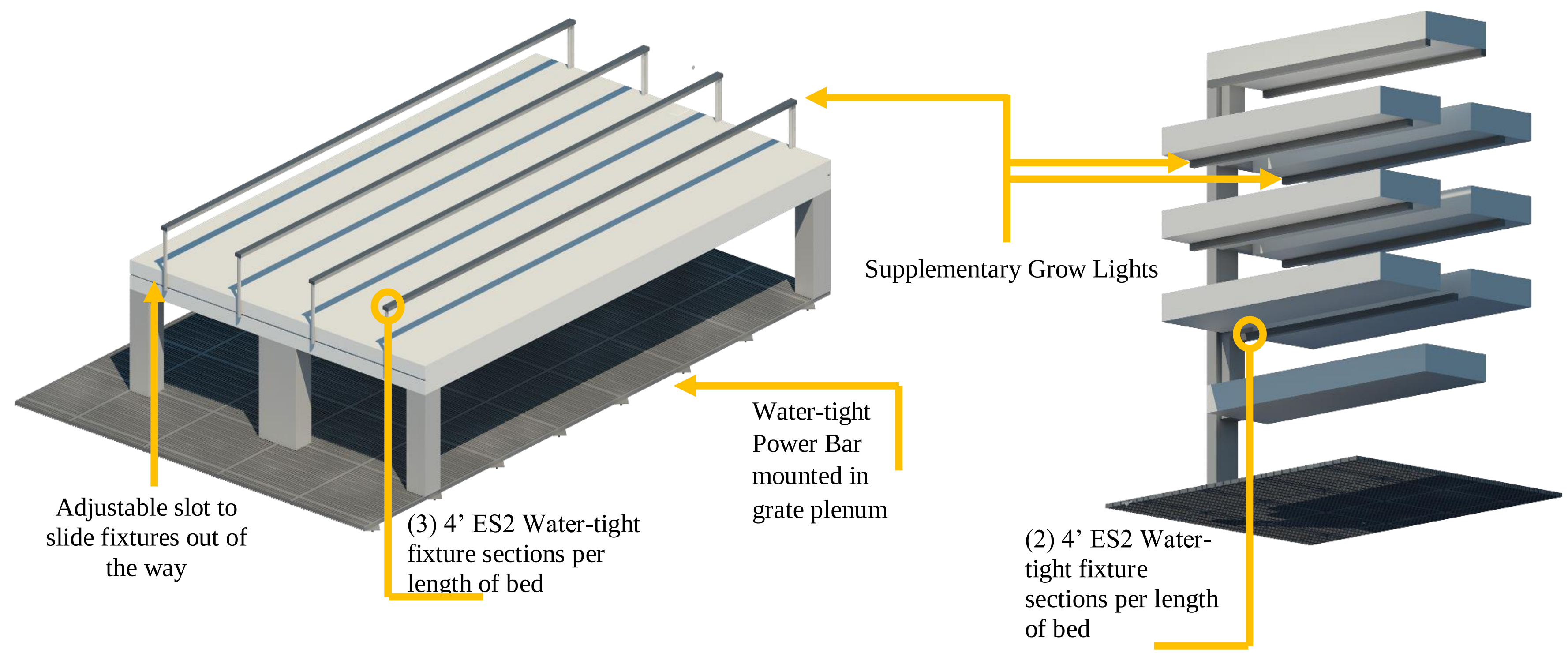
Spectrum emitted by ES2 Fixtures

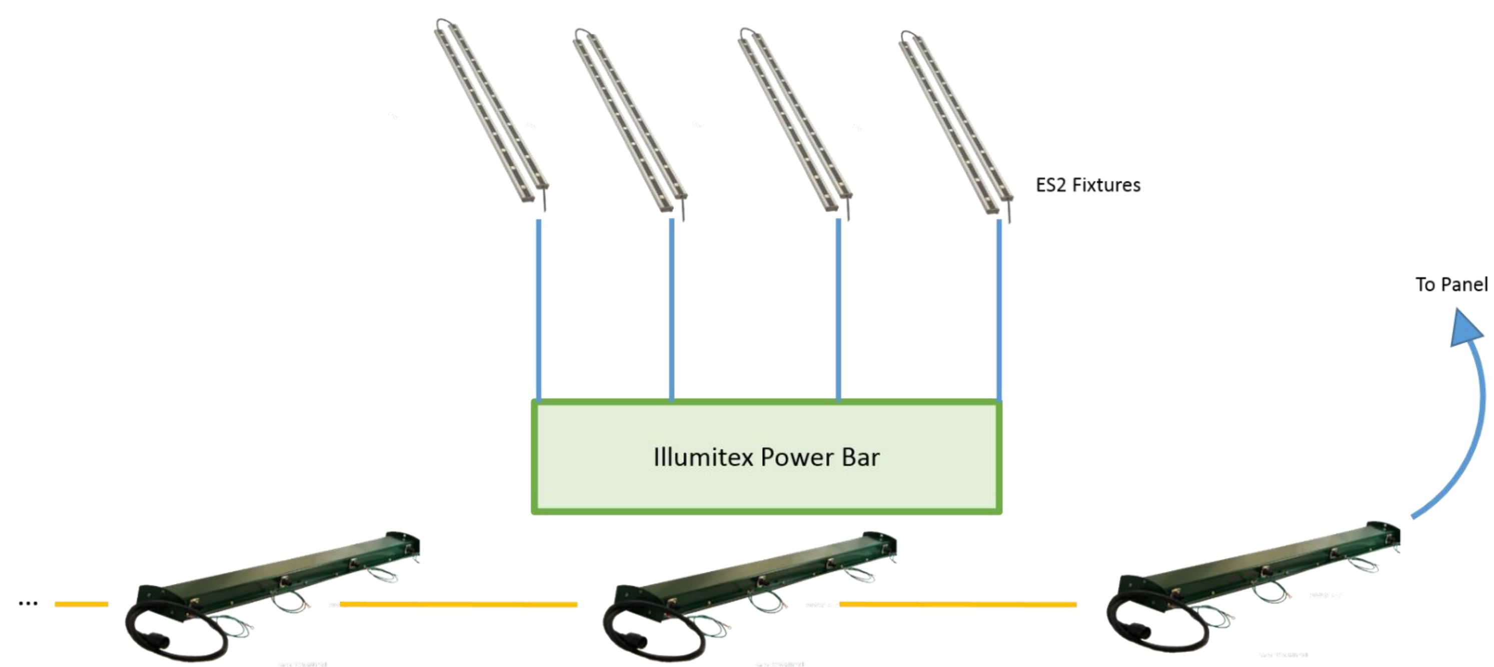


Results	Value	Notes
Total # of LEDs in Design	72	# of LEDs
LED Spacing(Length)	0.333	Use 0.333 ft (c) in between parts, 0.1665 ft (d) on edges
LED Spacing(Width)	2	Use 2 ft (e) in between parts, 1 ft (f) on edges
*Average PPFD Value	79	µmol/(m²s)

Example calculator output

SUPPLEMENTARY GROW LIGHTS DESIGN



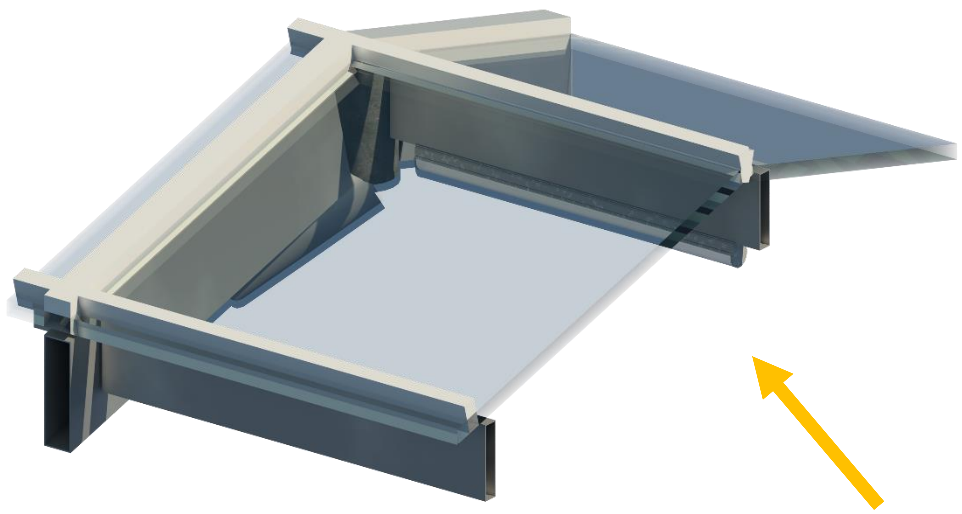


(4) ES2 Fixtures, each having (2) 4' sections, can be connected to one Power Bar. With 4 ES2's connected, each power bar contains 520W, so a maximum of 8 power bars can be circuited together to a 277V panel.

GENERAL OCCUPANT LIGHTING FOR GREENHOUSES

Linear LED strip fixtures (D8) were mounted to the overhead structure in the greenhouses for general ambient lighting for the occupants. The specified fixture is wet-location rated to protect the fixture from inevitable moisture forming in the greenhouses.

TOP GREENHOUSE	LOWER GREENHOUSES



Fixture mounted to structure above

Fixture mounted to structure above

LIGHTING & DAYLIGHTING DESIGN FOR COMMUNITY SPACES

FAÇADE DESIGN

DESIGN ITERATIONS

1. Solarban 70XL
2. Solarban 67 + Vertical Fins

The first iteration required that the shades be pulled most of the day in order to maintain the target illuminance. This prevented occupants from views to the outside.

As a result, a glazing with a lower visible transmittance value but a similar U-value and solar heat gain coefficient was used. Vertical fins were also added on the east and west facades in order to block direct sunlight. This solution allowed for less shade deployment and more views to the outside.

Moreover, energy savings through automated controls (dimming electric light through photosensors) were greater in the new solution.

DESIGN PROPERTIES

Dimensions of the window were chosen in order for the window to fit modularly into the rain screen façade.

Glazing Properties Comparison [13]

	Iteration 1	Iteration 2
	SOLARBAN 70XL Solar Control Low-E Glass	SOLARBAN 67 Solar Control Low-E Glass
Visible Light Transmittance	0.64	0.54
Winter U-Value	0.28	0.29
Solar Heat Gain Coefficient	0.27	0.29
Light to Solar Gain Ratio	2.37	1.86

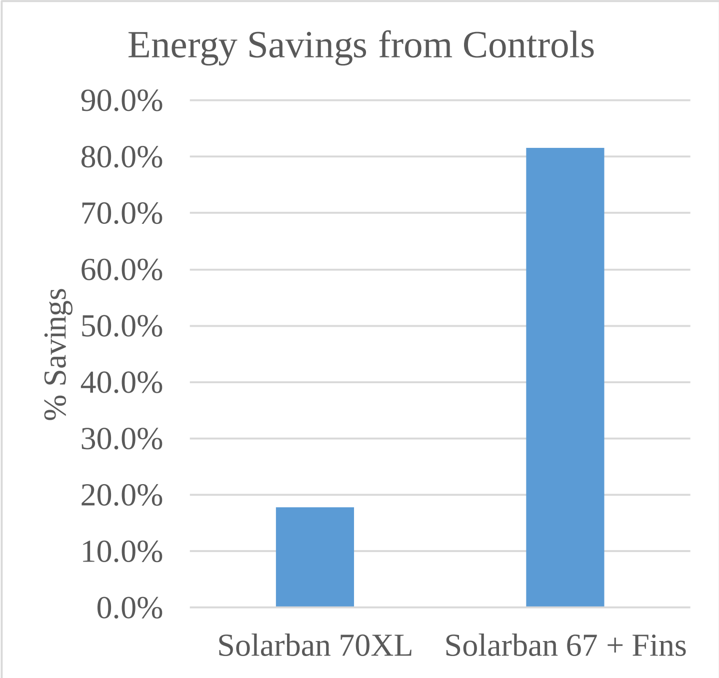
Shade Properties [12]

	Solar Reflectance	Visible Transmittance	Openness Factor
Mechoshade Thermoveil 0901	0.72	0.04	0.0

RESULTS

Shade Deployment Comparison

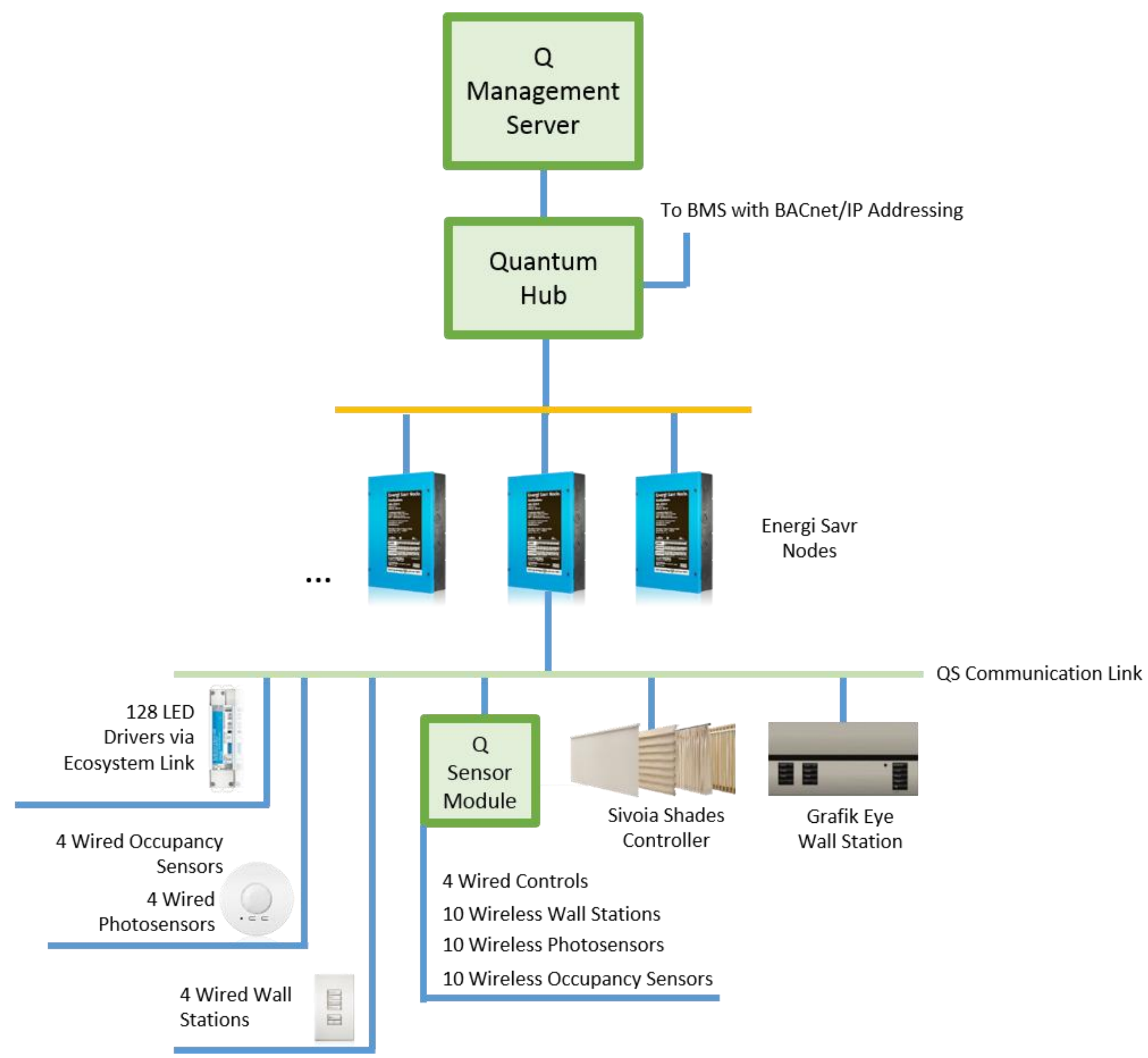
	Iteration 1	Iteration 2
% of Year Shades Deployed	40.31%	12.65%



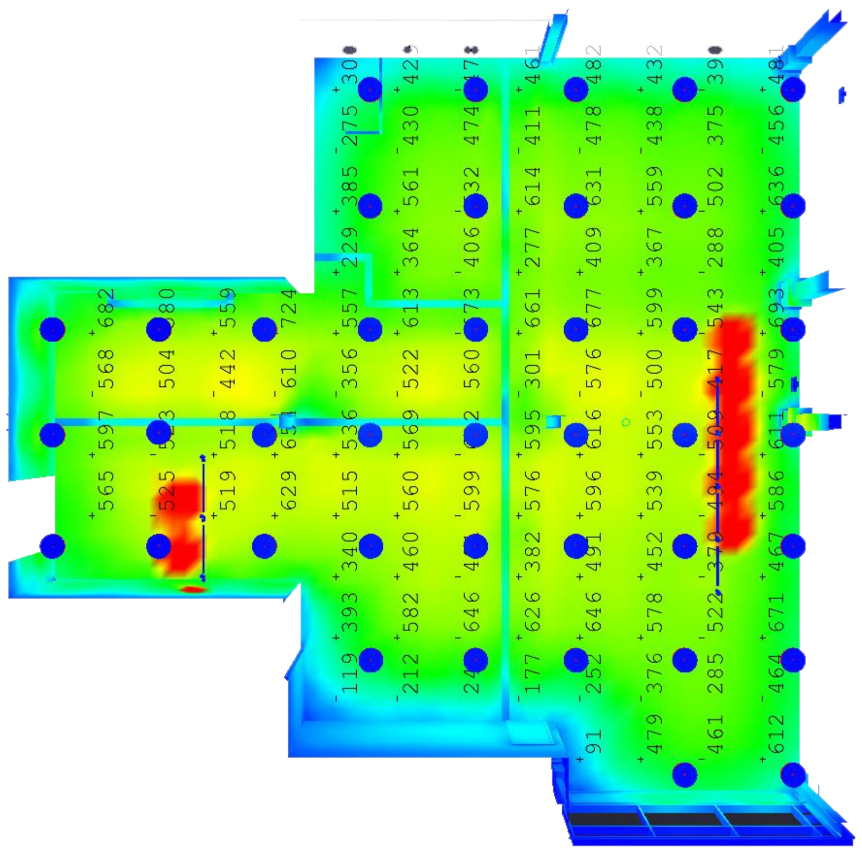
LIGHTING CONTROLS

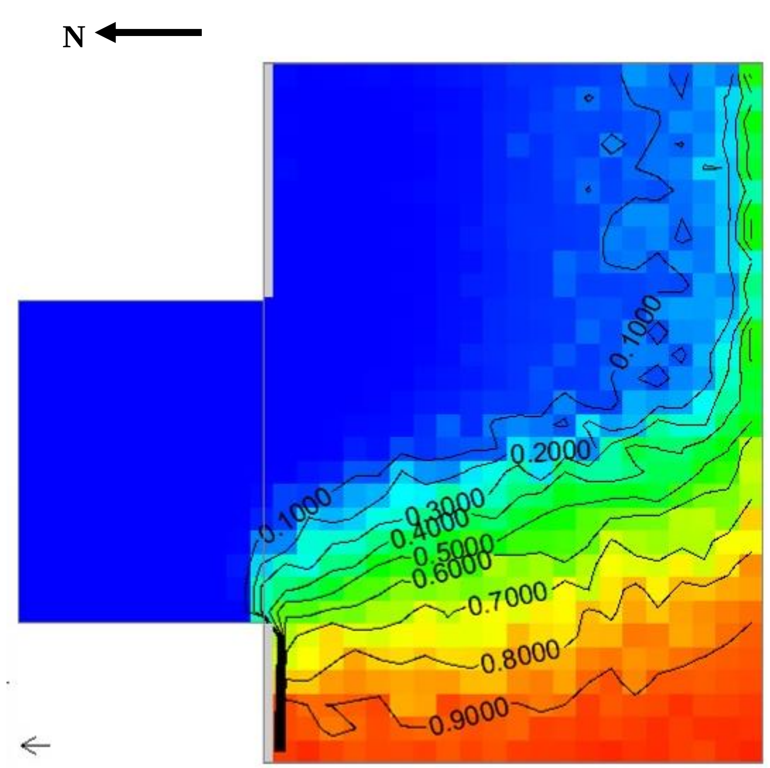
LUTRON ENERGI SAVR NODE WITH ECOSYSTEM

TBD has implemented into the design a digitally addressable lighting control system. *Lutron's Energi Savr Node System* provides an integrated solution to many different types of lighting controls via the *QS Communication Link* [11]. Each *Energi Savr Node* can control (2) loops of 64 LED Drivers on the *Ecosystem* link, as well as some wallstations, photosensors, and occupancy sensors. All fixtures to be digitally addressed are specified as compatible partners with *Ecosystem* drivers. For more controls, a *Q Sensor Module* can be added to the communication link which provides access for wireless controls. Other systems can be connected to the communication link, such as the *Grafik Eye* wall station, which provides preset scene control, and the *Sivoia shades* controller. Nodes refer back to the *Quantum hub*, which can interact with the overall building network, and all systems on the communication link can be viewed at the *Q management server*, which is a user-interface program. This system is beneficial because it allows Growing Power to easily monitor and control its entire lighting system, and zones of fixtures can be easily reconfigured. More so, it interacts with the overall building network, which provides for a seamlessly integrated building.



INTERIOR SPACES
MARKET





LIGHTING & DAYLIGHTING DESIGN RESULTS

E_{target} / E_{design} = 500 lux / 508 lux (avg)

$W_{designed}$/$W_{allowed}$: 5048 W / 3302 W

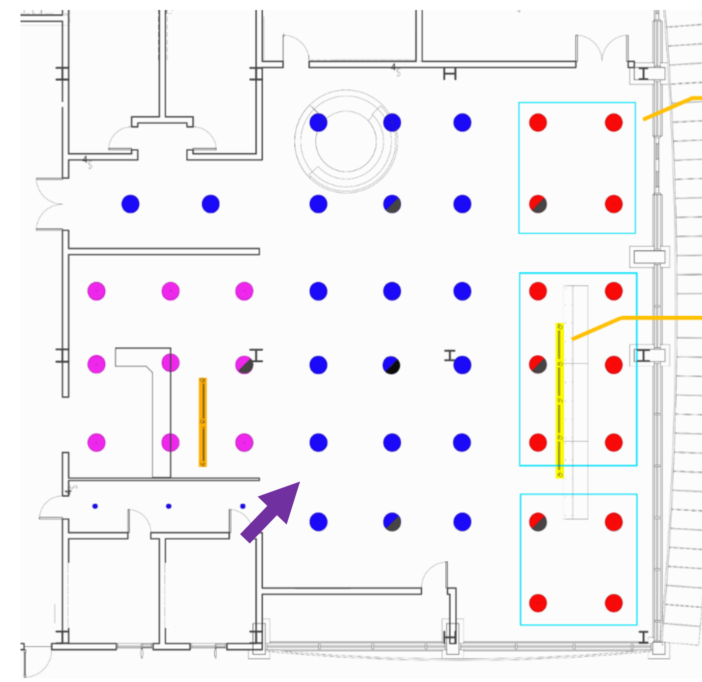
$sDA_{400lux,\ 50\%}$ = 27.68%

Photosensor Energy Savings per control zone: 46%

Left: *Illuminance psuedocoloring*

Bottom Left: *Contours for the Spatial Daylight Autonomy*

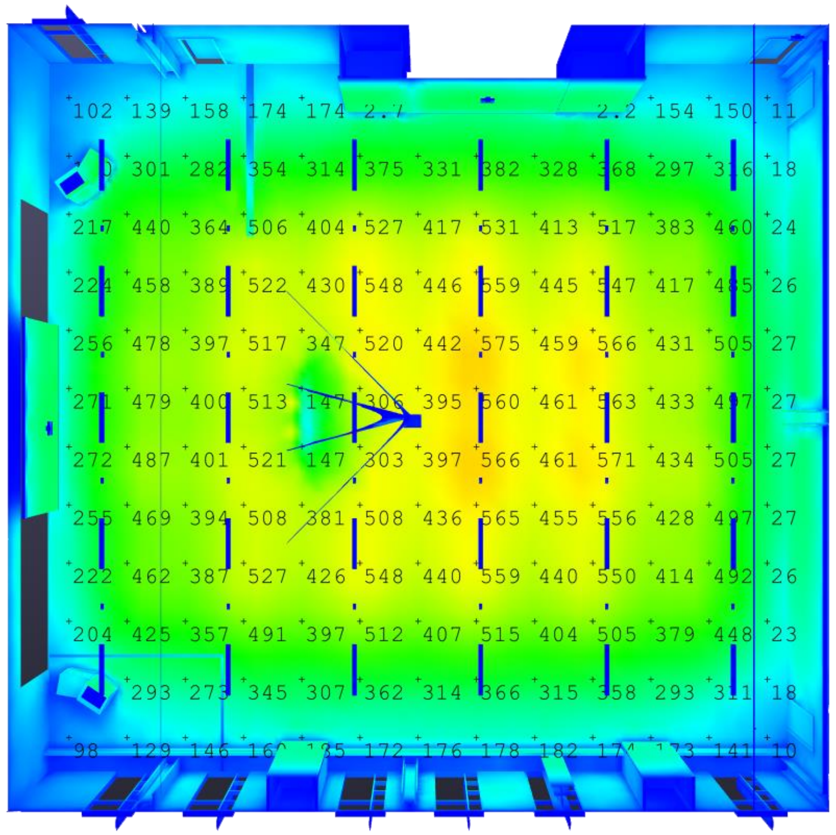
CONTROLS SCHEMATIC



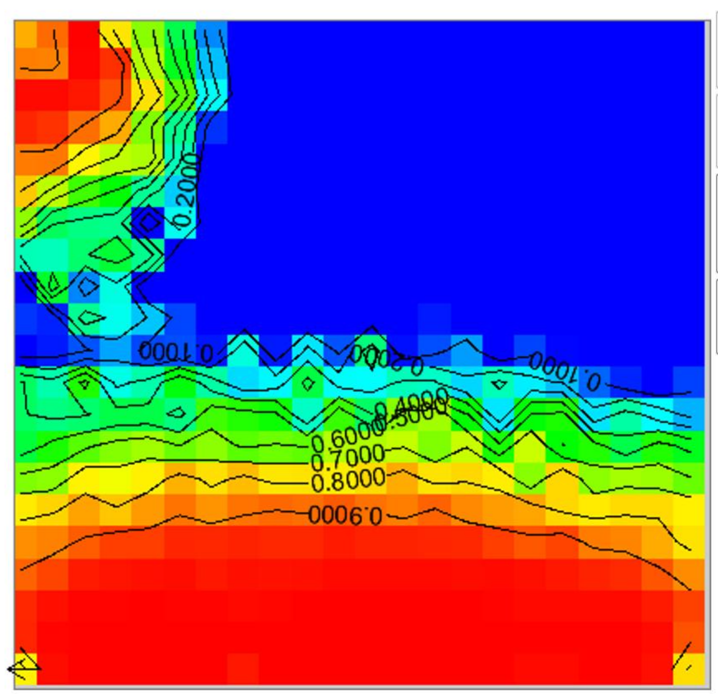
During the day, fixtures will be on and dimmed accordingly by photosensors, and the lighting management system's time clock will turn the fixtures off at night. However, the timeclock can be overridden by vacancy sensors (D8).

Left: *Switching zones are shown through colored fixture symbols, photosensor zones are shown in cyan boxes, render view is indicated by the purple arrow.*

GATHERING SPACE



N ←



LIGHTING & DAYLIGHTING DESIGN RESULTS

E_{target} / E_{design} = 50 lux / 361 lux (avg)

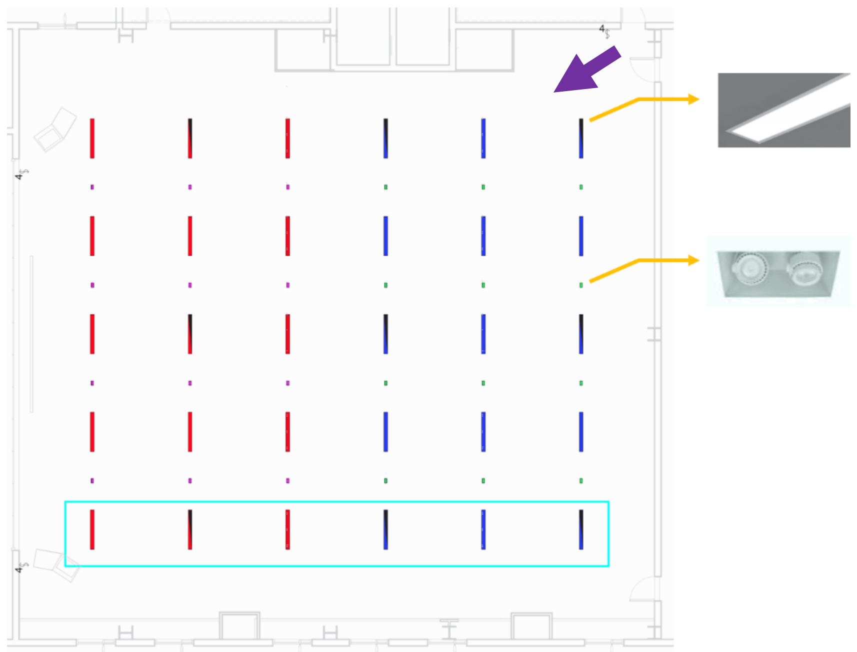
$W_{allowed}$ / $W_{designed}$: 3600 W / 942 W

$sDA_{100lux,\ 50\%}$ = 45.67%

Left: *Illuminance psuedocoloring*

Bottom Left: *Contours for the Spatial Daylight Autonomy*

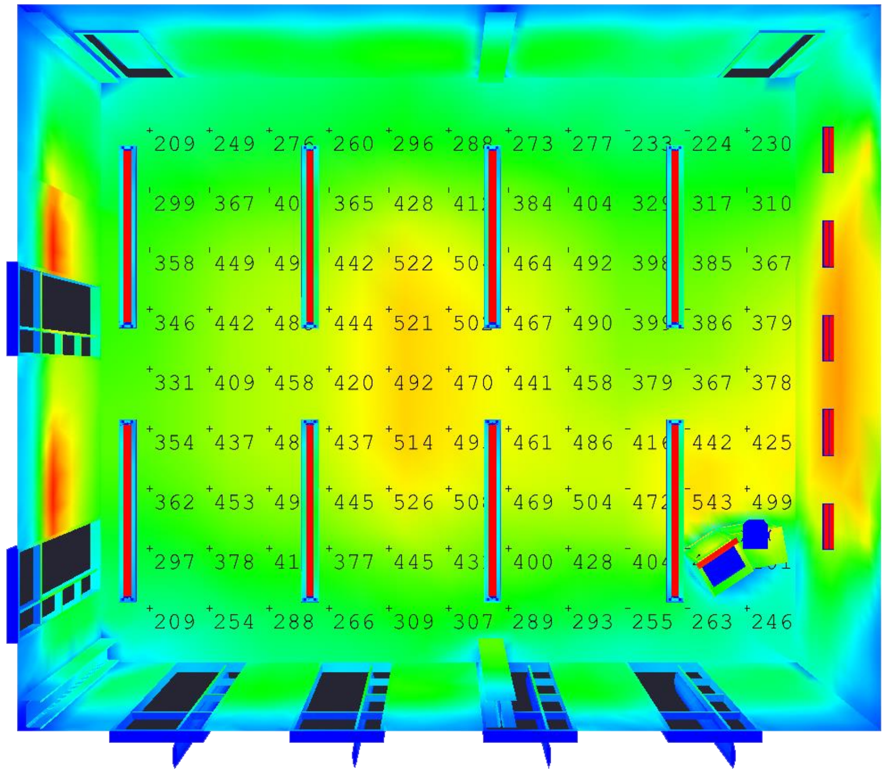
CONTROLS SCHEMATIC



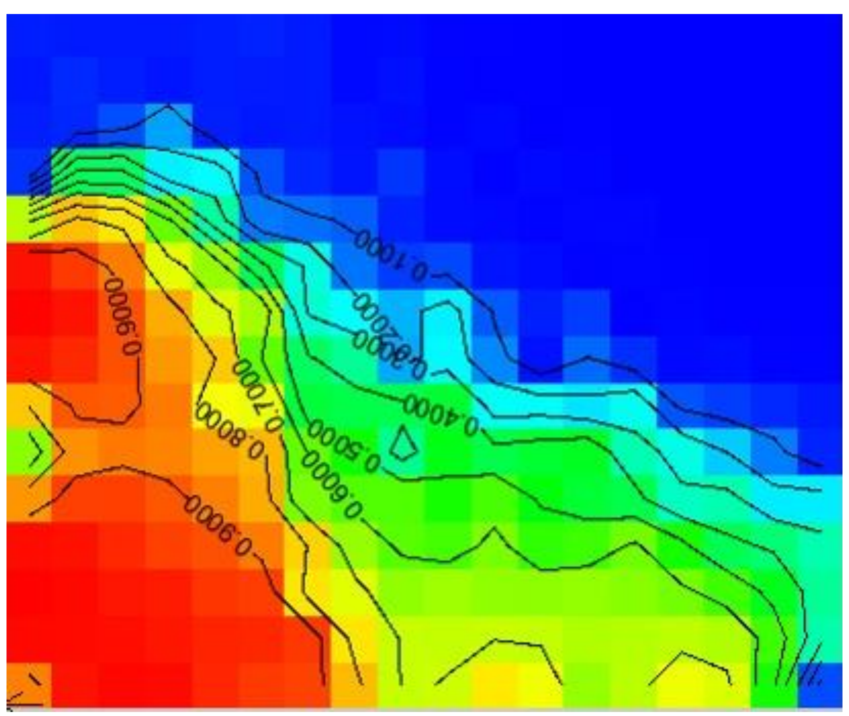
Fixtures will be turned on by users and turned off via a vacancy sensor. However, if the space is being used for a specific event, the lighting management system will override the vacancy sensors and keep the fixtures on as needed (D8).

Left: *Switching zones are shown through colored fixture symbols, photosensor zones are shown in cyan boxes, and render view is indicated by the purple arrow.*

WESTERN CLASSROOM



N ←



LIGHTING & DAYLIGHTING DESIGN RESULTS

E_{target} / E_{design} = 400 lux / 389 lux (avg)

$W_{allowed}$ / $W_{designed}$: 1470 W / 722 W

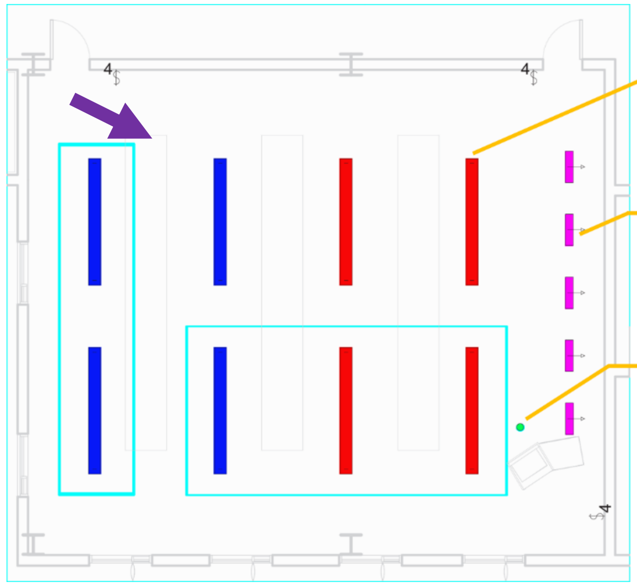
$sDA_{400lux,\ 50\%}$ = 41.11%

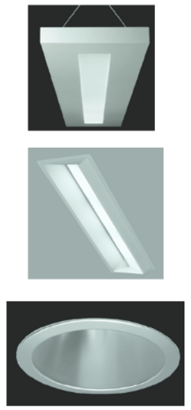
Photosensor Energy Savings per control zone: 86.4%

Left: *Illuminance psuedocoloring*

Bottom Left: *Contours for the Spatial Daylight Autonomy*

CONTROLS SCHEMATIC

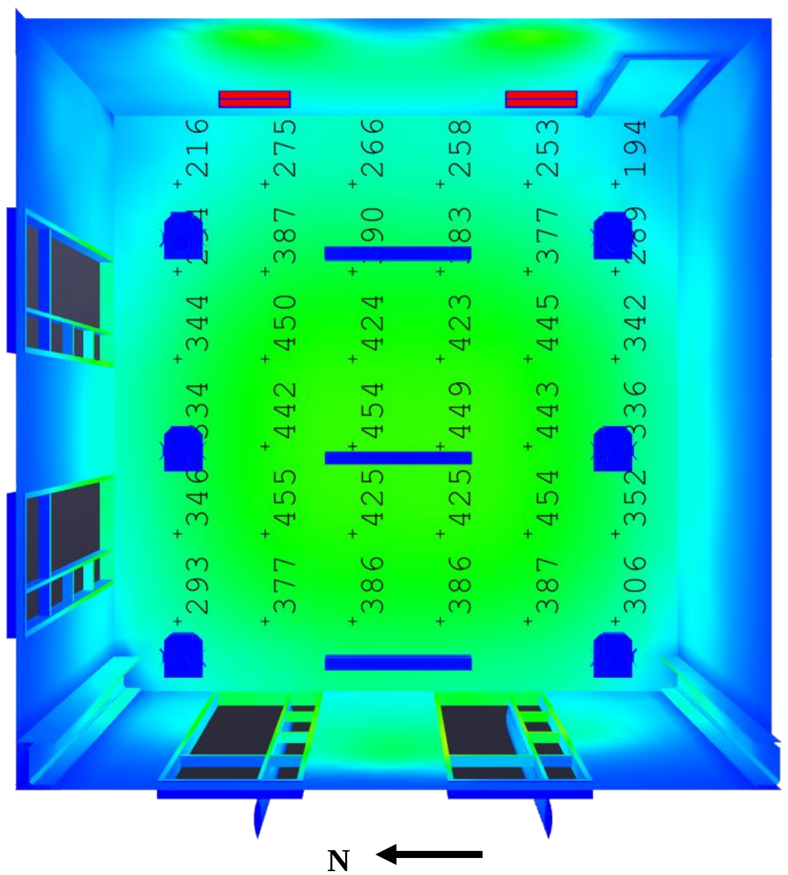


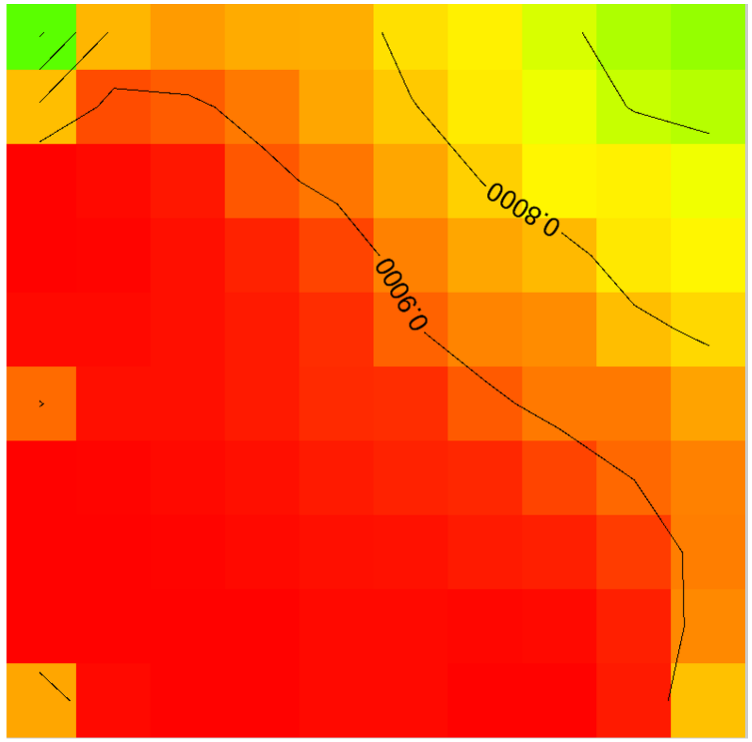


Fixtures will be turned on by users and turned off via a vacancy sensor (D8).

Left: *Switching zones are shown through colored fixture symbols, photosensor zones are shown in cyan boxes, and render view is indicated by the purple arrow.*

CONFERENCE ROOM





LIGHTING & DAYLIGHTING DESIGN RESULTS

$\mathbf{E_{target}}$ / $\mathbf{E_{design}}$ = 300 lux / 363 lux (avg)

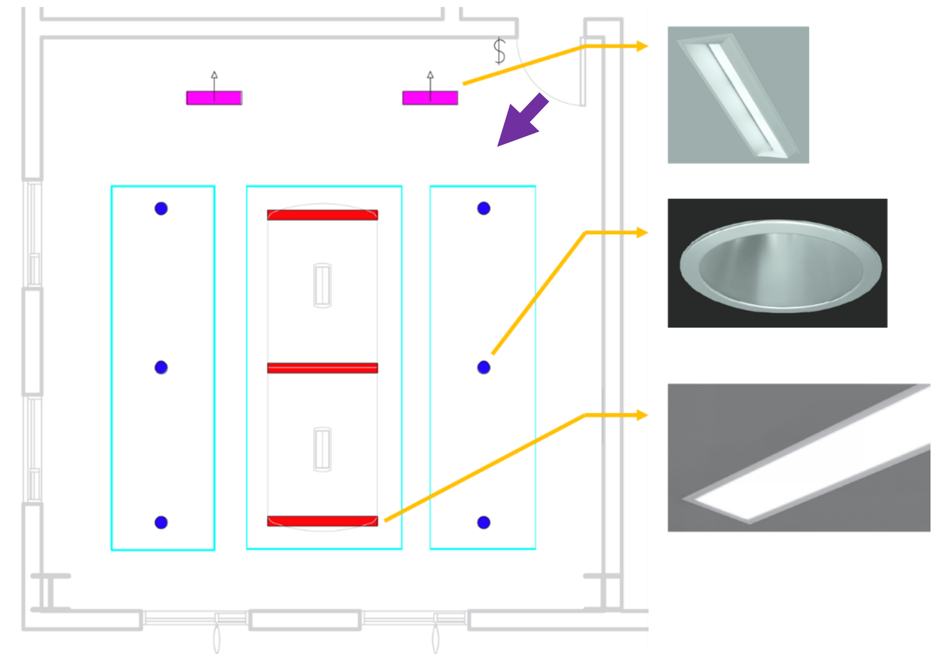
$\mathbf{W_{allowed}}$ / $\mathbf{W_{designed}}$: 517 W / 227 W

$\mathbf{sDA_{300lux,\,50\%}}$ = 100%

Left: *Illuminance psuedocoloring*

Bottom Left: *Contours for the Spatial Daylight Autonomy*

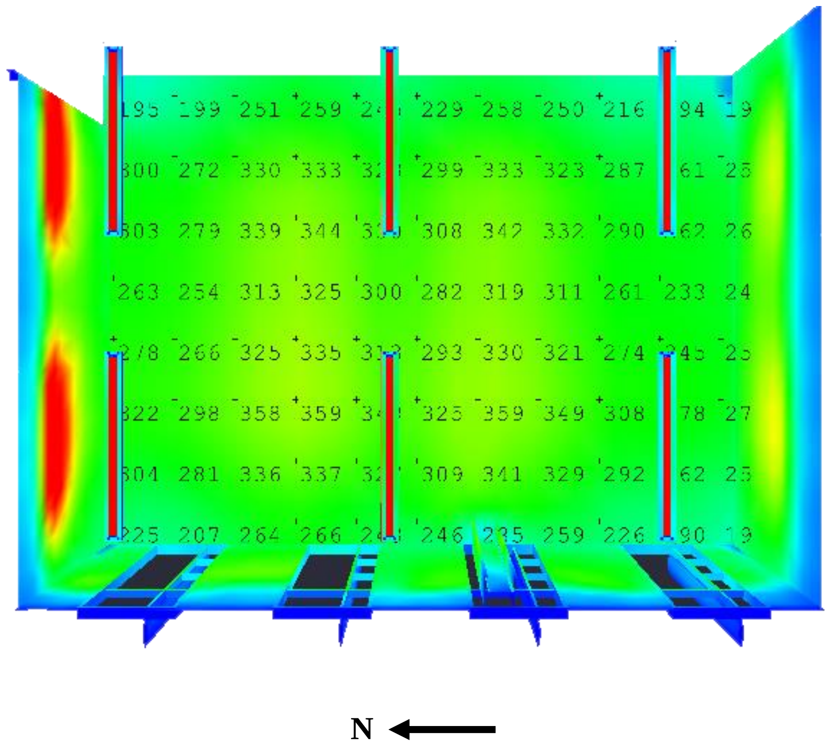
CONTROLS SCHEMATIC

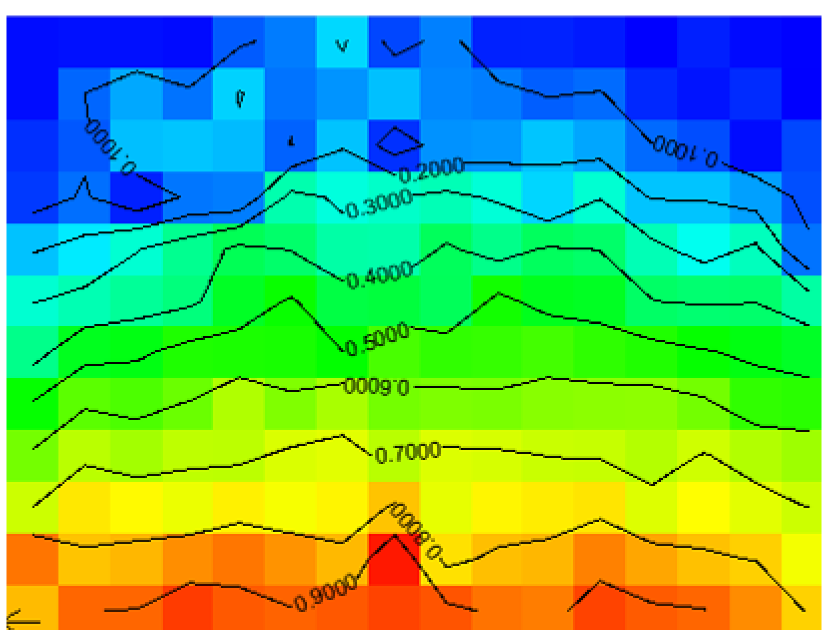


Fixtures will be turned on by users and turned off via a vacancy sensor (D8).

Left: *Switching zones are shown through colored fixture symbols, photosensor zones are shown in cyan boxes, and render view is indicated by the purple arrow.*

OPEN OFFICE





LIGHTING & DAYLIGHTING DESIGN RESULTS

E_{target} / E_{design} = 300 lux / 285 lux (avg)

$W_{allowed}$ / $W_{designed}$: 718 W / 432 W

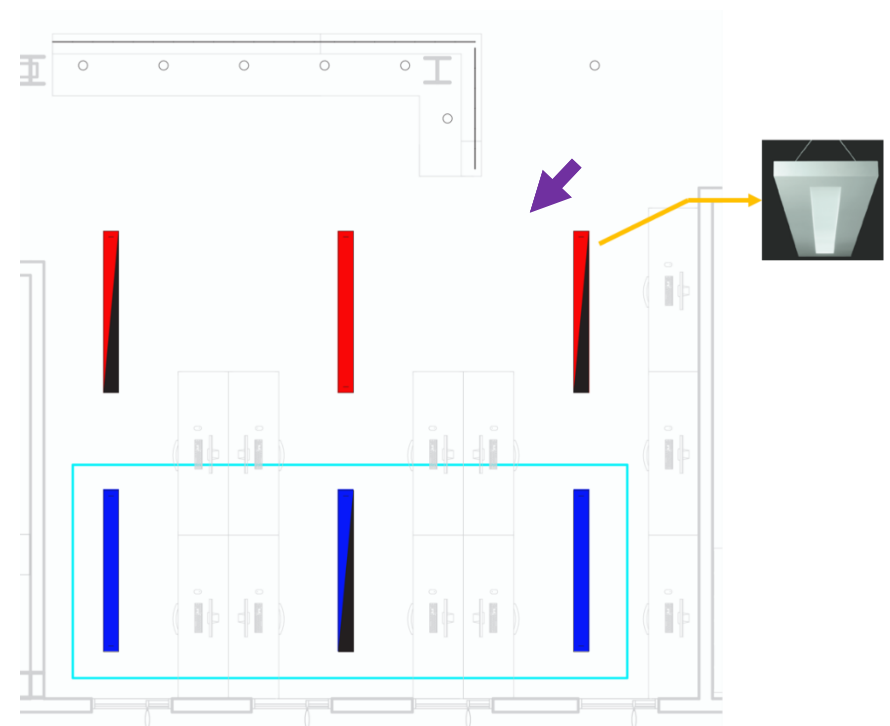
$sDA_{300lux, 50\%}$ = 48.44%

Photosensor Energy Savings per control zone: 80%

Left: *Illuminance psuedocoloring*

Bottom Left: *Contours for the Spatial Daylight Autonomy*

CONTROLS SCHEMATIC



During the day, occupancy sensors will control the fixtures, and they will be dimmed accordingly via photosensors. The lighting management system's time clock will turn the fixtures off at night. However, the timeclock can be overridden by the occupancy sensors. Task lighting will also be utilized to meet the illuminance target (D8).

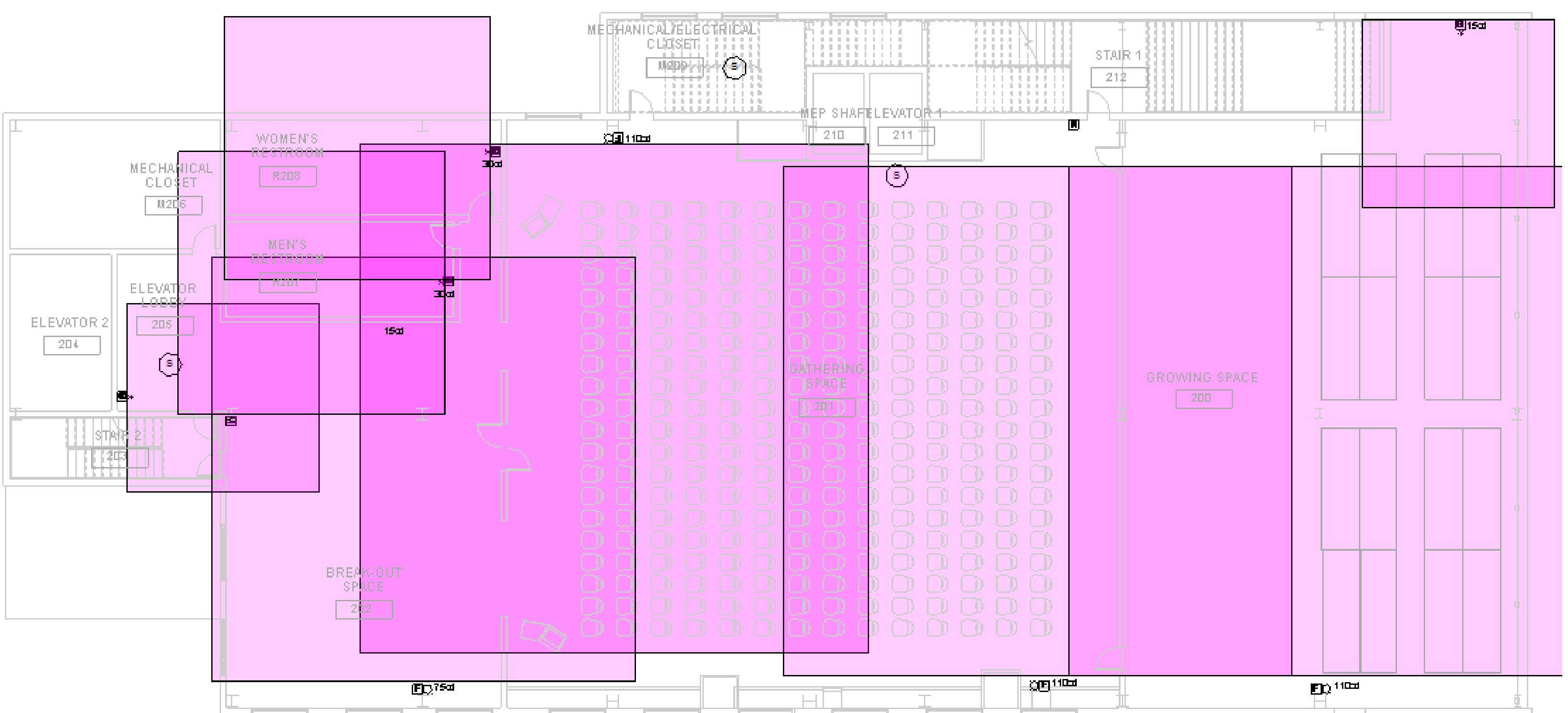
Left: *Switching zones are shown through colored fixture symbols, photosensor zones are shown in cyan boxes, and render view is indicated by the purple arrow.*

FIRE ALARM DESIGN CRITERIA

The main fire alarm equipment is placed in the main mechanical/electrical room in the basement. These include a Digital Alarm Communicator transmitter (DACT), a Fire Alarm Terminal Cabinet (FATC), and a Fire Alarm Control Panel (FACP). The Fire Alarm Annunciator Panel (FAAP) is located at the fire department's entrance, which is at the northeast loading dock. A list of the equipment and their purpose is outlined below:

DACT	Sends alarm signal to fire department
FATC	Houses wiring
FACP	Controls fire alarm devices within the building
FAAP	Shows fire department the location of the fire within the building

DESIGN LAYOUT



Manual pull stations were placed at appropriate exit locations. Additionally, strobes and horn/strobes were located throughout the building based on their visual area of coverage according to their candela rating, seen in the table below by NFPA72. The diagram on the left shows a successful layout of the strobes on the second floor, as the whole area is accounted for.

Candela Rating (cd)	Area of Coverage
15	20' x 20'
30	28' x 28'
75	45' x 45'
110	54' x 54'

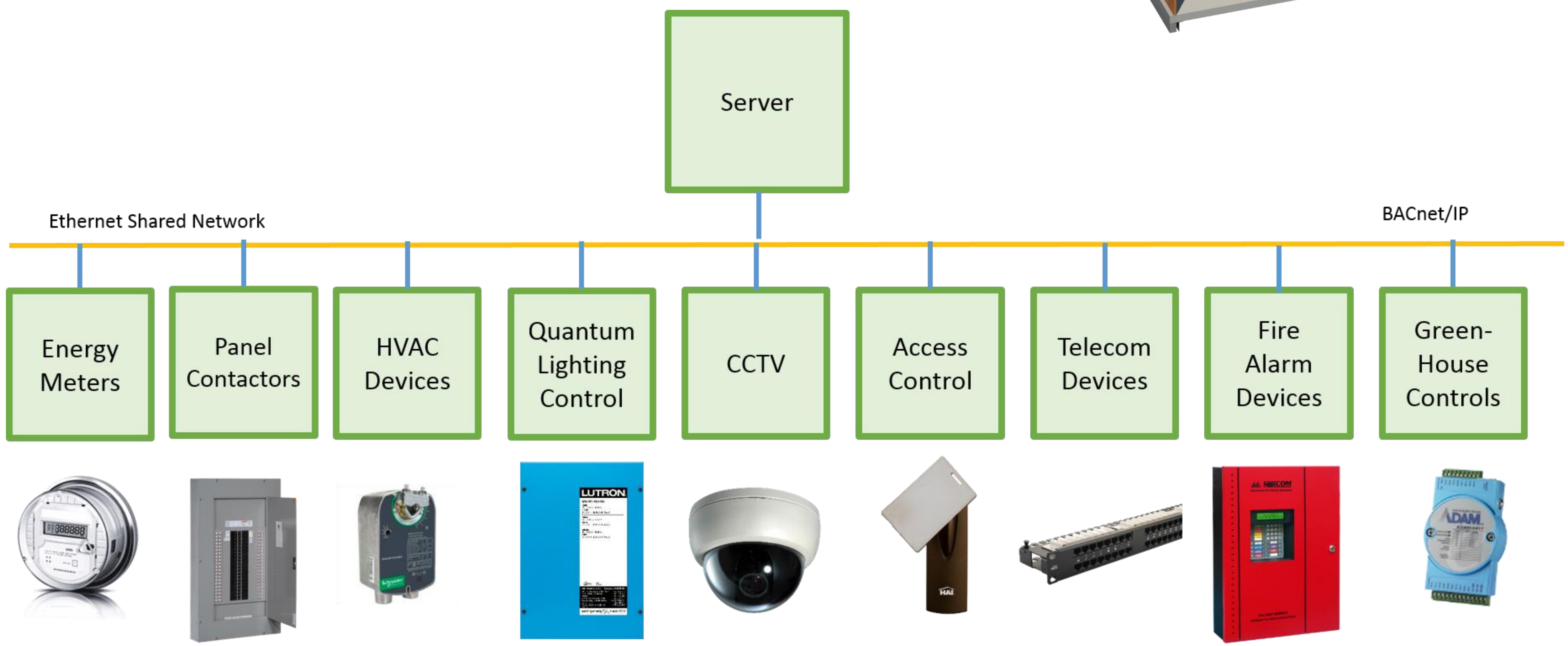
TOTAL BUILDING NETWORK DESIGN

BUILDING SYSTEMS INTEGRATION

Below is a more detailed diagram of the building control and monitoring network. Through BACnet/IP wiring, a shared network is created to integrate building systems. The systems listed below will be controlled and monitored via a remote server [14].

Key components to the building electrical operations take part in this network.

- Electrical demand data collected from meters can be monitored.
- To prioritize loads on the generator, contactors upstream of a panel can be controlled to shut off all the loads on an entire panel.
- The Quantum Hub lighting control can communicate with other systems such as HVAC devices.
- Greenhouse devices such as pumps, fans, and other systems integral to its operation can be monitored and controlled along with the building controls.



EQUIPMENT LEGEND

	DISCONNECT SWITCH
L1	PANEL
T	TRANSFORMER
	SYSTEM OR EQUIPMENT GROUND
	CEILING OR WALL MOUNT JUNCTION BOX
M	METER
	CONTACTOR
	GROUND BAR
VFD	VARIABLE FREQUENCY DRIVE
L1-1	HOMERUN TO PANEL L1 VIA 1-POLE CIRCUIT BREAKER
L1-1,3,5	MULTI CIRCUIT HOMERUN TO PANEL L1 VIA 1-POLE CIRCUIT BREAKERS INDICATED BY NUMBER OF ARROWHEADS
SB	SWITCHBOARD SECTION

WIRING DEVICES LEGEND

G	WALL, FLOOR, CEILING MOUNT DUPLEX RECEPTACLE. SUBSCRIPTS: "G" GROUND FAULT CIRCUIT INTERRUPTER "WP" WEATHERPROOF "MIC" DEDICATED FOR MICROWAVE "COFF" DEDICATED FOR COFFEE MAKER
	QUADRUPLEX RECEPTACLE
P	POWER SECTION OF SYSTEMS FURNITURE, WALL MOUNTED
	SPECIAL RECEPTACLE SUBSCRIPT "REF" FOR REFRIGERATOR
FBX	RECESSED POKE THRU DEVICE. PROVIDE TWO DUPLEX RECEPTACLES AND TWO DATA OUTLETS
$	SINGLE POLE TOGGLE SWITCH
$3	THREE-WAY TOGGLE SWITCH
$4	FOUR-WAY TOGGLE SWITCH

LIGHTING EQUIPMENT LEGEND

	LINEAR FIXTURES, CEILING AND RECESSED
	DOWNLIGHT, RECESSED
	WALL WASHER, SEMI-RECESSED
	PENDANTS
	WALL SCONCE
	TRACK FIXTURE
	STRIP FIXTURE
	EXIT SIGN, CEILING MOUNT. PROVIDE DIRECTIONAL ARROWS AND FACES AS INDICATED ON PLANS

FIRE ALARM DEVICE LEGEND

F	AUDIBLE AND VISUAL ALARM SIGNAL. NUMBER INDICATES CANDELA RATING
S	VISUAL ONLY ALARM SIGNAL. NUMBER INDICATES CANDELA RATING
M	MANUAL PULL STATION
S	SMOKE DETECTOR
FATC	FIRE ALARM TERMINAL CABINET
FAAP	FIRE ALARM ANNUNCIATOR PANEL
FACP	FIRE ALARM CONTROL PANEL
DACT	DIGITAL ALARM COMMUNICATOR TRANSMITTER

COMMUNICATION DEVICES LEGEND

	VOICE/DATA TELECOMMUNICATIONS OUTLET
D	TELECOM SECTION OF SYSTEMS FURNITURE, WALL MOUNTED

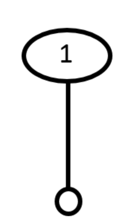
SECURITY DEVICES LEGEND

CR	CARD READER
	CLOSED CIRCUIT TELEVISION

SENSOR LEGEND

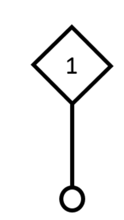
OC	OCCUPANCY / VACANCY SENSOR, CEILING MOUNTED
PS	PHOTOSENSOR, CEILING MOUNTED

FEEDER
TAG SYMBOL

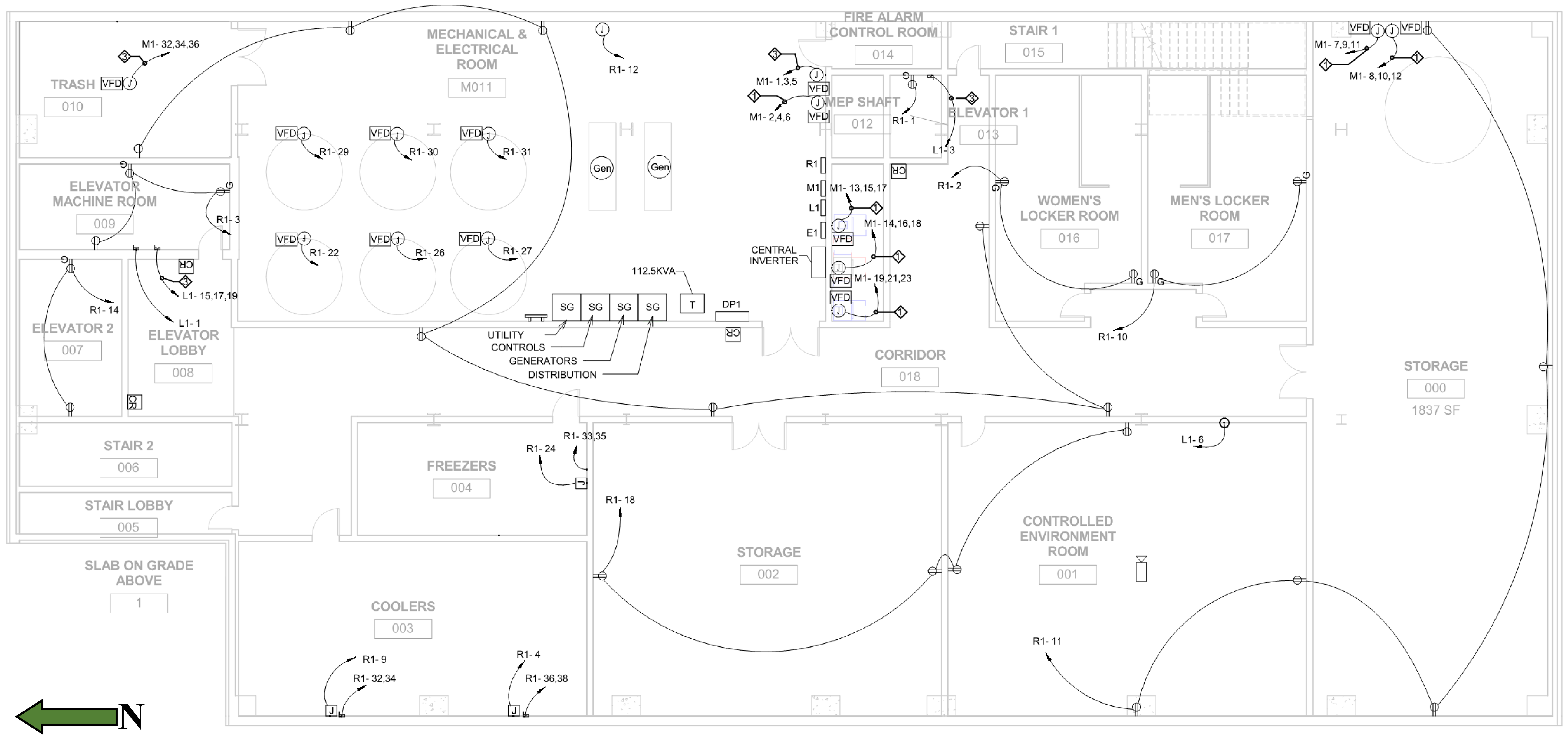


FEEDER SCHEDULE			
TAG #	WIRE	GROUND	CONDUIT
1	4#1	1#6G	2"C
2	4#1/0	1#6G	2"C
3	4#4/0	1#4G	2-1/2"C
4	4-600kcmil	1#2G	4"C
5	3#6	1#8	1-1/4"C
6	3#4/0	1#4G	2.5"C
7	5#4/0	1#1/0G	(2)3"C

BRANCH CIRCUIT
TAG SYMBOL

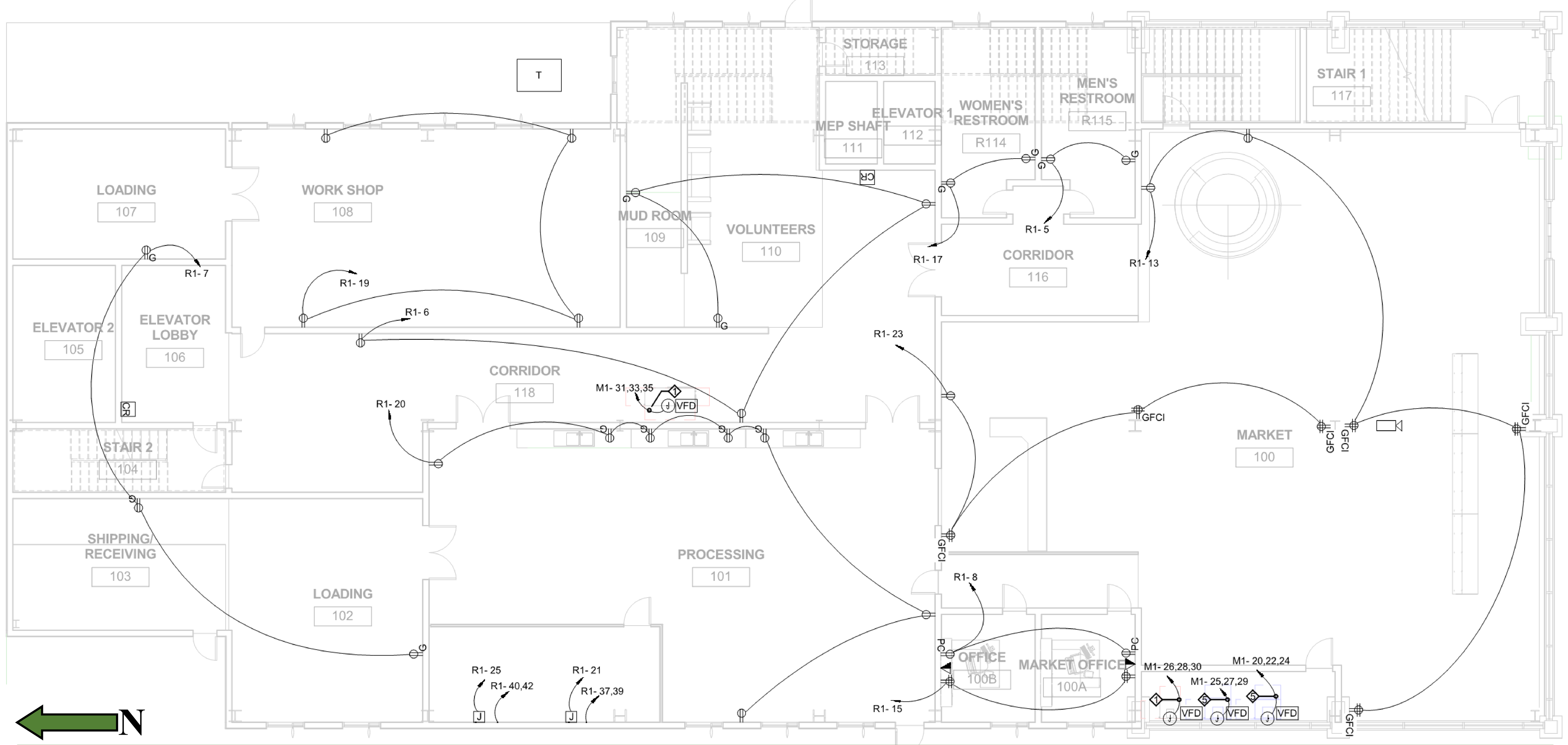


BRANCH CIRCUIT SCHEDULE			
TAG #	WIRE	GROUND	CONDUIT
1	3#12	1#12	3/4"C
2	3#10	1#10	3/4"C
3	3#6	1#8	1-1/4"C
4	3#4	1#8	1-1/4"C
5	3#10	1#10	3/4"C
6	3#8	1#8	1"C



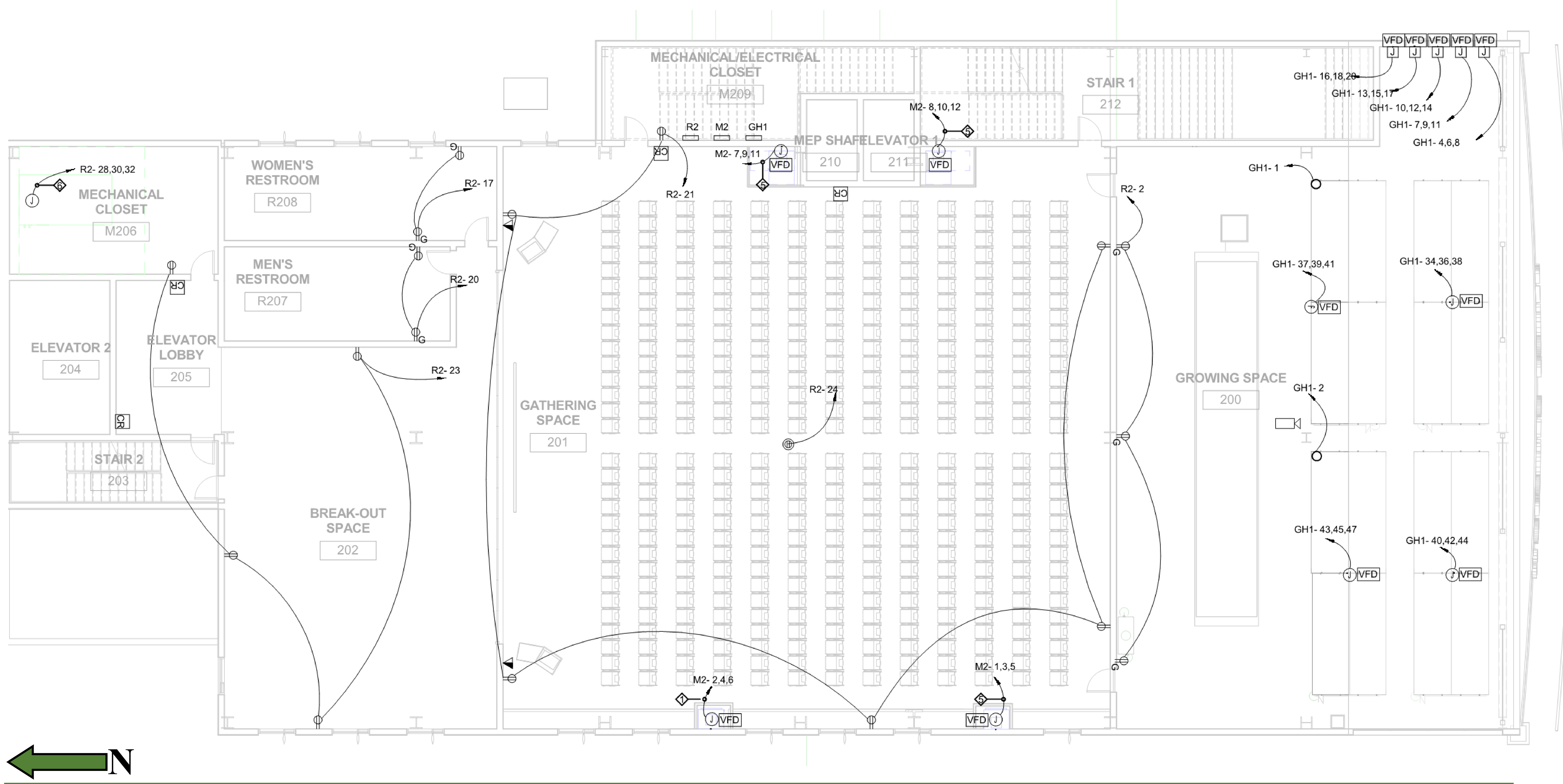
Basement

Scale: 1/8” = 1’



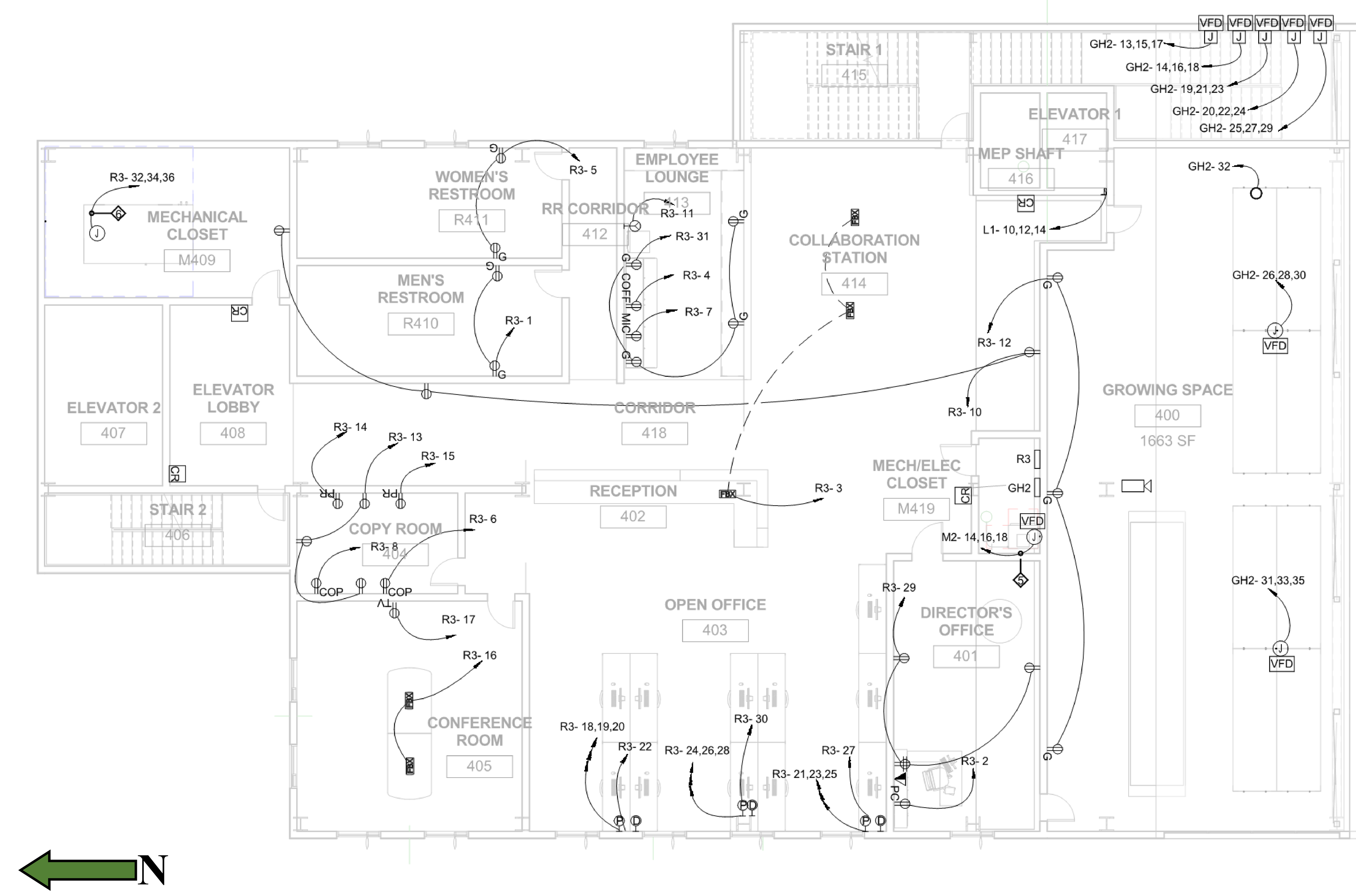
First Floor

Scale: 1/8” = 1’



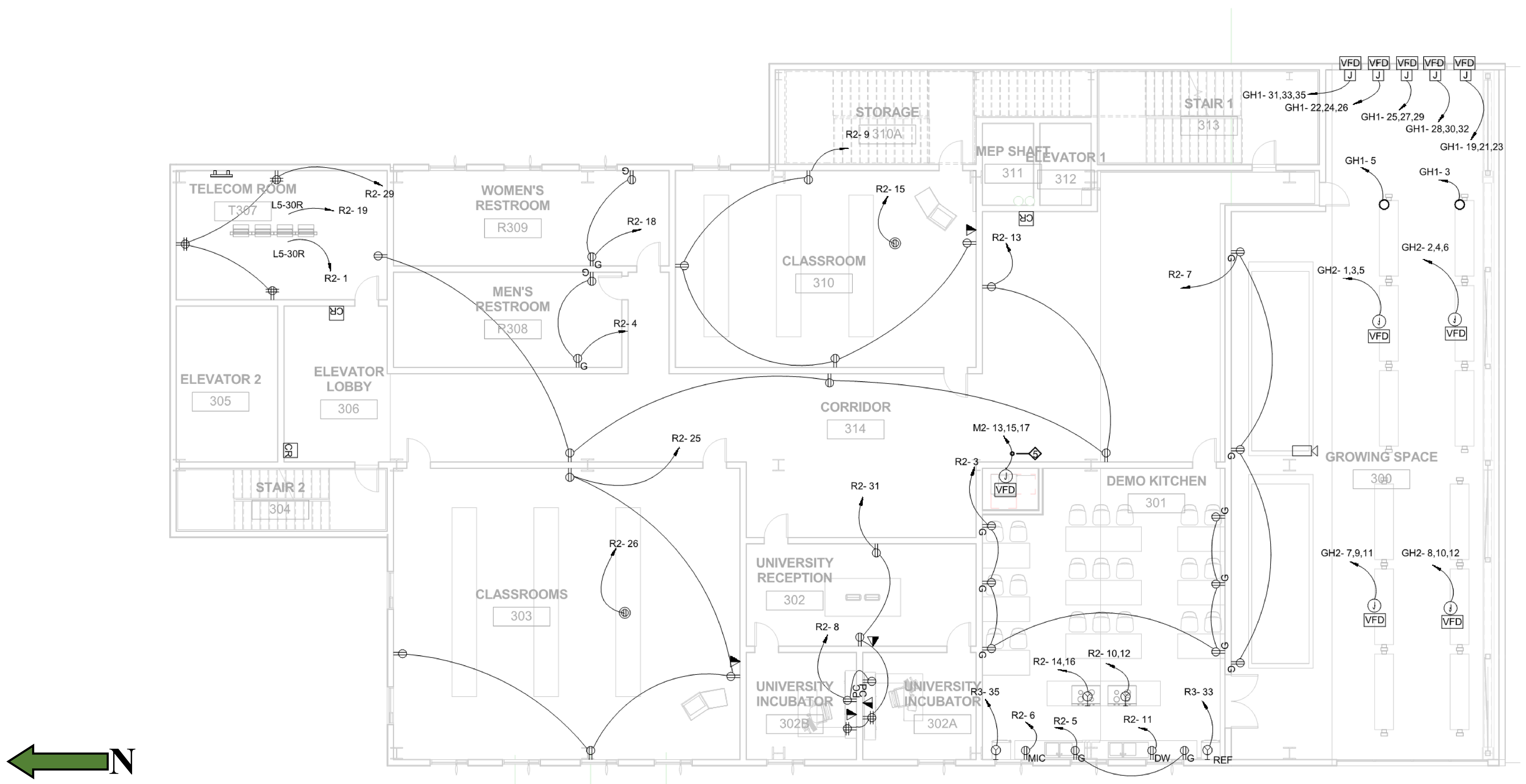
Second Floor

Scale: 1/8" = 1'



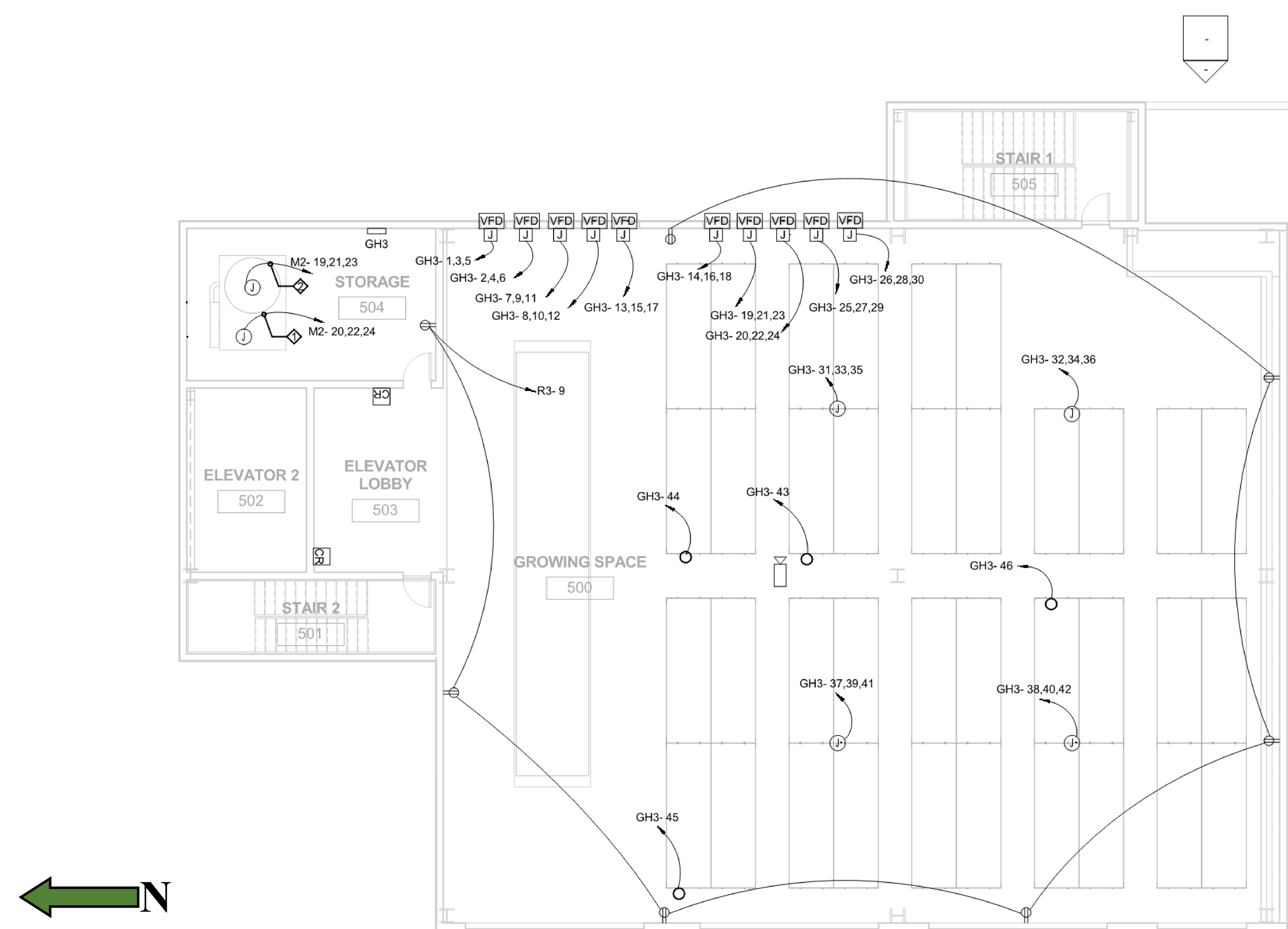
Fourth Floor

Scale: 1/8" = 1'



Third Floor

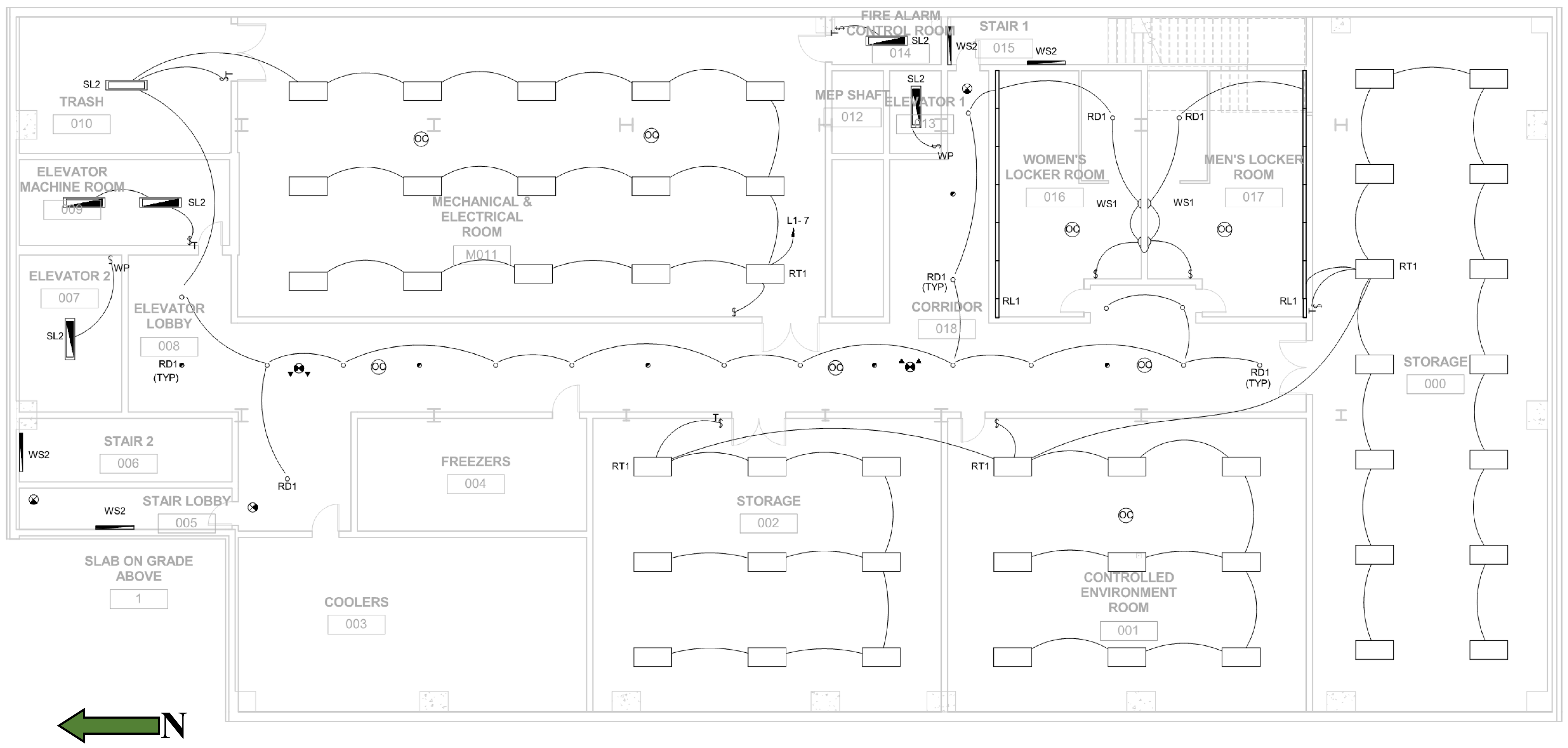
Scale: 1/8" = 1'



Fifth Floor

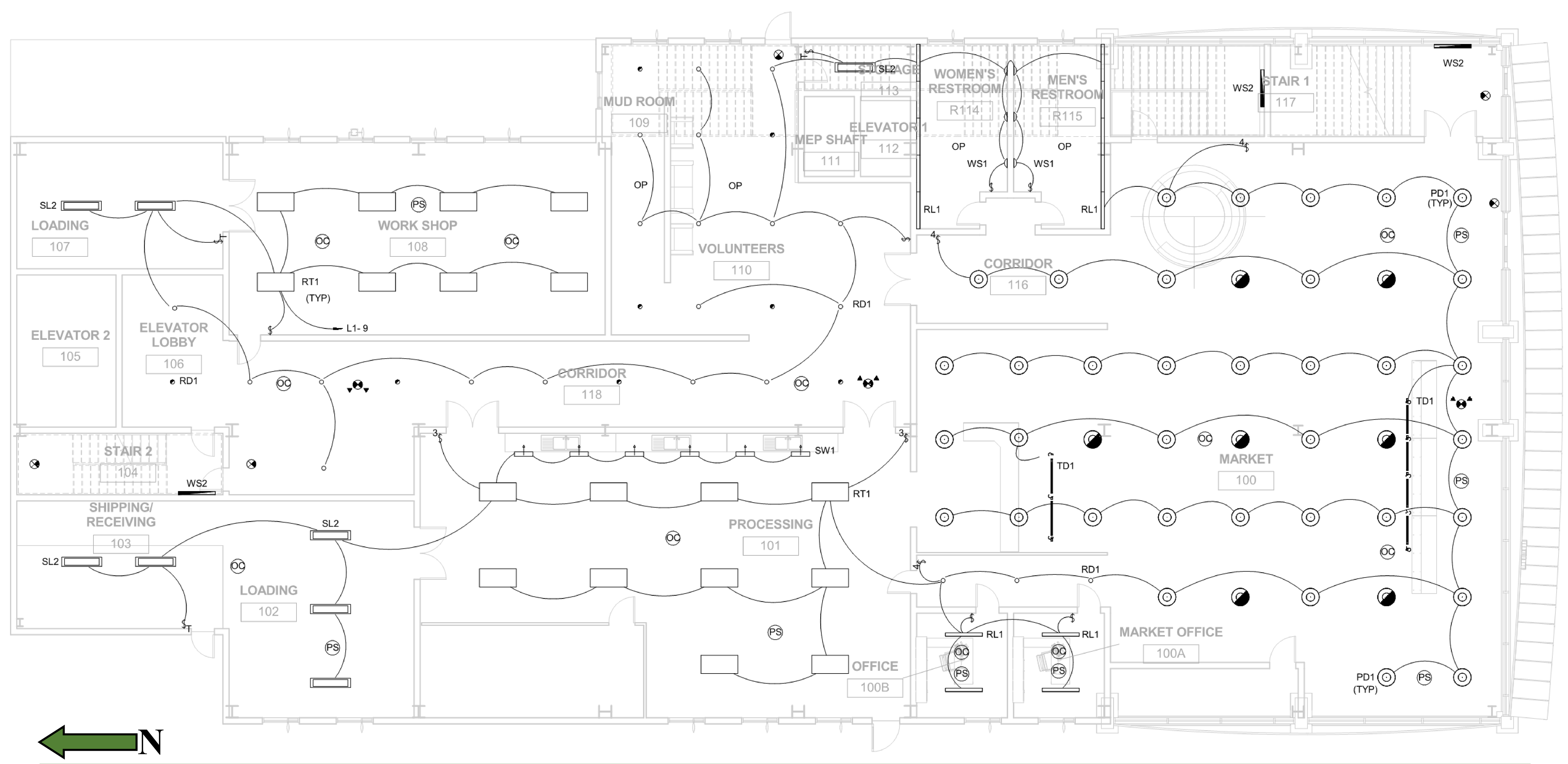
Scale: 1/8" = 1'

TBD Engineering | Lighting Plan



Basement

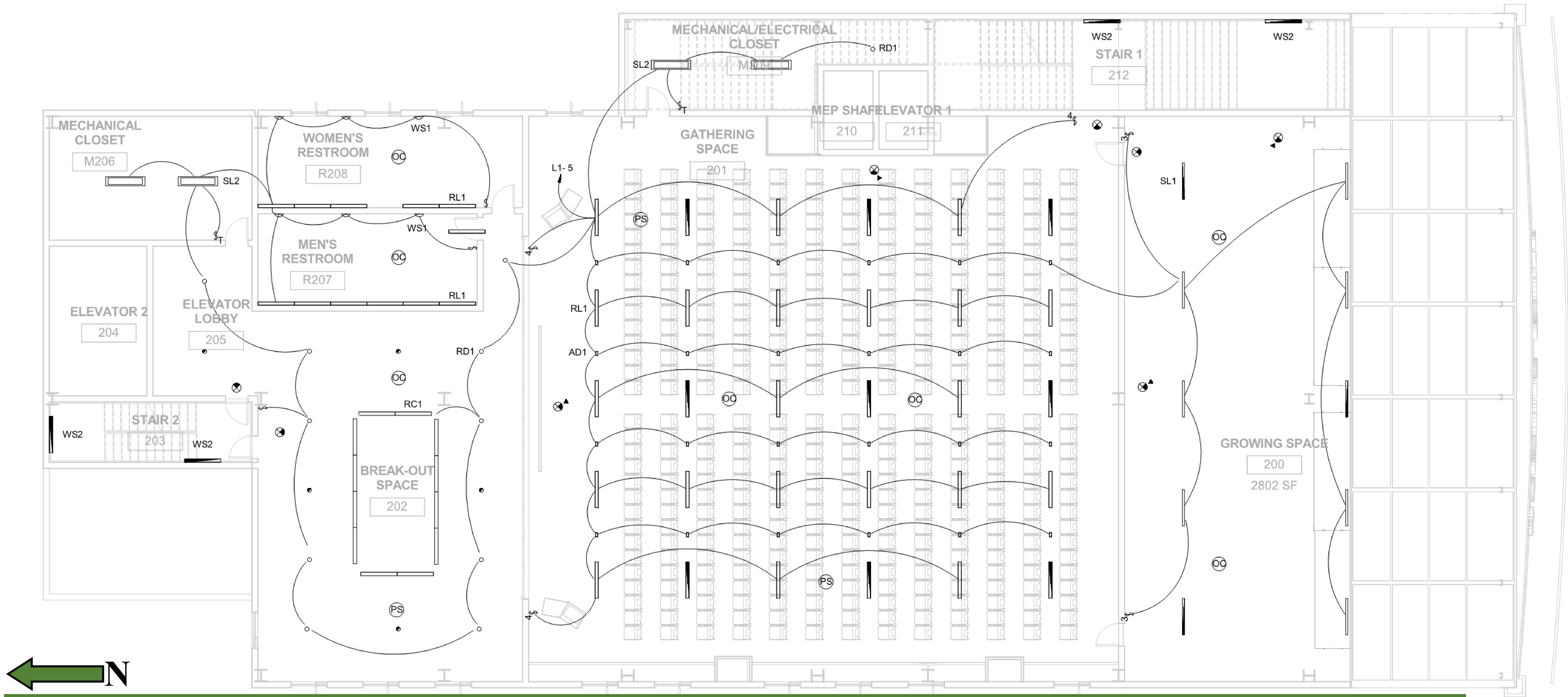
Scale: 1/8" = 1'



First Floor

Scale: 1/8" = 1'

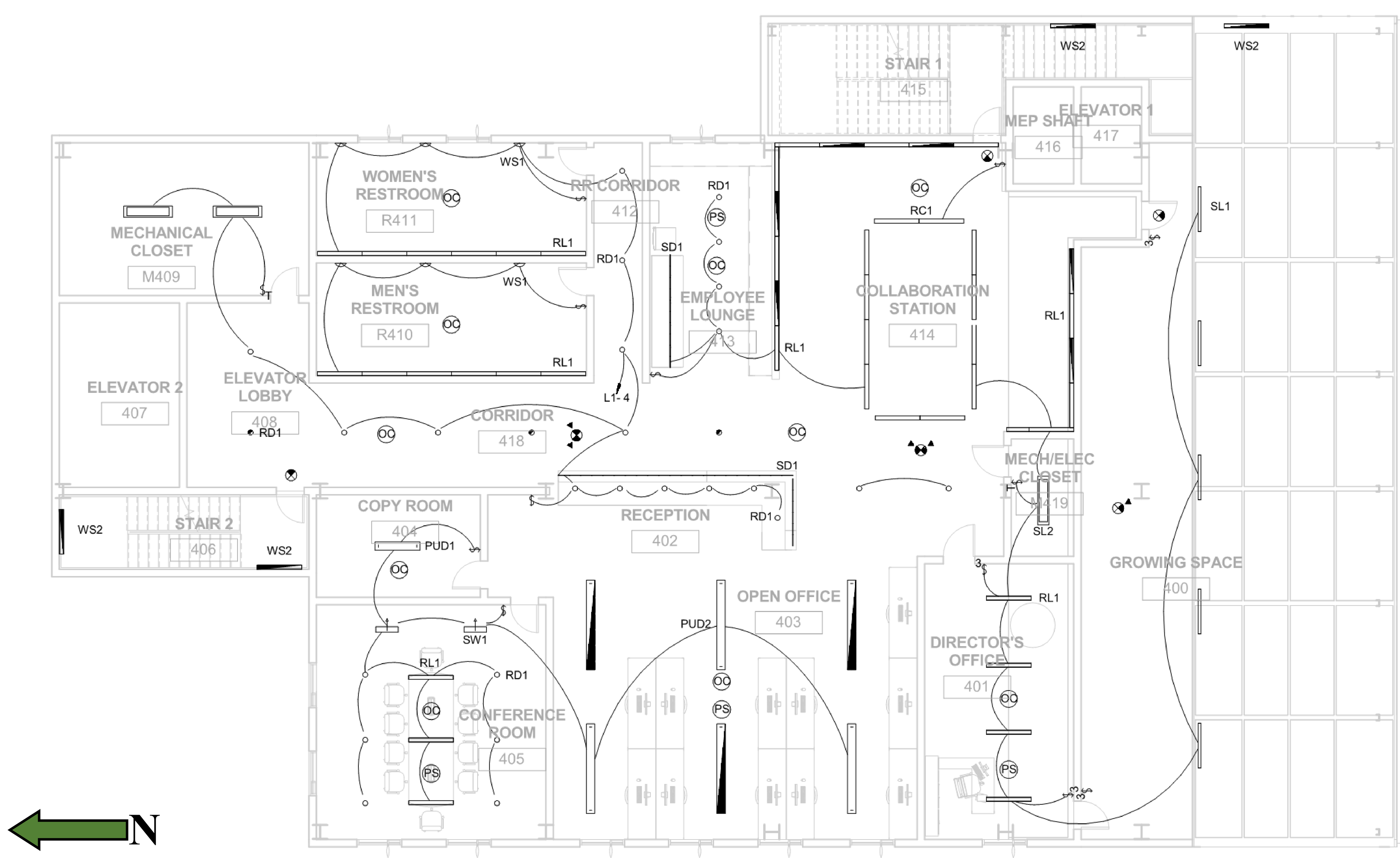
TBD ENGINEERING | LIGHTING PLAN



N

Second Floor

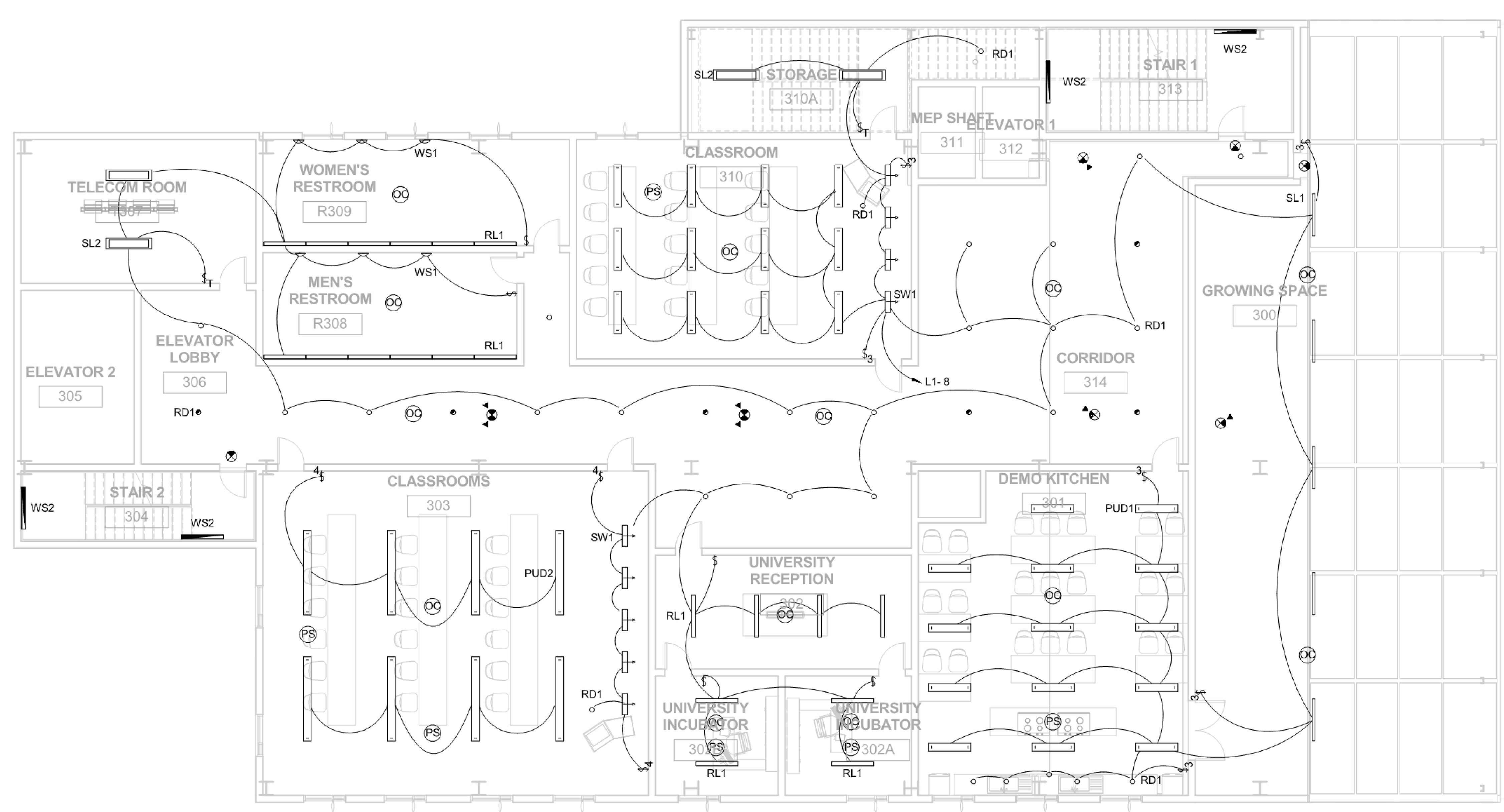
Scale: 1/8" = 1'



N

Fourth Floor

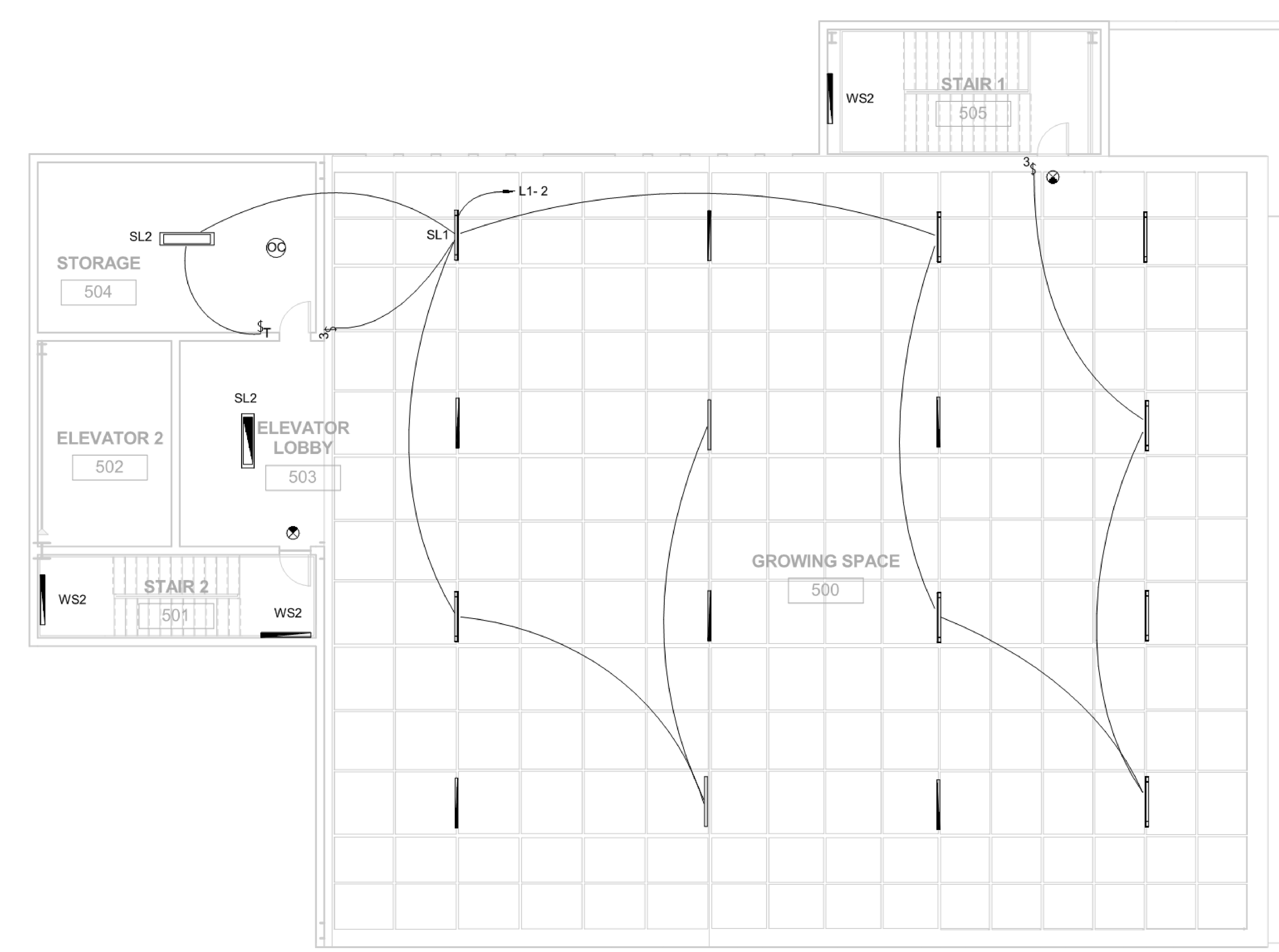
Scale: 1/8" = 1'



N

Third Floor

Scale: 1/8" = 1'

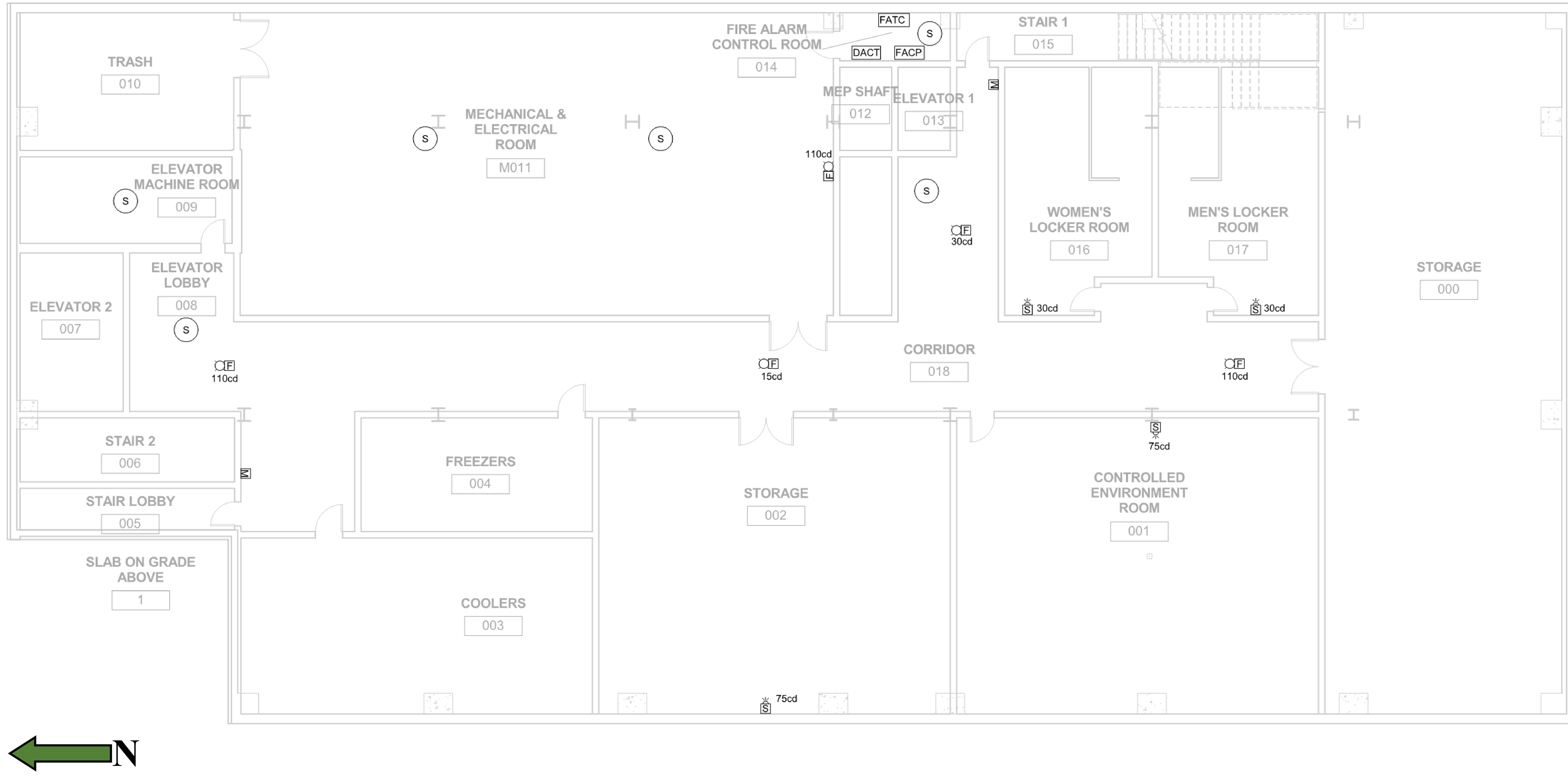


N

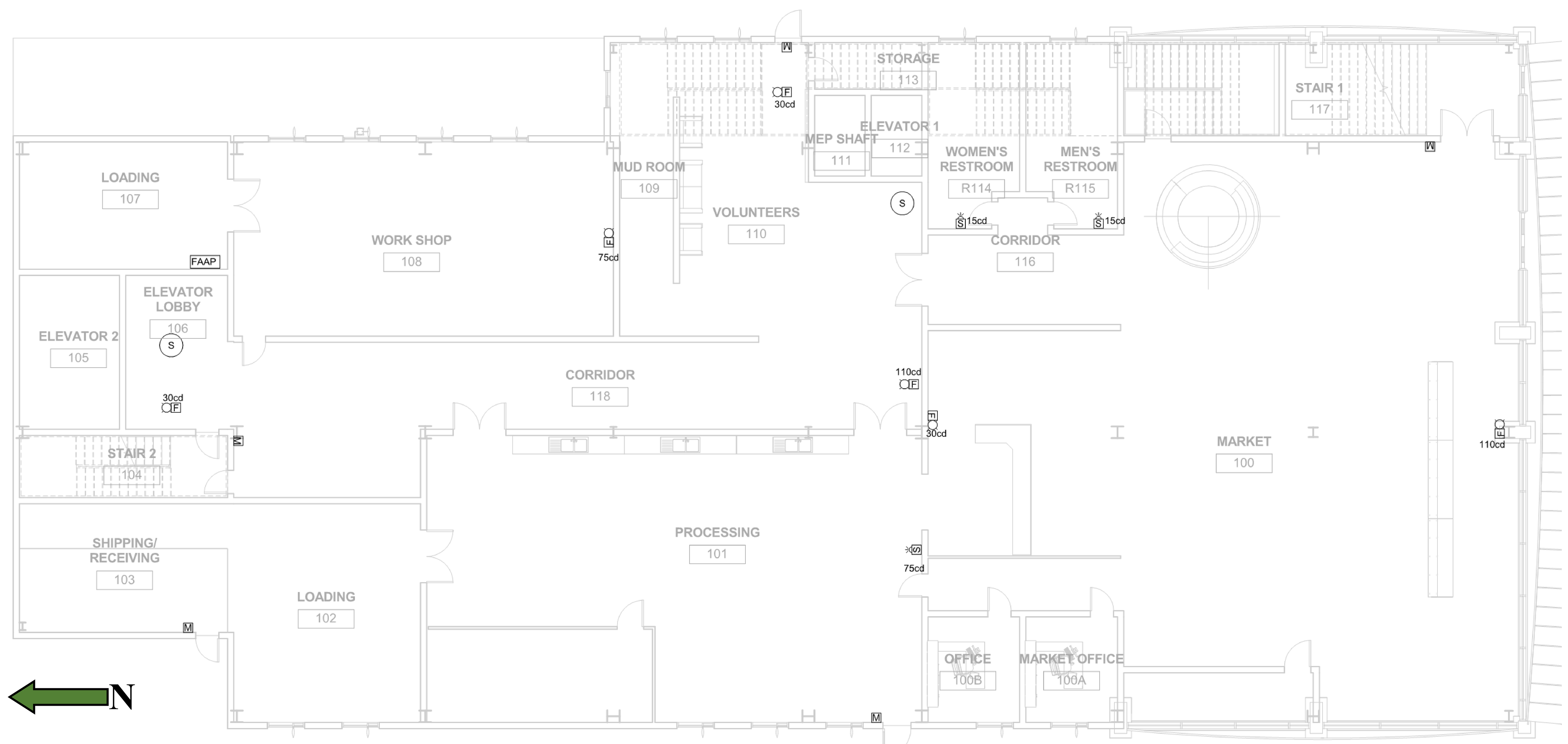
Fifth Floor

Scale: 1/8" = 1'

TBD ENGINEERING | FIRE ALARM PLAN

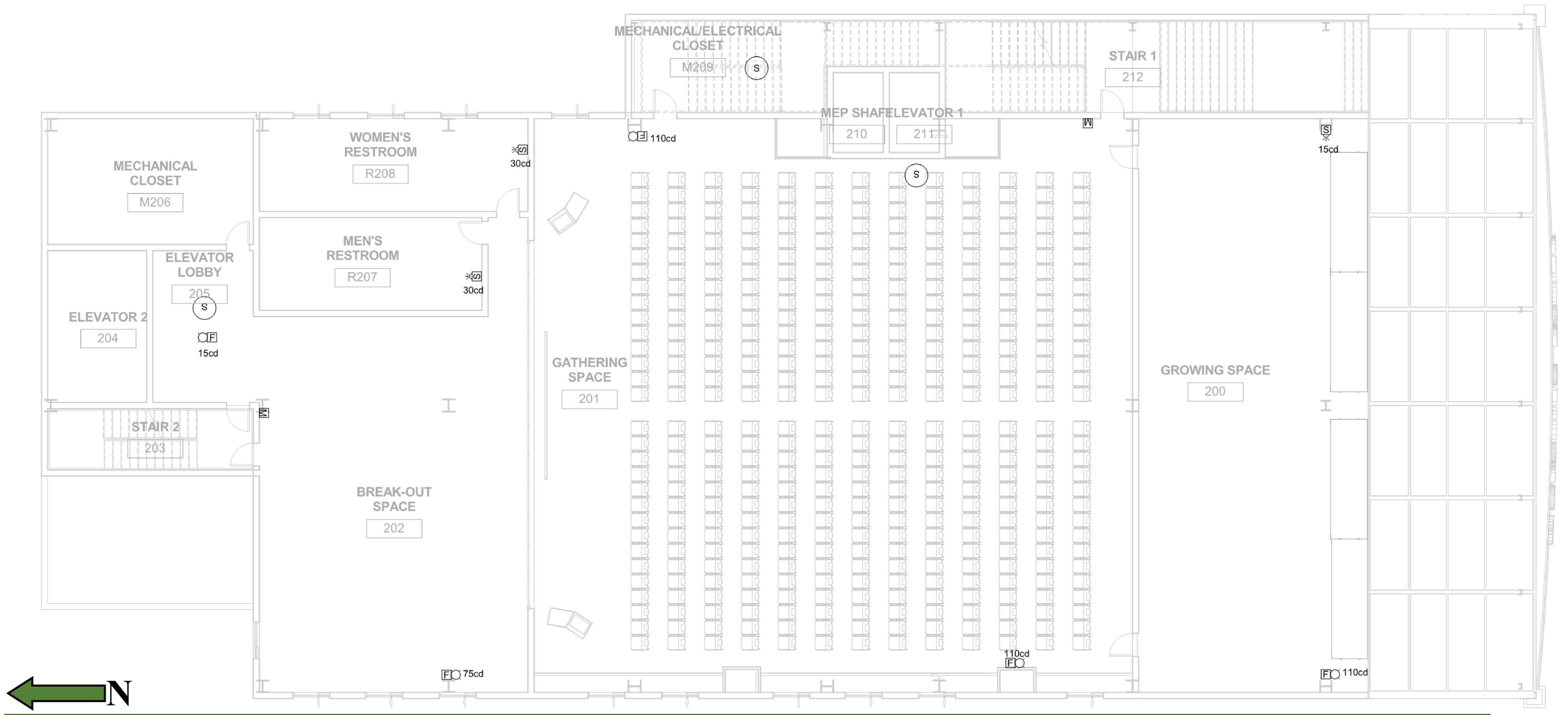


Basement Scale: 1/8" = 1'



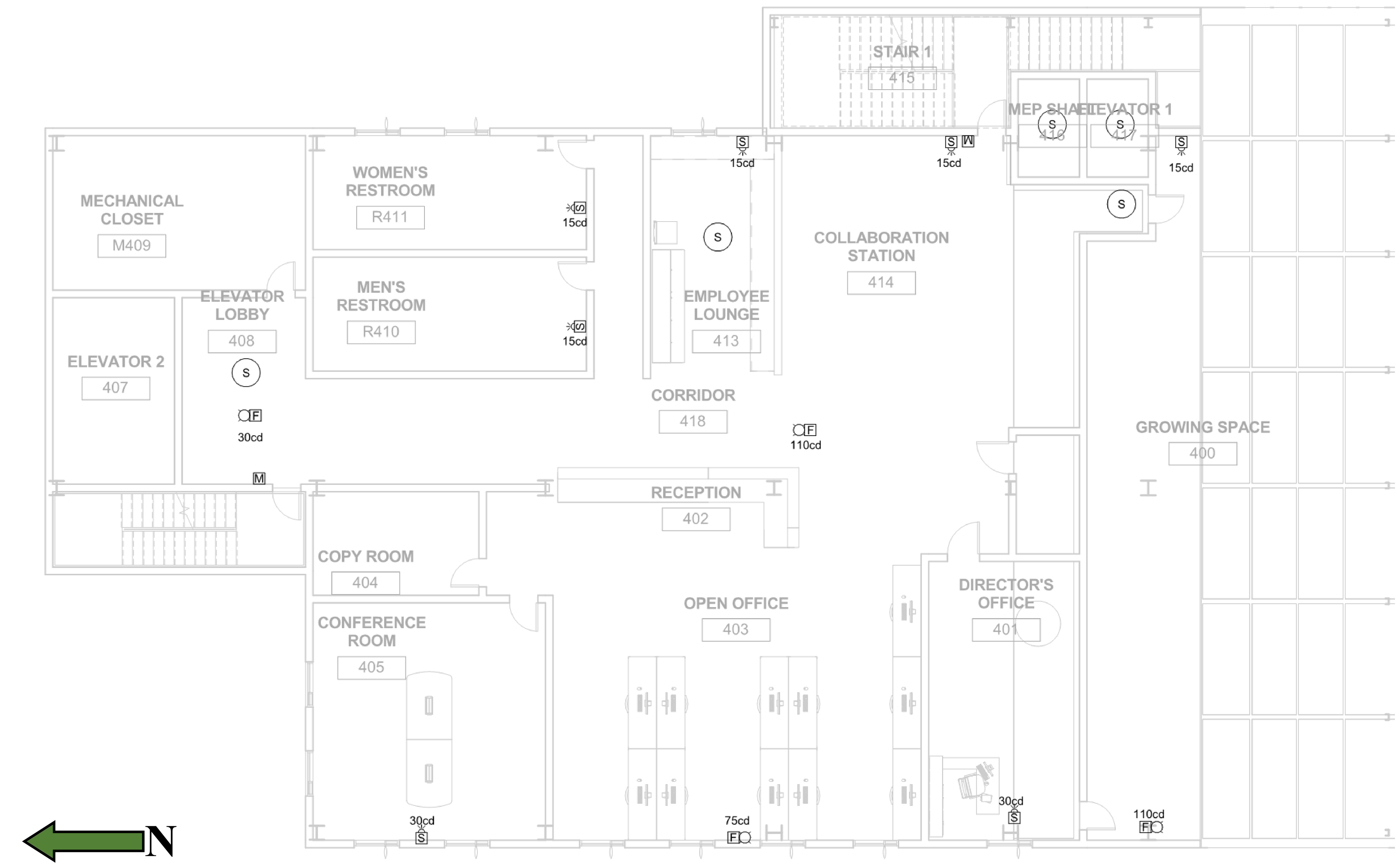
First Floor Scale: 1/8" = 1'

TBD ENGINEERING | FIRE ALARM PLAN



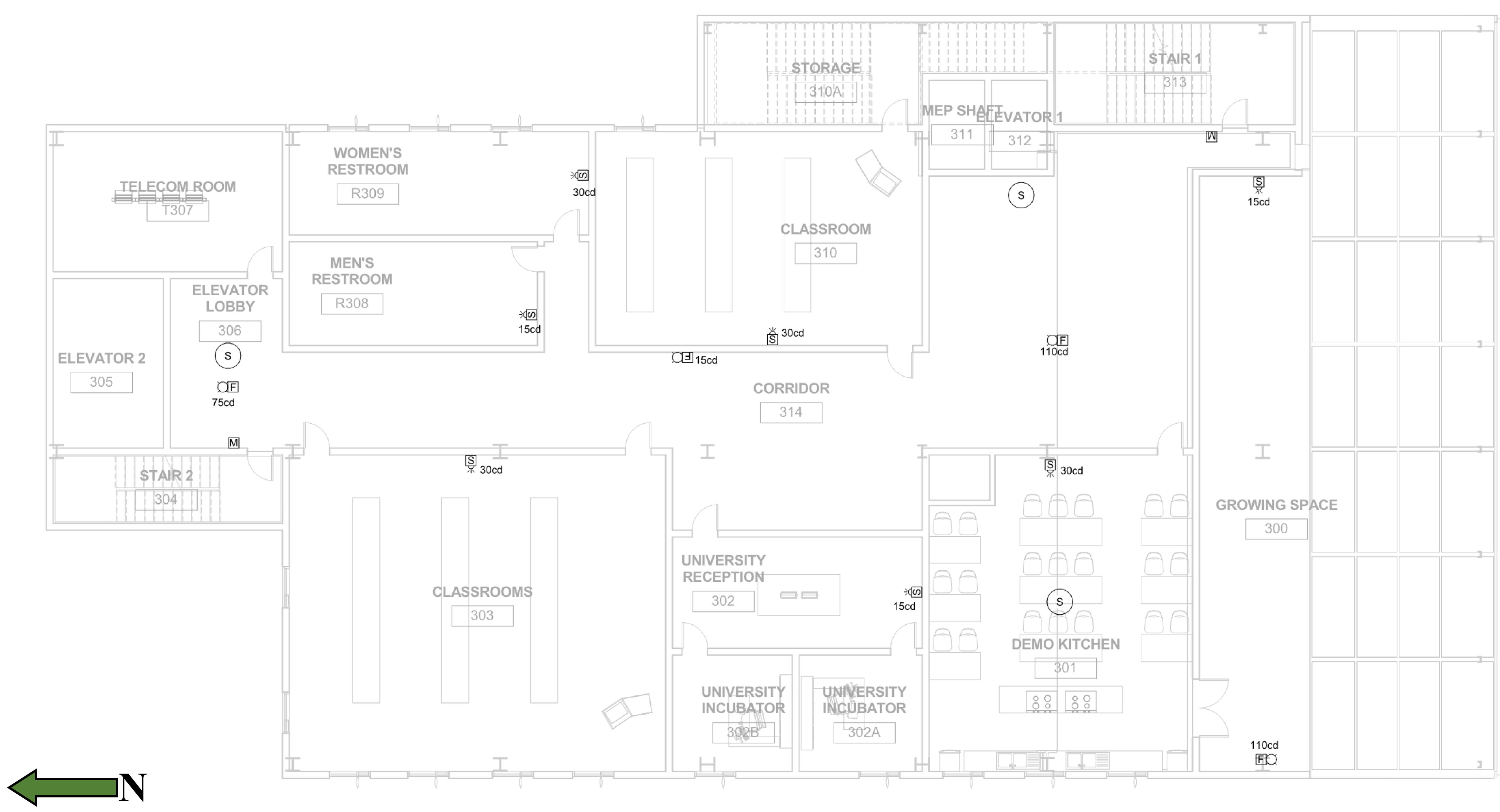
Second Floor

Scale: 1/8" = 1'



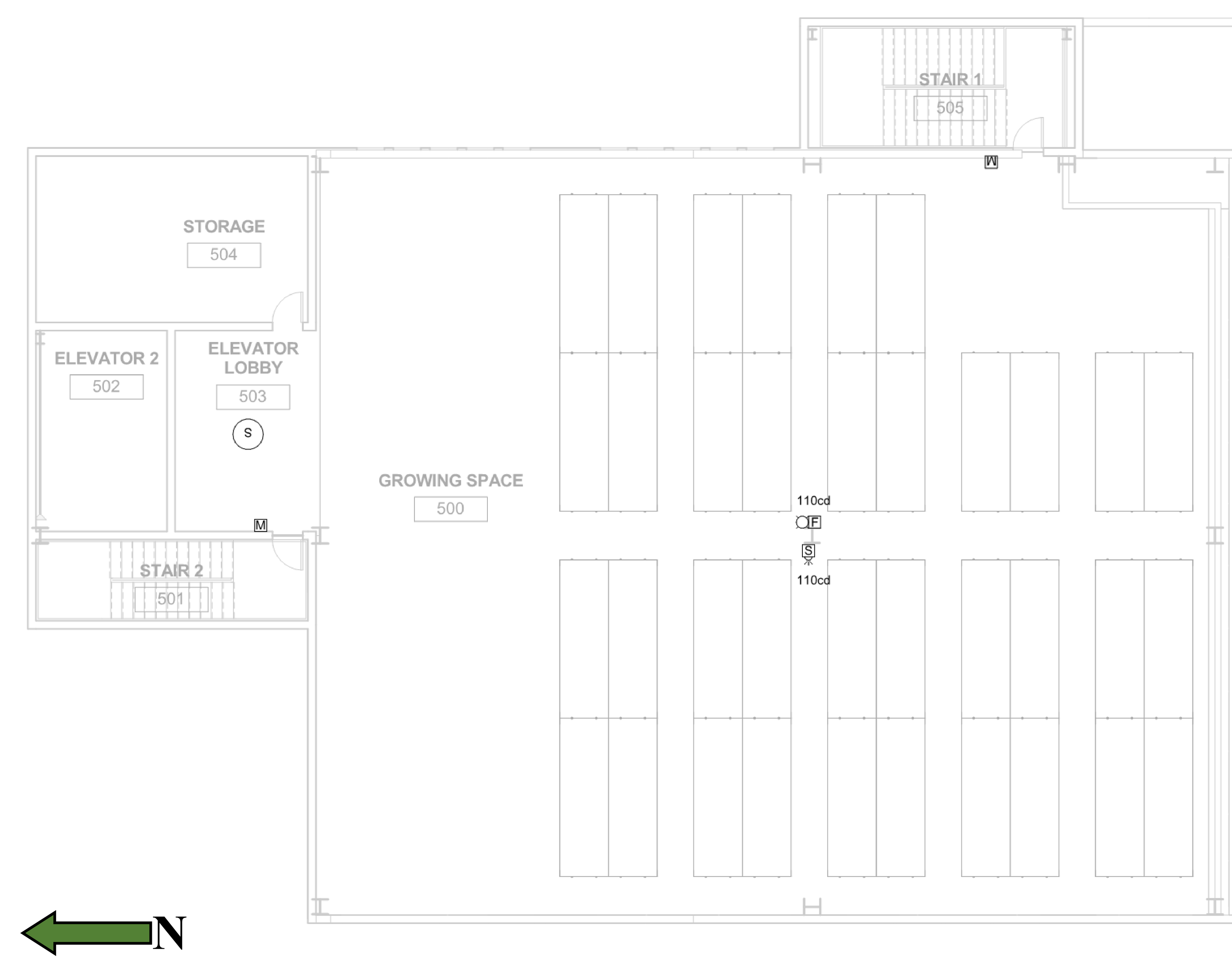
Fourth Floor

Scale: 1/8" = 1'



Third Floor

Scale: 1/8" = 1'



Fifth Floor

Scale: 1/8" = 1'

TBD Engineering | Schedules

FIXTURE SCHEDULE

TYPE	DESCRIPTION	MANUFACTURER MODEL	LAMP	WATTS	CCT	VOLTAGE	DIMMING	MOUNTING	COMMENTS
AD1	Recessed Adjustable 2 Light LED	Amerlux Hornet High Power, Recessed Trimless Multi-ple 2 Light LED	LED	18	4000K	277	Lutron Hi-Lume	Recessed	
PD1	Low Bay Pendant in Matte White	Spectrum Lighting, Inc. LED Aluminum EXT Mini-Bay	LED	55	4000	277	0-10V	Pendant	
PUD1	Linear 1x4 Direct/Indirect Pendant with Microgrow Lens	Focal Point Twelve	LED	36	4000K	277	Lutron A-Series Ecosystem	Provide 1' Chain	
PUD2	Linear 1x4 Direct/Indirect Pendant with Microgrow Lens	Focal Point Twelve	LED	72	4000K	277	Lutron A-Series Ecosystem	Provide 1' Chain	
RC1	Recessed Linear Cove	Elliptipar S301	LED	7W/F	4000K	277	Lutron A-Series	Recessed	4' sections
RD1	Recessed 4.5" Circular Downlight	Focal Point id 4.5"	LED	21	4000K	277	Lutron A-Series Ecosystem	Recessed	
RL1	Recessed 4" Linear Fixture	Focal Point Seem 4	LED	17	4000K	277	Lutron A-Series Ecosystem	Flush Recessed	4' sections
RT1	2'x4' Lensed Trouffer	Cooper Metalux 2GR LED	LED	38	4000K	277	0-10V DALI	Recessed	
SD1	LED Tape Light Strip	Tivoli TivoTape Indoor SB	LED	3w/ft	3500K	277	0-10V	Surface Mount	
SL1	4' Linear Strip Fixture with Clear Acrylic Lens	Lithonia FEM LED	LED	64	4100K	277	0-10V	Surface	Wet Location Rated
SL2	1'x4' Lensed Surface Mount	Cooper Corelite Divide	LED	32	4000K	277	Lutron	Surface	
SW1	Semi-Recessed Linear Wall Washer	Elliptipar S224	LED	25	4000K	277	Lutron A-Series	Semi-Recessed	
TD1	Track Fixture with Narrow Flood Distribution	Cooper Lighting Halo L805MED Stasis	LED	17	4000K	277	Lutron	Track	Provide Halo Power Trac
WS1	12" Curved Wall Sconce in Matte White	Cooper Lighting 662 Series	LED	16	4000K	277	Lutron	Wall	
WS2	Linear Wall Mount Direct/ Indirect Fixture	Cooper Neo-Ray 23-DIW	LED	7	4000K	277	Lutron DALI	Wall	
X1	Pendant/Surface Mounted Exit Sign	Cooper Sure-Lites ES6	LED	N/A	N/A	277	N/A	Pendant/ Surface	Provide Number of Faces and Di-rectional Arrows as Indicated on Plans

Branch Panel: L1

Location: MECHANICAL EQUIPMENT ROOM 011 **Volts:** 480/277V **A.I.C. Rating:** 65,000
Supply From: Switchboard Distribution **Phases:** 3 **Mains Type:** MCB
Mounting: Surface **Wires:** 4 **Mains Rating:** 225 A
Enclosure: Type 1 **MCB Rating:** 225 A

Ckt	Circuit Description	Trip	Poles	A		B		C		Poles	Trip	Circuit Description	Ckt
1	Freight Elevator Cab Lights	20	1	28 VA	176 VA					1	20	Fifth Floor Lighting	2
3	Passenger Elevator Cab Lights	20	1			28 VA	1952 VA			1	20	Fourth Floor Lighting	4
5	Second Floor Lighting	20	1					1781 VA	4160 VA	1	20	Grow Lights CER 001	6
7	Basement Lighting	20	1	2495 VA	2609 VA					1	20	Third Floor Lighting	8
9	First Floor Lighting	20	1			3826 VA	9422 VA						10
11	Spare		1					0 VA	9422 VA	3	70	Passenger Elevator	12
13	Spare		1	0 VA	9422 VA								14
15						14410...	0 VA			1		Spare	16
17	Freight Elevator	100	3					14410...	0 VA	1		Spare	18
19				14410...	0 VA					1		Spare	20
21	Spare		1			0 VA	0 VA			1		Spare	22
23	Spare		1					0 VA	0 VA	1		Spare	24
25	Spare	0	1	0 VA	0 VA			0		1		Spare	26
27	Spare		1			0 VA	0 VA			1		Spare	28
29	Spare		1					0 VA	0 VA	1		Spare	30
31	Spare		1	0 VA	0 VA					1		Spare	32
33	Spare		1			0 VA	0 VA			1		Spare	34
35	Spare		1					0 VA	0 VA	1		Spare	36
37	Spare		1	0 VA	0 VA					1		Spare	38
39	Space		--			0 VA	0 VA			--		Space	40
41	Space		--					0 VA	0 VA	--		Space	42
		Total Load:		29141 VA		29638 VA		29774 VA					
		Total Amps:		105 A		107 A		108 A					

Load Classification	Connected Load (VA)	Demand Factor	Estimated Demand (VA)	Panel Totals	
Lighting	17478 VA	100.00%	17478 VA		
Receptacle	0 VA	0.00%	0 VA		
Power	71498 VA	100.00%	71498 VA	Total Conn. Load:	89004 VA
Motor	28 VA	100.00%	28 VA	Total Est. Demand:	89004 VA
HVAC	0 VA	0.00%	0 VA	Total Conn.:	107 A
Other	0 VA	0.00%	0 VA	Total Est. Demand:	107 A

Notes: Provide 2#12, #12G, 3/4#C for all branch circuits unless otherwise noted on floor plan.

Branch Panel: E1

Location: MECHANICAL EQUIPMENT ROOM 011 **Volts:** 480/277V **A.I.C. Rating:** 65,000
Supply From: Switchboard Distribution **Phases:** 3 **Mains Type:** MLO
Mounting: Surface **Wires:** 4 **Mains Rating:** 100 A

Ckt	Circuit Description	Trip	Poles	A		B		C		Poles	Trip	Circuit Description	Ckt
1	Fifth Floor Emergency Lighting	20	1	181 VA	574 VA					1	20	First Floor Emergency Lighting	2
3	Third Floor Emergency Lighting	20	1			159 VA	411 VA			1	20	Fourth Floor Emergency Lighting	4
5	Basement Emergency Lighting	20	1					274 VA	276 VA	1	20	Second Floor Emergency Lighting	6
7	Spare		1	0 VA	0 VA					1		Spare	8
9	Spare		1			0 VA	0 VA			1		Spare	10
11	Spare		1					0 VA	0 VA	1		Spare	12
13	Spare		1	0 VA	0 VA					1		Spare	14
15	Spare		1			0 VA	0 VA			1		Spare	16
17	Spare		1					0 VA	0 VA	1		Spare	18
19	Spare		1	0 VA	0 VA					1		Spare	20
21	Spare		1			0 VA	0 VA			1		Spare	22
23	Spare		1					0 VA	0 VA	1		Spare	24
		Total Load:		755 VA		570 VA		550 VA					
		Total Amps:		3 A		2 A		2 A					

Load Classification	Connected Load (VA)	Demand Factor	Estimated Demand (VA)	Panel Totals	
Lighting	2040 VA	100.00%	2040 VA		
Receptacle	0 VA	0.00%	0 VA		
Power	0 VA	0.00%	0 VA	Total Conn. Load:	2040 VA
Motor	0 VA	0.00%	0 VA	Total Est. Demand:	2040 VA
HVAC	0 VA	0.00%	0 VA	Total Conn.:	2 A
Other	0 VA	0.00%	0 VA	Total Est. Demand:	2 A

Notes: Provide 2#12, #12G, 3/4#C for all branch circuits unless otherwise noted on floor plan.

Branch Panel: M1

Location: MECHANICAL EQUIPMENT ROOM 011 **Volts:** 480/277V **A.I.C. Rating:** 65,000
Supply From: Switchboard Distribution **Phases:** 3 **Mains Type:** MCB
Mounting: Surface **Wires:** 4 **Mains Rating:** 400 A
Enclosure: Type 1 **MCB Rating:** 400 A

Ckt	Circuit Description	Trip	Poles	A		B		C		Poles	Trip	Circuit Description	Ckt
1				14410...	3880 VA								2
3	WSHP Distribution Pump	100	3			14410...	3880 VA			3	30	Hot Water Distribution Pump	4
5								14410...	3880 VA				6
7				2106 VA	2106 VA								8
9	Rain Water Pump	20	3			2106 VA	2106 VA			3	20	Rain Water Pump	10
11								2106 VA	2106 VA				12
13				1690 VA	1690 VA								14
15	WSHP Size 26	20	3			1690 VA	1690 VA			3	20	WSHP Size 26	16
17								1690 VA	1690 VA				18
19				1690 VA	4268 VA								20
21	WSHP Size 26	20	3			1690 VA	4268 VA			3	25	WSHP Size 72	22
23								1690 VA	4268 VA				24
25				4268 VA	1690 VA								26
27	WSHP Size 72	25	3			4268 VA	1690 VA			3	20	WSHP Size 26	28
29								4268 VA	1690 VA				30
31				1690 VA	14410...								32
33	WSHP Size 26	20	3			1690 VA	14410...			3	100	Anaerobic Grinder	34
35								1690 VA	14410...				36
37	Spare		1	0 VA	0 VA					1		Spare	38
39	Spare		1			0 VA	0 VA			1		Spare	40
41	Spare		1					0 VA	0 VA	1		Spare	42
		Total Load:		53899 VA		53899 VA		53899 VA					
		Total Amps:		195 A		195 A		195 A					

Load Classification	Connected Load (VA)	Demand Factor	Estimated Demand (VA)	Panel Totals	
Lighting	0 VA	0.00%	0 VA		
Receptacle	0 VA	0.00%	0 VA		
Power	0 VA	0.00%	0 VA	Total Conn. Load:	161698 VA
Motor	161698 VA	100.00%	161698 VA	Total Est. Demand:	161698 VA
HVAC	0 VA	0.00%	0 VA	Total Conn.:	194 A
Other	0 VA	0.00%	0 VA	Total Est. Demand:	194 A

Notes: Provide 2#12, #12G, 3/4#C for all branch circuits unless otherwise noted on floor plan.

Branch Panel: M2

Location: STORAGE 209 **Volts:** 480/277V **A.I.C. Rating:** 65,000
Supply From: Switchboard Distribution **Phases:** 3 **Mains Type:** MCB
Mounting: Surface **Wires:** 4 **Mains Rating:** 225 A
Enclosure: Type 1 **MCB Rating:** 225 A

Ckt	Circuit Description	Trip	Poles	A		B		C		Poles	Trip	Circuit Description	Ckt
1				3298 VA	1690 VA								2
3	WSHP Size 49	20	3			3298 VA	1690 VA			3	20	WSHP Size 44	4
5								3298 VA	1690 VA				6
7				3907 VA	3907 VA								8
9	WSHP Size 64	20	3			3907 VA	3907 VA			3	20	WSHP Size 64	10
11								3907 VA	3907 VA				12
13				3907 VA	4268 VA								14
15	WSHP Size 64	20	3			3907 VA	4268 VA			3	25	WSHP Size 72	16
17								3907 VA	4268 VA				18
19				5820 VA	2106 VA								20
21	Cooling Tower Fan	40	3			5820 VA	2106 VA			3	20	Cooling Tower Evaporative Cooler Pump	22
23								5820 VA	2106 VA				24
25	Spare		1	0 VA	0 VA					1		Spare	26
27	Spare		1			0 VA	0 VA			1		Spare	28
29	Spare		1					0 VA	0 VA	1		Spare	30
31	Spare		1	0 VA	0 VA					1		Spare	32
33	Spare		1			0 VA	0 VA			1		Spare	34
35	Spare		1					0 VA	0 VA	1		Spare	36
37	Spare		1	0 VA	0 VA					1		Spare	38
39	Space		--			0 VA	0 VA			--		Space	40
41	Space		--					0 VA	0 VA	--		Space	42
		Total Load:		28903 VA		28903 VA		28903 VA					
		Total Amps:		104 A		104 A		104 A					

Load Classification	Connected Load (VA)	Demand Factor	Estimated Demand (VA)	Panel Totals	
Lighting	0 VA	0.00%	0 VA		
Receptacle	0 VA	0.00%	0 VA		
Power	0 VA	0.00%	0 VA	Total Conn. Load:	86710 VA
Motor	86710 VA	100.00%	86710 VA	Total Est. Demand:	86710 VA
HVAC	0 VA	0.00%	0 VA	Total Conn.:	104 A
Other	0 VA	0.00%	0 VA	Total Est. Demand:	104 A

Notes: Provide 2#12, #12G, 3/4#C for all branch circuits unless otherwise noted on floor plan.

Branch Panel: DP1

Location: MECHANICAL EQUIPMENT ROOM 011 **Volts:** 208/120V **A.I.C. Rating:** 65,000
Supply From: 112.5kVA Transformer **Phases:** 3 **Mains Type:** MCB
Mounting: Surface **Wires:** 4 **Mains Rating:** 400 A
Enclosure: Type 1 **MCB Rating:** 400 A

Ckt	Circuit Description	Trip	Poles	A		B		C		Poles	Trip	Circuit Description	Ckt
1				9132 VA	0 VA					1		Spare	2
3	Panel R1	125	3			6902 VA	0 VA			1		Spare	4
5								9172 VA	0 VA	1		Spare	6
7				11543...	11593...								8
9	Panel R4	125	3			13803...	10883...			3	125	Panel R2	10
11								13683...	11693...				12
13	Spare		1	0 VA	0 VA					1		Spare	14
15	Spare		1			0 VA	0 VA			1		Spare	16
17	Spare		1					0 VA	0 VA	1		Spare	18
19	Spare		1	0 VA	0 VA					1		Spare	20
21	Spare		1			0 VA	0 VA			1		Spare	22
23	Spare		1					0 VA	0 VA	1		Spare	24
25													26
27													28
29													30
31													32
33													34
35													36
37													38
39													40
41													42
		Total Load:		32269 VA		31589 VA		34549 VA					
		Total Amps:		270 A		263 A		289 A					

Load Classification	Connected Load (VA)	Demand Factor	Estimated Demand (VA)	Panel Totals	
Lighting	0 VA	0.00%	0 VA		
Receptacle	66780 VA	57.49%	38390 VA		
Power	1700 VA	100.00%	1700 VA	Total Conn. Load:	98406 VA
Motor	10466 VA	100.00%	10466 VA	Total Est. Demand:	70016 VA
HVAC	19460 VA	100.00%	19460 VA	Total Conn.:	273 A
Other	0 VA	0.00%	0 VA	Total Est. Demand:	194 A

Notes: Provide 2#12, #12G, 3/4#C for all branch circuits unless otherwise noted on floor plan.

TBD Engineering | Schedules

Branch Panel: R1

Location: MECHANICAL EQUIPMENT ROOM 011 **Supply From:** DP1 **Mounting:** Surface **Enclosure:** Type 1
Volts: 208/120V **Phases:** 3 **Wires:** 4
A.I.C. Rating: 10,000 **Mains Type:** MCB **Mains Rating:** 125 A **MCB Rating:** 125 A

Ckt	Circuit Description	Trip	Poles	A		B		C		Poles	Trip	Circuit Description	Ckt
1	Receptacles Passenger Elevator Pit	20	1	180 VA	360 VA					1	20	Receptacle Women's 016	2
3	Receptacles Freight Elevator Mach.Room	20	1			540 VA	250 VA			1	20	Cooler Lights and Heater Basement	4
5	Receptacle Men's R115	20	1					360 VA	900 VA	1	20	Receptacle 118 & 109	6
7	Receptacles 102,103,107	20	1	540 VA	800 VA					1	20	Computers Office 100A&B	8
9	Cooler Lights and Heater Basement	20	1			250 VA	360 VA			1	20	Receptacles Men's 017	10
11	Receptacles Rooms 000 & 001	20	1					900 VA	1200 VA	1	20	Boiler	12
13	Receptacles Market 100	20	1	1440 VA	360 VA					1	20	Receptacles Freight Elevator Pit	14
15	Receptacles Offices 100A&B	20	1			720 VA	1260 VA			1	20	Receptacles 018 & M011	16
17	Receptacles Women's R114	20	1					360 VA	720 VA	1	20	Receptacles Rm 001 & 002	18
19	Receptacle Work Shop 108	20	1	720 VA	1260 VA					1	20	Receptacle Processing 101	20
21	Cooler Lights and Heater First Floor	20	1			250 VA	1536 VA			1	20	Anerobic Digester Motor	22
23	Receptacles Market 100	20	1					1260 VA	250 VA	1	20	Freezer Lights and Heater Basement	24
25	Cooler Lights and Heater First Floor	20	1	250 VA	1536 VA					1	20	Anerobic Digester Motor	26
27	Anerobic Digester Motor	20	1			1536 VA							28
29	Anerobic Digester Motor	20	1					1536 VA	1536 VA	1	20	Anerobic Digester Motor	30
31	Anerobic Digester Motor	20	1	1536 VA	50 VA					2		Cooler Evaporator Basement	32
33	Cooler Evaporator Basement		2			50 VA	50 VA						34
35								50 VA	50 VA	2		Cooler Evaporator Basement	36
37	Cooler Evaporator First Floor		2	50 VA	50 VA								38
39						50 VA	50 VA			2		Cooler Evaporator First Floor	40
41	Spare		1					0 VA	50 VA				42
			Total Load:	9132 VA		6902 VA		9172 VA					
			Total Amps:	79 A		58 A		79 A					

Load Classification	Connected Load (VA)	Demand Factor	Estimated Demand (VA)	Panel Totals	
Lighting	0 VA	0.00%	0 VA		
Receptacle	13040 VA	88.34%	11520 VA		
Power	1700 VA	100.00%	1700 VA	Total Conn. Load:	25206 VA
Motor	10466 VA	100.00%	10466 VA	Total Est. Demand:	23686 VA
HVAC	0 VA	0.00%	0 VA	Total Conn.:	70 A
Other	0 VA	0.00%	0 VA	Total Est. Demand:	66 A

Notes: Provide 2#12, #12G, 3/4#C for all branch circuits unless otherwise noted on floor plan.

Branch Panel: R2

Location: STORAGE 209 **Supply From:** DP1 **Mounting:** Surface **Enclosure:** Type 1
Volts: 208/120V **Phases:** 3 **Wires:** 4
A.I.C. Rating: 10,000 **Mains Type:** MCB **Mains Rating:** 125 A **MCB Rating:** 125 A

Ckt	Circuit Description	Trip	Poles	A		B		C		Poles	Trip	Circuit Description	Ckt
1	Rack Receptacle T307	20	1	180 VA	540 VA					1	20	Receptacles Growing Space 200	2
3	Receptacle Demo Kitchen 301	20	1			180 VA	360 VA			1	20	Receptacle Men's R308	4
5	Receptacle Demo Kitchen 301	20	1					360 VA	1300 VA	1	20	Receptacle Demo Kitchen 301	6
7	Receptacles Growing Space 300	20	1	540 VA	800 VA					1	20	Computers University Incubators 302A&B	8
9	Receptacle Classroom 310	20	1			720 VA	2250 VA			2	20	Range Demo Kitchen 301	10
11	Receptacle Demo Kitchen 301	20	1					1400 VA	2250 VA				12
13	Receptacles Corridor 314	20	1	900 VA	2250 VA					2	20	Range Demo Kitchen 301	14
15	Projector Classroom 310	20	1			800 VA	2250 VA						16
17	Receptacles Women's R208	20	1					180 VA	360 VA	1	20	Receptacles Women's R309	18
19	Rack Receptacle T307	30	1	180 VA	360 VA					1	20	Receptacle Men's R207	20
21	Receptacles Gathering Space 201	20	1			1080 VA	0 VA			1		Spare	22
23	Receptacles Breakout 202 & M206	20	1					720 VA	800 VA	1	20	Projector Gathering Space 201	24
25	Receptacle Classroom 303	20	1	720 VA	800 VA					1	20	Projector Classroom 303	26
27	Spare		1			0 VA	3243 VA						28
29	Receptacles T307	30	1					1080 VA	3243 VA	3	30	DOAS M206	30
31	Receptacle University Spaces 302, 302A&B	20	1	1080 VA	3243 VA								32
33	Spare		1			0 VA	0 VA			1		Spare	34
35	Spare		1					0 VA	0 VA	1		Spare	36
37	Spare		1	0 VA	0 VA					1		Spare	38
39	Spare		1			0 VA	0 VA			1		Spare	40
41	Space		--					0 VA	0 VA	--		Space	42
			Total Load:	11593 VA		10883 VA		11693 VA					
			Total Amps:	98 A		91 A		98 A					

Load Classification	Connected Load (VA)	Demand Factor	Estimated Demand (VA)	Panel Totals	
Lighting	0 VA	0.00%	0 VA		
Receptacle	24440 VA	70.46%	17220 VA		
Power	0 VA	0.00%	0 VA	Total Conn. Load:	34170 VA
Motor	0 VA	0.00%	0 VA	Total Est. Demand:	26950 VA
HVAC	9730 VA	100.00%	9730 VA	Total Conn.:	95 A
Other	0 VA	0.00%	0 VA	Total Est. Demand:	75 A

Notes: Provide 2#12, #12G, 3/4#C for all branch circuits unless otherwise noted on floor plan.

Branch Panel: R3

Location: MECH/ELEC CLOSET 419 **Supply From:** DP1 **Mounting:** Surface **Enclosure:** Type 1
Volts: 208/120V **Phases:** 3 **Wires:** 4
A.I.C. Rating: 10,000 **Mains Type:** MCB **Mains Rating:** 125 A **MCB Rating:** 125 A

Ckt	Circuit Description	Trip	Poles	A		B		C		Poles	Trip	Circuit Description	Ckt
1	Receptacle Men's R410	20	1	360 VA	400 VA					1	20	Computer Director's Office 401	2
3	Floor Boxes Reception 402 & Collab 414	20	1			1080 VA	1200 VA			1	20	Coffee Maker Employee Lounge 413	4
5	Receptacle Women's R411	20	1					360 VA	1500 VA	1	20	Copier Copy Room 404	6
7	Microwave Employee Lounge 413	20	1	1300 VA	1500 VA					1	20	Copier Copy Room 404	8
9	Receptacles Growing Space 500	20	1			1260 VA	540 VA			1	20	Receptacles Corridor 418 & M409	10
11	Refrigerator Employee Lounge 413	20	1					1800 VA	540 VA	1	20	Receptacles Growing Space 400	12
13	Receptacles Copy Room 404	20	1	540 VA	600 VA					1	20	Printer Copy Room 404	14
15	Printer Copy Room 404	20	1			600 VA	720 VA			1	20	Floor Boxes Conference Room 405	16
17	TV Conference Room 405	20	1					600 VA	720 VA	1	20	Systems Furntiture Open Office 403	18
19	Systems Furntiture Open Office 403	20	1	720 VA	720 VA					1	20	Systems Furntiture Open Office 403	20
21	Systems Furntiture Open Office 403	20	1			720 VA	960 VA			1	20	Systems Furntiture Open Office 403	22
23	Systems Furntiture Open Office 403	20	1					720 VA	720 VA	1	20	Systems Furntiture Open Office 403	24
25	Systems Furntiture Open Office 403	20	1	720 VA	720 VA					1	20	Systems Furntiture Open Office 403	26
27	Systems Furntiture Open Office 403	20	1			960 VA	720 VA			1	20	Systems Furntiture Open Office 403	28
29	Receptacles Director's Office 401	20	1					720 VA	960 VA	1	20	Systems Furntiture Open Office 403	30
31	Receptacles Employee Lounge 413	20	1	720 VA	3243 VA								32
33	Receptacle DEMO KITCHEN 72		1			1800 VA	3243 VA			3		DOAS M409	34
35	Receptacle DEMO KITCHEN 72		1					1800 VA	3243 VA				36
37	Spare		1	0 VA	0 VA					1		Spare	38
39	Spare		1			0 VA	0 VA			1		Spare	40
41	Spare		1					0 VA	0 VA	1		Spare	42
			Total Load:	11543 VA		13803 VA		13683 VA					
			Total Amps:	96 A		118 A		117 A					

Load Classification	Connected Load (VA)	Demand Factor	Estimated Demand (VA)	Panel Totals	
Lighting	0 VA	0.00%	0 VA		
Receptacle	29300 VA	67.06%	19650 VA		
Power	0 VA	0.00%	0 VA	Total Conn. Load:	39030 VA
Motor	0 VA	0.00%	0 VA	Total Est. Demand:	29380 VA
HVAC	9730 VA	100.00%	9730 VA	Total Conn.:	108 A
Other	0 VA	0.00%	0 VA	Total Est. Demand:	82 A

Notes: Provide 2#12, #12G, 3/4#C for all branch circuits unless otherwise noted on floor plan.

Branch Panel: GH1

Location: STORAGE 209 **Supply From:** Switchboard Distribution **Mounting:** Surface **Enclosure:** Type 1
Volts: 480/277V **Phases:** 3 **Wires:** 4
A.I.C. Rating: 65,000 **Mains Type:** MCB **Mains Rating:** 100 A **MCB Rating:** 100 A

Ckt	Circuit Description	Trip	Poles	A		B		C		Poles	Trip	Circuit Description	Ckt
1	Grow Lights Growing Space 200	20	1	3120 VA	3120 VA					1	20	Grow Lights Growing Space 200	2
3	Grow Lights Growing Space 300	20	1			3640 VA	582 VA						4
5	Grow Lights Growing Space 300	20	1					4160 VA	582 VA	3	20	Fans Growing Space 200	6
7				582 VA	582 VA								8
9	Fans Growing Space 200	20	3			582 VA	582 VA						10
11								582 VA	582 VA	3	20	Fans Growing Space 200	12
13				582 VA	582 VA								14
15	Fans Growing Space 200	20	3			582 VA	582 VA						16
17								582 VA	582 VA	3	20	Fans Growing Space 200	18
19				582 VA	582 VA								20
21	Fans Growing Space 300	20	3			582 VA	582 VA						22
23								582 VA	582 VA	3	20	Fans Growing Space 300	24
25				582 VA	582 VA								26
27	Fans Growing Space 300	20	3			582 VA	582 VA						28
29								582 VA	582 VA	3	20	Fans Growing Space 300	30
31				582 VA	582 VA								32
33	Fans Growing Space 300	20	3			582 VA	582 VA						34
35								582 VA	582 VA	3	20	Pump Growing Space 200	36
37				582 VA	582 VA								38
39	Pump Growing Space 200	20	3			582 VA	582 VA						40
41								582 VA	582 VA	3	20	Pump Growing Space 200	42
43				582 VA	582 VA								44
45	Pump Growing Space 200	20	3			582 VA	0 VA			1		Spare	46
47								582 VA	0 VA	1		Spare	48
49	Spare		1	0 VA	0 VA					1		Spare	50
51	Spare		1			0 VA	0 VA			1		Spare	52
53	Spare		1					0 VA	0 VA	1		Spare	54
55	Spare		1	0 VA	0 VA					1		Spare	56
57	Space		--			0 VA	0 VA			--		Space	58
59	Space		--					0 VA	0 VA	--		Space	60
			Total Load:	14383 VA		11783 VA		12303 VA					
			Total Amps:	52 A		43 A		45 A					

Load Classification	Connected Load (VA)	Demand Factor	Estimated Demand (VA)	Panel Totals	
Lighting	14040 VA	100.00%	14040 VA		
Receptacle	0 VA	0.00%	0 VA		
Power	0 VA	0.00%	0 VA	Total Conn. Load:	38470 VA
Motor	24430 VA	100.00%	24430 VA	Total Est. Demand:	38470 VA
HVAC	0 VA	0.00%	0 VA	Total Conn.:	46 A
Other	0 VA	0.00%	0 VA	Total Est. Demand:	46 A

Notes: Provide 2#12, #12G, 3/4#C for all branch circuits unless otherwise noted on floor plan. For all pumps & fans, provide 3#12, #12G, 3/4#C.

Branch Panel: GH2

Location: MECH/ELEC CLOSET 419 **Supply From:** Switchboard Distribution **Mounting:** Surface **Enclosure:** Type 1
Volts: 480/277V **Phases:** 3 **Wires:** 4
A.I.C. Rating: 65,000 **Mains Type:** MCB **Mains Rating:** 100 A **MCB Rating:** 100 A

Ckt	Circuit Description	Trip	Poles	A		B		C		Poles	Trip	Circuit Description	Ckt
1				582 VA	582 VA								2
3	Pump Growing Space 300	20	3			582 VA	582 VA			3	20	Pump Growing Space 300	4
5								582 VA	582 VA				6
7				582 VA	582 VA								8
9	Pump Growing Space 300	20	3			582 VA	582 VA			3	20	Pump Growing Space 300	10
11								582 VA	582 VA				12
13				582 VA	582 VA								14
15	Fans Growing Space 400	20	3			582 VA	582 VA			3	20	Fans Growing Space 400	16
17								582 VA	582 VA				18
19				582 VA	582 VA								20
21	Fans Growing Space 400	20	3			582 VA	582 VA			3	20	Fans Growing Space 400	22
23								582 VA	582 VA				24
25				582 VA	582 VA								26
27	Fans Growing Space 400	20	3			582 VA	582 VA			3	20	Pump Growing Space 400	28
29								582 VA	582 VA				30
31				582 VA	3120 VA					1	20	Grow Lights Growing Space 400	32
33	Pump Growing Space 400	20	3			582 VA	0 VA			1		Spare	34
35								582 VA	0 VA	1		Spare	36
37	Spare		1	0 VA	0 VA					1		Spare	38
39	Spare		1			0 VA	0 VA			--		Space	40
41	Spare		1					0 VA	0 VA	--		Space	42
			Total Load:	9518 VA		6398 VA		6398 VA					
			Total Amps:	34 A		23 A		23 A					

Load Classification	Connected Load (VA)	Demand Factor	Estimated Demand (VA)	Panel Totals	
Lighting	3120 VA	100.00%	3120 VA		
Receptacle	0 VA	0.00%	0 VA		
Power	0 VA	0.00%	0 VA	Total Conn. Load:	22315 VA
Motor	19195 VA	100.00%	19195 VA	Total Est. Demand:	22315 VA
HVAC	0 VA	0.00%	0 VA	Total Conn.:	27 A
Other	0 VA	0.00%	0 VA	Total Est. Demand:	27 A

Notes: Provide 2#12, #12G, 3/4#C for all branch circuits unless otherwise noted on floor plan. For all pumps & fans, provide 3#12, #12G, 3/4#C.

Branch Panel: GH3

Location: MECHANICAL/ELECTRICAL CLOSET 504 **Supply From:** Switchboard Distribution **Mounting:** Surface **Enclosure:** Type 1
Volts: 480/277V **Phases:** 3 **Wires:** 4
A.I.C. Rating: 65,000 **Mains Type:** MCB **Mains Rating:** 100 A **MCB Rating:** 100 A

Ckt	Circuit Description	Trip	Poles	A		B		C		Poles	Trip	Circuit Description	Ckt
1				582 VA	582 VA								2
3	Fans Growing Space 500	20	3			582 VA	582 VA			3	20	Fans Growing Space 500	4
5								582 VA	582 VA				6
7				582 VA	582 VA								8
9	Fans Growing Space 500	20	3			582 VA	582 VA			3	20	Fans Growing Space 500	10
11								582 VA	582 VA				12
13				582 VA	582 VA								14
15	Fans Growing Space 500	20	3			582 VA	582 VA			3	20	Fans Growing Space 500	16
17								582 VA	582 VA				18
19				582 VA	582 VA								20
21	Fans Growing Space 500	20	3			582 VA	582 VA			3	20	Fans Growing Space 500	22
23								582 VA	582 VA				24
25				582 VA	582 VA								26
27	Fans Growing Space 500	20	3			582 VA	582 VA			3	20	Fans Growing Space 500	28
29								582 VA	582 VA				30
31				582 VA	582 VA								32
33	Pumps Growing Space 500	20	3			582 VA	582 VA			3	20	Pumps Growing Space 500	34
35								582 VA	582 VA				36
37				582 VA	582 VA								38
39	Pumps Growing Space 500	20	3			582 VA	582 VA			3	20	Pumps Growing Space 500	40
41								582 VA	582 VA				42
43	Grow Lights Growing Space 500	20	1	3640 VA	3640 VA					1	20	Grow Lights Growing Space 500	44
45	Grow Lights Growing Space 500	20	1			3640 VA	3120 VA			1	20	Grow Lights Growing Space 500	46
47	Spare		1					0 VA	0 VA	1		Spare	48
49	Spare		1	0 VA	0 VA					1		Spare	50
51	Spare		1			0 VA	0 VA			1		Spare	52
53	Spare		1					0 VA	0 VA	1		Spare	54
55	Space		--	0 VA	0 VA					--		Space	56
57	Space		--			0 VA	0 VA			--		Space	58
59	Space		--					0 VA	0 VA	--		Space	60
			Total Load:	15423 VA		14903 VA		8143 VA					
			Total Amps:	59 A		58 A		29 A					

Load Classification	Connected Load (VA)	Demand Factor	Estimated Demand (VA)	Panel Totals	
Lighting	14040 VA	100.00%	14040 VA		
Receptacle	0 VA	0.00%	0 VA		
Power	0 VA	0.00%	0 VA	Total Conn. Load:	38470 VA
Motor	24430 VA	100.00%	24430 VA	Total Est. Demand:	38470 VA
HVAC	0 VA	0.00%	0 VA	Total Conn.:	46 A
Other	0 VA	0.00%	0 VA	Total Est. Demand:	46 A

Notes: Provide 2#12, #12G, 3/4#C for all branch circuits unless otherwise noted on floor plan. For all pumps & fans, provide 3#12, #12G, 3/4#C.

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